



ELECTROTECHNOLOGY
SERIES

9TH EDITION

ELECTRICAL WIRING PRACTICE

**Mc
Graw
Hill**

PETHEBRIDGE / NEESON / LOWE
DAND / JONES / NEWMAN / WICKSTEAD



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PREFACE

The ninth edition of *Electrical Wiring Practice* continues to be a trusted resource for electrical apprentices, with an emphasis on clear visuals and readability. The content has been strengthened to address new units of competency, including coverage of popular Telecommunications electives. The resource continues to build on visual elements to illustrate the practices and understanding required for working with electrical equipment and Standards. New contributors bring their varied knowledge and experience in the electrotechnology industry to the resource.

Because so much modern human activity and the goods we produce incorporate electrotechnology, Standards for its safety and functionality have become a worldwide concern. The trend towards the development of internationally aligned Standards and the adoption of new methods and materials mean that compliance Standards are constantly changing. Readers need to be aware that the references to Standards in this book are given as guides, with examples of their application, but are in no way intended to replace them.

ABOUT THE AUTHORS AND CONTRIBUTORS

Keith Pethebridge, a passionate teacher and mentor, sadly passed away in March 2010. However, his insight and commitment, going as far back as the 1970s, to creating a text devoted to electrical wiring lives on. Now in its ninth edition, *Electrical Wiring Practice* can be regarded as Keith's legacy to the electrical industry. Thanks, Keith.

Ian Neeson is a vocational education and training consultant specialising in electrotechnology. He was involved in the development of the National Competency Standards for Electrotechnology and continues to provide assistance to the National ElectroComms and Energy Utilities Skills Council (EE-Oz Training Standards) in its program of continuous improvement.

Ian also represents the National Skills Council on the Wiring Rules Committee (EL-001) and Hazardous Areas Competency Standards Committee (P-12). He is a member of an IECEx Working Group for Personnel Competencies. For the past few years, Ian has also been a member of the judging team for the National Electrical and Communications Association (NECA) NSW Excellence Awards.

Paul Lowe has been involved in the electrotechnology field for more than 40 years. During the past 19 years Paul has worked for TAFE NSW as a teacher, head teacher and, more recently, developing training and assessment resources for state-wide use. Paul has been an active participant in the development of training package qualifications and units for the last 11 years and is a member of several technical advisory committees. He is currently part of the Commonwealth Industry Skills Committee as a technical expert, representing the Electrotechnology Training Package.

Tony Jones has worked in the electrotechnology industry performing equipment maintenance, breakdown, diagnostics and repairs in servicing and production environments for more than 30 years. He has worked in the VET sector for the past 16 years, 11 of those as an electrical trade teacher. He has also served as a technical advisory committee member, NECA Excellence Awards judge and industry mentor for apprentices. Tony has continued to develop learning and assessment resources for the Electrotechnology Training Package on projects over the past three years.

Robert Wickstead discovered his calling when he wanted to be an electrician at age 12 and did his apprenticeship working in the engine room of a US Navy nuclear-powered cruiser. After moving to Australia, he has been involved in electronic security and telecommunications since the early 1980s, became a qualified electrician and registered electrical contractor in the early 1990s and has spent the last 25 years teaching in the public and private TAFE system, as well as helping to develop modules for the Electrotechnology, Information and Communications Technology, and Property Services (Technical Security) Training Packages. He is currently at Swinburne University of Technology working with electrical apprentices.

Simon Dand has almost 30 years' experience in the electrotechnology industry and is currently a full-time electrical trades teacher for TAFE NSW. He started his career as an electrical apprentice in the coal-fired power stations on the Central Coast of NSW and worked for many years as both a software engineer developing industrial process control software and a maintenance electrician in the food and beverage FMCG industry. Simon's passion for imparting electrical knowledge led him to TAFE NSW where he has taught for almost 20 years. During his career at TAFE NSW, Simon has taught post-trade, diploma and TVET students along with electrical apprentices.

Simon holds a qualified Electrical Contractors Licence, an Electrical Trade Certificate, a Certificate III in Electrical Fitting, an Advanced Diploma in Electrical Engineering, a Bachelor's Degree in Computer Science and a Certificate IV in Workplace Training and Assessment.

Rebecca Newman has been working in the electrotechnology industry for more than 25 years. The mother of three boys, she started her apprenticeship with her dad working in different areas, including industrial, domestic and commercial. Rebecca moved to the mining industry later in her career, where she worked as an electrician on the plant. For the past three years, Rebecca has been teaching in the TAFE sector where she has completed her Associate Degree in Vocational Education and Training.

ACKNOWLEDGMENTS

The production of a book covering such a wide range of topics would not be possible without the contributions made by members of the electrotechnology industry in Australia and New Zealand. Our thanks go to these groups and organisations, who are listed here and cited throughout the text: Australian Communications and Media Authority · Boutique Power · Communications Alliance Ltd · EBM Computers · EDMI Pty Ltd · Emona Instruments · Energy Safe Victoria · EzyStrut/Korvest · Fluke Corporation · Fuji SMBE Harwal Pty Ltd · IDEAL INDUSTRIES · Imperva · Legrand Australia Pty Ltd · Middy's / Middendorp Electric Co Pty Ltd · Rob Bernard · Schneider Electric · Selectronic Australia Pty Ltd · Signify · Standards Australia/SAI Global.

The development of this edition would not have been possible without the help and encouragement of our colleagues in vocational education and training and in industry. Thank you Quentin Field and Steve Hall for your review comments and feedback.

We would also like to thank the publishing team at McGraw Hill for their hard work throughout the production of this book.

Keith's legacy lives on.

Ian Neeson and Paul Lowe

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TEXT AT A GLANCE

LEARNING OUTCOMES

These points orient students to what they can expect to learn from the chapter and aid self-assessment.

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- explain the regulations for licensing to undertake electrical work
- list the types of electrical licences, the scope of work they cover and how they are obtained
- describe the purpose of Standards and how they are developed and used
- explain the layout of the *Wiring Rules*, the electrical installations it covers and how it incorporates other Standards
- describe the purpose of the *Appendices* in the *Wiring Rules* and how they differ from the main text
- use the *Table of Contents* to locate specific information in the *Wiring Rules*
- list the essential safety performance requirements of an electrical installation and the methods of protection available to guard against dangers and damage
- illustrate the relationship between *Part 1* and *Part 2* of the *Wiring Rules*
- list common types of electrical insulation and their typical uses, and the conditions that degrade the effectiveness of electrical insulation
- explain the concept of leakage current.

CHAPTER INTRODUCTION

Each chapter begins with an introduction to provide a big picture overview and identify the key concepts to be covered in the text.

The transmission, reticulation and distribution of electrical energy from the power station to the consumer's equipment are carried out over great distances and sometimes through intricate and complicated circuits. This is achieved by the use of electrical conductors or cables interconnecting the various systems and eventually terminating at equipment that converts the electrical energy to some other form of energy that can be used by the consumer.

In the interests of efficiency, the conductors used for supply or interconnection of electrical equipment must offer minimum opposition to the flow of electric current: that is, their resistance must be low, otherwise an uneconomical power loss will occur within the conductors. The wiring of an installation is designed to have relatively low power loss and the aim is for almost all power conversion to take place within the consuming equipment.

To ensure the effective transmission of voice and data information, the cables used for communications must offer minimum interference to the information from cable characteristics such as impedance, electromagnetic radiation (EMR) and mutual inductance. The cabling of communications services is designed to have minimum loss or distortion of the information transmitted.

EXAMPLES

The text contains a wealth of examples to ensure student understanding and application.

EXAMPLE 8.3

An illuminance of 200 lx is present at a distance of 3 m from a light source. If the inverse square law is applicable to the situation, what is the luminous intensity of the source?

$$F = \frac{I}{d^2}$$
$$I = Ed^2$$
$$= 200 \times 9$$
$$= 1800 \text{ cd}$$

INFORMATION BOXES

These box features highlight dangers, hazards and information that students should be aware of in the field.

 **CAUTION**

Smoke alarm disposal

Although ionisation smoke alarms contain only an extremely small amount of radioactive material, if they are to be discarded they should be returned to the manufacturer or advice should be sought from local waste authorities. Photoelectric alarms do not contain any radioactive material and may therefore be disposed of in the normal way.

 **SAFETY ALERT**

Lamps must be disposed of responsibly through an accredited lamp-recycling service. All gas-discharge lamps contain mercury, which is extremely toxic and known to cause both chronic and acute poisoning. Sodium in discharge lamps is potentially explosive, and generates flammable hydrogen and caustic sodium hydroxide on contact with water.

NOTE: As a result of these efficiency measures, incandescent lamps have been almost completely removed from service. They have long been part of everyday life for many people and, while customers may ask for them, they should be educated about the modern alternatives.

 **DANGER**

The danger of not complying with the principle of overcurrent protection is that the high value of energy dissipated might cause excessive and destructive damage to wiring and equipment. Associated heating and arcing present a high fire risk and, more importantly, a person working close to an arc produced in an uncontrolled release of energy could sustain a fatal injury. There is always the possibility of shock hazard due to leakage current causing potentials above earth on parts of the installation that are normally at earth potential or isolated from earth.

 **DID YOU KNOW?**

Standards and guidelines: CPRs

The *Telecommunications Cabling Provider Rules (2014)* (CPRs) cover all sectors that involve customer cabling work—including telephone, data, fire and security alarm systems cabling—that connects or is intended to connect with the telecommunications network. This work must be performed by a registered cabling provider or carried out under the direct supervision of a registered cabling provider.

FIGURES

Extremely detailed and informative illustrations clearly explain key concepts. These figures are a valuable visual tool for learning and teaching.

About licensing

Types of licences issued by all jurisdictions

Electrician's licence

- Permits the holder to carry out electrical work unsupervised.
- Permits the supervision of such work.
- Does not permit such work to be done for commercial gain.

Electrical contractor licence

- Permits the holder to undertake electrical work for commercial gain.
- Can be held by an individual, partnership or company.
- Work must be carried out or supervised by the holder of an electrician's licence.

Restricted electrical work licence

Issued to particular non-electrical tradespersons to carry out restricted electrical work that is incidental to their normal duties. For example, mechanical maintenance fitters have the need from time to time to disconnect a motor in order to carry out mechanical repairs on plant or machinery.

- Generally confined to disconnecting and reconnecting equipment like for like.
- Categorised by the different types of equipment permitted. Some jurisdictions issue licences for electrical fitting work and electrical service work.

Electrical apprentices

In some jurisdictions electrical apprentices are issued with a permit, while in others their status to carry out electrical work under supervision is restricted to local training regulations.

How to qualify for a licence

Electrical Regulatory Authorities Council (ERAC) represents all states, territories and New Zealand on matters of technical electrical regulation. For uniformity of electrical licensing across all jurisdictions ERAC developed 55 essential capabilities that must be demonstrated through:

- Training Package qualification
- recognition of current competencies
- a combination of both of the above.

Restricted electrical work licences are only issued for certain categories of work, and to qualify a person must:

- possess trade-level skills in a specified category
- demonstrate a need for the licence
- undergo a prescribed competency-based training program.

Responsibilities of licence-holders

Electrical licences are issued on behalf of the community to persons who have shown they are competent to do the work for which the licence is issued. With this comes the responsibility to uphold the standards expected, there is no excuse for a licensed person to work incompetently. These responsibilities include:

Holders of an electrician's licence

- Must comply with the requirements of the Wiring Rules, local distributors' service rules and any other statutory requirements such as those of a local or national building code.
- Verify their completed work complies with the Standards.
- Complete and issue a Certificate of Compliance for work for which they are the licence holder.
- Supervise the work of trainees/apprentices.

Holders of an electrical contractor licence

- Assume the responsibilities of the licensed electrician where they are carrying out the work themselves.
- Engage licensed electricians to carry out the work of an electrician.
- Keep all records required by statutory regulations.

Holders of a restricted electrical work licence

- Work strictly within the scope permitted by the licence.
- Ensure electrical circuits/equipment worked on are safe to use.
- Notify of the need for a licensed electrician where the work to be done is beyond the scope of restricted electrical work.

Who issues licences

Electrical licences are issued by the authority with the regulatory responsibility for electrical safety in your jurisdiction. These authorities and those with regulatory authority for work health and safety are listed at the end of this book and are current at the time of writing.

FIGURE 4.1 About electrical licensing

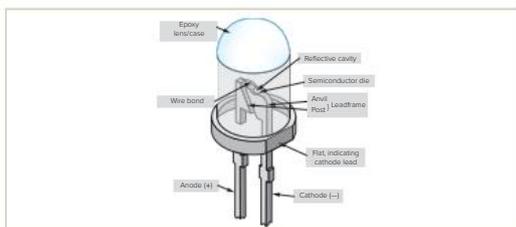


FIGURE 8.27 Basic construction of an LED

EXERCISES

Throughout the book are a number of exercises for students to test their knowledge.

EXERCISE 4.1

Open the *Wiring Rules* at Section 4 Selection and installation of appliance and accessories. Note that all the clauses start with the number of the section, in this case 4, and the main requirements for each aspect of Selection and installation of appliances and accessories are listed under clauses numbered 4.1, 4.2, 4.3 and so on.

Now look up Clause 4.4 Socket-outlets. As the information about socket-outlets becomes more specific, that part of the clause is given a new heading and an additional point and number. In this case Clause 4.4.1 covers 'Types' (of socket-outlets), while under the heading 'Types' the more specific requirement for suitability, the clause 'General', is given number Clause 4.4.1.1. Clauses like 4.4.1 and 4.4.1.1 are often called *sub-clauses*.

CHECK YOUR UNDERSTANDING

Questions at the end of each major section give students the opportunity to test their knowledge.

CHECK YOUR UNDERSTANDING

- Draw a basic circuit, labelling all the components.
- In a circuit, what is the purpose of a switch?
- In a practical circuit, why is the voltage drop in the circuit conductors kept to a minimum?
- Explain the features and characteristics of series circuits and parallel circuits.
- Identify the series and parallel circuits of the following components in an installation:
 - energy meter
 - main switch
 - circuit-protection devices
 - socket-outlets
 - light points
 - light switches.

SUMMARY

The chapter summary provides a quick review of the key learning outcomes.

SUMMARY

- All electrical circuits are made up of a source of energy, a protection device, a form of control and a load.
- There are two basic types of circuit connections: series, in which components are connected end to end and parallel, where components are connected across the same supply source and the voltage is the same value throughout the circuit.
- Types of electrical diagrams include circuit diagrams, wiring diagrams, single-line diagrams and block diagrams, and they are used for installation, maintenance and the diagnosis of faults.
- Types of circuits in an installation can include lighting, power, permanently connected appliances and distribution boards.
- Socket-outlets are connected in parallel and looped from point to point.
- Correct polarisation of socket-outlets is essential.
- Wiring of a single-phase motor contains an active and a neutral and three-phase motors contain three actives.

REVIEW QUESTIONS

Review questions at the end of each chapter test student knowledge of the key learning outcomes.

REVIEW QUESTIONS

- The objective of any lighting installation is to satisfy what?
- Which concept of rays of light makes possible the practical design of reflectors, diffusers and refractors?
- AS 1680.2.4 recommends a minimum lux level for the general working area of an office as 320 lx. If the working area is 350 m², calculate the value of the useful flux incident on the working plane.
- At what height should a light source be mounted if its vertical luminous intensity is 4500 cd and it is required to provide an illuminance of 150 lx on the working plane?
- Identify two categories that luminaires are considered to fall into.
- What condition could cause a premature failure of ancillary equipment needed to operate modern gas-discharge lamps?
- What is the role of the dichroic reflector in an ELV lamp?
- Describe the function of the internal reflective coating in an ELV lamp.
- What test equipment is used for measuring light levels?
- List three advantages of a compact fluorescent lamp over an incandescent lamp.

ACRONYMS

Important acronyms are included in a listing at the end of the book.

ACRONYMS

A	amp	HVDC	high-voltage direct current
a.c.	alternating current	IEC	International Electrotechnical Commission
ACIF	Australian Communications Industry Forum	IDC	insulation displacement connection
ACMA	Australian Communications and Media Authority	IP	International Protection
ACSR/GZ	aluminium conductor galvanised steel reinforced	IPCC	Intergovernmental Panel on Climate Change
AEMC	Australian Energy Market Commission	ISP	internet service provider
		ISO	International Organization for

CHAPTER 1

Electrical energy—past, present and future

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ explain the principles of producing electricity
- ▶ illustrate how electricity is transmitted and distributed
- ▶ illustrate the different arrangements for electricity distribution to consumers
- ▶ describe the arrangements for electricity distribution within an electrical installation
- ▶ discuss the processes for the connection of electricity to a consumer's installation and the need for compliance with safety standards
- ▶ discuss renewable energy use in Australia, including the use of inverters, standalone systems and hydrogen-powered technologies
- ▶ identify the effect of renewables on the electricity grid
- ▶ explain curtailment, electrical inertia and grid strengthening.

1.1 Producing electricity

A significant amount of electrical energy produced today is obtained from a rotating turbine attached to an electrical generator that uses electromagnetic induction to produce energy (**Figure 1.1**). Energy used to drive turbines is extracted from steam, flowing water, hot gases and wind. In Australia, as in many other countries, the prime source for producing steam to drive turbines is coal. **Figure 1.2** shows the principles of coal-powered thermal power generation. However, this is changing with the adoption of renewable energy sources driven by the need to reduce greenhouse gas emissions from burning fossil fuels. In a number of other countries, nuclear energy is the prime source. Although nuclear power stations are similar in many respects to other thermal power stations, they are identified separately because of the additional equipment required to control the process, the associated risk of a nuclear accident and the problems of nuclear waste containment.

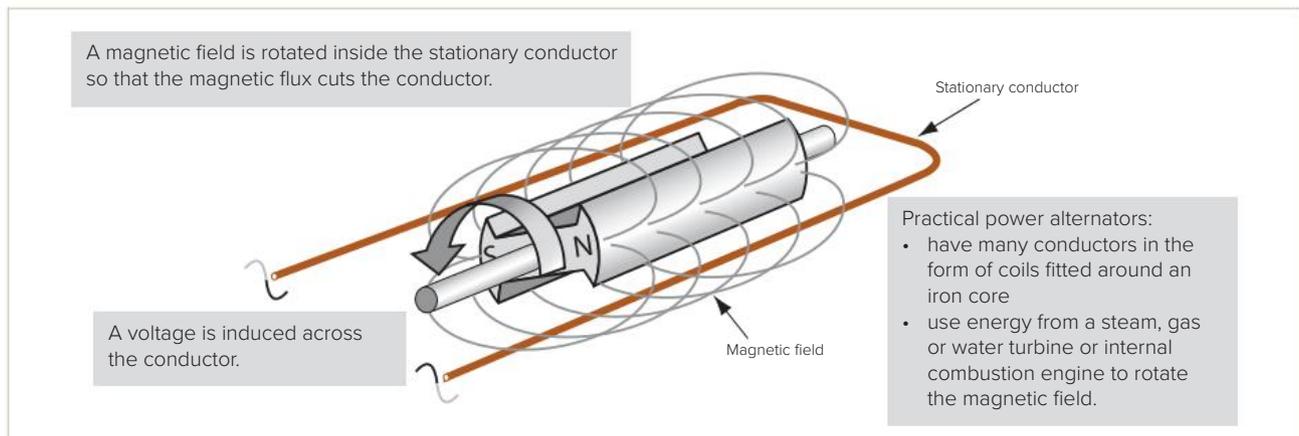


FIGURE 1.1 The law of electromagnetic induction applied in generators

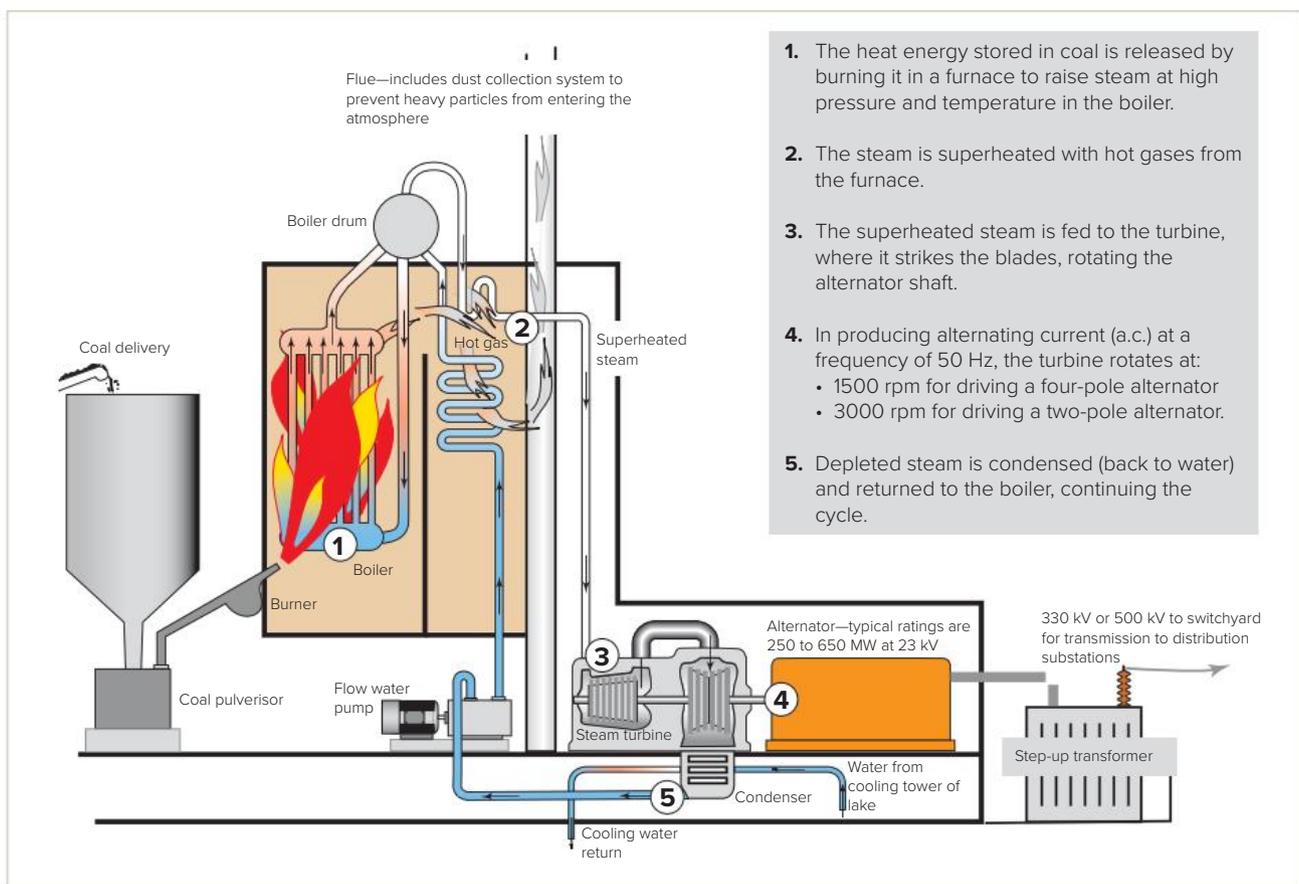


FIGURE 1.2 Principles of coal-powered thermal power generation

There are many small diesel engine-driven generators, as well as solar and wind farms, for electricity supply in areas remote from main power networks. Microgrids and standalone systems, particularly in Western Australia, are becoming more prevalent as standby supplies in non-domestic installations. Note that electricity produced for the main power network is alternating current, which has some distinct advantages over direct current.

The voltage or pressure at which the current is produced ranges from 11 000 V to 23 000 V. Transformers are used to step up the voltage for transmission and step it down for utilisation of the electrical energy. The ease with which voltage can be transformed is one of the main advantages of using a.c.

Hydroelectric power stations, such as those used in the eastern states of Australia and South Island, New Zealand, use the kinetic energy of moving water to drive turbines. These plants can provide both base-load and peak-load demands for power at a relatively low cost provided sufficient water is available. Hydroelectricity has the advantage

of being able to store electricity. The generators can be used as a motor to pump water from a lower holding dam to the storage dam store. This is done during periods of low demand on the network.

Table 1.1 outlines common sources of energy and methods for producing electricity.

TABLE 1.1 Common sources of energy and methods for producing electricity

Energy from materials by extracting thermal energy			
Energy source	Method for producing electricity	Application	Figure
Burning coal, oil or natural gas to produce steam or hot gases	Steam-turbine generator sets	Network base-load power	1.2 and 1.5
Burning gas to produce high-pressure combustion gases	Gas-turbine generator sets	Network base-load power	1.3 and 1.5
Nuclear reaction to produce steam	Steam-turbine generator sets	Network base-load power	1.4 and 1.5
Burning renewable organic matter (commonly known as biomass) to produce steam (emerging technology)	Steam-turbine generator sets	Supplementary supply to network and industrial consumers	
Fuels, typically diesel or biofuel, in combustion engine	Combustion engine-generator sets	Standby generation in critical facilities such as hospitals and data centres, and remote areas	
Energy existing in nature			
Energy source by conversion	Method for producing electricity	Application	Figure
Kinetic energy of moving (falling) water	Water-turbine generator set	Renewable base-load power and storage	1.6 and 1.7
Kinetic energy of wind	Wind-turbine generator set	Renewable energy in the supply network	1.11
Solar energy	Photovoltaic effect in solar cells	Consumer's own energy needs with supplementary power supplied to network	1.9
Solar energy concentrated to produce steam (emerging technology)	Steam-turbine generator sets	Renewable energy in the supply network	1.10
Heat energy in geothermal field to produce steam	Steam-turbine generator sets	Renewable base-load power in New Zealand only	1.8
Kinetic energy of ocean waves (developing technology)	Hydraulic-turbine generator set	Renewable energy in the supply network	

1.1.1 Generating and using energy efficiently

The efficiency of energy use can be increased by utilising the energy lost to the atmosphere through flue and exhaust systems to either generate electricity or provide the thermal energy needed for other processes. For example, a hospital might generate electricity using a gas turbine, and the hot exhaust gases from the turbine could be used to produce hot water and steam for hospital cleaning and sterilising purposes (see **Figure 1.3**). Any excess electricity could be fed into a public grid system, resulting in a reduced cost of electrical energy for the hospital. This arrangement is known as co-generation and is being used in manufacturing processes where thermal energy is required.

1. Air is drawn into the compressor and compressed.
2. Exhaust gases heat the compressed air in the preheater.
3. Heated compressed air is fed to the combustion chamber.
4. Gas is burnt in heated compressed air in the combustion chamber, producing high-pressure combustion gases.
5. Combustion gases are fed to the turbine, where they strike the blades, rotating the alternator shaft.
6. Energy-reduced combustion gases are emitted as exhaust.

In co-generation systems the exhaust gas is used in space, water or process heating, increasing the thermal efficiency of the system to as much as 90 per cent.

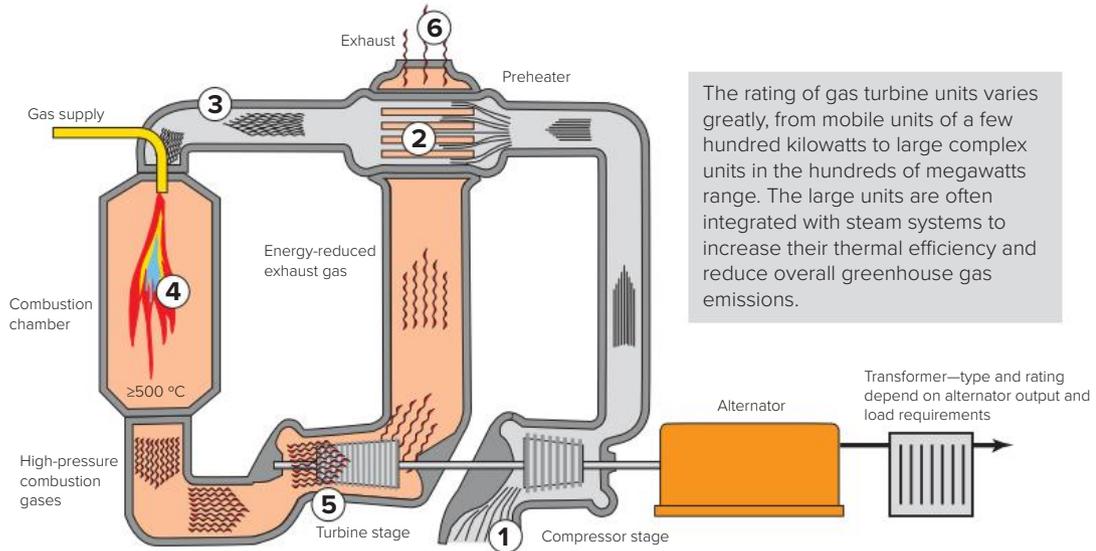


FIGURE 1.3 Principles of gas-powered thermal power generation

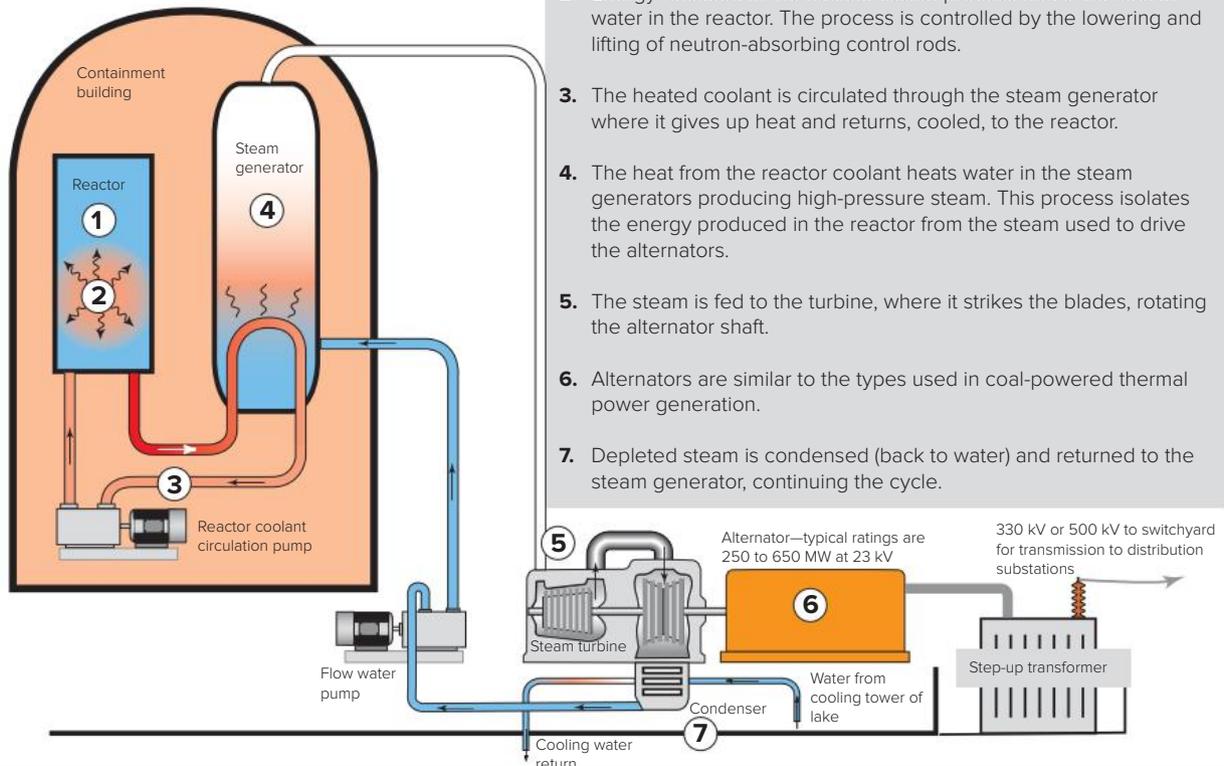


FIGURE 1.4 Principles of nuclear-powered thermal power generation

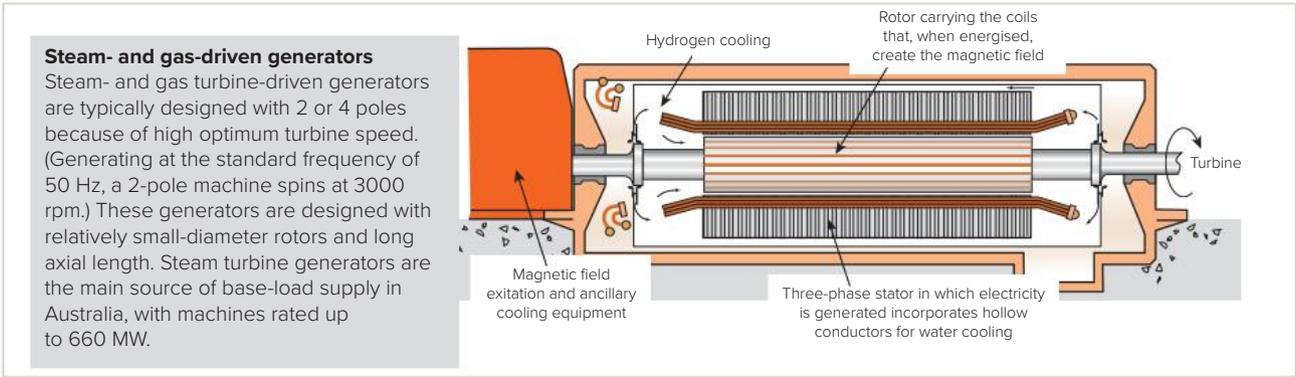


FIGURE 1.5 Features of steam turbine generators

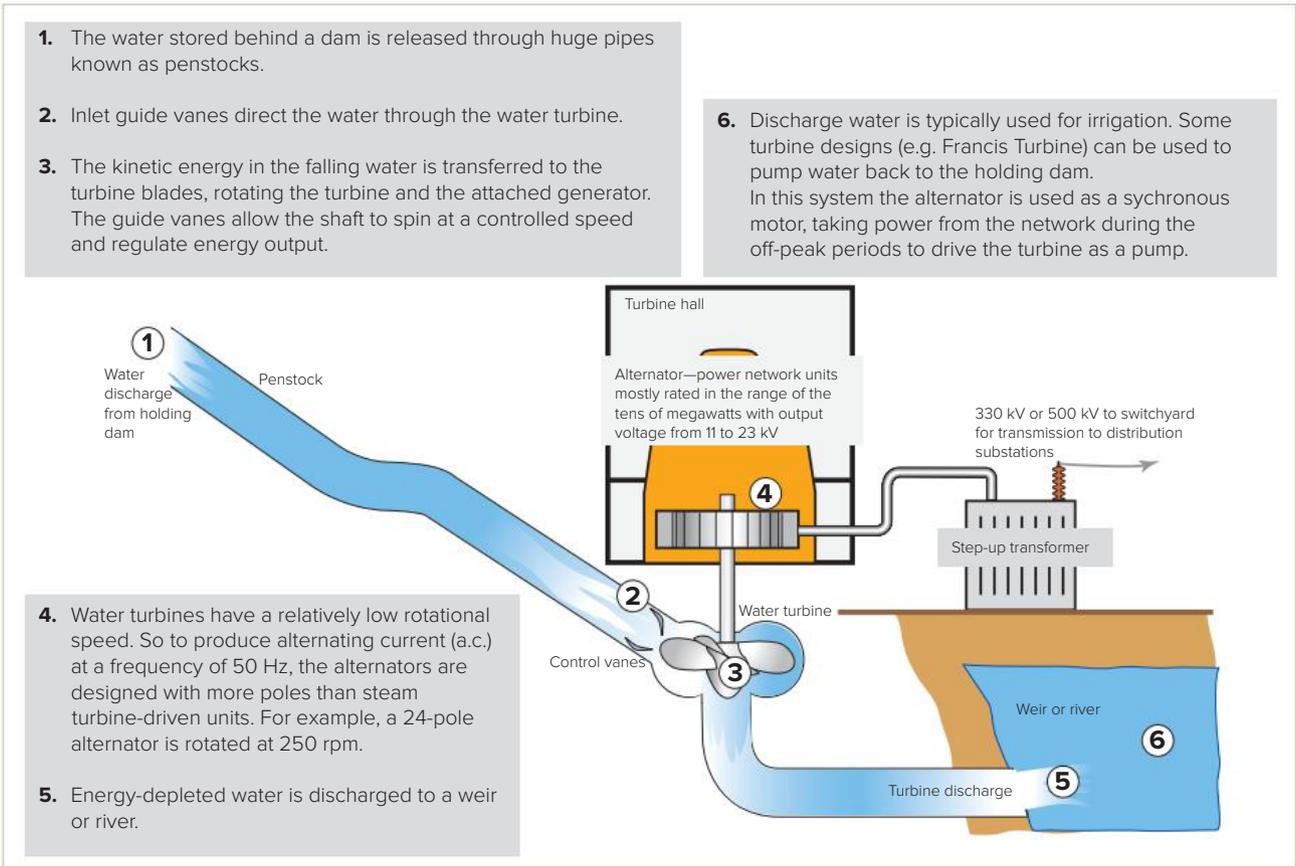


FIGURE 1.6 Principles of hydro power generation

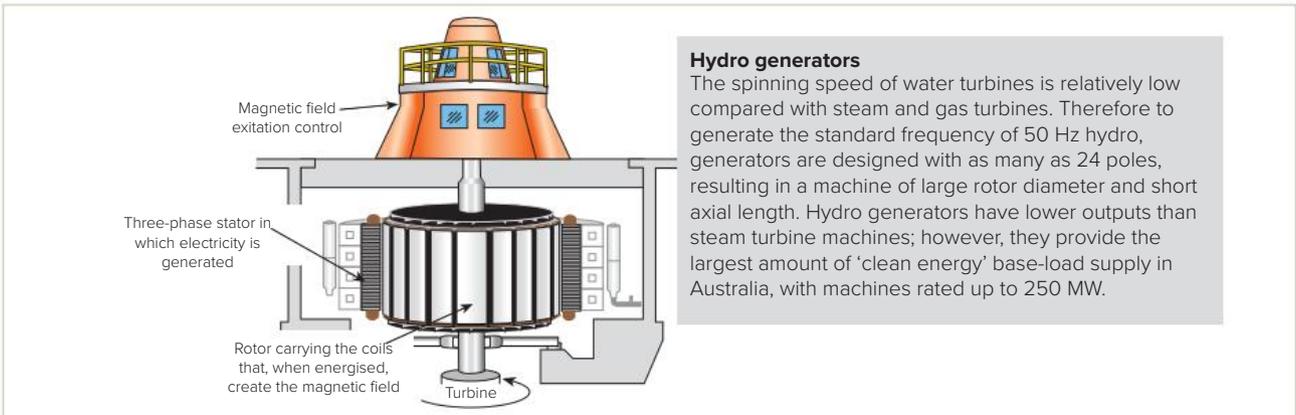


FIGURE 1.7 Features of water turbine generators

1. Water is injected deep into heat-bearing rocks.
2. The heat from the deep rocks is captured as steam and brought to the surface.
3. The steam gives up heat to a secondary (drive) fluid, which boils to become a high-pressure vapour.
4. The high-pressure vapour is fed to the turbine, where it strikes the blades and rotates the alternator shaft.
5. Depleted vapour is condensed (back to a fluid) and returned to the heat exchanger, continuing the cycle.

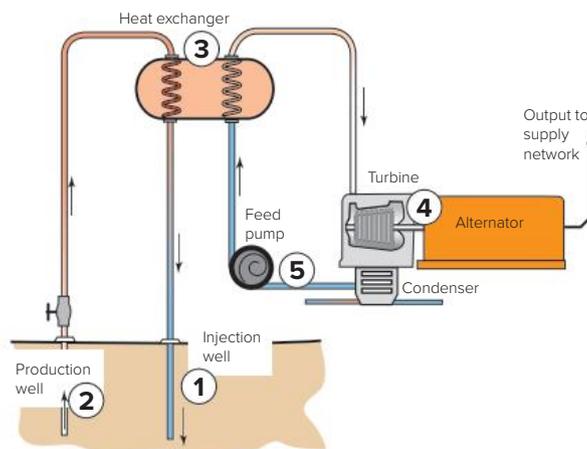
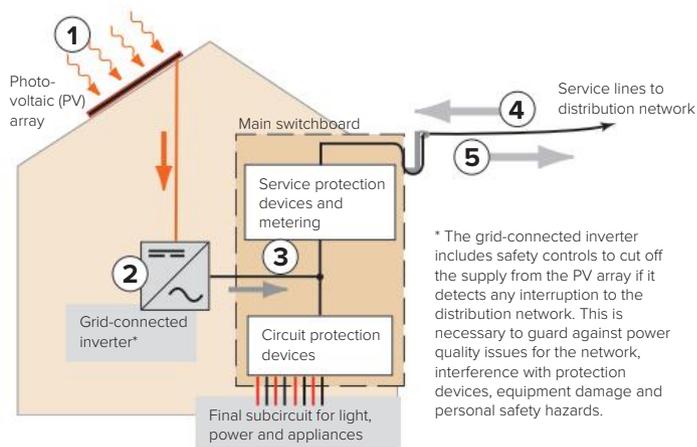


FIGURE 1.8 Principles of geothermal power generation

The National Construction Code (NCC) in Australia and the Building Code in New Zealand (NZBC) include requirements for buildings to be more energy efficient. The electrical installation has a part to play in this. You will learn more about this and sustainable work practices in following chapters and as you progress through your training.



1. Energy from sunlight falling on the array of photo-voltaic cells is converted to d.c. electrical energy.
2. The d.c. from the PV array is fed into the grid-connected inverter, which 'inverts' the d.c. to 230 V a.c.
3. Supply from the inverter is fed to supply loads to the consumer's installation or to the distribution network.
4. When the consumer's demand is greater than the energy generated by the PV array, energy is supplied from the distribution network.
5. When the consumer's demand is less than the amount of energy generated by the PV array, energy is supplied to the distribution network. In this way, the consumer gains credits for the energy supplied.

FIGURE 1.9 Application of direct solar power generation

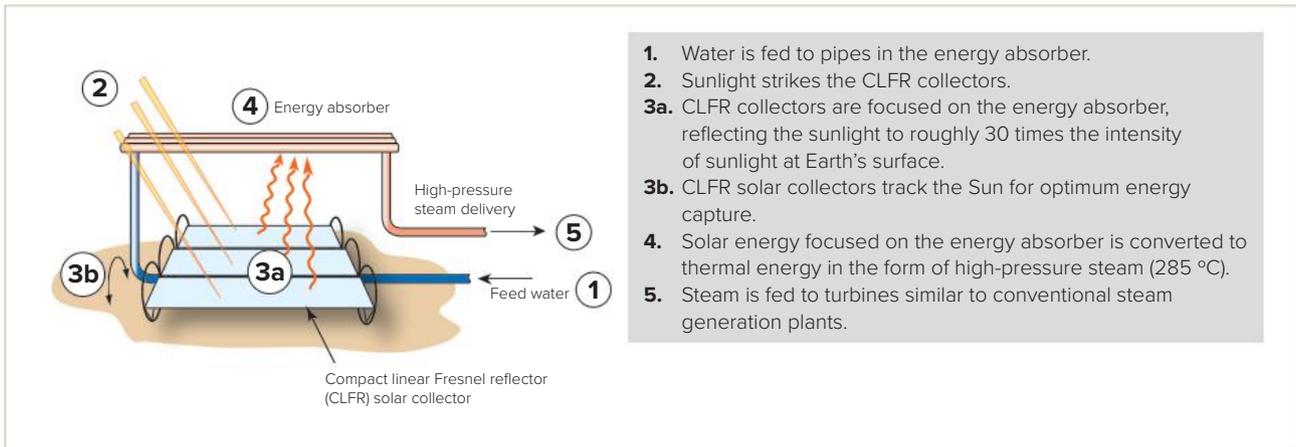


FIGURE 1.10 Principles of concentrated solar thermal power generation

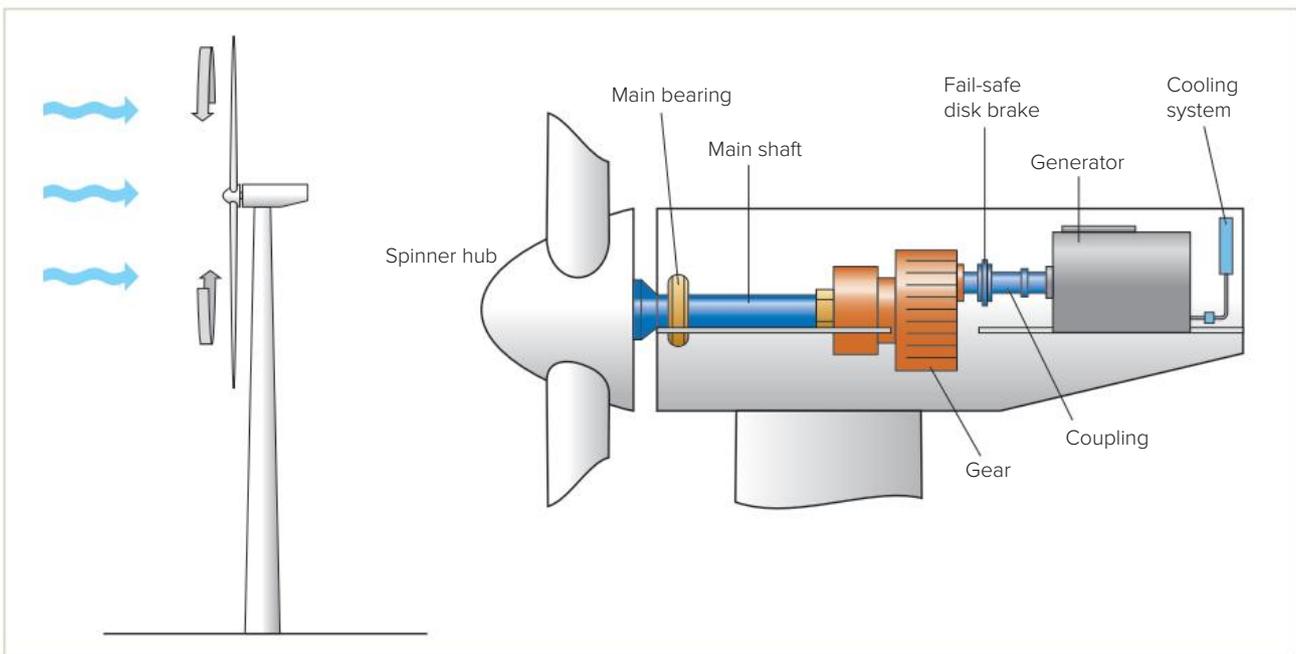


FIGURE 1.11 Principles of wind power generation



CHECK YOUR UNDERSTANDING

1. Name the three characteristics that distinguish nuclear power stations from thermal power stations.
2. Briefly describe how biomass is used to produce electricity.
3. Give five methods of producing electricity used in Australia and New Zealand.
4. What energy sources are used in steam-turbine generator sets for producing electricity?
5. Which two clean energy sources are used in steam-turbine generator sets for producing electricity?

1.2 Electrical energy transmission and distribution

Until recent years, the main sources of electrical energy were large power stations located on fuel reserves such as coal fields. These power stations produce alternating current, which has some efficiency advantages over direct current, as shown in **Figure 1.12**. This electricity is made available to consumers through a national grid system of transmission and distribution lines. Some of the advantages of this include:

- ▶ larger generating units, including solar and wind farms, are considered more efficient than smaller ones
- ▶ less reserve plant is required to supply peaks of supply demand or emergency demand
- ▶ remote places such as rural areas that would be considered inaccessible to a normal supply system, may be supplied by *tapping off* the state grid
- ▶ the interchange of power is possible both within the grid system and interstate; the eastern grid scheme interconnects the power systems of Queensland, New South Wales, Victoria, South Australia, Tasmania and Snowy Hydro Limited; the New Zealand grid interconnects the power systems of the North and South Islands; the interconnection of different grid systems is made possible by the development of high-voltage direct current (HVDC) transmission (**Figure 1.13**)
- ▶ centralised control is economical in both generation and operation.

A recent disruption to this arrangement has been the adoption of renewable energy systems, in particular the installation of photovoltaic arrays by individual consumers who feed electricity excess to their needs to the energy network. This equates to adding many small power stations and has caused some stability problems for energy networks. This will be discussed in more detail later in this chapter and in **Chapter 11**.

1.2.1 Distribution and transmission companies in Australia

Electricity in Australia is supplied by a number of providers:

- ▶ Australian Capital Territory—Evoenergy
- ▶ New South Wales—Essential Energy, Ausgrid, Endeavour Energy, TransGrid
- ▶ Northern Territory—Power and Water
- ▶ Queensland—Energy Queensland, PowerLink
- ▶ South Australia—South Australia Power Networks, ElectraNet
- ▶ Tasmania—TasNetworks
- ▶ Victoria—Powerscor, Citipower, Jemena, AusNet Services, United Energy Distribution
- ▶ Western Australia—Western Power, Horizon Power, Synergy.

1.2.2 Energy and the electricity grid in Australia

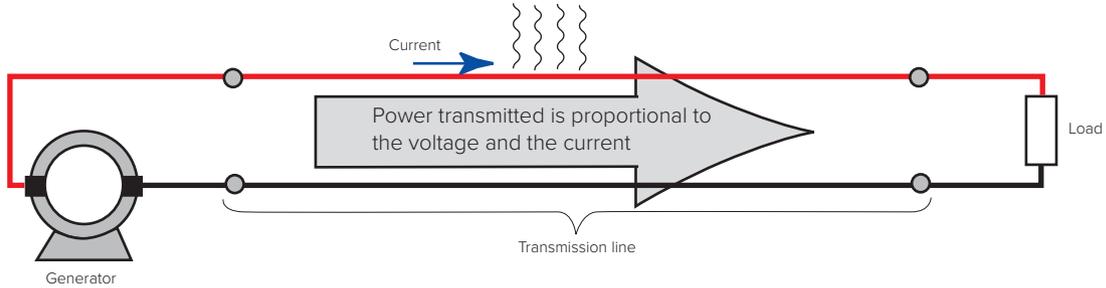
Australia has two main electricity grids, these being the high voltage transmission and distribution grids, which are designed for the reliable delivery of electricity to businesses and households around the country. The system strength of these grids has traditionally been achieved by synchronous generators (powered by coal, gas and hydro) physically coupled to the grid, ensuring electricity supply remains stable; that is, voltage waveforms are smooth and frequency range constant.

Threats to transmission and distribution grid infrastructure assets can result from lightning strikes, storms and bush fires. A grid supply failure can result when generators, loads and network elements do not operate correctly, disconnecting from the system as a self-protection mechanism. This disconnection of system elements can further de-stabilise the system frequency, leading to a cascading failure.

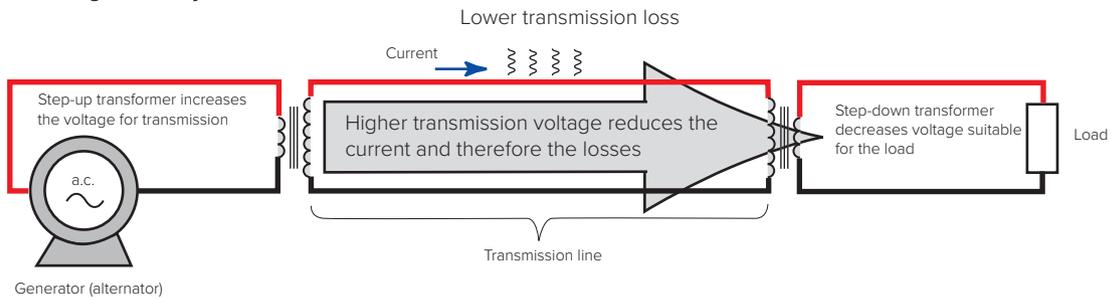
System strength remediation schemes known as *do no harm rules* were introduced in 2017, partly as a response to the 2016 blackouts in South Australia. The 2016 blackout system event was a cascading failure resulting from storm damage to transmission lines.

Disadvantage of early d.c. systems:

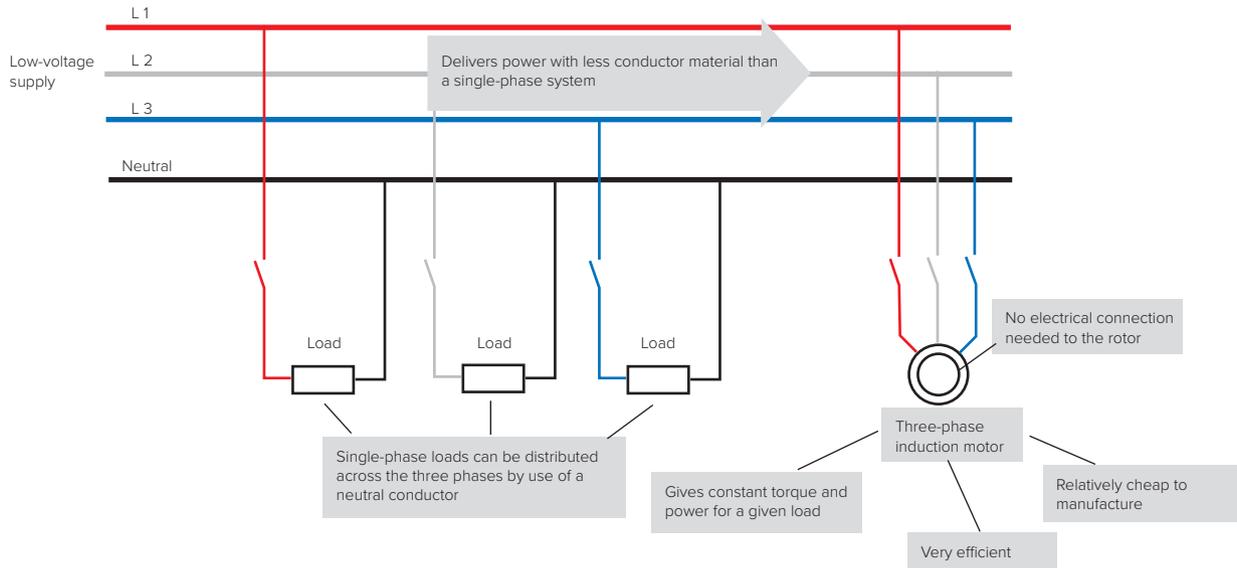
Transmission power loss due to heat in wires is in proportion to the current squared. For example, halving the current will reduce the power lost to one-quarter, i.e. $(\frac{1}{2})^2$.



Advantage of a.c. systems:



Some advantages of three-phase a.c. systems:



Designation of a.c. conductors:

The three-phase system has three active conductors, each known as a phase or line. They are most commonly designated by: line numbers L1, L2 and L3; by their colour code (*Clause 3.8*), Red Active, White Active and Blue Active; as Phase 1, Phase 2 and Phase 3; or as A Phase, B Phase and C Phase. While the terms line and phase are, strictly speaking, not synonymous, in practice a load is more often referred to as being connected, say, between phase and neutral rather than between line and neutral, or between phases rather than between lines.

FIGURE 1.12 Direct current and alternating current systems

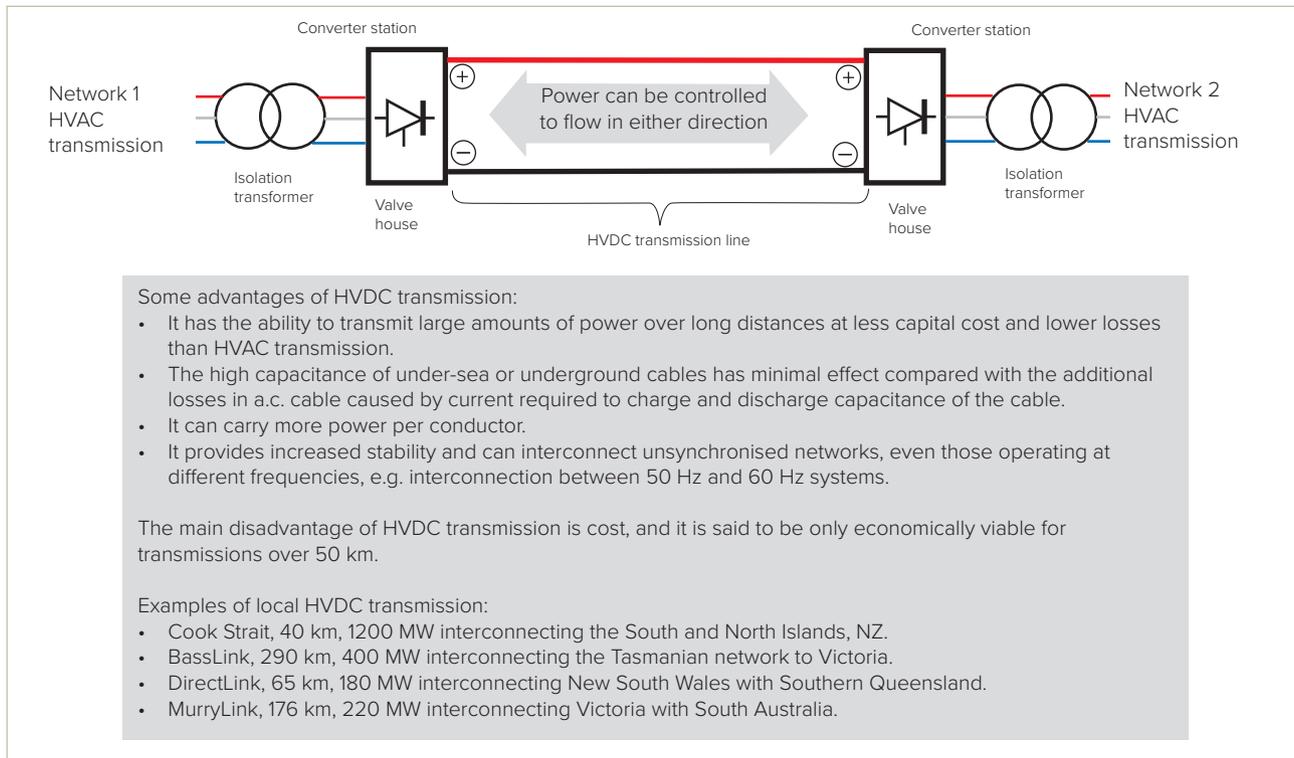


FIGURE 1.13 Modern d.c. transmission

Grid stability depends upon the system strength of the grid to deal with disruptions, power failures and other disturbances that affect electricity distribution and transmission. Grid stability is a balancing act between energy supply, production, demand and consumption.

The eastern grid scheme of transmission requires thousands of kilometres of high-voltage transmission lines. A small percentage of these lines might be underground, where a concentrated load occurs in large cities, but the major grid system is overhead as aerial lines. Western Australia maintains generation, transmission and distribution systems separate from the eastern grid scheme. The main system services the metropolitan and southwest areas while the more remote areas are serviced by smaller local networks. For complete reliability and service, the design of the transmission system must provide for the:

- ▶ continuity of supply under any conditions of breakdown, overload or emergency
- ▶ full protection of the system from external or internal hazards
- ▶ complete flexibility of the system for maintenance, power interchange or switching purposes.

Note: The circuit diagrams in this chapter do not show mandatory protection and control devices. This is because the diagrams are intended to convey general concepts of transmission and distribution.

Both thermal and hydroelectric power stations generate three-phase power at voltages dependent on the generator's specifications. Typical generation voltages are 11 kV, 17 kV, 22 kV and 23 kV for thermal stations; and 6.6 kV, 11 kV and 22 kV for hydroelectric generation. The generation voltage is usually too low for long-distance transmission and must be stepped up by transformers to transmission voltages of, typically, 66 kV, 132 kV and 330 kV. Primary grid transmission is usually at 330 kV. Victoria, New South Wales and South Australia have grid sections at 500 kV. At these high transmission voltages, less current is required to transmit a given amount of power, allowing economies to be effected in both the installation and utilisation of the power line. An overview of the whole system is shown in **Figure 1.14**.

Control of the power system is affected by transmission network operator control centres in each state in which computer-based facilities continuously monitor energy needs and system stability in communication with distributor and generator control centres. As consumers switch on electrical loads such as lighting or electrical machines, more energy is drawn from the system, and likewise less energy is needed as electrical loads are switched off. In this way

The transmission grid lines are interconnected for control, switching, protection and transformation purposes at regional and zone substations. Another function of these substations is the supply of secondary transmission systems at lower voltages, and local distributors tap off this secondary system for supply and distribution within their own franchise area.

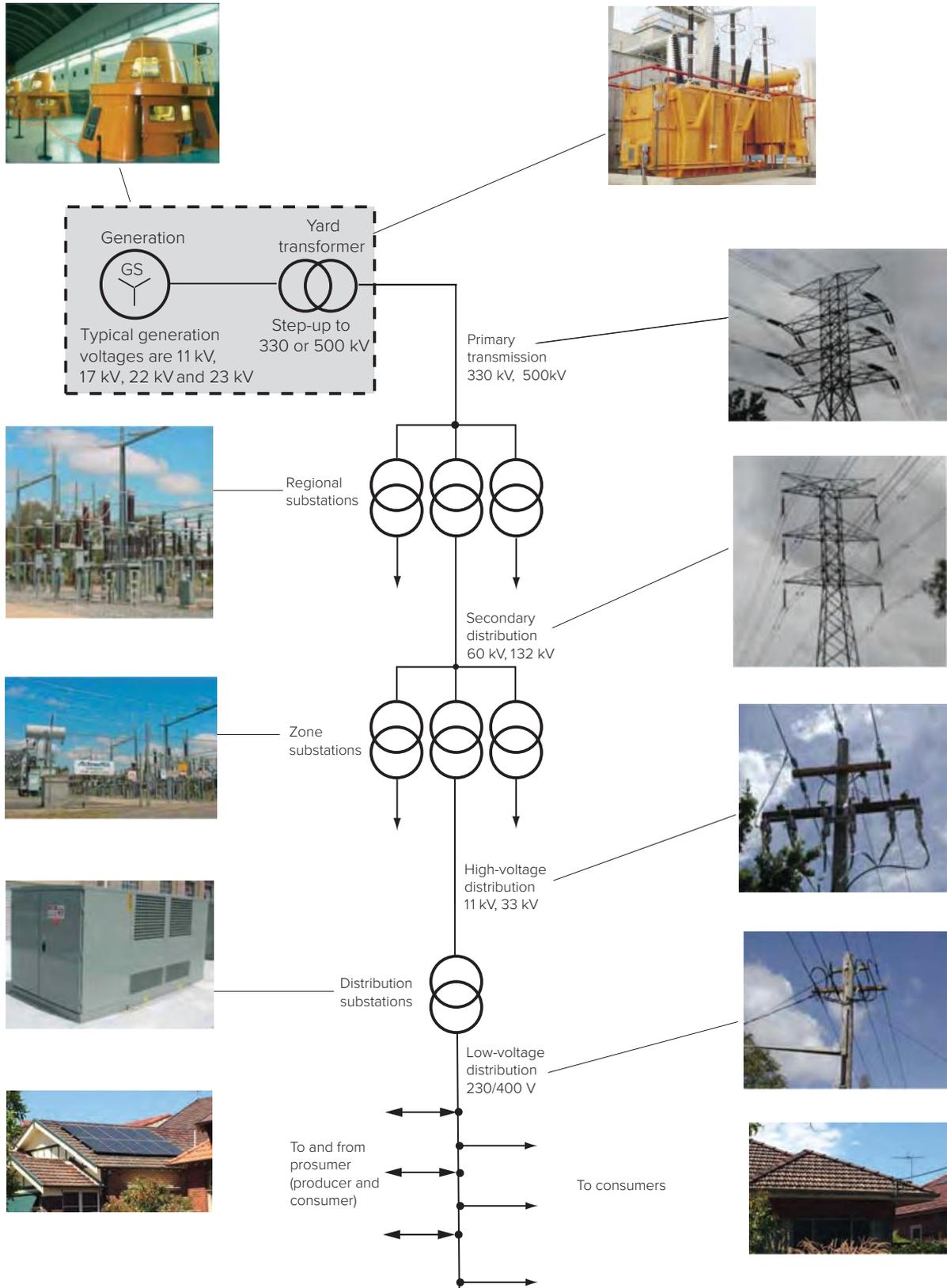


FIGURE 1.14 From power station to consumer

the consumer determines the amount of energy the system needs to supply at any point in time. These changes in energy demand cause instability in the system and any change in phase relationship or fluctuation in voltage and frequency must be controlled by the network operators within the limits set down by the Australian Energy Regulator. Voltages above or below limits specified by the Energy Regulator can cause damage to electrical devices.



CHECK YOUR UNDERSTANDING

6. Identify the distribution and transmission company in your state/territory.
7. What are the two types of electricity grid operating in Australia?
8. Identify three threats to grid infrastructure.
9. Briefly describe the cause and effect of a grid supply failure.
10. State three factors that the design of transmission systems must incorporate to ensure reliability and service.

1.3 Distribution of electricity to consumers

The generation and transmission system brings electricity supply to the point of final distribution. The low-voltage distribution system is the second-last link in the chain joining the power station generator to the consuming device on the consumer's premises, the last link being wiring within the premises. The final distribution of power is accomplished by high-voltage feeders to bulk supply consumers and a low-voltage network to other industrial, commercial and domestic consumers, as shown in **Figures 1.15** and **1.16**.

Innovation and technologies are being developed in the energy supply space that exists between generation and transmission systems, and the low-voltage distribution to industrial, commercial and domestic consumers. These technologies include renewable energy systems, stand-alone power systems and microgrid infrastructure mentioned in **Section 1.6.1** later in this chapter.

Stand-alone power systems are covered in further detail in **Chapter 11**, while switchboards, control panels and metering are covered in **Chapter 14** and installation planning and design is covered in **Chapter 16**.



CHECK YOUR UNDERSTANDING

11. Explain the function of the fourth conductor in the three-phase low-voltage distribution system.
12. Illustrate a SWER system, showing the typical voltages it supplies.
13. List the configurations of low-voltage supply to consumers.
14. How is the protective earth and neutral (PEN) conductor arranged in the consumer's installation?

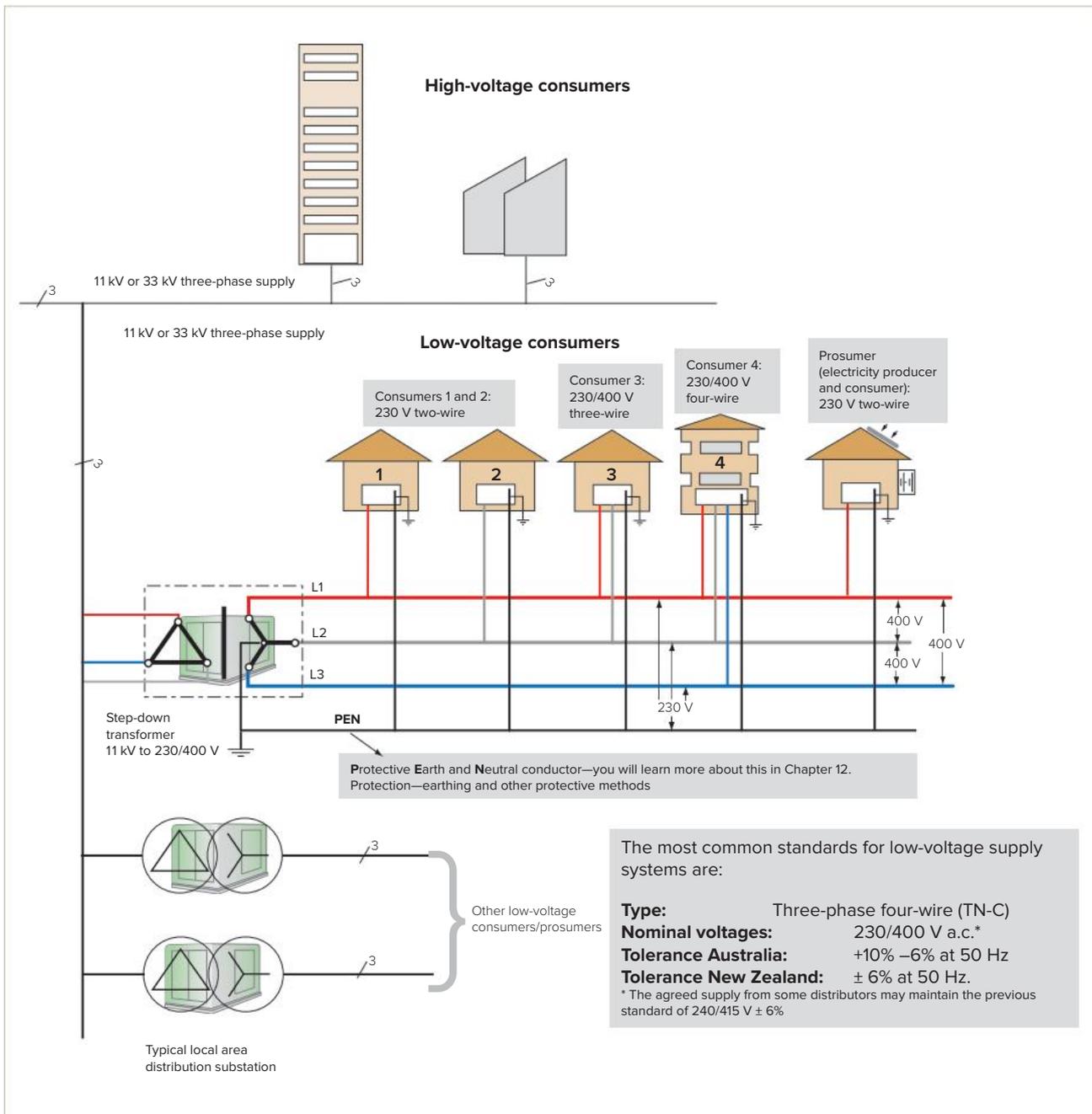
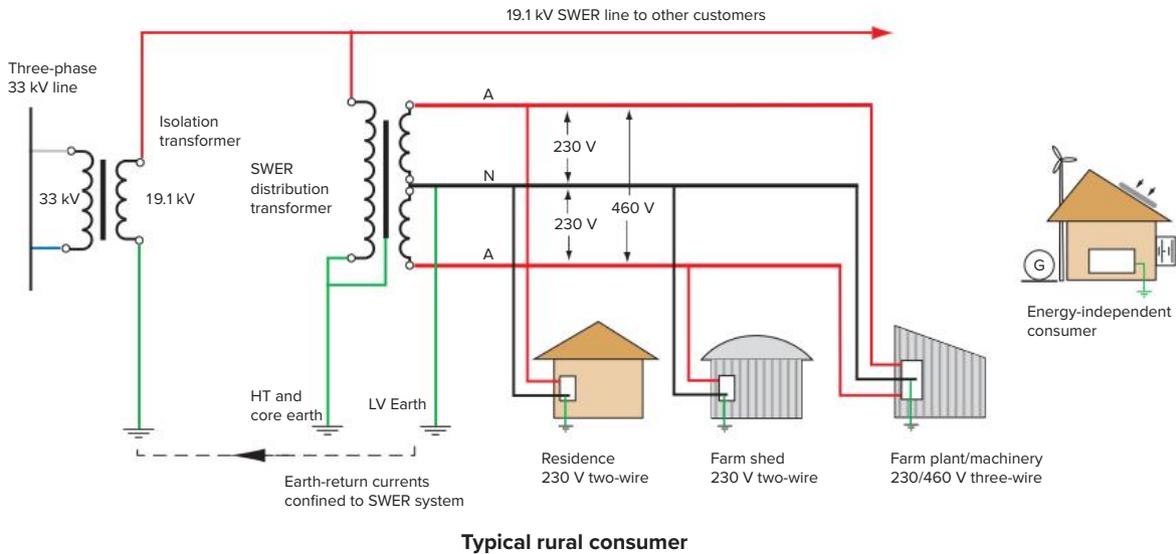


FIGURE 1.15 Distribution to urban consumers

A single-phase three-wire 230/460 V a.c. system is in current use for isolated supplies, usually in remote rural districts. The system is known as the single-wire earth-return (SWER) as the primary transformer is supplied by a single wire, the return being via the general mass of earth. In some remote areas it is less costly for a consumer to produce electricity themselves using renewable energy such as solar and wind, with battery storage and backup generation.



Single-Wire Earth-Return (SWER) system

Because of the simplicity and low cost of the SWER system, it is popular in rural areas where loads are light and consumers few. It is not suitable for urban areas. The two main working problems of the system are maintaining the effectiveness of the earth-return circuit and minimising interference with communication circuits.

FIGURE 1.16 Distribution to rural/remote consumers

1.4 Distribution of electricity in the consumer's installation

Safety and efficiency are the prime considerations in the electrical generation, transmission and distribution systems discussed in this chapter. In the final step of delivering electricity for use in lighting and appliances, that is, the consumer's own electrical installation, safety is paramount. All electrical installations must comply with the fundamental safety requirements of the *Wiring Rules*. Electricity safety regulations in all jurisdictions require a process to be followed for obtaining connection of supply to a consumer installation. They also require verification that the installation complies with all safety requirements of the *Wiring Rules* and any additional local service and installation rules. You will learn more about the safety aspects of electrical installations in subsequent chapters and as you progress in your training. For now, the focus is on the basic concepts of how electricity is distributed within an electrical installation.

The *Wiring Rules* require that an electrical installation be divided into circuits with devices for control and protection against faults and overcurrent. Basic arrangements for a small and larger installation are shown in **Figure 1.17**. An important difference between the low-voltage distribution supply to the consumer and the consumer installation is that the protective earth and neutral (PEN) conductor of the distribution system is divided in the consumer's installation into separate protective earth (PE) conductors and neutral conductors (N). You will learn more about this in **Chapter 13**.

Connection of the completed and tested installation to the local distributor's mains is the final step in getting a supply of electricity to the consumer's premises. Forms that are provided by various electricity distributors for completion by the electrical contractor or customer are similar, and generally only differ in detail and layout.

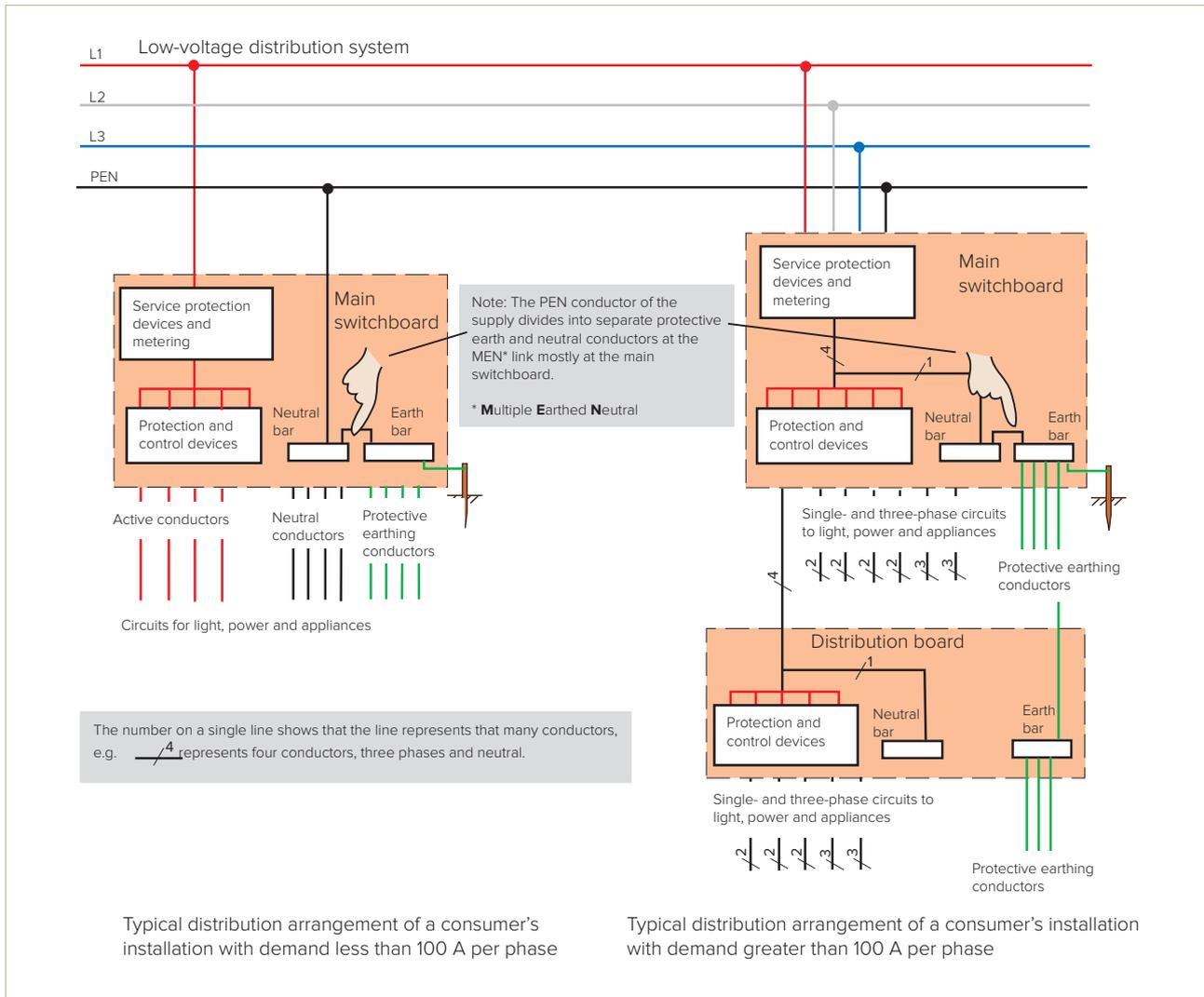


FIGURE 1.17 Examples of the typical arrangement of consumer installations

1.4.1 Getting connected to the supply network

Electrical work, whether a new installation or an alteration or addition to an existing installation, requires cooperation between the customer/consumer, the distributor and the electrical contractor. To this end, distributors and electrical regulatory authorities have in place processes to ensure the network's quality of service to all consumers and that the service and electrical installations are safe to use. Across most jurisdictions the processes for connecting an electrical installation to the supply network are much the same and are outlined in the following points.

Notification of intention to carry out electrical work

Well before supply is given, and prior to the installation of wiring, it is necessary to submit an application for supply or notice of intention to carry out electrical installation work to the local energy distributor. This notification of intention to commence electrical work should be completed in detail and signed by the consumer or electrical contractor, and applies to work that requires a change to the load or type of supply. The main purpose of such notification is to inform the distributor of the extent of work so that they can make arrangements to ensure they have the capacity and the infrastructure to supply electricity to their customers. The technical information typically provided in a notification is as follows:

- ▶ *Type of installation*—Whether the installation is new, an alteration to an existing installation or separation of existing supply for multiple customers or tariffs

- ▶ *Service connection*—Whether the service is underground, overhead or a combination of both and/or connected directly to a pole-mounted transformer
- ▶ *Service size*—Whether the installation requires 100 A, 200 A, 300 A, 400 A or a specified greater rating
- ▶ *Number of installations*—Whether it is a single or multiple installation; for a multiple installation, the number of houses or units involved
- ▶ *Premises type*—Whether the premises is commercial, domestic or a combination of both
- ▶ *Maximum demand*—Current demand determined for each phase of the supply
- ▶ *Other aspects*—Estimated length of the service; whether high-voltage supply is required; whether proposed equipment such as welders may cause excessive voltage fluctuation; whether the installation includes a generator or other alternative source.

Financial contribution

The distributor may require a financial contribution by a customer or developer of installations or projects that require major alterations or upgrading of supply network infrastructure in order to supply electricity to the customers. Even in relatively modest installations such as a single house, the final connection from the distributor's network to the consumer's installation comes at a cost to the consumer.

Verification of compliance

When the electrical installation is complete, the installing electrical contractor or supervising electrician must:

- ▶ visually inspect the work for compliance with the wiring regulations
- ▶ conduct tests in accordance with *Clause 1.8* and *Section 8* of the *Wiring Rules* and as prescribed by local regulations.

This is to ensure that the installation is safe and operates as intended (refer to **Chapter 15**). Once the installation has been proven safe and complies with the *Wiring Rules* and local regulations (e.g. service and installation rules, see **Figure 1.18**), the electrical contractor must give the customer a signed formal document verifying compliance of the installation. The title of the compliance document may vary, and could for example be Certificate of Compliance or Certificate of Electrical Safety, depending on the jurisdiction. However, the purpose is the same: to maintain a safe electrical environment and a record for helping to ensure electrical installation work is only carried out by licensed and competent persons. A copy may be given to the consumer.

Connecting the supply

Before connecting supply, the energy distributor visually inspects and tests the installation. This is generally confined to the consumer mains (see **Chapter 16**), the main earthing conductor (see **Chapter 12**), the main switchboard (see **Chapter 14**) and particular types of installations such as those in hazardous areas (see **Chapter 18**). However, in some cases the whole installation might be inspected under the distributor's regulatory obligation to conduct a schedule of checks to monitor the standard of electrical installation work carried out by electrical contractors and their employees. If the job is satisfactory, supply is connected. In some jurisdictions, licensed and registered independent inspectors are engaged to carry out inspection work.

In most areas an electrical contractor may gain authorisation status to carry out the connection of supply, and seal service and metering equipment to prevent illegal tampering with it. In order to do this, the contractor must be specially trained and carry specific safety and test equipment for the work.

Consequences of defective electrical work

Where an electrical installation does not comply with the required regulations or is incomplete, the energy distributor has the right to refuse supply. If the defect in the installation is major, that is, connecting it to the supply would render the installation potentially dangerous, the distributor will not connect supply to the installation. On the other hand, if a technical or service rule-related defect is considered to be a minor one, supply is usually given. In either case, an

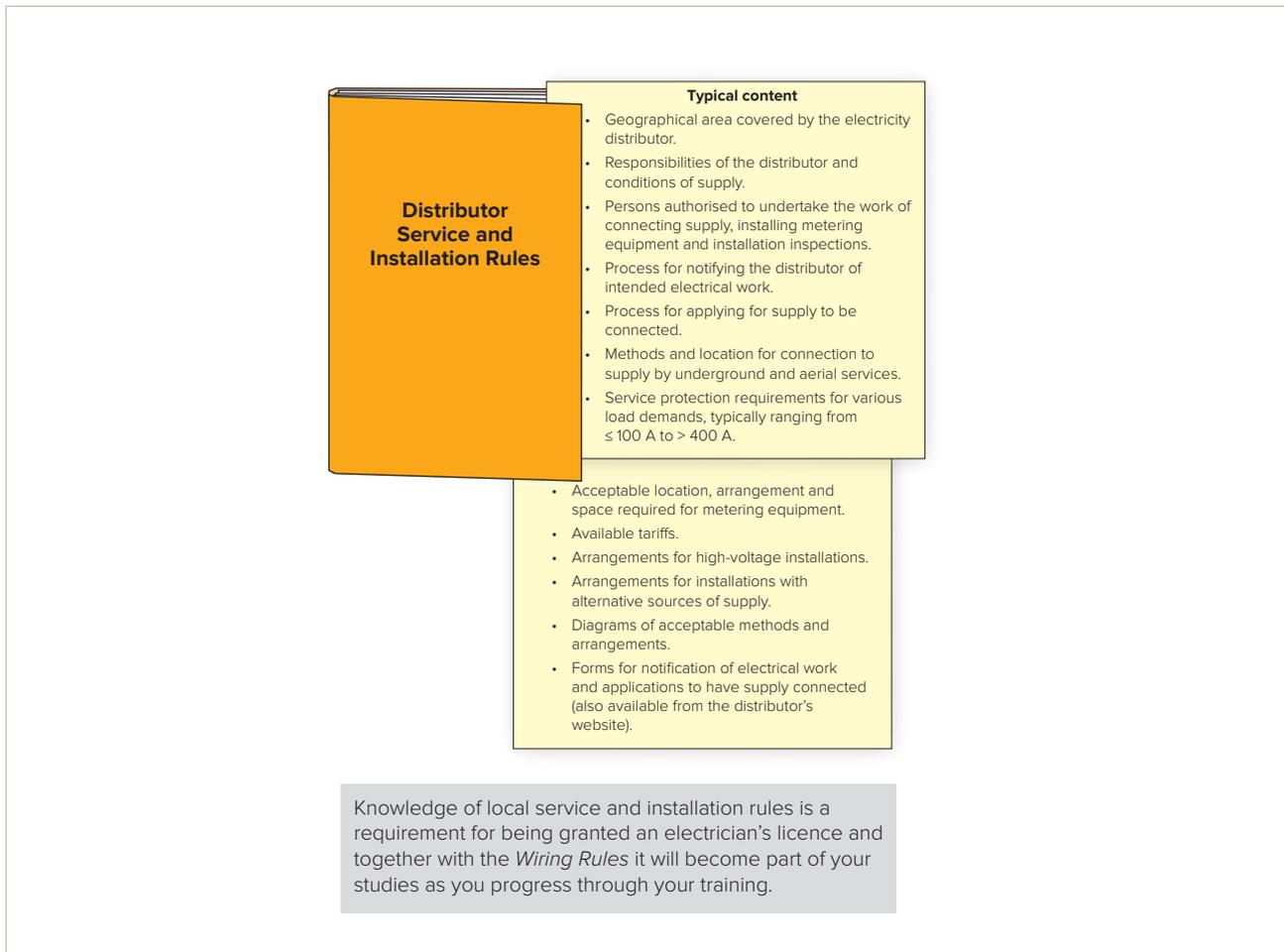


FIGURE 1.18 Distributor service and installation rules

installation inspector notifies the registered electrical contractor and the customer, listing any defect of the installation; the electrical contractor must remedy any defect, arrange for a re-inspection and issue a new certificate of compliance. Disciplinary action against electrical contractors for breach of compliance standards can be severe, depending on the degree of risk they pose or where there is repetition of offences. An offending contractor may incur more frequent inspections of their work until they can show work that is consistently free of defects. More serious offences may attract an infringement notice (fine), licence suspension and/or a recommendation to undertake further training.

Situations requiring special procedures

There are occasions where special procedures must be followed or arrangements made that alter or supplement those mentioned above. Examples are:

- ▶ connection of inverters for feeding consumer-produced electricity to the network
- ▶ where a progress inspection is necessary, such as in a large factory or large building where sections might be required to operate before the completion of the whole installation
- ▶ a building service supplying electrical equipment during building operations
- ▶ where additions or alterations require a changeover from the existing metering, switchboard or consumer's mains to a new position or arrangement, particularly where minimum disruption of supply is required
- ▶ where there is an emergency or breakdown, or where circumstances are such that the usual procedures would not provide the services required.



CHECK YOUR UNDERSTANDING

15. Identify the *AS/NZS 3000* clauses that relate specifically to tests for verification of compliance for electrical installations.
16. Which generation and transmission system brings electricity supply to the point of final distribution?
17. State three consequences of defective electrical work.
18. What is the title for the document that an electrical contractor is required to provide to the customer verifying compliance of an installation?
19. Provide three examples of application information required for a typical notification to carry out electrical installation work.

1.5 Energy usage now and into the future

In Australia, the use of renewables to generate energy continues to grow, with the Clean Energy Council reporting in 2021 that use had almost tripled over the previous decade. Globally, the growth of renewable energy sources now outpaces the growth of fossil fuels sources, with the uptake of solar and wind technology accounting for much of this expansion.

Concerns over climate change are driving much of the uptake of renewables, with more people keen to use electricity produced from renewable sources that generate clean or zero emissions (clean energy) rather than non-renewable sources, such as fossil fuels, that generate polluting emissions (known as dirty energy).

Following the 2021 Glasgow Conference of the Parties summit (COP26), there have been calls for countries around the world to seek out and invest in new renewable technologies and innovation that will enable existing energy production systems to produce clean energy and the uptake energy derived from renewable, zero-emissions sources.

The Australian Government has responded to this call by setting a target to reduce emissions to zero by 2050. State and territory governments are also seeking ways to reduce their emissions, and notable examples of this can be seen in their increasing uptake of renewable energies to power transport systems:

- ▶ Sydney trains and NSW TrainLink, which covers metro, intercity and regional services, has now transitioned to a 100 per cent renewable electricity supply with net-zero emissions after signing a deal with Red Energy. It was one of the first public transport systems in Australia to make the transition.
- ▶ Sydney Metro purchases both electricity and renewable energy certificates from a solar farm.
- ▶ Canberra Metro is powered by renewable energy projects.
- ▶ All 8000 buses in Sydney Buses' fleet are in the process of converting from diesel to electric.
- ▶ Melbourne's tram network has entered a contract to purchase power from a solar farm.
- ▶ The City of Melbourne is in the process of shifting to a council vehicle fleet that will be 100 per cent electric.

Such moves are important as the transport sector is responsible for between 20 and 30 per cent of global CO₂ emissions through the combustion of fossil fuels. The shift to electric and hybrid vehicles is a growing industry trend and public transport operators and governments in Australia are increasingly proactive in replacing diesel vehicles with electric models. Installation of charging stations is a critical infrastructural development in the uptake of electric vehicles. Electrotechnology workers and electrical contractors will play a key role in this growth area of the energy sector.



CHECK YOUR UNDERSTANDING

20. What was the Australian Government's emissions target that was announced as part of the 2021 Glasgow Conference of the Parties summit?
21. State the two fastest-growing sources of renewable energy.
22. Explain the difference between clean energy and dirty energy.
23. Several Australian transport operators have adopted renewable energy sources to power their fleet. Give three examples.
24. The transport industry accounts for what percentage of global CO₂ emissions?

1.6 The use of renewable energy in Australia

1.6.1 Renewable energy systems

A number of renewable energy and alternative energy supply systems have seen many advances in recent years and will continue to provide opportunities for mainstream electricity requirements for homes and businesses. In particular, improvements in the use of hydrogen-powered technologies, inverters and standalone power systems that incorporate batteries (among other measures) have driven an uptake in these technologies in some parts of the country.

Inverter systems

In recent years inverter systems, which are used to convert d.c. electricity derived from photovoltaic arrays to a.c. electricity, have undergone significant performance improvement and development, becoming lighter, cheaper and more versatile. Such advances in technologies and fine-tuning of inverter settings have proved useful to wind and solar farms in Queensland, assisting them to deal with the problem of curtailment. Queensland went from having the highest level of wind and solar curtailment in late 2020 to zero curtailment by early 2021.

Inverter systems are covered in detail in **Chapter 11**.

Stand-alone power systems

Stand-alone power systems (SAPS), which are electricity generation and supply systems incorporating renewables, are increasingly playing a role in energy provision and are being used to power residential homes, businesses and even large-scale mining operations. Western Australia is developing isolated, self-supported networks to take whole towns off the ageing grid and operate independently, with at least 90 per cent renewables, as disconnected microgrids. Western Power and Horizon Power have led the country in designing and installing SAPS for customers in remote locations.

Microgrid infrastructure is also seen as a way of saving money from having to upgrade ageing poles and wires that are vulnerable to winds, storms and bushfires in remote locations. Corin Dam in the Australian Capital Territory is a SAPS example of bush fire risk mitigation. Networks in the eastern states are also looking at the modular grid concept.

Standalone power systems are covered in further detail in **Chapter 11**.

Hydrogen-powered technology

Hydrogen produced using renewable energies is a resource for storing energy to use at a later time. Using hydrogen as a substitute for burning fossil fuels could substantially reduce CO₂ emissions and assist in decarbonising Australia's natural gas network. Green hydrogen is a clean fuel produced by using renewable electricity to electrolyse water, splitting it into hydrogen and oxygen—it produces water vapour and heat when combusted. **Figure 1.19** illustrates the hydrogen production process and its applications.

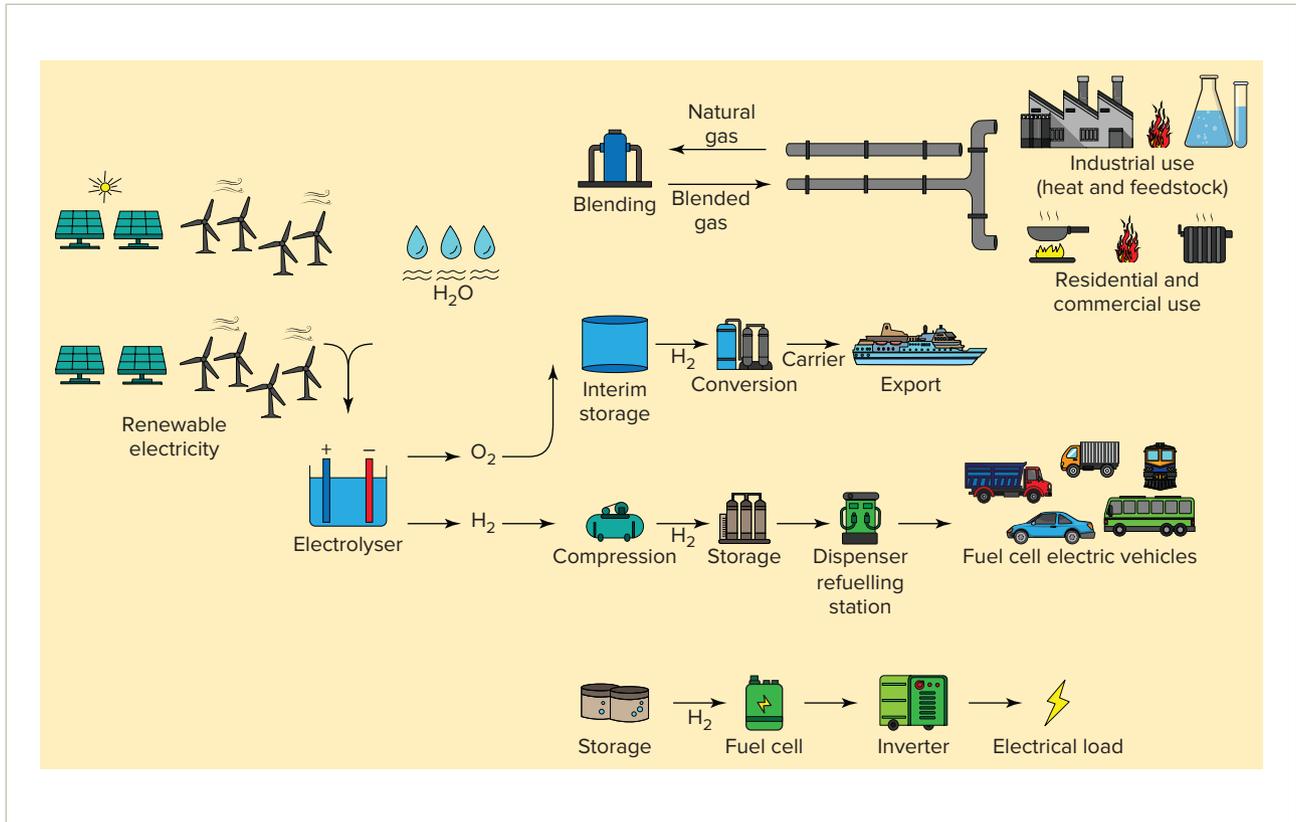


FIGURE 1.19 Hydrogen production and application

Blue hydrogen is produced from the reformation of natural gas (methane), splitting it into hydrogen and CO_2 . While fitting carbon capture technology onto traditional steam methane reformation plants only captures 60 per cent of this CO_2 , modern, purpose-built blue hydrogen production technologies will capture up to 97 per cent of the CO_2 .

Increasingly, hydrogen is becoming a viable option as a renewable energy source. The Western Australia Renewable Hydrogen Strategy sees renewable hydrogen as an emerging technology for the State's clean energy future. The strategy sees hydrogen blending in non-renewable liquefied natural gas networks, for alternative feedstock, transport and for exporting energy internationally.

Western Australia is also home to the recently opened Clean Energy Innovation Hub. The hub produces renewable hydrogen through a solar-powered electrolysis process. It is seen as a significant step in Western Australia's move towards a hydrogen economy.

ATCO Australia, which represents a full range of energy infrastructure services, has also received funding from the Australian Renewable Energy Agency to establish Australia's first commercial-scale, renewable hydrogen supply chain for producing, storing and transporting hydrogen to network injecting points for blending into Western Australia's gas distribution network. The Clean Energy Innovation Park will be co-located at the Warradarge Wind Farm in Western Australia's mid-west. The wind farm will provide the needed renewable energy to power a 10 MW electrolyser producing up to 4.3 tonnes of hydrogen per day.

See **Chapter 11** for additional information on the operation of renewable energy systems.

1.6.2 Renewables and the energy grid

Energy grids are in transition from being powered by coal and gas to being supplied by renewables, in Australia and around the world. Due to various weaknesses in energy grids, the use of renewable energies to supply grids has resulted in a supply generation issue known as curtailment. Curtailment is the deliberate reduction in output below

what could have been produced due to transmission constraints or to balance energy supply and demand. Solar and wind electricity generation in particular are subject to curtailment and have been most notable in places such as Queensland and South Australia.

The transition to renewables has also caused a reduction in network inertia, which is how a power system can stabilise and resist changes in system frequency and rebalance sudden changes in supply and demand following a disturbance.

Long-term solutions to the problems experienced when using renewables to supply the grid are needed if the full capacity of renewables is to be harnessed. Recent attempts to address supply issues have been described by The Australian Energy Market Commission (AEMC) as overly reactive and hastily introduced, badly coordinated and costly for renewable projects. These costs included the installation of synchronous condensers on wind and solar farms. Synchronous condensers are large spinning machines that do not burn fuel but provide the same system inertia as coal and gas synchronous generators.

Electrical inertia

Electrical system inertia is provided by large spinning machinery associated with synchronous generators and synchronous condensers. The more inertia in a power system, the easier for frequency control services to respond to system disturbances.

The Australian Energy Market Commission (AEMC) has announced major changes to the way Australia's main grid system strength is to be managed. The rules relate to system strength and a fast frequency response (FFR). FFR refers to the management of a rapid increase or decrease in electricity generation or distribution network load, in a timeframe of two seconds or less. Existing fast services associated with synchronous generator inertia operate within a six-second timeframe.

Recommended changes set a clear direction for how transmission networks, the Australian Energy Market Operator and new energy generators should work together to keep system voltage stable in the future.

Grid strengthening

Electrical inertia, grid forming and other advanced inverter systems are grid-strengthening technologies. Battery storage systems are grid-strengthening technologies that allow for the storage of excess power for use at a later time. They provide frequency control, synthetic inertia and can be grid forming. Many see these renewable technologies as having a future role to play in Australia's grid. The Australian Renewable Energy Agency recently funded the Grid Innovation Hub at Monash University to conduct a desktop study into using renewables to strengthen the power grid. The Monash University study will consider grid stability issues, including site location and operations of technology and will explore techniques to manage these issues. The technology includes synchronous condensers, wind and solar farms and battery systems incorporating advanced inverter systems. The study will examine the electricity grid in Australia, looking at the role of renewables, grid inertia, inverters and grid strengthening.



CHECK YOUR UNDERSTANDING

25. What are condensers?
26. What are standalone power systems (SAPS)?
27. Explain how battery storage systems can assist with grid strengthening.
28. Give three examples of grid-strengthening technologies.
29. What is green hydrogen?

SUMMARY

- ▶ Most electricity today is produced by a rotating turbine attached to an electrical generator that uses electromagnetic induction to produce energy.
- ▶ Electricity produced for the main power network is alternating current (a.c.).
- ▶ Transformers are used to step up the voltage for transmission and step it down for utilisation of the electrical energy. The ease with which voltage can be transformed is one of the main advantages of using a.c.
- ▶ Australia has two main electricity grids, the high-voltage transmission and distribution grids.
- ▶ Grid system strength ensures electricity supply remains stable, voltage waveforms smooth and frequency range constant.
- ▶ Grid stability is a balancing act between energy supply, production, demand and consumption.
- ▶ A Certificate of Compliance or Certificate of Electrical Safety is a compliance document to ensure electrical installation work is safe and has been carried out by licensed and competent electricians.
- ▶ The use of renewable energy sources such as the Sun and wind to generate electricity is increasing and is driven by concerns over climate change.
- ▶ Inverters, standalone systems and hydrogen-powered technologies are increasingly being used in Australia as renewable energy sources.
- ▶ Green hydrogen is a clean fuel produced by using renewable electricity to electrolyse water, splitting it into hydrogen and oxygen.
- ▶ Grid supply problems can occur when renewables supply energy to the grid.

REVIEW QUESTIONS

1. Which country uses geothermal power as part of the base-load grid?
2. How does coal-powered thermal generation work?
3. Describe the basic principle of electricity generation in an alternator.
4. At what voltage do steam turbine-driven alternators produce electricity?
5. How is the steam that is used to drive the turbine isolated from the reactor in nuclear-powered thermal generation?
6. How is the thermal efficiency of a gas turbine alternator increased?
7. Why is it important to drive a generator at a particular constant speed?
8. Apart from being a clean energy source, what are some advantages of hydro generation over steam generation?
9. What is hot rock technology?
10. How can water be reused for power generation in a hydro scheme?
11. What form of energy describes the losses in d.c. transmission?
12. What is the name given to the system that distributes electricity over a wide geographical area?
13. What device is used to increase and decrease the voltage in a.c. distribution?
14. What are the advantages of three-phase a.c. systems?
15. What is the main disadvantage of the original d.c. supply systems?
16. Describe the principles and advantages of modern d.c. transmission.
17. How are the conductors in a three-phase low-voltage system designated?
18. What are the primary and secondary transmission voltages?
19. What role do substations play in the transmission and distribution of electricity?
20. Who determines how much energy is needed from the electricity supply system at any one time?

CHAPTER 2

Workplace and electrical safety

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ describe the basic legal requirements covering health and safety in the workplace
- ▶ explain the role of safe work method statements in managing health and safety risk in the workplace
- ▶ outline the safety training and instruction requirements that must be undertaken for personal safety in the workplace
- ▶ identify common potential workplace hazards and typical measures for accident prevention
- ▶ identify types of protective equipment and tools required to work safely
- ▶ identify requirements for working on alternate and multiple supply systems
- ▶ safely and correctly connect flexible cords and extension leads
- ▶ describe the risks and control measures associated with high voltage, low voltage, extra-low voltage and high currents
- ▶ identify procedures for low-voltage rescue and application of CPR for an electric shock victim.

Learning how to achieve safety in the workplace is one of the most important aspects of your vocational training and education, and you will continue to put this knowledge into practice throughout your working life. Electricians have multiple roles when it comes to safety.

Firstly, they must carry out their work safely and observe all measures needed to protect themselves and fellow workers against workplace hazards. In addition to common workplace hazards, they must also deal with the dangers of working with electricity. This requires an understanding of the use of work safety practices and how safety is managed in the workplace, including a willingness to cooperate with other workers to recognise and deal with health and safety risks.

Secondly, electricians have a liability to ensure that the electrical systems and equipment they install and maintain are safe and remain safe for all who use them. This requires a thorough knowledge of electrical principles, the *Wiring Rules* and regulations, and the skills to apply this knowledge.

In addition to this, if an accident does occur, those able to give assistance should know how to rescue any victims safely and how to apply emergency treatment.

2.1 Work health and safety

Work health and safety is a major field of study covering a wide range of activities, such as education and training, engineering, science, management, medicine, law and all types of work itself. This chapter gives you an introduction to work health and safety, as well as to your responsibility to work and act safely. You are obliged by law to learn and apply safety practices as part of your electrical education and training, and to continue to do so throughout your career. A person is not competent if they cannot work safely.

Each jurisdiction, that is, each state and territory of Australia and New Zealand, enacts its own laws on work health and safety and, although some of the terminology may differ, these laws are all based on the same principles. Work health and safety (abbreviated as WHS) is the term used in this text when referring to safety at work.

In each jurisdiction the WHS laws are enforced by regulations, and it is essential that you know and understand the particular regulations that apply to your work.

It is every individual's responsibility to take all reasonable steps to ensure the safety of themselves and others!

2.1.1 Regulations, codes of practice and Standards

In Australia, the Federal Government works together with all states and territories and their Work Safe authorities, through Safe Work Australia, to continually improve safety by encouraging policy discussion and research, and promoting consistency in the WHS laws and regulations of the states and territories. **Figure 2.1** provides a snapshot of the purposes and mechanisms of WHS.

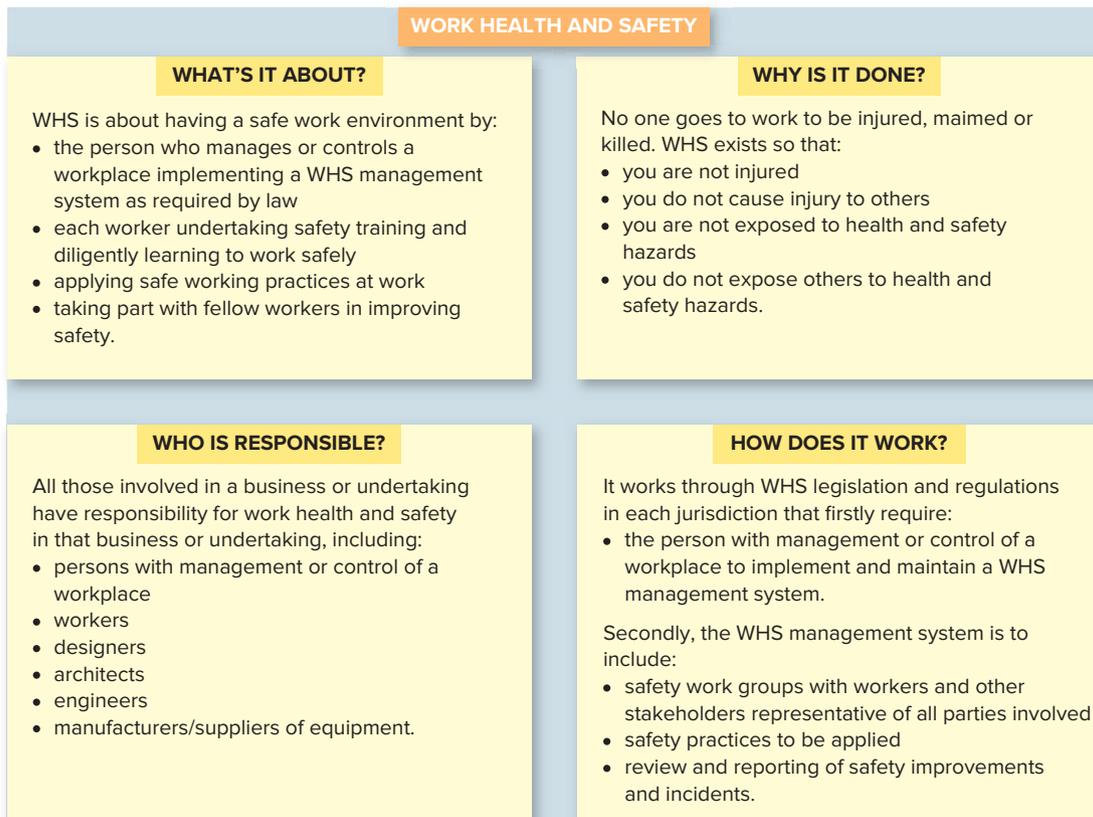


FIGURE 2.1 About work health and safety (WHS)

WHS laws and regulations are supported by codes of practice that are available from the work safety authority in each jurisdiction. These cover work identified as high risk or hazardous, which, for example, is governed by the *Code of practice—Managing electrical risks in the workplace*, as well as dangerous materials and the work environment. In addition, WHS regulations may mandate compliance with a Standard, for example, *AS/NZS 3012 Electrical installation—Construction and demolition sites*.

2.1.2 Managing risk

Persons conducting businesses or undertakings involving management or control of workplaces (commonly employers) have a responsibility to assess any risks to health and safety associated with a hazard, task or circumstance and to implement control measures. A *hazard* is something that has the potential to cause harm or adverse effects, and can take many forms (from liquids that could spill to standing on a ladder), whereas a *risk* is the chance or probability that a person will be harmed or experience an adverse health effect if exposed to a hazard.

The hierarchy of control shown in **Figure 2.2** describes each step in the process for managing risk in the workplace. It has six measures:

1. eliminate
2. substitute
3. isolate
4. engineering controls
5. administrative controls
6. use personal protective equipment (PPE).

Engineering control measures involve a physical change in the workplace as a means of removing the hazard. These could include physical barriers, falling from heights mechanical protection and air ventilation. Administrative control measures include policies and procedures, signage, induction and training.

It is important that each part of a WHS system is formally documented and records are maintained, including minutes of WHS consultations, the need to review any control measures, records of training undertaken by employees, and any health or safety incidents.

2.1.3 Safe work method statements and hierarchy of control

Managing risk in the workplace refers to applying risk-control measures. Safe work method statements (SWMS) are a mandatory requirement for any high-risk work and list control measures to reduce risk in such environments. Working at heights or in confined spaces and working with electricity are examples of high-risk work. A combination of feasible and effective risk-control measures may be needed, depending on the nature of the work to be undertaken, to ensure work tasks are completed safely. Any risk-control measures that are required must be stated in the SWMS. **Section 2.3** covers workplace hazards and control.



CHECK YOUR UNDERSTANDING

1. What is the purpose of codes of practice?
2. What is the purpose of health and safety regulation in the workplace?
3. Who is responsible for safety at work?
4. List four important steps an employer should take to ensure a safe and healthy workplace.
5. State the hierarchy of feasible and effective controls that must be contained in safe work method statements.

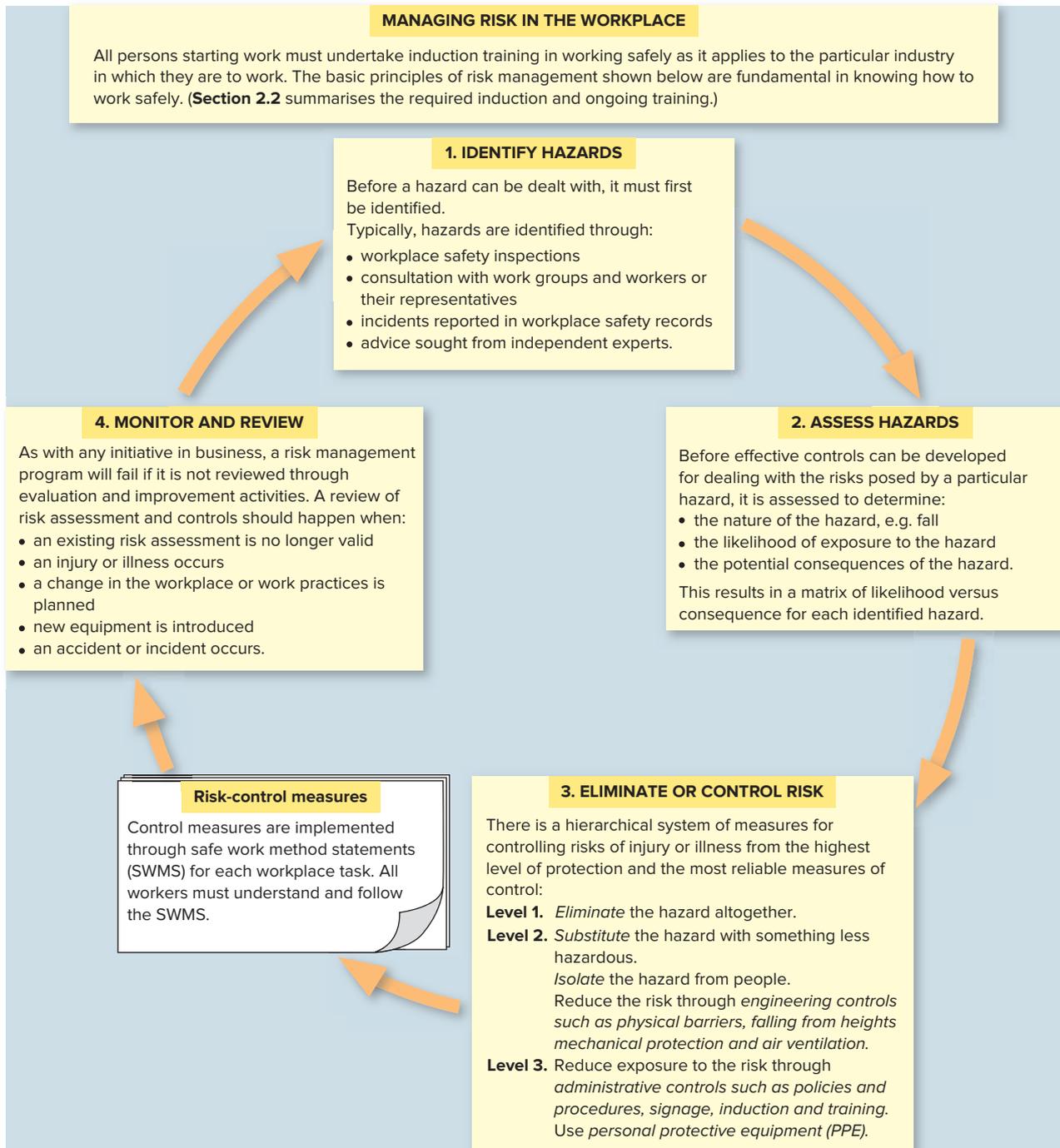


FIGURE 2.2 Managing risk in the workplace

2.2 Instruction, training, information and supervision

To enter and work on a construction site, a person must have complete induction training for construction work, as noted in **Figure 2.3**. The induction training is conducted by a designated registered training organisation that issues what is commonly called a white card as evidence of completion. In addition, electrical apprentices and trainees must undertake WHS competencies specific to electrical work, as summarised in **Figure 2.3**. These are a prerequisite to all other competencies required in order to achieve the status of electrician.



FIGURE 2.3 Work health and safety (WHS) induction

As shown in **Figure 2.3**, WHS induction continues with the enterprise you work for and, over time, as electrical work takes you to different workplaces, each will have its own induction. The induction will cover at a minimum an orientation to the workplace layout and facilities, and any specific hazards. Further to this, work information and training related to safety are provided on an ongoing basis, and you are obliged to participate in this. The content of this information, training and instruction is summarised in **Figure 2.4**.

INFORMATION, TRAINING AND INSTRUCTION

Your employer is required to provide a healthy and safe workplace. This requires the provision of ongoing training. Familiarity and complacency can pose the highest risk. It is commonly the role of an immediate supervisor to provide clear information and instruction on the work at hand and be satisfied you are trained to do the work in the role you are given. The importance of safety can be communicated through pre-start and tool-box talks. The most important things that should be communicated to people starting on a worksite include:

- possible hazards and unsafe situations, particularly in unfamiliar work environments, and the safe work methods to be applied
- clear instruction on the tasks to be undertaken and each individual's role
- clear instruction on the safe work methods to be used
- that PPE is to be used as prescribed in the safe work method statement (SWMS) or job safety analysis (JSA)
- the importance of participating in any safety-related discussions.

SUPERVISORS

Additional WHS training is provided for supervisors as they need a greater understanding of workplace hazards and control measures. This is particularly important for supervising apprentices.

THE WORK UNDERTAKEN BY AN APPRENTICE MUST BE SUPERVISED AT ALL TIMES.

Supervision is to be in accordance with WHS, electrical safety and training regulations.

FIGURE 2.4 Information, training and instruction

**CAUTION**

Electrical workers in service or maintenance roles will often find themselves in unfamiliar working environments. Each time electrical workers encounter an unfamiliar workplace, they should request an orientation on the health and safety hazards present, and the procedures for controlling the risk of illness or injury in the new environment.

The continuing need to work safely means that you are obliged to keep updating your WHS knowledge. Updates are easily obtained through the relevant authority websites.

Remember, you have a responsibility to work safely by following the correct safety procedures at all times. If you believe you are being exposed to a hazard without sufficient controls in place, or you have any doubts about health and safety in your workplace, you are entitled to raise the issue with your supervisor or employee representative.

**CHECK YOUR UNDERSTANDING**

6. Outline the purpose of WHS orientation and training.
7. Why do work supervisors receive additional training?

2.3 Workplace hazards and risk-control measures

A commitment to work safety starts with the enterprise undertaking the work, whether the enterprise is a small or large company or even a sole trader. The commitment is usually reflected in a written policy about how the enterprise will manage WHS and related aspects like risk.

Many industry bodies provide advice on managing WHS, including templates for risk management policy and SWMS. The National Electrical and Communications Association (NECA) has developed a number of these documents that are applicable to the electrotechnology industries. Although at this stage of your apprentice training you will have limited levels of knowledge and skills in electrical work, it is imperative that you understand the hazards and risks and follow all safety instructions and requirements.

Table 2.1 outlines some of the more immediate management policies and practices recommended by NECA NSW with regard to safety.

TABLE 2.1 WHS safety practices developed by NECA NSW

Name	Practice
START RIGHT	<p>START RIGHT is an informal process where an individual or a group pauses and takes time to consider potential WHS aspects of work activities prior to the activities being performed. For each task, simply:</p> <ol style="list-style-type: none"> 1. Stop, step back and observe 2. Think through the task 3. Assess the hazards, pathways and impacts 4. Review and document findings if required 5. Talk it through and complete the task.
STOP RIGHT	<p>STOP RIGHT authorises any individual to stop work if they feel their own safety is being compromised or if they believe the safety of others in the workplace is in doubt. Situations can arise where: a task or hazard is not fully understood; circumstances change and increase a risk; a new hazard is created. Any person or team member can exercise their STOP RIGHT authority in good faith without retribution. To call attention to a STOP RIGHT situation, it is recommended that a team establishes a code such as STOP NOW.</p>
PRE-START (HRA)	<p>Where there is an element of WHS risk on a job, the supervisor may require a <i>hazard risk assessment</i> (HRA) or pre-start to be completed prior to commencing work. This is done in addition to, or as a result of, the START RIGHT. An HRA is a two-stage documented process: stage one assesses task hazards and site-specific hazards; and stage two identifies any SWMS that apply.</p>

2.3.1 Lifesaving rules

The lifesaving rules are a set of rules that relate specifically to high-risk activities and are intended to be strictly applied across all worksites. These rules are an industry benchmark and are reviewed by NECA NSW (see **Figure 2.5**), together with other organisations. They are designed to protect employees and contractors from serious injury or death and have been adopted by many electrical companies as part of the way they work.

LIFESAVING RULE #1

I will always Lock and Tag out all energy sources

Danger tags are for the personal protection of individual employees. No plant, switch, equipment, valve or any other controlling device should ever be operated if a Danger tag is attached.

The isolation of any power source should only be conducted by competent and qualified personnel.

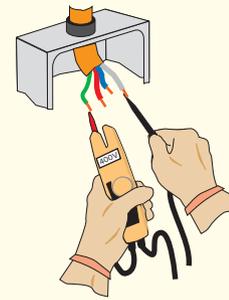


LIFESAVING RULE #2

I will always 'Test before I touch' and confirm DEAD before work

The industry mantra is: TEST EVERY TIME BEFORE YOU TOUCH.

When you isolate, you must test for de-energising. Testing for de-energising is LIVE WORK because you need to make positive contact with the conductors and there is a possibility that the circuit is energised. You must be licensed and competent and, as a minimum, follow the live testing rules.



You must check your test instruments both before and after testing.



Note: Proximity sensors are non-contact indicators and must not be used to prove isolation. They can be useful to detect electrical signals, but are not a reliable confirmation of safe de-energisation or isolation.

LIFESAVING RULE #3

I will never remove another person's Danger tag without written authorisation

Personal Danger tags and locks must be removed by the person who placed them, after the danger or threat has been rectified.



FIGURE 2.5 WHS lifesaving rules developed by NECA NSW

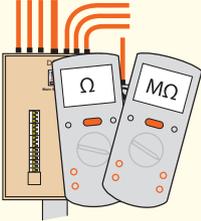
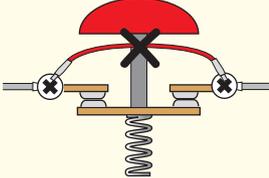
LIFESAVING RULE #4	
I will always thoroughly test completed electrical work before completion	
<p>You are required to undertake work to set standards of workmanship and quality in order to meet reliability, functionality and safety aspects.</p>	
<p>All electrical work is to be carried out in accordance with relevant Australian Standards, and in particular <i>AS/NZS 3000</i> (the <i>Wiring Rules</i>).</p>	
<p>In addition, wiring and equipment installed for construction work and the related electrical practices on construction and demolition sites are to be in accordance with <i>AS/NZS 3012</i>.</p>	
LIFESAVING RULE #5	
I will never disable or override a safety device without written authorisation	
<p>Safety devices must not be overridden, disabled or bypassed without written authorisation. Any authorisation must include the specific device to be disabled or overridden, the reason and approved period of time prior to reactivation, and any additional risk controls to be implemented.</p>	
<p>Examples of safety devices include:</p> <ul style="list-style-type: none"> • alarm systems—cranes, fire systems, overfill alarms, temperature alarms • safety switches/interlocks • trip switches, earth leakage systems (electrical and mechanical) • dead-man switches, E-stops (emergency stops) on conveyors etc. 	
LIFESAVING RULE #6	
I will never work with asbestos without authorisation	
<p>If you and your workers are not trained for asbestos awareness and minor asbestos work, then you are exposed to prosecution under WHS legislation. Having had appropriate training and being authorised by your manager, you can undertake minor asbestos work.</p>	
<p>To work on asbestos, you need to have safe systems of work in place (e.g. SWMS for HRCW and SWP).</p>	

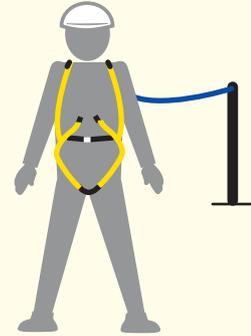
FIGURE 2.5 WHS lifesaving rules developed by NECA NSW (Continued)

(Continues)

LIFESAVING RULE #7

I will always use fall-prevention techniques where there is a risk of falling more than 2 metres

Accidents and incidents associated with working at heights from roofs, unfinished floors, work platforms and ladders are major causes of serious injury and fatality. Be particularly wary of skylights and other fragile, slippery and sloping surfaces on roofs. It is critical to observe all appropriate precautions when working at heights.



LIFESAVING RULE #8

I will always obtain authorisation before entering a confined space

Before entering a confined space:

- A responsible person must confirm and authorise each entrant to enter the confined space.
- A responsible person must confirm the confined space entry as safe.
- All entrants must be trained.
- All entrants must sign on to a confined space entry permit.

Common confined spaces include: sewer and storm water manholes, pits, tanks, excavations deeper than 1.5 m, drains and pipes.



LIFESAVING RULE #9

I will only use the correct tools and equipment for the job it was intended and within its set safety limit

If you are using plant and equipment in the workplace, you must ensure that:

- you are using the equipment in the way it was intended by the manufacturer, i.e. for the purpose for which it was made or constructed; for example, a man lift shouldn't be used as a crane.
- if the plant or equipment has set limits, you are within those limits; an example is the safe workload of an excavator or a crane.



FIGURE 2.5 WHS lifesaving rules developed by NECA NSW (Continued)

LIFESAVING RULE #10	
I will never begin a skilled task, or operate equipment and machinery unless qualified	
No one should commence a task or attempt to operate machinery that requires a qualification unless they hold that specific qualification and it is current.	
Examples of skilled tasks include: trades work that requires licensing—gas work, electrical work, refrigeration etc. They also include other trades work such as work with EWPs, scaffolding, excavators, and hazardous work such as confined space entry, work at heights including ladder work, asbestos work etc.	

FIGURE 2.5 WHS lifesaving rules developed by NECA NSW (Continued)



SAFETY ALERT

- ▶ Danger tags are for the personal protection of individual employees. No plant, switch, equipment, valve or any other controlling device should ever be operated if a Danger tag is attached.
- ▶ The isolation of any power source should only be conducted by competent and qualified personnel.

In addition, NECA NSW has developed a number of generic SWMS related to hazardous work and these are listed in **Table 2.2**.

WHS regulations allow the same risk assessment to be used for similar work in several locations or circumstances where the hazards and risks are comparable, as long as its applicability has been checked for each place or circumstance. This is intended to simplify the process of identifying hazards, assessing risks and setting control measures before commencing work where generic SWMS can be used.

However, the scope of a generic SWMS may be too broad or additional hazards may be identified for a task in a given place or circumstance. In that case, an SWMS for the task and location/circumstance is developed based on the relevant aspect of the related generic SWMS. An example is shown in **Figure 2.6**. As mentioned previously in **Section 2.2**, the hazards, risk-control measures and SWMS for a worksite and job are introduced to workers in WHS induction and reinforced through ongoing training.

TABLE 2.2 Generic SWMS relevant to electrical work

Construction-related SWMS	Examples of hazards
Set-up of worksite and use of tools and equipment	Noncompliance with site rules, overhead powerlines, electrical supplies, ingress/egress of machinery
Use of ladders	Falls from height, faulty ladders
Scaffolds	Clearance from electrical and other services, compliance of structure (authorised persons)
Elevated work platform (EWP)	Non-licensed personnel, surrounding equipment and workers, travelling surface
Restraint and fall-arrest systems	Incorrect selection of equipment, no testing of equipment for compliance, attachment points
Excavation	Incorrect evacuation paths, unclear instructions
Confined spaces	Gaseous atmospheres, low-oxygen atmospheres, undefined escape paths, lack of monitoring
Ceilings, subfloors and other restricted spaces	Confined movement, restricted egress, shock hazard, heat hazard
Working with asbestos	Known cancer-causing substance, zero tolerance, lack of specific work plan
Working with materials containing silica	Respirable crystalline silica dust resulting from chasing, drilling or grinding concrete and tile products and surfaces. Over time this can cause fatal lung disease (silicosis), fibrosis, chronic obstructive pulmonary disease, chronic bronchitis and lung cancer. Hazards can result from poor or no silica dust control plan and lack of air monitoring.
Hazardous areas	Hazards include fumes, vapours, poisons, acids, flammable substances and so on.
Working around high-pressure gas lines	Flammable gases, potential explosion, potential structural failure
Hot works	Burns, scalding, heat stroke
Directional drilling	Hidden services, gas pockets, watertable
Working in artificial extremes of temperature	Effects of extreme heat or cold, lack of breaks from exposure, inappropriate workwear to deal with extremes
Electrical-specific SWMS	Examples of hazards
Low-voltage isolation	Electric shock, incorrect location of isolation, failure to confirm DEAD, lack of communication of required processes to stakeholders
Testing for energised and de-energised states	Faulty test equipment, incorrect selection of equipment to test
Energising and commission	Existing workers still involved, possible fault scenarios associated with equipment malfunction
Data and electrical cable installation	Falls, confined spaces

Example Safe Work Method Statement

A Safe Work Method Statement (SWMS) or equivalent must be completed by the contractor prior to the commencement of any high-risk work.

Name of Contractor responsible for compliance with SWMS:	Helen Jane Sparky	Date:	2/5/19
Company name:	Sparky Enterprises	Workplace location:	Big box factory
High risk job description	Installation of electrical equipment in an existing installation	Completion of Confined Space Entry Permit?	Yes <input type="checkbox"/> N/A X (N/A should only be selected when not working in a confined space)

Personal Protective Equipment (PPE) required to complete the job						
Gloves	Face mask	Eye protection	Working mask	Appropriate footwear	Hearing protection	Protective clothing
<input type="checkbox"/>	<input type="checkbox"/>	X	<input type="checkbox"/>	X	<input type="checkbox"/>	X

What are the work tasks involved? Briefly describe the steps required to perform the task in the order they are carried out.	What are the hazards and risks? List against each step the possible hazards that could cause injury/damage when the task step is carried out.	How will hazards and risks be controlled? List the control measure required to eliminate or minimise the risk.
Identify the work area that the task is to be performed	Unknown environment, local risks, unfamiliar site	Liaise with site representative and ensure local hazards and site safety plans are understood

Version 2.4 MHE Sample

Transport products and installation equipment to site location	Manual handling	Use of appropriate manual handling techniques and trolleys as required
Identify location of switchboard and outlets to be installed	Incorrect switchboard identified	Use site plans and onsite personnel to identify switchboard and what equipment it feeds
Install outlets and cabling	Use of power tools and hand tools	Ensure correct PPE including safety glasses and footwear are used
Test installed circuit and outlets	Low risk, de-energized circuit extra low voltage tester	Ensure safety glasses are kept on
Identify the correct circuit to isolate distribution board isolate and lock out feed to distribution board	Incorrect circuit identified	Use site plans and site personal, check circuit markings on both feeding board and supplied board
Determine distribution board is isolated and de-energized	Board still "energized"	Using a training coworker and an flash protective clothing test distribution board for dead, once confirmed retest instrument on known supply to ensure its function is OK
Fit circuit breaker and cable to the board	Incorrect installation	Ensure correct position of cable and circuit breaker in the distribution board meeting installation rules

Version 2.4 MHE Sample

Reinstall distribution board cover and then energize supply	Manual handling and correct location of isolated supply	Use assistance if required to replace cover and double check supply to be re-energized
Test completed installation	Electric shock	Using a training coworker and an flash protective clothing test new installation as per AS3000
Pack up at end of job and advise customer	Manual handling, new equipment in installation	Ensure manual handling techniques, provide documentation to customer regarding new outlets and advise of completion.

Name	Signature	Date
I have provided site specific risk controls to manage the hazards identified above and will comply with the controls listed above.		
Contractor:	Helen Jane Sparky	
		2/5/19

I understand the risk controls listed above to be implemented to manage the identified hazards associated with the works to be undertaken.

Version 2.4 MHE Sample

FIGURE 2.6 Example safe work method statement (SWMS) for additions to an existing electrical installation

2.3.2 Isolating supply

One of the most important and common safety tasks in electrical work is isolating the supply to a circuit and ensuring the lockout of the circuit so it remains isolated for as long as required. **Table 2.3** illustrates the process for conducting safe isolation of low-voltage supply. An SWMS for the task of 'Isolate, lock out and tag' would reflect all the steps shown in the table.

TABLE 2.3 Isolate, lock out and tag—an example of how it's done.

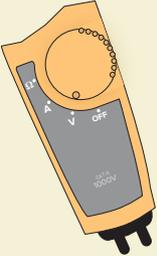
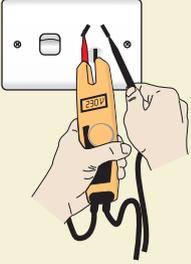
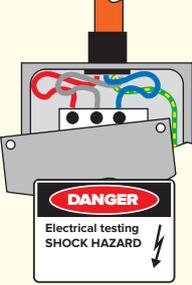
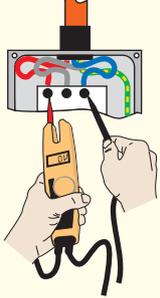
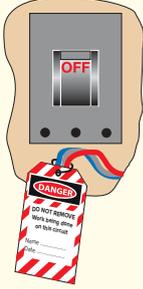
Isolation, lock out and tag steps	Example: isolate, lock out and tag a pump motor circuit		
<p>1. Select, adjust and confirm operation of testing device.</p>	 <p>A Category III meter with the required voltage range is selected.</p>	 <p>The meter is adjusted to measure voltage in the required range.</p>	 <p>The meter is tested to ensure that it is operating correctly on a known live supply.</p>
<p>2. Identify the circuit you are to work on and the point of supply.</p>	 <p>The circuit-breaker labelled as controlling supply to the circuit is switched off, locked off and tagged.</p>	 <p>The area is made safe before the pump switch gear cover is removed.</p>	 <p>A voltage test at the switch gear terminals indicating 0 volts shows that the circuit-breaker probably de-energised the circuit.</p>
<p>3. Confirm the isolation device at the point of supply is correct.</p>	 <p>The lock-off and tag are removed from the circuit-breaker identified as controlling supply to the circuit and it is switched on.</p>	 <p>A voltage test at the switch gear terminals showing a line voltage of 400 volts confirms that the circuit-breaker does control supply to this circuit.</p>	

TABLE 2.3 Isolate, lock out and tag—an example of how it's done (Continued)

Isolation, lock out and tag steps	Example: isolate, lock out and tag a pump motor circuit		
4. Complete and secure isolation.	 <p>The circuit-breaker identified and confirmed as controlling supply to the circuit is switched off, locked off and tagged.</p>	 <p>A voltage test at the switch gear terminals showing 0 volts finally confirms that the circuit-breaker has de-energised the circuit.</p>	 <p>An alternative measure where locking facilities are not fitted is to disconnect circuit conductors from the circuit-protection device and tag.</p>

It is important to always check test instruments are working properly before and after testing. If a supply source is not known, test equipment proving devices are commercially available for this purpose, such as those shown in **Figure 2.7**. This figure shows an instrument capable of proving multimeter a.c. and d.c. voltage measurements and another with the capability for proving multimeter a.c. voltage measurements and volt sticks.

**FIGURE 2.7** Proving devices for testing instruments

Tony Jones

When testing a supply, a measurement reading of zero volts can mean one of two possibilities: the circuit under test is de-energised OR a failed test instrument—it is important to know which one has occurred, so it is essential to ensure instruments are working correctly. Checking your test instrument both before and after testing requires a known live supply or a proving device. More detailed information on testing devices and testing methods is provided in **Chapter 15**.

The most important safety advice is this: do not work live and ALWAYS treat all conductors as energised until proven otherwise. Test before you touch! (See **Figure 2.8**.)

Special care needs to be taken when working with circuits in an existing installation and, in particular, if they have been added to or altered. In these installations, circuit markings are not always clear and an incompetent or unqualified person may have done the work. Advice provided for electrical apprentices and electrotechnology workers in many jurisdictions is to follow the ABC of:

- ▶ Assume nothing
- ▶ Believe no-one
- ▶ Check everything.



FIGURE 2.8 Test before you touch

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In addition, sometimes cable insulation deteriorates and accessories become brittle over time, adding to the hazards for an electrical worker. Areas of greatest risk in these installations are switchboards and spaces where movement is restricted, such as within ceilings and under floors.



SAFETY ALERT

Isolate and lock out ALL supplies to equipment to be worked on. Some equipment can become energised by the operation of control devices, such as hot-water systems with off-peak supply.

Like any electrical work, a job in an existing installation must start with a hazard risk assessment and, if the testing of energised circuits cannot be avoided, the safe work method will invariably include the assistance of a competent person. Note that the occupier of a premises is obliged to justify why a circuit or installation cannot be de-energised in order that electrical work may be carried out safely.

It is worth noting that in Western Australia and other jurisdictions, it is now illegal to work in a domestic roof space without de-energising the installation, as covered in the electrical regulations. The WA regulator has provided documentation to give to a homeowner/business owner outlining why the installation must be de-energised. There have been multiple cases resulting in electric shock and electrocution in domestic roof spaces.

2.3.3 Isolating alternate and multiple supplies

Isolating alternate and multiple supplies involves first thoroughly preparing for the task ahead, identifying known supply, circuits and the specific circuit to be isolated and tested, and then performing the isolation of the installation.

Preparing to work on alternate supplies and multiple supply systems

Preparing to work on alternate supplies involves reviewing equipment, building and services information relevant to the installation. The nature of the site is captured in specific information found in manuals, drawings and operational information. Electrical drawings, together with existing shutdown and start-up operational procedures for plant, equipment and energy supplies, should be available for workers to refer to.

Relevant WHS/OHS workplace procedures should also be reviewed. Workplace hazards associated with start up, shutdown, operation and isolation of energy sources need to be identified, risks assessed and appropriate control measures put into place.

Electrotechnology workers need to be aware of the impact of electrical supply on other energy sources used with operational plant and equipment. Shutdown and start-up procedures are different from isolation, de-energisation and energisation procedures.

Prior to any supply system shutdown, relevant affected parties need to be consulted and advised of what the work will entail. Permission and authorisation approval(s) is required and the consultation process may involve dealing with your supervisor, the site foreperson, manager, designated staff members and other affected trade or services areas.

Preparation for this work includes ensuring the required tools, equipment, testing devices and workplace procedures are required and available. Tools, equipment and testing devices must be checked for correct operation, function or damage. Preparation includes assessing the worksite and typically involves:

- ▶ locating and interpreting site-specific information
- ▶ locating switchboard(s) and circuits
- ▶ applying awareness of unidentifiable supply systems
- ▶ locating inverter energy systems (IES) and supply systems
- ▶ identifying and locating isolation devices
- ▶ identifying and locating supply systems conductors.

Identifying alternate supplies and multiple supply systems

Site procedures for isolation and shutdown must be obtained and interpreted using documentation and drawings showing the switchboard(s) involved, known supply, circuits, and the specific circuit to be isolated and tested. Labelling and indications of generation system/s connected on site are to be located, interpreted and checked against electrical diagrams. These system include:

- ▶ renewable energy IES
- ▶ grid connected IES with standalone functionality
- ▶ standalone IES
- ▶ photovoltaic array systems
- ▶ micro-inverters
- ▶ engine-driven generating sets
- ▶ battery energy storage systems.

Isolating and re-instating alternate and multiple supply systems

Isolation can be performed once preparation for work and identification of all energy systems, sources (electrical and non-electrical) and isolation points has been carried out and site-specific organisational policies and procedures have been observed. Supply system shutdown procedures must be carried out following safe work practices, in accordance with site-specific information and OHS/WHS and workplace and regulatory requirements, which include:

- ▶ identifying correct isolation device(s)
- ▶ applying safe isolation practices
- ▶ identifying live conductors
- ▶ correctly using testing equipment
- ▶ confirming systems are isolated
- ▶ tagging out all supplies.

Supply system circuits are to be tested, confirmed as de-energised and locked out. Battery storage system integrity should be checked and systems inspected and tested for compliance with industry standards and regulatory requirements.

The supply system is then re-instated after isolation, tested for correct operation and confirmed as re-energised in accordance with site-specific information and organisational and workplace requirements.

Completing work and document records

On completion of the isolation of the installation, the various tasks and activities performed are to be recorded in order to meet organisational and compliance purposes and to keep electrical drawings and documents updated. The worksite should be cleaned, any waste material removed and the work area made safe. Relevant personnel should be notified of re-instatement of supply systems, in accordance with workplace procedures and regulatory requirements.

Battery energy storage systems and battery safety

Working with battery systems requires specific precautions, and *AS/NZS 5139:2019* outlines requirements for general installation and safety requirements for battery energy storage systems (BESS). BESS are designed to capture and accumulate energy from different sources, storing it in rechargeable batteries for later use. BESS may be set up as:

- ▶ renewable energy IES
- ▶ grid-connected IES with stand-alone functionality
- ▶ standalone IES
- ▶ engine driven.

Working with batteries has a number of potential hazards, which include:

- ▶ Arc flash from a short-circuit or fault can have temperatures above 12 000 °C, which are capable of causing fires and explosions or melting metal.
- ▶ Hazardous chemicals can result from excessive temperatures and pressure generated within the battery from over-charging or a short-circuit, causing the battery to rupture or explode. Fluid or gel electrolyte can leak from a ruptured casing, resulting in toxic fumes, burns, corrosion or explosion.
- ▶ Fire and explosion can result from inadequate ventilation for the emission of hydrogen, oxygen and flammable gases.
- ▶ Banks of battery cells can deliver a severe electrical shock and must be electrically isolated while any work is being performed. Terminals must be isolated with secure insulating caps or barriers.

BESS documentation must include manufacturers' maintenance requirements.

Islanding and anti-islanding

Anti-islanding is a network safety condition for grid-tied IES. For standalone systems and microgrids, intentional islanding during an outage, disconnecting the local circuit from the grid, results in the distributed generator(s) and battery system to power the entire local load.

During a network outage or fault condition, generating sources feeding the grid need to be disconnected for safety reasons (anti-islanding). Uncontrolled supply into a de-energised grid system will cause parts of the grid to become live and present an electric shock hazard for electrical workers.

2.3.4 Personal protective equipment and tools

An essential part of electrical work is knowing about personal protective equipment (PPE) and how and when it must be used. SWMS usually specify the PPE that must be used for a task. Typically, the minimum dress code for an electrotechnology worker is a shirt with sleeves, shorts, approved steel-capped work shoes or boots and an approved hard hat. Clothing should not be loose fitting, and jewellery and footwear such as sports shoes, sandals or thongs must never be worn in the workplace. Conditions in some worksites may call for full-length sleeves and work trousers or overalls. An example is switchboard work and electrical meter upgrades (see **Figure 2.9**).

Table 2.4 lists common types of PPE and the work activities they are typically used for. In situations that expose workers to live components and arc flash, PPE rated for greater than the incident arc-flash energy at the location of the work must be used.



FIGURE 2.9 Switchboard work

Tony Jones

TABLE 2.4 Workplace hazards and risk control—personal protective equipment (PPE) and tools

Approved* PPE	Required use
Minimum dress code: <ul style="list-style-type: none"> • shirt with sleeves • shorts, trousers or overalls • steel-capped work shoes or composite boots 	These must be worn in all workplaces. Steel-capped work shoes or composite boots provide the best protection against foot injuries. Composite toe caps are lighter than steel caps and made of non-conductive materials like Kevlar, plastic, fibreglass and carbon fibre. Workplaces where flammable materials may be present require clothing to be of antistatic material. Although the minimum rating of garments is 4 Cal/cm ² (calories per square centimetre) flame-retardant material, these should be a minimum ATPV of 5.6 Cal/cm ² .
Hard hats	These are required on all construction sites and any other workplaces where there is a risk of head injury.
Gloves	General work gloves are used in manual handling or where there is a risk of cuts or abrasions. Manufacturers' instructions in handling chemical glues, like those used for PVC conduit and chemical fixings, may include the use of special protective gloves.
Goggles or safety glasses	Any cutting, drilling or grinding operation requires eye protection. Wraparound types are more effective in providing full eye protection. There are less obvious activities where eye protection may be necessary, such as the termination of some cables like steel wire armoured (SWA) types.

(Continues)

TABLE 2.4 Workplace hazards and risk control—personal protective equipment (PPE) and tools (Continued)

Approved* PPE	Required use
Anti-flash glasses	These are worn in the vicinity of welding operations to prevent ultraviolet (UV) damage to the eye. They are not to be used for welding itself.
Face masks	These are used where full-face protection is necessary, such as in some metal-grinding operations.
Ear muffs/ear plugs	These are worn when noise levels exceed 85 decibels; this includes any cutting, drilling or grinding operation. They are also needed around any construction or plant machinery.
Respirators	These are selected for the particular dusts and chemical vapours or fumes from which protection is required. Dust from cutting and drilling operations is probably the most common respiratory hazard in electrical work.
Harnesses and anchors	These are worn when working at height (e.g. above 1.8 m) to arrest falling.
Mats, barriers and gloves	These are used when working in the proximity of live electrical equipment.
Arc-flash protection	The level of arc-fault protection increases with the prospective short-circuit (PSC) current. For PSC of 40 to 80 kA, a minimum ATPV of 20 Cal/cm ² is required.
Insulated tools	These are used when working in the proximity of live electrical equipment.

*Approved PPE means equipment that is designed and manufactured to comply with the relevant Australian Standard.



SAFETY ALERT

Tips for the safe use and maintenance of hand tools:

- ▶ Seek advice from a trainer or mentor on the correct use of tools you have never used. Don't assume you know.
- ▶ Check the condition of a tool before you use it—damaged tools can be dangerous.
- ▶ When using adjustable tools, always adjust them to the correct setting before use.
- ▶ Select the tool designed for the job. For example, using a screwdriver as a chisel will damage the handle, insulation and tip, making it unusable for the job it is intended for, namely, tightening and loosening screws. In addition, the tip of the screwdriver may break and fly off, injuring you or other workers.
- ▶ Select spanners and screwdrivers to suit the type and size of bolt, nut or screw they are to be used on. Otherwise they will slip; this is a common cause of hand injuries.
- ▶ Store tools properly to protect them from damage and corrosion.
- ▶ Repair or replace damaged tools. For example, the so-called mushroom head that develops with use of impact tools such as masonry chisels should be periodically ground back to prevent the shattering that causes fragments to fly off.
- ▶ When the insulation on insulated tools is damaged, the tool should be replaced.
- ▶ Keep the cutting edges of cutting tools such as drill bits and chisels appropriately sharp.



SAFETY ALERT

Tips for the safe use and maintenance of power tools:

- ▶ Seek advice from a trainer or mentor on the correct use of a power tool you have never used. Don't assume you know.
- ▶ Check the condition of portable power tools before use—mains-connected tools must have a current safety tag.
- ▶ Check the condition of extension leads before use with a portable power tool—they must have a current safety tag.
- ▶ Ensure mains-powered tools are supplied from a socket-outlet protected by a residual current device (RCD) in accordance with *AS/NZS 3012* (or equivalent code of practice)—this is a mandatory requirement for construction sites.
- ▶ Use personal protective equipment (PPE)—usually eye and hearing protection is a minimum requirement.
- ▶ When using power tools, make sure you are in a secure and balanced position.
- ▶ Do not use power tools in a flammable atmosphere. ALL power tools dissipate enough energy to ignite a flammable gas or vapour in the atmosphere. Some of the less obvious flammable atmospheres are found around curing adhesives such as contact and PVC cements.
- ▶ Store tools properly to protect them from damage and corrosion.

Electrical workers have a huge variety of hand and power tools available to them, each designed for a particular job. How well they do the job largely depends on user competence, that is, whether you use them safely and correctly. Incorrect use and poor maintenance are the greatest hazards posed by hand and power tools. Do not assume that you know or should know how to use a tool if you have not been instructed in its use. The correct techniques for using even common hand tools are not always obvious, and failure to use those techniques is likely to result in cuts, abrasions, bruising and possibly more serious injuries.

2.3.5 Hazardous manual tasks

When completing any task, it is essential to consider whether the task can or is likely to cause harm to the person undertaking it or to other people. This is especially important when considering manual handling tasks, which include lifting, pulling, pushing, holding or restraining materials or equipment. Consider the following before undertaking any of these tasks.

Lifting and lowering

Situations where a worker is required to lift or lower an item of equipment or material are very common and must be planned to avoid injury. The nature of the task and the weight of the item must be determined and the correct procedure used. This may involve using more than one person, or using a trolley, hoist or crane. If lifting and lowering are not properly planned, serious injuries to the back and other parts of the body can result. These injuries may last a lifetime and can be caused by even the simplest of tasks if undertaken incorrectly. The risk should not be taken lightly!

Pushing and pulling

When moving materials or equipment, they may need to be positioned and repositioned in the correct location. These activities can also place the worker at risk of serious injury if proper planning and procedures are not followed. The use of jacks, lifting equipment, rollers and levers is often required, and the task needs to have an appropriate risk assessment undertaken and details of the weights obtained. Pushing and pulling tasks include positioning switchboards, moving large cable drums and locating motors.

Holding and restraining

During the process of equipment installation, there will be occasions when plant or equipment needs to be permanently or temporarily restrained or held in position. When undertaking these tasks, a worker must fully understand both the item to be restrained and the method to be used. Many injuries have resulted from poor methods of restraint that have resulted in equipment falling or moving, causing injury or death. Equipment used for holding and restraining should be rated for the task and should meet the appropriate safety standards and certification. Allowing a worker to simply hold in place a large or moving item places the worker at significant risk of harm; suitable methods, including ropes, restraints and fixings, should be employed.

2.3.6 Workplace safety signs

Safety signs are an effective way of drawing attention to potential hazards and risks, and are colour coded to help readers quickly identify the action to be taken or the procedure to be followed. **Table 2.5** shows common safety signs encountered in the workplace.

TABLE 2.5 Common workplace safety signs

	<p>Mandatory signs These signs specify an instruction that must be carried out. Symbols (or pictograms) are depicted in white on a blue circular background. Sign wording, if necessary, is in black lettering on a white background.</p>
	<p>Prohibition signs These signs specify behaviour or actions which are not permitted. The annulus and slash are depicted in red over the action symbol in black. Sign wording, if necessary, is in black lettering on a white background.</p>
	<p>Warning signs These signs warn of hazards or a hazardous condition that is not likely to be life-threatening. The hazard symbol is black on a yellow background and a triangle is depicted around the hazard symbol. Sign wording, if necessary, is in black lettering on a yellow background.</p>
	<p>Fire signs These signs advise the location of fire alarms, fire-fighting equipment or emergency phones. They contain a white symbol and/or text on a red background.</p>
	<p>Emergency information signs These signs indicate the location of, or directions to, emergency-related facilities (exits, first aid, safety equipment, etc). They feature a white symbol and/or text on a green background.</p>
	<p>Danger signs These signs provide warning when a hazard or a hazardous condition is likely to be life-threatening. The word DANGER is featured inside a red oval inside a black rectangle.</p>
<p>General information signs These signs are not referred to in <i>AS 1319</i> but are available due to popular demand. They communicate information of a general nature and often refer to housekeeping practices, company practices and logistics.</p>	

Fire safety

Fires and fire safety are a very important area of knowledge and understanding in the electrical industry. You may be faced with fires created by others, but the nature of electricity can also create the heat and sparks to start fires. Fire awareness and the correct selection of fire-fighting equipment are vital skills, and you should always make time to familiarise yourself with the equipment on the worksite and its correct use.

Figure 2.10 is a typical fire selection chart for the correct selection of fire extinguishers to put out specific types of fires. Individual fire extinguishers will have these details written on them as well. Incorrect selection and use of fire extinguishers can make a situation worse.

FIRE EXTINGUISHER SELECTION CHART								
Class & type of fire	Colours	A	B	C	D	(E)	F	
Type of extinguisher		Wood, paper, plastic	Flammable & combustible liquids	Flammable gases	Combustible metals	Electrically energised equipment	Cooking oils and fats	
Water		✓	✗	✗	✗	✗	✗	Dangerous if used on flammable liquid, energised electrical equipment and cooking oil/fat fires
Carbon dioxide (CO ₂)		LIMITED	LIMITED	✗	✗	✓	✗	Not suitable for outdoor use or large class A fires
Dry chemical powder (ABE/BE)		✓ AB(E)	✓	✓	✗	✓	✗ AB(E)	Look carefully at the extinguisher to determine if it is a BE or ABE unit
		✗ B(E)					✓ B(E)	
Foam		✓	✓	✗	✗	✗	LIMITED	Dangerous if used on energised electrical equipment
Wet chemical		✓	✗	✗	✗	✗	✓	Dangerous if used on energised electrical equipment
Fire blanket		LIMITED	LIMITED	✗	✗	✗	✓	Fire blankets most effective against oil and fat fires, and for extinguishing clothes on fire; must be replaced after each use

As per AS 2444 & AS 3745

FIGURE 2.10 Fire extinguisher selection chart

2.3.7 Dealing with harmful substances

Harmful substances are those that can affect health, from minor short-term irritations to life-threatening and long-term illnesses. Manufacturers' instructions in the safe use of potentially harmful materials commonly used in electrical work, such as chemical fixing and jointing resins and PVC adhesives, should be included in risk-control methods.

All substances used in the workplace must have a *material safety data sheet* (MSDS) available for them in a defined location on the site. The MSDS allows workers to fully understand the risks and procedures associated with the substances they will be working with and around. MSDS are available from a variety of sources, and the sellers and producers of these substances must produce an MSDS on request. Some typical harmful products used in electrical work are adhesives, chemical fixings and insulating materials.

Asbestos and polychlorinated biphenyl

Asbestos and polychlorinated biphenyl (PCB) are two very hazardous substances, now banned from use, that may be found in older existing installations and electrical equipment. Asbestos may be present in electrical insulation of cables subject to high temperatures, such as wiring in heating and cooking appliances, general insulation, pipe

lagging, construction sheeting and many other locations. Most metering panels installed up to 1998 can be assumed to contain asbestos as a reinforcing material. Asbestos is recognised as causing mesothelioma, asbestosis, pleural plaques and lung cancer. There is a requirement for organisations to maintain an asbestos register that identifies all locations that contain asbestos-related materials. PCB is a colourless, odourless, viscous fluid, similar to a synthetic oil, that was used as a **dielectric** (insulator) in capacitors and transformers. PCB is known to cause severe skin rashes and chemical-induced acne, and has been linked to the development of liver cancer.

Therefore, it is very important that the labelling, handling and storage of dangerous chemical goods is carried out with extreme care, particularly when it comes to:

- ▶ substances used for fixing, such as Chemfix
- ▶ resins used in insulation and termination of seals
- ▶ chemicals used for cleaning electrical components.

The imperative in this is to carefully follow all WorkCover and SafeWork codes of practice for handling harmful substances, including their disposal.



CHECK YOUR UNDERSTANDING

8. Identify four examples of site-specific documentation.
9. Who needs to be consulted to ensure work is coordinated effectively with others?
10. Provide three examples of inverter energy systems.
11. What is a key requirement for isolating alternate supplies and multiple supply systems?
12. Name eight common industry hazards.

2.4 Safety of electrical installations and equipment

The minimum standards for ensuring the safety of electrical installations are set out in the Australian/New Zealand Standard for Electrical Installations, known as the *Australian/New Zealand Wiring Rules AS/NZS 3000:2018*. Electrical workers engaged in the installation, repair and maintenance of electrical systems and equipment have a responsibility to ensure that such systems and equipment comply with this Standard and are safe for others to use.

The hazards associated with electrical installations and the risk-control measures in the *Wiring Rules* are summarised in **Figure 2.11**.

You will learn more about how to apply the *Wiring Rules* and other Standards in later chapters. However, there are three aspects of the safety of electrical installations and equipment that you need to be aware of at this stage. These are: (1) the purpose of earthing; (2) flexible cords and extension leads; and (3) special requirements for electrical installations in environments that may degrade normal safety measures.

2.4.1 Protective earthing

The correct earthing of all exposed conductive parts of electrical equipment is one of the most important factors in protecting the user of electrical equipment from the risk of electric shock. The rules for earthing are covered by the *Wiring Rules* in *Section 5 Earthing arrangements and earthing conductors*.

The purpose of earthing is illustrated in **Figure 2.12**, which shows current flow in the protective earthing conductor when insulation fails. The RCBO senses the difference in the active and neutral current, almost instantly trips open and so removes the danger. All RCBO trips should be properly investigated!

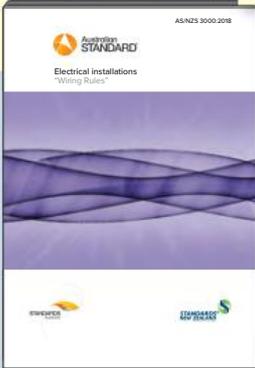
ELECTRICAL INSTALLATION — HAZARDS	ELECTRICAL INSTALLATION — RISK-CONTROL MEASURES
<ul style="list-style-type: none"> • Electric shock • Physical injury • Burn injury • Fire • Explosion 	<ul style="list-style-type: none"> • Protection against contact with live parts or exposed conductive parts if a fault occurs in the system • Protection against the ignition of flammable materials and spread of fire • Protection against high temperatures and the magnetic effects of overcurrent or fault currents • Protection against the hazards of abnormal voltages • Protection against injury from mechanical movement of electrically actuated equipment.
	
<p>The Standard provides this protection by stipulating the requirements for:</p> <ul style="list-style-type: none"> • methods of control and protection • the design of the installation • the electrical equipment used • the methods of installing electrical equipment • inspecting and testing the installation to ensure it is safe to use. 	

FIGURE 2.11 How the *Wiring Rules* set the standard for ensuring the safety of electrical installations

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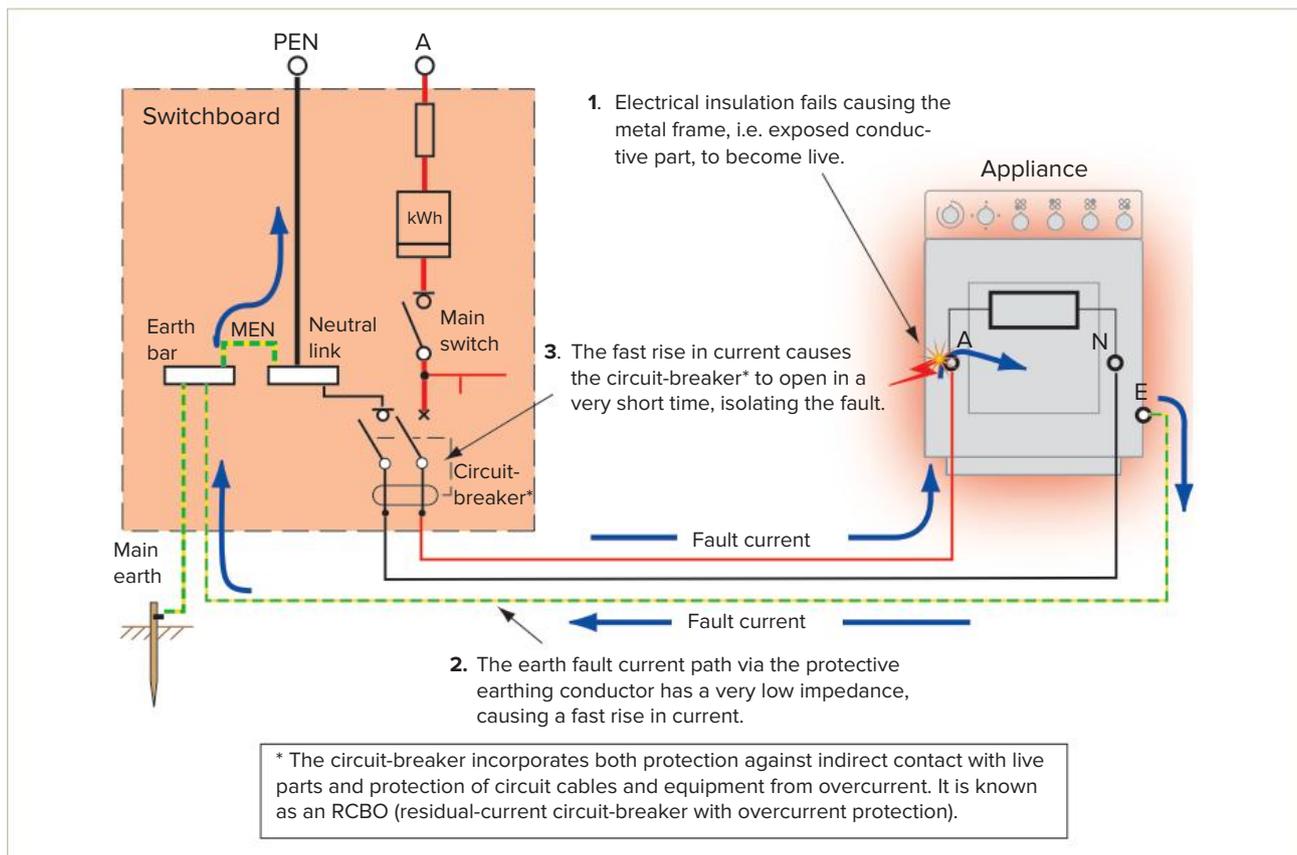


FIGURE 2.12 Purpose of earthing

Appliances marked **DO NOT EARTH—DOUBLE INSULATED** or with the symbol  must not be earthed. You will learn more about earthing in **Chapter 12**.

2.4.2 Flexible cords and extension leads

The number of electrical fatalities in Australia and New Zealand associated with damaged, deteriorated or incorrectly connected flexible cords and extension leads has significantly reduced in recent years. The probable reasons for this are:

- ▶ the supply of appliances from manufacturers with molded plug-and-cord sets already fitted
- ▶ the availability of ready-made molded extension lead sets
- ▶ the requirement in most jurisdictions for commercially used cord-connected appliances and extension lead sets to be periodically inspected and tested
- ▶ the mandatory installation of residual current devices (RCDs) as additional protection against indirect contact with live parts (*Clause 2.6.3 Additional protection by residual current devices*).

However, homemade leads and plug-and-cord sets made up by unskilled persons are still found to be the cause of electrical accidents. Only use leads and appliances with a manufacturer's or current safety tag.

As a skilled electrical worker, there will be many occasions when you are called on to make up or repair cords and extension leads. Examples are shown in **Figures 2.13** and **2.14**.

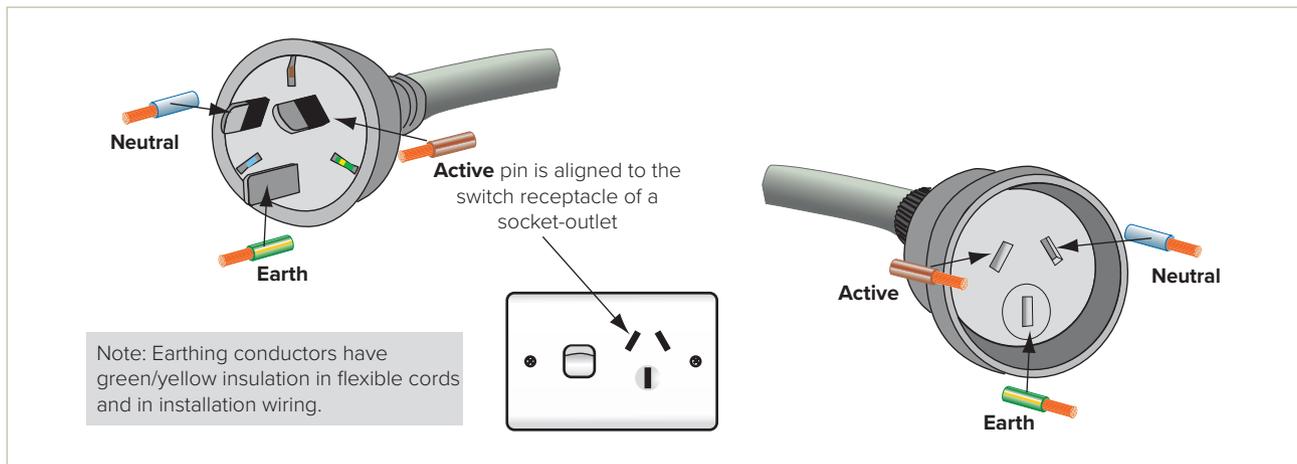


FIGURE 2.13 Making up a single-phase cord extension lead

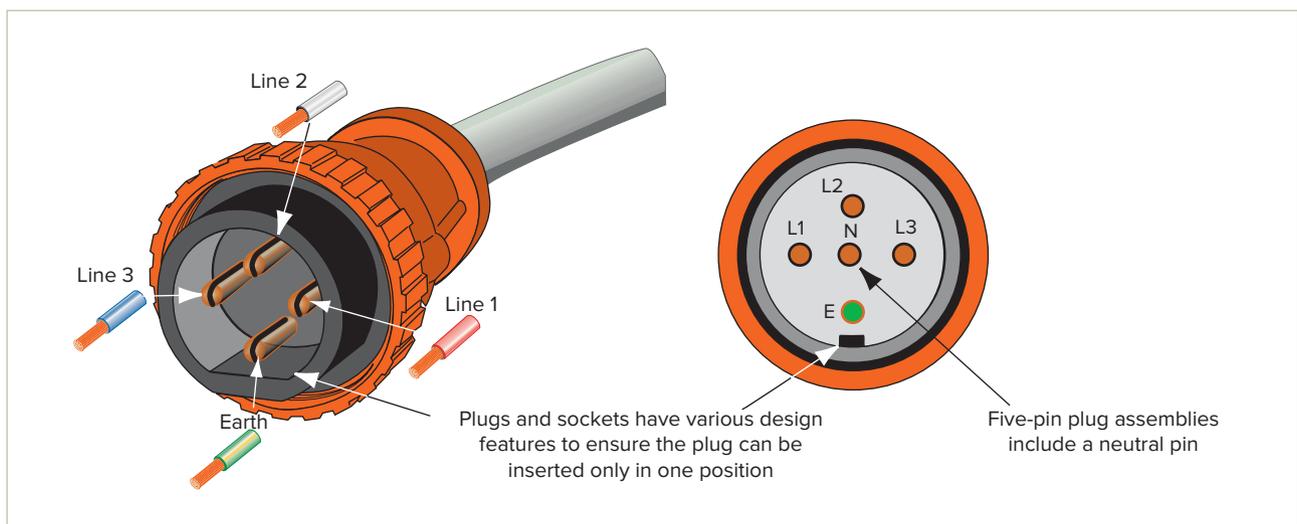


FIGURE 2.14 Connecting a multi-phase plug and cord

AS/NZS 3760 In-service safety inspection and testing of electrical equipment sets out the procedures for appliance inspection and testing and is covered in **Chapter 15**.

2.4.3 Damp areas

Another part of electrical installations where the user may be at risk of electric shock is areas that are damp or wet in normal use. For example, people in a swimming pool or spa pool area usually wear little clothing and have bare feet and wet skin. This makes them more susceptible to a serious electric shock because effective body resistance is lower than in most other situations. It is possible under some fault conditions for the water of a pool or bath to become live, and even a small electrical current in the water can cause a range of physiological effects that can cause harm to a person.

Section 6 of the *Wiring Rules* calls these areas *damp situations*, a term that covers the rules for electrical installations in bathrooms and around swimming pools, water features, refrigerated rooms, saunas and areas that are regularly hosed down. In summary, the rules restrict the location of socket-outlets, switches and appliances within designated areas, and the types of enclosures that may be used. These rules, along with rules for other parts of electrical installation, are covered in future chapters.



CHECK YOUR UNDERSTANDING

13. What is the main purpose of the *Wiring Rules*?
14. Why is it important to ensure that exposed conductive parts are electrically connected to the general mass of earth?
15. What method of supplementary protection is used to protect from indirect contact to the earthed parts of a domestic appliance?
16. Name one type of appliance construction that must not be earthed.
17. List four areas of the electrical installations known as *damp situations* covered by the *Wiring Rules*.

2.5 Hazards of working with electricity

Regard all electricity as extremely hazardous whether the voltage is high (greater than 1000 V a.c. or 1500 V d.c.), low (less than high voltage but greater than 50 V a.c. or 120 V d.c.) or extra-low (less than low voltage). The primary hazard of electricity is an electric shock affecting normal breathing and heart function. In addition, as current and its duration through the body increase, body tissue is burnt irreversibly. The secondary hazard is falling or being thrown by an electric shock, even one at very low voltages, causing impact injuries.

The other main hazard of electricity is the amount of energy that is released in an arcing fault when the air ionises—becoming a conductor and heating to more than 3000 °C. This is followed by an explosion caused by rapid expansion of the surrounding air and the spraying of molten metal from electrical components caught in the arc (as shown in **Figure 2.15**). The frightening thing is that this all happens in much less than a second. Any person within the vicinity of such an event, if not killed, will suffer horrific and disabling burns, damaged eyesight due to the ultraviolet (UV) radiation and possibly other physical injuries.

Irrespective of the voltage, any electrical source that can supply a high current, even the humble 12 V car battery, has the potential to produce a hazardous arc fault. Note that *Clause 2.5.5* of the *Wiring Rules* requires arc-fault protection for switchboards with a supply current of 800 A or more while in service or undergoing maintenance.

An arc fault can be caused by a build-up of dirt and moisture across insulation between parts, a voltage transient or by an electrical worker inadvertently causing a short-circuit through unsafe work practices.



Any person in the vicinity of this switchboard when the arc fault occurred would be seriously injured, if not killed.

FIGURE 2.15 Results of an arc fault



SAFETY ALERT

Do not be exposed to electrical hazards

Exposure to such hazards is totally unnecessary and is easily avoided by the following control measures:

- ▶ Do not work *live*.
- ▶ Never draw cables into an enclosure with exposed live parts, such as a live switchboard.
- ▶ If it is necessary to work in the vicinity of exposed live parts, follow all hazard-control measures, including use of insulation barriers and personal protective equipment (PPE).
- ▶ Follow all isolation and lock-out hazard-control measures. There may be more than one source of supply; for example, off-peak supply, alternative energy sources such as photovoltaic arrays and standby generators.
- ▶ Identify isolation by testing—do not rely on switchboard markings.
- ▶ Follow all hazard-control measures when testing for isolation and finding faults.

Another situation that poses a high risk of electric shock is fallen distribution wires caused by a storm or road accident, as illustrated in **Figure 2.16**. Dealing with fallen, broken or sagging distribution lines is not within the domain of most electricians, and it should be left to the energy distributor and emergency services to remedy the situation.

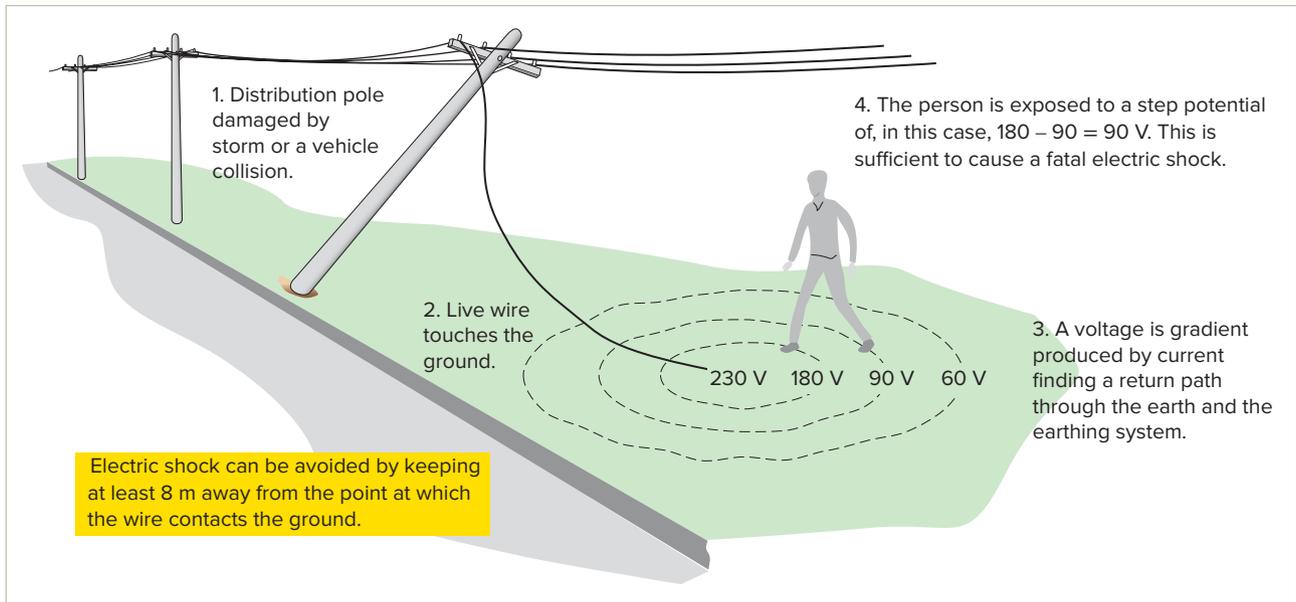


FIGURE 2.16 Fallen distribution wires

2.5.1 Effects of electric current on the human body

Electric shocks caused by direct contact with live parts of an electrical installation, or by indirect contact with metal structures made live by a fault, can occur without warning and are often fatal.

It is the amount of current and the duration and path of its flow through the body that injure and kill. Warnings about voltage are given because the amount of current flow is dependent on the voltage; that is, the higher the voltage, the higher the current for a given impedance (Ohm's Law). The impedance in this case is that of the skin and the current path through the body. Present knowledge of body impedance and effects of current is based on statistical evidence gathered over many years of experimentation and real-life incidents, and is expressed as a probability for a percentage of the population. See **Figure 2.17** for an example.

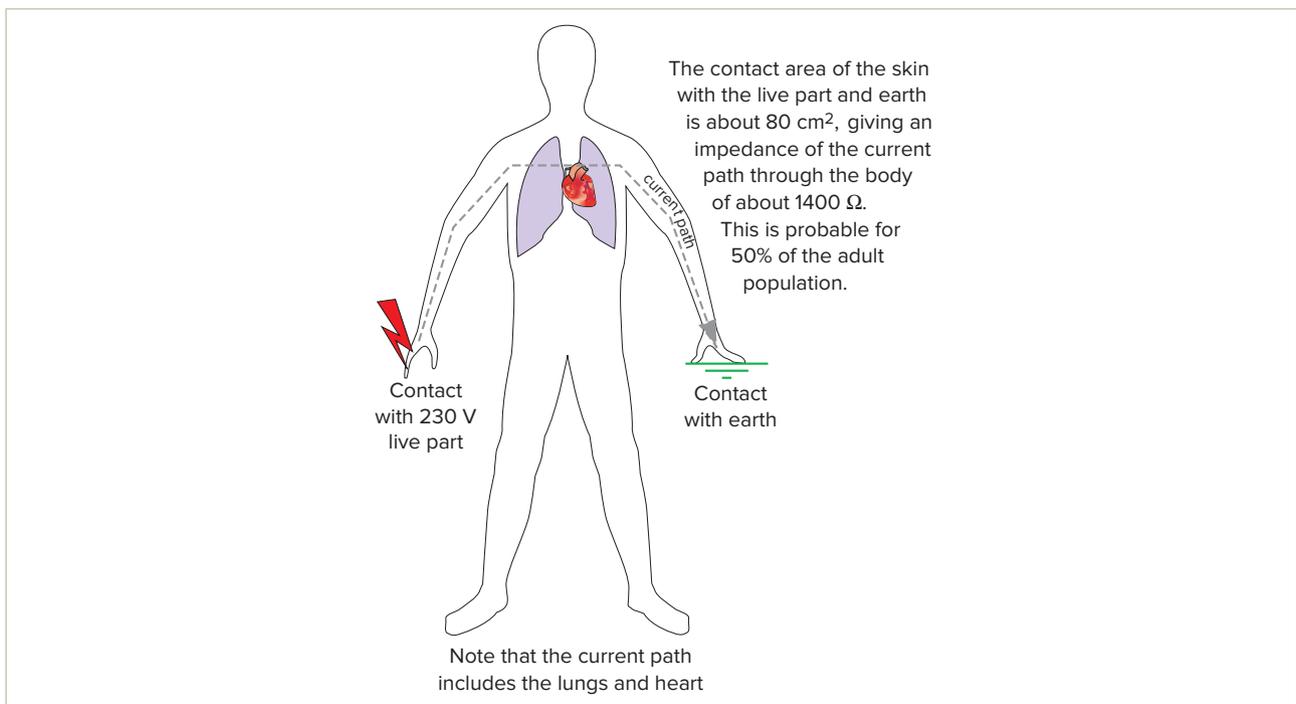


FIGURE 2.17 Hand-to-hand electric shock

EXAMPLE 2.1

In this example, the current through the body as determined by Ohm's Law is:

$$I = \frac{V}{Z}$$

where

I = current in amperes

V = touch in voltage

Z = impedance of current path through the body in ohms

$$I = \frac{230}{1400}$$

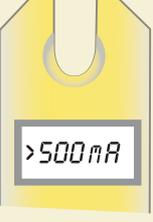
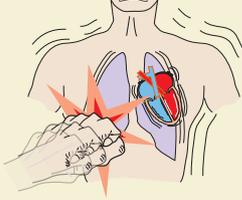
Then:

$I = 0.164$ A or 164 milliamperes, less than that drawn by a 40 watt lamp.

(Z is made up mainly of resistance in the examples in this text. Where reactance is significant, this will be noted.)

The effect on the victim will depend on how long they remain in contact with the live part. As time passes, the skin begins to react and burn and will eventually carbonise, reducing impedance and increasing the current. At this stage, the situation is potentially very serious for the victim. **Table 2.6** gives an indication of the probable effects of increasing values of current for a hand-to-hand shock for different lengths of time.

TABLE 2.6 Effects of electric current

Current through the body	Duration of current flow	Effects on the body
		 Let-go reaction, mild jolt.
		 Cramping, can't let go, heavy unpleasant jolt. Cramping, difficulty in breathing, continued unpleasant jolt.
		 Cardiac and breathing arrest likely. Severe burns may occur. Heavy blow like a king hit.

Other factors affecting shock current impedance are the area and pressure of contact with the live part, the moisture level and physical condition of the skin, the insulating qualities of clothing worn by the victim and the current's path and natural conditions prevailing at the time.

There are three ways in which electric shock can be directly fatal:

1. *Respiratory arrest.* Although uncommon, there is a possibility that a shock current passing through the head in the region of the respiratory centre at the back of the skull will cause immediate cessation of respiration.
2. *Asphyxia.* There is a reasonable probability that a current greater than 30 milliamps (mA) for a duration of more than 2 seconds will cause contraction of the diaphragm and arrest respiration for as long as the current flows.
3. *Ventricular fibrillation.* This is a condition where the blood-pumping action of the heart is interrupted, as illustrated in **Figures 2.18** (normal heart function) and **2.19** (ventricular fibrillation caused by electric shock).

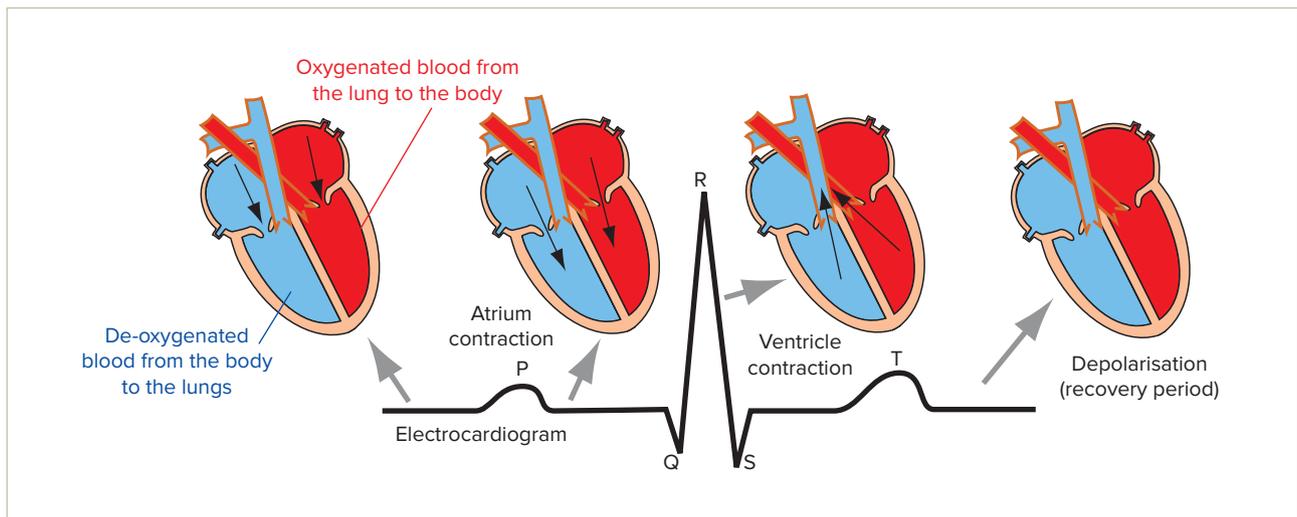


FIGURE 2.18 Normal heart function

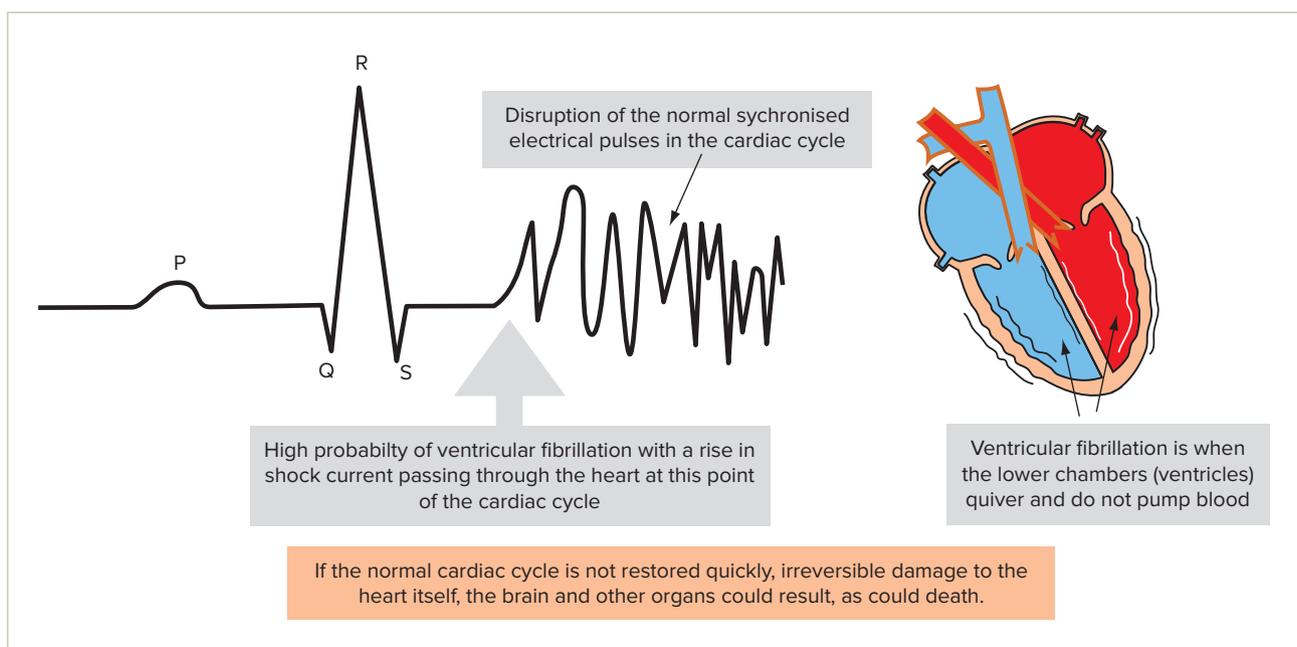


FIGURE 2.19 Ventricular fibrillation caused by electric shock



SAFETY ALERT

High-voltage shock victim

Until the circuit has been switched off, do not attempt to assist a victim in contact with high voltage, that is, exceeding 1000 V a.c. or 1500 V d.c. Otherwise, there is a high risk of the rescuer also becoming a victim.



CHECK YOUR UNDERSTANDING

18. What potentially fatal effects are caused by electric shock?
19. Describe the condition of the heart that is termed *ventricular fibrillation*.
20. List four factors that affect the impedance (resistance) of the human body to the passage of an electric current.
21. List three possible consequences of an electric shock.
22. Describe the dangers of high-current sources.

2.6 Electrical incidents

An unconscious victim of electric shock requires immediate resuscitation if they are to survive. However, before applying resuscitation to the victim, it is essential to ensure that they are not still in contact with any live conductor. Before going to the rescue, take precautions against receiving a shock yourself and never take any action that could render you helpless to assist. Remember that, until the victim is released from the shock source, their body is at the same potential as the voltage of that source.

2.6.1 Removing victim of electric shock from contact with live parts

It is impossible to lay down a definitive removal procedure for all circumstances in which a victim of electric shock is believed to be in contact with live parts. The use of low-voltage rescue kits is the preferred method in any live work. No rescue should be performed without complete isolation of supply, regardless of the situation or use of these approved kits.

Described in **Figure 2.30** are the effective means of releasing someone in danger of electrocution. Observe the use of insulated gloves and rope by the well-trained co-worker to pull the victim away to safety.



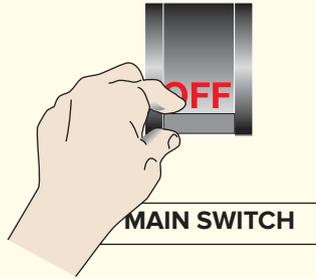
DANGER

Do not make direct contact with the victim or put yourself at any other risk.

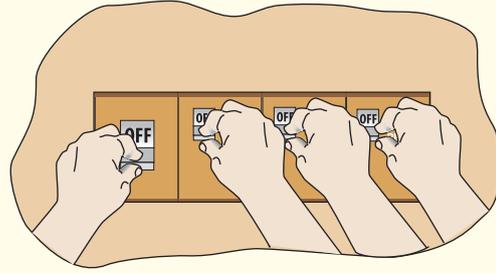
2.6.2 Electrical accidents—applying cardiopulmonary resuscitation

Cardiopulmonary resuscitation (CPR) is a first-aid technique used to keep victims of cardiac (heart) arrest or pulmonary (breathing) arrest alive until emergency-response professionals arrive. The purpose of CPR is to keep oxygenated

If the appropriate switch or circuit-breaker can be quickly identified and easily reached, switch off supply.



If the switch cannot be positively identified, open all switches or circuit-breakers.



If the supply cannot be easily or quickly switched off, the victim can be released using a low-voltage rescue kit.



Should rescue be required above ground level, due care must be exercised to prevent the victim from falling to the ground when released from the live conductor or when the circuit is de-energised.

FIGURE 2.20 Rescuing a victim from contact with live parts

blood flowing through the body to delay tissue death and extend the opportunity for successful resuscitation without permanent brain damage. A defibrillator is usually needed to restart the heart to normal function.

Advice on what to do in an electrical accident and the basic steps in applying CPR are given in **Figures 2.21** and **2.22**.

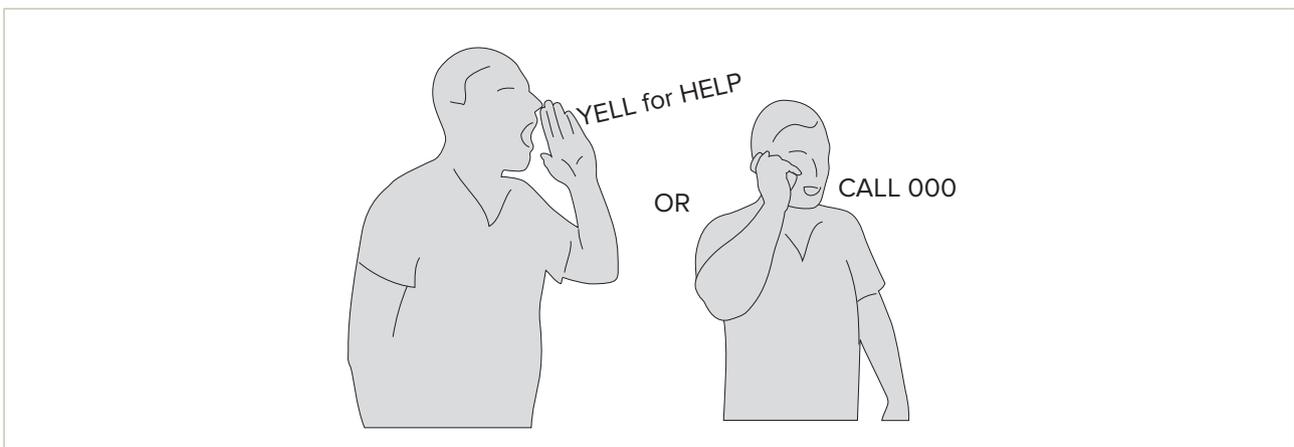


FIGURE 2.21 Electrical accident—what to do first

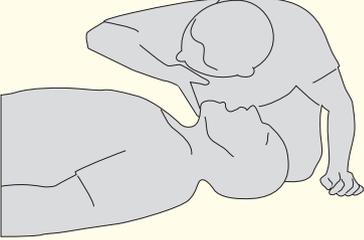
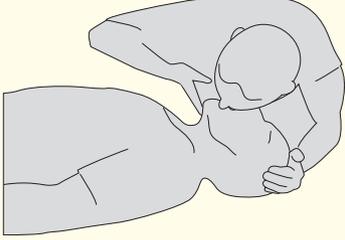
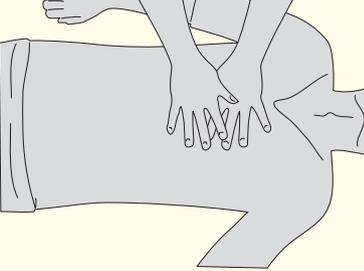
	<p>1. Place the victim on their back, tilt their head well back to ensure a clear airway to the lungs, and check for breathing and response.</p>		<p>2. Blow two (2) breaths into the victim's lungs, trying to obtain a good seal between your mouth and the victim's face.</p>
		<p>Press your cheek against the victim's nose while inflating their lungs to prevent air leaking.</p>	
	<p>3. Position your hand on the centre of the victim's chest.</p>		<p>4. Firmly push down 30 times to compress the chest, then follow with two (2) breaths*.</p>
		<p>Continue to repeat the cycle of 30 compressions, 2 breaths until professional help arrives*.</p> <p>The rate of compressing the chest is 100 per minute or almost 2 per second.</p>	

FIGURE 2.22 Electrical accident—basics of CPR

*The two breaths to compression ratio has not been considered a requirement for performing CPR and dropped from the procedure in recent years. There is an argument for this from research. One of the reasons for this is that uncirculated oxygen remains in the bloodstream when sudden cardiac arrest occurs. Chest compressions without rescue breaths can be effective to circulate this oxygen for the first few minutes of performing CPR. The main purpose of CPR is to maintain oxygenated blood flow to the brain.

The methods of CPR are updated from time to time and you should always be aware of the latest method being used. In many jurisdictions annual refresher courses are a mandatory requirement for electrical workers.

As stated at the start of this chapter, an electrician's priority should be to work in a way that ensures both their own safety and that of others. This requires electricians to commit to keeping updated with the application of safe working methods and technical standards throughout their working lives.



CHECK YOUR UNDERSTANDING

23. What is the first personal priority of a rescuer?
24. On witnessing an electric shock, what is the first thing you should do?
25. What precaution is needed when rescuing a shock victim situated above ground level?

SUMMARY

- ▶ It is every individual's responsibility to take all reasonable steps to ensure the safety of themselves and others!
- ▶ To enter and work on a construction site, a person must have completed induction training for construction work.
- ▶ An essential part of electrical work is knowing about personal protective equipment (PPE) and how and when it must be used.
- ▶ Safety signs are an effective way of drawing attention to potential hazards and risks.
- ▶ The ABCs of electrical safety advise: Assume nothing, Believe no-one, Check everything.
- ▶ Tools, equipment and testing devices require checking for correct operation, function or damage.
- ▶ Check your test instrument both before and after testing on a known live supply or a proving device.
- ▶ A *hazard* is something that has the potential to cause harm or adverse effects.
- ▶ A *risk* is the chance or probability that a person will be harmed or experience an adverse health effect if exposed to a hazard.
- ▶ Harmful substances are those that can affect health, from minor short-term irritations to life-threatening and long-term illnesses.
- ▶ Electric shocks are caused by direct contact with live parts of an electrical installation or by indirect contact with metal structures made live by a fault.
- ▶ The correct earthing of all exposed conductive parts of electrical equipment is one of the most important factors in protecting the user of electrical equipment from the risk of electric shock.

REVIEW QUESTIONS

1. Name the legislation and regulations governing workplace health and safety in your jurisdiction.
2. Describe, in order of importance, measures for controlling the risk from hazards in the workplace.
3. Describe a specific task or process that improves safety in the workplace.
4. List four ways in which hazards are identified.
5. Give an example of how the level of a risk is assessed.
6. What does it mean when a risk level is assessed as high?
7. List some of the types of information given in an SWMS.
8. What precautions should an electrician take before entering an unfamiliar workplace?
9. Name eight common industry hazards.
10. List the activities in an electrical work task, identify the associated hazards and risks and suggest measures for controlling the risks.
11. What is the most common cause of fatal electric shock?
12. What are BESS?
13. Explain the purpose of anti-islanding.
14. Name three hazards in an electrical installation.
15. Confirm how earthing conductors are identified.
16. In an electrical installation, what is the increased hazard for people in areas that are damp or wet in normal use?
17. What is the primary hazard with electricity at any voltage?
18. Describe what happens during an arc fault.
19. List some control measures for avoiding exposure to shock hazards.

CHAPTER 3

Workshop fabrication

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ list common safety hazards and risks associated with the fabrication of components for electrical work
- ▶ understand how to safely use hand and power tools in a variety of applications
- ▶ explain the types, planning requirements and applications of metallic and non-metallic fabrication materials commonly used in the electrical industry
- ▶ interpret information given in mechanical drawings using symbols and drawing conventions according to Australian Standards, including freehand sketching
- ▶ describe the objectives of marking out and the tools and procedures that relate to it
- ▶ list the tools commonly used for holding/ securing components during fabrication
- ▶ apply relevant techniques and describe the tools commonly used for safely cutting and shaping metallic and non-metallic components during fabrication
- ▶ identify and use a variety of hole-drilling, equipment as well as threads and thread-cutting equipment
- ▶ describe the joining techniques commonly used in electrical work
- ▶ apply the methods used to dismantle and reassemble equipment and components.

When carrying out electrical installations, modifications, maintenance and repairs, it is common for an electrician to be required to fabricate custom components to suit the installation conditions of the job. Electricians commonly fabricate brackets, supports, covers, enclosures and barriers to protect and support electrical equipment. These components form a permanent, and often protective, part of a finished installation, so it is important that they are fabricated to a high degree of quality and accuracy.

In addition, electricians are often required to dismantle and assemble components, particularly for the purpose of performing routine maintenance on electrical equipment such as motors and contactors. It is important to follow a logical procedure when dismantling and assembling equipment to ensure that components are not damaged and the equipment will function safely and correctly.

In order to successfully fabricate, dismantle and assemble electrical components and equipment, electricians must be skilled at selecting materials, interpreting diagrams, measuring and marking out and using a variety of hand and power tools.

To ensure workplace safety, sustainability and the quality of finished products, workshop tasks must be carefully and logically planned. Planning workshop tasks involves identifying and implementing safe work practices, minimising cost in both materials and labour, reviewing job documentation and selecting appropriate materials and tools.

A sustainable work plan must also be identified prior to commencing work. Sustainable work practices should aim to minimise waste, reduce energy consumption and avoid damage to the environment. This can be achieved by selecting environmentally friendly materials, minimising offcuts, recycling waste and using energy-efficient tools and equipment.

3.1 Workshop safety practices

Prior to commencing an installation or any other job, you should always familiarise yourself with any applicable safe work method statements (SWMS) and carry out a job safety analysis (JSA) for the task. As was explained in **Chapter 2**, carrying out a JSA involves identifying existing and potential hazards in the workplace, assessing the risks associated with those hazards and implementing control measures to reduce or eliminate those risks, as summarised in **Figure 3.1**.

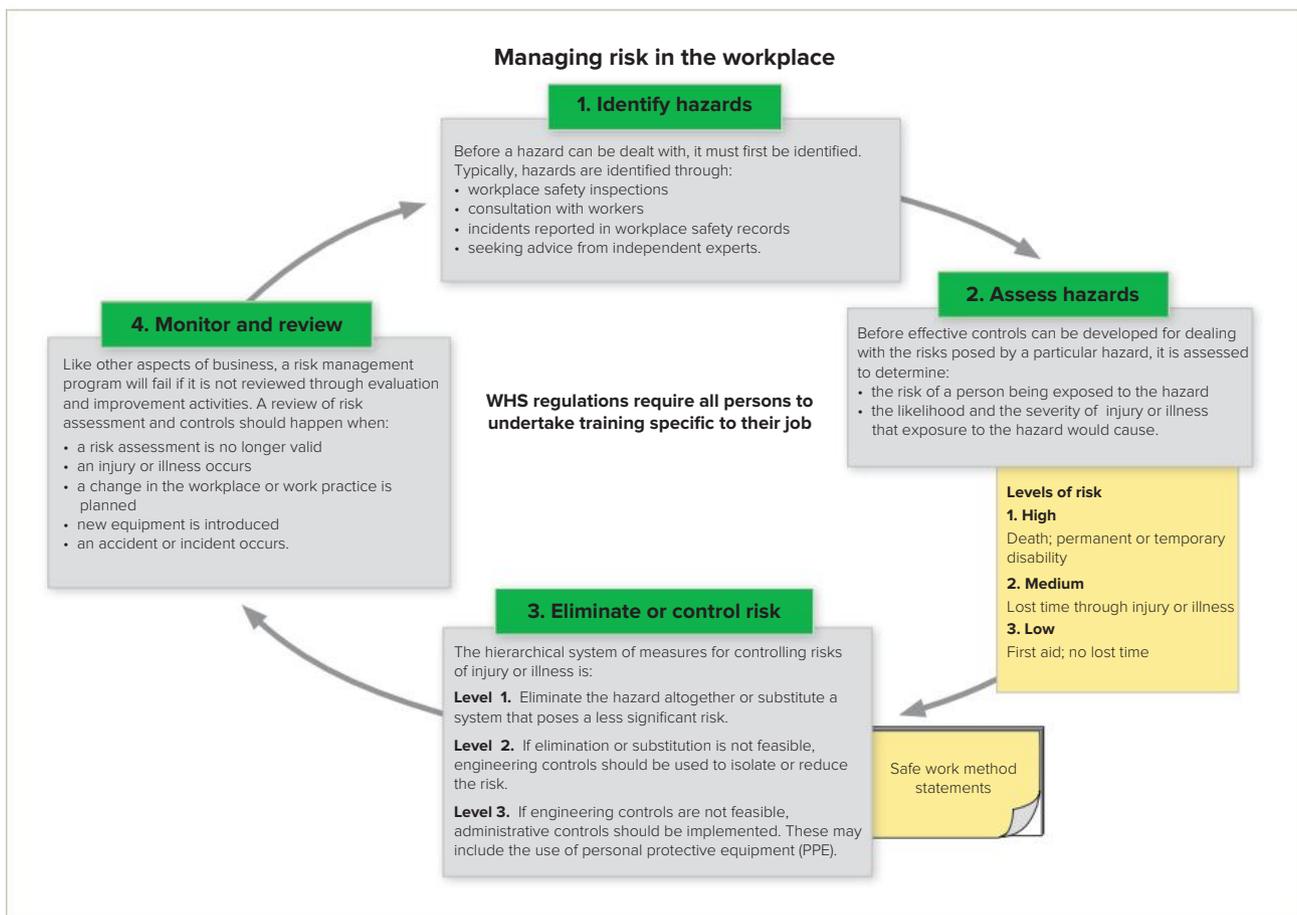


FIGURE 3.1 Managing risk in the workplace

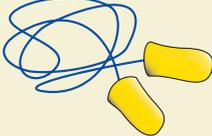
Typical hazards associated with workshop tasks include points, sharp edges, sparks, swarf (sharp-edged metallic waste from machining), heavy objects, electrical leads and rotating machines. Hand tools and power tools are common sources of workplace injuries. A range of hand and power tools are used to carry out tasks in the workshop such as clamping, cutting, shaping, filing and drilling. Always select the correct tool to perform a task and check the condition of the tool prior to use. Damaged tools can be dangerous and should be replaced before work is carried

out. To prevent damage, tools must be stored and maintained correctly, and should only be used in the manner for which they were designed. Using a screwdriver as a chisel, for instance, can cause chipping or weakening of the blade, resulting in it slipping or breaking the next time a screw is tightened.

Workshop tasks may be undertaken in a variety of locations, such as a purpose-built workshop or a construction site. The surrounding work environment must always be carefully considered when carrying out risk assessments.

Where elimination, substitution and engineering controls are not feasible, administrative controls are applied. This invariably includes the use of personal protective equipment (PPE), as shown in **Table 3.1**.

TABLE 3.1 Summary of common workshop risks and PPE required

Workshop task	Risk	PPE
Cutting, grinding or drilling fabrication materials	Eye and face injury could lead to blindness.	  
	Damage to eardrums could lead to hearing loss or tinnitus.	 
	Airborne fibres could lead to respiratory distress.	 
Manually handling fabrication materials	Sharp edges could cause cuts to the hands.	
	Dropping heavy materials could cause foot injuries.	
Working in locations where others are working overhead	Falling objects could cause head injuries.	



CAUTION

Personal protective equipment (PPE)

PPE should always be correctly selected, fitted and worn prior to commencing a work task. Remember that wearing PPE does not make you invincible; it is an indication that the work you are performing is inherently dangerous, so proceed with caution!



CHECK YOUR UNDERSTANDING

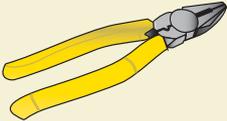
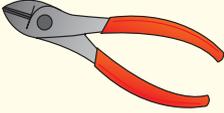
1. What should be done with PPE before commencing a task?
2. List five types of PPE worn in the workshop.
3. List common workshop risks associated with cutting, drilling or grinding.

3.2 Tools used in electrical work

3.2.1 Hand tools

To carry out workshop tasks safely and accurately, an electrical worker must be able to select the correct tools for a task and use them safely and effectively. For this reason, a good working knowledge of tool types and applications is required. **Table 3.2** provides an introduction to the main hand tools used to perform electrical work.

TABLE 3.2 Hand tools and their accessories

Tool	Typical use
Combination pliers 	Combination pliers are one of the most commonly used tools in an electrician's toolbox. Various types can be used to cut, shape and grip materials.
Side cutters 	Side cutters are commonly used to cut through cable insulation and conductors.
Screwdrivers 	Screwdrivers consist of a handle, body and tip or 'drive'. The tip is shaped to provide a mechanical advantage when slotted into a matching screw head.
Hacksaws 	A hacksaw consists of a replaceable cutting blade mounted on a steel frame that can be used to cut metals and plastics.
Tin snips 	Tin snips are constructed in a similar fashion to a pair of scissors but are used for cutting sheet metals.

(Continues)

TABLE 3.2 Hand tools and their accessories (Continued)

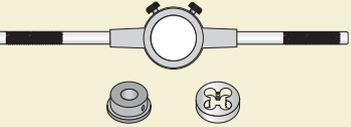
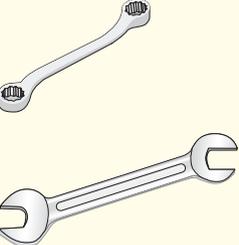
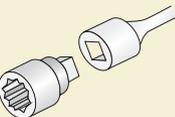
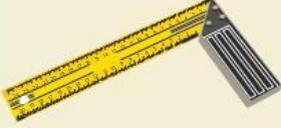
Tool	Typical use
Files 	Files come in various shapes and types. They are used to shape materials, remove burred edges and produce finished surfaces. The body of a file has forward-facing teeth that are used to cut metals and plastics on the forward stroke.
Drill bits 	Drill bits are cylindrical in shape and consist of a shank, body and tip with cutting lips. A wide variety of drill bits are available for various applications.
Taps and wrenches 	Taps are cylindrical in shape and consist of a shank and a body with cutting edges and flutes. A tap wrench is used to rotate the tap in a hole to cut an internal thread.
Dies and stocks 	Dies are circular in shape, with internal flutes and cutting edges. A stock or ratchet is used to rotate the die around the exterior of a round stock or pipe to cut an external thread.
Spanners 	Spanners typically come in sets and are used to grip nuts and bolts for tightening or loosening. Care must be taken to select the correct size of spanner for a job, as incorrect selection is likely to result in damage to nuts and bolts and hand injuries due to slipping.
Sockets 	A socket set consists of one or more wrenches on which a variety of different-sized sockets can be fitted. As with spanners, the purpose of the socket is to fit over and grip a nut or bolt to allow tightening or loosening.
Claw hammer 	A claw hammer consists of a handle and a head. The head has one side designed for striking objects and surfaces and the other designed for removing nails from timber.
Soft-head hammer 	The face of a soft-head hammer consists of a replaceable insert made from a soft material such as rubber. It can be used to adjust the position of components where striking with a harder hammer may cause damage.

TABLE 3.2 Hand tools and their accessories (Continued)

Tool	Typical use
Steel rule 	A steel rule can be used as a straight edge, or to take measurements and facilitate marking out.
Square 	A square consists of two edges that are exactly 90° apart from one another. Various types and sizes of squares exist. One type of square consists of a steel rule and a stock that can be adjusted and fastened along the length of the rule.
Level 	Levels come in a wide variety of types and sizes. A level is commonly used when marking out and fastening equipment to ensure that equipment is level and square.

3.2.2 Workshop tools

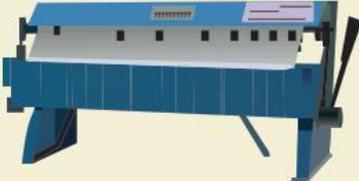
When carrying out work in an electrical workshop environment, a range of additional specialist fabrication tools are typically available. **Table 3.3** lists some of these tools.

TABLE 3.3 Workshop tools and their accessories

Tool	Typical use
Vices 	Vices are used to secure materials between jaws that can be opened and closed by turning a threaded handle.
Pedestal drill 	Stationary drills can be used with a wide variety of drill bits to produce holes in fabrication materials. <i>Note: Safety glasses must always be worn when operating any kind of drill.</i>
Pedestal grinder 	Stationary or pedestal grinders consist of two rotating wheels and are useful for shaping and surface finishing. Caution must be exercised when using grinders as they have the potential to cause severe injuries.

(Continues)

TABLE 3.3 Workshop tools and their accessories (Continued)

Tool	Typical use
Guillotine 	A guillotine is useful for cutting sheet metals to size. Manual foot pedal-operated and mains-powered models are available.
Bender 	A bender is used to bend sheet metals at various angles. Manual and automatic magnetic benders' are available.

3.2.3 Portable power tools

These tools allow the cutting, shaping and joining of fabrication materials in locations where a fully equipped electrical workshop is unavailable. **Table 3.4** shows a range of portable power tools that are commonly used in the electrical industry.

TABLE 3.4 Portable power tools and their accessories

Tool	Typical use
Power drill 	Power drills are commonly used to drill holes in metals, plastics, wood and masonry. They are available in a wide range of mains-powered and battery-powered models. They are also used on the slow setting with a screwdriver bit to speed up the securing process with fasteners.
Grinder 	Portable grinders consist of a single cutting wheel used for grinding and cutting metals and masonry. Grinders are available in mains-powered and battery-powered models.
Jigsaw 	A jigsaw consists of a small reciprocating blade that is suitable for cutting shapes out of thin materials.
Drop saw 	Drop saws are available in a wide variety of portable and stationary types. They are suitable for cutting metals, plastics and timber.

There are specific requirements for the tagging and testing of portable power tools to ensure safety. This tagging can only be completed by a licensed electrician or another qualified person. This requirement does not apply to battery-operated tools; however, they should be inspected regularly for damage or wear.

3.2.4 Compressed gas tools

In addition to power- and battery-operated tools there is an extensive range of compressed gas tools (also known as air-tools) available. These include tools for drilling, cutting, grinding and many other applications. These tools require oiling and maintaining as per manufacturers' instructions to ensure correct functioning.



CHECK YOUR UNDERSTANDING

4. What power tool would you use to cut a shape in thin material?
5. List five hand tools used in the electrical industry.
6. List three power tools used in the electrical industry.
7. Why is it important to select the correct size spanner for a given job?
8. Provide examples of PPE that are required when using a drop saw.

3.3 Materials used for custom components

Workshop materials can be split into two broad groups: metallic and non-metallic. The type of material selected for a job will depend on the required characteristics of the finished product. A product may require strength, toughness, hardness, ductility, durability and conductive or insulating properties (see **Figures 3.2** and **3.3**).



DID YOU KNOW?

What are hot-dip galvanising and electroplating?

Hot-dip galvanising is a process of bathing steel in a bath of molten zinc. Electroplating involves running an electric current through the steel sheet and a zinc solution, resulting in a bonded zinc coating.

3.3.1 Non-metallic materials

Plastics are synthetic materials, most commonly derived from petrochemicals. They are classified into two distinct types: thermosetting and thermoplastics. Thermosetting resins can be formed only once, while thermoplastics can be re-formed over and over again by heating. Plastics are widely used in the electrical industry for their insulating properties.

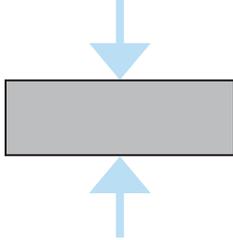
Fabrication plastics come in sheets and are available in a variety of grades (thicknesses). They are used to form custom insulating barriers for terminals and switchboards. Heat-shrink is a tubular type of plastic that shrinks when heated. It is commonly used for insulation and colour-coding of cables at terminations.

Paper is also used for insulating cables, capacitors, transformers and rotating machines. Insulating paper comes in rolls and is classified according to its thickness and purity. Thinner paper is referred to as tissue and thicker paper as board. Pressboard is commonly used in transformers and rotating machines to achieve high temperature ratings. Pressboard is a high-cellulose paper that is impregnated with an oil or resin.

Materials used in electrical work

Materials common in electrical work, such as steel, aluminium and copper, have the attributes illustrated below, in varying degrees.

Compression strength
Capacity of a material to withstand loads tending to reduce its size



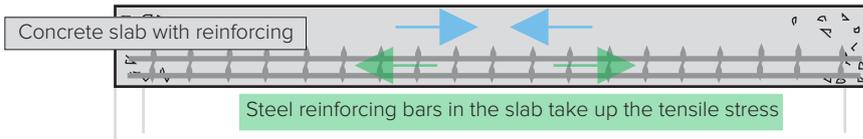
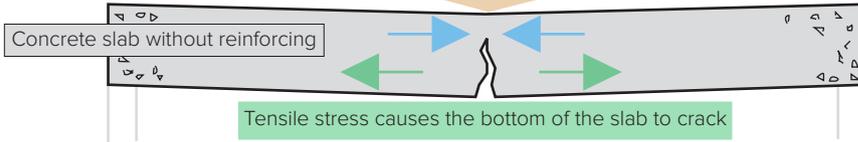
Tensile strength
The stress that a material can withstand without breaking while being stretched or pulled



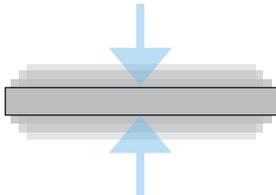
Examples

Concrete has high compression strength and low tensile strength, while steel has both high compression and tensile strength.

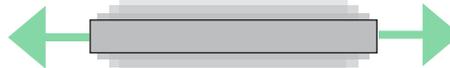
Load on slab causes compression and tensile stresses within the slab



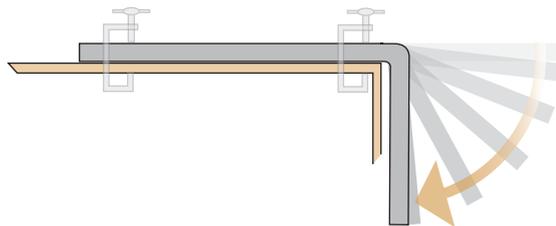
Malleability
Material's ability to deform under compression stress



Ductility
Material's ability to deform under tensile stress

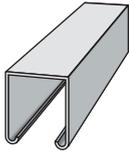


Plasticity
The ability of a material to undergo permanent deformation under load when compressed



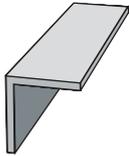
Hardness
The ability of a material to withstand penetration
Cutting tools such as drill bits and hand taps are hardened to allow penetration of softer materials. This increase in hardness, however, results in reduced malleability and ductility, meaning that they have a tendency to shatter when placed under excessive strain.

FIGURE 3.2 Properties to consider when selecting materials for fabricating custom components



Strut channel

Commonly used in electrical work for the fabrication and assembly of cable support systems, including cable tray, ladder tray, trunking and conduit. Strut channel is available in plain steel, galvanised steel, stainless steel, aluminium and fibre-reinforced plastic. The standard strut size is 40 mm × 40 mm. Shallow strut is also available with a depth of 20 mm, while deep strut provides a depth of 60 mm.



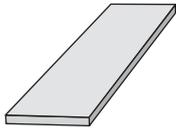
Angle iron

Commonly used in electrical work for the fabrication of brackets for cable supports or for the mounting of apparatus. Angle iron is typically untreated mild steel, sometimes called black steel due to the colour of the iron oxide finish. A wide range of sizes are available, including 20 mm × 20 mm, and 40 mm × 40 mm. Typical thicknesses are 3 mm, 5 mm and 6 mm.



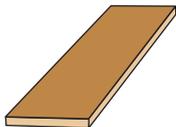
Channel iron

Commonly used in electrical work for the fabrication of supports and stands for the mounting of apparatus. Channel iron is typically untreated mild steel and comes in a range of sizes, including 75 mm × 40 mm, 100 mm × 50 mm, and 150 mm × 75 mm. Typical thicknesses are 3 mm, 5 mm and 6 mm.



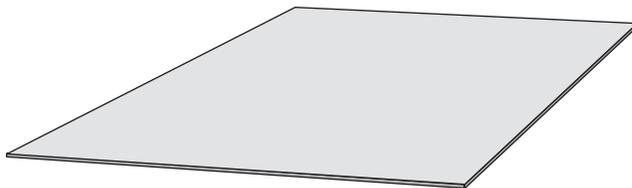
Flat bar

Flat bar has a broad range of applications in the fabrication of components for electrical work. It is readily available in a wide variety of sizes and materials and includes mild steel, stainless steel, brass and bronze. Common thicknesses range from 3 mm to 12 mm.



Copper bar

Commonly used in electrical work for busbars and links. Copper bar is available in a range of sizes and thicknesses to provide various current-carrying capacities.



Sheet metal

Commonly used in electrical work for the fabrication of panels, covers and enclosures. A wide variety of sheet metal materials are available, including plain steel, galvanised steel, Zinccaneal and tinfoil. Sheet metals are available in thicknesses ranging from less than 1 mm up to around 6 mm. The thickness of the sheet is known as the gauge.

FIGURE 3.3 Common materials used in fabricating custom components



CHECK YOUR UNDERSTANDING

9. Explain, with the aid of a diagram, compressive and tensile strength.
10. Define plasticity.
11. List the applications of Zincanneal sheet steel in electrical work.

3.4 Job planning

The type and amount of instruction provided for a fabrication project can vary depending on the scenario. In some cases a formal set of specifications may be provided, including detailed drawings and specified materials lists, while other projects may need to be designed. The latter can be common where job variations, unforeseen circumstances or irregular installation conditions prevent the use of standardised components. The successful design and fabrication of custom components call for a solid understanding of electrical installation requirements, mechanical design and sketching and fabrication tools, materials and techniques.

Throughout the remainder of this chapter, five specific fabrication projects, as shown in **Figures 3.4 to 3.8**, will be examined, from planning and preparation to fabrication and installation.

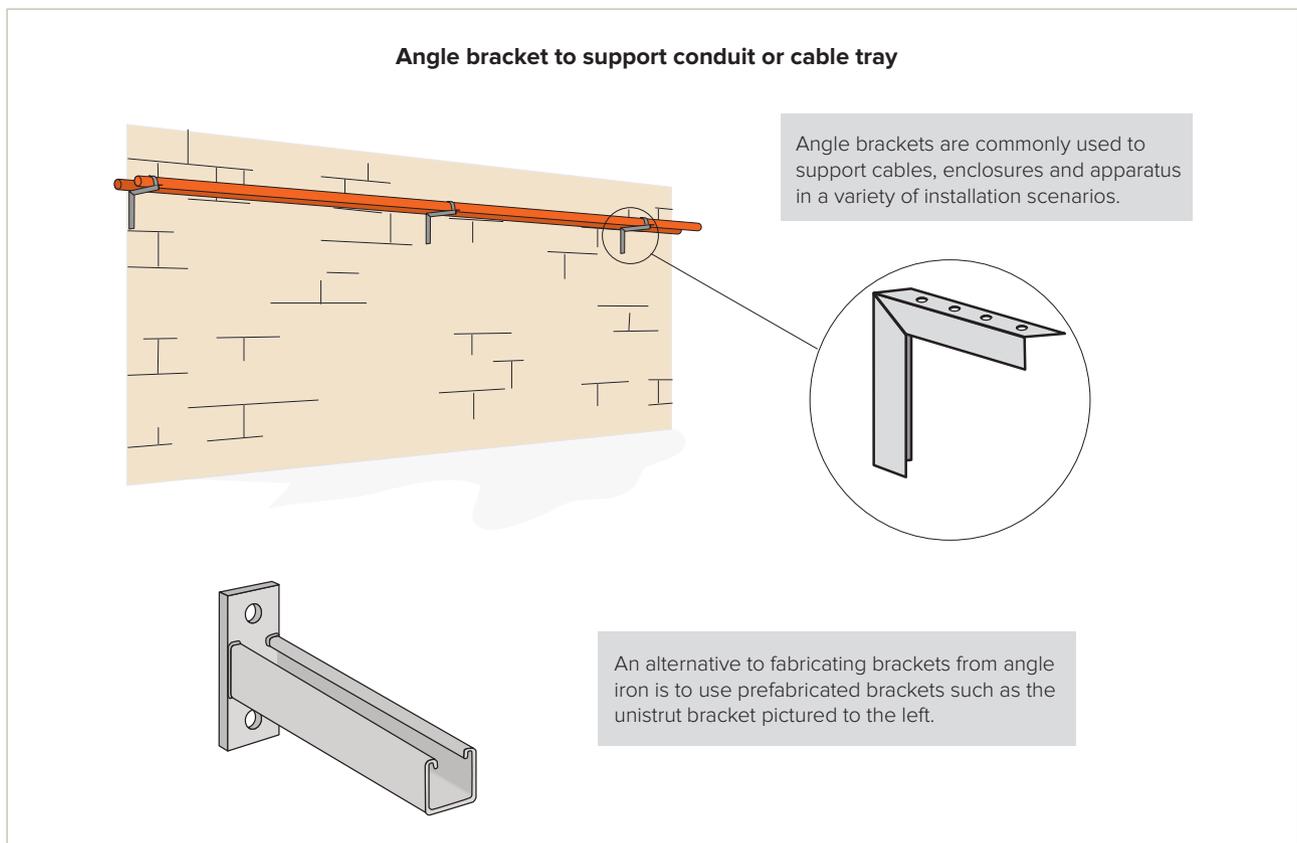


FIGURE 3.4 Typical custom component—angle bracket to support conduit or cable tray

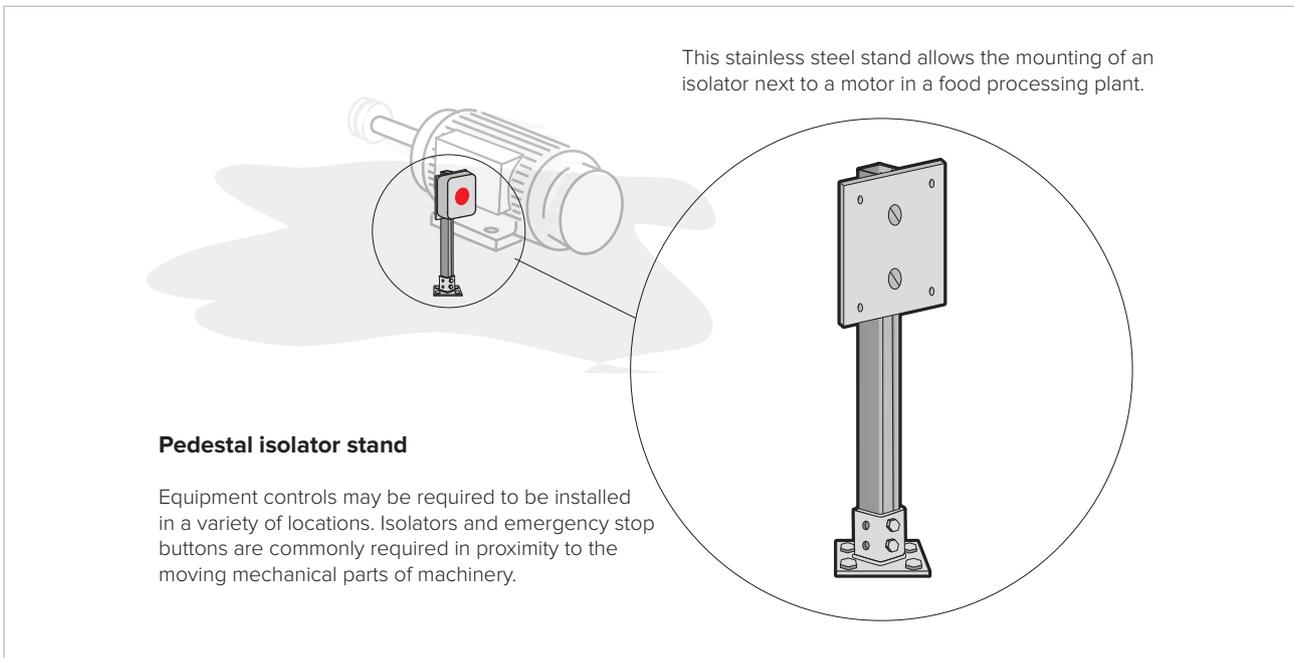


FIGURE 3.5 Typical custom component—pedestal to support a motor isolation switch

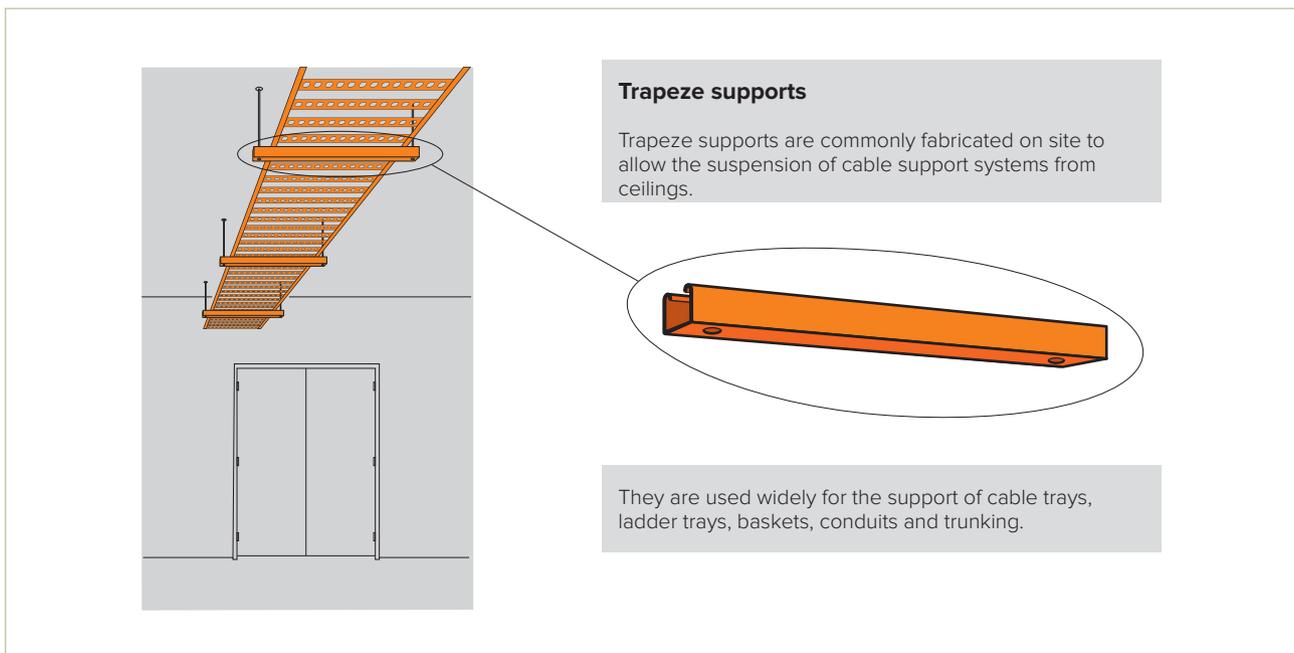


FIGURE 3.6 Typical custom component—strut trapeze to support suspended cable tray or ladder

3.4.1 Mechanical drawings

Mechanical drawings are used to communicate information about an object's shape, size and surface finish for the purposes of fabrication and assembly. Informal drawings can be produced using freehand sketching techniques, while formal mechanical drawings are usually produced using sophisticated drafting software.

Figure 3.9 shows the types of information provided in mechanical drawings.

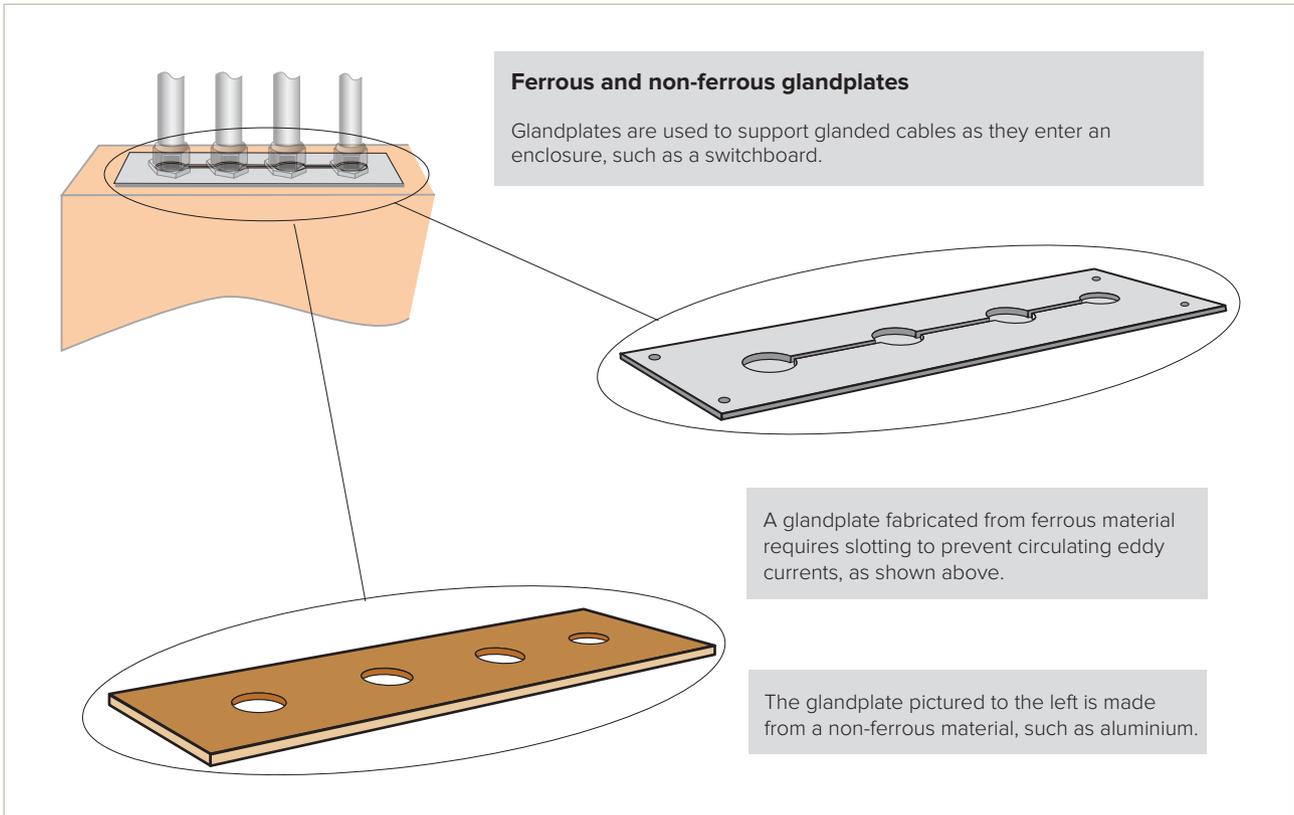


FIGURE 3.7 Typical custom component—glandplate for entry of single-core cables into a switchboard

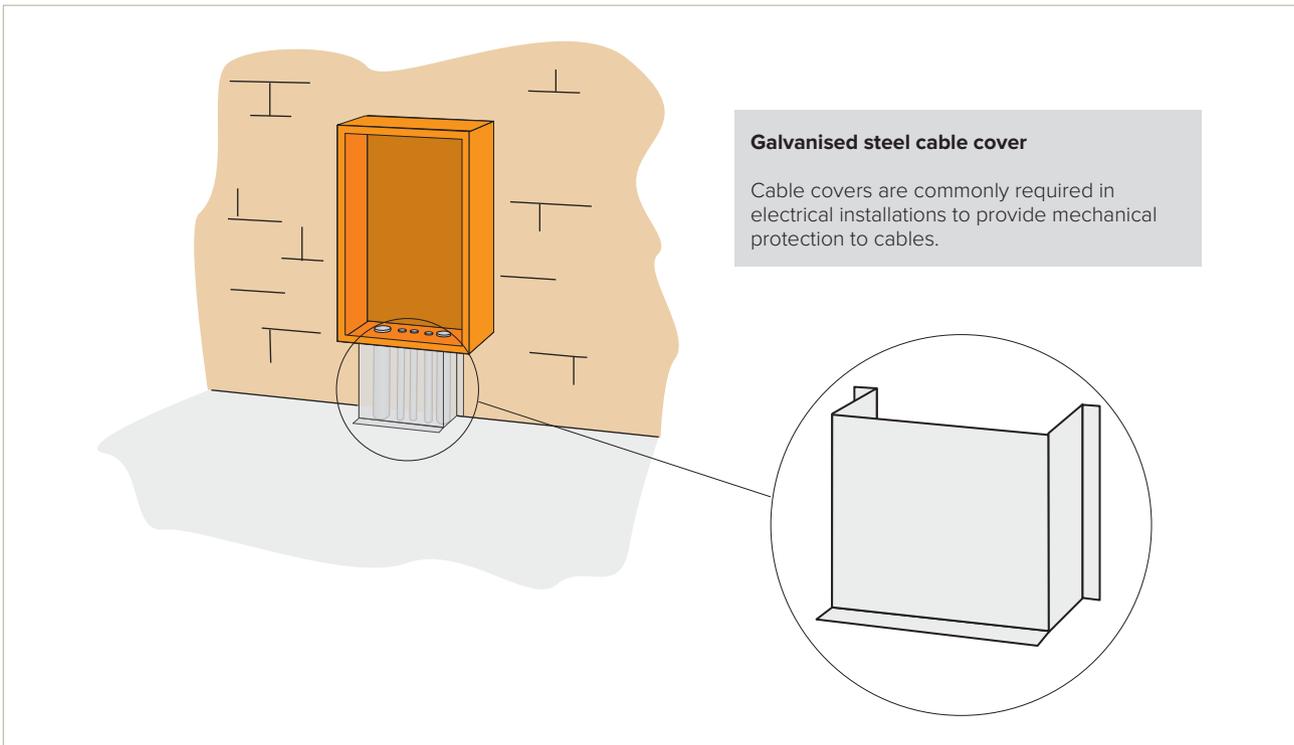
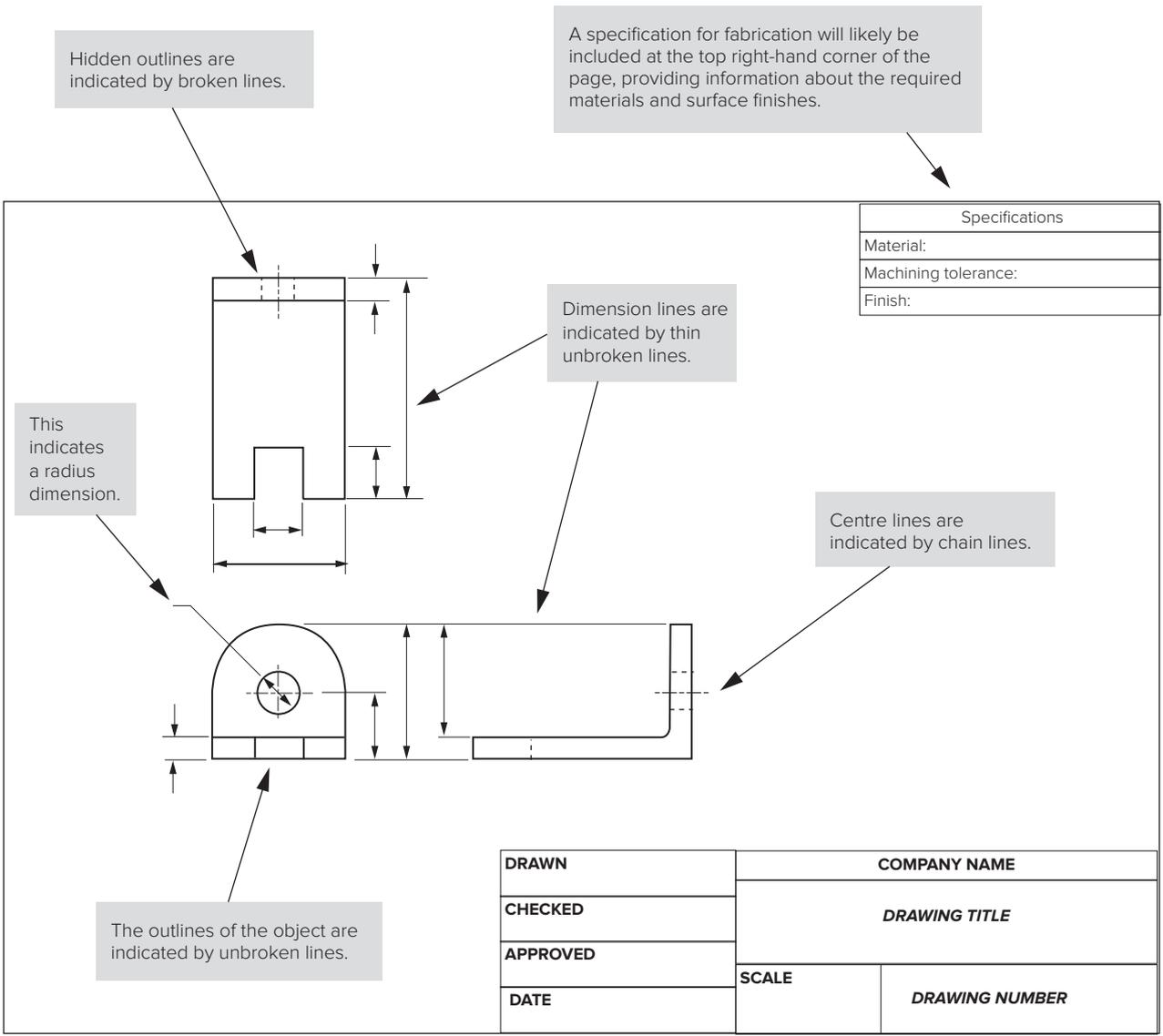


FIGURE 3.8 Typical custom component—cover for cables/conduits entering the bottom of a wall-mounted switchboard

Information provided in mechanical drawings

Mechanical drawings indicate the finished shape of an object. For clarity, dimensions are only shown once, and dimensioning lines are never drawn within the boundaries of the object, with the exception of radius indication.



Common abbreviations in mechanical drawings

- AF** across flats
- ANL** annealed
- NTS** not to scale
- RAD** radius
- UNO** unless noted otherwise

A standard mechanical drawing sheet consists of a title block in the bottom right-hand corner that provides information such as the date, name of the object, drawing number, sheet number, revisions, sheet size and scale.

FIGURE 3.9 Information given in mechanical drawings

Types of mechanical drawings

The common types of mechanical drawings used to complete electrical projects are described in **Table 3.5**.

TABLE 3.5 Types of mechanical drawings and their applications

Drawing	About	Application
Orthogonal projection	A three-dimensional object viewed in two dimensions by showing each surface of the object at right angles, as shown in Figure 3.10	Provides all the information required to fabricate a component, including full dimensioning and surface finish
Isometric projection	A three-dimensional pictorial view of an object in two dimensions, as shown in Figure 3.11	Indicates how a fabricated component should appear visually on completion
Exploded view	A pictorial view showing the order of assembly of the components of a mechanical object, as shown in Figure 3.12	Assists with dismantling and assembling of electrical equipment such as motors and contactors
Freehand sketch	May be any type of projection or view, drawn without the aid of drafting software, as shown in Figure 3.13	Used to record details for custom fabrication work, explain concepts, communicate ideas and clarify work plans

Reading mechanical drawings

Mechanical drawings use standardised symbols and conventions to ensure consistent interpretation throughout the engineering industries. Accepted standards for mechanical drawings can be found in the Standards Australia publication HB7–1993 (R2014) *Engineering drawing handbook*.

Freehand sketching

Freehand sketching can be a useful way of communicating ideas, explaining concepts or clarifying work plans. It is common in electrical work for figuring out a circuit arrangement or ensuring correct connections are made, as well as for creating custom components such as brackets to support a wiring enclosure. Methods that help to sketch neatly and in proportion are shown in **Figure 3.13**. Standard drawing conventions, including all relevant dimensioning and labelling, must be included if the information is to be conveyed accurately. *Note: Do not rely on memory!*

3.4.2 Selecting fabrication tools and materials

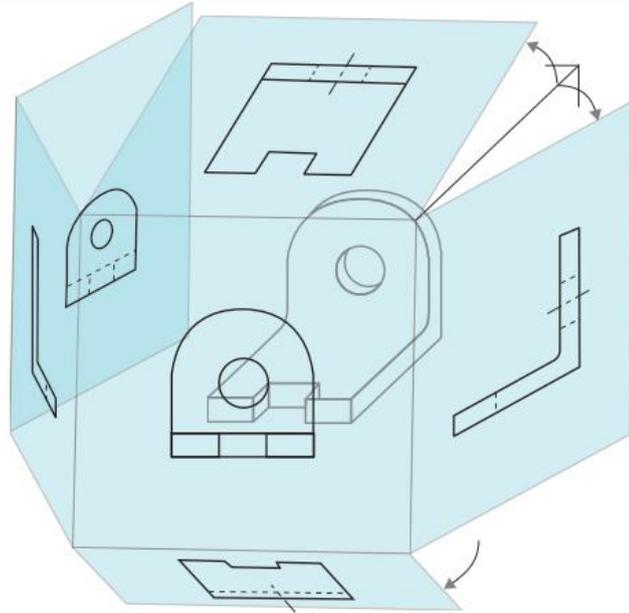
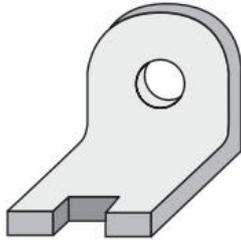
The two factors that are most likely to determine the choice of materials for a given fabrication project are the intended function of the component and the cost. For example, if the metallic cable cover of Project 5 was required to be installed in an outdoor location, galvanised steel or stainless steel (SS) would both be suitable choices due to their strength and resistance to corrosion. However, the high cost associated with SS would likely result in the selection of galvanised steel as a more affordable option.

The tools and PPE required to carry out the work should be selected and prepared in accordance with safe work methods. Finally, a JSA and environmental risk assessment should be carried out, and the results communicated to all those involved with the job.

Orthogonal projection

The most common type of mechanical engineering drawing gives all the information needed to manufacture or fabricate a mechanical component. It shows all views of a three-dimensional object in a two-dimensional plane and in their relative dimensions.

For example, when the contact terminal is placed inside a translucent box, the front, sides, top and bottom of the box each see a different view or projection of the object.



Once the box is unfolded, a view in relative sizes of each facet of the object becomes clear.

In practice, not all views of an object need to be shown, only those necessary to provide all information for an object's manufacture or fabrication. Most commonly, the plan or top view, front view and side elevation are sufficient.

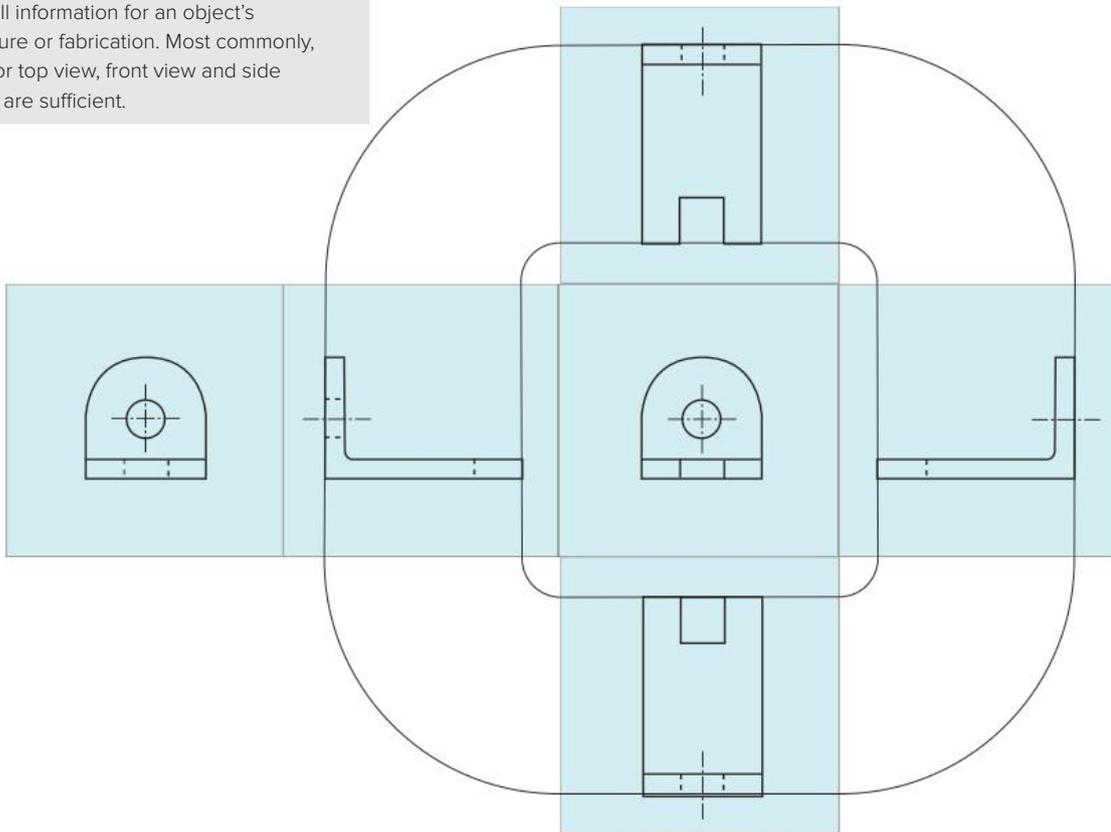


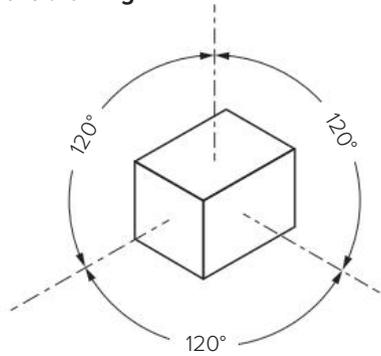
FIGURE 3.10 Orthogonal projection

Pictorial drawings in engineering

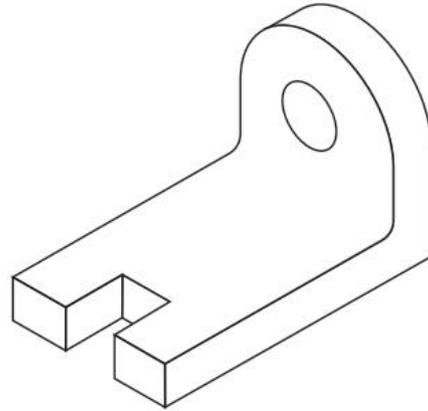
Orthogonal projection, as shown in **Figure 3.10**, is the most commonly used drawing for manufacturing and fabrication, as it shows all the details and views in relative scale. However, it is sometimes difficult to visualise the appearance of the object from an orthogonal projection, especially if you are unfamiliar with engineering drawing.

To overcome this, a pictorial representation known as axonometric projection (measured on an axis) is used. Of the three axonometric forms, the isometric projection is the most common as the axis of width, depth and height are projected in the same proportion, i.e. 1:1:1.

Isometric drawing



In isometric drawing, the three axis lines are drawn from the horizontal: height 90°, depth +30° and width -30°.



Isometric view of the contactor terminal shown in **Figure 3.11**.

FIGURE 3.11 Isometric projection

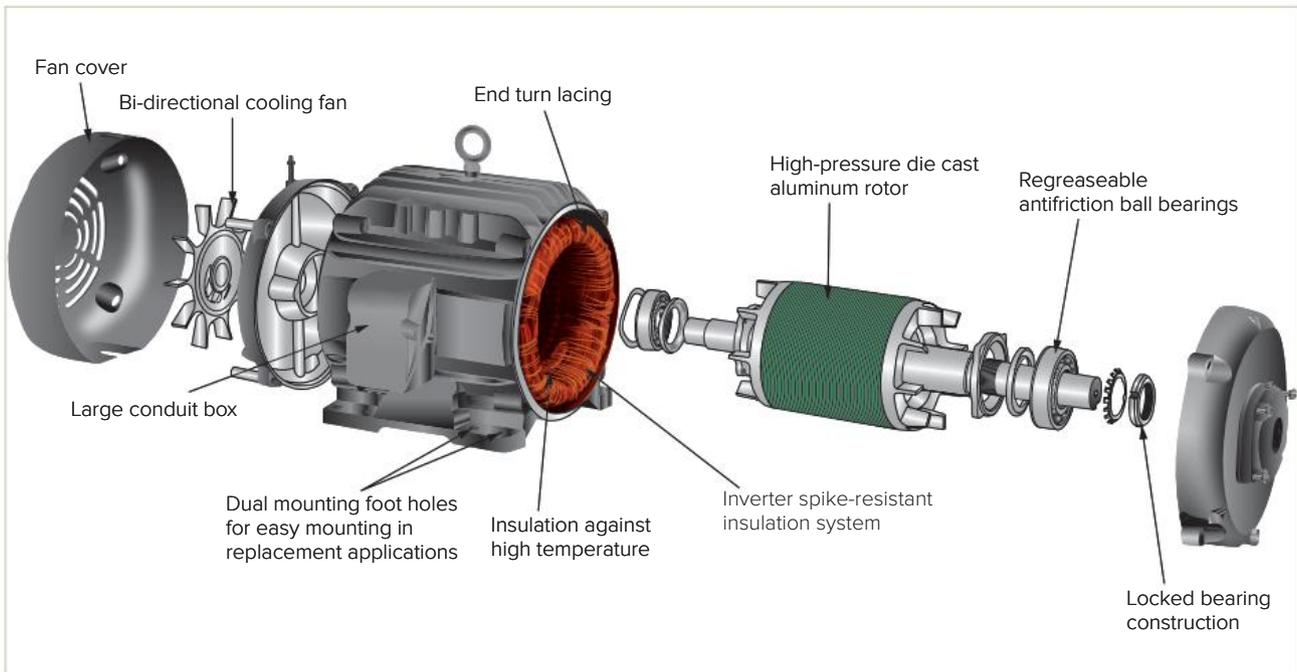
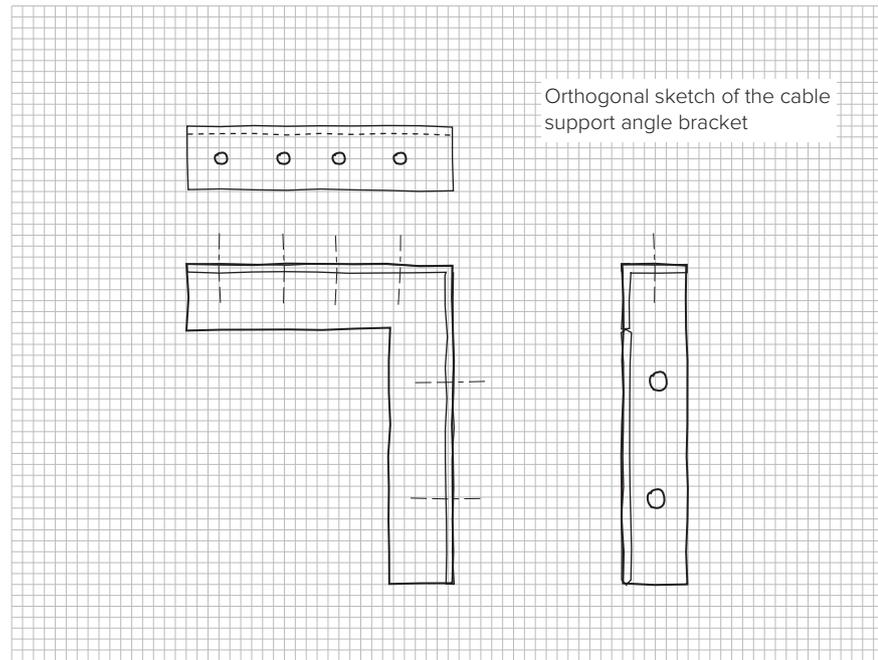


FIGURE 3.12 Exploded view

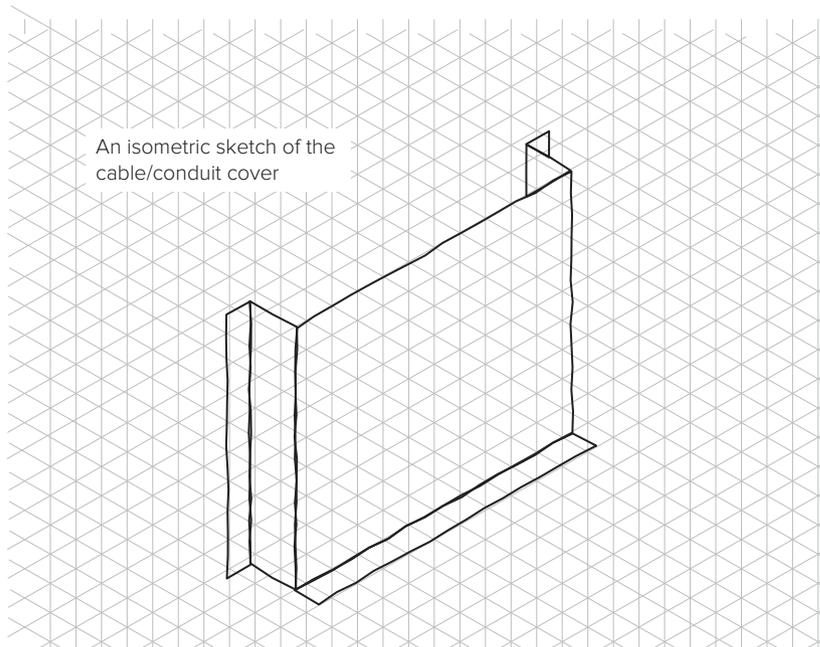
Freehand sketching

It is most likely that, while in the field, sketches will be made of components to be fabricated later in the workshop. The ability to convey information accurately in a freehand sketch is an asset. Two useful freehand sketching aids are isometric paper and graph paper. Both are available as notepads. Note that in all freehand sketching, engineering drawing conventions should be followed to ensure information is conveyed effectively.

The grid on metric graph paper is an ideal aid for freehand sketching of orthographic projections.



An isometric sketch of the cable/conduit cover



Isometric metric paper has a grid of vertical and +30° and -30° lines as a guide.

FIGURE 3.13 Freehand sketching methods

Table 3.6 shows suitable materials, tools and PPE for each of the five fabrication projects.

TABLE 3.6 Fabrication projects—materials and equipment

	Fabrication project	Materials	Tools	PPE
1	Angle bracket	Angle iron	Tape measure Tri-square Hacksaw Power drill Twist-drill bits Hand file	Safety goggles Ear muffs Steel-capped boots Overalls
2	Pedestal isolator stand	SS plate SS strut channel SS floor bracket SS screws SS spring nuts	Tape measure Tri-square Pencil/marker Drop saw Power drill Twist-drill bits Countersink bit Flat file Hand taps Bar-type wrench	Safety goggles Ear muffs Steel-capped boots Overalls
3	Trapeze support	Galvanised steel strut channel Steel-threaded rod Galvanised steel squares Steel nuts	Tape measure Pencil/marker Drop saw Power drill Twist-drill bits Flat file Round file Spanners	Safety goggles Ear muffs Steel-capped boots Overalls
4	Ferrous glandplate Non-ferrous glandplate	Steel plate Aluminium plate	Tape measure Square Pencil/marker Power drill Hole-saw kit Jigsaw Round/half-round file	Safety goggles Ear plugs Steel-capped boots Overalls
5	Cable/conduit cover	Galvanised steel sheet	Tape measure or steel rule Square Marking blue Scriber Guillotine Tin snips Bender Power drill Rivet tool Flat file	Gloves Safety goggles Steel-capped boots Overalls

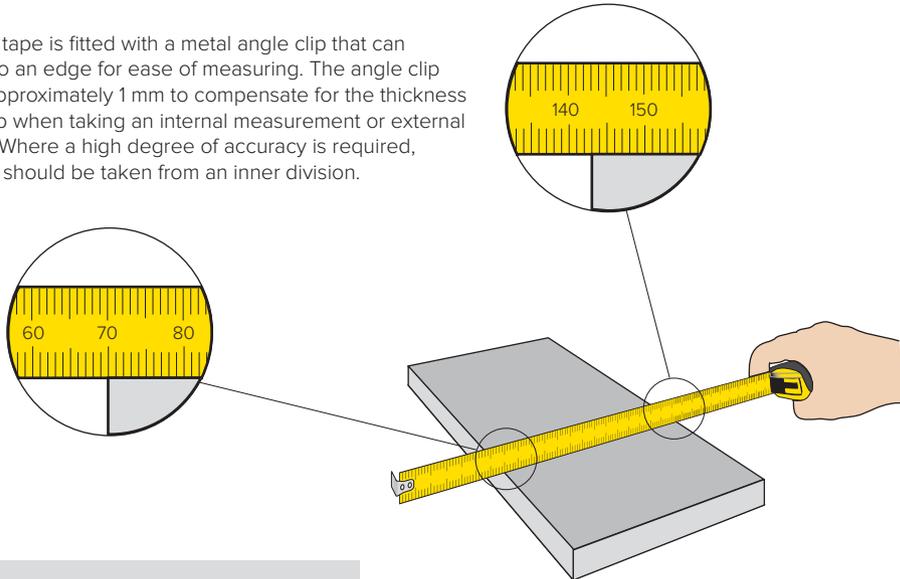
3.4.3 Measuring and marking out

Marking out is the process of indicating lines, curves and positions on a work piece to assist with fabrication. The accuracy of marking out has a huge effect on the quality of the finished job. Before measuring and marking out, the most efficient method of using materials should be determined in order to minimise offcuts and waste. Refer to Figures 3.14 to 3.17.

Measuring with a tape measure

A tape measure is probably the most commonly used measuring tool in an electrician's toolkit. They are conveniently portable and generally of robust construction, making them suitable for use on construction and heavy industrial sites.

The end of the tape is fitted with a metal angle clip that can be hooked onto an edge for ease of measuring. The angle clip has a give of approximately 1 mm to compensate for the thickness of the metal clip when taking an internal measurement or external measurement. Where a high degree of accuracy is required, measurements should be taken from an inner division.

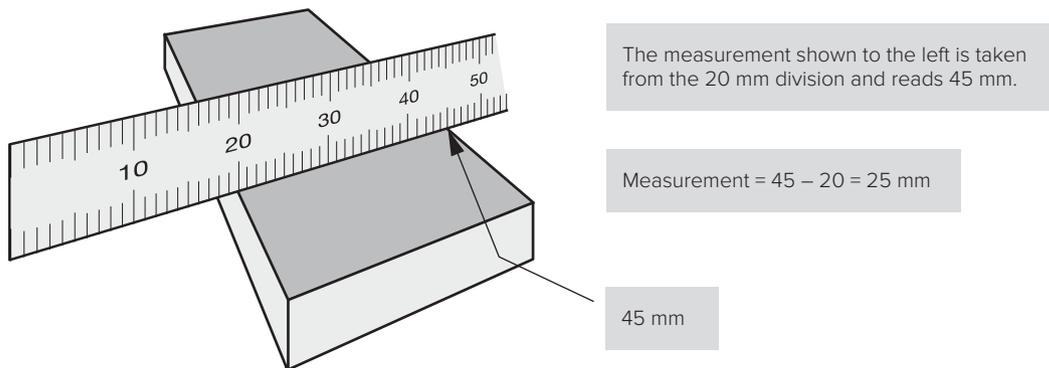


The measurement shown in the diagram is taken from the 70 mm division and reads 143 mm. The actual measurement can be determined by subtracting the starting division as follows:

$$\text{Measurement} = 143 - 70 = 73 \text{ mm}$$

Measuring with a steel rule

The ends of a steel rule can become worn over time, resulting in inaccurate readings when measuring from the tip. As with the tape measure, measurements should be taken from an inner division to ensure accuracy.



The measurement shown to the left is taken from the 20 mm division and reads 45 mm.

$$\text{Measurement} = 45 - 20 = 25 \text{ mm}$$

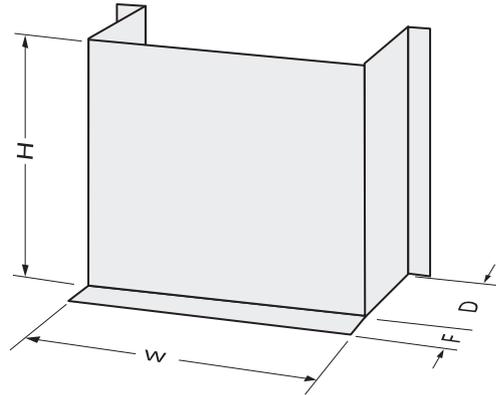
45 mm

Tip: Always remember to hold the tape measure or rule square against the work to ensure accurate measurements.

FIGURE 3.14 Measuring techniques

Measuring and marking a cable cover

Site measurements must be taken to determine the required height (H), width (W) and depth (D) for the cable cover. Suitable dimensions for the flange (F) will largely be determined by the type of fixings to be used.



Using a corner section of galvanised steel sheet reduces the number of cuts required and ensures efficient use of materials.

Care should be taken to plan out the sequence of bends.

Guillotine cut

Guillotine cut

H + F

Excess material can be removed using tin snips.

Clearance to allow for 90° bend.

Centred holes for mounting

V marked for removal to allow for 90° bend

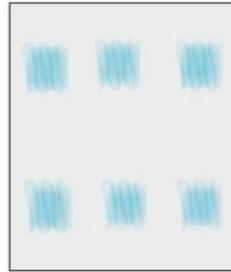
Measuring and marking out required to fabricate an angle bracket from a length of angle iron

FIGURE 3.15 Measuring and marking a cable cover and angle bracket

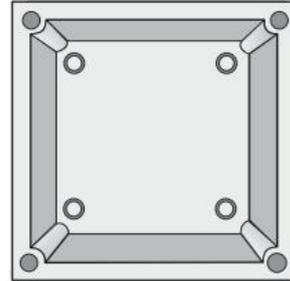
Marking out an isolator mounting plate

Step 1

A suitable marking medium is applied to the areas of the isolator mounting bracket that require marking.



Isolator mounting plate

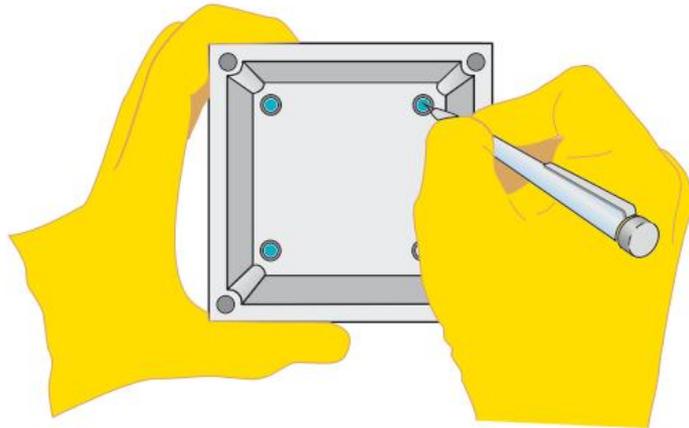


Isolator housing bracket

Step 2

A suitable square or level is used to accurately place the isolator bracket over the plate so that the mounting holes can be marked.

In addition, two mounting holes are measured and marked out along the centre line to allow mounting of the plate onto the strut channel.



Step 3

Each hole marked out on the isolator mounting plate is centre-punched to assist drilling.

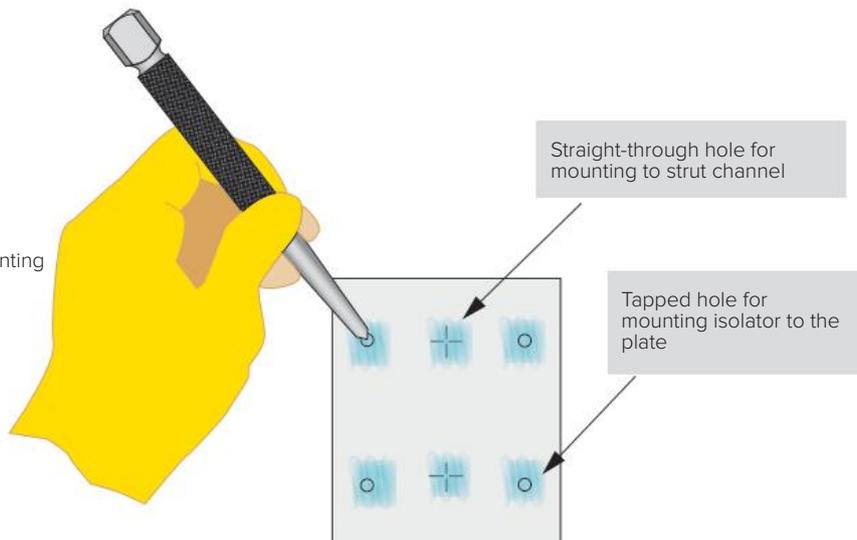
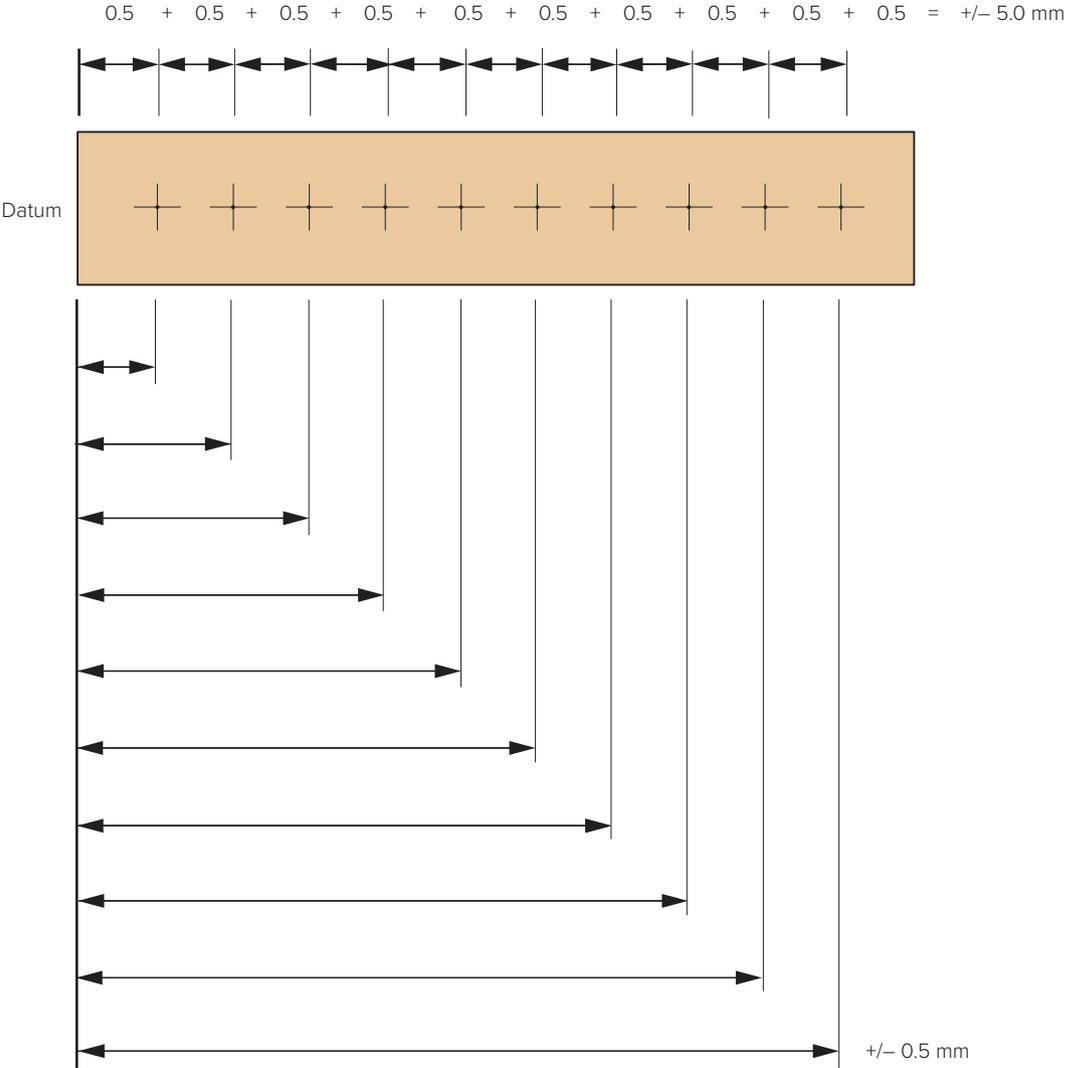


FIGURE 3.16 Marking out an isolator mounting plate

Measuring and marking-out techniques

Measurements made accurately with engineering measuring and marking-out equipment have a standard tolerance of +/- 0.5 mm. To prevent these errors from accumulating across a work piece, all measurements should be made from a single edge or point, known as a datum.

If measurements are progressively made from previously measured points, standard measuring errors can accumulate to produce large errors as indicated below.

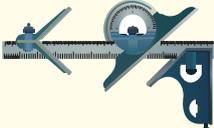


If all measurements are taken accurately from the same edge, measuring errors will be evenly distributed across the work piece and the maximum error for any one measurement will be +/- 0.5 mm.

FIGURE 3.17 Measuring and marking-out techniques

Specialist measuring and marking-out equipment, as shown in **Table 3.7**, is typically available in an electrical workshop.

TABLE 3.7 Specialist measuring and marking-out tools

Tool	About
Scriber 	A scriber consists of a hardened steel tip that has been ground to a fine point; it is used to scratch (scribe) lines into a work piece.
Dividers 	Spring dividers consist of two scribing legs joined at a pivot point with a screw thread for fine adjustment.
Jenny calipers 	Calipers have two legs joined with either a firm joint or bow spring. Various calipers exist for different applications, including outside calipers, inside calipers and odd-leg or jenny calipers.
Combination set 	A combination set consists of a square stock, centre stock and protractor that can be mounted and fastened to a steel rule.

Prior to marking out with scribes, dividers or jenny calipers, work pieces should be secured in position to prevent slipping. An appropriate vice or clamp should be selected, and care should be exercised to ensure the jaws do not mark or damage the work piece. Soft jaws may be required to prevent vice jaws from spoiling surfaces. Refer to **Table 3.8**.

To improve the visibility of scribed lines, a suitable marking medium should be applied to a work piece prior to using scribes, dividers or jenny calipers. Marking media can be easily washed off after fabrication or reapplied in the event of a marking error. Types include chalk, whitewash, copper sulfate and a blue dye commonly known as marking blue.

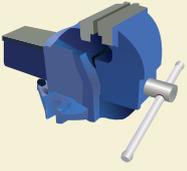
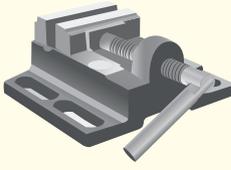
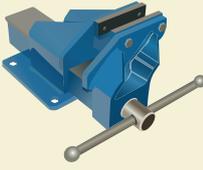
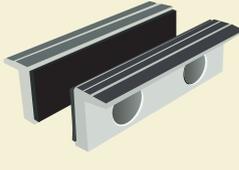
When scribing a straight line, the scriber should be inclined away from the guiding edge and in the direction of motion. Lines should be scribed just once and checked for accuracy after marking. Where lines are outside specified tolerances, marking media should be reapplied and the process started again.

A combination set can be used to provide the required guiding edge for scribing lines at various angles. The square stock consists of a square edge, an edge at 45° and a spirit level. The centre stock can be used to locate centre lines on a cylinder, and a protractor can be used to measure, check and scribe lines at various angles.

Arcs and circles can be scribed using a set of dividers adjusted to the required radial distance. One leg is placed accurately in the centre point while the other is drawn around radially. In some cases it can be preferable to punch the centre point of an arc to reduce the chance of slipping.

A prick punch has a narrow shank and a hardened tip ground to a point of approximately 30° , while the tip of the heavier centre punch is ground to a point of around 90° . Prick punches are used to make an initial precise indent, which can then be increased where required using a centre punch. Punches are manufactured to have varying degrees of hardness along their length, as the tip must be sufficiently hardened to penetrate a work piece while the end must be softer than the face of the hammer used to strike it. Centre points of holes should be punched to provide a guide for drilling. The accuracy of drilled holes can largely depend on the punch marks as the drill bit tends to be drawn into the punch mark.

TABLE 3.8 Specialist holding and clamping tools

Tool	About	Tool	About
Fitter's vice 	Used to secure materials with flat surfaces; jaws are opened and closed by turning a threaded handle.	Pipe vice 	Used to secure round stocks. Models using chain links instead of jaws are also available. Portable models mounted on three legs are commonly used for steel conduit work.
Swivel-base vice 	Similar to the fitter's vice, but with the addition of a swivel that allows for further adjustment.	Machine vice 	The slotted base provides points to secure the vice to machine tabletops. They are commonly used with bench and pedestal drills to secure work pieces for drilling.
Offset vice 	The jaws of this vice are offset, providing clearance to secure long items.	Soft jaws 	Aluminium or copper sheet metal, folded and fitted to the vice jaws to prevent marking the job when clamping it in the vice.

Various calipers exist for different applications, including outside calipers for checking the parallelism of outside surfaces and inside calipers for checking the parallelism of inside surfaces. Odd-leg calipers, also known as jenny calipers, have one inside leg and one scriber, allowing lines to be scribed parallel with an outside surface. **Table 3.9** shows the measuring and marking out required for each fabrication project.

TABLE 3.9 Fabrication projects—measuring and marking out

Fabrication project		Required marking out	Measuring and marking-out tools
1	Angle bracket	Lengths of edges Slotted vee Locations of holes	Tape measure Tri-square Pencil/marker
2	Pedestal isolator stand	Length of strut Locations for mounting holes Locations for tapped holes	Tape measure Square Pencil/marker
3	Trapeze support	Length of strut Length of rods Locations of holes	Tape measure Square Pencil/marker
4	Glandplates	Locations of holes Slots	Tape measure Square Pencil/marker
5	Cable/conduit cover	Length Overall width Widths to bends Locations of holes	Tape measure Square Marking blue Scriber

Specialist marking tools are precision instruments that must be treated with care. Rough handling can damage edges and points, resulting in measuring and marking errors. Proper maintenance involves storing them separately from other tools and keeping them lightly oiled.

With the exception of a centre punch, the marking tools discussed above are unlikely to be available in many field locations such as a construction site. A tape measure, square and marker or pencil will usually be sufficient to mark out most on-site fabrication jobs.



CHECK YOUR UNDERSTANDING

12. What type of drawing could you refer to for information needed to fabricate components?
13. Why would a manufacturer provide an exploded view of a product?
14. Draw a freehand sketch of a mechanical object of your choice.
15. List three items used for marking out.
16. List three types of vices.

3.5 Cutting and shaping

Cutting tools are used to sculpt workshop materials to the required lengths, widths, shapes and finishes. To ensure safety and accuracy, always secure a work piece prior to cutting, drilling, bending or machining. Unsecured work can slip or be propelled through the air by power tools, resulting in serious injuries and damage. **Table 3.10** shows the common types of hand and power saws used for electrical fabrication.

TABLE 3.10 Types of cutting saws

Tool	About
Hacksaw 	A hacksaw consists of a replaceable cutting blade mounted on a steel frame that can be used to cut metals and plastics.
Drop saw 	Drop saws are floor- or bench-mounted and consist of a table with a vice and a hinged blade assembly that is brought down onto a clamped item.
Jigsaw 	A jigsaw consists of a small reciprocating blade, similar to a hacksaw blade but with fewer teeth per inch. They are portable and are available in mains-powered and battery-powered types.

Hacksaw blades have standard lengths of 250 mm or 300 mm and are available in low-tungsten steel or high speed steel (HSS) varieties (**Figure 3.18**). Hacksaw blades should be fitted so that the teeth point down and forwards such that the hacksaw will cut on the forward stroke. The teeth are set to produce a cut that is wider than the body of the blade, thereby reducing friction. The width of a saw cut is known as the kerf.

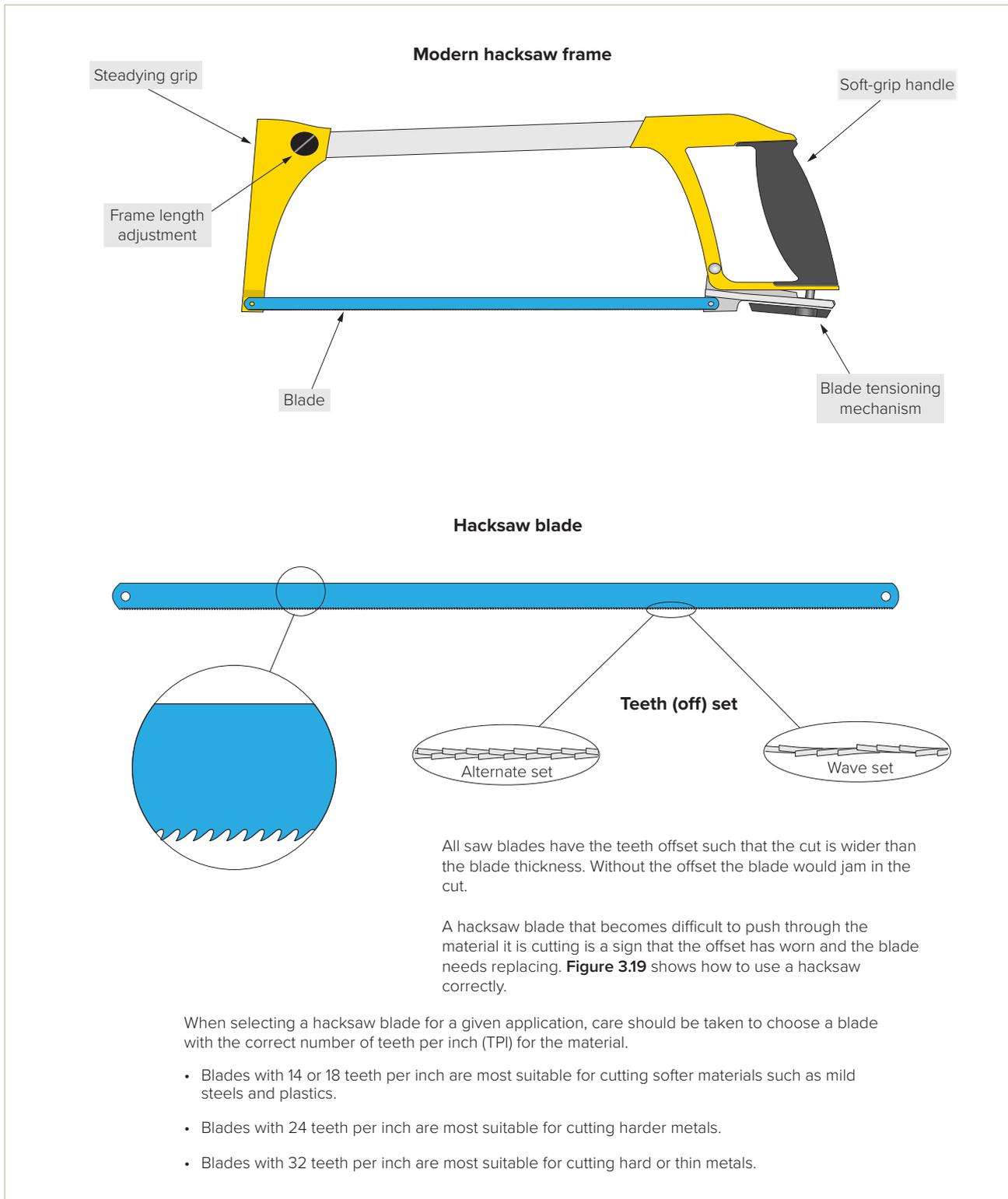


FIGURE 3.18 Hacksaws and hacksaw blades

3.5.1 Cutting techniques

When using a hacksaw, turn your body sideways to allow free back-and-forth movement of your forearm across your torso (**Figure 3.19**). Downward pressure should be applied only on the forward stroke, and a speed of around 50 to 60 strokes per minute should be used for most tasks. As a general rule, you should aim to keep at least three teeth in contact with the work piece at all times.

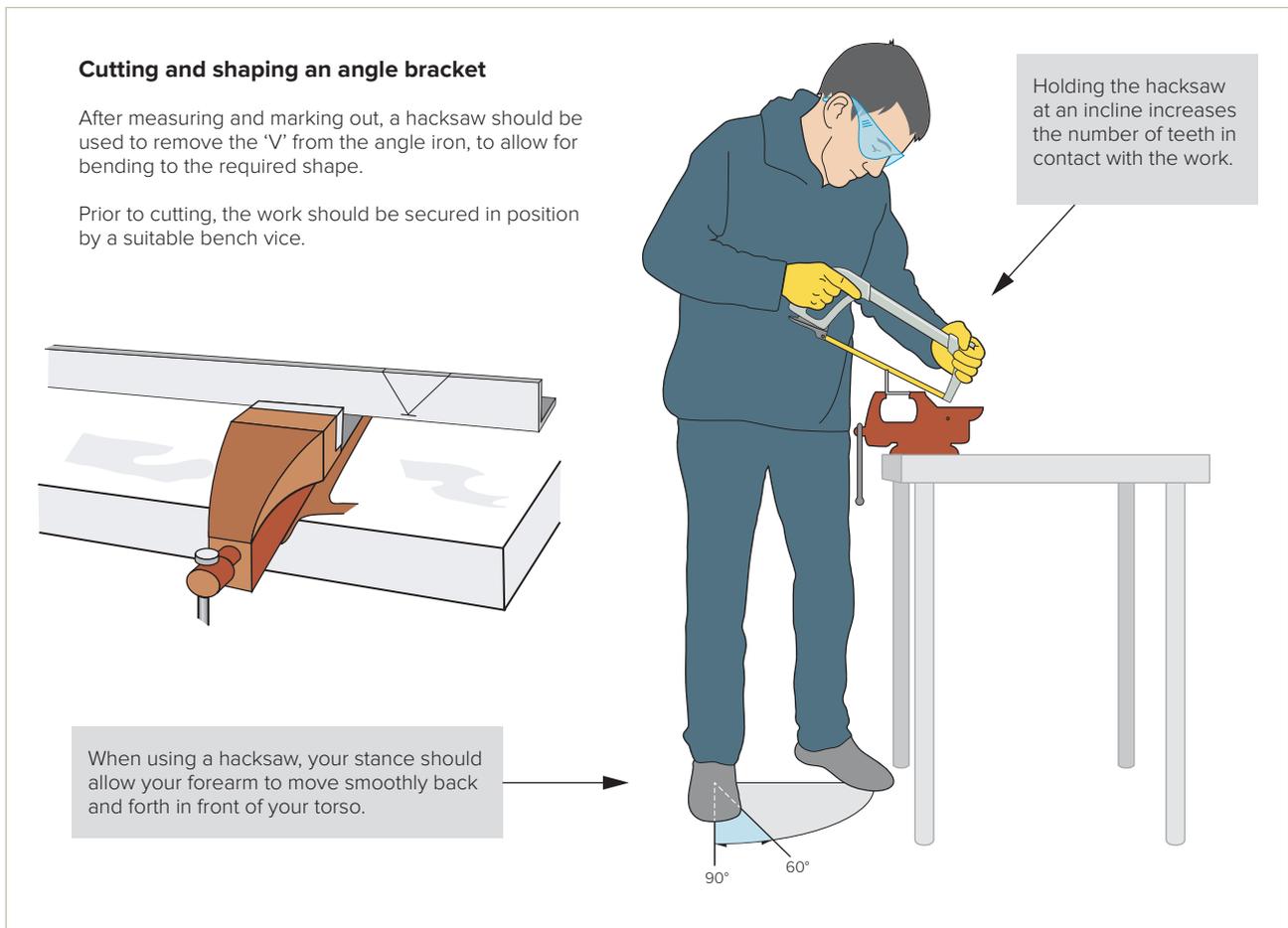


FIGURE 3.19 Cutting and shaping an angle bracket

An alternative to manually cutting materials is to use a drop saw. Drop-saw tables are typically fitted with a gauge to facilitate cutting multiple items to a specific length. The machine guard will automatically lift up as the blade is brought down, and some models will not start if the guard is being artificially held out of position. It is important to select the correct blade for each task because different blades are required for wood, metal and masonry. Abrasive drop-saw blades are commonly used in the electrical industry to cut metal strut channels and threaded rods.

Jigsaws are suitable for cutting straight lines and curves in thin materials, including metals, plastics and timbers. A typical application is to cut out a large cable entry into a switchboard enclosure.

3.5.2 Files

Files are used to shape materials, remove burred edges and produce finished surfaces. There are many different types of files available, and these are categorised by length, profile, cut and grade (**Figures 3.20** and **3.21**).

The 'cut' of a file refers to the arrangement of the teeth on the cutting surfaces. A single-cut file has teeth formed on the face of the file by parallel cuts made in one direction. The face of a double-cut file is formed by parallel sets of cuts that cross one another in different directions, resulting in the teeth having a diamond shape. The grade of a file refers to the size of the teeth. The three most common grades are smooth, second-cut and bastard. A bastard file has the largest teeth and so produces the roughest cut. It is useful for removing large amounts of material from a work piece. A second-cut file can be used to make finer adjustments for thin materials or as a general-purpose file. A smooth file should be used to make very fine adjustments and produce smooth surface finishes.

Other file types include mill-saw files and warding files. Factors to consider when selecting files for a workshop task include: the type of material required to be filed, the amount of material requiring removal, the required surface finish and the available access to the surfaces.

Cutting a strut channel with a drop saw

A drop saw with an abrasive blade is suitable for cutting a metal strut channel. Before starting the cut, ensure that all PPE is properly fitted and that the work is secure in the vice.

Cutting metals with an abrasive blade produces sparks—remember to locate the drop saw away from flammable materials and have suitable fire-fighting equipment on hand.

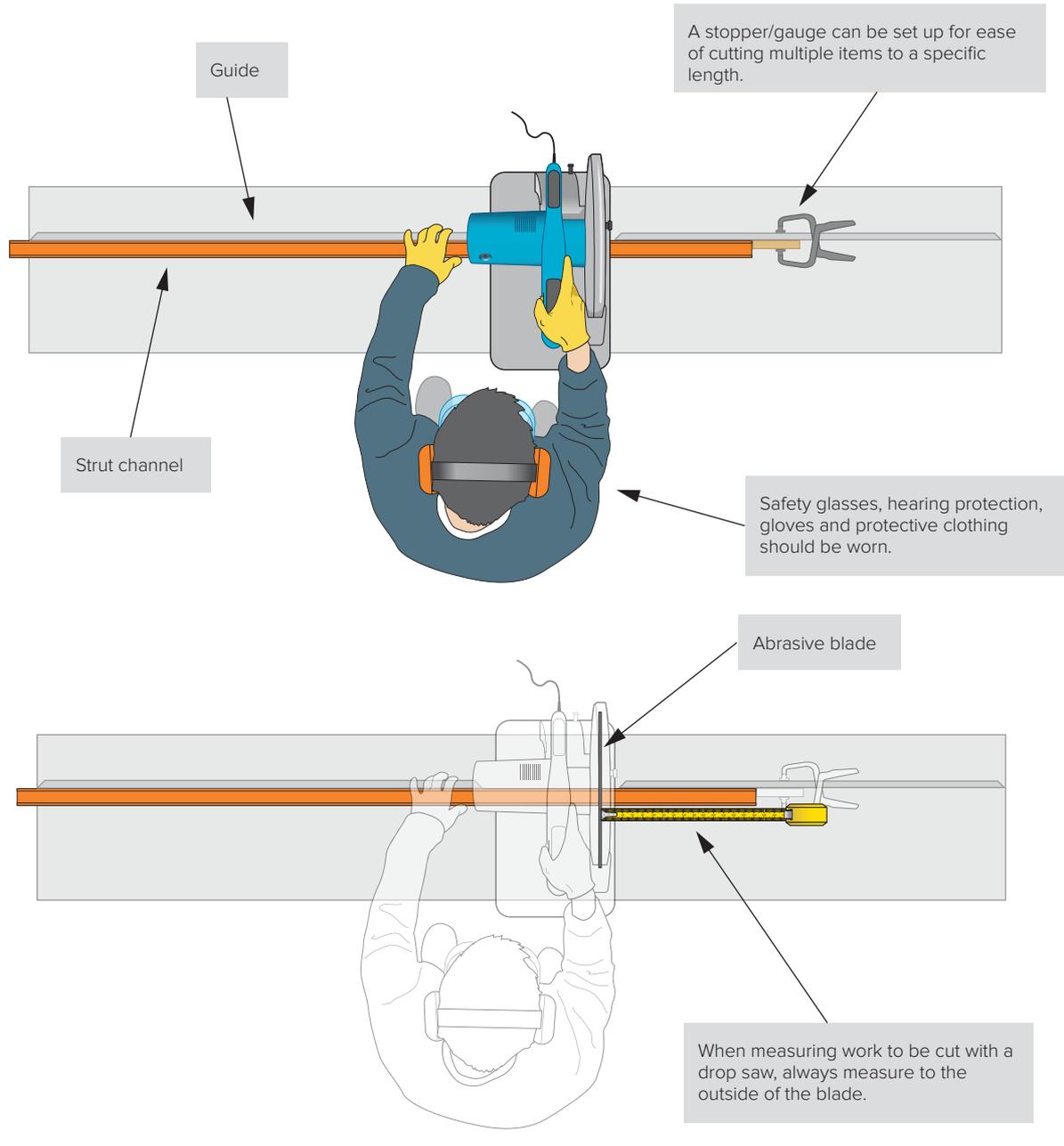
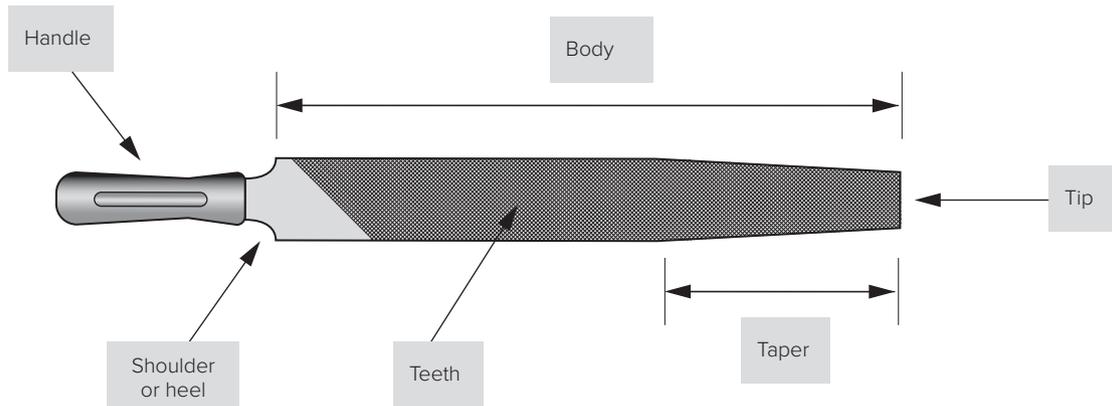


FIGURE 3.20 Cutting a length of strut channel

Before using a file, check the condition of the handle and body. Cracked or damaged files should be repaired or replaced. Check the face of the file for pinning (the accumulation of material between the teeth). These pins prevent the file from cutting and can protrude to produce scratches on the work piece. Pinning can be reduced by applying chalk prior to use, and existing pins can be removed using a file card. Care must be taken when handling files as the body is hard and brittle. Dropping a file could be sufficient to cause chips or fractures, and you should never use a file to strike an object.

Parts of a file



Common types of files



Flat

Flat files have a rectangular profile, are tapered at the tip and have cutting teeth formed on all sides.



Hand

Hand files also have a rectangular profile but are not tapered and have one edge with no teeth cut (referred to as the safe edge) to allow filing of a surface up to a corner.



Half-round

Half-round files have one flat side and one curved side. They are suitable for filing flat and curved surfaces and for removing burrs from large holes and pipes.



Round (rat's tail)

A round file, sometimes known as a rat's tail, has a cylindrical body suitable for enlarging drilled holes or removing burrs from pipe that has been cut to size.



Three corner

Three corner, triangular files have a triangular profile, with teeth formed on all sides. They are suitable for filing into corners that have acute angles.

Grades of files



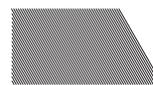
Bastard

Used for roughing



Second cut

General purpose use



Smooth

Used for finishing

FIGURE 3.21 Engineering files

Filing techniques

There are three main filing techniques: roughing, finishing and draw filing. Roughing refers to the removal of large amounts of material with no regard to surface finish, typically using a bastard file. Finishing refers to the process of removing material more slowly, making small adjustments to the shape of a work piece, typically using a second-cut file. Draw filing is usually performed with a smooth file and is mainly used to produce a smooth, even surface finish. One method of draw filing involves facing the work piece straight on, with the file held perpendicular. A smooth, even surface finish can be achieved using this technique.

When using a file, turn your body sideways to allow free back-and-forth movement of your arm across your torso. One hand should firmly grip the handle, while the palm of the other hand should be placed on the tip of the file to provide an even downward pressure on the forward stroke. Remember to check the shape of the work piece regularly to avoid over-filing.

3.5.3 Grinders

These tools come in stationary and portable varieties. Bench grinders are fastened to a bench top, while pedestal grinders are securely fixed to the floor. Both types usually have two grinding wheels: a coarse wheel for roughing and a smoother wheel for finishing. It should be noted that the wheels are not usually controlled independently of one another—when one wheel is rotating, the other will also be rotating—so caution must be exercised. Machine guards, located above each wheel, should be adjusted into position prior to use.

Portable grinders are available in mains-powered and battery-powered models, including angle grinders, die grinders and straight grinders. Care must be taken to select the correct wheel for each task. Different wheels are required for metal, masonry and grinding applications, and the wheel guard should always be adjusted into a suitable position to direct sparks away from your hands and body.

Grinding wheels are quite brittle and applying excessive pressure can cause the wheel to shatter. Pressure should never be applied directly to the face of the wheel when in use and chipped wheels should be discarded immediately. **Table 3.11** shows various types of grinders.

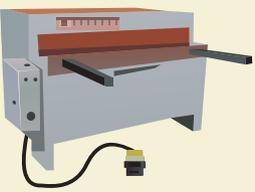
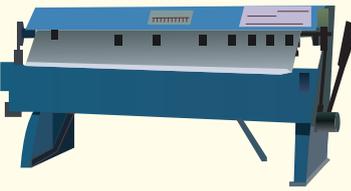
TABLE 3.11 Types of grinders

Tool	About
Pedestal grinder 	Bench and pedestal grinders both consist of two mains-powered grinding wheels for shaping and finishing surfaces. Care must be taken to ensure machine guards are fastened into position while grinding.
Bench grinder 	
Angle grinder 	

3.5.4 Sheet metal tools

Various types of specialised tools for cutting and shaping sheet metals are discussed in **Table 3.12**.

TABLE 3.12 Sheet metal cutting and shaping tools

Tool	About
Straight snips 	Snips can be used to cut straight and curved lines in sheet metals.
Aviation snips 	Aviation snips are usually preferred over straight snips because the design provides increased mechanical advantage and comfort for the user.
Guillotine 	A guillotine is used to cut sheet metal to size. It consists of a tabletop, a finger guard and a large blade, commonly operated by a foot pedal. Mains-powered guillotines also exist. A guide is usually present at one side of the tabletop and can be used to ensure each cut is square.
Finger-brake bender 	A finger-brake bender consists of a hinged tabletop with clamping fingers that are used to hold a metal sheet in place. With the sheet metal clamped on one side of the hinge, the other side of the tabletop can be moved to bend the metal along its length. Automatic sheet-metal benders use magnetic fields to place bends in metal sheets.

3.5.5 Cutting tools hazards and safety

Prior to using tools to cut and shape materials, ensure that the selected tool is appropriate for the task and that the cutting blade or wheel is appropriate for the material. It is important not to overstretch the capability of a cutting blade, as this can cause damage or even shattering of the blade, potentially resulting in severe injuries. Equipment training may be necessary prior to using some tools and a JSA should always be carried out prior to commencing work.

Cutting and shaping tools invariably pose risks of physical injuries such as cuts and abrasions. The potential severity of injury is increased when using mains-powered and battery-powered equipment. Power tools also pose the risks of electric shock, burns and eye injury. When using cutting tools that produce sparks, a work permit may be required and suitable fire-fighting equipment should be readily available. When in doubt about safety requirements or the techniques for using particular tools, advice should be sought from your supervisor.



CHECK YOUR UNDERSTANDING

17. In what direction do the teeth of a hacksaw point?
18. List common file types.
19. List three grades of file.
20. When using a file, when should downward pressure be applied?
21. List three common hacksaw blade teeth-per-inch ratings.

3.6 Drills and drilling

A complete drilling apparatus consists of a drill and a drill bit. The drill is usually a rotating electric machine but hand-operated drills, similar in construction to a set of old-fashioned eggbeaters, also exist. The drill bit is fastened into the drill chuck, which is rotated to perform the drilling operation (**Figures 3.22** and **3.23**).

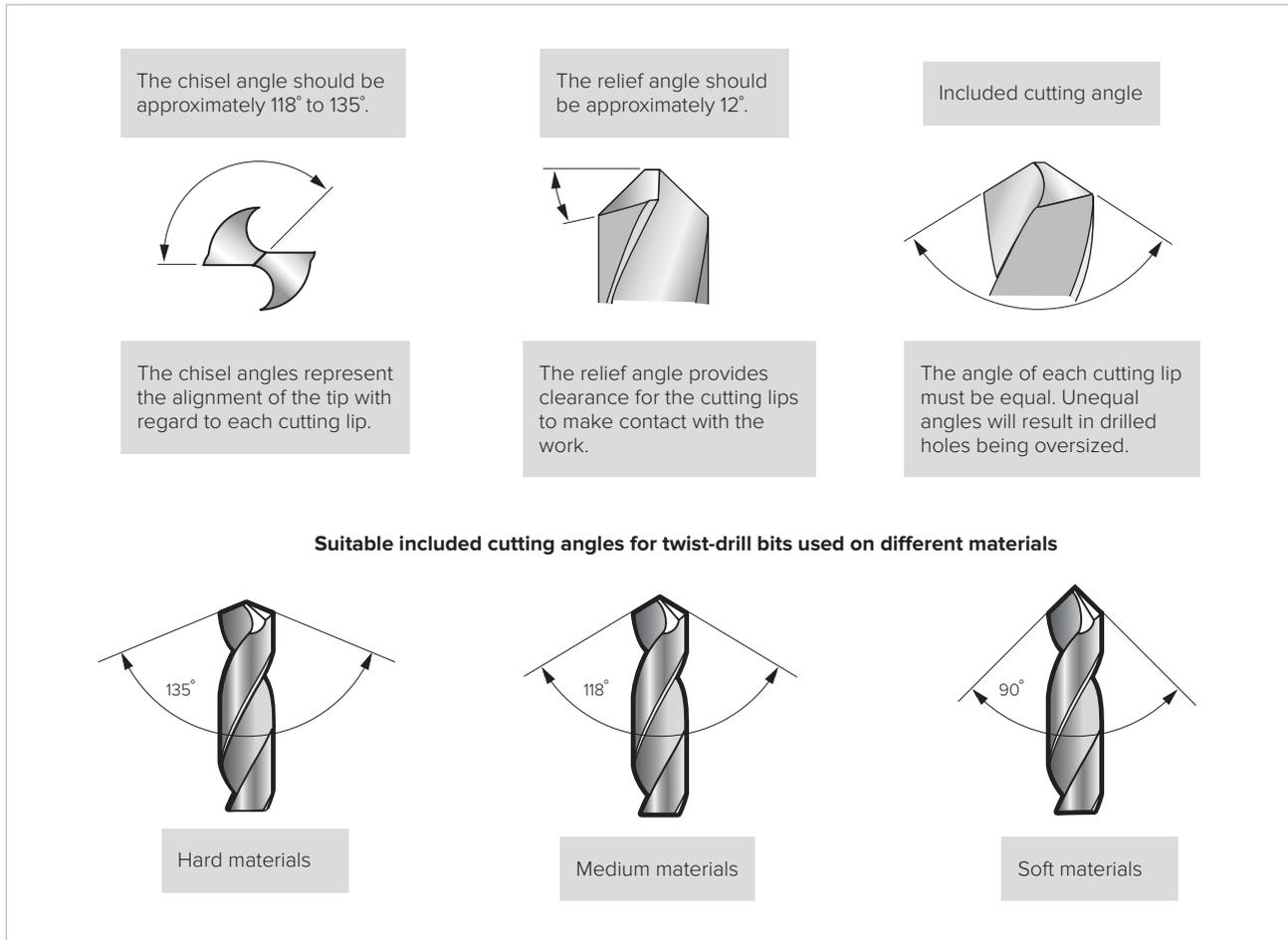


FIGURE 3.22 How a drill works

Holes may need to be drilled straight through, or just part of the way into, a work piece. (A hole that is drilled just part of the way is known as a blind hole.) Straight-through holes allow materials to be fixed to structures or joined using nuts and bolts. Blind holes can be ‘tapped’ to allow fastening of components where the use of nuts and bolts is impractical. A drill gauge should be used when drilling blind holes to ensure the correct depth.

3.6.1 Drill bits

These are cylindrical in shape and consist of a shank, body and tip (**Table 3.13**). They are most commonly fabricated from high speed steel. The shank is the part that is fastened into the drill chuck, and it can be straight, tapered or reduced in diameter. Some shanks are hexagonal to prevent slipping, and grooved proprietary shanks also exist to fit special hammer-function drill chucks. The body consists of corkscrew-style grooves known as flutes, to provide an entry path for coolant and an exit path for swarf; the remaining surface area of the body is referred to as ‘the land’. The tip consists of two cutting lips, which perform the actual cutting work.

Sharpening a twist-drill bit

Although automatic drill sharpeners are widely available, manual sharpening of drill bits is a simple and important skill to learn.

The three main factors to consider when sharpening the drill tip are the included angle of the cutting lips, the chisel angle and the relief angle. Upon completion, a drill gauge can be used to check the drill angles where necessary.

Drill sharpening is a highly practical task, so the only way to become skilled at it is to practise.

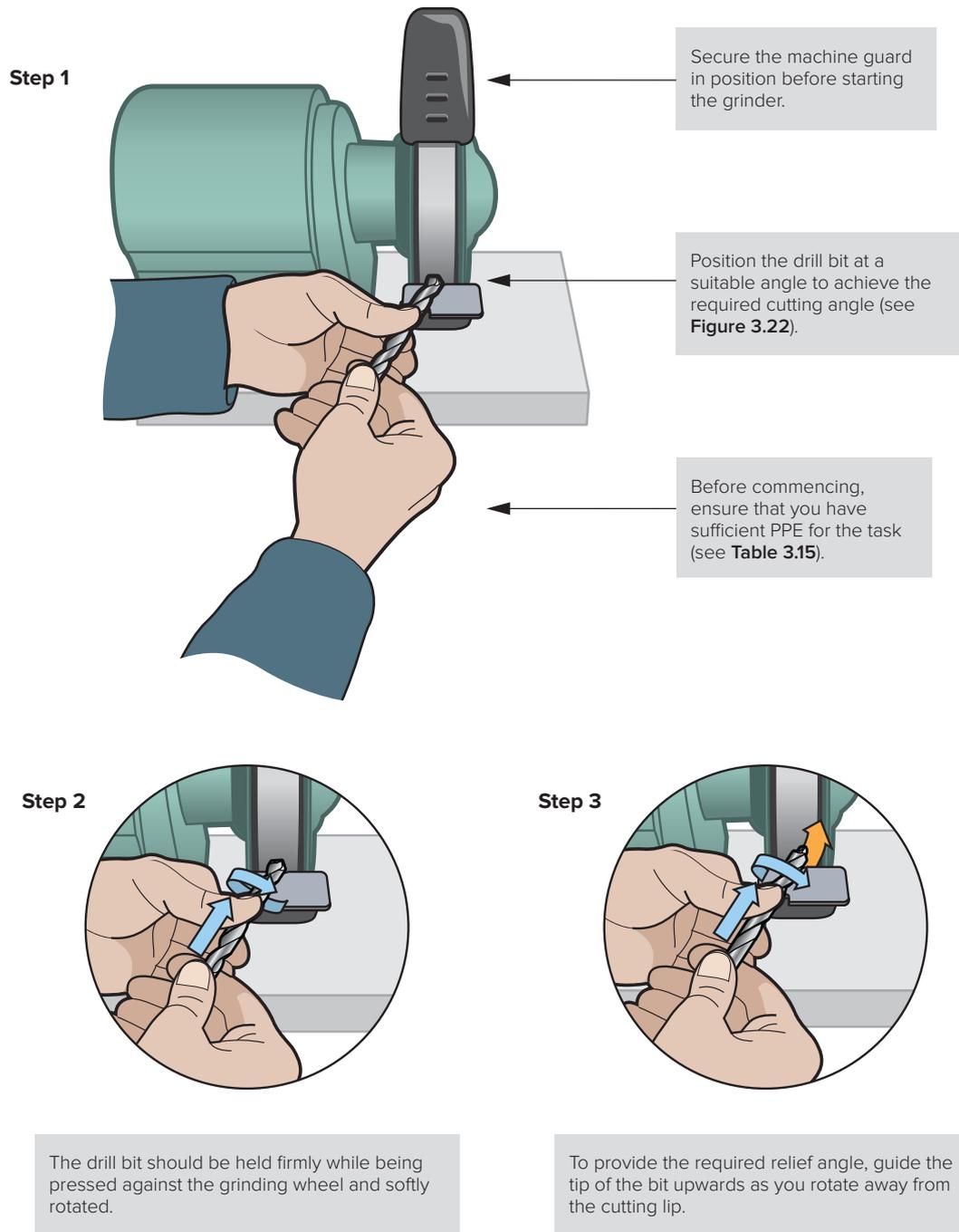


FIGURE 3.23 Sharpening a twist drill

TABLE 3.13 Common drill bits

Drill bit	Shank types	About
Twist-drill bit 	Straight Tapered Reduced	Twist-drill bits are available in a wide range of sizes and are suitable for drilling metals, plastics and timbers. A basic set of general-purpose twist drills will consist of approximately 20 bits in sizes from 1.0 mm up to 12.0 mm in diameter.
Masonry-drill bit 	Straight Reduced Proprietary	Masonry-drill bits consist of a bonded tungsten-carbide tip and are commonly used to drill holes into bricks, concrete, stone and ceramics. The body of a masonry-drill bit commonly has a reduced diameter when compared with the cutting lips. Proprietary shanks provide clip-in action to matching drill shanks.
Hole saw 	Straight Hexagonal	Hole saws are cylindrical saws that fit onto an arbour by way of a screw thread and/or locking mechanism. A twist-drill bit, fastened into the centre of the arbour, is used to start the hole and acts as a centring guide. Typical sizes used in the electrical industry include 16 mm, 20 mm, 25 mm, 32 mm and 40 mm. A hole saw usually has a hexagonal shank and is suitable for drilling thin metals, plastics and timbers. Care should be taken not to damage the teeth of the saw by using excessive speed or pressure.
Spade bit 	Straight Hexagonal	A spade bit is suitable for use on timber. It has a hexagonal shank and consists of two flat blades on either side of a sharp point. Commonly used sizes are 16 mm, 19 mm, 22 mm and 25 mm.
Auger bit 	Straight Hexagonal	An auger bit is useful for drilling holes in hardwoods that would quickly blunt a speed bore. It consists of a threaded screw-tip to facilitate starting, large flutes and typically a straight or reduced hexagonal shank. Auger bits are available in a wide range of sizes and lengths.

3.6.2 Drilling machines

Several types of drilling machines are commonly used in the electrical industry (**Table 3.14**). Stationary drills, such as pedestal drills, bench drills and radial drills, are commonly used in workshops; mains-powered and battery-powered portable drills are widely used on site.

3.6.3 Drilling operations

Prior to drilling a hole, check that the correct type of drill bit has been selected and that both the bit and the work piece are securely fastened in position. Ensure that all tabletop pivot points are secure when using a pedestal drill or bench drill. When using a chuck key, fasten the chuck in all three positions to ensure even pressure and always remember to remove the key prior to operating the drill. Any jewellery you are wearing should be removed, and clothing or hair that could become entangled should be secured out of the way before drilling. Finally, check that the drill is set to rotate in the forward (clockwise) direction as the drill bit will not cut when driven in reverse. Be aware of any automatic hold switches as they will keep the drill running without the need to maintain pressure on the trigger.

When carrying out drilling operations, safety glasses should be worn at all times because small particles of swarf can easily be flung into the eyes. Manufacturers' guidelines can be consulted to find recommended drill speeds for different applications. In general, smaller holes are drilled at faster speeds, while larger holes require slower speeds. It is important not to use excessive pressure when drilling hard materials, particularly with small drill bits, as this can cause the bit to snap. When using portable drills, ensure an even footing and maintain three points of contact when drilling from a ladder.

TABLE 3.14 Types of drilling machines

Drill	About
<p>Pedestal drill</p> 	<p>Bench and pedestal drills consist of a heavy base and shaft. The drill motor is housed at the top, along with the drill chuck and feed lever. An adjustable tabletop can be raised, lowered and rotated, and is slotted to allow fastening of a machine vice. Some drills include a depth gauge and machine guard mounted to the chuck.</p>
<p>Bench drill</p> 	
<p>Power drill</p> 	<p>Typical features of power drills include a forward–reverse selector, auto–hold, speed selector or a variable speed trigger, and drill/hammer functions. Some drill chucks can be tightened by hand, while others require the use of a chuck key.</p>
<p>Battery drill</p> 	<p>A wide variety of battery drills are available, with typical operating voltages of 12 V, 18 V, 24 V and 36 V. Features typically include forward–reverse selection, variable speed trigger and drill/hammer functions. Standard battery–drill chucks accommodate shanks of up to 12 mm in diameter and can be tightened by hand. The cost of a battery drill is mainly dictated by the quality of the battery and the motor technology.</p>

Rotary hammer drills should be set to drill and hammer when drilling masonry; however, remember that there are times when masonry should be drilled without the use of the hammer setting. Drilling straight through holes in masonry using the hammer setting can result in a crater blowing out as the drill punches through the rear side of the material. To avoid this, the drill-only setting should be used to complete the last part of these drilling operations.



CHECK YOUR UNDERSTANDING

22. A spade bit would be used for drilling what type of material?
23. What type of drill bit has a bonded tungsten-carbide tip?
24. A hole saw is most suitable for sawing which materials?

3.7 Thread cutting and tapping

The purpose of a thread is to provide a mechanical advantage on a shaft. The thread is used to fasten materials together, as with a nut and bolt, or provide a means of adjustment, as with a vice. **Figure 3.24** shows the common types of threads found in electrical and engineering equipment.

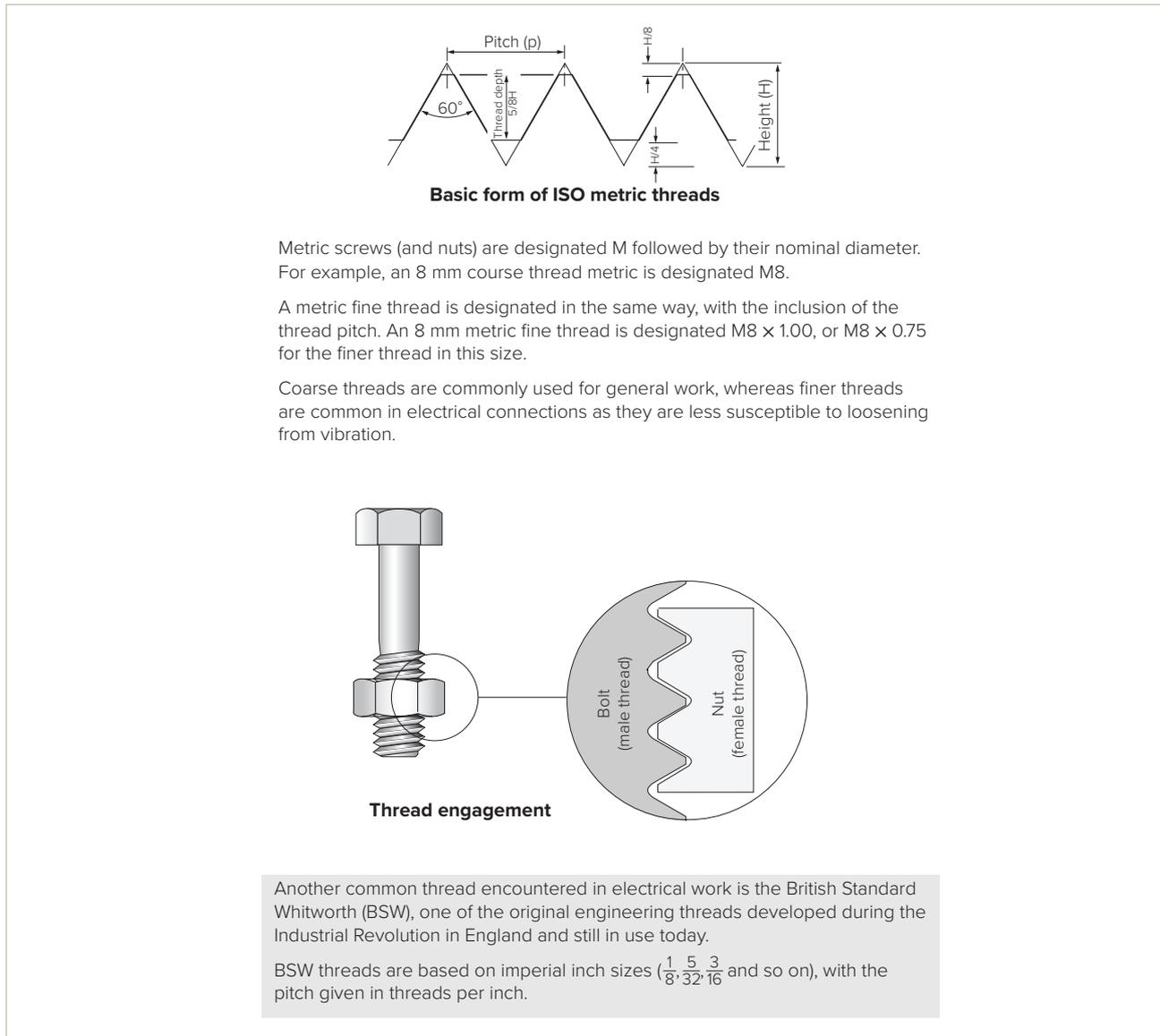


FIGURE 3.24 Engineering threads common to electrical work

3.7.1 Tapping

The process of cutting a thread on the internal surface of a hole is called tapping. Tapping is commonly carried out to allow fastening of components where the use of a nut is impractical or undesirable. Tapping is achieved by the use of specially designed tools called taps.

Prior to tapping, double-check that the hole has been drilled at the correct size for the tap, as a hole that is too large will result in a weak thread and a hole that is too small will increase the risk of the tap breaking. Select the appropriate tap and wrench and apply cutting lubricant to both the cutting lips of the tap and the hole. Locate the tap in the hole, ensuring the tap is square, before starting to rotate. When you are ready to start the tap, apply light pressure and rotate approximately one full turn forwards and then half a turn backwards, or similar. Be aware of the changes in pressure

required to rotate the tap as you go, and remember that using excessive force is likely to snap the tap. Clear the swarf from the flutes and the hole regularly to further reduce the chance of excessive pressure being placed on the tap.

Figure 3.25 shows tapping tools and equipment, **Figure 3.26** shows types of tap wrenches and **Figure 3.27** shows tapping techniques.

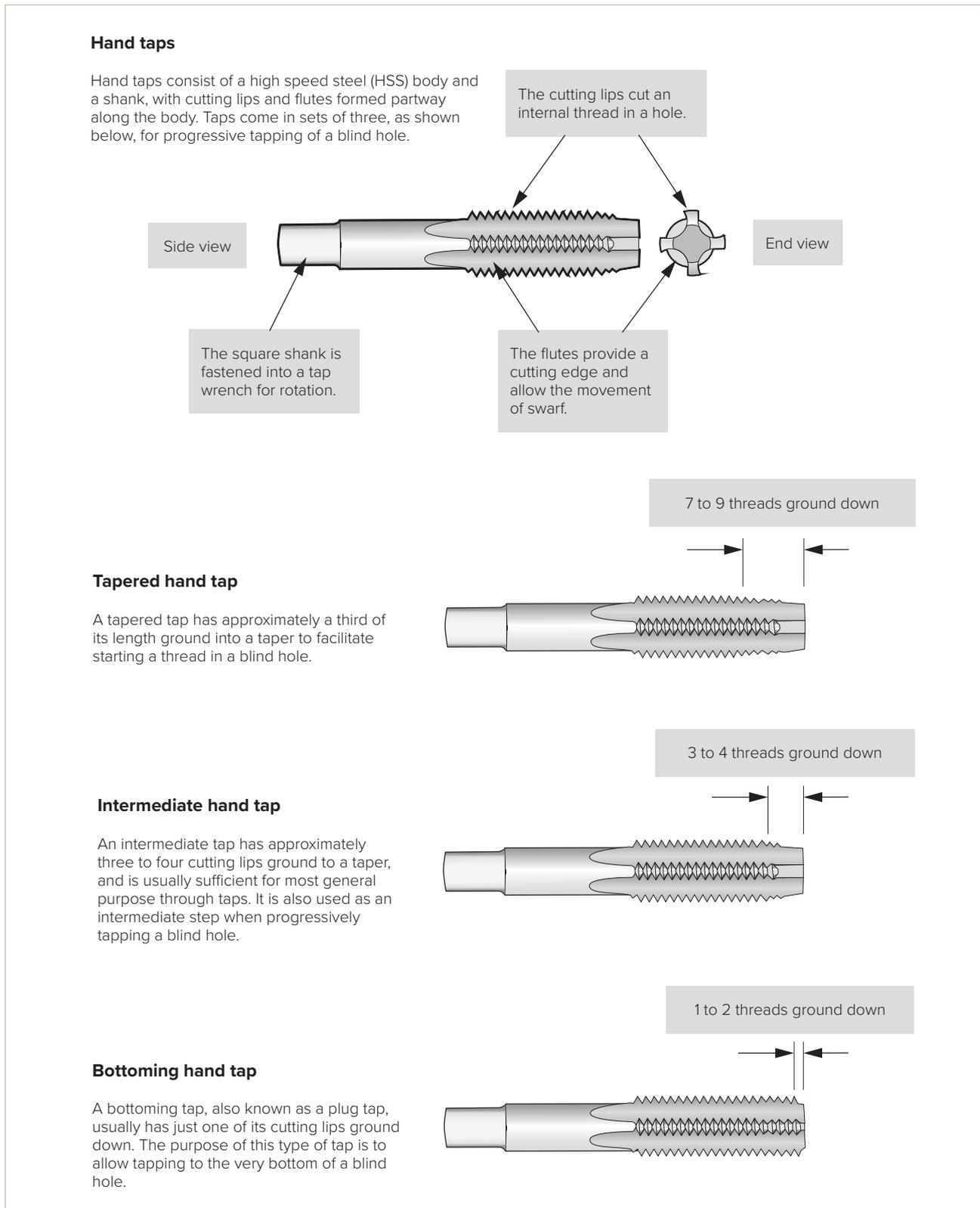
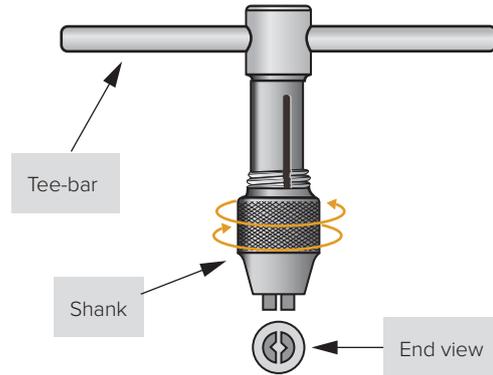


FIGURE 3.25 Tapping tools and equipment

Tee-type tap wrench

A tee-type wrench has a chuck that fastens onto the shank in a similar fashion to the chuck of a battery drill. The smaller overall length of the tee-bar offers less mechanical advantage when compared with a bar-type wrench but is more suitable for use in tight spaces. Some tee-type wrenches also incorporate a reversible ratchet function.



Bar-type tap wrench

A bar-type wrench has two 'V'-shaped clamps that can be moved by adjusting one of the bar handles to fasten onto a shank. The increased length of the bar provides a better mechanical advantage when compared with a tee-type wrench.

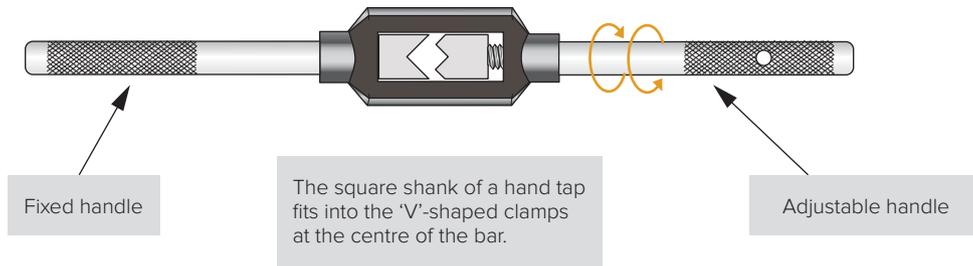


FIGURE 3.26 Types of tap wrenches

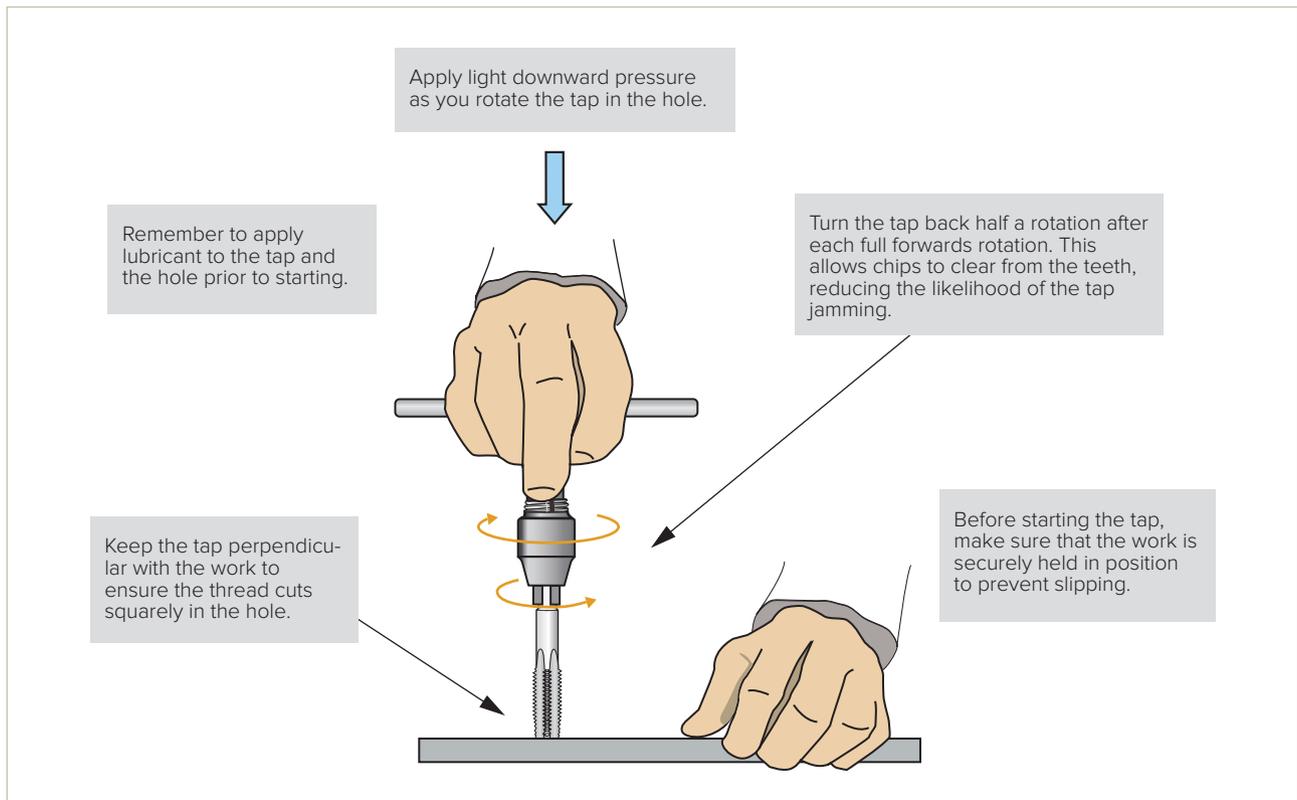


FIGURE 3.27 Tapping techniques

3.7.2 Threading

The process of cutting a thread on the external surface of a rod is known as threading. The tool used to cut external threads is known as a die. Dies are typically made of high speed steel and have internal flutes and cutting lips. As with taps, they are identified by their thread type, size and pitch. **Figure 3.28** shows some common dies and stocks.

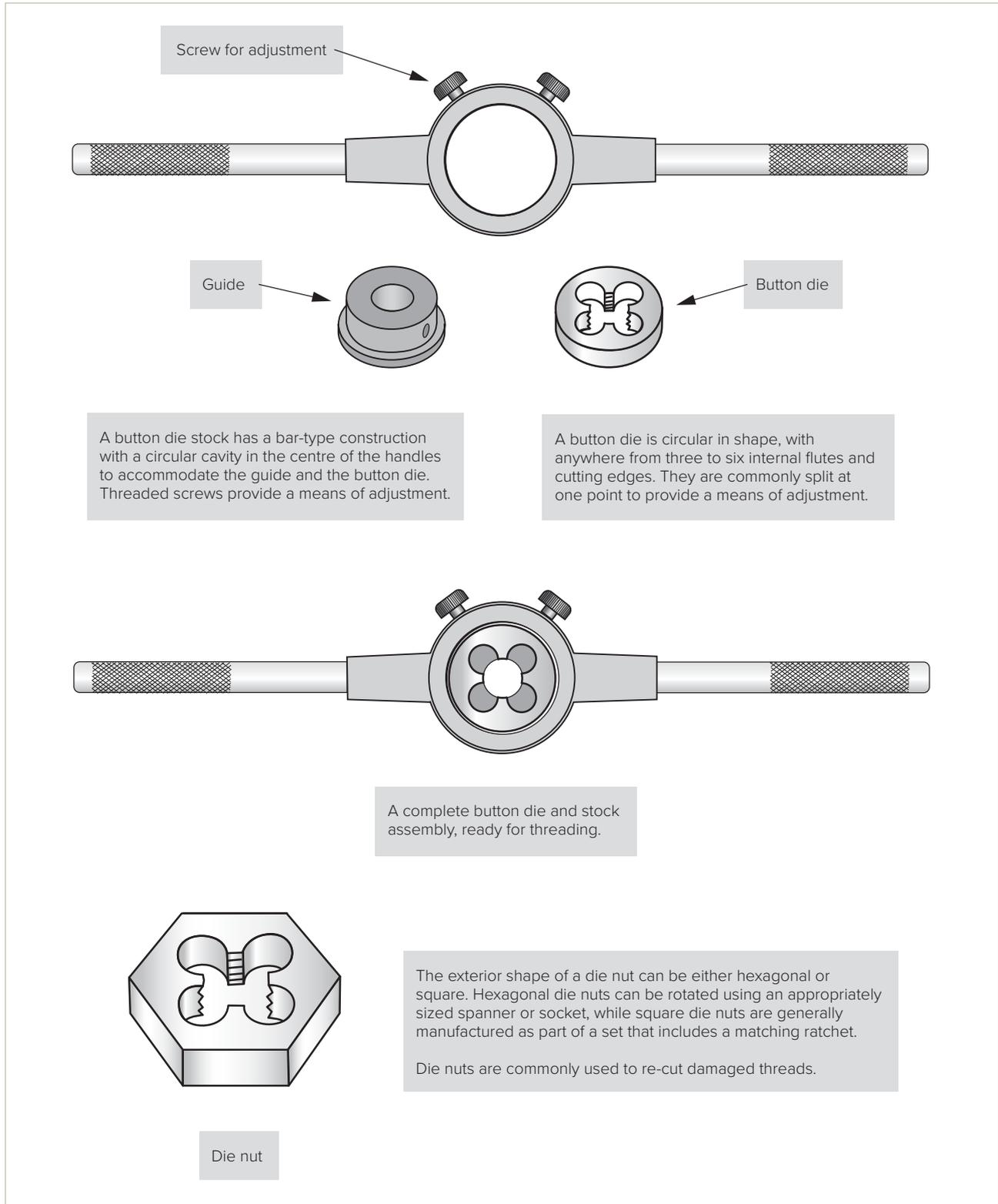


FIGURE 3.28 Threading dies and stocks

Prior to threading, secure the rod or pipe in a suitable pipe vice. Apply cutting lubricant to both the work and the die and, when threading with a die nut and spanner, ensure the spanner is the correct size to avoid slipping. Locate the die over the work and ensure the die is square. When you are ready to start threading, apply light pressure and rotate approximately one full turn forwards and then half a turn backwards, or similar. As with tapping, take note of the changes in pressure as you go, and clear the swarf from the flutes and the thread regularly.



CHECK YOUR UNDERSTANDING

25. List three hand taps used in electrotechnology work.
26. List two tap wrenches used in electrotechnology work.
27. What should be added to the work and the die to avoid creating a damaged thread?

3.8 Joining components

Components can be joined using a number of methods, the selection of which will depend largely on the required strength, along with other factors such as a need to be able to dismantle and reassemble parts.

3.8.1 Machine screws

Joining components with machine screws provides the advantages of a strong join and the ability to easily dismantle and reassemble parts. Machine screws can be screwed directly into tapped holes or fastened into through holes with the use of a nut. The main parts of a machine screw include the thread, head and drive. Standard machine screws are made of steel. Brass, stainless steel and high-tensile screws are also available, at increased cost, for situations requiring enhanced performance.

When selecting machine screws, the screw diameter and length must suit the application. A larger head provides increased mechanical strength while the style can provide the desired aesthetics. The drive type can be selected to provide security where required. Nuts used with screws should have a matching thread, diameter and material. Washers are commonly placed between machine screws and components. The surface area of a flat washer increases the compressive area of the join, while spring and star washers reduce the chance of the join loosening.

Refer to **Chapter 6, Figure 6.2** for a summary of the common types of machine screws used in electrical work.

3.8.2 Blind riveting

Blind rivets, commonly known as pop rivets, can be used to join sheet materials. They consist of two main parts: the rivet body and the mandrel. The body consists of a head and a hollow shaft. The mandrel is a metal pin with an enlarged head at one end. It sits in the hollow shaft of the body. A rivet tool grips the mandrel and draws the enlarged head up into the shaft of the rivet, causing it to bulge out. The pressure exerted between the rivet head and the expanded shaft is used to join materials together. Blind rivets are quick and easy to install but are not suitable for joins that will be subject to heavy mechanical loading.

Table 3.15 gives details about the cutting, drilling, shaping and tapping required in the five fabrication projects.

TABLE 3.15 Fabrication projects—cutting, drilling, shaping and tapping

Fabrication project		Cutting/Shaping tools	PPE	Techniques
1	Angle bracket	Hacksaw Power drill Twist-drill bits Hand file Vice grips Multi-grips Soft-faced hammer	Safety goggles Ear plugs Steel-capped boots Overalls Leather gloves	The angle iron is first cut to length. The mounting holes should then be drilled and the marked-out V should be removed. The work can then be bent to a 90° angle. A soft-faced hammer may be required to make fine adjustments during shaping.
2	Pedestal isolator stand	Drop saw Flat file Power drill Twist-drill bits Hand taps Tapping wrench	Safety goggles Ear muffs Steel-capped boots Overalls	A drop saw is first used to cut the strut channel to the required length, after which burrs and sharp edges should be removed with a file. Tapping holes should be drilled and then tapped in the SS panel.
3	Trapeze support	Drop saw Flat file Power drill Twist-drill bits	Safety goggles Ear muffs Steel-capped boots Overalls	A drop saw is first used to cut the strut channel and threaded rods to length, after which a file should be used to clean up any burred edges. Then the strut channel can be drilled to allow mounting to the rods.
4	Glandplates	Power drill Hole-saw kit Jigsaw Round/half-round file	Safety goggles Ear plugs Steel-capped boots Overalls	Once secured in position, holes should be drilled in the glandplate using a hole saw. Then the holes should be filed to remove burrs, and slots should be cut in ferrous glandplates to prevent circulating eddy currents.
5	Cable/conduit cover	Guillotine Power drill Twist-drill bits Finger-brake bender Flat file	Gloves Steel-capped boots Overalls	First, the sheet metal is cut to size using a guillotine and tin snips. The sheet should then be secured in place for drilling. After all holes have been drilled, the sheet can be shaped using a finger-brake bender. When the process is complete, any burrs or sharp edges should be removed with a file.

3.8.3 Introduction to welding

The principle of welding is to use high temperatures to fuse metals together. A welding rod is melted together with the materials to produce the fused joint. Different welding techniques use different methods to apply heat to the join, as outlined in **Table 3.16**.

TABLE 3.16 Welding methods

Method	Details
Gas welding	Oxy-acetylene is burned to produce a flame that burns at approximately 3500 °C. The flame is applied to the join using a specially designed gas torch.
Arc welding	Heat is produced by creating an electric arc between an electrode and the work piece. MIG and TIG welding use different types of electrodes, but are both forms of arc welding.
Spot welding	Two copper electrodes are pressed against the work and a high current is passed through the point of contact (the 'spot') to create heat, resulting in a strong, fused joint.

Welding can be an appropriate method of joining components where severe vibration may cause regular loosening of screws or excessive strain on rivets. Prior to carrying out welding, specific safety training must be undertaken on the equipment. Given that welding involves the production of considerable temperatures, a work permit is generally required prior to performing welding operations on site.

3.8.4 Installing fabricated components

To ensure the quality of a finished electrical installation, fabricated components must be accurately secured in place. Use a tape measure or spirit level as necessary to progressively check the positioning of components as you tighten fixings and fasteners. A soft-faced hammer may be required to adjust components into the correct position.

As a general rule, all fasteners in one area should be inserted part of the way before any single fastener is fully tightened. If, for example, three of four fasteners are inserted and tightened prior to starting the fourth, the pressure exerted by the fixings can distort the form of the component enough that the fourth hole will become misaligned.



CHECK YOUR UNDERSTANDING

28. What are two advantages of joining components with machine screws?
29. List three welding methods used in electrotechnology work.
30. What is an advantage of using blind rivets?

3.9 Dismantling and assembling equipment

Various types of electrical equipment will need to be dismantled and reassembled within their service life. Equipment such as motors and contactors may need to be dismantled so that repairs or routine maintenance tasks can be performed. It is essential to follow a logical sequence when dismantling and reassembling equipment to ensure the equipment functions correctly and safely when it is returned to active service.

3.9.1 Tools for dismantling and assembling

Table 3.17 lists the kinds of tools that are typically used to dismantle and assemble electrical equipment.

3.9.2 Dismantling equipment

Prior to dismantling an item of equipment, relevant documentation should be obtained and reviewed. Use the manufacturer's instructions and equipment manuals to familiarise yourself with the operation and configuration of equipment, and review as-installed drawings to identify arrangement and connection configurations. Inspect the equipment to locate and identify the types of fixings and fasteners used. Understanding the equipment will help you to select suitable tools, locate major components and identify any equipment-specific hazards that may be associated with the work.

Table 3.18 gives details of the joining methods for the five fabrication projects.



CAUTION

Any equipment to be dismantled must first be safely isolated from all sources of electrical supply.

TABLE 3.17 Tools used to dismantle and assemble equipment

Tools	Typical use
Centre punch	Used to produce witness marks to assist with accurate placement of parts during reassembly, such as on the end shields of a motor
Ball-pein hammer	
Rubber mallet	Used to seat, unseat and adjust or locate components such as motor coils
Screwdriver	Used to loosen and fasten the machine screws that hold components and parts together
Allen key	
Spanner	Used to loosen and fasten the nuts and bolts that hold components and parts together
Socket	
Vernier caliper	Used to measure components and clearances
Long-nosed pliers	Used to grip and adjust small components in tight spaces
Pen and paper	Used to document the process of dismantling and reassembly, and to record lists of components, equipment configurations and settings

TABLE 3.18 Fabrication projects—joining methods

Fabrication project	Joining methods	Tools	PPE
1 Metallic cable cover	Blind rivets Green plugs and screws	Rivet gun Hammer Screwdriver or battery drill	Steel-capped boots Overalls Safety goggles Ear muffs
2 Angle bracket	Welding Sleeve anchors	MIG welder Hammer Spanners and/or sockets	Welding mask Steel-capped boots Overalls Leather gloves
3 Glandplates	Machine screws Nuts	Screwdrivers Spanners and/or sockets	Steel-capped boots Overalls
4 Isolator stand	Machine screws Spring nuts Bolts Sleeve anchors	Screwdrivers Hammer Spanners and/or sockets	Safety goggles Ear muffs Steel-capped boots Overalls
5 Trapeze support	Galvanised steel squares Steel nuts	Spanners and/or sockets	Safety goggles Ear muffs Steel-capped boots Overalls

Prior to the disconnection of equipment, be sure to note down any settings or arrangements that may require reconfiguration when the equipment is returned to service, such as the phase rotation of a three-phase motor. As the equipment is being dismantled, keep a record of what you do at each step, along with a list of associated parts. Rough diagrams can help to aid understanding later when the equipment requires reassembly. Remember that it may be necessary to take and record measurements of some components or clearances prior to unseating them. Inspect the condition of parts as you go and make note of any damage. Remember to order any necessary replacements on completion. Placing loose parts into itemised containers is a good way to keep track of screws, bolts and other components.

3.9.3 Precision measurement

There are instances in electrical work where a measurement is required to be more precise than can be made with a steel rule or measuring tape. The accuracy that can be achieved on any graduated scale is half the smallest division or ± 0.5 mm, given that the smallest division on most common hand-measuring devices is 1 mm.

Typically, before reassembling dismantled equipment, parts suspected of wear need to be accurately measured so that the correctly sized replacement parts can be identified and ordered. The most versatile and accurate measurement device used in electrical work is the vernier caliper. Although it is not accurate to a micrometre, it is sufficiently precise for most electrical applications requiring accuracy to 0.02 mm. Apart from measuring equipment parts, vernier calipers are handy for checking the size of drill bits and stock materials, and measuring the size of cables.

There are many versions of the vernier caliper, catering for both common and specialist applications. The features common to all types of vernier caliper and how it is used are shown in **Figure 3.29**.

3.9.4 Assembling equipment

As with dismantling, when assembling equipment it is important to familiarise yourself with the equipment documentation. In addition to instructions, manuals and diagrams, any notes made during previous dismantling should be obtained, reviewed and kept on hand for reference. Before commencing assembly, loose components should be cross-checked with recorded parts lists to ensure that all equipment components are accounted for, and that any required replacement parts have been ordered and received.

When you are ready to reassemble the equipment, follow the manufacturer's instructions or use the notes made during dismantling in the reverse order. Check the condition of parts and tick them off the list as you go. Be sure to align all witness marks and match all recorded measurements and clearances when seating components. When joining parts, finger-tighten all machine screws and bolts and verify correct alignment prior to tightening.

Figures 3.30 to 3.34 show how to dismantle and reassemble a motor.



CHECK YOUR UNDERSTANDING

31. List five tools that can be used to dismantle an item of equipment.
32. What is the term given to the marks made by a centre punch that are used when dismantling equipment?
33. Why should certain components be accurately measured when dismantling an item of equipment?
34. When working on electrical equipment, what must always be checked?

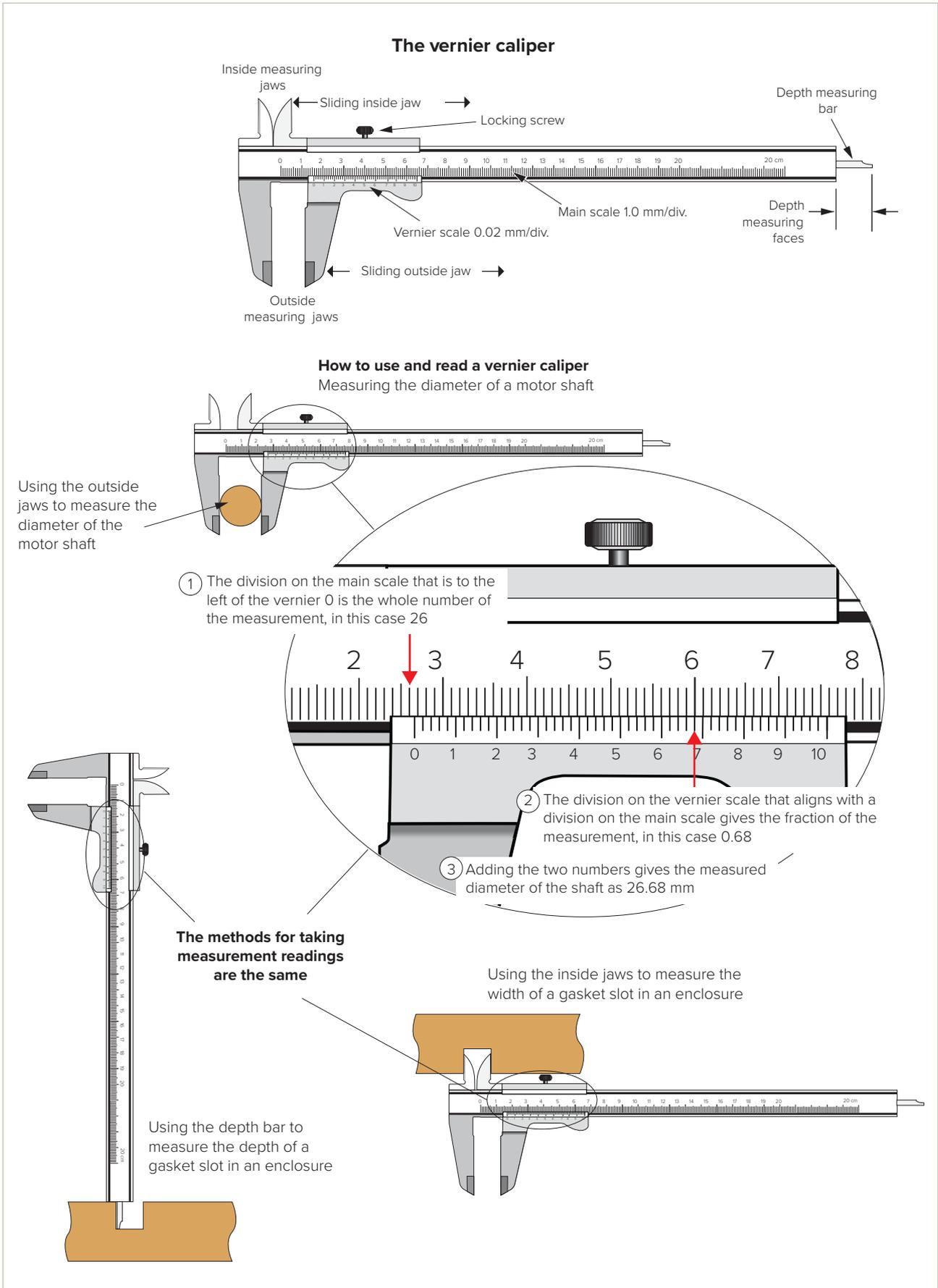
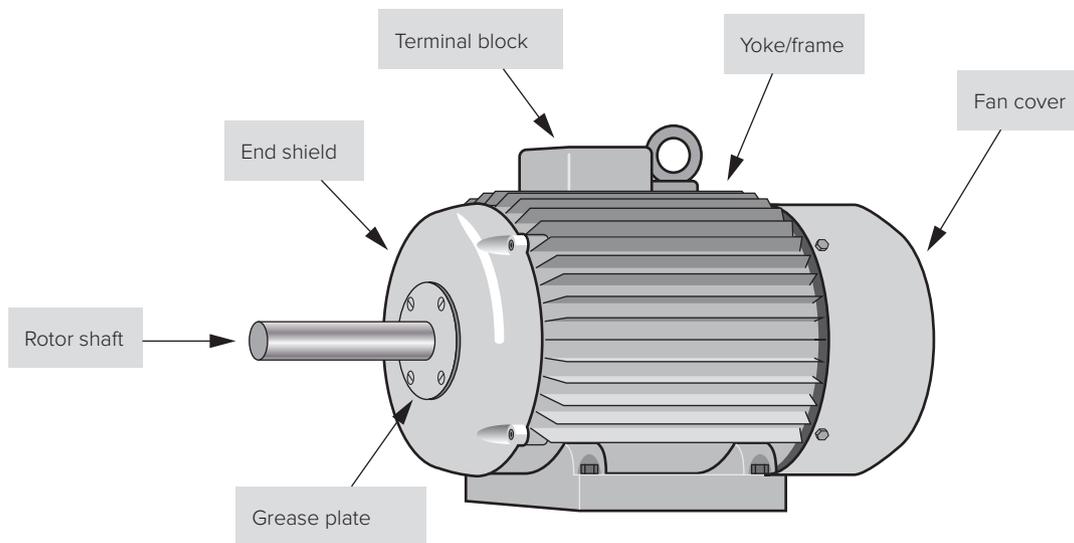


FIGURE 3.29 Vernier caliper

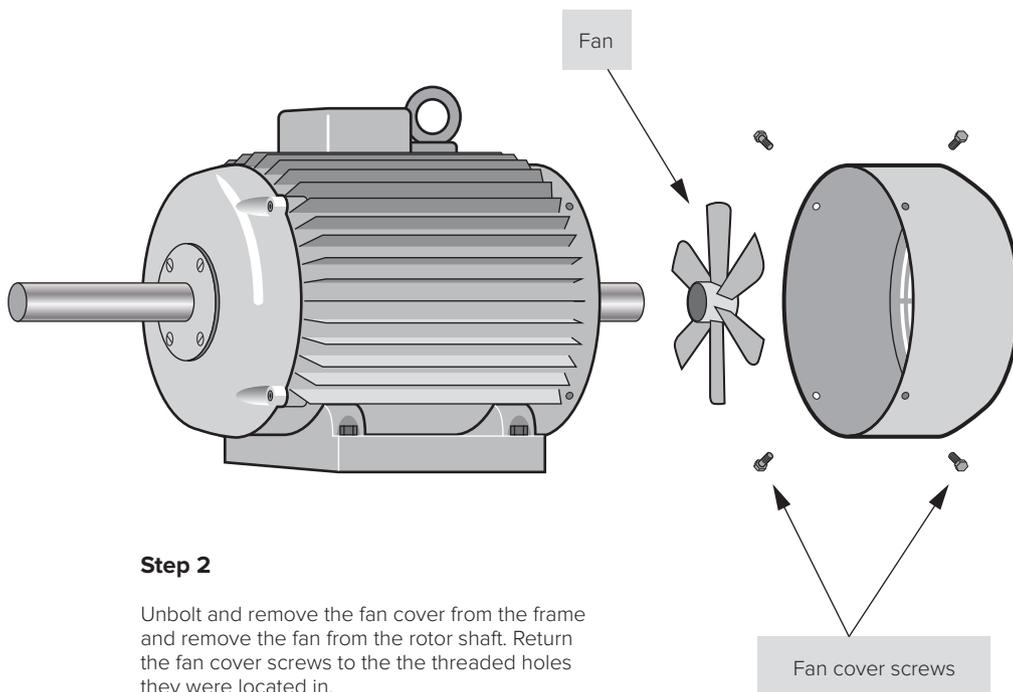
Dismantling and reassembling an induction motor



Step 1

Prior to dismantling, verify that the motor is isolated and locked out from all sources of supply. Test the motor windings for insulation resistance and continuity and record your test results.

Note: A low insulation resistance reading may indicate the presence of moisture.



Step 2

Unbolt and remove the fan cover from the frame and remove the fan from the rotor shaft. Return the fan cover screws to the the threaded holes they were located in.

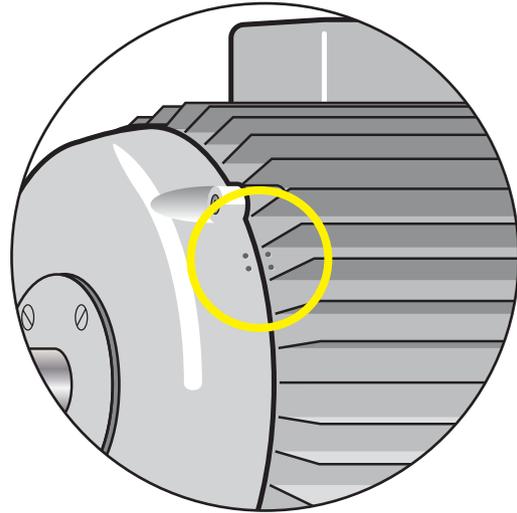
FIGURE 3.30 Dismantling and reassembling a motor—part 1

Step 3

Where necessary, make matching sets of witness marks on the end shields and frame using a suitable hammer and punch.

It is a good idea to make a set of two witness marks at one end of the motor and a set of three at the other. This ensures that the end shields can be distinguished from one another.

Note: Witness marks act as a guide for re-seating the end shields during reassembly; however, many modern motors will only fit together one way and so do not require witness marking.



A set of two matching witness marks facilitates alignment during reassembly.

Step 4

Unscrew and remove the external grease plates from the end shields.

Note: The grease plate screws are fastened into threaded holes in the internal grease plates, which are located behind each bearing.

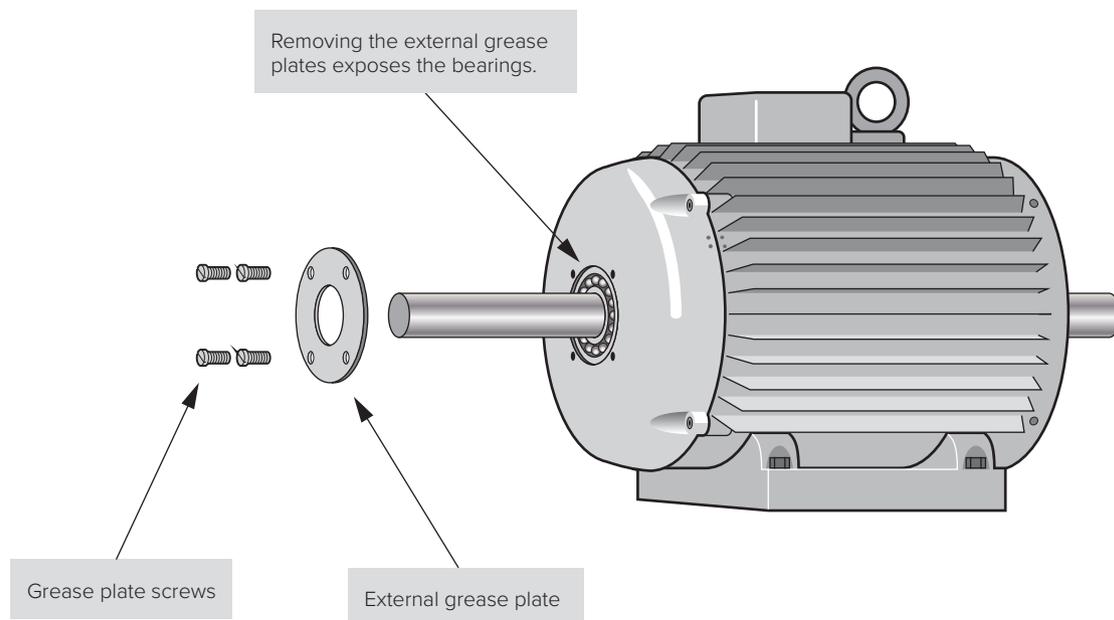
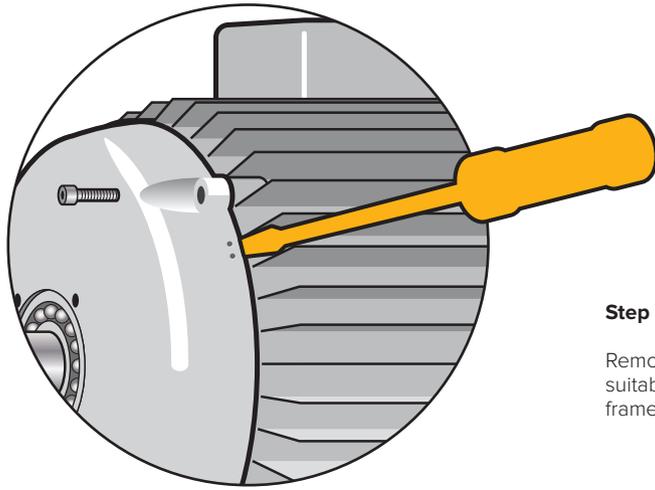


FIGURE 3.31 Dismantling and reassembling a motor—part 2

**Step 5**

Remove the end shield screws and then select a suitable tool to unseat the end shields from the frame.

Step 6

Once both end shields have been removed, carefully remove the rotor from the stator. Be sure to use correct manual-handling techniques, as rotors can be quite heavy.

Note: A mechanical aid, such as a cradle, may be required to remove and replace large rotors.

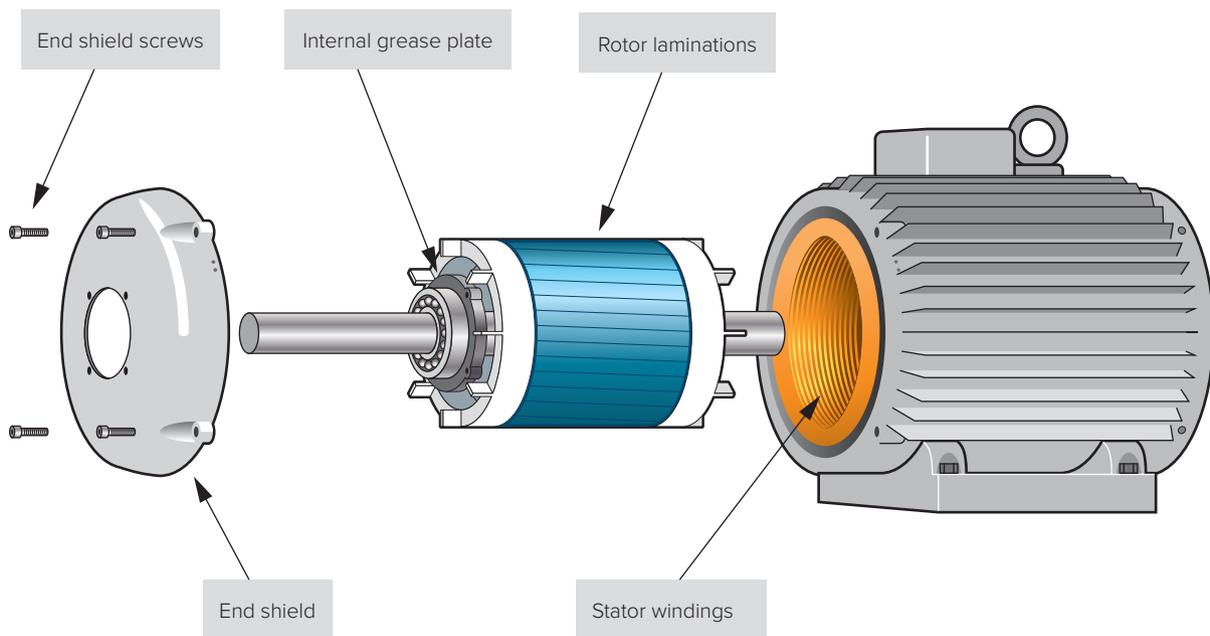
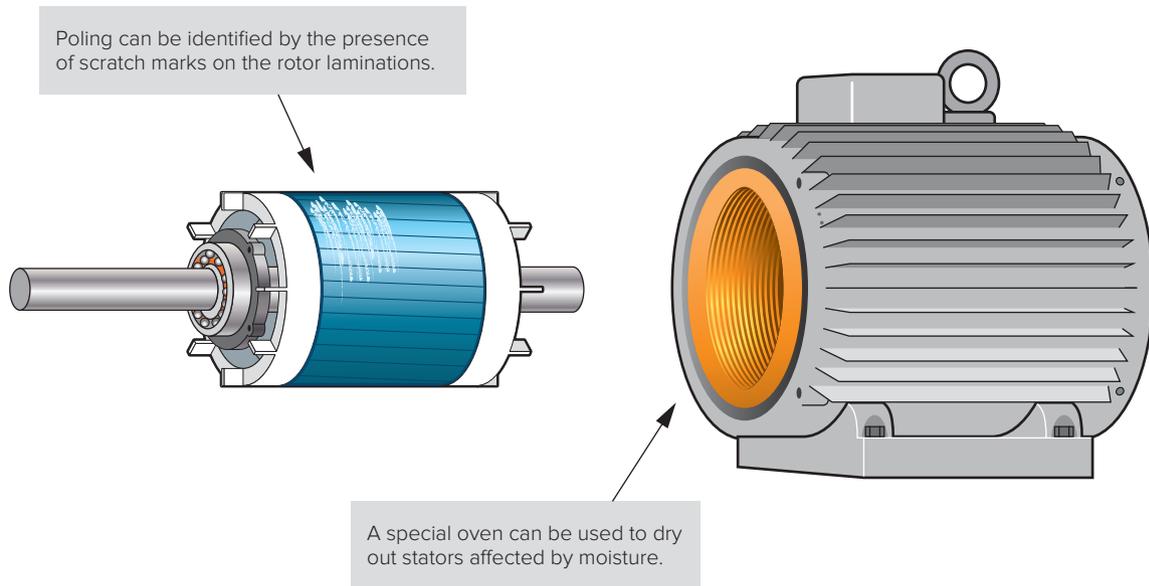


FIGURE 3.32 Dismantling and reassembling a motor—part 3

Step 7

Inspect the bearings, shaft, rotor bars, laminations and stator windings for any signs of piling, overheating or other damage.

**Step 8**

Damaged bearings should be replaced. Replacement bearings must be accurately matched to the motor—exchanging like-for-like is generally the safest bet.

A bearing puller can be used to remove damaged bearings. Bearing pullers generally consist of three adjustable gripping arms and a screw thread that provides the required mechanical advantage to draw the bearing along the rotor shaft.

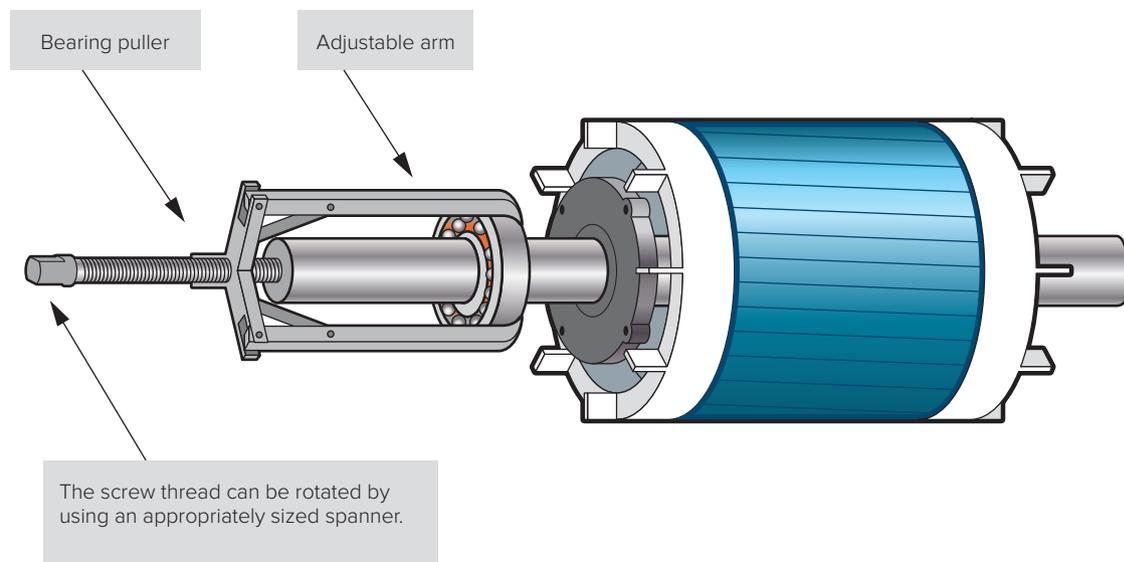
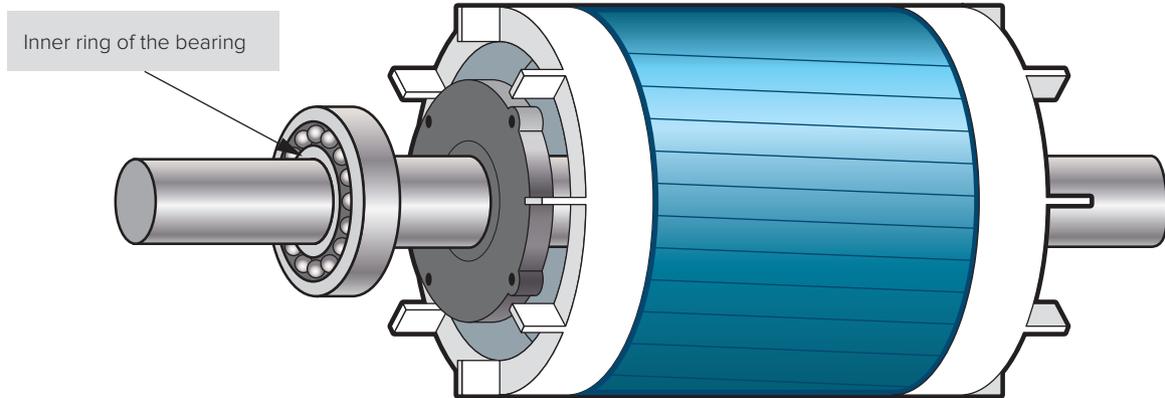


FIGURE 3.33 Dismantling and reassembling a motor—part 4

Step 9

Replacement bearings should be expanded prior to seating by gentle heating. A soft-faced hammer and seating tube should then be used to gently knock each bearing into position. To prevent damage, the seating tube should be sized such that it rests on the inner ring of the bearing.

**Step 10**

The motor can be reassembled by following Steps 1 to 7 in the reverse order. After reassembly, motors should be once again tested to verify winding resistance, insulation resistance and earth resistance before they are reconnected to the supply.

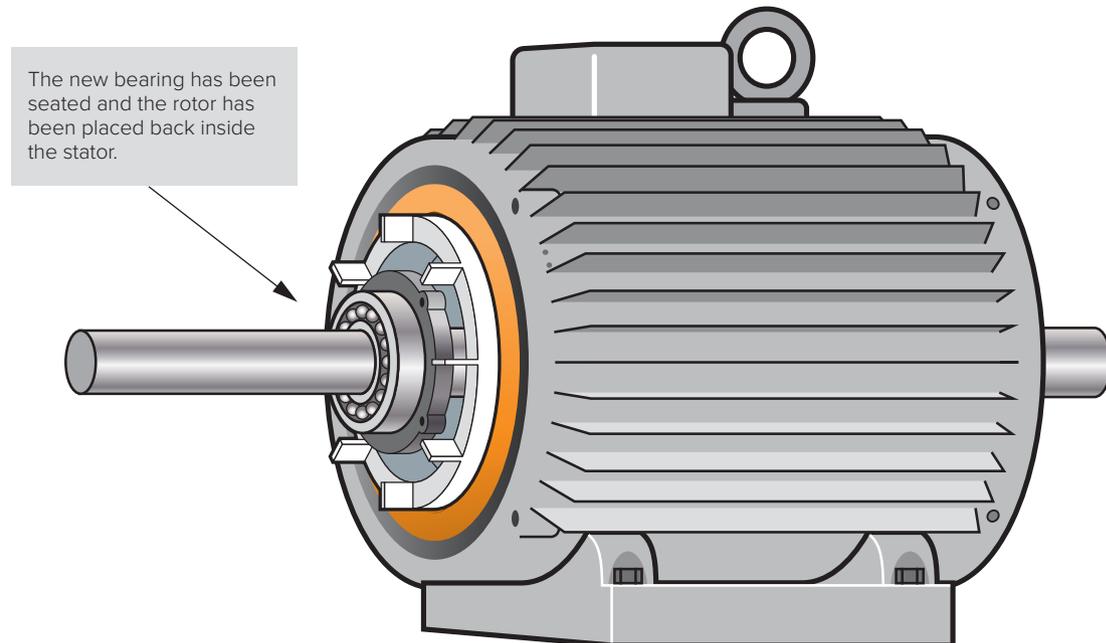


FIGURE 3.34 Dismantling and reassembling a motor—part 5

SUMMARY

- ▶ Prior to starting work, safe work method statements (SWMS) should be read and a job safety analysis (JSA) should be conducted.
- ▶ Personal protective equipment (PPE) should always be correctly selected, fitted and worn prior to commencing a work task.
- ▶ When performing workshop activities, you must select the correct hand and power tools for the required tasks.
- ▶ There is a wide variety of materials to be selected when manufacturing items.
- ▶ When planning and designing manufactured components it is important to have the correct drawings that provide adequate details.
- ▶ Accuracy in measuring and marking out is achieved by selecting the correct measuring and marking out tools and may involve specialist tools.
- ▶ To safely and effectively cut and shape materials, the correct tools and equipment must be selected in order to produce good-quality items.
- ▶ Selecting the correct drilling equipment ensures appropriate and accurate holes are created.
- ▶ The cutting of threads depends on the selection of the most appropriate tools and lubricants to produce good-quality usable threads.
- ▶ The joining of material can be safely and effectively achieved through the use of a variety of methods.
- ▶ Following prescribed methods allows for the successful dismantling and reassembling of electrical equipment.

REVIEW QUESTIONS

1. Name typical hazards encountered in the workshop.
2. List the tools required for cutting and finishing a short piece of flat bar.
3. Describe a situation where custom components may be needed.
4. In orthogonal projection how are hidden lines represented?
5. What two drill settings should be used when drilling masonry?
6. List four types of drills.
7. What should be applied to the tap before cutting a thread to prevent damaging the thread?
8. What sort of die is often used to repair damaged threads?
9. Describe how a blind rivet works.
10. Describe the three main types of welding used to fabricate components.
11. Why would you need a centre punch when dismantling a motor?
12. Name a precision measuring device most likely found in a workshop.
13. What tool is used to remove bearings from a motor shaft?
14. List the major components in an electric motor.

CHAPTER 4

Regulations and standards

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ explain the regulations for licensing to undertake electrical work
- ▶ list the types of electrical licences, the scope of work they cover and how they are obtained
- ▶ describe the purpose of Standards and how they are developed and used
- ▶ explain the layout of the *Wiring Rules*, the electrical installations it covers and how it incorporates other Standards
- ▶ describe the purpose of the *Appendices* in the *Wiring Rules* and how they differ from the main text
- ▶ use the *Table of Contents* to locate specific information in the *Wiring Rules*
- ▶ list the essential safety performance requirements of an electrical installation and the methods of protection available to guard against dangers and damage
- ▶ illustrate the relationship between *Part 1* and *Part 2* of the *Wiring Rules*
- ▶ list common types of electrical insulation and their typical uses, and the conditions that degrade the effectiveness of electrical insulation
- ▶ explain the concept of leakage current.

Arrangements for generating, distributing and supplying electricity to consumers in the competitive energy market in Australia are governed by the *Australian Energy Market Act*, which covers marketing of all forms of energy to ensure efficiency and safety of supply and fair pricing for consumers. Under this legislation, the development and administration of National Electricity Regulations and Rules are the responsibility of the Australian Energy Market Commission, a body representing all jurisdictions (state and territory governments). Penalties may be imposed on generation, transmission and distribution entities that do not adhere to the Regulations and Rules. Similar arrangements apply in New Zealand.

In addition to this, each jurisdiction has legislation and regulations related to electrical safety and consumer protection that include requirements for licensing persons to carry out electrical work and to undertake electrical work as a contractor. As a licensed electrician or contractor, in order to meet your legal responsibilities you must have a sound knowledge of the regulations and rules that govern the administration and technical requirements

for electrical systems and installations in buildings and premises. More importantly, you must be able to apply these regulations and rules. This includes specific regulations of the state authority and Australian or New Zealand Standards called up by legislation, in particular the principal technical legal requirement, which is published under the title *Australian/New Zealand Standard Electrical Installations* and is known as the Australian/New Zealand *Wiring Rules AS/NZS 3000:2018*.

For our purposes, this important publication will be referred to as the *Wiring Rules* and references to it and related Standards will be shown in *italic* font. The first step is to learn the format of the *Wiring Rules*. This, together with a detailed study of the definitions (*Clause 1.4*) used in the Standard, will give you the basic vocabulary of electrical terms necessary to access information. Through a study of *Part 1*, you will gain an understanding of essential safety requirements and the electrical installation process and Standards that your work must comply with. As you progress in your training, you will develop the ability to apply the *Wiring Rules* to each work situation.

4.1 Electrical licensing

The purpose of the licensing laws and regulations in Australia and New Zealand is to ensure the safety of members of the public and electricity users by protecting them from electrocution, and to reduce the possibility of property damage. To do this, the laws require that electrical work is carried out by licensed persons in a competent manner as expected of a trained electrician. The work carried out by licensed electricians must comply with the *Wiring Rules* and any relevant codes or requirements of statutory authorities, the service and installation rules of energy distributors and any additional specification that may apply to particular jobs. The term *electrician's licence* is a generic one, referring to an authorised document that states that the person is eligible to do particular electrical work. Although the title of an electrician's licence may vary across jurisdictions, they carry similar permissions and obligations.

The meaning of the term *electrical work* is important when discussing the legal requirement that such work shall be done by a licensed person. Although electrical work may be described in different ways across the various jurisdictions, it can be considered as installing, testing, maintaining and servicing low-voltage electrical equipment in buildings and premises.

Information on obtaining and using an electrical licence is given in **Figure 4.1**.

Licence-holders are obliged by these laws to show their licence if requested by a representative of an energy distributor, a licensing authority, a member of a police force or the owner or occupier of the property where the work is being carried out. A licence may be suspended or cancelled for any one of a number of reasons, which include making an unauthorised connection, tampering with meters or other property of an energy distributor, and carrying out work not in accordance with the *Wiring Rules* or within the scope permitted by the licence.



CHECK YOUR UNDERSTANDING

1. What is the purpose of electrical licensing regulations?
2. What requirements must the work of an electrician comply with?
3. What scope of work is permitted under a restricted electrical licence?
4. What type of licence is required to undertake electrical work for commercial gain?
5. Outline the regulation in your jurisdiction that permits an electrical apprentice to undertake electrical installations.

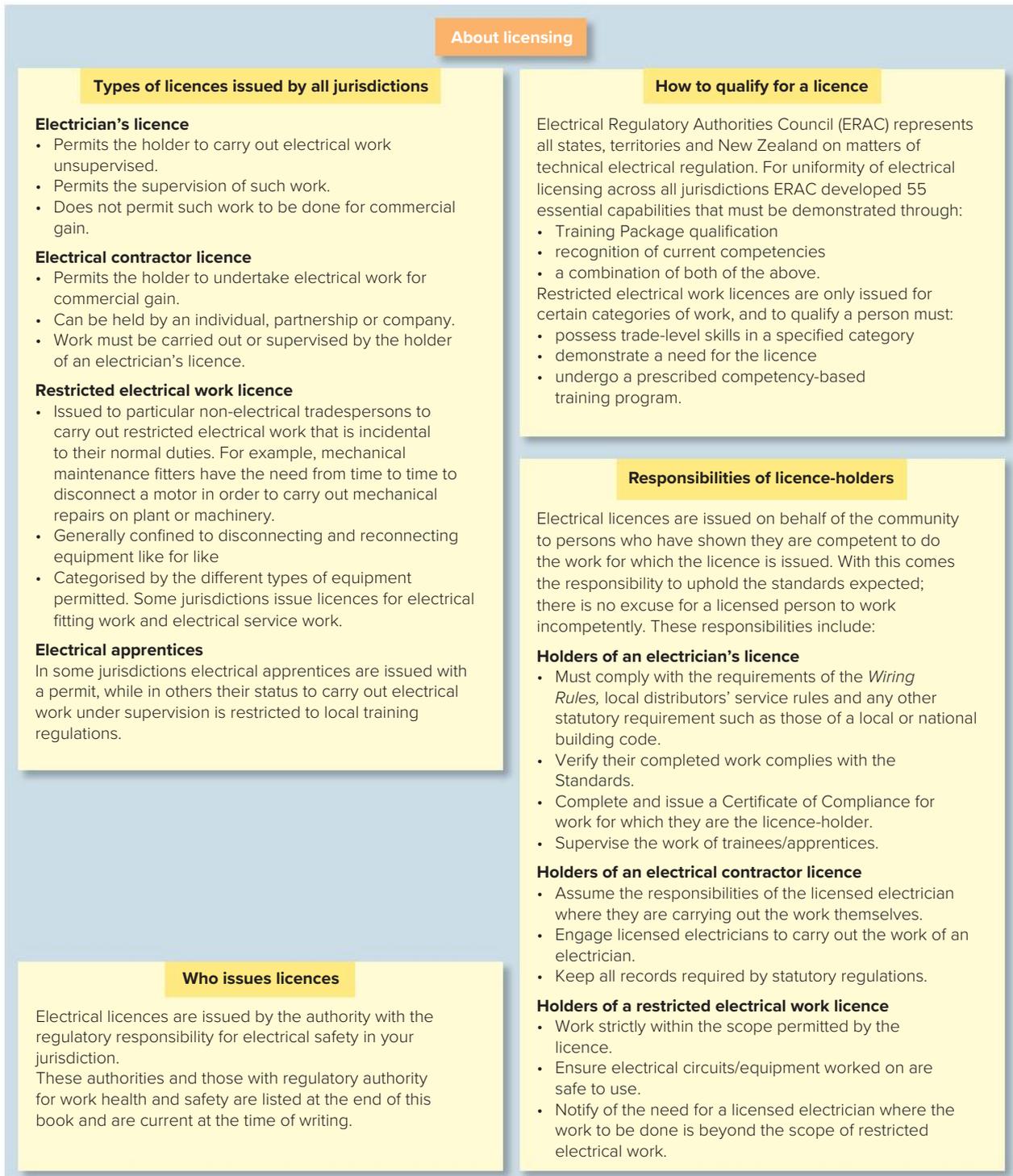


FIGURE 4.1 About electrical licensing

4.2 Standards

The purpose of Standards is to set minimum safety and performance requirements for the design of products and provision of services without stifling innovation or placing artificial barriers on trade between enterprises, states or countries. Many of the requirements described in Standards are to ensure that a product or service is safe and reliable.

Most Australian Standards are developed and published by Standards Australia, a non-profit organisation recognised by all Australian governments as the peak Standards body in Australia. Through economic ties between the two countries, Standards Australia has a formal agreement with Standards New Zealand to develop joint Standards. They are developed through various Standards committees made up of relevant stakeholders. They are published under a title that indicates their purpose and a number that includes the year of publication. Standards are under continual review and updated periodically.

The trend towards making Standards international is part of a strategy to assist fair trade between countries while maintaining the levels of quality and safety expected by consumers. Both Standards Australia and Standards New Zealand, as members of the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC), are major contributors and ensure that the views of Australian and New Zealand industries are represented.

Standards are often called up by a statutory regulation, and when this occurs they in fact become part of the regulation and must be complied with. Electrical workers must perform their work to comply with many Standards, in particular the *Wiring Rules*. This Standard in turn calls up related Standards and is referred to in other Standards. So an essential part of electrical work is knowing how to use the *Wiring Rules*. In addition, electrical workers must also meet the requirements of the local regulatory authority. Those charged with the design and installation of electrical wiring and equipment must be thoroughly familiar with the use and application of the *Wiring Rules* to ensure the safety and effectiveness of the electrical system in a building or premises.

The *Wiring Rules*, in setting out the safety and functional requirements that a completed electrical installation must conform with, contains numerous tables, references to other Standards, sample calculations and notes to permit, for example, the correct cable type, rating and enclosure to be chosen for a particular application. It should be remembered that the *Wiring Rules* are *minimum* requirements and, where necessary, the additional rules of any regulatory authority or energy distributor must be observed. Usually the main concern is the local energy distributor's service and installation rules.

Before commencing a job in an unfamiliar district, the first step is to obtain a copy of the service and installation rules for the supply of electricity in that district. These should be studied in conjunction with the *Wiring Rules*. An electrical installation must also comply with contractual arrangements, usually contained within a job specification. This topic is dealt with in detail in **Chapter 5**.

4.2.1 Development of the *Wiring Rules*

In the early days of the electrical industry, installations were primitive and often dangerous due to the lack of stringent control. Mainly because of fires that could be attributed to the new agent of electricity, fire-insurance companies quickly realised the need for regulations to govern the installation of electrical wiring, and each company initially had its own inspectors and rules.

The situation in those early days can only be described as chaotic; the various jurisdictions sometimes had widely differing rules. From the early 1900s, change came about with the rules of the English Institution of Electrical Engineers, with addenda, which were adopted by the Fire Underwriters' Association of NSW, VIC, QLD, SA and TAS. This was the starting point from which the *Wiring Rules* evolved.

Today the *Wiring Rules* are continually developed by the Wiring Rules Committee (designated EL-001), on which all sections of the electrical industry are represented, as listed at the front of the *Wiring Rules*. The EL-001 Committee also oversees the work of a number of subcommittees that develop other Standards that support the *Wiring Rules*, such as *AS/NZS 3017 Electrical installations—Verification guidelines*. The development process is managed by a Standards Australia project manager.

It is a fundamental policy of Standards Australia that suggestions and criticisms can be made by any person or organisation. These suggestions and criticisms are influenced by many factors, such as the interpretation of particular rules, development of new technologies and materials, changes in government policies, health and safety and environmental concerns, trends in international Standards and, simply, new ways of doing things. These matters are reviewed by the EL-001 Committee and may result in the publication of amendments to the current edition of

the *Wiring Rules*. Amendments are important changes to existing Standards. These changes can include editorial corrections, such as printing and clerical errors, as well as updating references to other Standards and in some circumstances updating technological issues.

When sufficient changes warrant the need for a new edition, the EL-001 Committee applies to the Standards Council for approval to produce one. Several months prior to the publication of a new edition of the *Wiring Rules*, Standards Australia issues a draft publication to invite comments from any interested group or individual. This feedback is reviewed by the EL-001 Committee and changes to the draft Standard are made where agreed. The whole process is based on agreement by all members of the committee, who vote on the final draft before publication. In this way, the *Wiring Rules* reflect the expectations of the whole electrical industry and the community as closely as possible.

The current *Wiring Rules* are the accepted Australian and New Zealand rules and are incorporated in the regulations in each jurisdiction; they are the minimum legal requirements and their provisions are enforceable by law. The 2000 edition of the *Wiring Rules* stipulated the requirements to which an installation must conform in terms of safety and functionality, and followed many aspects of the international Standard IEC *Publication 60364*. The performance approach to specifying Standards allows for much more innovation in installation design, at the same time requiring a complete understanding of electrical principles and how they apply, particularly in relation to providing protection and safety in electrical installations.

The 2000 edition was criticised for the absence of information that had been in previous editions that helped in applying the Standard. As a result, the 2007 edition and the 2018 edition include comprehensive guidance on ways to comply with the fundamental safety performance principles of the Standard.



CHECK YOUR UNDERSTANDING

6. Describe the purpose of a Standard.
7. How are Standards enforced?
8. Outline the process by which Standards are developed.
9. What is the first step when commencing a job in an unfamiliar district?
10. How can individual people have a say about a Standard?

4.3 Learning the *Wiring Rules AS/NZS 3000:2018*



DID YOU KNOW?

The best way to learn how to use the *Wiring Rules*

Start with the 'Content', as illustrated in **Figures 4.2 to 4.6**. You will see that the *Wiring Rules* follows a logical plan. The *Rules* commences at the supply end of the installation through to requirements for the selection and installation of wiring, equipment and earthing; these are followed by requirements for special types of installations and then verification by inspection and testing. It concludes with Appendices for information and guidance in applying the requirements of the Standard. Although tackling the *Wiring Rules* may seem difficult at first, by viewing the eight sections as a series of eight separate books (with the Appendices as the 'help' file), the task of using it will become much easier.

The *Wiring Rules* also includes an index, which should only be used once you have become adept at referencing information from the content.

All electrical installations shall comply with Part 1 (Section 1) of the *Wiring Rules*.
 Part 2 of the *Wiring Rules* (Sections 2 to 8) is 'deemed to comply' with Part 1. This means that an installation complying with the rules in Part 2 will comply with Part 1—this is the most common method of 'Means of compliance'.

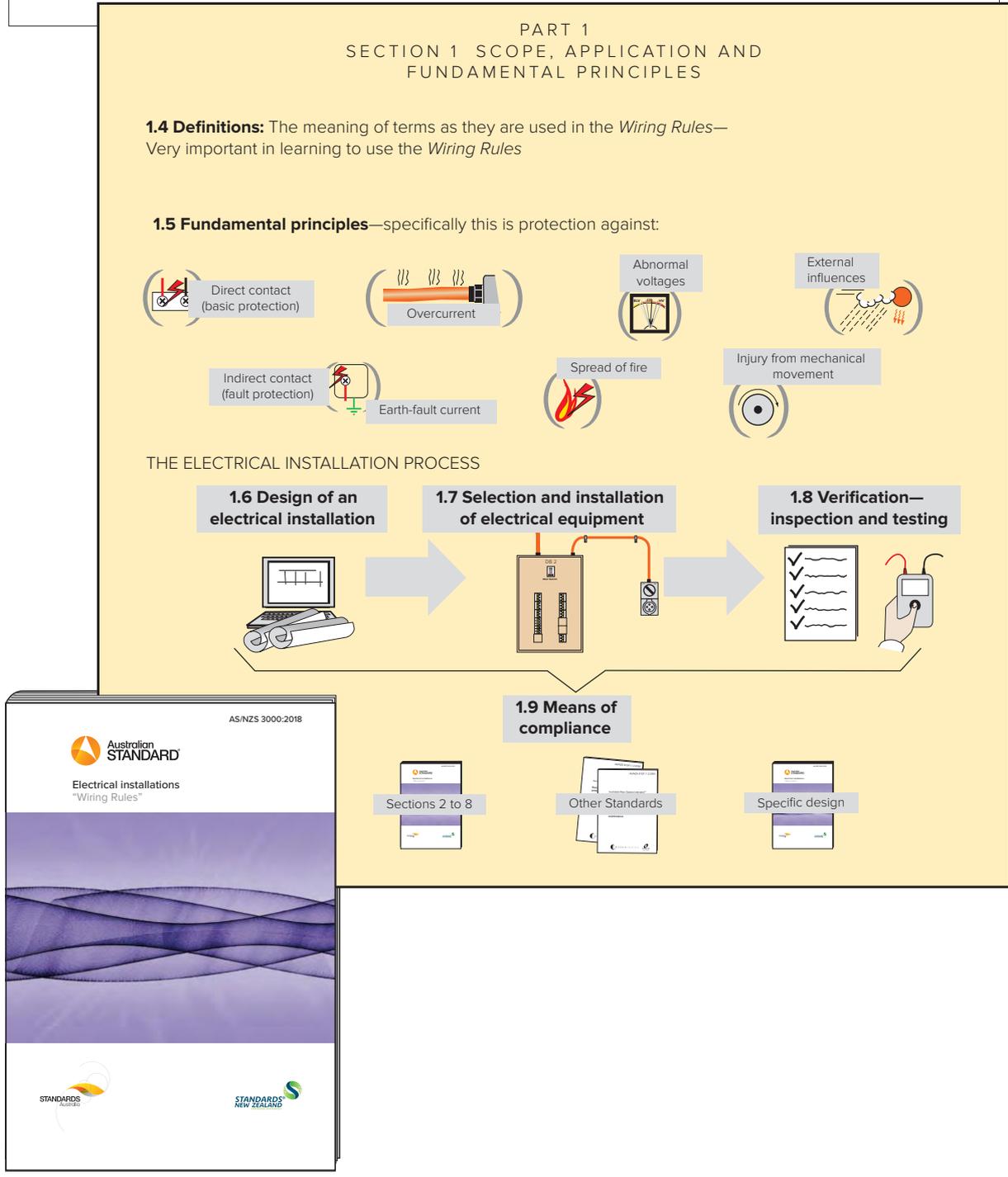
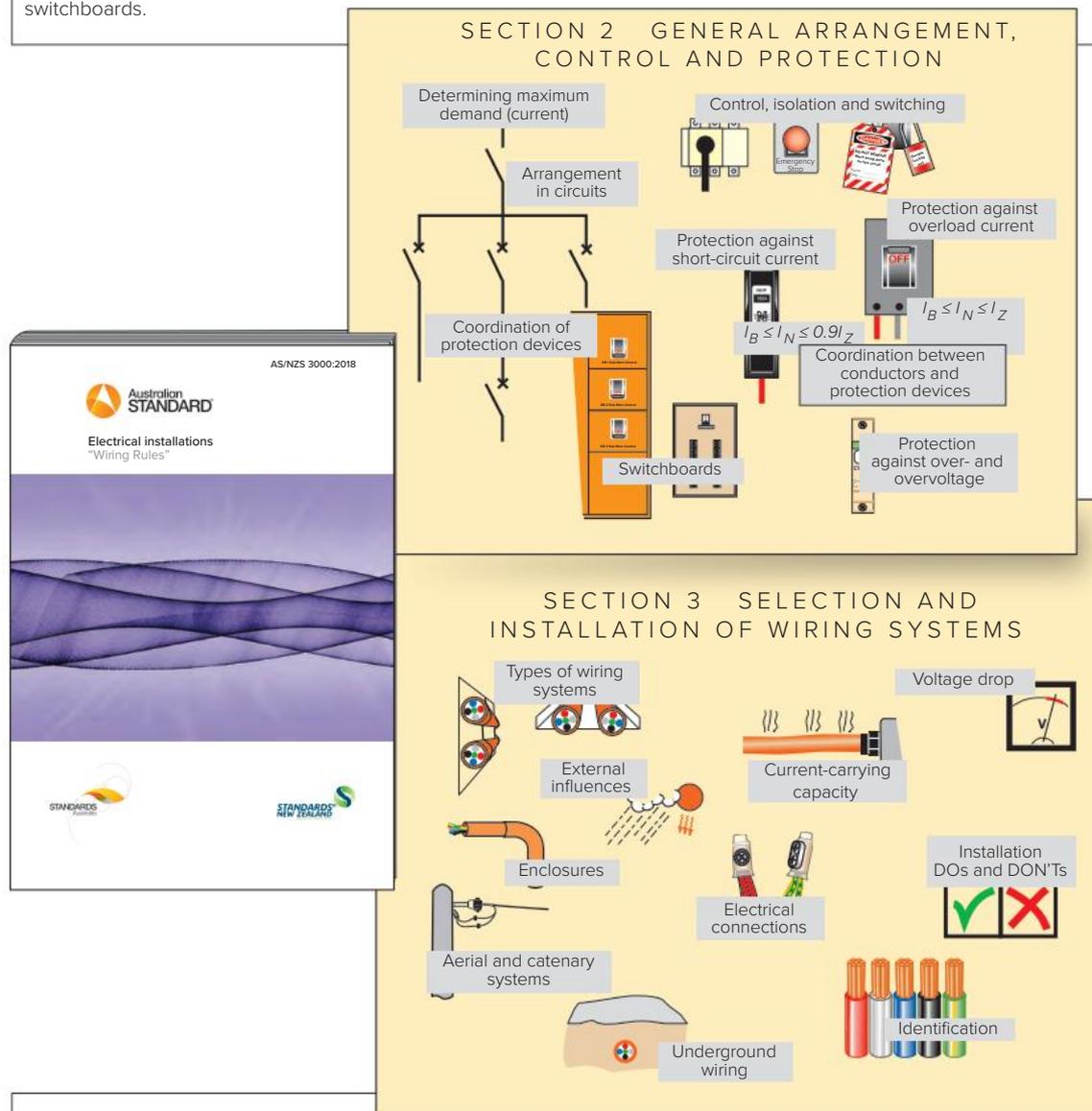


FIGURE 4.2 *Wiring Rules* format—Part 1 Fundamental principles

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Rules dealing with selecting and installing switch gear and control gear commence with supply requirements, circuit arrangements and control of the installation. This is followed by devices and arrangements for fault protection, protection against overcurrent, indirect contact and under- and overvoltage. The section also covers rules for switchboards.

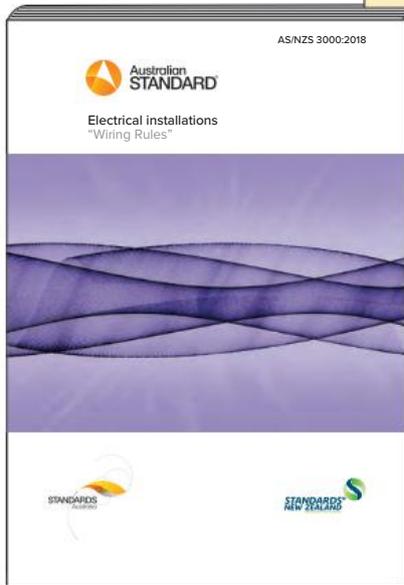


Rules for selecting and installing cables, cable support systems and protection methods. This covers the acceptable wiring systems, the current a cable can carry without overheating, permitted voltage drop, electrical connections and how the function of cables is to be identified. It includes everyday rules for installing cables and rules specific to wiring enclosures, underground and overhead wiring and busway systems.

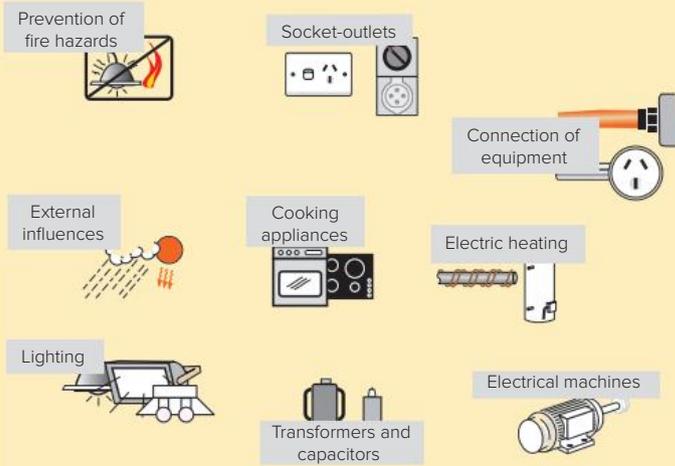
FIGURE 4.3 Wiring Rules format—Part 2, Sections 2 and 3

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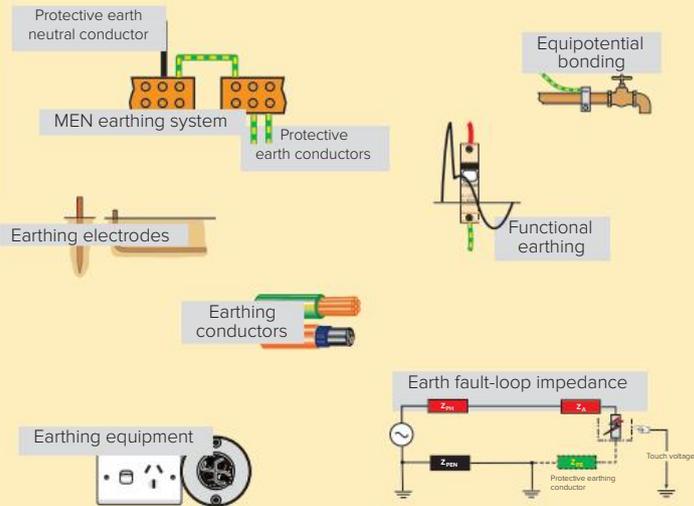
Rules about protecting property and persons from the heat generated by electrical equipment and acceptable methods of connecting electrical equipment. Also covered are rules particular to socket-outlets, lighting, smoke and fire detectors, cooking appliances, applications of electric heating and control, electrical machines, transformers, capacitors and batteries.



SECTION 4 SELECTION AND INSTALLATION OF ELECTRICAL EQUIPMENT



SECTION 5 EARTHING ARRANGEMENTS AND EARTHING CONDUCTORS

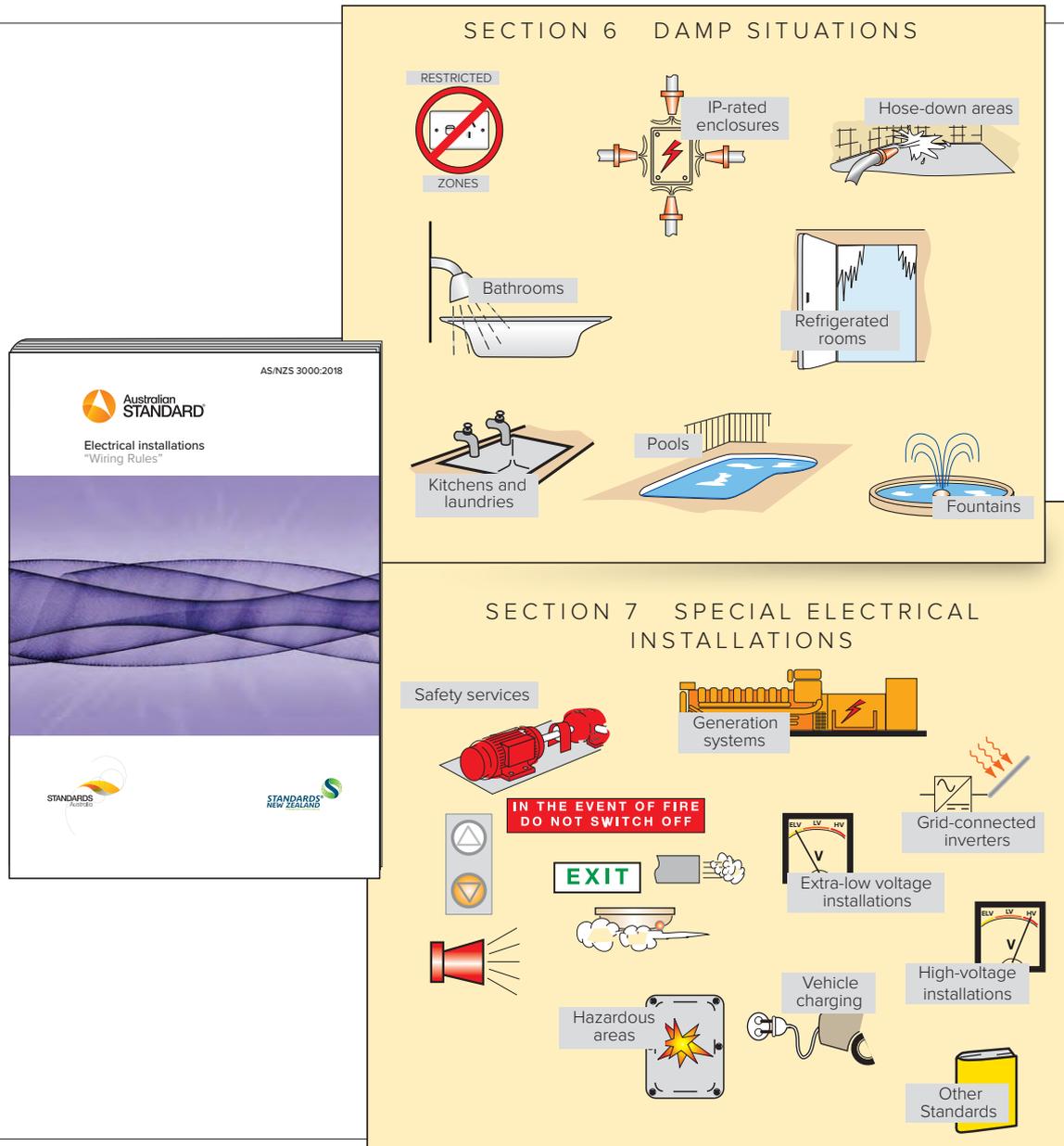


Important from a safety point of view, this section covers rules for acceptable arrangement of earthing in an installation, selecting earthing conductor sizes, selecting and installing earth electrodes, equipotential bonding and earth fault-loop impedance.

FIGURE 4.4 *Wiring Rules* format—Part 2, Sections 4 and 5

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Rules dealing with parts of an electrical installation in areas that are wet or damp at some time in their normal use. This covers restriction on installation of electrical equipment in designated areas (zones) in bathrooms, kitchens, laundries, saunas and around pools and fountains. Also, there are rules that apply to installations in refrigerated rooms and areas that are regularly hosed down, e.g. meat processing areas, greenhouses and livestock areas.



Rules for installing the electrical systems for the safety services in a building. These include fire and smoke detection and control and building evacuation services as required by construction and building codes. Rules included are those for installing generator sets, standalone power systems, battery systems, grid connected inverters, isolated supplies and extra-low voltage systems. The section refers readers to Standards for high-voltage installations and the Standards for installations in hazardous areas. Finally specific installation Standards and deemed-to-comply Standards are listed.

FIGURE 4.5 *Wiring Rules* format—Part 2, Sections 6 and 7

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The final activity of an electrician before power is connected and they hand over to the user is to verify that the installation complies with all safety requirements; that is, it complies with the *Wiring Rules*. The verification rules cover the visual inspection of the accessible parts of the installation, mandatory tests to be carried out and a record of the initial certification of the installation.

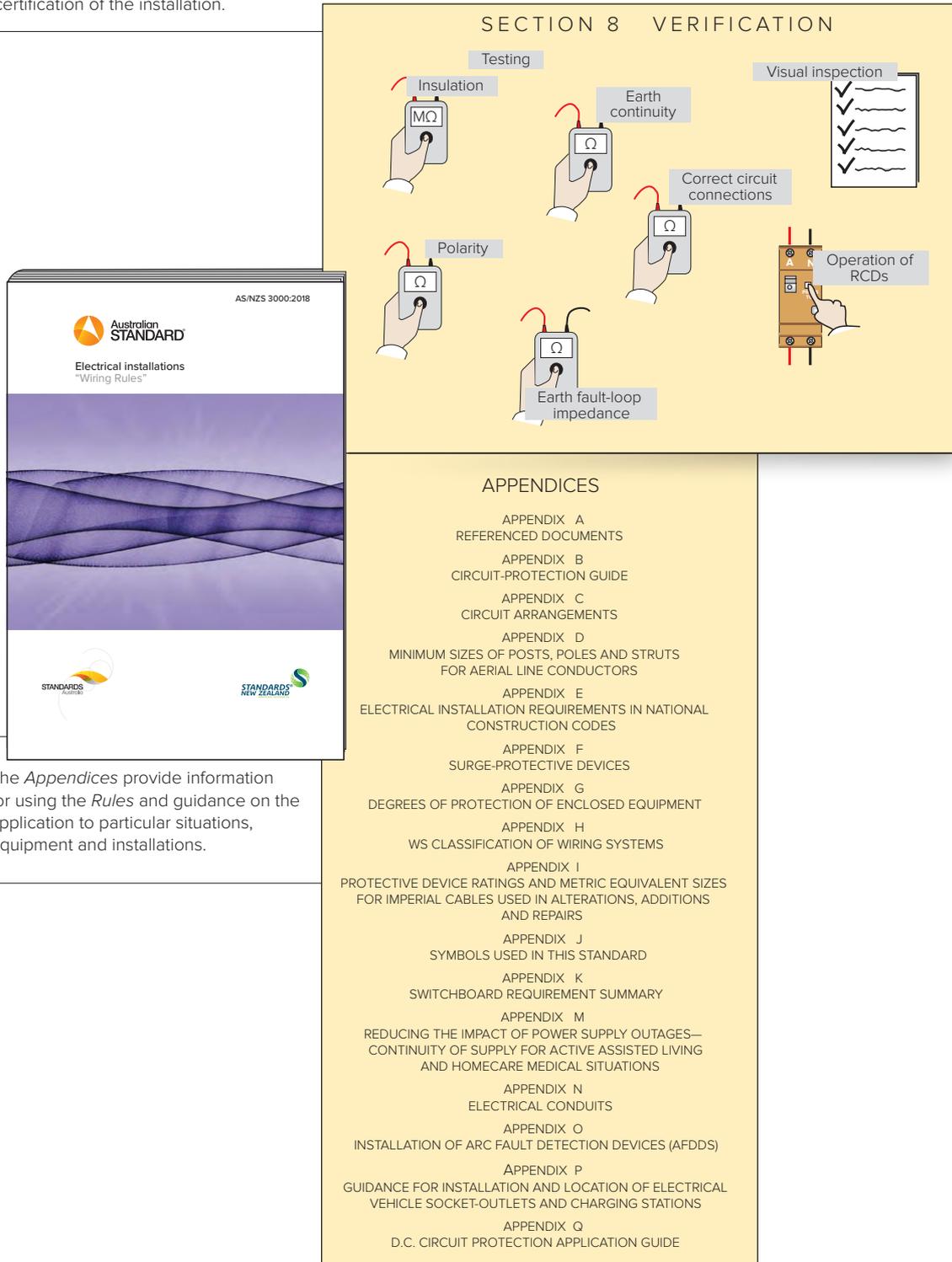


FIGURE 4.6 *Wiring Rules* format—Part 2, Section 8 and Appendices

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4.3.1 How the *Wiring Rules* are written

The *Wiring Rules* are written in the form of clauses designated by a point-numbering system, the first number being that of the section under which the clause appears. Try **Exercise 4.1**.

EXERCISE 4.1

Open the *Wiring Rules* at *Section 4 Selection and installation of appliance and accessories*. Note that all the clauses start with the number of the section, in this case 4, and the main requirements for each aspect of *Selection and installation of appliances and accessories* are listed under clauses numbered 4.1, 4.2, 4.3 and so on.

Now look up *Clause 4.4 Socket-outlets*. As the information about socket-outlets becomes more specific, that part of the clause is given a new heading and an additional point and number. In this case *Clause 4.4.1* covers 'Types' (of socket-outlets), while under the heading 'Types' the more specific requirement for suitability, the clause 'General', is given number *Clause 4.4.1.1*. Clauses like 4.4.1 and 4.4.1.1 are often called *sub-clauses*.

In addition to this arrangement of clause numbering, the information in clauses and sub-clauses is presented in a ranked order, each kind of information having a different typeface, as shown in **Table 4.1**.

TABLE 4.1 Purposes of different typefaces used in the *Wiring Rules*

Wiring Rules	Typeface used
Fundamental principle	Bold type—an opening statement that sets out the basic principles and purposes of the requirements that follow
Mandatory requirements	Normal type—these specify methods that may be employed to comply with the <i>Rules</i>
Exceptions	Italics—exceptions and/or variations to the mandatory requirements
Explanatory notes	Reduced type—notes that give further explanation or advice on the application of a clause

4.3.2 *Appendices*

The 2018 edition of the *Wiring Rules* makes more use of the *Appendices* than the previous edition, to provide information to help you apply them. *Appendices* are designated by a letter (A, B, C etc.) and are primarily for guidance. They give information and examples about application of the *Rules* and some theoretical background to the purpose of various requirements. As such, most are designated 'informative'. To differentiate it from the requirements given in the clauses, the information in the *Appendices* is given in numbered paragraphs identified by the letter of the appendix in which they appear. A numbering system similar to that used for the clauses then follows.



CHECK YOUR UNDERSTANDING

11. What aspect of electrical installation does each section of the *Wiring Rules* cover?
12. What is the difference between *Part 1* and *Part 2* of the *Wiring Rules*?
13. By what means may compliance requirements of an electrical installation be met?
14. Explain the form in which rules are written in the *Wiring Rules* and how they are structured.
15. What is the purpose of the different typefaces used in the *Wiring Rules*?

4.4 Using the *Wiring Rules*

Reference to the *Wiring Rules* is essential when planning an electrical installation. You do not need to remember the finer details in a clause, but you do need to be adept at finding, understanding and complying with the information given in a clause.

4.4.1 Starting with the *Table of Contents*

Starting with the *Table of Contents* greatly helps in building knowledge about the main components of electrical installations. With practice, you will develop a vocabulary of wiring language and become skilled at locating the section and clause where particular compliance requirements are specified. Try **Exercise 4.2**.

EXERCISE 4.2

To answer an enquiry about the requirements for locating a switchboard in a cupboard in a single domestic dwelling (i.e. a house or individual home unit) try the following procedure:

1. From the *Table of Contents*, select the section that is likely to contain the information required. Because *Section 1* deals with protection for safety and overall requirements, the required information is not likely to be there. Likewise for *Sections 3, 5, 6, 7* and *8* because these cover *Selection and installation of wiring systems, Earthing arrangements and earthing conductors, Damp situations, Special electrical installations and Verification*. This leaves *Sections 2* and *4* to consult.
2. Read the clauses listed under these two selected sections in the *Contents* and locate a clause that deals with switchboards: under *Section 2, Clause 2.10 Switchboards* is listed.
3. Turning to *Clause 2.10*, read the headings of the sub-clauses listed under this main clause until a sub-clause covering the needed information is found. In this example, *Clause 2.10.2 Location of switchboards* and its sub-clause seem to be specific to the enquiry.
4. Be sure to read the chosen clauses thoroughly, including all related notes, tables and cross-references. In this case, the information needed is provided by *Clause 2.10.2.5*, which restricts the location of a switchboard, and by *part (a)* of the clause, which prohibits the installation of a switchboard within 1.2 m of the ground, a floor or platform. However, *part (c)* of the clause allows a switchboard to be installed in a cupboard, with *parts (i) to (iv)* specifying how the switchboard and cupboard should be arranged.

The information obtained can now be applied when installing the switchboard.

4.4.2 How the references are used

A clause may refer you to an *Appendix* or to other Standards for further information or to determine specifics for a particular application. Try **Exercise 4.3**.

EXERCISE 4.3

You are selecting a cable for a particular circuit and need to know the smallest permitted conductor size that can be used. The conductor size of a cable is determined by its current-carrying capacity.

1. Open the *Wiring Rules* at *Section 3 Selection and installation of wiring systems* and turn to *Clause 3.4 Current-carrying capacity*.
2. Read that *Clause 3.4.1 General* refers to compliance with the *AS/NZS 3008.1* series of cable selection Standards.
3. Go to *Note 1* of the clause to find that *Appendix C, Paragraph C3* provides a set of current ratings for common simple circuits that comply with *AS/NZS 3008.1*.

This example of cross-referencing to other Standards is typical throughout the *Wiring Rules* and is how the *Appendices* are used to help apply the *Rules*.

4.4.3 Other standards

The *Rules* places equal responsibility on the electrical installation designer, the supplier and the installer to ensure only equipment that complies with the safety requirements and is suitable for the environment is installed. *Clause 1.7.3 Equipment selection* refers to a number of Standards that electrical equipment must comply with, particularly *AS/NZS 3820 Essential safety requirements for electrical equipment*. In the notes to the clause, attention is drawn to *Appendix A*, which contains a list of specific equipment-compliance Standards. For example, socket-outlets must comply with *AS/NZS 3112* or *AS/NZS 60884.1*, *AS/NZS 3123*, *IEC 60309* or *AS/NZS 3131*, depending on intended application and location, as specified by *Clause 4.4.1.1*. It is the manufacturer's responsibility to ensure that the products it marks as complying with a Standard do in fact comply with that Standard.

Equipment carrying the Regulatory Compliance Mark (RCM) can be assumed to satisfy the requirements for compliance. Industry, importers and regulators created the RCM scheme to reduce the variety of markings used to show regulatory compliance. Use of the RCM and requirements for meeting safety regulations and for electromagnetic compatibility are specified in the *AS/NZS 4417* series.



CAUTION

It is not necessary for an electrician to study equipment-compliance Standards in depth. What is important is for the electrician to follow the instructions issued by the manufacturer in regards to the installation of the equipment and its limits of use. These instructions form part of the compliance requirements (see *Clause 1.71 (c)*).



CHECK YOUR UNDERSTANDING

16. List the Standard relating to construction and demolition sites (hint: refer to *Appendix A*).
17. As an electrician, it is not always necessary to study equipment-compliance Standards in depth. What other documentation could provide an electrician with the relevant equipment information?
18. Which *Appendix* in *AS/NZS 3000:2018* applies to symbols used in the Standard?
19. List the main sub-clauses under *Visual inspection* in *AS/NZS 3000:2018*.
20. In *Table 5.1* of *AS/NZS 3000:2018*, what size earthing conductor would be required when installing a 50 mm² copper active conductor?

4.5 Wiring Rules—Clause 1.4 definitions

In electrical work, there are certain standardised words, terms and phrases that have precise meanings and form a technical or trade language that is used for clear communication. Newcomers to the field must learn the special meanings of this trade jargon, as it is sometimes called, as quickly as possible. The downside of not doing this would be misunderstanding or misinterpreting an instruction, possibly with dangerous or expensive results.

Without knowledge of the technical language, it would be virtually impossible to draft even a simple report on an electrical situation. For similar reasons, if the *Wiring Rules* are to be understood and interpreted correctly, it is first necessary to gain a clear understanding of the definitions under *Clause 1.4 Definitions* in *Part 1, Section 1*. These definitions are listed alphabetically. Some terms used in the *Wiring Rules* are not given a definition because their meaning is either in common use or made clear in the clauses where they appear. Only those requiring further explanation will be dealt with here, and for convenience and ease of recall they are considered in related groups. The explanations and example illustrations given in this section are intended to be studied in conjunction with the *Wiring Rules* definitions and other referenced clauses.

The need to fully understand precise meanings as used in the Standard is illustrated by the terms ‘Accessible, readily’ (*Clause 1.4.3*) and ‘Available, readily’ (*Clause 1.4.19*). **Figure 4.7** gives examples of how each of these terms is used. Many definitions are listed by a keyword, then followed by a term to qualify the keyword, as in the above examples: ‘Accessible’ and ‘Available’ are keywords that are qualified by ‘readily’. Another example is ‘installation wiring’, which is defined under ‘Wiring, installation’ (*Clause 1.4.132*).

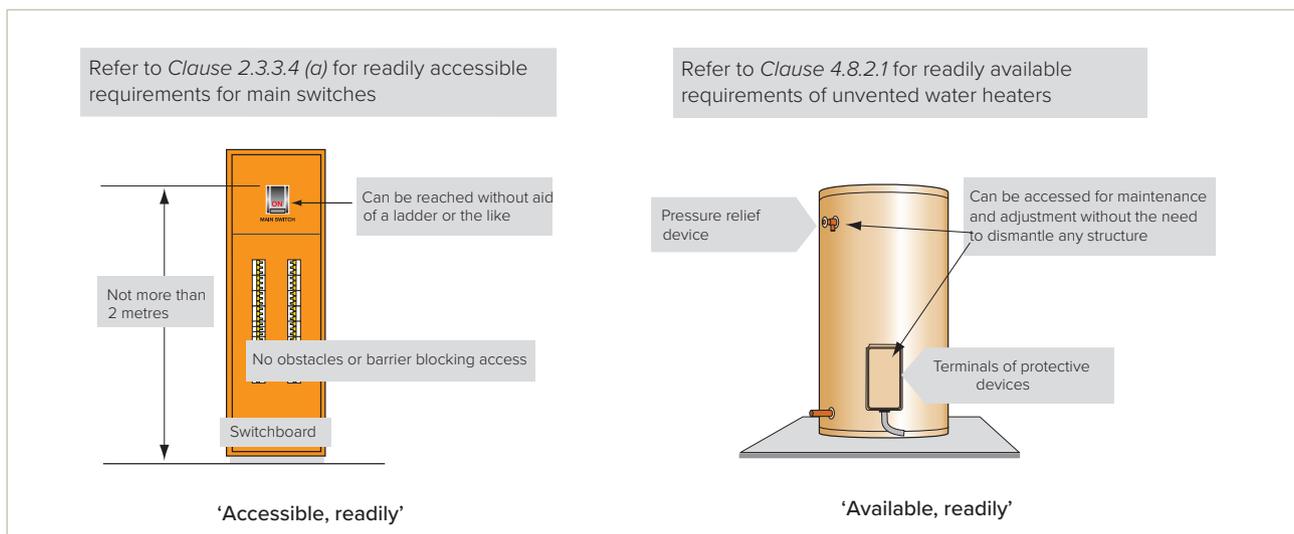


FIGURE 4.7 Example of how the *Wiring Rules* definitions for ‘Accessible, readily’ and ‘Available, readily’ are applied

A guide to the definitions of electrical equipment and its subcategories of accessory, appliance, luminaire, switchboard and wiring is given in **Figure 4.8**.

Equipment is also classified by how it provides protection against indirect contact; that is, protection against a fault causing an accessible conductive part to become live. These classifications and their protection measures are given in **Table 4.2**.

The meanings of the terms ‘Active (or active conductor)’ (*Clause 1.4.5*) and ‘Live’ (*Clause 1.4.78*) are important, particularly from a safety point of view. All conductors and parts of the electrical system intended to be ‘Energised’ (*Clause 1.4.59*), including the neutral conductor, are defined as ‘live’. This and examples of the active conductors in three different electrical systems are illustrated in **Figure 4.9**.

The meanings of terms related to cables and wiring can be confusing because trade names are often used; for example, ‘building wire’ is defined in *Clause 1.4.21* as a single-core cable (see **Figure 4.10**).

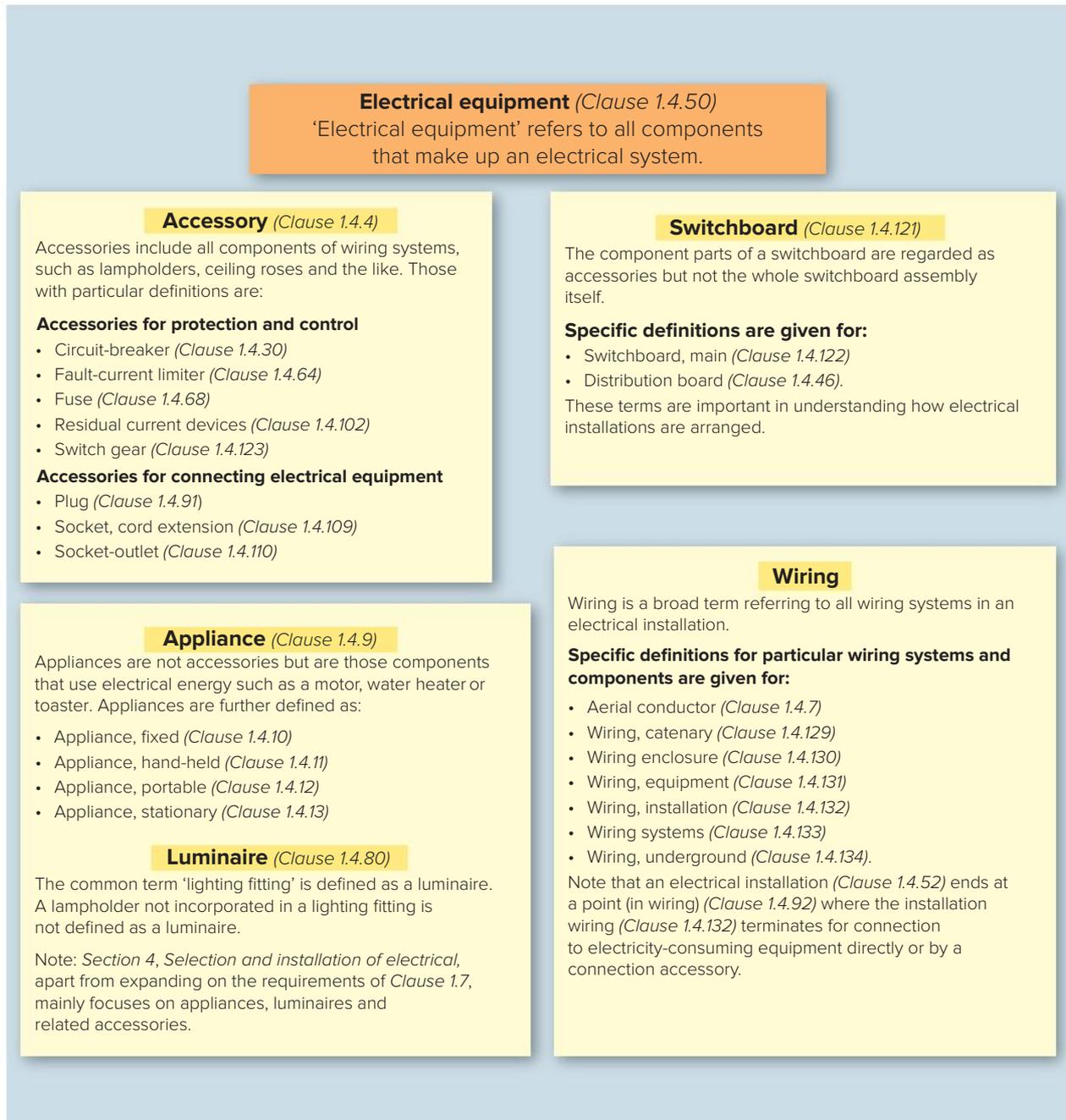


FIGURE 4.8 *Wiring Rules* definition for ‘Electrical equipment’ and related definitions for specific electrical equipment

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‘Wiring, catenary’ (Clause 1.4.129) is a system commonly used indoors to support double-insulated stranded cables and to provide separation from other services. It may be used outdoors in a similar way to ‘Aerial conductors’ (Clause 1.4.7), but the cable must be suitable for exposure to direct sunlight. Examples of catenary and aerial wiring are shown in **Figure 4.11**.

A comparison between the terms ‘Cord, flexible’ (Clause 1.4.40) and ‘Cable, flexible’ (Clause 1.4.24), as illustrated in **Figure 4.12**, shows that a flexible cord is a flexible cable with a limited conductor size and number of cores appropriate for its intended use. Although the term ‘duct’ is no longer defined, any trade references to it are defined as ‘Trunking, cable’ (Clause 1.4.127).

TABLE 4.2 Classes of equipment

Equipment class	Protective measures	Equipment mark
I (1.4.31)	Basic insulation (1.4.73 (a)) + protective earth	
II (1.4.32)	Basic insulation + supplementary insulation (1.4.73 (b)) or reinforced insulation (1.4.73 (d)). The combination of basic and supplementary insulation is known as double insulation (1.4.73 (c))	
III (1.4.33)	Separated extra-low voltage (1.4.106)	

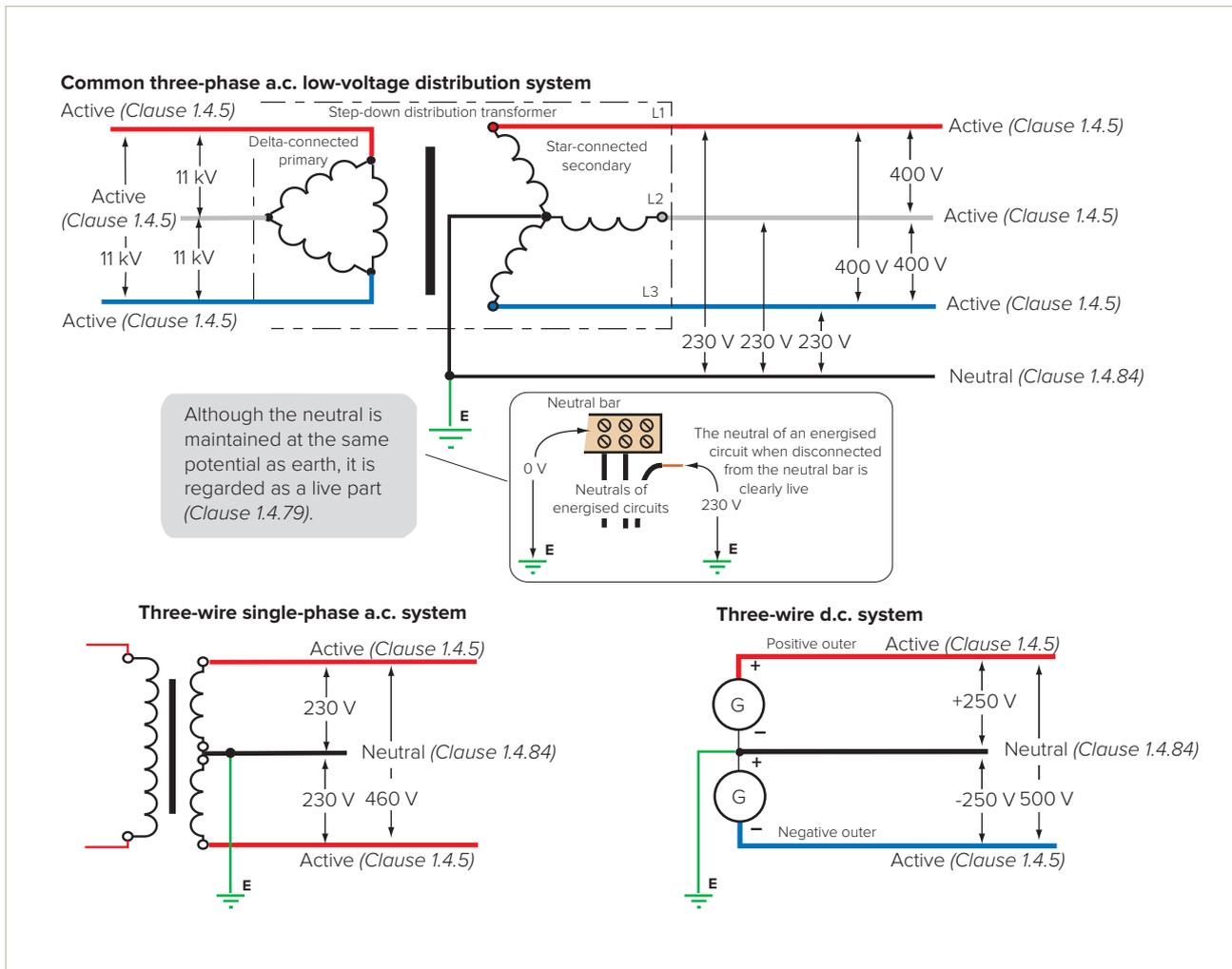


FIGURE 4.9 Examples of the terms ‘active’, ‘neutral’ and ‘live’

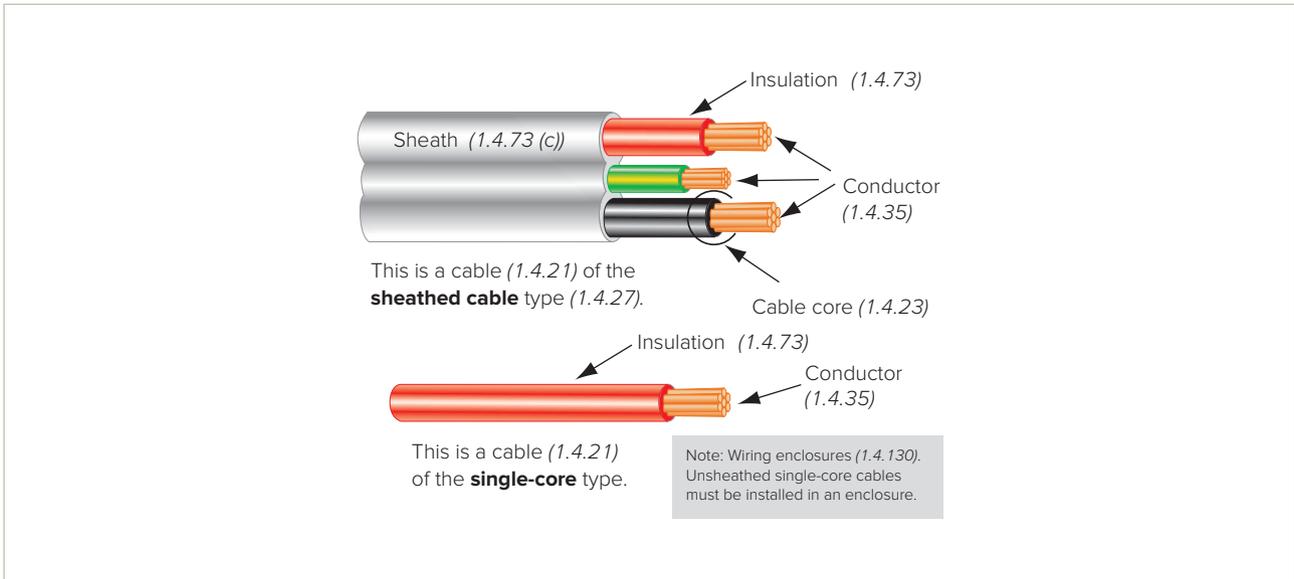


FIGURE 4.10 Examples of *Wiring Rules* definitions of cables and wires

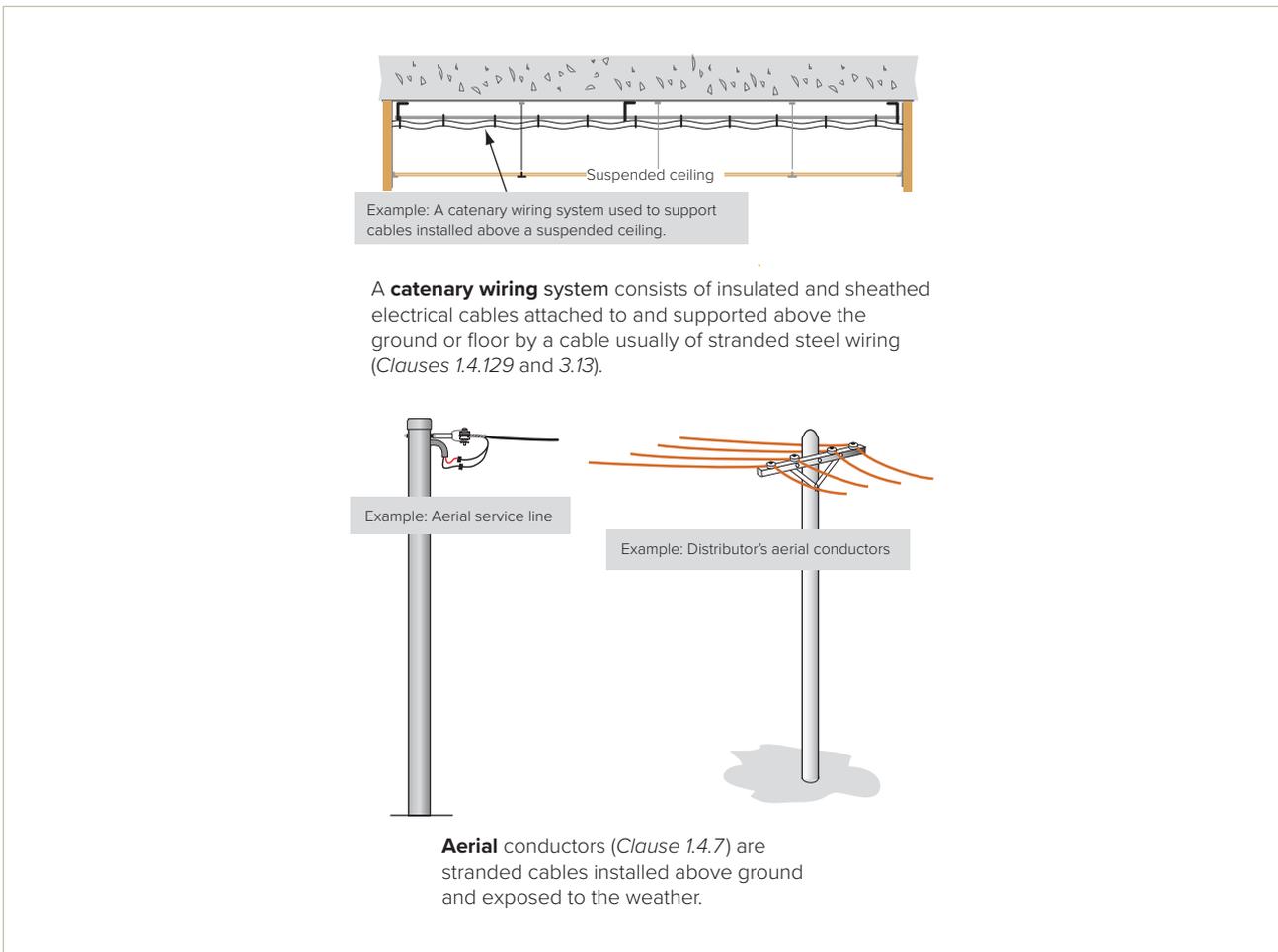


FIGURE 4.11 Comparison of *Wiring Rules* definitions of catenary and aerial wiring systems

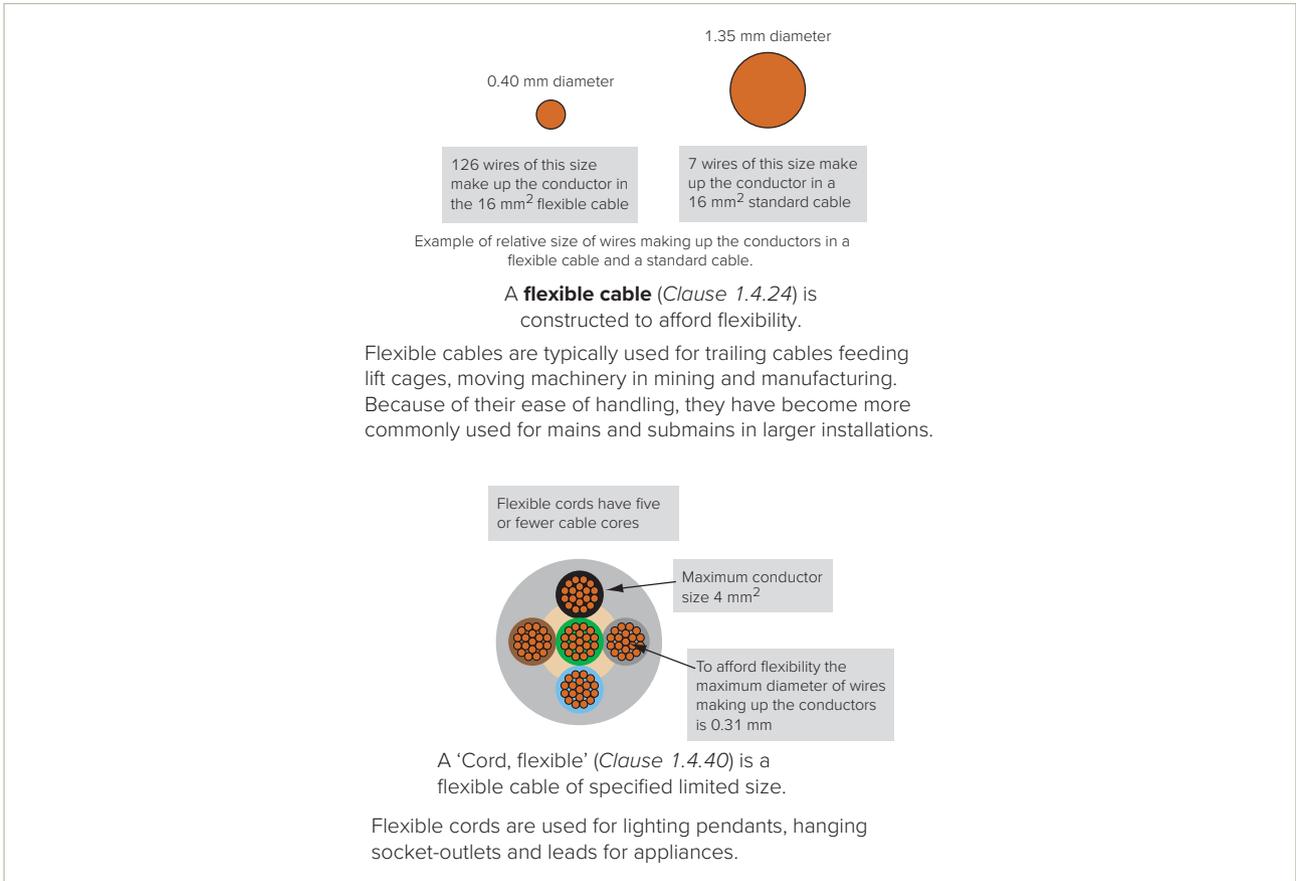


FIGURE 4.12 Comparison of *Wiring Rules* definitions of flexible cables and flexible cords

Figures 4.13 to 4.17 provide illustrations of some of the important cable and wiring terms. A number of definitions used in relation to consumer service arrangements are not always well understood, and these important terms are illustrated in Figures 4.14, 4.15 and 4.16 as an aid to understanding.

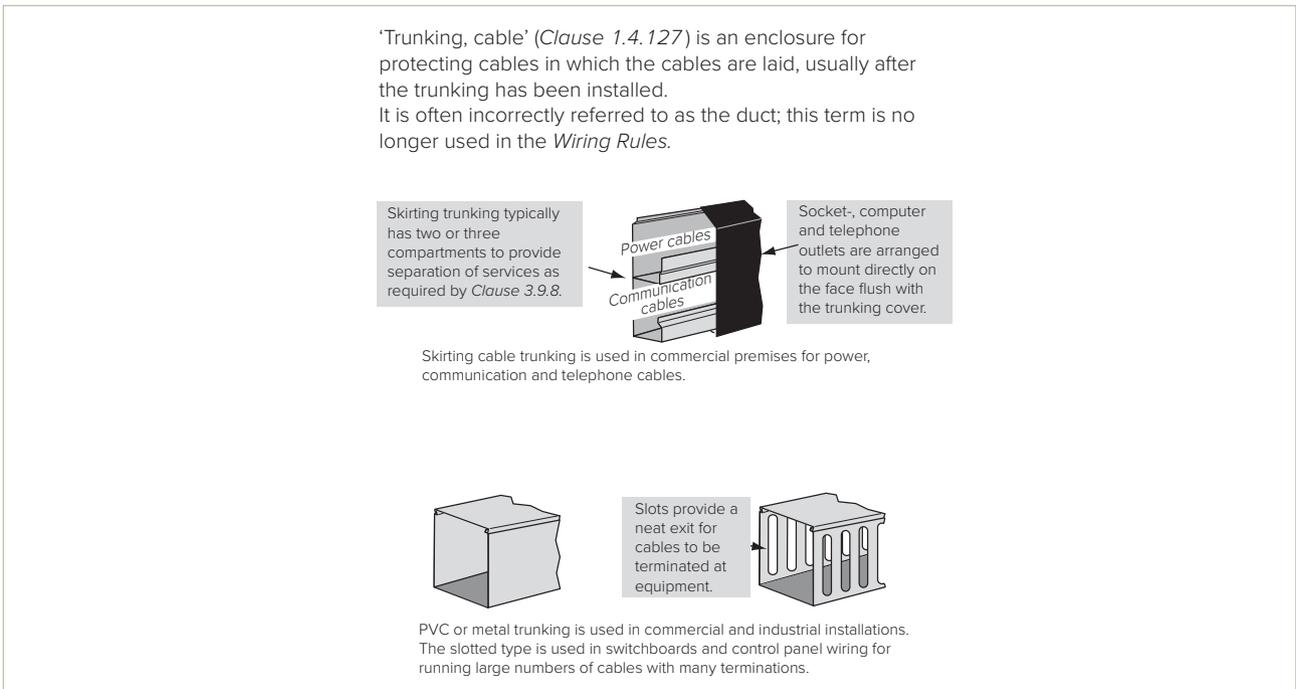


FIGURE 4.13 Comparison of *Wiring Rules* examples of trunking

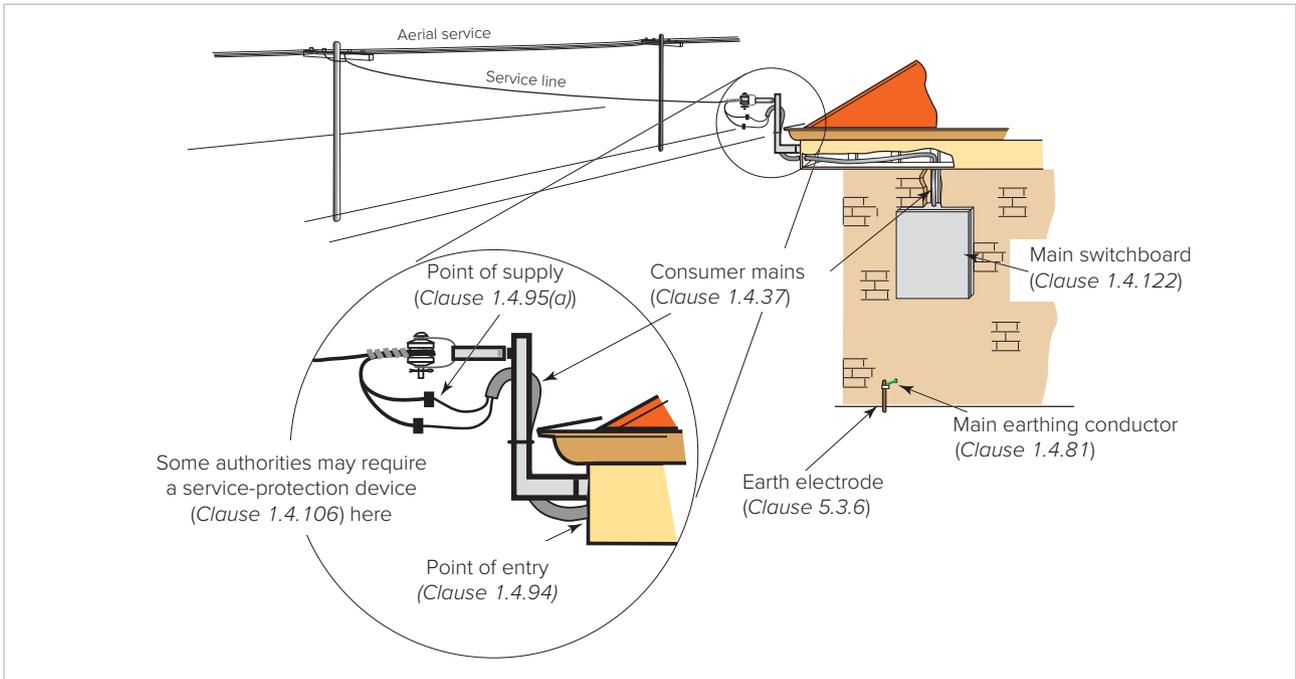


FIGURE 4.14 Examples of aerial supply arrangements and related *Wiring Rules* definitions

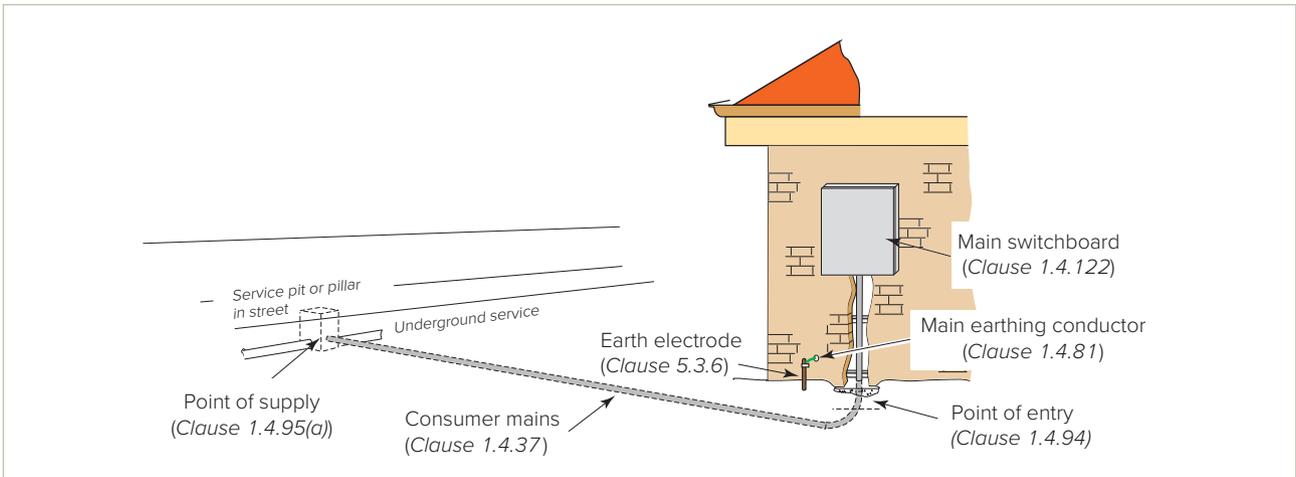


FIGURE 4.15 Examples of underground supply arrangements and related *Wiring Rules* definitions

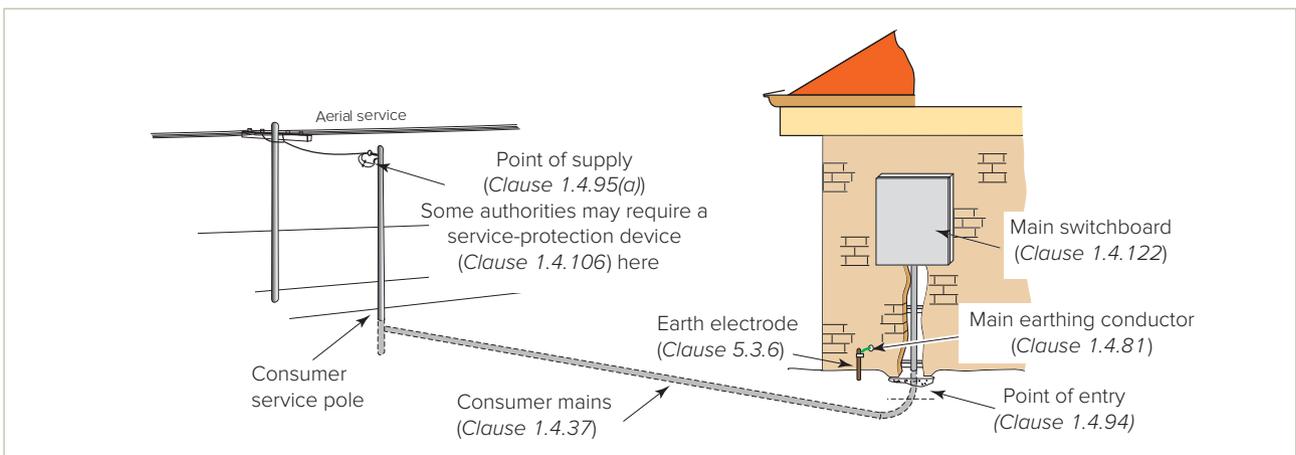


FIGURE 4.16 Examples of aerial/underground supply arrangements and related *Wiring Rules* definitions

The *Wiring Rules* ensure the safety of people, livestock and property against the dangers and damage that may arise in the reasonable use of electrical installations. This includes protection against ‘shock current arising from contact with parts that are live in normal service [defined as ‘Contact, direct’, *Clause 1.4.38*] and contact with parts that become live under fault conditions’ (defined as ‘Contact, indirect’, *Clause 1.4.39*). The methods of protection against direct contact with ‘Live parts’ (*Clause 1.4.79*) are by the use of ‘Barriers’ (*Clause 1.4.20*), ‘Obstacles’ (*Clause 1.4.87*) or ‘Basic insulation’ (*Clause 1.4.73(a)*).

Protection against indirect contact brings together a number of related terms. The most common method of protection is effected by automatic disconnection of supply using circuit-breakers, fuses or a residual current device (RCD). These in turn rely on the earthing systems and protective earthing conductor to interrupt the supply in the shortest time possible. *Clause 1.4.62* defines an ‘Exposed conductive part’ as a conductive part that can be touched by a standard test finger and is not live but can become live if basic insulation fails. The standard test finger is a probe about the size of an average little finger—the dimensions and use of which are given in a separate Australian Standard on probes and similar devices. This is not to be confused with an ‘Extraneous conductive part’ (*Clause 1.4.63*), which does not form part of an electrical installation but may be at the electrical potential of a local earth. **Figure 4.17** gives examples of these important terms and how they relate to electrical installations.

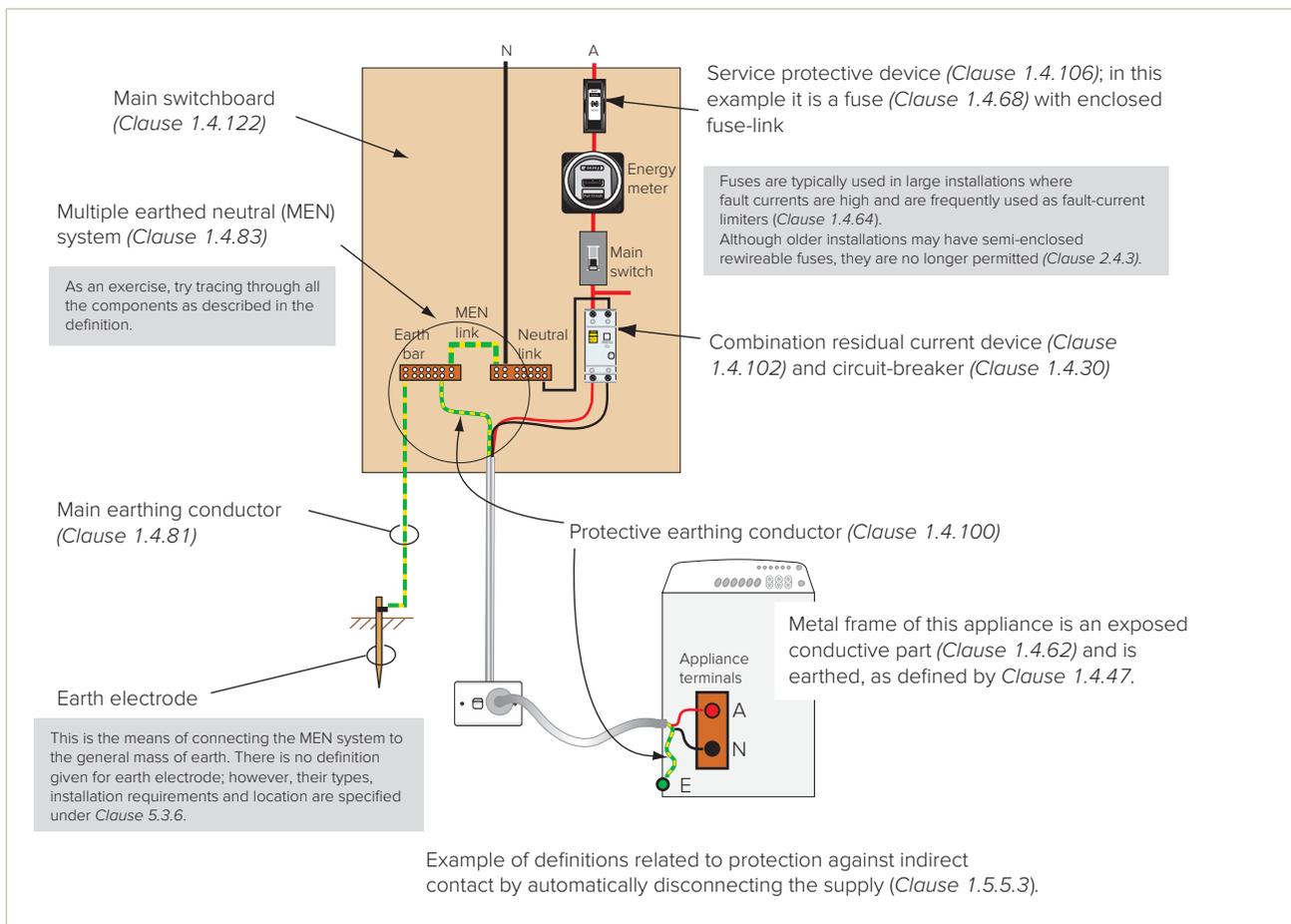


FIGURE 4.17 Example of definitions related to fault protection by automatically disconnecting supply (*Clause 1.5.5.2(a)*)

A ‘socket-outlet’ (*Clause 1.4.110*) (sometimes referred as a ‘plug base’ or ‘receptacle’) may be fixed or suspended, or a socket cord extension (*Clause 1.4.109*) for attachment to a flexible cord. Examples of a point (in wiring) are given in **Figure 4.18**.

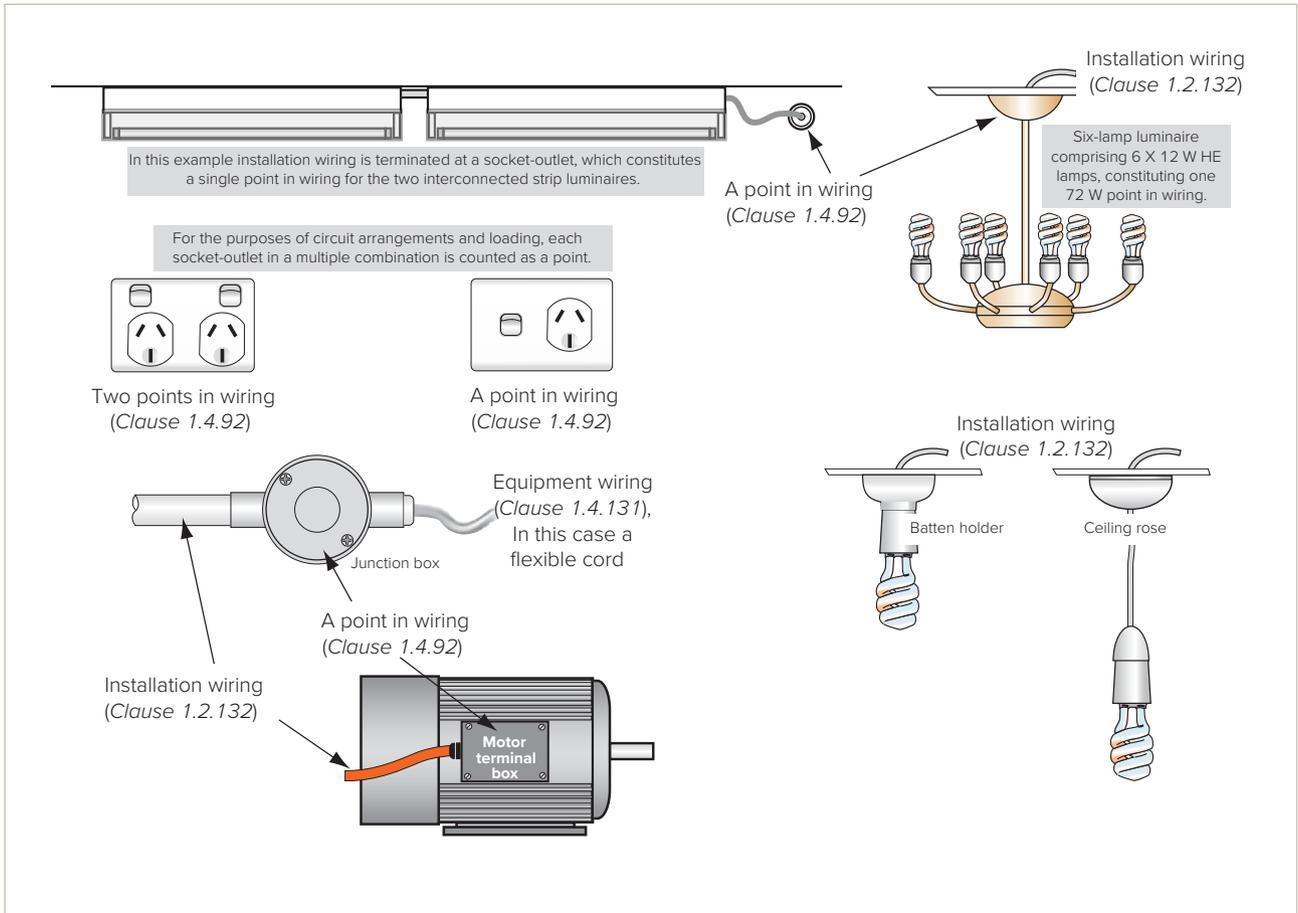


FIGURE 4.18 Examples of the *Wiring Rules* definition of a ‘point’ in wiring

In the body of the *Rules*, there is frequent reference to terms such as ‘point’ in determining the number of points per circuit and the ratings of points. A point (in wiring) is defined in *Clause 1.4.92*. Three voltage divisions are illustrated in **Figure 4.19**.

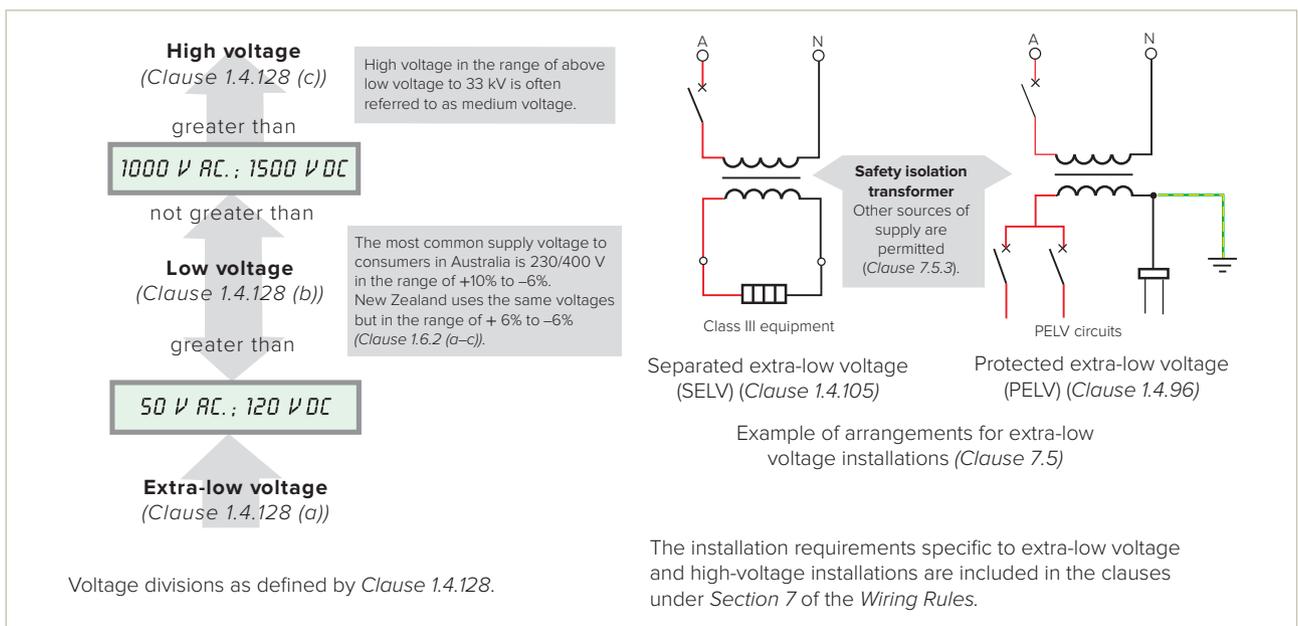


FIGURE 4.19 *Wiring Rules* definitions for ‘voltage’ and voltage levels

Equipment operating at voltages well below 230 V, which is the standard voltage for single-phase circuits, is often incorrectly referred to as ‘low voltage’. A typical example is so-called ‘low-voltage lighting’ that operates at 12 V, when this is actually extra-low voltage in terms of ‘voltage’ (*Clause 1.4.128(a)*). Three voltage divisions are illustrated in **Figure 4.19**.

The *Rules* are mainly formulated for low-voltage conditions; however, they include two systems for extra-low voltage. These are separated extra-low voltage (SELV), defined in *Clause 1.4.105*, which is separated from earth and other systems, and protected extra-low voltage (PELV), defined in *Clause 1.4.96*, which is not separated from earth.

It is worth noting that high voltages in the range above low voltage to 33 kV are often referred to as ‘medium voltage’. The installation requirements for extra-low voltage and the compliance standards for high-voltage installations are included in the clauses under *Section 7*.



CHECK YOUR UNDERSTANDING

21. Identify the key word under which the following information is referenced in the *Wiring Rules*:
 - ▶ testing continuity of earthing
 - ▶ segregating switch gears for safety services
 - ▶ oil-filled capacitors
 - ▶ protection against burns
 - ▶ calculating maximum demand for a non-domestic installation
 - ▶ installing luminaires near fountains.
22. List the Standards in the *Wiring Rules* with which a fixed installation residual current device (RCD) must comply.
23. What is the difference between an appliance and an accessory?
24. Explain the difference between a cable trunking and a duct.
25. In what voltage division would 24 V d.c. be placed?

4.6 Fundamental requirements (*Wiring Rules Part 1*)

An electrical tradesperson is bound by law to install all wiring and equipment in accordance with the *Wiring Rules*, and this must be done in a manner befitting a qualified tradesperson. *Part 1* essentially sets out the standards to which an electrical installation must conform in terms of safety and process. The principles relating to the safety of persons and property, as laid down in *Clause 1.5 Fundamental principles*, provide the basis on which the *Rules* are formulated. The responsibilities of those engaged in electrical installation work, that is, electricians, technicians, engineers and electrical contractors, are set out in *Clause 1.6 Design of an electrical installation*, *Clause 1.7 Selection and installation of electrical equipment* and *Clause 1.8 Verification (Inspection and testing)*. Every electrical installation (no matter how large or small) should be undertaken in the same order that these clauses follow. This is fundamental to ensuring that an installation is safe, that all protection measures are in place and that the installation functions correctly.

The ways in which these clauses can be complied with are specified in *Clause 1.9 Means of compliance*. The preferred way is by complying with all the requirements of *Part 2*, and this is the main focus of the *Wiring Rules* in this text. Alternatively, an installation or part thereof can be of specific design and installation, directly addressing the requirements of *Part 1*. This is only done for unusual installations that cannot be covered by *Part 2* and involves design and comprehensive documentation by competent persons showing how the performance requirements are met and providing justification for the approach taken.

The *Fundamental principles* of *Clause 1.5* are essential safety performance requirements of all electrical installations to protect against dangers and damage that may occur in their normal use. In summary, these are:

- ▶ electric shock
- ▶ the temperature rise and heat dissipated from electrical equipment
- ▶ hazards associated with an electrical installation
- ▶ effects of harmful abnormal voltages on electrical equipment and other systems
- ▶ damaging effects on electrical equipment itself from the environment in which it is installed.

4.6.1 Protection against electric shock

Basic protection, that is, protection against direct contact (*Clause 1.5.4*), is normally taken to mean in relation to inadvertent contact. It is impossible to protect a person from a deliberate attempt to come into contact with live parts. This distinction between inadvertent and deliberate contact must be clearly understood; for example, overhead bare low-voltage street distributors are a shock hazard if a deliberate attempt is made to come into contact with the line by, say, climbing a ladder, while inadvertent contact is not normally possible. Such lines are placed out of reach, which is one of the methods of basic protection elaborated on in *Clauses 1.5.4.3* to *1.5.4.6*. A common method of basic protection is illustrated in **Figure 4.20**.

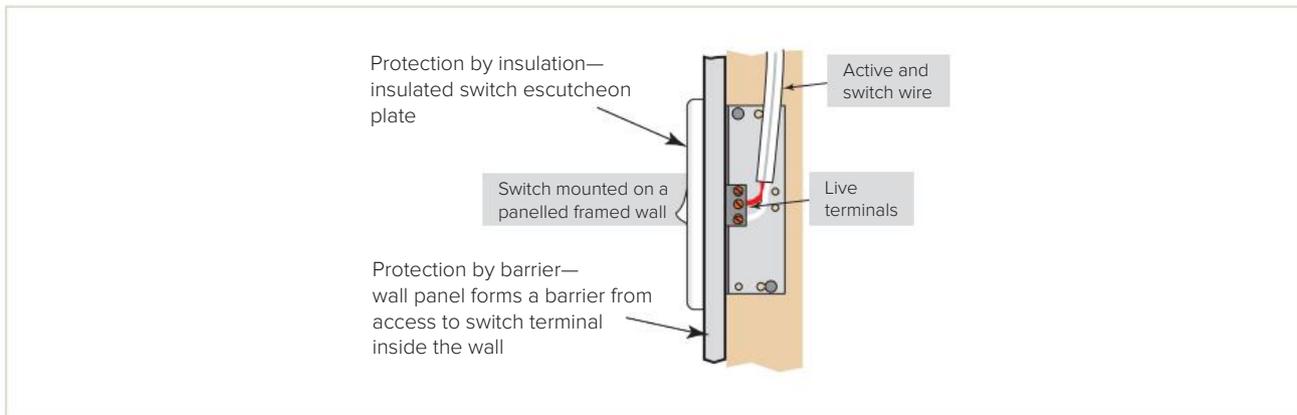


FIGURE 4.20 Examples of basic protection against direct contact

The importance of insulation as a method of basic protection is emphasised by the fact that it must be shown by testing to be not less than 1 megaohm ($M\Omega$) (*Clause 8.3.6*) before an installation is energised. This is a minimum value and a competent electrician should investigate when the insulation resistance is not much greater than 1 $M\Omega$.

Fault protection, that is protection against indirect contact (*Clause 1.5.5*), is most commonly effected by automatic disconnection of the supply by a circuit-protective device, such as a circuit-breaker or fuse, when a fault occurs. To protect a person from electric shock when such a fault occurs between an active conductor and an earthed exposed conductive part (*Clause 1.4.62*), the circuit-protective device must operate as quickly as possible to isolate the fault in order to limit the touch voltage (*Clause 1.4.125*) to the value specified by *Clause 1.5.5.3(b)*. To do so, the protective earthing conductor, together with the circuit active conductor, must be capable of carrying sufficient current to operate the circuit-protective device. This is effected by ensuring that the earthing system impedance is sufficiently low, as specified by *Clause 1.5.5.3(c)*. Fault protection is enhanced by *Clause 1.5.6 Additional protection* by the use of RCDs. See **Figure 4.21**.

4.6.2 Protection against temperature rise and heat dissipated

The *Wiring Rules* include the requirement to prevent people from being burnt by contact with the surfaces of electrical equipment when the equipment is operating normally. Limits are placed on the temperature of parts of electrical equipment that are within arm's reach (*Clause 1.4.16*). For example, *Clause 4.2.3, Table 4.1* specifies the maximum allowable temperatures in normal use of metallic and non-metallic accessible parts.

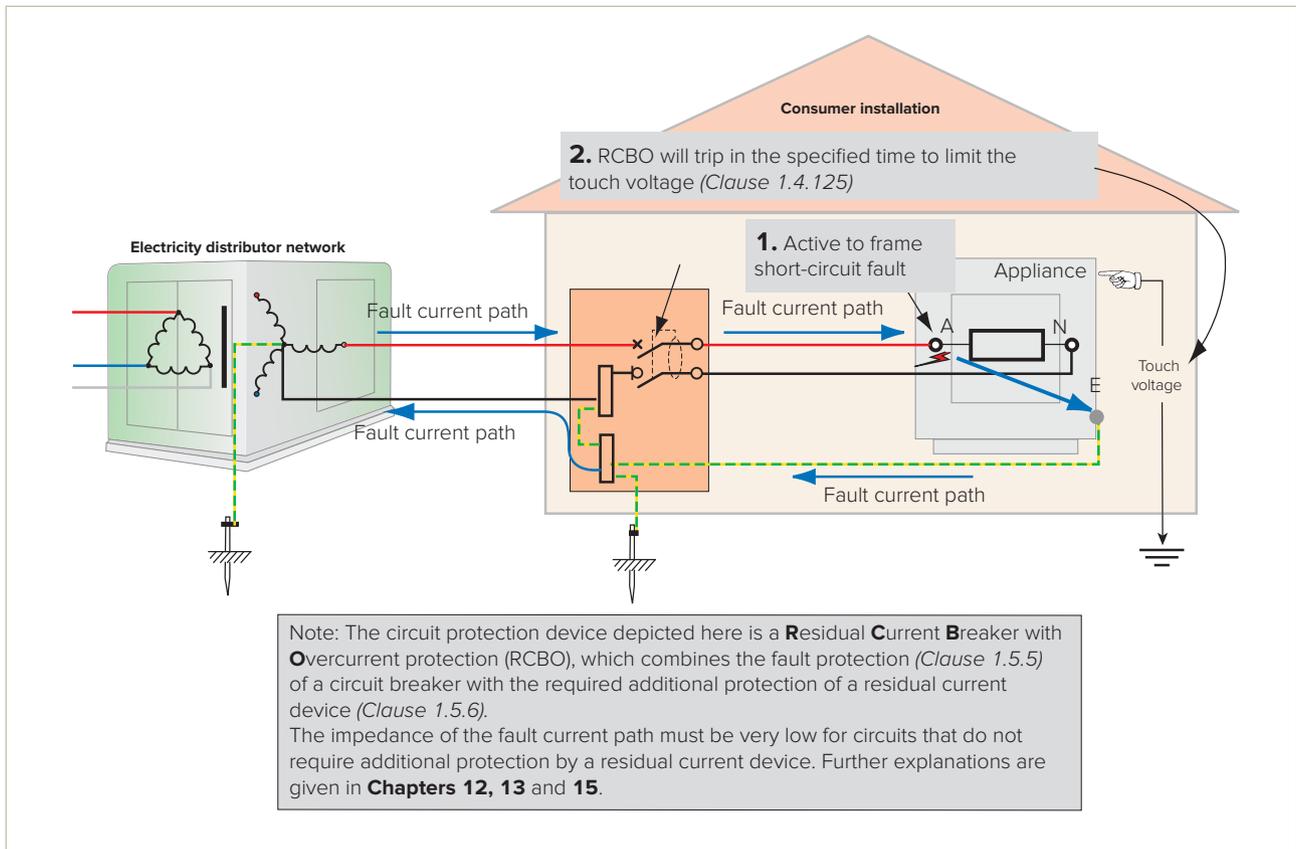


FIGURE 4.21 Example of the importance of protective earthing in protecting against indirect contact by automatic disconnection of supply

The requirements for protection against overcurrent and earth faults are primarily to prevent the rapid rise in temperature and unconfined release of energy that can occur if the fault is not quickly disconnected from the supply. In addition, the forces created by the magnetic field from high fault currents can be very damaging to electrical equipment.

Fire is a hazard that must be constantly guarded against. Fires may originate due to combustible materials being subject to high temperature, or be caused by arcing, overheating due to electrical failure or the absence of preventive measures. *Clause 1.5.8* requires that any part of equipment operating at an elevated temperature must be installed so that there is no risk of igniting flammable materials such as wood. Various ways to achieve this are outlined in *Clause 4.2.2 Prevention of fire hazard*. For example, the high operating temperatures of incandescent lighting could ignite a fire if preventive measures are not taken.

Minimum clearance distances separating a lamp from illuminated flammable materials are given in *Clause 4.5.2, Table 4.2*. The same clause stipulates minimum separation of recessed luminaires and ancillary equipment (e.g. transformers) from flammable structural members. Recessed luminaires are also classified with regard to separation from thermal insulation.

Clause 1.5.12 refers to the protection against an electrical installation starting a fire or causing a fire to spread. Attention is given to switchboards, where a fire could start, and in particular where the risk of a fire spreading could be increased by the cable entries acting as vents and fanning the fire. The *Note to Clause 2.10.7* suggests the need for close-fitting cable entries and, in some cases, internal sealing. Measures for protection against the spread of fire are among a number of requirements of construction and building codes affecting electrical installations. An outline of these requirements is given in *Appendix E* of the *Wiring Rules*.

It should be obvious from the above that the installing electrician has an extensive duty-of-care responsibility in making sure equipment is installed so that injury or damage from the thermal effects of electric current will not occur. **Figure 4.22** shows how the fundamental principles and performance standards specified in *Part 1* are met by application of the rules in *Part 2*.

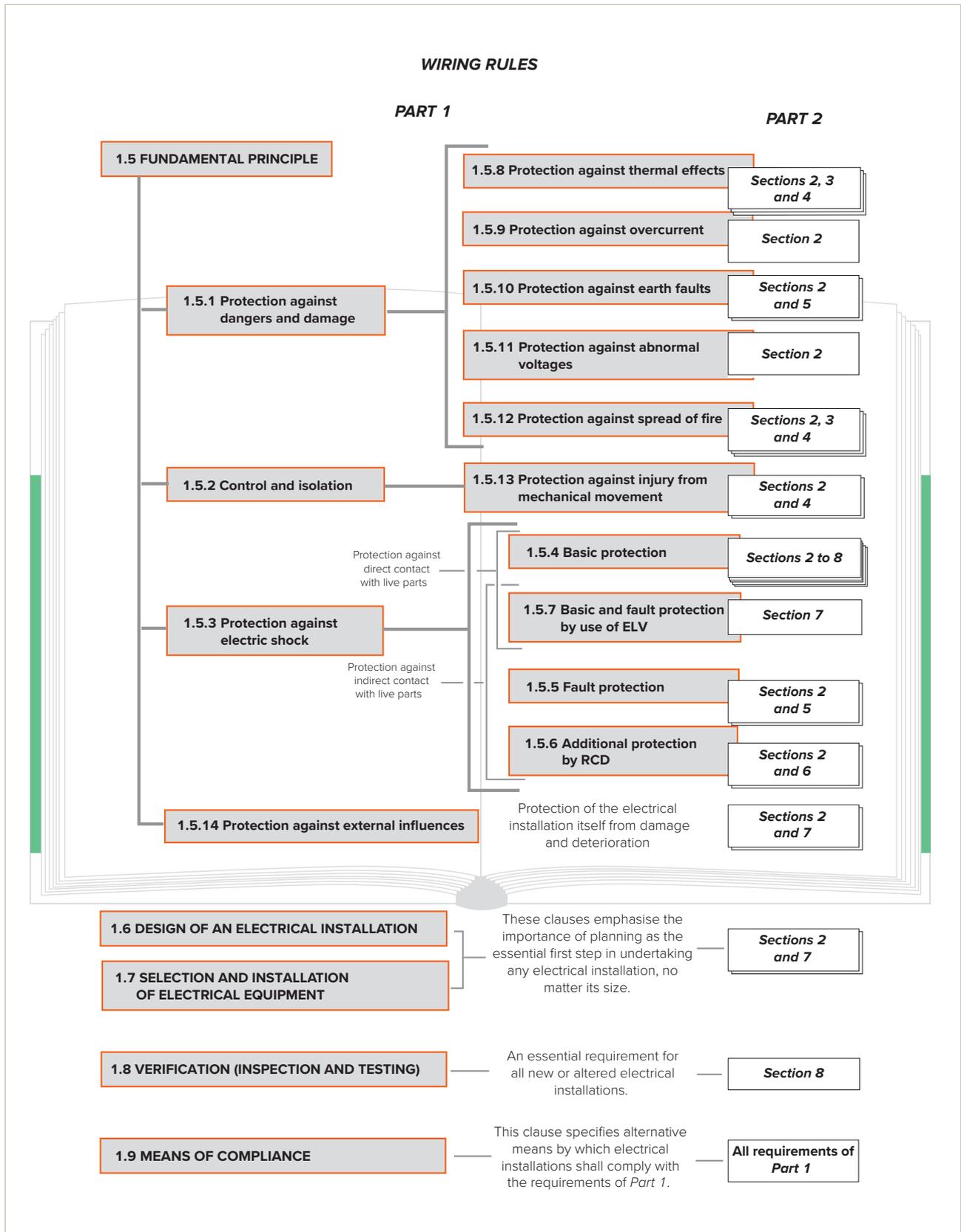


FIGURE 4.22 Wiring Rules—relationship of Part 1, Section 1 to Part 2, Sections 2 to 8

4.6.3 Hazards associated with electrical installation

The protective requirements of the *Wiring Rules* should be seen as necessary, given the potential hazards of an electrical installation discussed so far. In addition, *Clause 1.5.2* requires the provision of a switch or switches (control devices) to isolate equipment from the supply. For example, a person working on mechanical equipment driven by an electric motor is likely to sustain severe injury if they cannot isolate the motor from the supply in a manner that prevents others from switching the supply back on while the work is being done. Provision of an isolation device for this purpose is stipulated by *Clause 1.5.13*.

The design of an electrical installation includes the need to divide the installation into circuits as required by *Clause 1.6.5*. This is supported by *Clauses 2.3* and *2.4*, which set out deemed-to-comply requirements regarding control and protection of each electrical circuit in an installation.

4.6.4 Protection against effects of harmful abnormal voltages

For electrical circuits to operate as designed, it should be self-evident that different wiring systems must be kept electrically separate. This separation is of vital importance when considering the circuit wiring belonging to different voltage systems; for example, those of a telephone and 400 V power wiring, where a breakdown between the two systems would constitute an extremely dangerous shock hazard. The *Wiring Rules* recognise this potential danger and the general requirements for segregation of different services are included in *Clause 1.5.11*. **Figure 4.14** shows an example of multichannel skirting trunking for the segregation of power and communication cabling. Other acceptable methods for prevention of harmful effects between services are given in *Clause 3.9.8*.

Note that the requirements regarding the segregation of services include cable terminations and the wiring on switchboards and control panels. In these situations, the separation is usually more easily achieved by the use of rigid spacing, screens, barriers or other approved methods.

It may not be obvious at first, but dangerous voltages can be induced in unused cables, particularly where they are in close proximity to high-voltage conductors. *Clause 1.5.11.4* requires such cables to be terminated and protected as live cables. It is not a requirement of the *Wiring Rules* to protect electrical installation against overvoltage such as that caused by lightning. However, with the large amount of supply-connected sensitive electronic equipment in use today, it is more than likely that overvoltage (or surge) protection will be a requirement specified by the consumer. Guidance on overvoltage protection is given in *Clause 2.7* and *Appendix F* of the *Wiring Rules*.

4.6.5 Protection against damaging effects on electrical equipment itself

The electrician must be ever alert for any conditions that would adversely affect the efficiency or safety of an installation (*Clause 1.5.14*). For example, cables installed in a location where heavy materials are handled may need to be further protected against mechanical damage by, say, enclosing the cables in a steel conduit. Over time, corrosion can reduce the effective life of both metallic and non-metallic parts of electrical equipment. For instance, the sap in some Australian hardwoods will corrode metallic sheathing, and salt-laden atmospheres cause corrosion of metallic enclosures, conductors and terminations. Both polyvinyl chloride (PVC) conduit and PVC sheathing will deform under mechanical pressure and heat, and thick layers of dust or dirt may act as a blanket, causing the temperature of equipment to rise.

Many locations in which electrical equipment is installed must comply with specific rules, such as damp situations covered in *Section 6* of the *Wiring Rules* and hazardous areas covered by *Clause 7.7* and other mandatory Standards. A study of *Clause 5.1* and its sub-clauses shows that the emphasis of the *Wiring Rules* is on safety and protection.

In addition to fulfilling these minimum legal requirements, a qualified electrician must strive for a high standard of work at all times. Most electrical apprentices will start by developing their skills through installing electrical equipment. As they progress in their training, they will gain the skills necessary to select equipment, test an installation and design an installation. It is of prime importance that the correct attitudes are adopted by new apprentices right

from the beginning of training, as it is easy to fall into a slipshod approach, resulting in substandard work and perhaps the creation of a safety hazard.



CHECK YOUR UNDERSTANDING

26. Name the essential safety performance requirements for electrical installations.
27. List the methods for protection against direct and indirect contact with live parts.
28. Describe the two methods of protection against overcurrent.
29. List the criteria for the selection and installation of electrical equipment with regard to protection against the spread of fire.
30. List the aspects of electrical installation compliance covered by the *Wiring Rules* in each of Sections 2–8.

4.7 Insulating materials

Apart from being the most commonly used basic method of protection against direct contact, insulation is necessary in order for electrical circuits and systems to work as intended. The current in a circuit must be confined to the designed current paths, that is, the conductors within the circuit. To achieve this and to prevent excessive leakage (or worse, short-circuits), these current paths are electrically isolated from one another, and from earth, by an insulating material.

Electrical insulating materials, or *dielectrics*, are materials that resist the conduction of electricity, and they can be solids, liquids or gases. The mechanical, electrical, chemical and thermal characteristics of the insulating materials are strictly controlled to suit the particular application. The most common types of electrical insulation materials and their applications are summarised in **Table 4.3**.

Insulating materials are chosen for their properties to greatly limit any current flow other than through the conductors they insulate; however, as they have resistance, there will be some leakage current ($I = \frac{V}{R}$), as shown in **Figure 4.23**. You will learn in later chapters about the importance of a high value of insulation resistance to minimise leakage currents, which can cause nuisance tripping of residual current devices (RCDs).

As previously discussed, *Clause 1.5.14* of the *Wiring Rules* specifies that an electrical installation must be designed to protect it against the damaging effects expected from the environment and other external influences in which it is installed. Heat, moisture, ultraviolet (UV) radiation from sunlight and various compounds can accelerate the ageing of some insulation materials, while poorly installed equipment such as cable insulation subjected to unnecessary stress may result in insulation breakdown.

4.7.1 Effect of heat on insulation

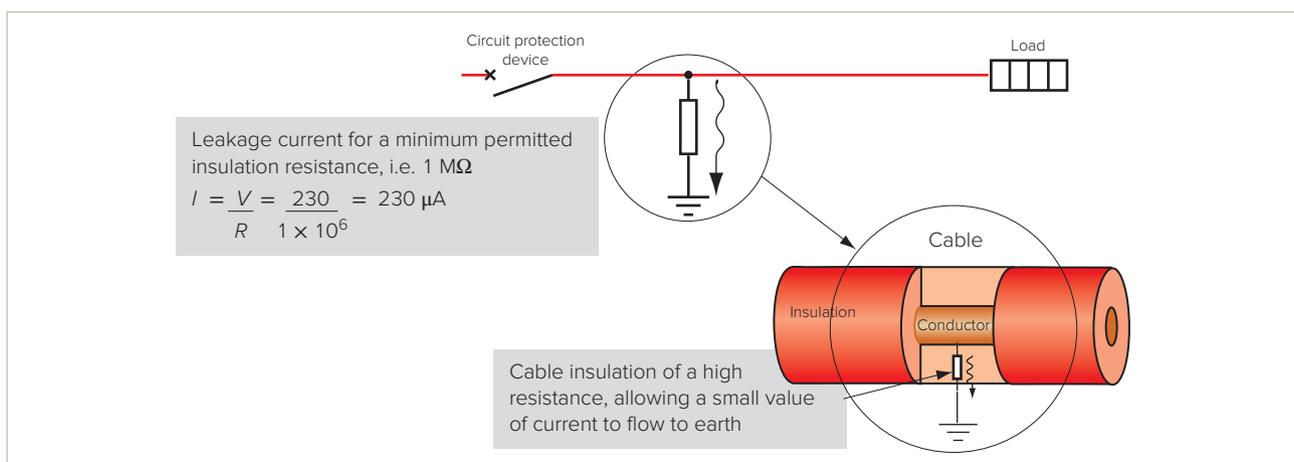
Insulants can withstand heat well in excess of their rated temperature for short periods. However, when operated at excessive temperatures continuously, they first become brittle and then charred, finally breaking down altogether. The minimum and maximum operating temperatures for electrical equipment specified by a manufacturer are an indication of the temperature limits of its insulation (see **Chapter 8** for the temperature limits for cables).

4.7.2 Effect of moisture on insulation

Most insulation contains some moisture; the amount of moisture depends on how hygroscopic it is. A material is described as hygroscopic when it tends to absorb moisture from the air. This is the case with electrical equipment such as electric motors, transformers and some switch gear when it is shut down and left to stand for some time,

TABLE 4.3 Common electrical insulation materials

Form	Common materials	Typical application
Solid	Ceramics	These were used for many years in low-voltage and high-voltage aerial line insulators. Terminals subject to high temperatures, such as those for electrical heating elements, are often of ceramic material.
	Fibrous materials	Fibreglass-based materials are used for cables where higher temperatures are likely, such as the internal wiring of heating elements of appliances and in some luminaires.
	Polymeric compounds	These are the most commonly used insulation for electrical and communication cables. (Cable insulants are covered in detail in Chapter 7 .) They are also used in the insulated components of switch gear, appliances, electrical terminals and tapes.
	Silicone rubber	This is an ideal insulant where electrical wiring and components are subject to higher or low temperatures or ageing by chemical reaction; for example, the internal wiring around the hotter parts of electrical equipment, such as heating elements, lead-out connections of motor windings and some luminaires, or where oils and other chemicals harmful to polymeric insulants are present. It is an alternative to ceramics for high-voltage cable aerial insulators.
Liquid	Transformer oil	This is a highly refined mineral oil used to insulate and cool transformers and in some switch gear and capacitors.
	Silicone	In a fire, liquid silicone compounds have a lower heat release rate, lower smoke generation and lower toxicity of combustion by-products than mineral transformer oils. They are therefore used in transformers located indoors and in other fire-sensitive areas.
	Varnishes	Epoxy-based and silicone-based materials are used to impregnate coils and windings in electric motors, generators and transformers. They are applied as a liquid and designed to set hard during a curing process specified by the manufacturer.
Gas	Air	This is the most common gaseous insulator. It forms the insulation between conductors on aerial circuits from low voltage to the extra-high voltages of distribution and transmission lines.
	Nitrogen	This is used in high-voltage gas-filled cables and as coolant in large generators.
	Sulfur hexafluoride	This is used extensively in high-voltage gas-insulated switch gear and other electrical equipment. In many instances it replaces the harmful PCBs discussed in Chapter 2 .

**FIGURE 4.23** Insulation resistance and leakage current

reducing the insulation resistance. When the insulation resistance is unsatisfactorily low, the moisture must be driven out, usually with a heat gun or oven. Sheathed heating elements are notorious for their initially low insulation resistance but can be dried out by connection to the supply, provided their initial resistance is not less than $0.01 \text{ M}\Omega$ (see *Clause 8.3.6.3* for minimum insulation test results). Moisture is the main cause of breakdown in liquid and gas dielectrics. Transformer oil, for instance, is treated to remove moisture before it is used.

4.7.3 Effect of exposure to the elements on insulation

Direct sunlight has the potential to degrade insulation in two ways: (1) by the action of UV radiation on the chemical composition of the insulation; and (2) by effectively raising the ambient temperature and in turn the insulation temperature above its permitted maximum operating value. The ambient temperature affects the current-carrying capacity of cables, which is covered in cable selection in **Chapter 16**. *Clause 3.3.2.11* of the *Wiring Rules* requires cables exposed to direct sunlight to be suitable for such, as advised by the manufacturer, or protected in accordance with *Clause 3.3.2.2*.



CHECK YOUR UNDERSTANDING

31. What type of liquid insulation is used in a power transformer installed indoors?
32. Determine the leakage current to earth of a cable for a 230 V a.c. circuit with a tested insulation resistance of $10 \text{ M}\Omega$. Provide your answer in μA .
33. Describe the conditions that degrade the effectiveness of electrical insulation.
34. What is the main cause of breakdown in liquid and gas dielectrics?
35. In what two ways can direct sunlight degrade insulation?

SUMMARY

- ▶ Most Australian Standards are developed and published by Standards Australia.
- ▶ There are three main types of electrical licences.
- ▶ Licensed electricians must comply with the *Wiring Rules*, relevant codes or statutory authorities, service and installations rules of energy distributors and any additional specifications that apply to their work.
- ▶ The Electrical Regulator Authorities Council (ERAC) represents all states, territories and New Zealand regarding matters of technical electrical regulation.
- ▶ The EL-001 Committee assists in the development of the *Wiring Rules* and other Standards.
- ▶ The *Wiring Rules* follow a logical plan and are divided into *Part 1* and *Part 2* with *Appendices* designated by letter.
- ▶ To build knowledge of the *Wiring Rules* it is recommended to start with the *Table of Contents*, *Definitions of Terms* and *Fundamental Requirements*, which are found in Part 1, Section 1.
- ▶ Electrical insulating materials are materials that do not conduct electricity and can be comprised of solid, liquid or gas.
- ▶ Insulation materials can be affected by excess heat, increased moisture and exposure to the elements.

REVIEW QUESTIONS

1. Describe the term *electrical work*.
2. Briefly describe the difference between an electrician's licence and a restricted electrical work licence.
3. Who is eligible to receive an electrician's licence?
4. Who is responsible for ensuring that a new electrical installation is safe and complies with the *Wiring Rules*?
5. What is the purpose of the *Wiring Rules Appendices* and how are they structured?
6. Choose one main clause from each of *Sections 2, 3, 4 and 5* in the *Wiring Rules* and list the main sub-clauses under each.
7. Which *Appendix* in *Section 3.6.2* applies to surge protective devices (SPD)?
8. The cross-sectional area of each conductor of a three-core cable is $6 \text{ mm}^2 \left(\frac{88}{0.30} \right)$. Is the cable classified as a flexible cord or a flexible cable?
9. What term is given to the connection between the electricity distributor's conductors and the consumer mains?
10. Describe the differences between equipment class I, class II and class III.
11. If equipment is required to be readily accessible, what is the maximum height at which it may be mounted above a floor or platform?
12. Briefly describe what is meant by an earthed situation.
13. What is defined as a point in electrical wiring?
14. Explain the terms 'exposed conductive part' and 'extraneous conductive part'.
15. What is a damp situation?
16. Briefly describe the parts of an electrical installation that are designated as safety services.
17. Although the required minimum insulation resistance of installed circuits is $1 \text{ M}\Omega$, what value should be expected for circuits with route length up to 50 m?
18. Identify the table in the *Wiring Rules* used to identify the maximum allowable temperatures in the normal use of metallic and non-metallic accessible parts.
19. Name the four most common solid materials used for an electrical insulator.
20. What are the three ways by which insulation can be degraded?

CHAPTER 5

Drawings, diagrams, schedules and documents used in electrical work

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ identify the series and parallel components in practical circuits
- ▶ show the difference between circuit diagrams and wiring diagrams, and develop a wiring diagram from a circuit diagram
- ▶ interpret information given in manufacturers' installation and service instructions
- ▶ interpret electrical drawings and diagrams using knowledge of drawing conventions and symbols
- ▶ outline the purpose of a contract to provide electrical services and manage work using smart devices
- ▶ describe the purpose, typical format and types of information of a job specification
- ▶ explain the format and purpose of a schedule and identify equipment given in location diagrams and schedules
- ▶ make up a materials list from information given in job specifications and drawings
- ▶ use standard drawing conventions in freehand drawings to record and convey electrical information and ideas to others
- ▶ use standardised drawing conventions to correct in freehand original job drawings to show final *as-installed* arrangements.

The training of electricians includes carrying out practical work that involves the control of light and power circuits. To perform this work efficiently they must work with, and be able to interpret, electrical diagrams. Electricians must also have a plan for the precise location of equipment, outlets and control positions; this requires a working knowledge of building construction methods and the sequence in which tasks should be performed. In addition, the conduit/cable runs and layout require planning and, unless a job is small, a diagram of switchboard layout and wiring is usually necessary.

The actual wiring circuits and connections require reference to wiring diagrams, unless they are standard simple types, in which case the diagram is carried as a mental picture. However, remembering even the simplest wiring circuit or layout initially requires the study of relevant diagrams and circuits.

In the case of a simple installation such as an additional light point or socket-outlet, both the wiring layout and the necessary job materials would also probably be retained in the memory of the electrician on the job. However, even in this simple example, although there is no written record, the requirements still exist.

So, for all jobs, no matter how simple or how complex, it is essential for plans, specifications, materials lists and schedules to be prepared. The number and extent of these will depend on the extent and complexity of each job. This chapter deals with the development and interpretation of electrical drawings and specifications, and how they are used in preparing materials lists.

5.1 Series and parallel circuits in wiring

There are only two basic circuit connections in any electrical circuit—series connection and parallel connection. A complete circuit may contain many such connections, in combination with various voltages and devices including signal sources—all interconnected. But basically the most involved circuitry consists of a multitude of series and parallel connections. All electrical circuits comprise: a source of supply; some form of protection; some form of control; a load, which converts electrical energy to some other energy form; and a return to the source of supply. This basic circuit arrangement is shown in **Figure 5.1**.

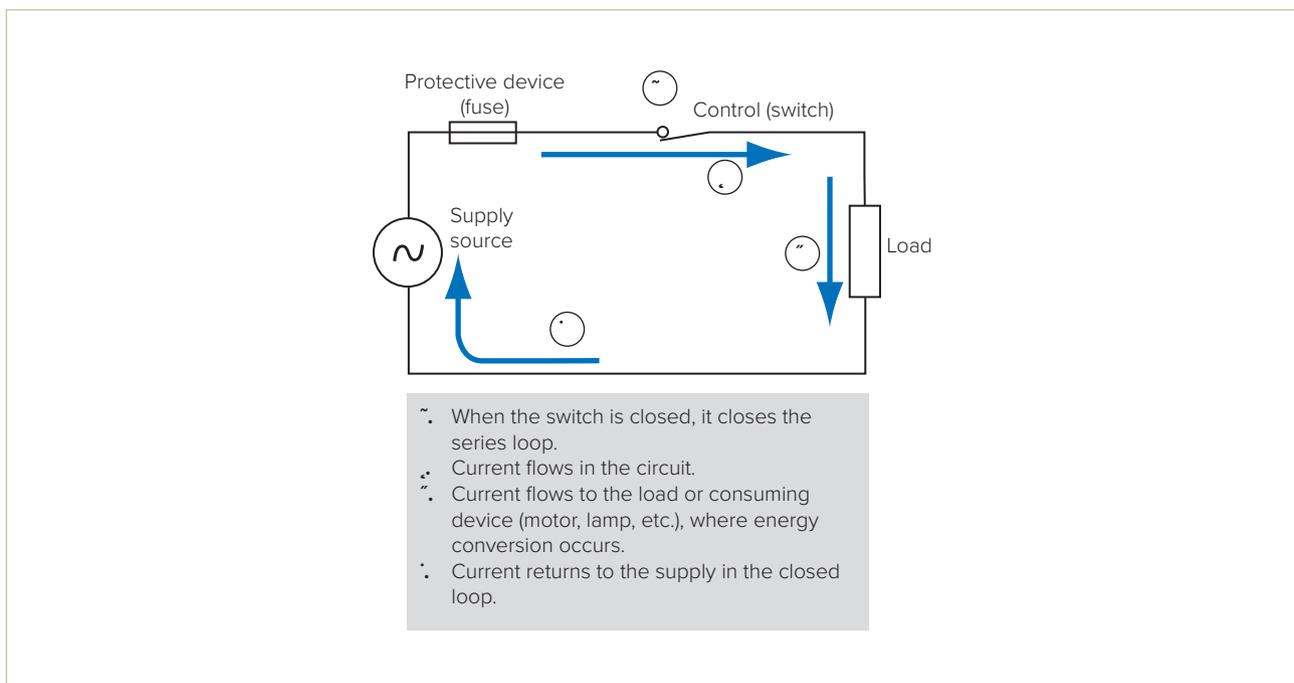


FIGURE 5.1 The basis of all electrical circuits

In a *series* circuit, an interruption or open circuit in any path, including the internal circuit of the supply source, will stop the current flow. In a *practical* circuit, the protective device, usually a fuse or circuit-breaker, automatically opens the circuit under predetermined fault conditions.

In normal circuits, most of the supply voltage is expended in driving the current through the load. For a practical circuit, as shown in **Figure 5.2**, the combined voltage drops of the circuit conductors feeding the load, which are equivalent to a series resistance, are kept to a minimum, to minimise energy loss and to ensure that the rated voltage appears at the load terminals.

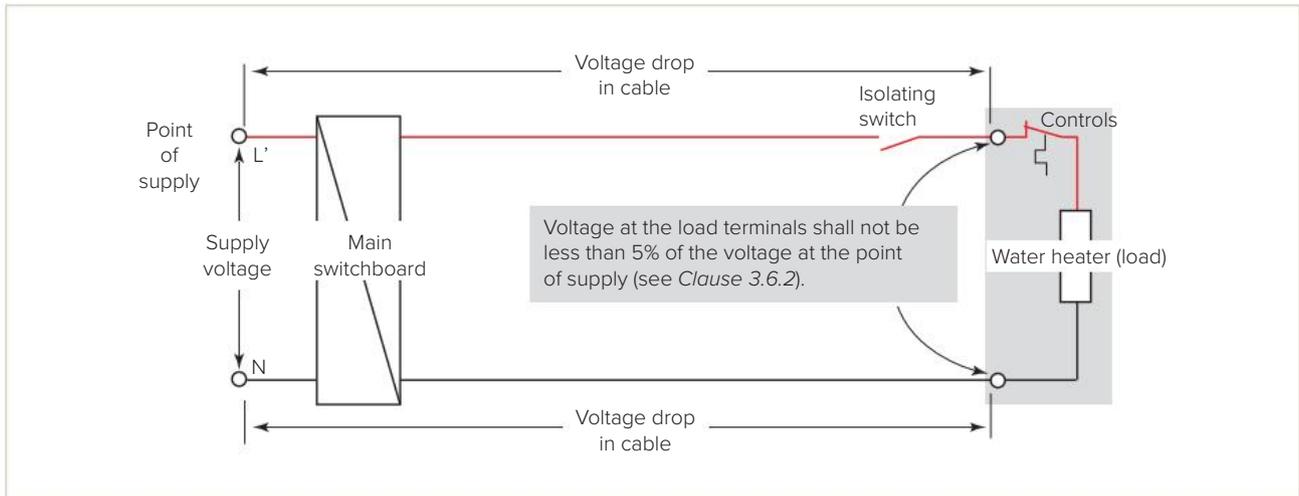


FIGURE 5.2 Effect of cables in a practical circuit

The main differences between series-connected and parallel-connected loads are illustrated by two practical circuits in **Figure 5.3**.

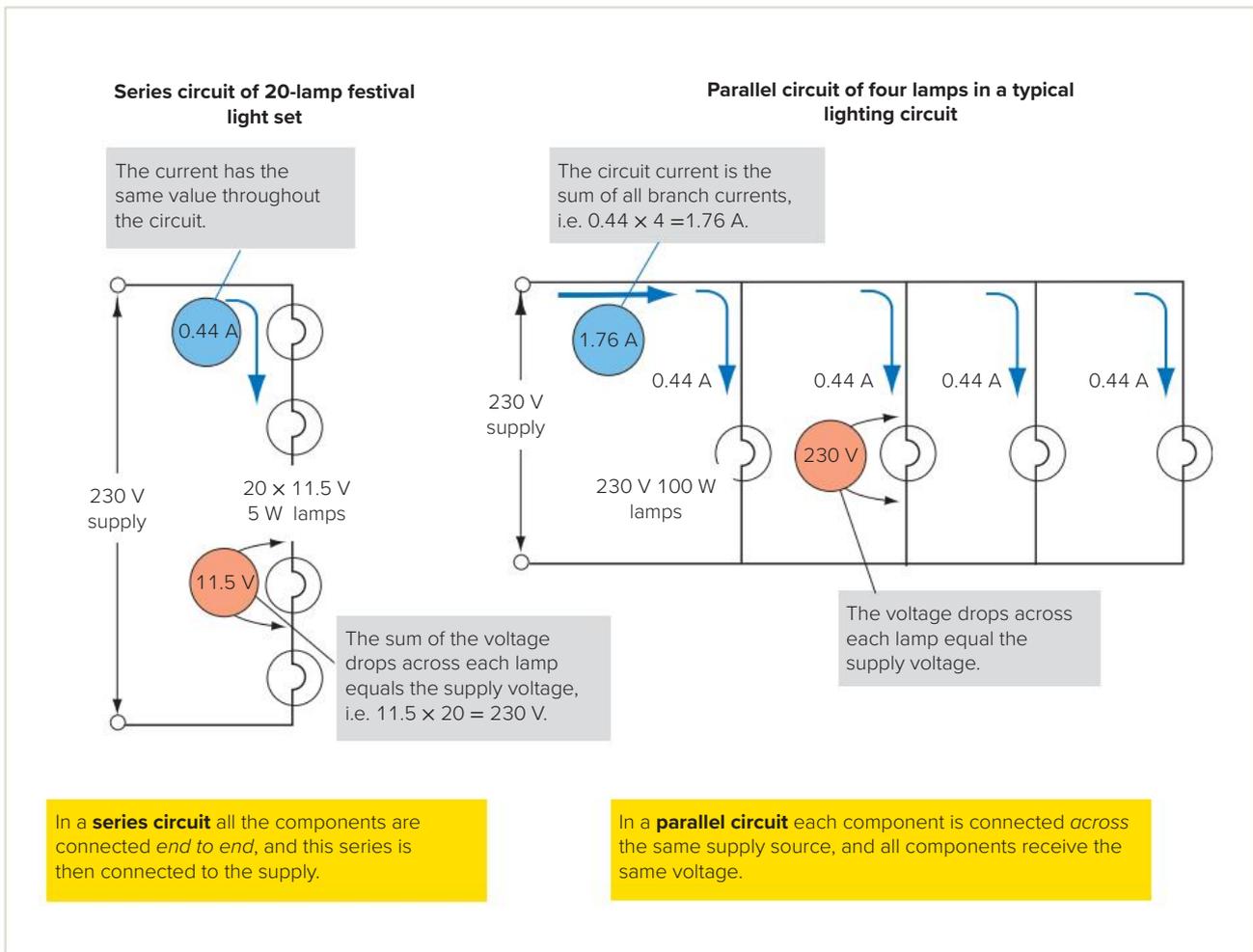


FIGURE 5.3 Comparison of series and parallel circuits

In Australia and New Zealand, low-voltage appliances and lamps are rated to be operated, within the accepted tolerances, at 230 V single-phase and 400 V multiphase. Because the voltage ratings of appliances and lamps are the same, it follows that parallel connection is the method commonly used for installation wiring. In fact, the circuits emanating from a switchboard are each a parallel branch in the whole installation. In circuits that supply more than one point, such as lighting and socket-outlets, the points are connected in parallel. Although the circuits in an installation are connected in parallel, each circuit has a number of series components, as shown in **Figure 5.4**.

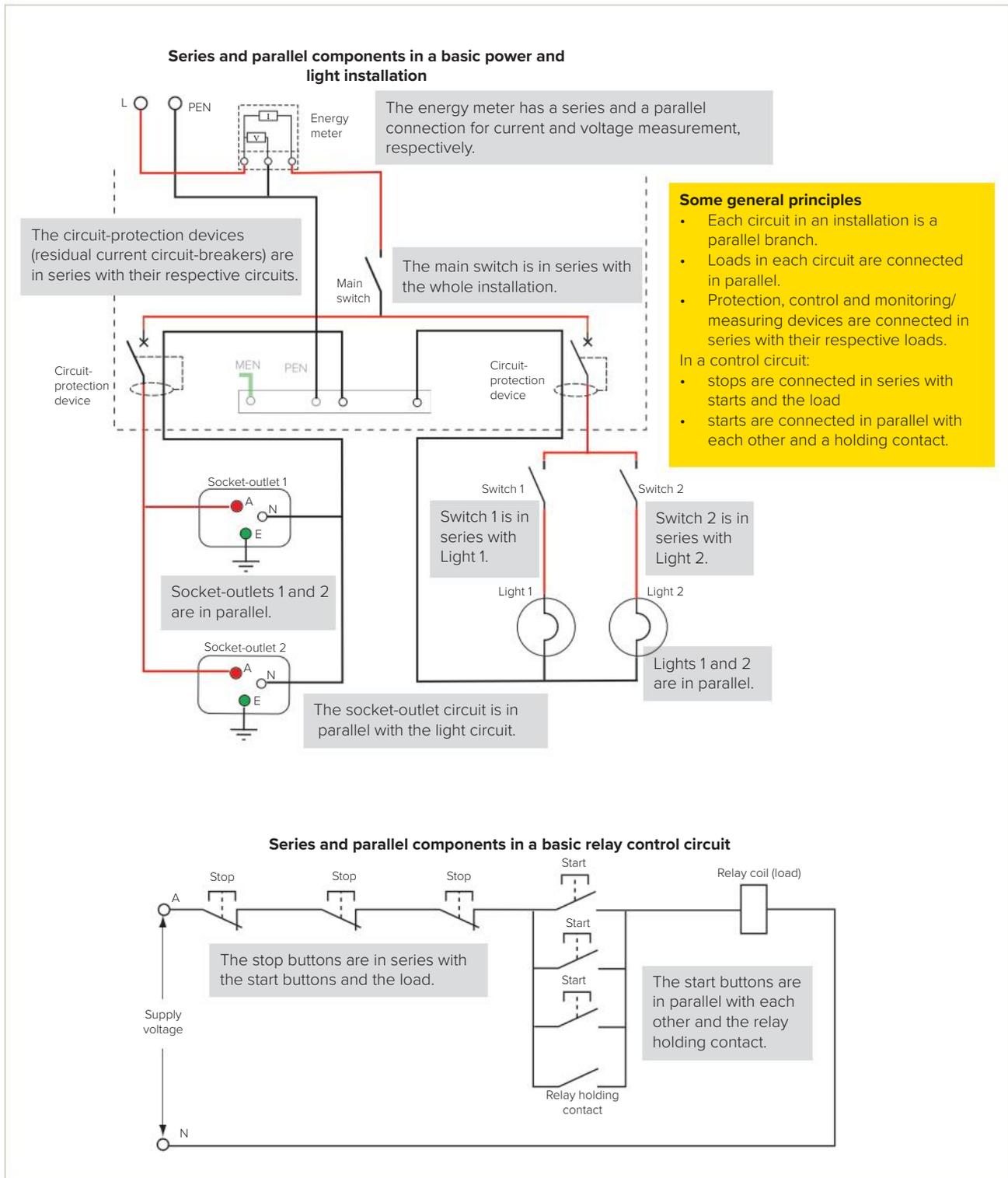


FIGURE 5.4 Series and parallel connected components



CHECK YOUR UNDERSTANDING

1. Draw a basic circuit, labelling all the components.
2. In a circuit, what is the purpose of a switch?
3. In a practical circuit, why is the voltage drop in the circuit conductors kept to a minimum?
4. Explain the features and characteristics of series circuits and parallel circuits.
5. Identify the series and parallel circuits of the following components in an installation:
 - ▶ energy meter
 - ▶ main switch
 - ▶ circuit-protection devices
 - ▶ socket-outlets
 - ▶ light points
 - ▶ light switches.

5.2 Electrical circuits and wiring diagrams

It is necessary to describe adequately the exact manner in which the electrical components of even the most basic electrical circuit are connected and how they interact, the location of electrical equipment and other services in a building, and how the parts of an appliance are assembled. This could take pages and so some short-cut method or picture is needed; for this, the electrician has diagrams that use commonly understood symbols and conventions so that interpretation is simple for any tradesperson familiar with the common language of drawing practice.

The main two types of electrical diagrams used by electricians are the following:

- ▶ The *circuit diagram* (*schematic* in American terminology) shows the scheme of an electrical circuit in the logical sequence of how it functions. Circuit diagrams are drawn from left to right and top to bottom, in a cause-effect order, using symbols to represent circuit components and a layout that may not resemble their physical circuit.
- ▶ The *wiring diagram* is a pictorial representation of the circuit, with the components shown in their actual relative physical positions and the wiring connections shown between them.

How these two types of diagrams differ is illustrated by the control circuit of a direct-on-line (DOL) starter shown in **Figure 5.5**.

5.2.1 Where circuit and wiring diagrams are used

With the aid of a good wiring diagram, even a relatively inexperienced person could wire up the circuit. A skilled electrician will use it as a reference for the actual physical layout of a job such as a large control board. This type of diagram is often provided for electrical service or maintenance of appliances such as washing machines, stoves and water heaters, and assists in tracing the location of defective devices or wiring if a fault has been diagnosed. Compare the wiring diagram with the circuit diagram for an off-peak mains-pressure water heater shown in **Figure 5.6**.

As electricians become more experienced, they tend to prefer the circuit diagram to the wiring diagram. It would be almost impossible to design, install or efficiently test complex electrical equipment without the use of a circuit diagram at some stage. For anyone familiar with electrical work, it is easy to trace out and follow a circuit if the wiring is visible, but in the average electrical installation the wiring is concealed within the structure or hidden within equipment.

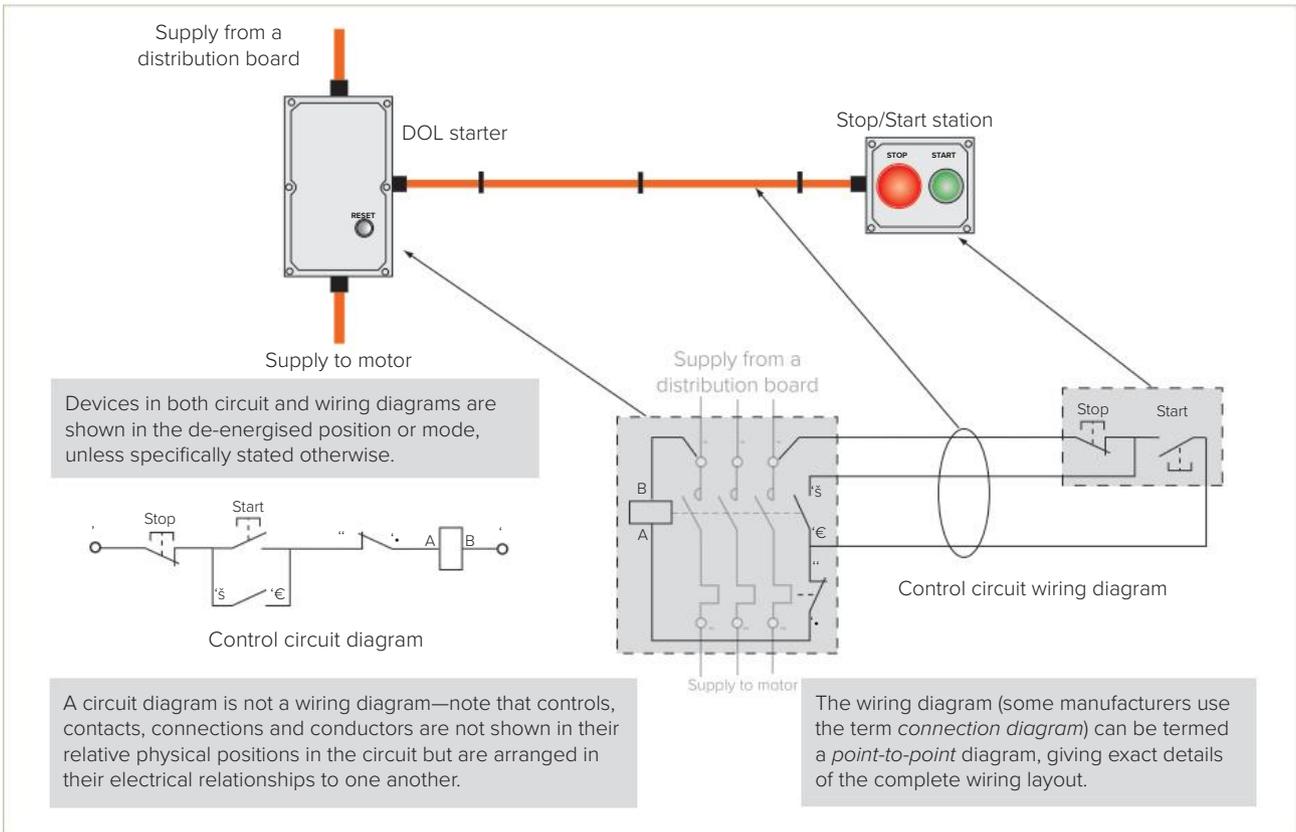


FIGURE 5.5 Comparison of a circuit diagram and a wiring diagram

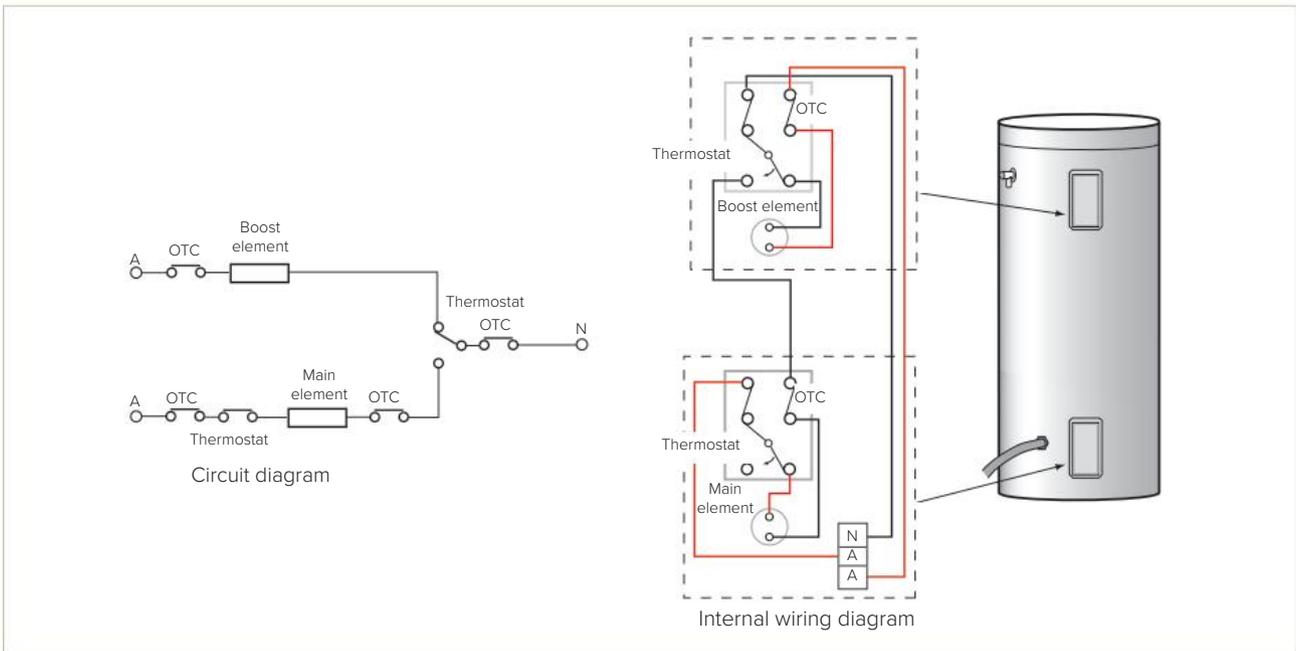
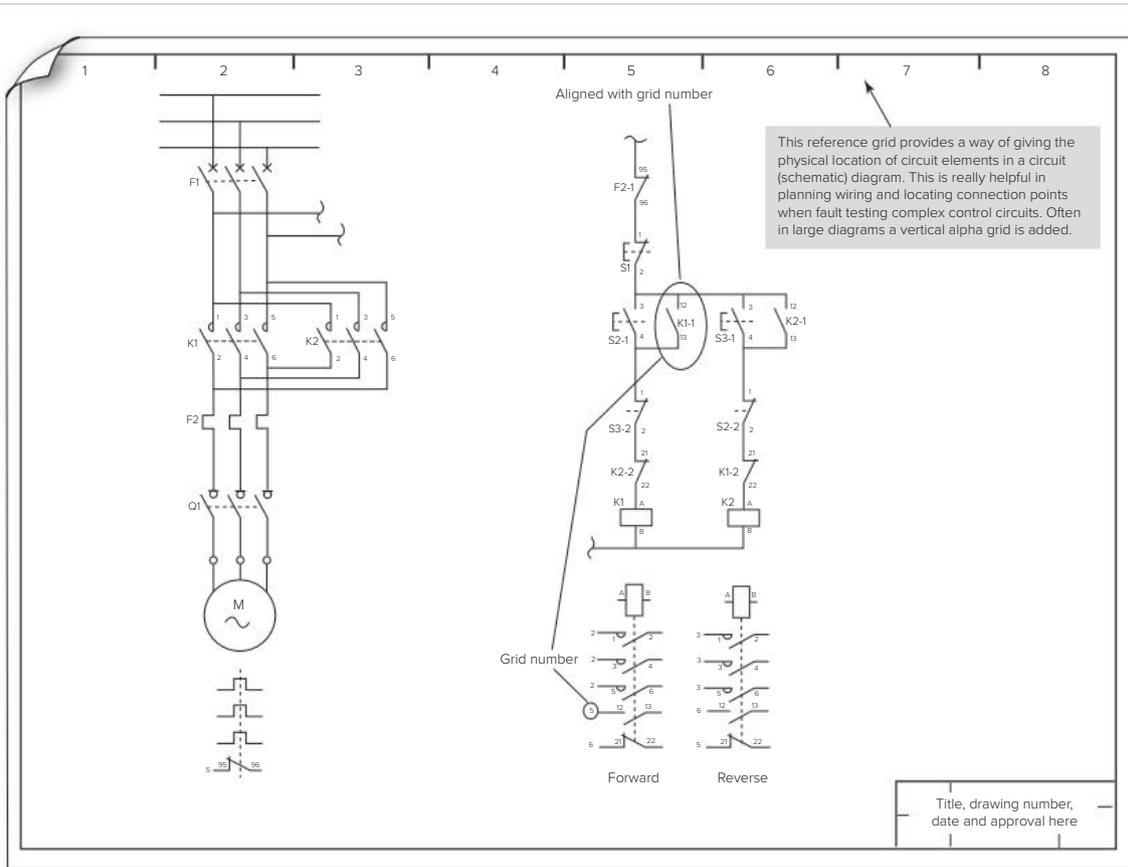


FIGURE 5.6 Two ways of representing the internal circuits of an off-peak mains-pressure water heater

With the aid of a good circuit diagram, the necessary tests for short-circuits, leakage paths, open circuits and malfunction of circuit devices can be performed without dismantling equipment or pulling the installation apart.

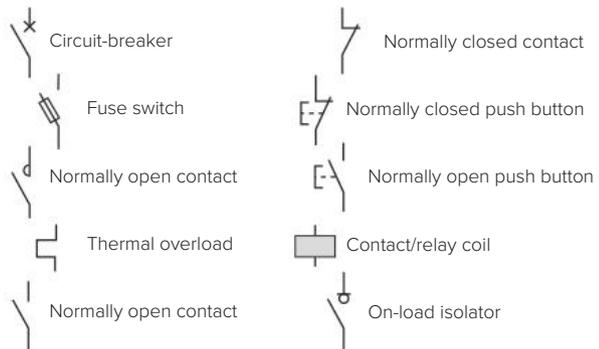
The agreed way of presenting information in electrical diagrams is based on various local and international standards. Although these may vary, the drawing conventions summarised in **Figure 5.7** provide a basis for interpreting most electrical diagrams.



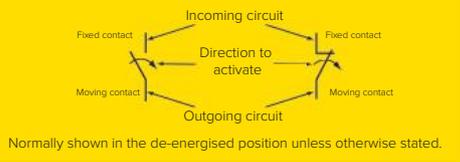
Item designation

- F Protection—fuses, circuit-breakers and overload devices
- K Relays and contacts
- M Motors
- S Switching devices in control circuits
- Q Power circuit switching devices

Symbols



The conventions for symbols representing switching devices are:



Symbols used in circuit diagrams are most often those of the IEC60617 series: *Graphical symbols for diagrams*. Once you understand the function of the devices represented by these symbols, you should easily be able to interpret symbols based on other Standards. In many cases, where symbols deviate from the Standard a legend is included on the drawing.

FIGURE 5.7 Example of conventions used in electrical diagrams

5.2.2 Other types of electrical diagrams

The single-line diagram is another form of circuit diagram, used mainly to show the arrangement of switching that controls the way equipment is interconnected in power distribution systems and installations. A simple example is shown in **Figure 5.8**.

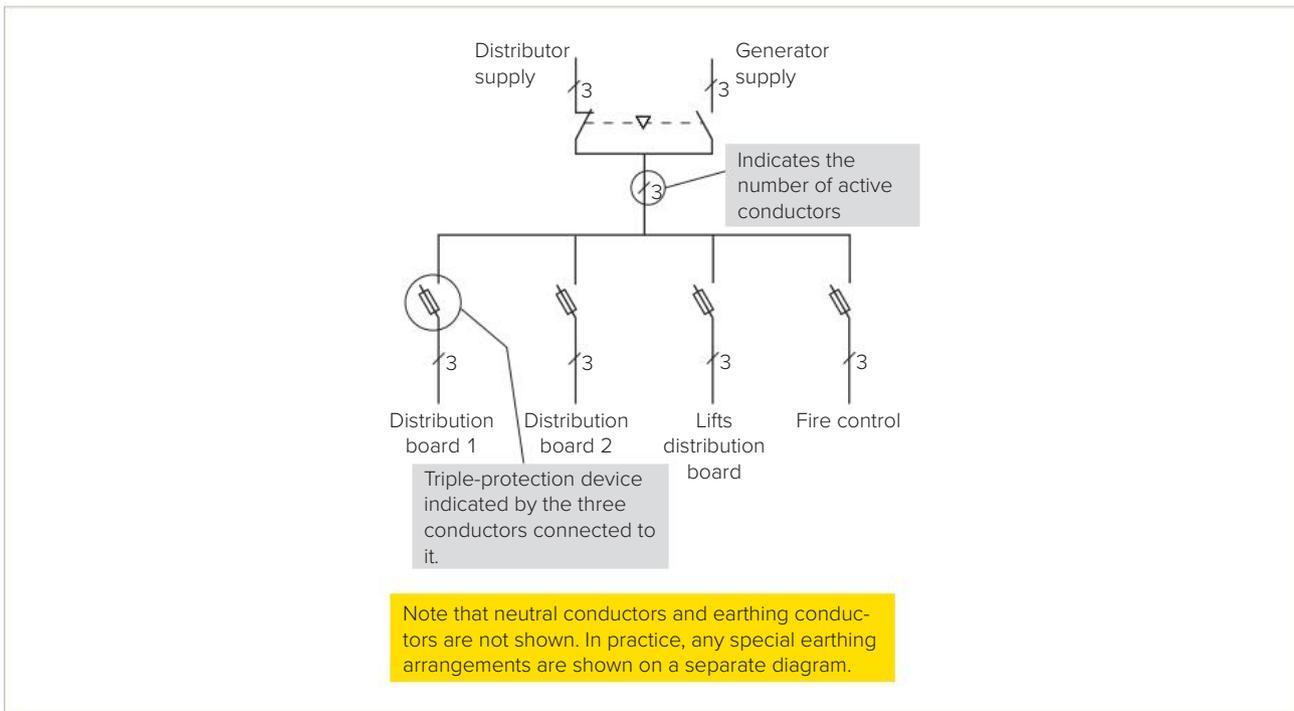


FIGURE 5.8 Single-line diagram of the distribution and control arrangements for a large installation

In a block diagram, blocks are drawn to represent complete component circuits or elements. **Figure 5.9** illustrates a simple block diagram for a primary resistance starter for an induction motor.

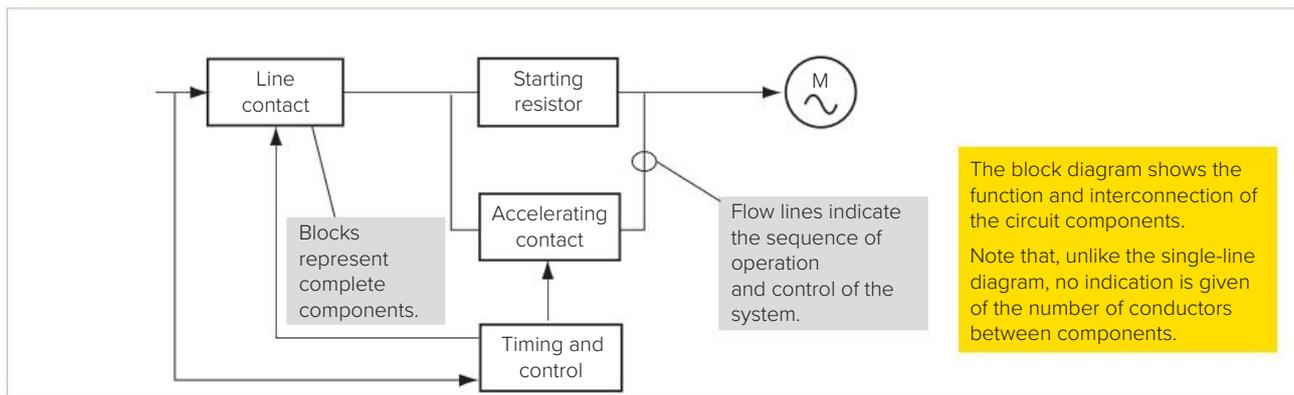
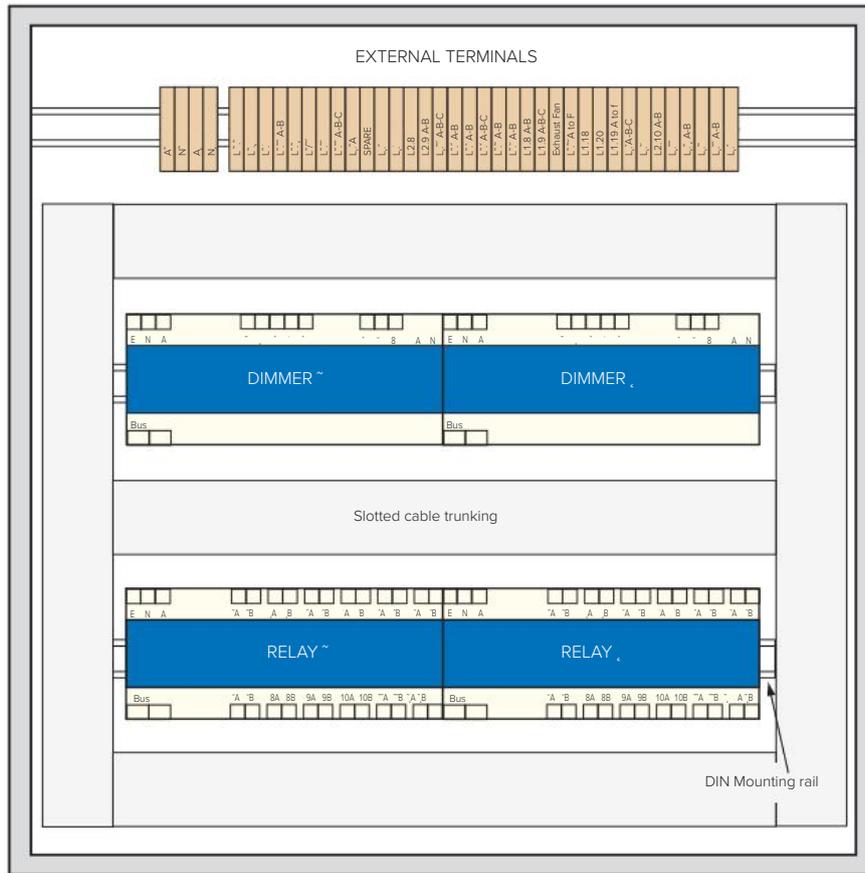


FIGURE 5.9 Example of a block diagram

Block diagrams are most useful in the diagnosis of faults, in the design stages of circuits and in installation. They are widely used in the supply industry, for example in system diagrams.

Wiring connection tables or cable schedules, as shown later in **Figure 5.19**, are another form of communicating electrical information, and can be easier to follow where many cables and connections are involved. They are typically used in switchboards and control panels or the point-to-point cabling in large installations. They are illustrated in **Figure 5.10**, which shows a panel layout and connection table for a lighting control system.

STUDY HINT: Do not attempt to memorise the numerous circuits available covering specific applications unless you are working on them continually. Learn the basics and adapt them to the job in hand.



Dimmer 1 terminal	External terminal	Relay 1 terminal	External terminal	Relay 2 terminal	External terminal
A	A1	A	A1	A	A2
N	N1	N	N1	N	N2
1	L1.1	1A	A1	1A	A2
2	L1.2	1B	L1.13A-B	1B	L2.6A-B-C
3	L1.4	2A	A1	2A	A2
4	L1.11A-B-C	2B	L1.5A-B	2B	L2.7
5	L1.12	3A	A1	3A	A2
6	L1.13	3B	L1.6A-B-C	3B	L2.10A-B
7	L1.15	4A	A1	4A	A2
8	L1.16A-B-C	4B	L1.14A-B	4B	L2.11
Dimmer 2 terminal	External terminal	5A	A1	5A	A2
		5B	L1.7A-B	5B	L2.12A-B
A	A2	6A	A1	6A	A2
N	N2	6B	L1.8A-B	6B	L2.14
1	L2.1A	7A	A1	7A	A2
2	L2.2	7B	L1.9A-B-C	7B	L2.15A-B
3	SPARE	8A	A1	8A	A2
4	L2.3	8B	Exhaust fan	8B	L2.5
5	L2.4	9A	A1	9A	A2
6	L2.8	9B	L1.17A to D	9B	
7	L2.9A-B	10A	A1	10A	A2
8	L2.13A-B-C	10B	L1.18	10B	
		11A	A1	11A	A2
		11B	L1.20	11B	
		12A	A1	12A	A2
		12B	L1.19A to F	12B	

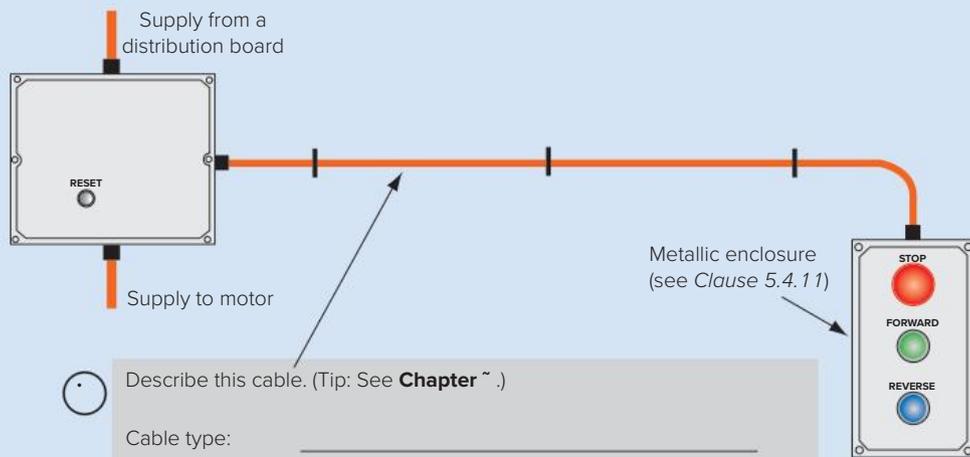
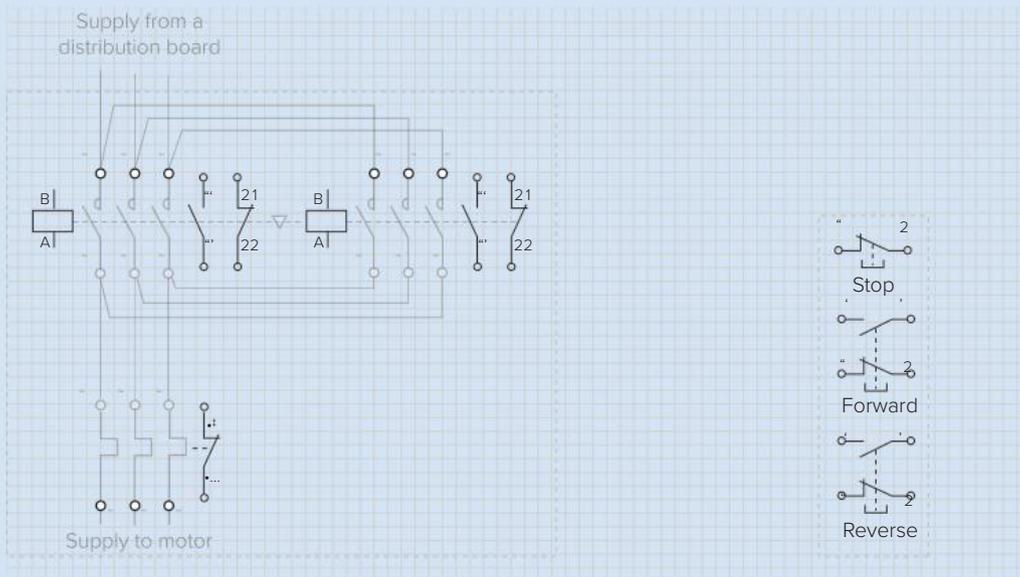
FIGURE 5.10 Lighting control panel and connection table

CHECK YOUR UNDERSTANDING

- Describe the features and the purpose of a circuit diagram and a wiring diagram.
- What are the main uses of wiring diagrams?
- How are circuit diagrams used?
- Complete the control circuit wiring diagram in **Figure RQ5.1**. The circuit diagram is shown in **Figure 5.5**. (Tip: Connect the numbers.)
- Why is an earth wire required at the stop; reverse station in Question 9?



Complete the wiring diagram for the reversing starter below.
 The circuit diagram (schematic) is shown in **Figure 5.5**.
 (Tip: Connect the numbers.)



Describe this cable. (Tip: See **Chapter 5**.)

Cable type: _____

Conductor size: _____

Number of cores: _____

FIGURE RQ5.1

5.3 Circuits in general wiring

The circuits in an installation are categorised by the types of loads they supply. Generally, these categories are:

- ▶ lighting
- ▶ power (socket-outlets)
- ▶ mixed circuits supplying both lighting and socket-outlets
- ▶ permanently connected appliances, which include motors and composite machines
- ▶ submains supplying distribution boards, the load being the combination of all loads supplied from the distribution board.

The actual wiring of circuits, that is, the locations from and to where wiring is run, will depend on the location of the load (the parallel component) in relation to its control devices (the series components). The various cable routes through different types of building structures are discussed in **Chapter 17**; for now, the emphasis is on the importance of planning the wiring. It would be embarrassing for an electrician at the final connecting stage (fitting out) of an installation, when most building finishes have been completed, to find they are short of a cable core at a connection point. A little time spent planning will go a long way towards avoiding this type of situation, and planning is never more critical than for lighting circuits.

5.3.1 Lighting circuits

In the electrotechnology industry, there are several methods of lighting control. Single-pole or one-way control from one position is the most common and is used in residential premises, for example, to switch on a laundry light or bedroom light. Other lighting control methods include single-pole double-throw or two-way control from two positions. This method is used when there are two entrances to a room such as might occur in a living room or a kitchen. Another lighting method is two-way and intermediate control, which is used when there are three or more light switch positions. A common place to find this switching control is in stairwells. More information regarding single- and multi-position lighting control is in **Chapter 8**.

Both one-way control and two-way control use the same mechanism for installation. Two-way and intermediate switching control uses an extra mechanism known as an intermediate switch mechanism. **Section 8.10** of **Chapter 8** covers in detail the correct mechanisms needed for each lighting control method and examples are shown in **Figures 8.35** to **8.37**.

There are two methods used to wire a lighting control circuit: loop at the light or loop at the switch, commonly known as the loop-in systems. Lighting accessories such as batten holders and ceiling roses come with a spare loop connection. The loop connection found in these accessories is used in the loop at the light method. The difference between the two looping methods is explored further in **Section 8.10.1** and highlighted in **Figure 8.38**.

5.3.2 Socket-outlet circuits—circuit and wiring arrangements

Socket-outlets provide the convenience of connecting portable and cord-connected appliances to the supply. Where there is more than one outlet on a circuit, as is commonly the case, they are connected in parallel so that an appliance plugged into any outlet is connected to the supply voltage. Socket-outlets are perhaps the easiest of parallel circuits with regard to wiring, because they are usually looped from point to point, as shown in **Figure 5.11**. Twin TPS cable with an enclosed earthing conductor is the most common cable type used. A similar looping method applies to circuits using single-insulated cables in surface or concealed conduit wiring.

It is appropriate here to emphasise that, for the safety of persons using socket-outlets, correct polarisation of the outlets is essential when connecting them to the circuit wiring and is mandated by the *Wiring Rules* (see *Clause 4.4.5*). This also applies to the phase sequencing on all multiphase outlets in an installation, as shown in **Figure 5.12**.

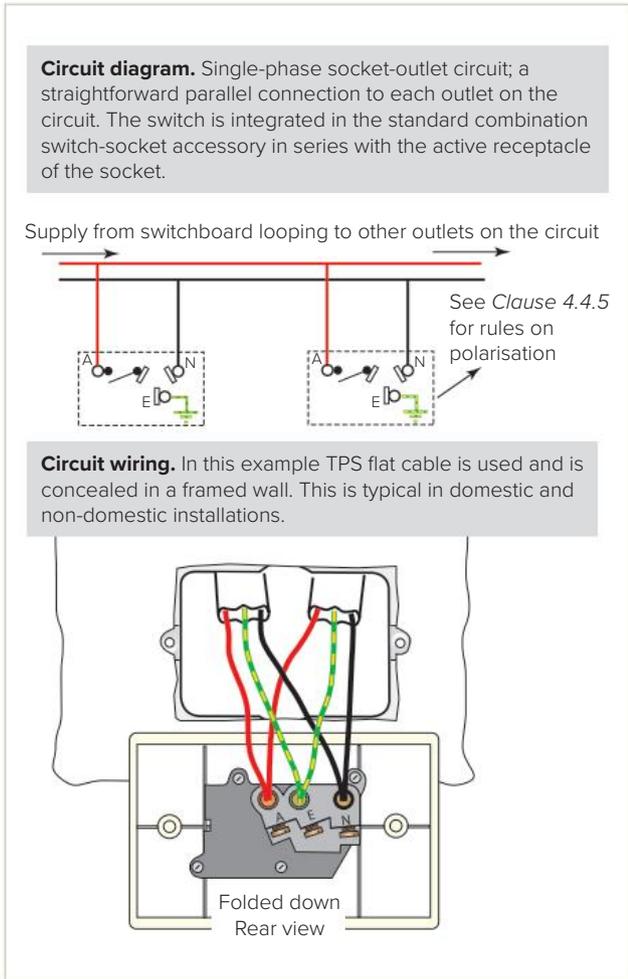


FIGURE 5.11 Socket-outlet circuits

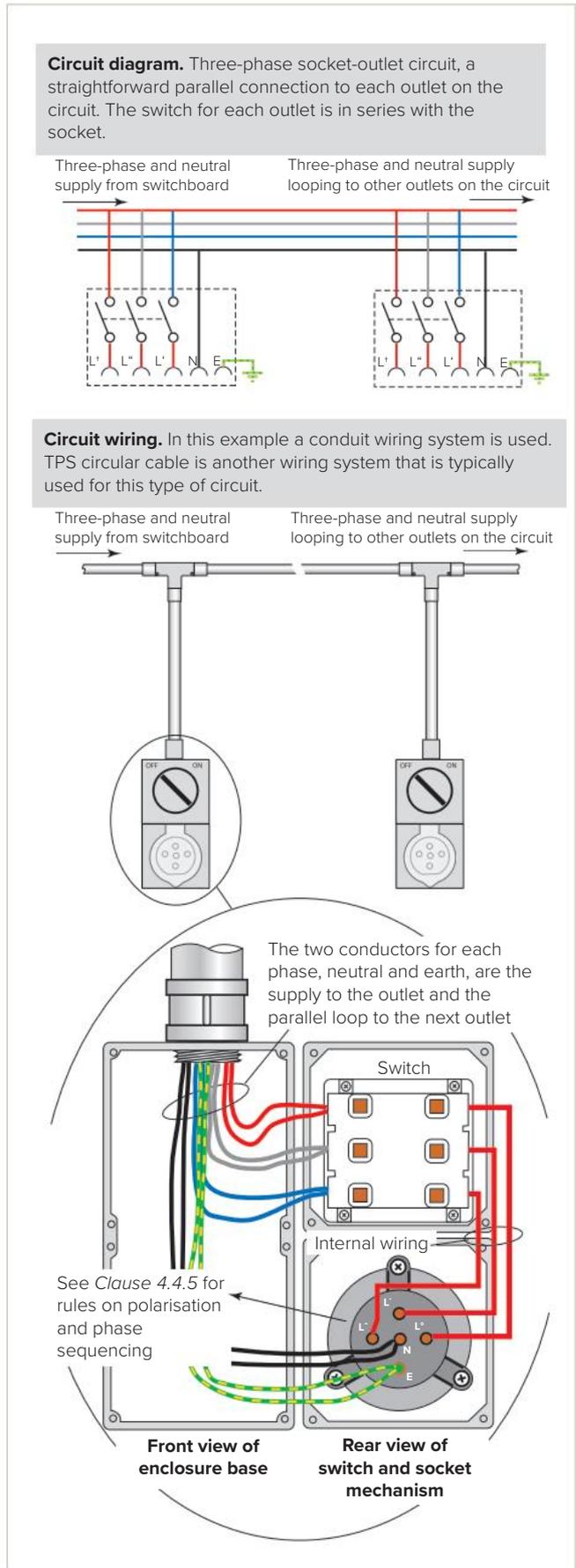


FIGURE 5.12 Three-phase socket-outlet circuits

A number of variations are permitted by *Clause 4.4.4.3* in the location of a switch controlling a socket-outlet, but generally the switch should be as close as practicable to the outlet and, if not obvious, permanently marked accordingly. This recognises the use of socket-outlets as a means of connecting a specific appliance such as an exhaust fan.

The wiring to one such outlet, using a loop-in method and a junction box respectively, is illustrated in **Figure 5.13**. The circuit is essentially the same as that used for the control of a light outlet or appliance from one position.

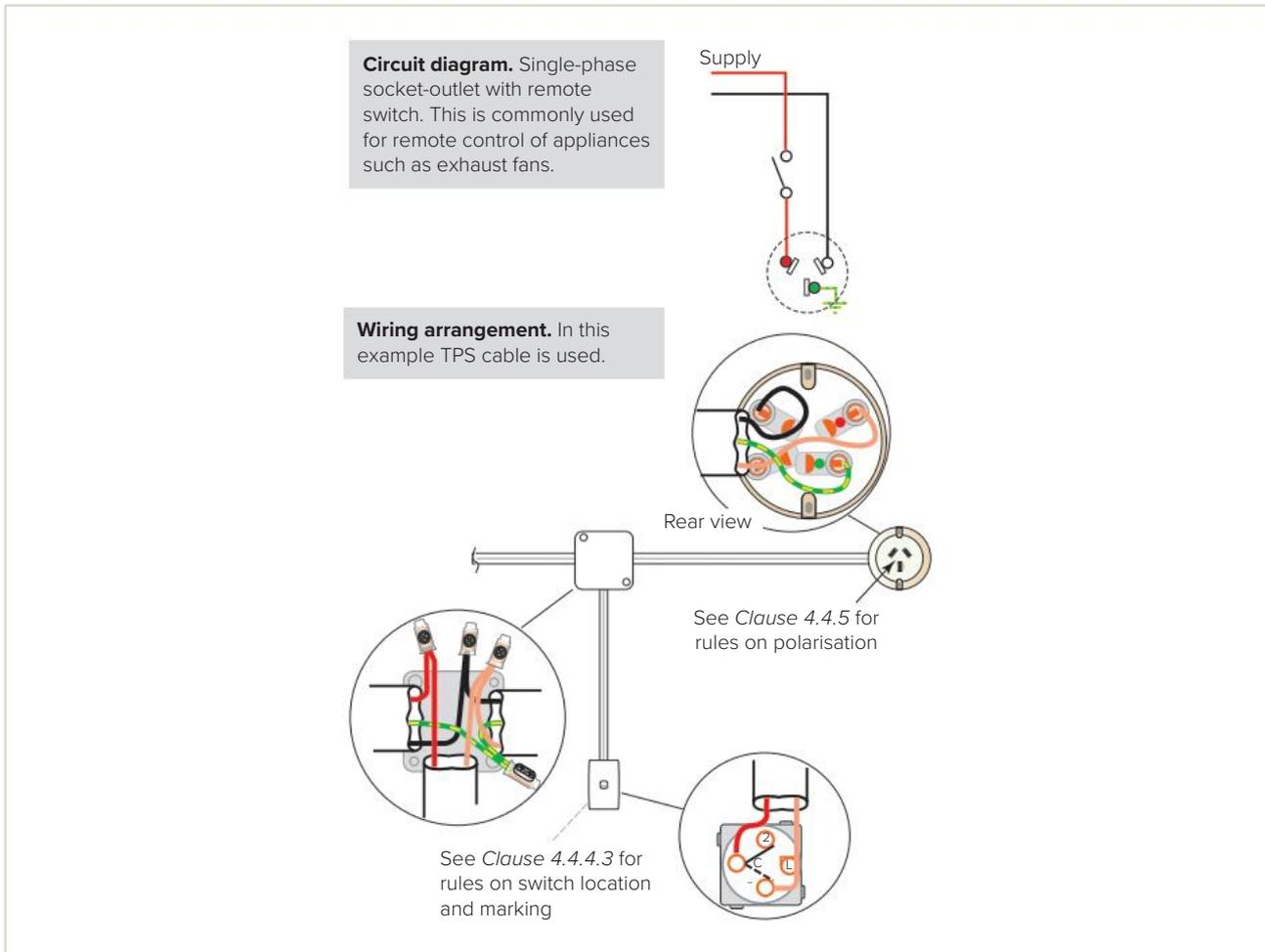


FIGURE 5.13 Remote switching of a socket-outlet

The conditions for switching a neutral conductor stipulated by *Clause 2.3.2.1.2(b)(ii)* are applied to the switching of pendant-type socket-outlets where both active and neutral conductors are required to be open (*Clause 4.4.4.4* with exceptions to multiphase pendant-type socket-outlets); that is, a suitable double-pole switch must be used.

This chapter is necessarily limited in scope, being an introduction to wiring circuits, but the same principles are employed in all the diverse applications met in practice. If you understand these principles, they can be applied to any of the thousands of applications in an electrician's experience. The principles are universal.

5.3.3 Appliance circuits—circuit and wiring arrangements

While circuits supplying socket-outlets are often used to connect the small single-phase motors that are incorporated into appliances such as air-conditioners, washing machines, refrigerators and portable tools, larger appliances are usually supplied by a separate circuit. Remember that an *appliance* is a device other than a lamp that converts electricity into any other form of energy or changes electrical characteristics (*Clause 1.4.9*). By definition, electric heating equipment, motors, transformers, power supplies and the like are all appliances.

Installation of the wiring for appliances follows the same sequence as for other circuits, commencing at the switchboard and passing through a protection and control device to the appliance terminals.

Motor circuits

To understand the reasons for particular circuits and wiring arrangements, some background knowledge is needed, particularly in relation to motor circuits.

The wiring to motors usually entails a single run of wiring from the supply source either to an isolating switch adjacent to or on the motor, or to a starter or control panel. The wiring for a single-phase motor will contain an active and neutral conductor, and for a three-phase motor, three actives. A neutral is not required for a three-phase motor because it is a balanced load. The number of wires from the starter or control panel to the motor will depend on the motor and starter types.

The device for switching motors is termed a *starter* and basically comprises: one or more contactors; a switch operated by an electromagnetic coil; and an overload device to prevent overheating of the motor (*Clause 4.13.3*). The starter includes a control circuit with start and stop buttons, as shown in **Figure 5.5**, or automatic controls.

A common method for starting three-phase induction motors is the *direct-on-line* (DOL) starter, in which the starter switches the motor directly to the supply. However, when switched directly to the supply, an electrical motor can draw up to seven or eight times its normal full load current. This is not a problem with smaller motors, but the starting current drawn by larger motors will cause the voltage in the local electrical distribution network to fluctuate enough to interfere with the effective operation of the installations of other consumers. For this reason, electricity distributors impose rules on consumer installations to limit the starting currents of motors over a given size. Consult local distributor service rules for specific requirements that apply in the area.

Reducing the voltage applied to the motor while starting is the general principle used in starters designed to limit starting current. The most common types are:

- ▶ the star–delta starter, which connects the motor in *star* mode at starting, reducing the voltage across each winding of the motor to the phase value, that is, 230 V for low-voltage-rated motors; when the motor has gained sufficient speed, the starter switches the motor to *delta* mode
- ▶ the autotransformer starter, which applies a reduced voltage to the motor windings at starting, then switches the motor directly to the line when sufficient speed is achieved
- ▶ the primary resistance starter, which operates on the same principle as the autotransformer starter but uses resistors in series with the motor windings to reduce the voltage at starting.

Although these starters reduce the starting current, they also reduce the starting torque (turning effort) to a point that may not overcome the inertia of the load at rest. The development of electronic power switching has helped to resolve this problem with the soft starter, which is in many instances replacing the other starters described above. The soft starter has the advantage of reducing starting current, controlling starting torque within the design limits of the motor and providing a smoother run-up and run-down (soft stopping) of the motor, which reduces wear and tear on mechanical components. The variable-speed drive provides similar performance, with the added advantage of being able to control running speed.

Some examples are shown in **Figure 5.14** and **Figure 5.15**.

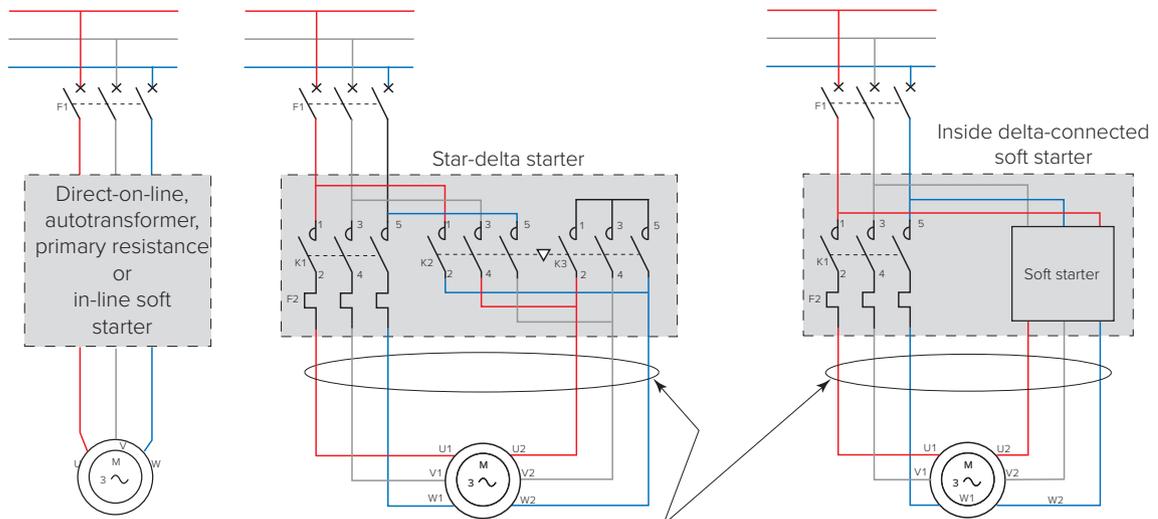
Other circuits not covered in this chapter are heating-control circuits and circuits relevant to community lighting control and light dimming. Metering and switchboard-wiring circuits (see **Chapter 14**), as well as circuits used in the installation of residual current devices (RCDs), are dealt with in **Chapter 13**.

Installation instructions

As well as the circuit and wiring diagrams, the other important diagrams used in electrical work are component assembly diagrams, which often accompany a manufacturer's installation instructions and service manual. Following an electrical equipment supplier/manufacturer's installation instructions is a fundamental requirement of the *Wiring Rules* (*Clause 1.7.2*). **Figure 5.16** shows an example of a manufacturer's installation instructions.

Circuit diagram

Several methods for switching three-phase induction motors.



Because the six conductors are carrying phase current of the delta-connected winding in the run position, the current-carrying capacity of the cable from the starter to the motor may be reduced, provided the requirements of *Clause 2.5.3.1* are met.

The inside delta connection of a soft starter has the advantage of reducing the rating of the switchgear to 58% of that needed for in-line connections.

Wiring arrangement

There are several methods of switching three-phase induction motors using circular TPS cable. Other suitable wiring systems are single-insulated cable in conduit or XPLE sheathed or SWA cable where additional mechanical protection is needed.

Direct-on-line, autotransformer, primary resistance or in-line soft starter

Star-delta starter or inside delta-connected soft starter

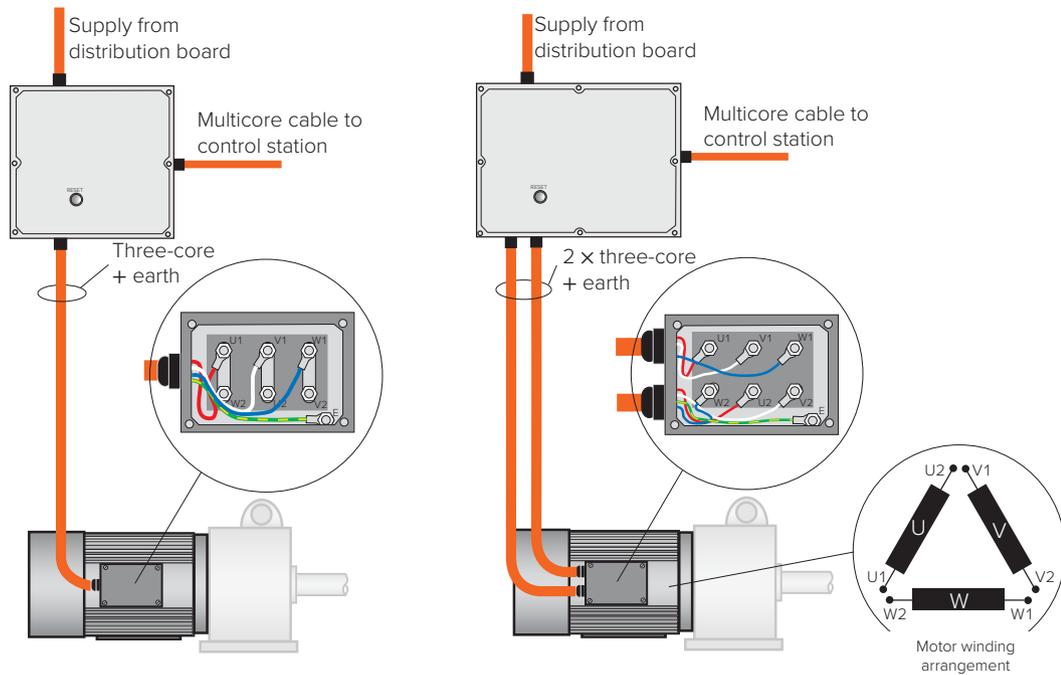


FIGURE 5.14 Examples of wiring for motors

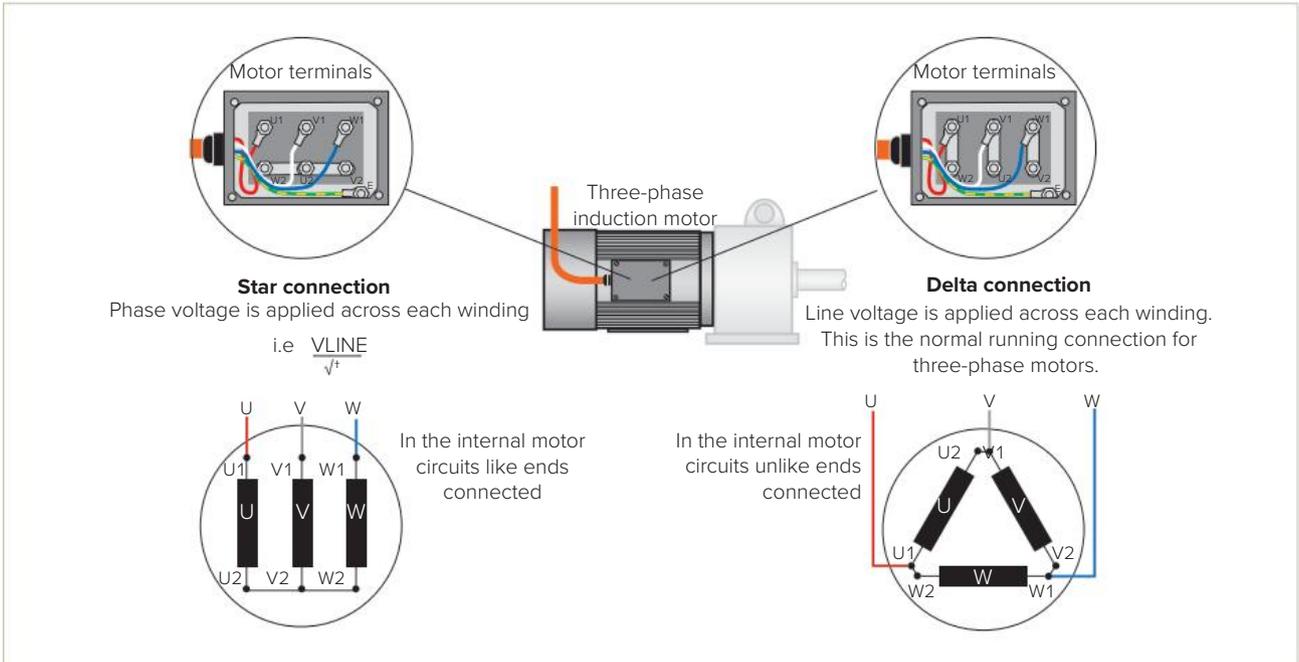
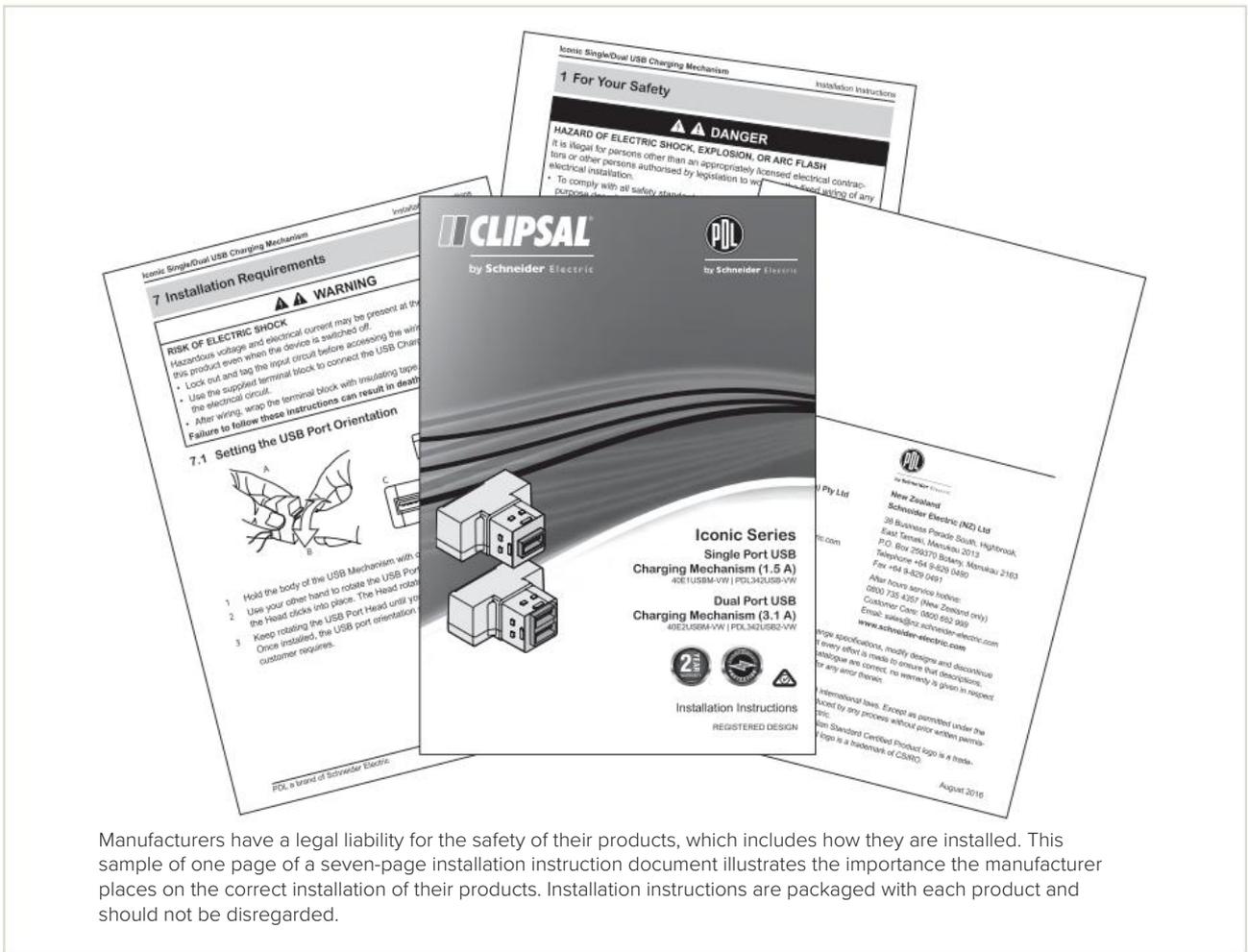


FIGURE 5.15 Comparison of star and delta connections



Manufacturers have a legal liability for the safety of their products, which includes how they are installed. This sample of one page of a seven-page installation instruction document illustrates the importance the manufacturer places on the correct installation of their products. Installation instructions are packaged with each product and should not be disregarded.

FIGURE 5.16 Example of a manufacturer's installation instructions

Schneider Electric



CAUTION

Irrespective of a specification, all electrical installations must comply with *Part 1 (Section) Scope, application and fundamental principles* of the *Wiring Rules*.



CHECK YOUR UNDERSTANDING

11. What clause in the *Wiring Rules* relates to the polarisation of socket-outlets?
12. In **Figure 5.13**, there are four multi positions for the lighting circuit. How many intermediate mechanisms would be required for a six-multi-position lighting circuit?
13. Apart from installation instructions, what other content is in a manufacturer's installation instructions document?

5.4 Undertaking electrical work

Electricians are called upon to undertake a variety of electrical work, including servicing and maintenance, attending to electrical breakdowns, making alterations or additions to existing installations and carrying out new installation work. No matter what type of work needs to be done, for it to be completed successfully there needs to be a business relationship between the electrical contractor and their client/customer. This is typically created through a contract between the parties that covers the scope of the work, its cost, the deadline for the work to be completed and how and when payment for the work is to be made. Within the contract, references are made to technical documents; that is, *specification* with *schedules* and *drawings*. These documents (see **Figure 5.17**) inform the electrician of the details of the work to be done.

The contract between the client/customer and the electrical contractor for the supply of service as described in the specification (and drawings) also includes terms of payment, indemnity, liquidated damages, maintenance period, extending of guarantees, and commencing and completion dates.

5.4.1 Specifications for electrical work

Figure 5.18 outlines the purpose of electrical specifications, how they are used and their typical content. Although a specification may apply to an installation, a maintenance program, a plant shut-down or any other contracted work, the focus here is on installation work. Mastering the use of specifications for installation jobs will equip you to handle specifications for most other kinds of work.

The level of detail of information given in a specification increases with the complexity of the work. For example, the specification for a small job—the renovation of a typical suburban house, say—may only consist of general instructions from the owner or builder. In such cases, it is important that the electrician obtains agreement on the location of lighting points and switches, socket-outlets and fixed appliances from the owner/builder and marks them up on a copy of the builder's plan. In the same way, the types of lighting control, general accessories and luminaires should be listed and signed as agreed to, before the work is commenced. The number of circuits, wiring systems, cable sizes, protection, switchboard arrangements etc. are left to the electrician to determine, remembering at all times that the installation must comply with the *Wiring Rules* and local service requirements. In larger and more

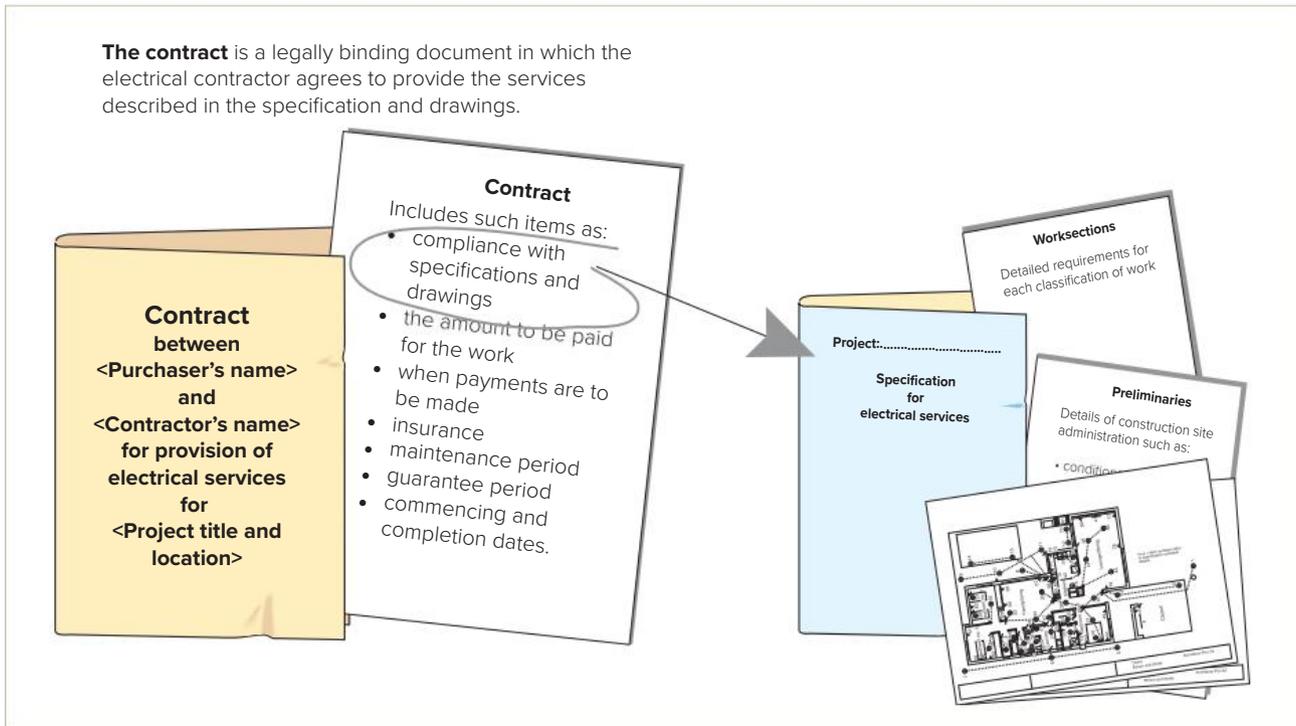


FIGURE 5.17 Documents in a contract to undertake electrical work

prestigious jobs, a specification is likely to detail the types of wiring and wiring methods to be employed, luminaires, types and positioning of accessories, number of circuits and the types of circuit protection needed.

As a general rule, for jobs where the electrical work is regarded as straightforward, such as domestic and smaller commercial installations, a specification is provided by the architect. For more complex work such as commercial and multiple-occupancy buildings, hospitals and schools, the specification is developed by a professional electrical engineer.

An industry specification such as one based on a NATSPEC (National Building Specification) template will not conflict with the requirements of the *Wiring Rules* or any other relevant standards but may restrict the choices that a standard allows. For example, a specification may require all cables to have copper conductors although the *Wiring Rules* allow the use of cables with aluminium conductors.

Most of the specifications you will deal with in your career will be based on the NATSPEC system. NATSPEC is a not-for-profit organisation owned by the design, building, construction and property industries through professional associations and government property groups. Its major function is the maintenance of the comprehensive national specification system that is endorsed by government and professional bodies.

NATSPEC provides templates covering every aspect of building, to assist architects and engineers in writing clear and concise specifications. They all follow a similar format and are written in plain English and carefully edited so that contractors do not waste time clarifying project requirements.

Figure 5.18 gives an overview of a specification, while **Table 5.1** provides part of a contract document that details some of the types of technical information given in a NATSPEC worksection template. Each project will have tailored content to meet its requirements and will include sections like products, existing systems, switchboards, seismic considerations, accessories, certification and many more.

Schedules

A schedule is a tabulated list of equipment with columns for each item of relevant information about the equipment, and often cross-referenced to the electrical drawings or included on the drawings themselves. Schedules are a convenient way of consolidating detailed information about the equipment involved, assisting in estimating, planning and checking work completions. They may be incorporated in job drawings or the specification itself. Examples of the information given in various types of schedules are shown in **Figure 5.19**.

Electrical specifications

What is their purpose?

An electrical specification is a document that informs contractors wishing to undertake an electrical job details of the work as required by an owner, architect or engineer.

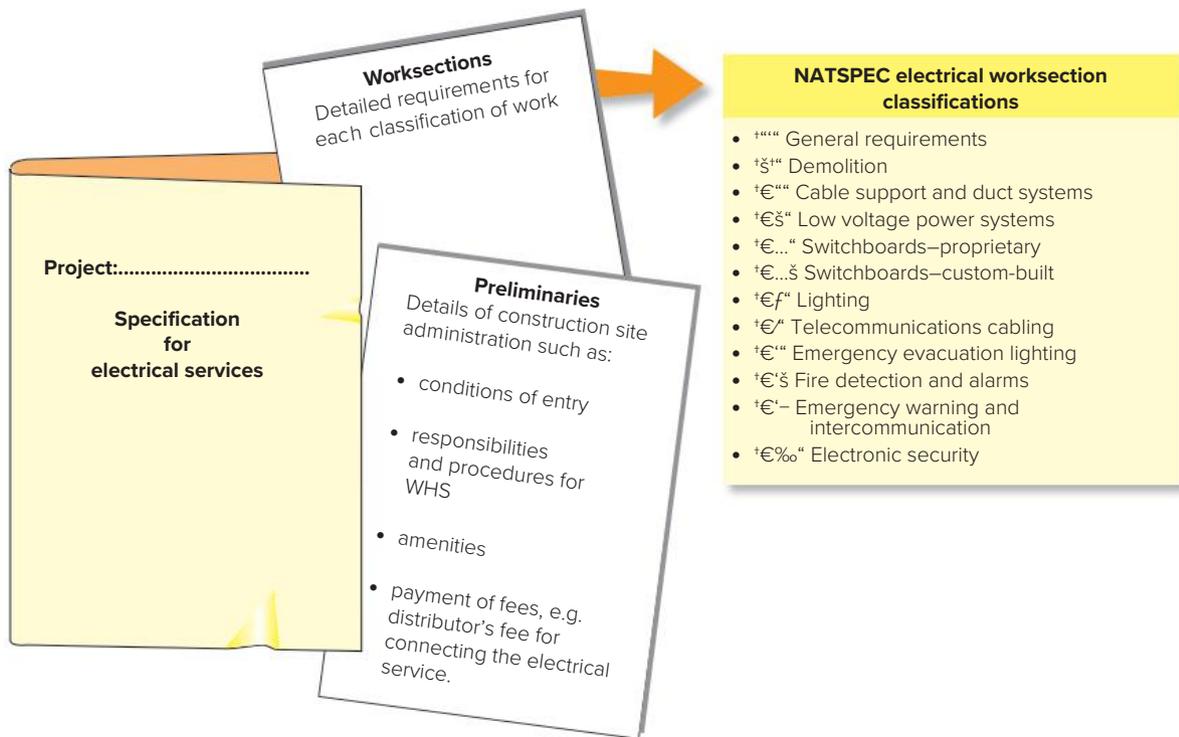
A specification may apply to:

- an electrical installation
- programmed maintenance
- plant shut-down
- any work carried out under a formal contract.

How are they used?

The specification:

- is the basis on which a quotation or tender, that is, the price to do the work, is submitted by an electrical contractor to a client/customer
- is named in a legally binding contract between a client/customer and the electrical contractor as the means of compliance for payments for the work as it is completed
- is used, together with drawings, in planning and managing the work, ordering materials and equipment and checking work completion.



NATSPEC electrical worksection classifications

- " General requirements
- " Demolition
- " Cable support and duct systems
- " Low voltage power systems
- "... Switchboards—proprietary
- "... Switchboards—custom-built
- " Lighting
- " Telecommunications cabling
- " Emergency evacuation lighting
- " Fire detection and alarms
- "— Emergency warning and intercommunication
- "% Electronic security

Notes on specifications

- Specifications are written in a format of sections and clauses similar to technical standards like the *Wiring Rules*.
- No two jobs are exactly the same, and although specifications may look the same, every specification is different.
- How detailed a specification is depends on the extent of the design brief given by the engineer or architect.
- No matter the amount of detail in a specification, there will always be some design aspect required by an electrical contractor.
- The worksections that appear in the specification will vary according to the type of project and the works required.
- Not all worksections listed above are included in a specification if they are either not included in a project or are subject to a separate contract.
- A worksection makes reference to other worksections on which it relies. For example, the worksection 'Cable support and duct systems' may rely on aspects of the 'Service trenching' worksection in a separate contract covering site works.
- A specification will not conflict with the requirements of the *Wiring Rules* or any other relevant standards.
- **Do not assume** that what is permitted by the *Wiring Rules* or any other relevant standard is permitted by a specification. A specification often restricts the choice permitted by a standard. For example, although non-metallic corrugated conduit is an acceptable enclosure under the *Wiring Rules*, a specification may not allow its use.
- To avoid costly rework—**before starting a job, read the specification.**

FIGURE 5.18 Overview of a specification

TABLE 5.1 Summary of the work sections in a specification

Sections	Types of information given in clauses and sub-clauses
General	1.1 Responsibilities Requirement: Provide the electrical services, as documented.
	1.2 Design Design for durability: Develop the design so the systems achieve the documented performance, reliability, service life, energy efficiency and safety requirements, and are easily maintainable.
	1.3 Precedence The requirements of other worksections of the specification override conflicting requirements of this worksection. The requirements of worksections override conflicting requirements of their referenced documents. The requirements of the referenced documents are minimum requirements.
	1.4 Cross-references Conform to the requirements as detailed within the document to ensure that other requirements of the project are undertaken.
	1.5 Standards Requirement: To <i>AS/NZS 3000</i> , unless otherwise documented.
	1.6 Contracts documents Conform to the 0171 General requirements worksection.
	1.7 Submission Submit certification that the plant and equipment submitted meets the requirements and capacities of the contract documents except for departures that are identified in the submission.
	1.8 Inspections Conform to the 0171 General requirements worksection and any other additional inspections as detailed.
Products	2.1 <i>Electrical accessories</i> Responsibilities: Provide accessories as documented and to the requirements of low-voltage power systems. Proprietary equipment: If proprietary equipment is selected by the contractor, the requirements of this specification override the specifications inherent in the selection of a particular make and model of accessory. Uniformity: Provide all accessories and outlets located in close proximity of the same manufacture, size, finish and material.
Execution	3.1 <i>Work on existing systems</i> General: Decommission, isolate, demolish and remove from the site all existing redundant equipment including minor associated components that become redundant as a result of the demolition. Breaking down: Disassemble or cut up equipment where necessary to allow removal. Recovered materials: Recover all components associated with the listed items. Minimise damage during removal and deliver to the locations documented.
	3.2 <i>Switchboards</i> General: Fixing wall-mounted switchboards: Fix direct to wall framing for framed wall constructed walls and to masonry or concrete walls. Fixing floor/wall-mounted switchboards: Fix to floor plinths and direct wall framing for framed wall constructed walls and to masonry or concrete walls by suitable fasteners. Fixing floor-mounted island switchboards: Fix switchboard to floor plinths by suitable fasteners able to withstand seismic events nominated in the project documents.
	3.3 <i>Support of plant and equipment</i> Ground level: <ul style="list-style-type: none"> ▶ If the ground slope is $\geq 15^\circ$ or the area of the plant and equipment is extensive, obtain the advice of a professional engineer for the documentation of a suitable slab or platform. ▶ In all other cases, provide proprietary plastic or concrete supports installed with falls that achieve a raised, impervious and water-shedding bearing surface.

Accessories schedule

Component	Manufacturer and catalogue no.	Special requirements	Protection rating	Installation
Three-phase socket-outlets	<i>(To be submitted by contractor)</i>	Solvent resistant	IP 56	Surface mounted
Isolating switches for maintenance	<i>(To be submitted by contractor)</i>	Solvent resistant	IP 56	Surface mounted
Functional switches	<i>(To be submitted by contractor)</i>		NA	Flush mounted
Single-phase socket-outlets	<i>(To be submitted by contractor)</i>		NA	Flush mounted

Lighting types and illumination schedule

The type of information in this schedule is becoming more common with the adoption of energy efficiency regulations in building design. Contract progress and final payments are test results showing compliance with the specified requirements.

Area	Efficiency (w/m ²)	Type	Illumination (lux)	Completion test (lux)
Lobby	10	LED downlights	150	<i>(To be completed by the contractor)</i>
Main office	10	LED recessed office lighting	— TM	<i>(To be completed by the contractor)</i>
Board room	10	LED downlights	— TM	<i>(To be completed by the contractor)</i>
Plant rooms	10	LED high bay	250	<i>(To be completed by the contractor)</i>

Cable schedule

Cable schedules are often used in complex installations where many cables are installed and precise cable routes are to be followed such as installations for industrial plants.

Circuit	Cable	From	To (Drawing grid reference)	Route
Pump 1	SWA 16 mm ² four-core and earth	Load centre 1/1	6-C	Cable tray 1 and vertical unistrut support
Pump 2	SWA 16 mm ² four-core and earth	Load centre 1/2	—C	Cable tray 1 and vertical unistrut support
Roller drive	Symmetrical, copper-screened XPLE 35 mm ² four-core and earth	Load centre 1/3	—D	Cable tray 2 and vertical structural support
Blower	PVC circular 10 mm ² four-core and earth	Load centre 1/4	—A	Cable tray 1 and drop in surface-fixed steel conduit

FIGURE 5.19 Types of information given in schedules

5.4.2 Architectural electrical drawing plans

Architectural electrical drawings show detailed locations of electrical equipment in an installation. They include floor plans, with outlets, luminaires and control devices marked at their required locations using standardised symbols and building elevations, and sections that assist in planning cable routes. These may appear on the general drawings for small jobs but, as the size of a job or its complexity increases, it is customary to draw a special plan for each trade. Standard symbols used on electrical plans are generally based on *IEC 60617*. The Australian Standard symbols conform to those agreed on by the International Electrotechnical Commission (IEC). Despite this, there is often some variation between architects and engineers with regard to the use of symbols; if in doubt, cross-reference information in drawings with the specification and schedule. Examples of electrical plans are shown in **Figures 5.20 to 5.22**.

Building information modelling (BIM) is now commonly used for major projects. BIM is produced via intelligent 3D modelling software programs that allow the coordination of various building services and rely on data entry to produce working drawings. This has become a highly specialised field and it requires proprietary software.



CHECK YOUR UNDERSTANDING

14. What is the purpose of a contract between an electrical contractor and a client?
15. List the types of items covered in a contract.
16. What is the purpose of a specification?
17. Why are schedules used in a specification?
18. List the types of information given in a typical lighting schedule for an installation.

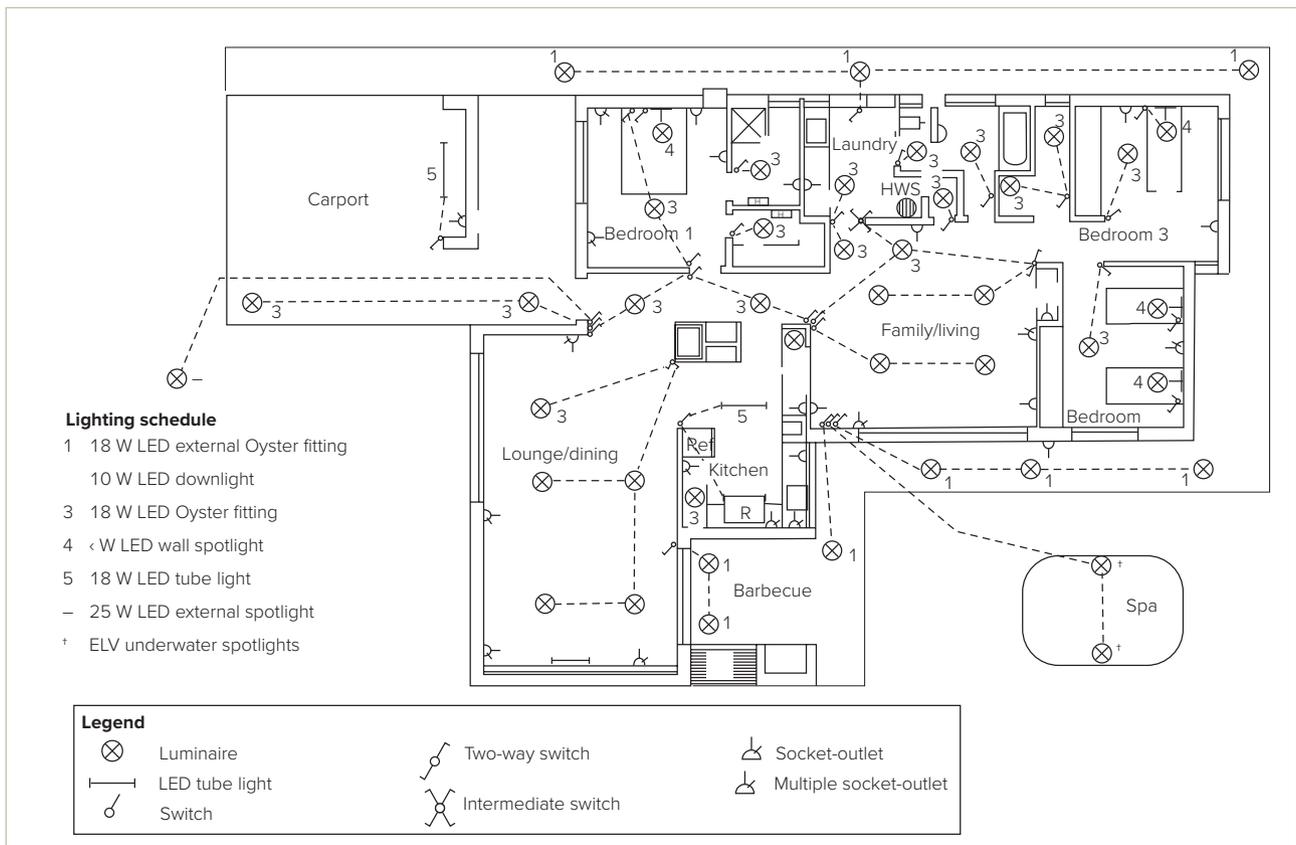


FIGURE 5.20 Architectural electrical plan of a domestic installation

In drawings for larger and complex installations the locations and arrangements for lighting, power and other electrotechnology services are usually shown on separate diagrams so that the information they convey is clearly presented. In addition it is becoming more common to switch and control lighting through integrated systems. These systems use a proprietary information bus, similar to a computer network, and microprocessor-equipped devices to manage energy use. For

example, the fluorescent luminaires in the layout below are likely to be equipped with digital addressable lighting interface (DALI) ballasts. They enable light output from each luminaire to be automatically controlled to maintain a constant light level which can be overridden by manual switch arrangements. For these types of installations there are likely to be separate layout drawings and schedules for lighting, integrated system equipment, power and emergency services.

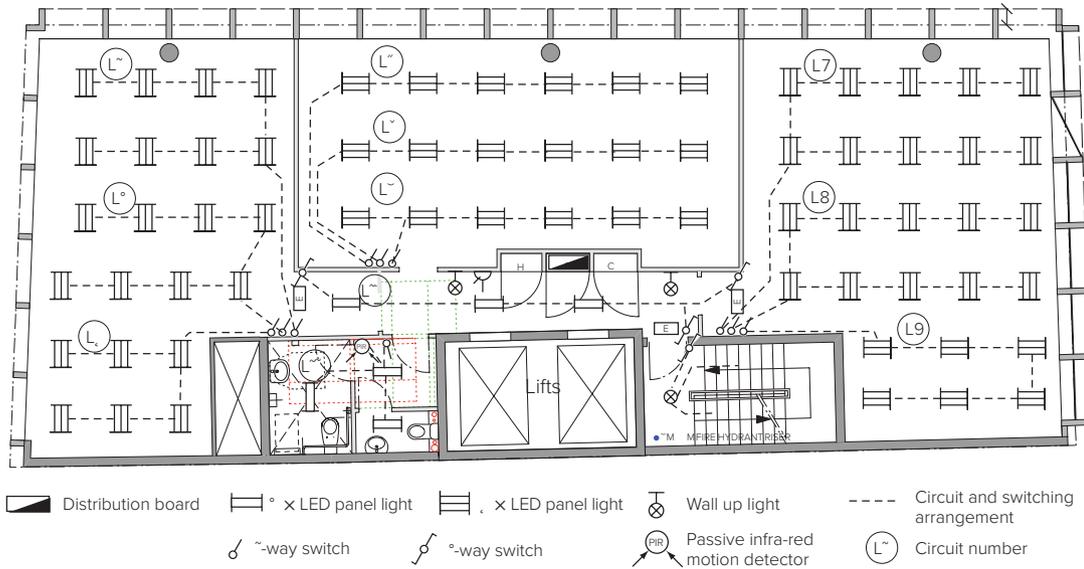
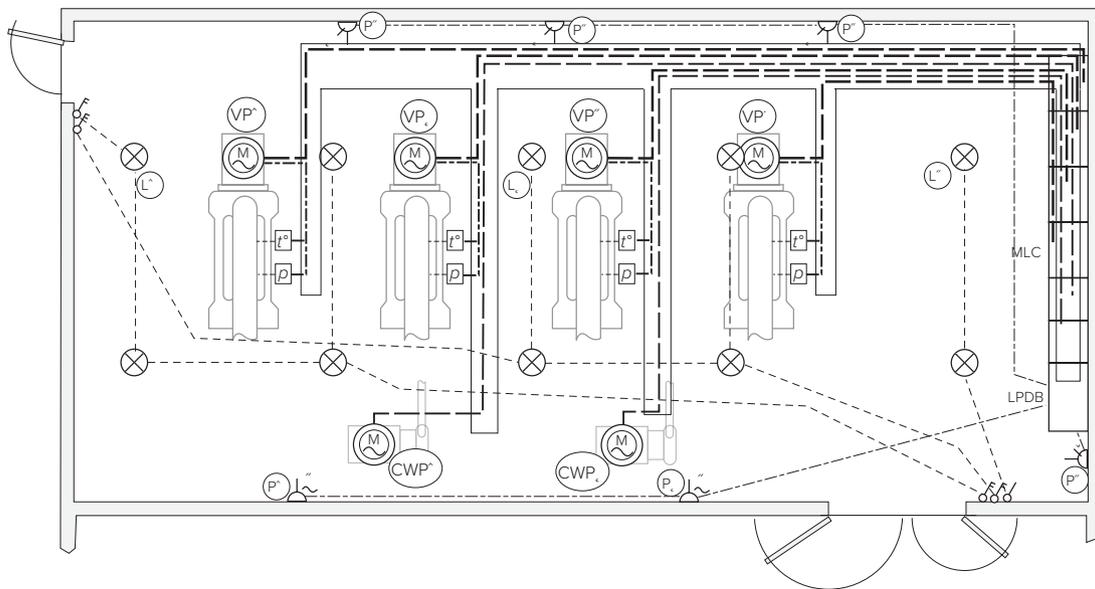


FIGURE 5.21 Architectural electrical plan of a commercial installation



Apparatus	Cable	Support/protection	
Vacuum pump power and control	<ul style="list-style-type: none"> × C + E 70 mm² R-HF-70 sheathed cable × C + E 70 mm² R-HF-70 sheathed cable 	Cable ladder	MLC Motor load centre
Cooling water pumps	<ul style="list-style-type: none"> × C + E 70 mm² R-HF-70 sheathed cable 	Cable ladder	LPDB Light and power distribution board
Vacuum pump local controls	<ul style="list-style-type: none"> × C 70 mm² R-HF-70 sheathed cable 	Cable ladder	VP Vacuum pump
Light and power	<ul style="list-style-type: none"> 70 mm insulated cables and earth 	HFT conduit	CWP Cooling water pump
			L Light circuit
			P Power circuit
			⊗ 70 W LED low bay pendant

FIGURE 5.22 Architectural/engineer's electrical plan of a plant room

5.5 Working with specifications, schedules and drawings

At some point in your career, you may choose to move into job supervision, leading to project management or estimating and tender preparation, where you will work more closely with specifications. However, the most immediate use of specifications for a person in training is extracting information as a start to learning to plan an installation. You will probably start with a small component of an installation, say, the installation of a final subcircuit. Initially this will require the compiling of a materials list.

In planning an installation and compiling a materials list, the correct interpretation of the plans, specifications and/or schedules is of fundamental importance. You must be familiar with the standard symbols used in plans; any non-standardised ones should be contained in a legend on the plan itself.

CAUTION

In extracting information, the following points should be kept in mind:

- ▶ Read the specification carefully and critically for the scope of work it covers, the compliance standards and codes with which the installation is to conform and other work in the project that may affect the electrical installation work.
- ▶ Check for requirements that restrict or prevent things otherwise permitted by standards.
- ▶ The specifications and drawings together should provide complete information on the services to be installed, so read the specification in conjunction with the drawings to check that they are complementary to the plans of the building.
- ▶ The space allocated for switchboards is sometimes inadequate and, in such cases, this must be resolved in consultation with the architect or engineer. Note that the location of switchboards and access must comply with the requirements of the *Wiring Rules, Clause 2.10.2*.
- ▶ Electrical plans usually show only the approximate locations of light and power outlets and appliances. The mounting heights of switches and socket-outlets are usually given in the specification.
- ▶ Cable routes or route lengths of circuits are not usually indicated on site drawings, except for complex installations such as industrial plants. Where cable routes are shown, they are often cross-referenced with a cable schedule.
- ▶ To enable decisions about cable routes and lengths to be made, plans with elevations and/or sections of a building structure must be studied. The typical cable routes in a building should be checked for available space and access. For example, the space above a suspended ceiling will include fire-sprinkler piping, air-conditioning ducts and other services. This will have a bearing on the sequence of the electrical work with other trades to ensure reasonable access to install the necessary cables.
- ▶ Conduits for cables in reinforced concrete slabs and columns must be determined early as installing them requires working cooperatively with the trades preparing formwork and laying the reinforcing steel.
- ▶ A rough estimate of cable route lengths can be made by scaling off site drawings. Take care in using the scale shown on a drawing copy as it may not be the same size as the original.



CAUTION

Don't rely on memory—write it down. Even on small jobs, several weeks can pass between roughing in the wiring and fitting out. If the job is a renovation, the cable routes you would normally use in a new structure may not be accessible, often resulting in convoluted cable runs. A record in a job notebook and on a plan of what you intend to do and what you have done can save a lot of time and prevent costly mistakes.

5.5.1 Planning

As previously discussed, for small jobs, schedules, plans and specifications may not have been produced and, in these circumstances, equivalent information may be provided by means of sketches or notes made in consultation with the customer/client. Any verbal instructions should be written down and confirmed with the customer/client. The most important and essential factor, however, is a personal one: the electrician compiling the information must have adequate background experience of job procedures and requirements, and must be able to use creative thinking in order to visualise the best wiring layout and method of wiring to be employed. The electrician must also be able to plan a systematic approach to the work to ensure the efficient utilisation of labour and materials.

Figure 5.23 illustrates the case of a renovation of a 60-year-old ground-floor flat where the only formal documentation is an architectural plan.

Other aspects of planning are:

- ▶ identifying the work health and safety (WHS) procedures and safe work methods for the work
- ▶ deciding on the appropriate routes for cables
- ▶ sourcing the tools and equipment needed
- ▶ determining the number and skills of persons needed to complete the work in the given time.

Listing materials

Before a list of materials can be prepared, the electrician must be conversant with all the relevant requirements of the *Wiring Rules*, the local service rules and any special codes or regulations applicable to the installation. The electrician must be able to refer to an electrical schedule or its equivalent for a list of luminaires, appliances and outlets, and the plans and specifications or their equivalents must also be available. The principles involved in the preparation of a materials list for a small job or a large multistorey building are basically the same. They entail having adequate information on all job details and requirements to permit the systematic listing of data, which should follow an estimated flow pattern.

One logical pattern follows that of the electricity supply, as outlined below:

1. source of supply
2. consumer mains
3. main switchboard
4. submains and/or rising mains
5. distribution boards
6. final subcircuits:
 - (a) lighting
 - (b) power (socket-outlets)
 - (c) appliance circuits
7. any other special provisions.

If the electrician is responsible for the wiring of auxiliary services such as telephones, internal data and communications systems, public address systems and fire alarms, these might be similarly treated, commencing at the source of supply.

300 mm clearance under kitchen bench

- Job #106
 False ceiling in entry and bathroom
 300 mm underfloor clearance – builder to lift boards for access
 300 mm clearance under kitchen bench
 Wall lights and floodlight supplied by customer
 Main switchboard – 1 63A circuit breaker with surface enclosure
 DB-1 mainswitch, lights 1 x 16 A RCB/RCB, power 2 x 20 A RCD/RCB, range 1 x 25A MCB, hot water 1 x 20 A MCB
 1 x 11 module enclosure with earth and neutral bars
 1 x 4 gang switch
 1 x 2 gang switch
 2 x single switches
 5 x BC batten holders
 3 x 4 gang socket-outlets
 3 x 2 gang socket-outlets
 4 x single socket-outlets
 1 x 25 A appliance socket + plug
 2 x 75Ω TV sockets
 1 x 2 lamp heater/light
 1 x 150 mm ducted ceiling exhausts

- 12 x plaster brackets
- 2 x standard mounting flanges
- 15 m x 16 mm² T+E
- 100 m x 1.5 mm² T+E
- 100 m x 2.5 mm² T+E
- 12 m x 4.0 mm² T+E

Cables

Cable	From	To
L1 1.5 mm ² T+E	DB	LS1-4
L2 1.5 mm ² T+E	LS1	LP 1
L3 1.5 mm ² T+E	LP 1	LP 2
L4 1.5 mm ² T+E	LP2	LP 3
L5 1.5 mm ² T+E	LS 2	LP 6
L6 1.5 mm ² T+E	LS 3	LP 4
L7 1.5 mm ² T+E	LS3	LP 5
L8.1 2.5 mm ² T+E	LS 5	LP 7
L8.2 2.5 mm ² single	LS 5	LP 7
L9 1.5 mm ² T+E	DB	LS 6
L10 1.5 mm ² T+E	DB	LP 9
L11 1.5 mm ² T+E	DB	LP 8
L12 1.5 mm ² T+E	LS 1	LP 8
L13 1.5 mm ² T+E	LP 8	SA
L14 1.5 mm ² T+E	LP8	LP 10
L15 1.5 mm ² T+E	LP 10	LS 7

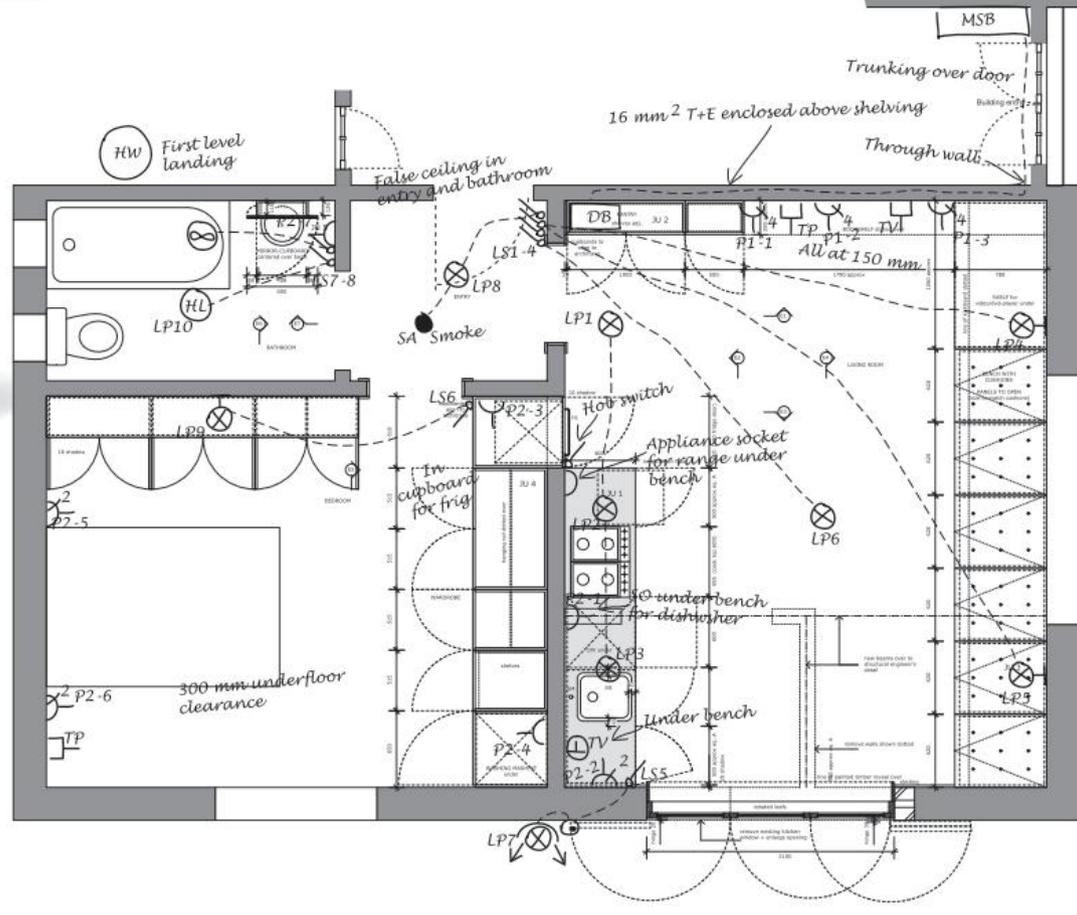


FIGURE 5.23 Example of preparation for a small installation job

The compiler of the list must be supplied with data sheets, plans, specifications, schedules and layout and/or circuit sketches giving an overview of the job procedure and work plan. The materials lists must include all materials, with the exception of sundry items of relatively low value such as screws, nails and clouts. These items are covered under an average estimate for each run and the total is listed under 'incidentals' or 'sundries'; otherwise, the time spent itemising these would cost more than the items themselves. This averaging technique can also be applied to items such as lighting circuits where, for example, the average length of switch feeds and the distance between outlets may be multiplied by the number of outlets to obtain a total for the circuit. This assumes that the outlets are reasonably uniformly spaced. The cable run from the subcircuit distribution board to the first outlet of the circuit must also be added and allowance must be made for any extra cable required, such as for two-way switching.

The materials or order list will be different from an estimator's materials take-off estimating form or pricing sheet, in that materials are arranged for delivery as they are needed. This is important in enabling a contracting business to maintain financial viability, particularly for projects that extend over periods of more than a month.

Installation design

It will become apparent when preparing a materials list which parts of the installation require some design by the electrical contractor. This can range from design of a simple switchboard layout to determining loadings on fixings to support heavy cables, demand and voltage-drop calculations for the selection of cables and protection devices and arrangements for control of the installation. The design required to be done by the electrical contractor will depend on the details given in a specification. You will learn more about installation design in **Chapter 16**.



CHECK YOUR UNDERSTANDING

19. Name two aspects of planning other than drawing up architectural plans.
20. List the required socket-outlets needed for the ground-floor flat in **Figure 5.23**.
21. When listing materials for a job what logical plan should be followed?
22. For the ground-floor flat in **Figure 5.23**, the main switchboard should be installed at what height?
23. What is not included in a materials list?

5.6 Use of software and mobile devices in electrical work

Electricians today have access to a multitude of software and mobile-based applications to assist with their day-to-day work. With the sheer number and variety of mobile apps available, and their ability to automatically update the information provided, computers have the potential to save the electrical contractor considerable amounts of time. They can improve the contractor's productivity, minimise errors and improve the flow of information required for the successful completion of projects (see **Figure 5.24**).



CAUTION

'Junk in' means 'junk out'

Software packages are available for managing and controlling all types of electrical work covering large, medium and small projects.

One of the purposes of this publication is to provide you with an understanding of the practices and compliance requirements that underlie the processes that these software programs provide. Like all computer programs, 'junk in' results in 'junk out'.

Programs for electrical design and tendering have been around for many years. However, over the past ~ years, with the increased capacity of computer hardware and proliferation of cloud-connected smart devices, these programs have become an indispensable tool in undertaking electrical work.

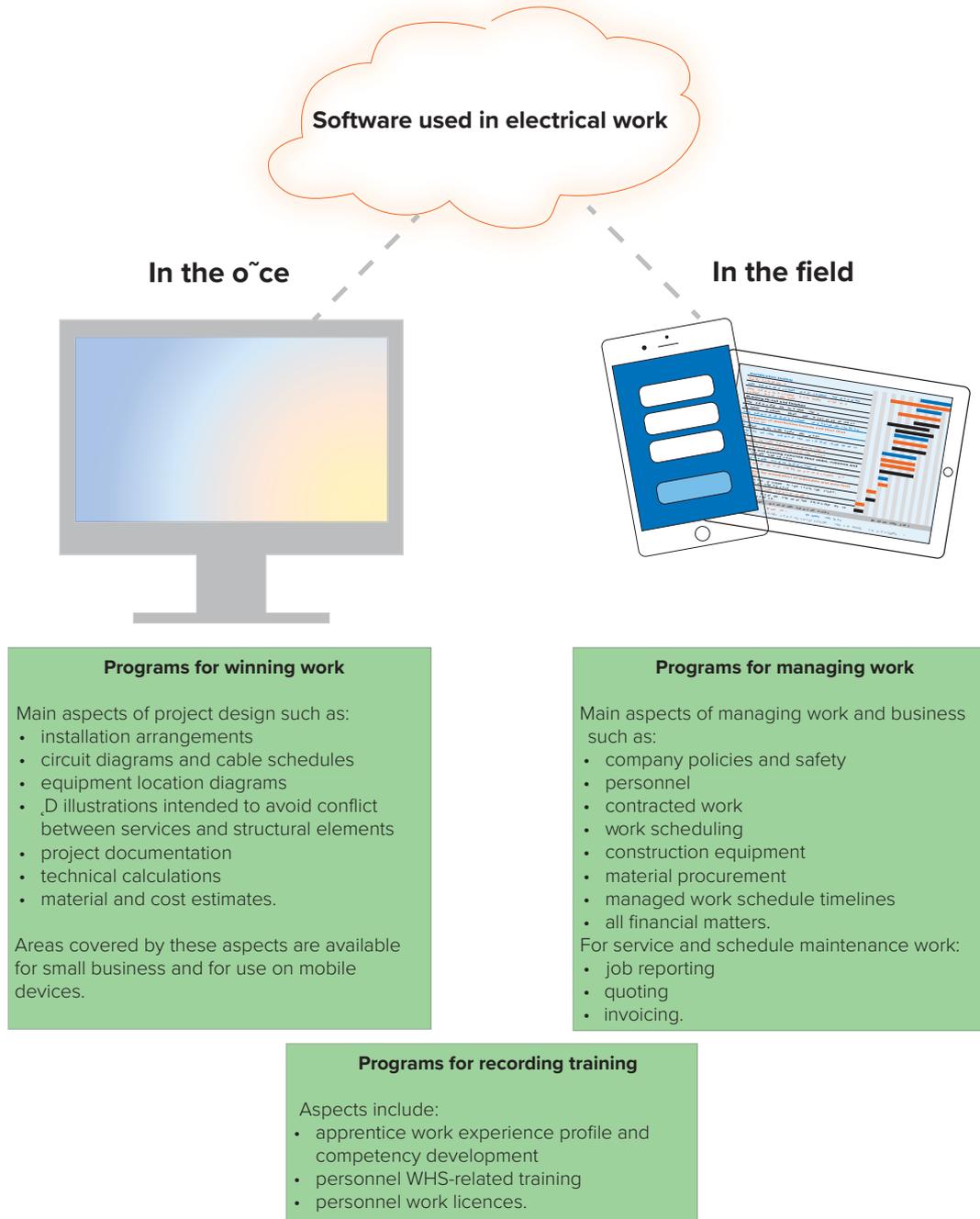


FIGURE 5.24 Software used in electrical work



CHECK YOUR UNDERSTANDING

- List two ways a computer program can help an electrical contractor.
- What type of programs could be used for service and schedule maintenance work in the electrical field?

SUMMARY

- ▶ All electrical circuits are made up of a source of energy, a protection device, a form of control and a load.
- ▶ There are two basic types of circuit connections: series, in which components are connected *end to end* and parallel, where components are connected *across* the same supply source and the voltage is the same value throughout the circuit.
- ▶ Types of electrical diagrams include circuit diagrams, wiring diagrams, single-line diagrams and block diagrams, and they are used for installation, maintenance and the diagnosis of faults.
- ▶ Types of circuits in an installation can include lighting, power, permanently connected appliances and distribution boards.
- ▶ Socket-outlets are connected in parallel and looped from point to point.
- ▶ Correct polarisation of socket-outlets is essential.
- ▶ Wiring of a single-phase motor contains an active and a neutral and three-phase motors contain three actives.
- ▶ Direct-on-line is a common method for starting three-phase induction motors.
- ▶ Use of the star-delta starter, autotransformer starter and primary resistance starter are common methods of reducing the starting current in motors.
- ▶ Manufacturers' installation instructions and service manuals are important documents in electrical work.
- ▶ A contract covers the scope of the work between the electrical contractor and their client/customer and can include terms of payment, indemnity, liquidated damages, maintenance period, extension of guarantees and commencing and completion dates.
- ▶ Specification for electrical work can apply to an installation, a maintenance program, a plant shut-down or any other contracted work.
- ▶ NATSPEC (National Building Specification) is a not-for-profit organisation providing templates covering every aspect of building—its templates will not conflict with the requirements of the *Wiring Rules* or any other relevant standards.
- ▶ Architectural electrical drawings show detailed locations of electrical equipment in an installation.
- ▶ Standard symbols used in electrical plans are based on *IEC 60617*.
- ▶ Understanding plans, specifications and/or scheduling and standard symbols can help with planning an installation and compiling a materials list.
- ▶ Electricians must be able to plan a systematic approach to work, to ensure the efficient utilisation of labour and materials.
- ▶ Before preparing a materials list, an electrician must be familiar with relevant standards, local service rules and any special codes or regulations, and they must follow a logical pattern when listing materials.
- ▶ Software and mobile devices are used by electricians in the office and in the field on a day-to-day basis to help improve productivity, minimise errors and improve the flow of information needed to complete a project.

REVIEW QUESTIONS

1. Draw a series circuit including a supply source, protective device, control switch and four lamps. Label the components.
2. With the aid of a sketch, describe the conventions for a symbol used to represent a normally closed contact and normally open push button.
3. How are switches and contacts usually drawn in circuit diagrams?

4. Explain what a block diagram is and what it is used for.
5. Complete the wiring diagram for an outside security floodlight shown in the circuit diagram in **Figure RQ5.2**. The wiring is to be in circular TPS cable with supply to the override switch located inside the building.

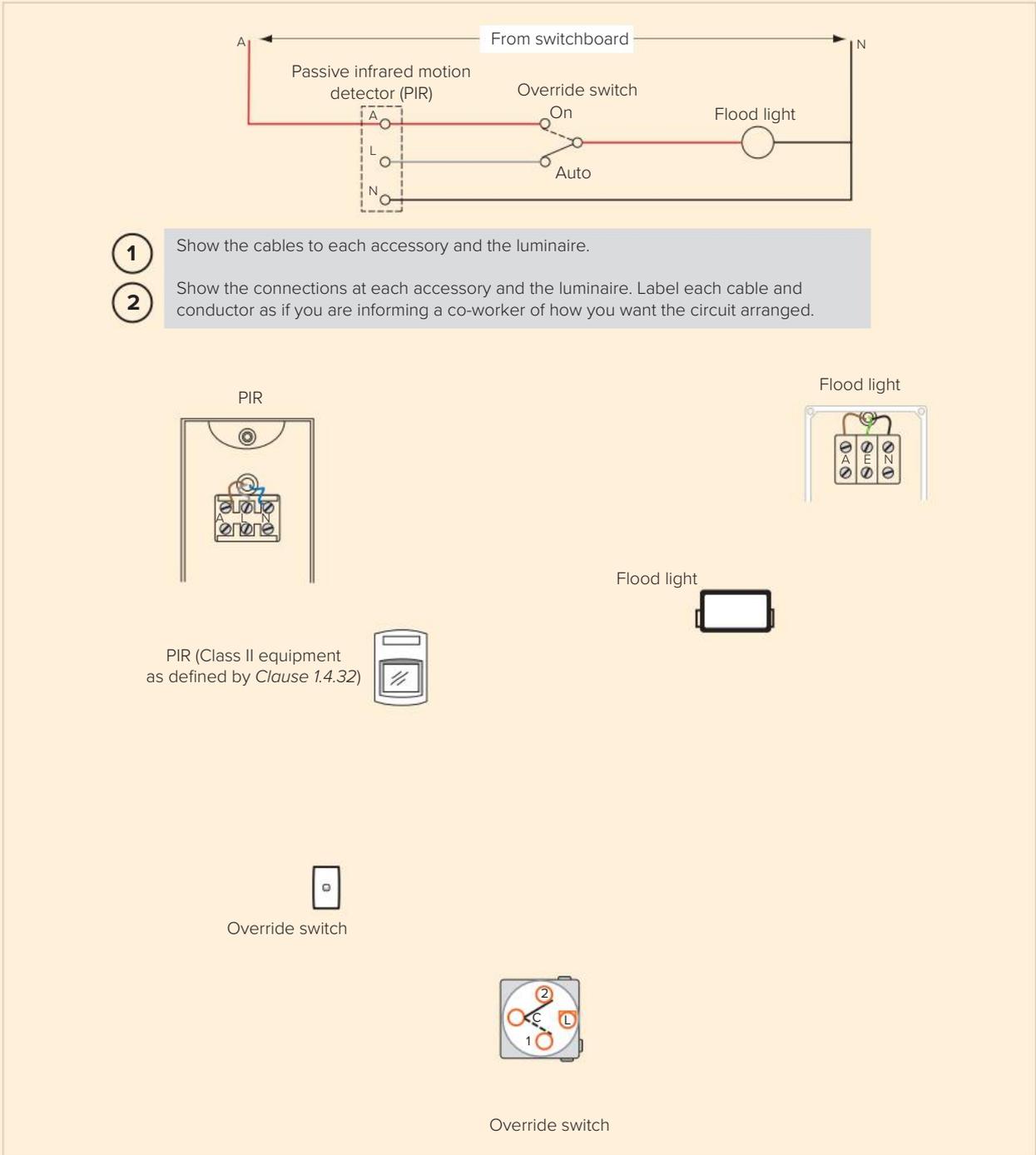


FIGURE RQ5.2

6. What clause specifies that a pendant-type socket-outlet attached to a flexible cord must interrupt all live conductors?
7. What is the importance of equipment supplier/manufacturers' installation instructions?

8. Label the electrical symbols in the three-phase delta-connected induction motor circuit shown in **Figure 5.14**.
9. How are specifications used?
10. Describe the format of a typical specification.
11. What information is included in the work sections of a typical specification?
12. In the cable schedule in **Figure 5.19**, the roller drive protective device can be found in which switchboard?
13. Describe the item represented by the location symbols shown in **Figure RQ5.3**.

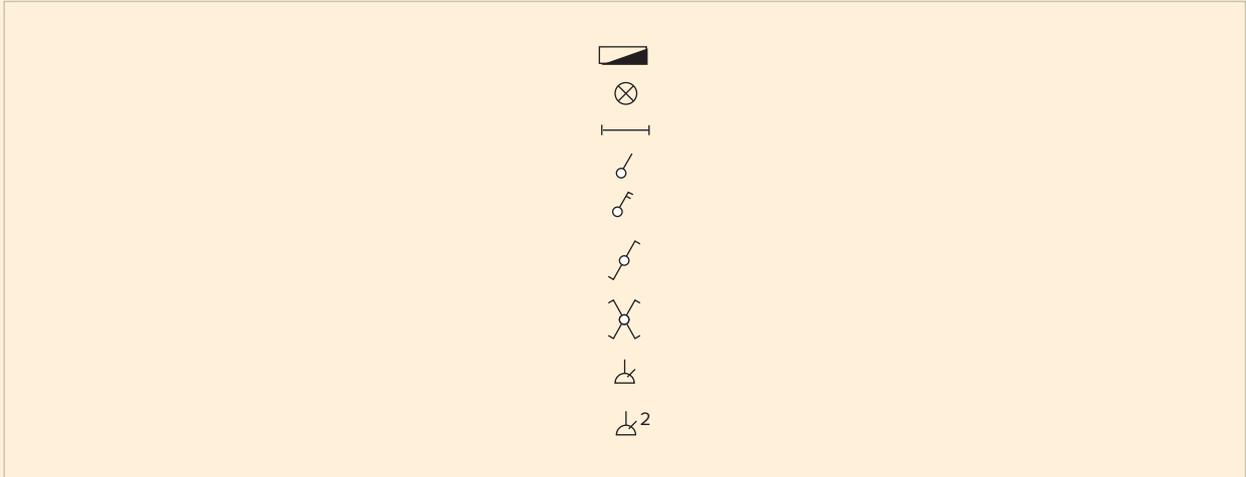
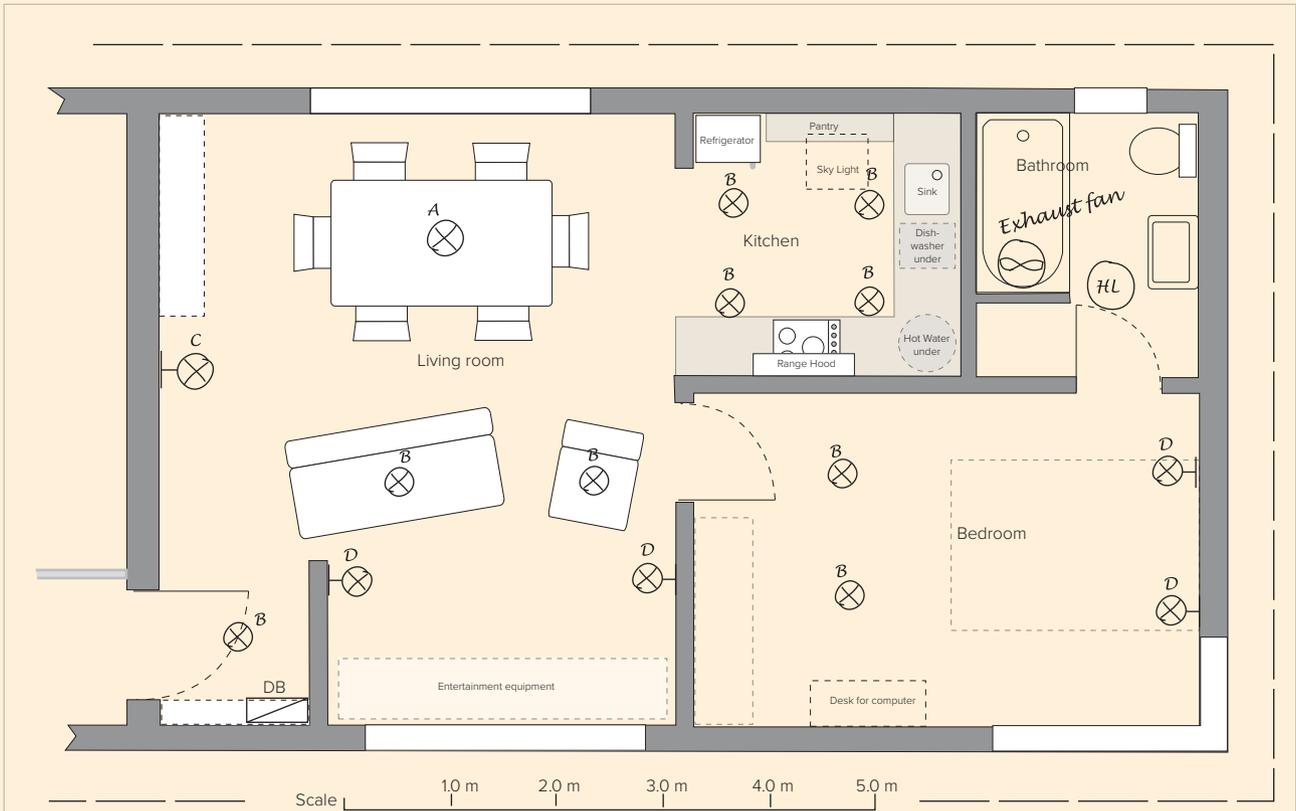


FIGURE RQ5.3

14. A builder has given you a drawing and basic specifications—see **Figure RQ5.4**—for a one-bedroom unit that is to be completely renovated. On the drawing, show the locations of the following items, using standard location symbols:
 - ▶ switches and the points they control
 - ▶ socket-outlets
 - ▶ telephone and communication outlets
 - ▶ TV outlets.

Tip: Think about the most likely and convenient locations for these items.
15. Compile a materials list for the installation in **Question 14**.
16. List two sundry items that would not be added to a materials list.
17. List two software programs that electrical contractors could use to help them win a contract.



Specification

The site

The unit is on the top floor of a two-storey unit block. The construction is full brick with a pitched tile roof and tiled concrete floors. There is access to the ceiling space above the unit. Ceiling height in the unit is 2.7 m.

Circuits

Half the number of light points and socket-outlets are to be distributed across each of two 16 A circuits.

Notes:

1. Socket-outlets are required for the refrigerator, dishwasher and range hood.
2. Check *Clause 6.2.4* for restrictions on socket-outlets, accessories and luminaires in bathrooms and near water containers.

The range is rated at 10 kW and is to be protected by a 25 A circuit-breaker.

Note: Check *Clause 4.7.1* for requirement for switching devices for cooking appliances.

The continuous water heater is rated at 3.6 kW and is to be protected by a 16 A circuit-breaker.

Cables

The submains are to be 16 mm² two-core and earth TPS. Route length to the main switchboard is 9.0 m.

Use *Table C6* in *Appendix C* of the *Wiring Rules* to select cables.

Notes:

1. Cable sizes are given in Column 1 of the table.
2. Protection device ratings are given in Column 3 as the most onerous conditions for this installation are 'In thermal insulation partly surrounded'.

Lighting schedule

A	Three-lamp pendant	Supplied by owner
B	Recessed compact fluorescent down light	Supplied by electrical contractor
C	Wall-mounted halogen up light	Supplied by owner
D	Wall-mounted compact fluorescent	Supplied by electrical contractor
HL	Heat lamp	Supplied by electrical contractor

FIGURE RQ5.4

CHAPTER 6

Fixing methods and accessories for electrical and data/communications installations

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ select the appropriate nails, screws or bolts for fixing accessories and equipment in a given electrical situation
- ▶ describe the principles of fasteners used to fix accessories to timber, metal, hollow structures and masonry and concrete surfaces
- ▶ select and install fixings, fasteners, mounting brackets, plates and boxes appropriate to a given electrical situation, and identify typical hazards and the relevant control measures
- ▶ describe the application of double-sided mounting tape and the limits of its use
- ▶ explain the principles of fasteners and types of tools and accessories used to drill, chase and secure fixings in masonry and concrete
- ▶ describe the *Wiring Rules* classifications and basic purposes of switching for control of an electrical installation
- ▶ identify and describe common switching accessories, lighting accessories, data and communication accessories and state where they are used in an installation
- ▶ describe the safety features of common socket-outlets and the importance of polarisation
- ▶ identify accessories used for protection against faults and overcurrent, and explain why they are used
- ▶ describe the system for rating electrical enclosures for the protection they provide against the intrusion of solids, objects, dust and water.

Except for switchboards, lamps and luminaires, all electrical equipment in an electrical installation is classified as either an accessory or an appliance, as defined by *Clauses 1.4.4* and *1.4.9*. Accordingly, if the energy-consuming devices (luminaires and appliances) are excluded, all the remaining pieces of equipment are classified as accessories.

Each type of wiring system is complete with its own particular accessories, and each appliance such as a motor, oven, furnace or luminaire requires control and protective equipment, all of which are classified as accessories. The functions of control and protection are repeated at the commencement of every circuit, including final subcircuits, submains and mains, at the switchboard and at the source of supply, thus requiring additional accessories.

Even the fasteners used for the support and fixing of accessories are themselves classified as accessories. What is more, the vast number and variety of accessories used in electrical installation work are constantly being added to via the development of new products and improved installation methods.

This chapter presents the common types of accessories by their purpose and application; however, there are many variations designed to cover most situations. You are encouraged to extend your knowledge of accessories through the many illustrated catalogues and the great range of trade literature provided by manufacturers.

Cable and conductor termination accessories are covered in **Chapter 7**, while accessories that form part of wiring systems are included in **Chapter 17**.



CAUTION

When selecting accessories

Make sure all equipment, including accessories, selected for an electrical installation are safe, in accordance with *Clause 1.7.3* of the *Wiring Rules*. The installing electrician may be required by the inspecting authority to provide evidence that the equipment does in fact comply with a recognised standard. Standards are listed in *Appendix A* of the *Wiring Rules*.

6.1 Accessories for fixing and support

6.1.1 Fixings and fasteners

Accessories are fixed to, or supported on, surfaces that are made of many different materials, such as timber, steel, sheet metal, concrete, brickwork and wallboards of various types, thicknesses and compositions. The surface conditions will vary and may be soft or hard, and dry, damp or wet.

Fixing might have to be permanent, or removal or replacement of the accessory might be possible. In addition, the finished appearance should be considered, together with the mechanical strength of the fixing method. All of these factors must be taken into consideration to ensure that the fixing used is generally suitable for the purpose.

Fixings and fasteners cover a vast array of available nails, screws, bolts and adaptive devices from wall plugs to chemical fixings. The proprietary names of a number of fixing and fastening devices have come into general use; for example, Rawlplug for a masonry wall plug and Dynabolt for a metal thread fixing into concrete. Although a tradesperson may prefer one brand of fixing to another, all employ similar techniques for each type of fixing. What is important is that the fixing must be:

- ▶ selected to suit the material it is to be used with
- ▶ able to support the weight to be exerted when it is in service
- ▶ installed correctly.

Basic nails and screws

Fixing to timber can be achieved by nailing or screwing; in practice, nail-type fixing is limited in use, due mainly to its permanent nature. Any type of nail fixing in mortar joints should be avoided. **Figure 6.1** shows nails commonly used in electrical work.

Wood screws find universal application for fixing accessories to timber and are available in various lengths, gauges and head shapes. Those most commonly used in electrical work are shown in **Figure 6.2**.

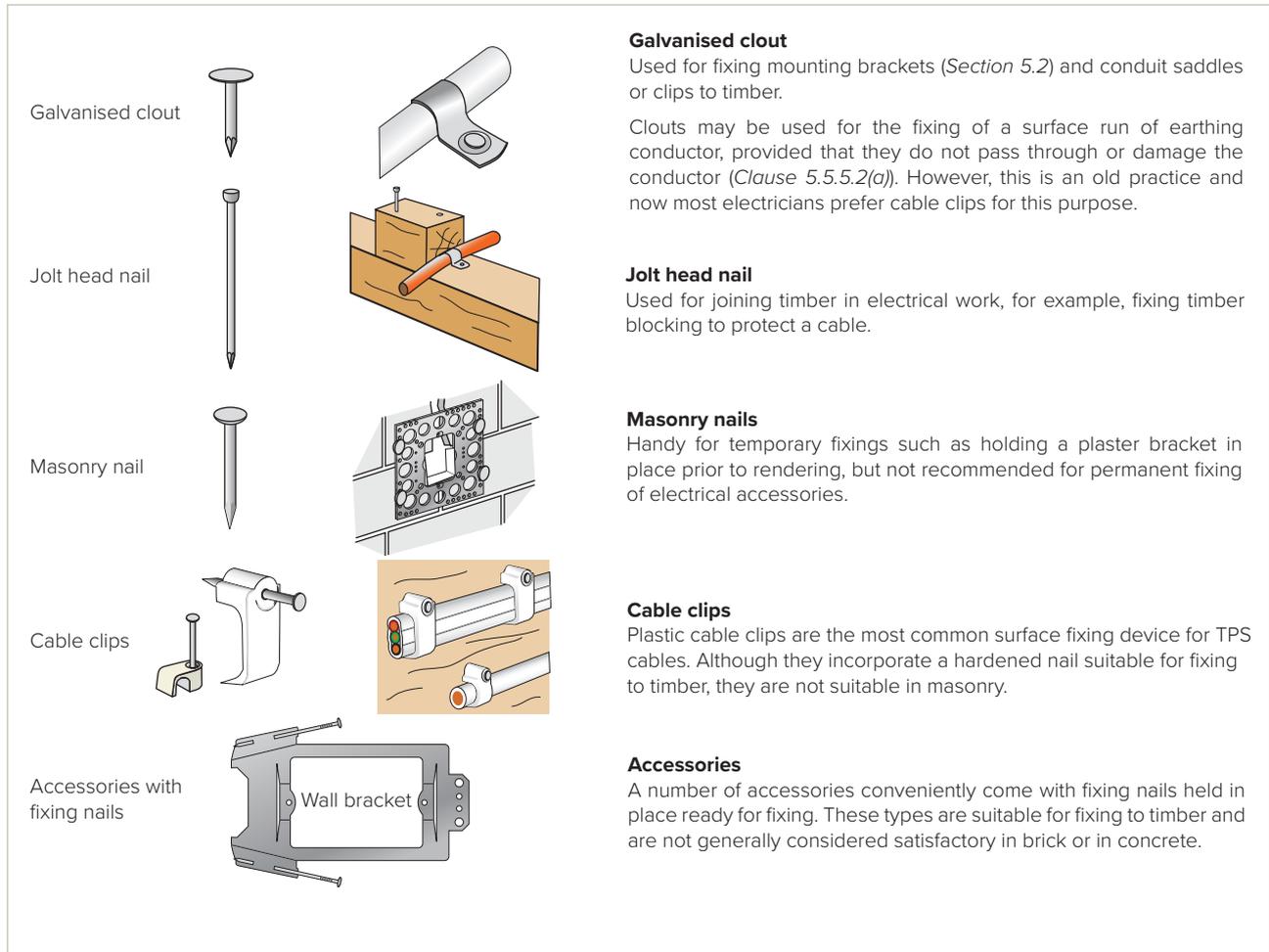


FIGURE 6.1 Nails commonly used in electrical work

Fixing to concrete and masonry

The specialised range of fixing accessories suitable for concrete, brick, stone and other similar materials is impressive; some are patented or of registered design, the most common being the plastic wall plug. In very old installations (pre-1950s) you may come across wooden plugs, usually cedar, driven into a neat hole in the masonry. A wood screw was then screwed into the plug, causing it to expand and grip firmly against the hole's sides. The principle of outward pressure on the sides of a tight-fitting hole in the masonry to secure a wooden plug is the same principle used today in all dry fixings in concrete and masonry (**Figure 6.3**). What has changed are the plug and anchor materials and design, and the tools and method for applying them. Examples of concrete and masonry fixings and how they are applied are shown in **Figures 6.4** and **6.5**.

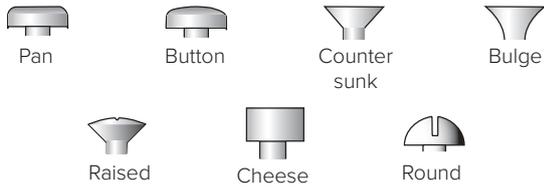
The adhesive method of fixing into masonry, particularly concrete, uses a two-part resin-based adhesive to secure an anchor rod, as shown in **Figure 6.6**. This method is particularly useful where the outward pressure exerted by the plug method might cause cracking of the masonry, for example near a corner.

An innovation in efficient fixing is the development of double-sided adhesive mounting tape. Suitable for the permanent fixing of lightweight accessories such as mini-trunking and labels, this tape is available for different surface textures and applications. Examples of how it is used are shown in **Figure 6.7**.

Fixing to hollow structures

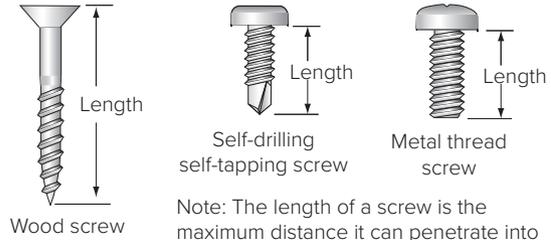
Fixing to hollow structures, such as wallboard fitted to timber or metal studs or hollow blockwork, uses a clamping principle. This is shown in **Figures 6.8** and **6.9** with examples of the most common types of screws.

Common screw heads



Those shown above are the most common screw head types found in electrical work. They are available as wood screws, self-tapping screws for sheet metal and metal thread screws. The round head screw is less commonly used and is available as a wood screw and metal thread screw up to 10 mm.

Common screw types and threads



Note: The length of a screw is the maximum distance it can penetrate into or through the material it secures.

Apart from head type, wood screws and self-tapping screws are described by their length and gauge (diameter), six and eight gauge being the most common in electrical work. Metal thread screws are described by their length, diameter and thread form. There are many thread forms but common to electrical work are metric fine and metric coarse. An anomaly is the screw that secures accessories such as socket-outlets to mounting bracket/blocks, which is an American wire gauge screw 6/32.

Although more expensive than the wood screw, the self-tapping screw, which was originally designed for metal, is often used and preferred by many electricians for general work. Advantages claimed are that, due to its hardened steel construction, it is more robust and easier to install and it is suitable for use on other materials in addition to wood and sheet metal, thus reducing the number of screw types needed to be held in stock.

Screw heads and drivers



Phillips

The Phillips screw is designed so when high torque is applied by the screwdriver it slips (or cams) out to prevent over-tightening.



Pozidriv®

The Pozidriv is similar to the Phillips but is designed not to slip out.



Combination (flat/Phillips)

The advantage to an electrician of a screw that accommodates both flat-blade and Phillips screwdrivers is applied to many common accessories such as cable connectors, socket-outlets, switches and conduit fittings.



Hexagon or Allen



Square or Robertson

Metal thread screws are mostly used for industrial accessories, appliance and mechanical assemblies. The square socket is common to explosion-protected accessories.



The matching screwdriver must be used with each screw head type and size if damage to the screw is to be avoided.

Special screws



Sentinel®

Cannot be removed



Tri-wing®

These screws require a special screwdriver



Torx®

These are typical metal thread screws used in appliances. The Sentinel was developed to stifle access and tampering by unauthorised persons. The Tri-wing and Torx were developed for production line assembly of appliances.



Hexagon head bolt

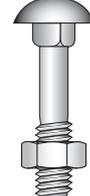


Nut

Screws and bolts are used in heavy-duty fixing and assembly of such items as switchboard modules, busbars and connections intended to carry high currents. Although there is no universally agreed definition, it is generally accepted that a bolt has a portion of unthreaded shaft.



Cup-head bolt



The cup-head bolt is used for fastenings in timber struts and poles for aerial wiring. The square section under the head bites into the timber, preventing the bolt from turning as the nut is tightened.



Flat washer

A flat washer placed between the nut and the work gives a greater bearing surface to the nut.



Spring washer

The spring washer prevents the nut from loosening by forcing the nut away, pressing it firmly against the thread.

FIGURE 6.2 Types of screws commonly used in electrical work

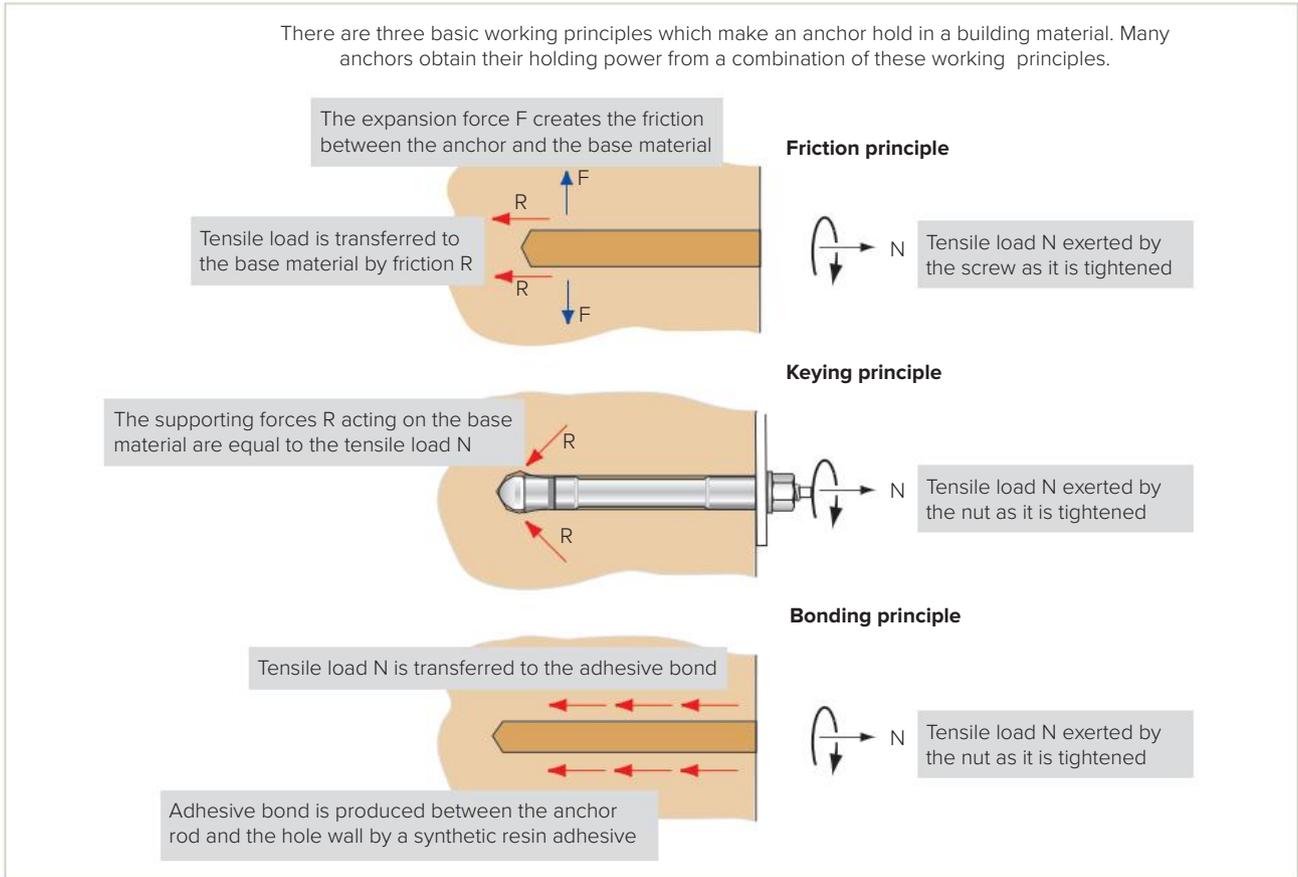


FIGURE 6.3 Three basic principles of fixing in concrete and masonry

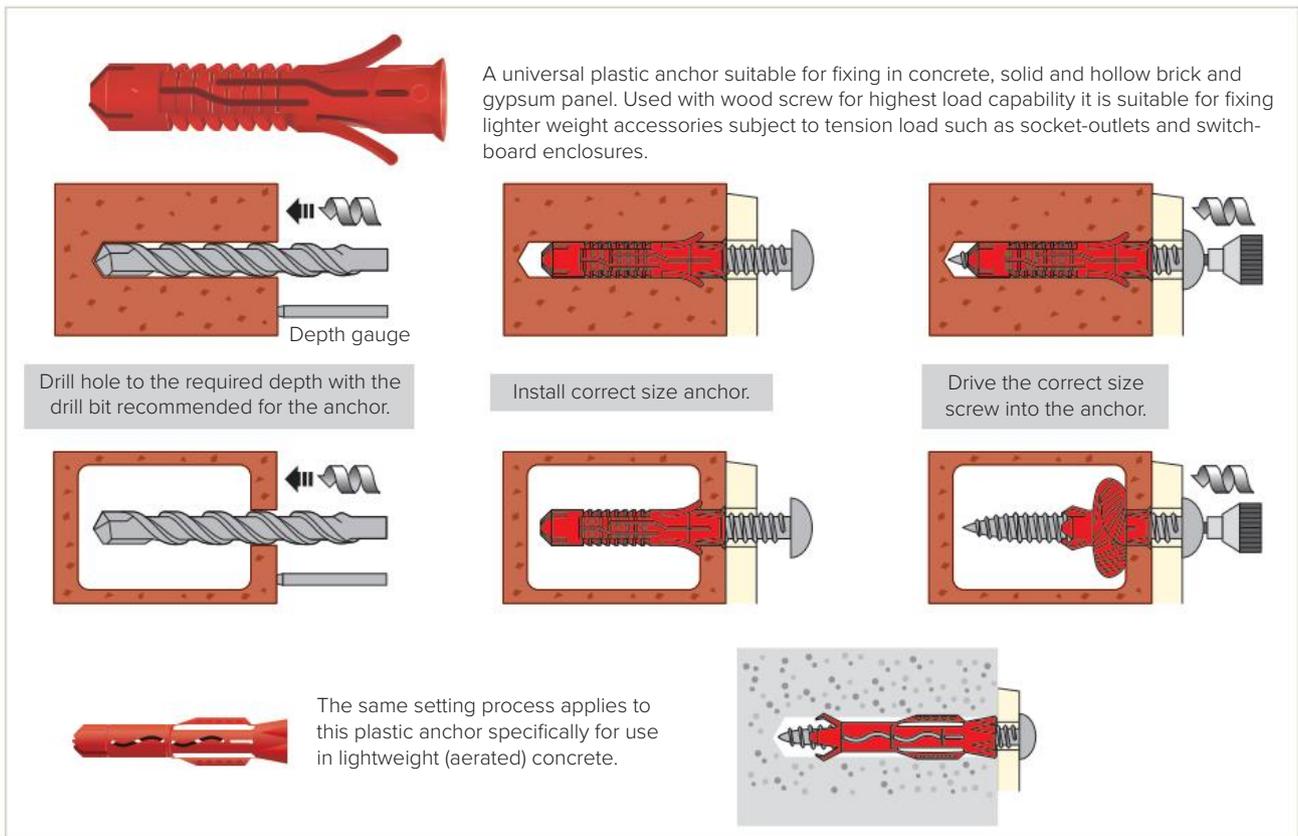


FIGURE 6.4 Setting a plastic anchor in masonry

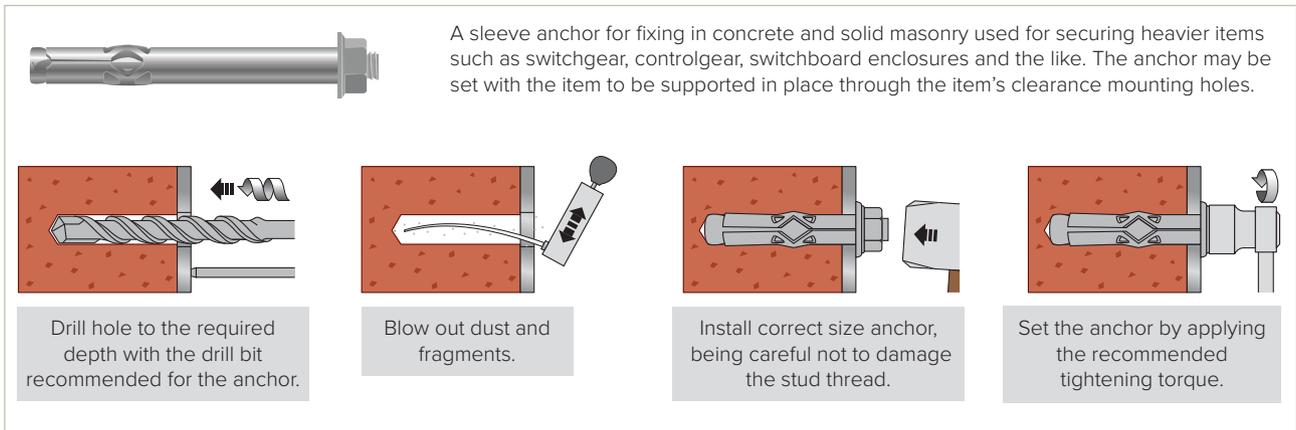


FIGURE 6.5 Setting a stud anchor in masonry

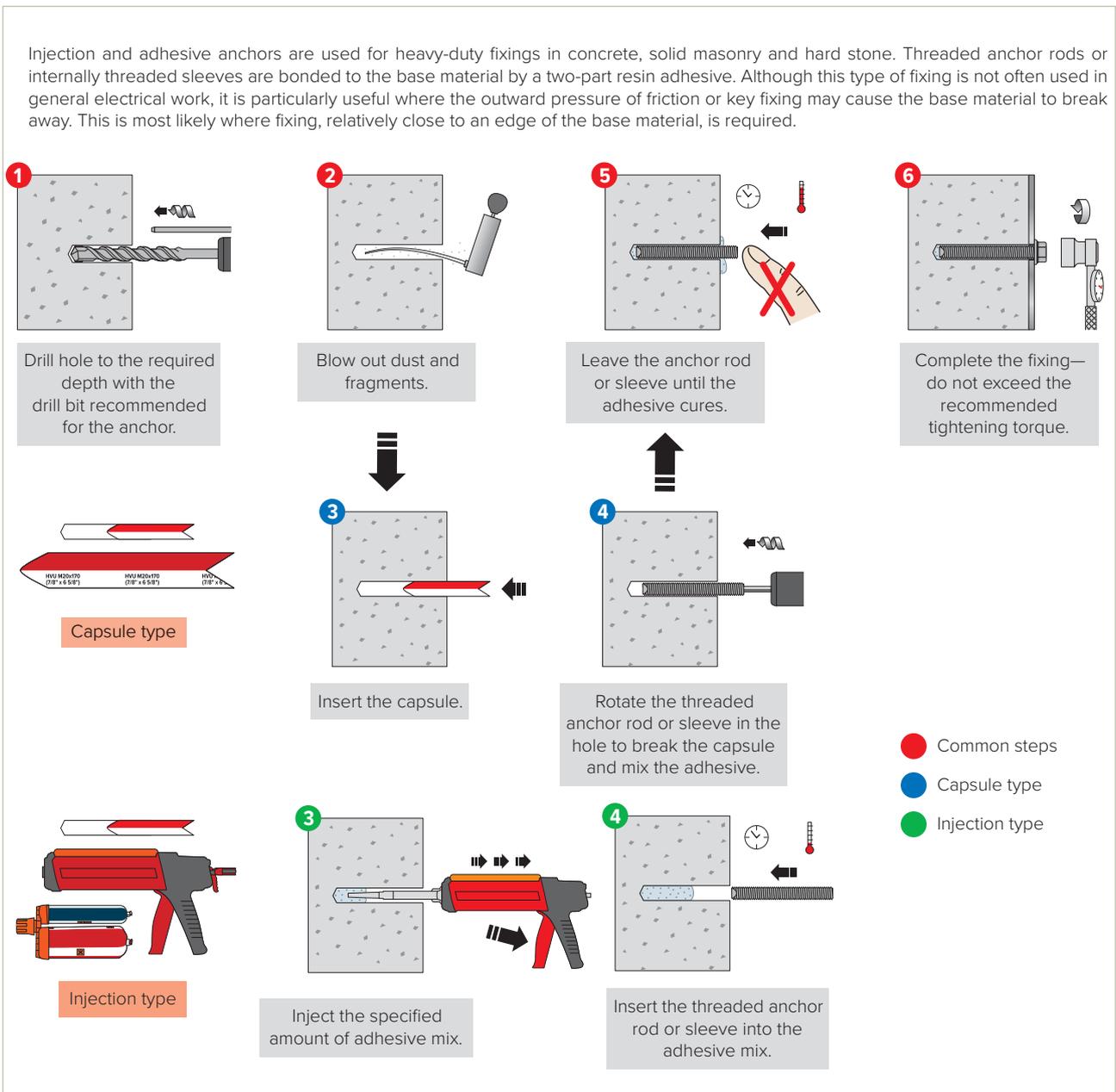


FIGURE 6.6 Setting an adhesive anchor in concrete

Another fixing product that falls into the category of adhesive or chemical methods is the industry standard double-sided tape. Shown here is mini trunking supplied with the tape ready for application. Care must be taken in assessing the suitability of the surface for the adhesive tape.

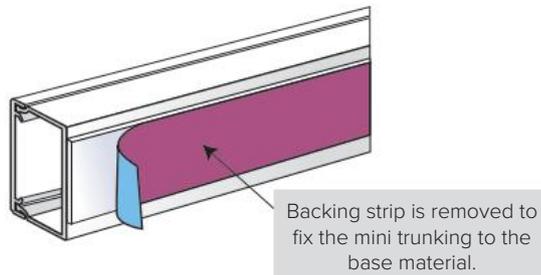


FIGURE 6.7 Applying double-sided adhesive mounting tape

There are a number of different types of anchors for fixing to hollow structures such as framing lined with plasterboard and hollow block walls. All these anchors are based on the same basic holding principle, shown here with a plastic toggle-type anchor.

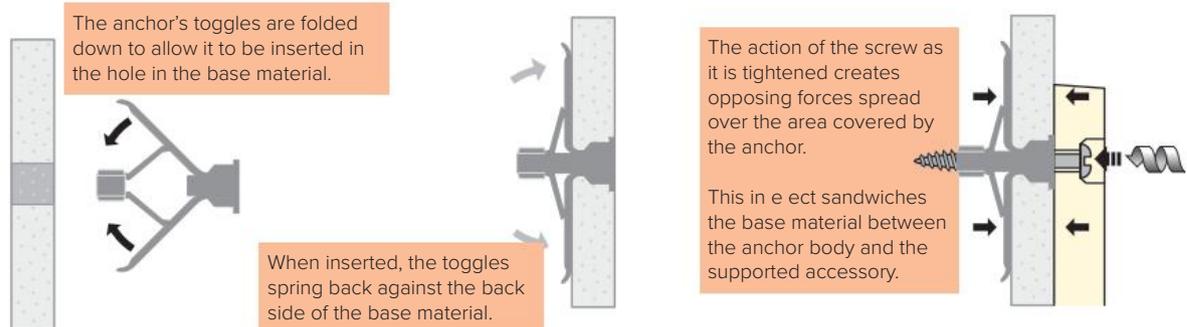


FIGURE 6.8 Principle of fixing to hollow structures

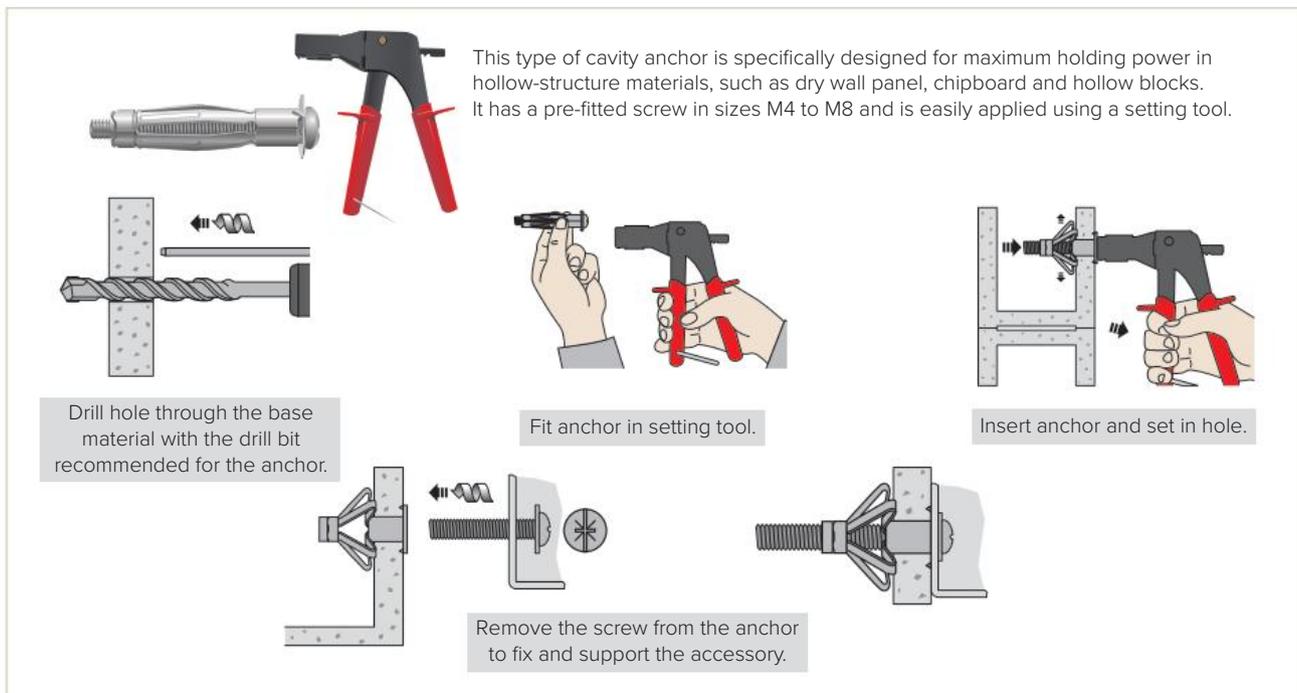


FIGURE 6.9 Fixing to hollow structures

6.1.2 Powder/gas fixing methods

A highly productive method of installing fixings is the use of percussion tools operated either by a powder, that is an explosive charge, or by a compressed gas. This method uses a special tool with a piston driven by a powder charge or compressed gas, which in turn drives a special type of nail, screw or stud into brick, concrete or even solid steel such as a structural steel beam (shown in **Figure 6.10**). This is particularly efficient where multiple fixings are required, such as for cable supports in concrete above suspended ceilings, and runs of conduit, cable tray and cable ladder. A certificate of competency for the operator of a powder-actuated tool is required in most jurisdictions.

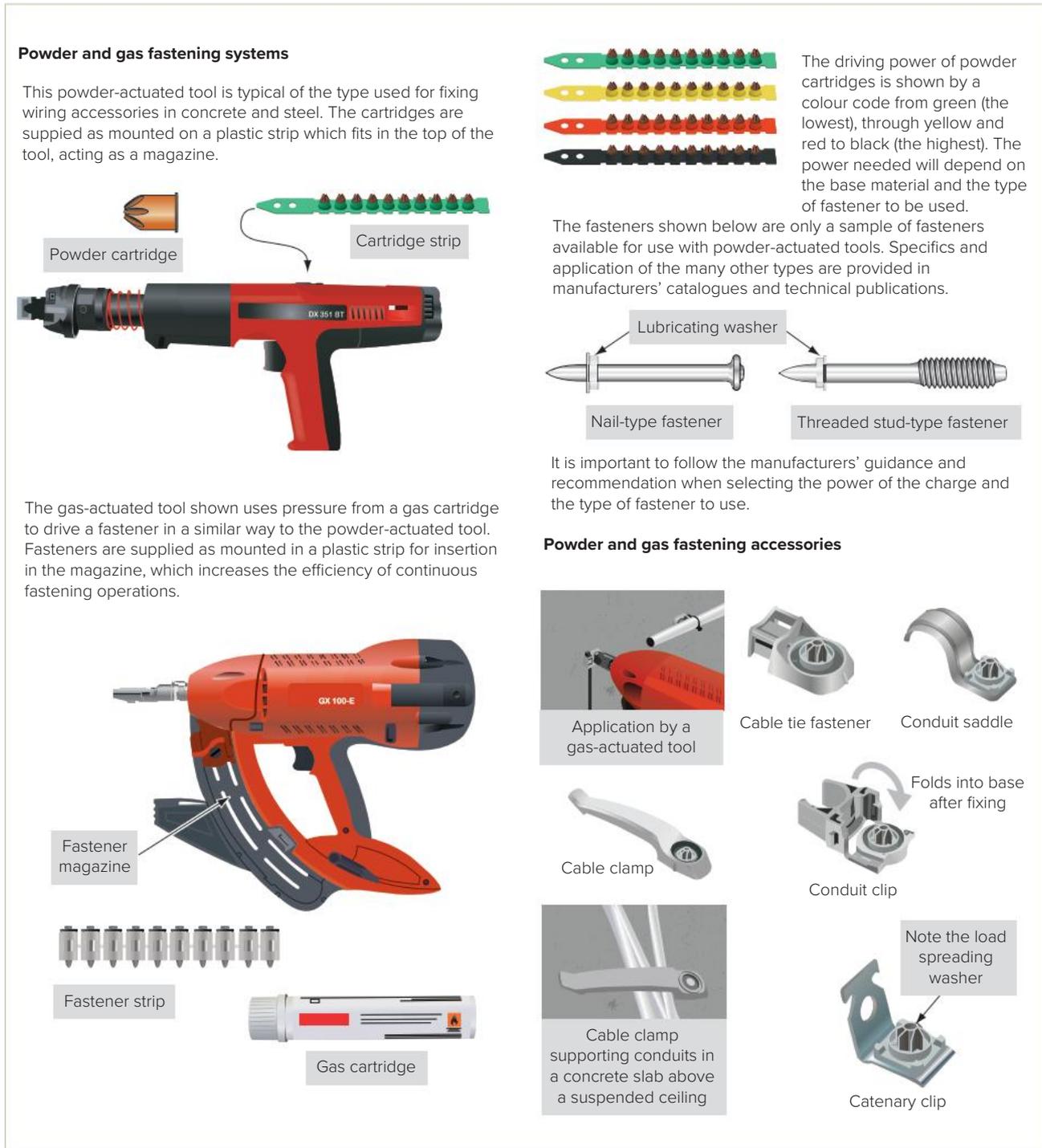


FIGURE 6.10 Powder and gas fastening systems and accessories for electrical work



CAUTION

When setting anchors, make sure the manufacturer's instructions and recommendations are followed. This includes:

- ▶ selecting a suitable anchor for setting the base material
- ▶ selecting an anchor and screw that will safely support the item to be fixed
- ▶ drilling the anchor hole to the diameter and depth recommended for the anchor
- ▶ using sufficient torque to set the anchor and safely secure the item being supported.



CAUTION

Follow the manufacturer's instructions

In this chapter, you have been shown various types of fixings and fasteners that are used in electrical work, as well as the general principles and techniques involved in using them. However, when selecting and installing fixing and fasteners, the manufacturers' guides and instructions must be followed (see the *Wiring Rules, Clause 1.7.2(b & j)*).

6.1.3 Drilling and chasing concrete and masonry

The most common tools for drilling masonry and concrete are the hammer drill and tungsten-tipped drill bit. Powerful hammer drills are available in cordless models that suit most electrical tasks. Some have torque control, which, when set correctly, prevents torque 'kicking back' if the drill bit is jammed by reinforcing in the concrete. A less common drilling activity is coring, where a through-hole is needed in a concrete floor or masonry wall for the passage of cables or conduits. Coring operations use special high-speed drills with diamond-tipped coring bits. Examples are shown in **Figure 6.11**.

It is often necessary for the electrician to cut channels or grooves in concrete and masonry surfaces to install conduits or cable before the surface finish is applied. This process is known as chasing. A common method for chasing masonry and concrete is to use a chasing machine fitted with two masonry-cutting bits. The distance that the blades are set apart and their depth are both adjustable and this defines the width and depth of the chase. The material between the two cuts is then chiselled out to complete the chase, as shown in **Figure 6.11**.

There are limits to the depth, length and direction in which a chase may be cut. Chases should be planned with the approval of the builder; otherwise, they could reduce the structural integrity of a wall and/or the fire resistance level (FRL) and acoustic performance rating (APR) for which the building structure is designed. The FRL and APR are set by the performance-based national building codes for different building types; that is, in Australia the National Construction Code (NCC) and the New Zealand Building Code (NZBC).

Fixing safety

The hazards associated with installing fixings and chasing masonry are summarised in **Table 6.1**. The safety features designed into power tools have greatly improved over time. Some of these are shown in **Figures 6.10** and **6.11**. As emphasised in **Chapter 2**, always seek advice from a trainer or mentor on the correct use of power tools you have not previously used.

Drills typically used in electrical work

The energy source for the most commonly used power tools is the rechargeable battery.



Cordless hammer drill powered by a 36 V rechargeable battery is used for heavy-duty fixing work.

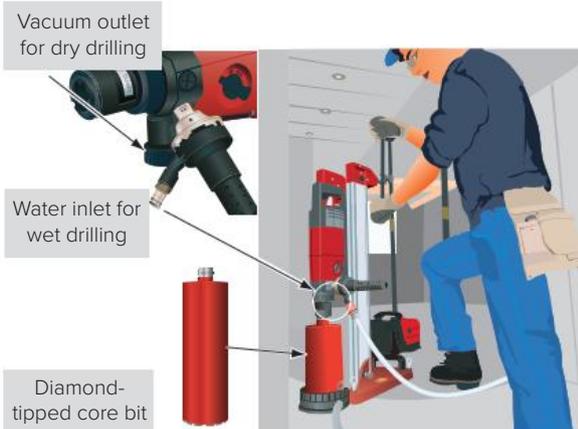


Cordless hammer drill/driver powered by an 18 V rechargeable battery is ideal for general electrical work.

The drilling operation shown below uses a hammer drill fitted with a dust removal system ideal for dustless drilling in inhabited areas or in areas where equipment is sensitive to dust.



Below is a rig set-up for drilling core holes into reinforced concrete. Water is used to cool the diamond drilling bit in operating this drill through hard aggregate and steel reinforcing bars.



Drill bits commonly used in electrical work

A number of types of drill bits are used in electrical work, with each designed for a specific purpose. Choosing the correct bit for a particular application not only makes the job easier and more efficient but is also very important in maintaining safe working methods.



Jobbing bit (twist drill) for general drilling of metal, wood, plastic and the like. Common sizes used in electrical work 1 to 12 mm.



Tungsten-tipped hammer drilling bit designed with a forward drawing action reduces the effort required by the operator.

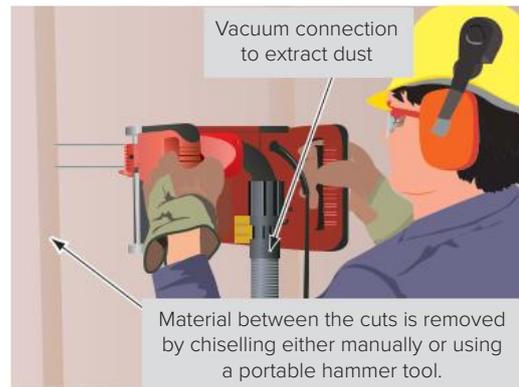


This stepper drill is very handy for drilling or enlarging holes into sheet metal, wood, plastic and laminates.



Hole saws are available in common clearance sizes from 16 to 100 mm. These are invaluable in electrical work for making entries into switchboard enclosures, access holes in panelled structures and accurate openings for flush accessories and lighting.

Chasing operations



Making the width of the chase a tight fit (without damage) for the conduit or cable helps to hold it in the chase until the surface finish is completed.

Cables embedded in the surface of walls, floors or ceilings must comply with the requirements of Clause 3.9.4.

FIGURE 6.11 Drills and bits typically used in electrical work

TABLE 6.1 Hazards associated with fixing and chasing masonry

Hazard	Typical control measures
Working at heights and overhead (which is a common requirement)	Follow safe work methods for using stepladders, ladders, scissor lifts and elevated work platforms (EWP), and for working overhead.
Creation of dust from drilling and chasing operations	Use dust-extraction equipment and respiratory protection.
Creation of high noise levels from drilling, chasing operations and powder-actuated tools	Use hearing protection and limit exposure.
Creation of a shock hazard to self or others by drilling or driving fasteners into existing electrical wiring	Use a cable-locating device before commencing drilling or fixing operations. Use appropriate personal protective equipment.
Creation of water or gas hazards by drilling or driving fixings into these services	Use a service-locating device or consult relevant authorities before commencing drilling or fixing operations.
Damaged power tools	Inspect tools for damage before use. Tag damaged tools and send them for repair.
Damaged powder-actuated and gas-powered tools	Inspect tools for damage before use. Tag damaged tools and send them for repair.



CHECK YOUR UNDERSTANDING

- Give examples of where the following nails would be used in electrical work:
 - masonry nail
 - clout nail
 - jolt head nail.
- What is the difference between a Phillips screw and a Pozidriv screw?
- Why is it important to match a screwdriver with the screw head type and size?
- What determines the length of a screw or bolt?
- Explain the principle of the powder and gas fastening systems that are typically used in electrical work.

6.2 Mounting brackets, plates and boxes

Accessories such as switches, socket-outlets and communication outlets must be securely mounted in place in order to withstand the strain placed on their fixing by constant use. If the terminal of an electrical accessory becomes exposed by failed fixings, the user is no longer protected from direct contact with live parts. There are four basic types of mounting accessories: mounting brackets for lined stud walls; wall boxes; plaster-mounting brackets; and mounting blocks. Examples and their uses are shown in **Figures 6.12 to 6.15**.

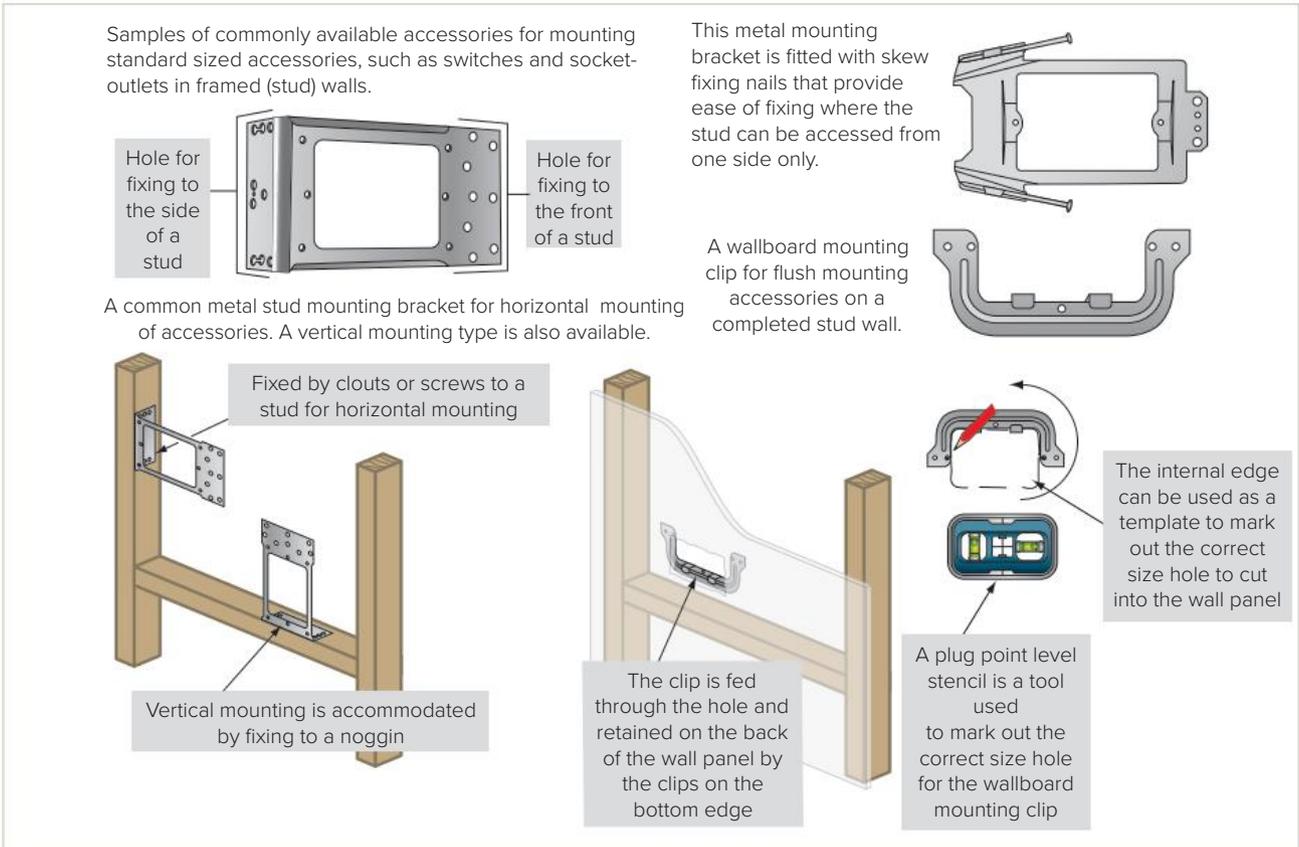


FIGURE 6.12 Examples and applications of mounting brackets

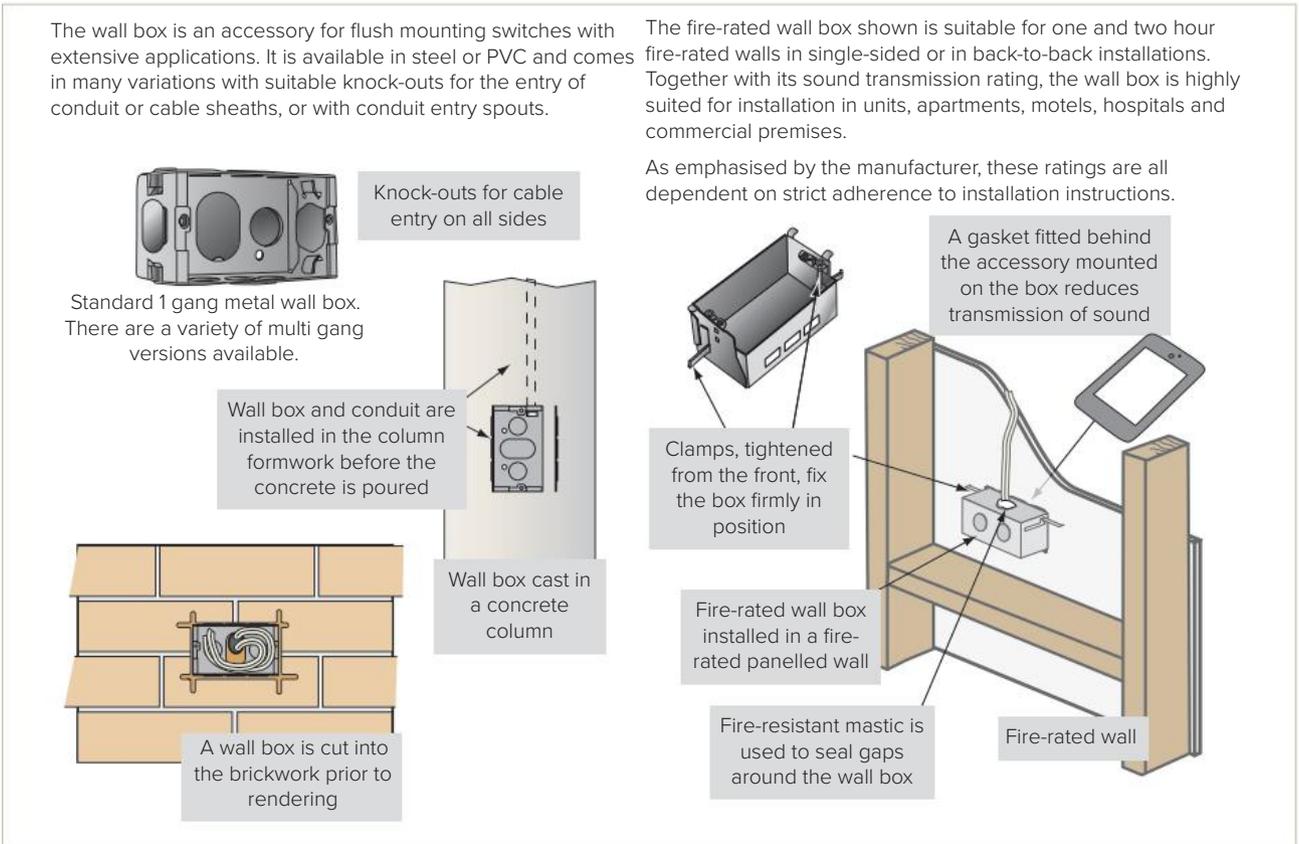


FIGURE 6.13 Examples and applications of wall boxes

Shows plaster brackets for a plaster or cement-rendered wall where an enclosing box is not necessary. These are also used in reconstruction or additions to existing structures, where a galvanised metal bracket as shown is often grouted into the surface render.

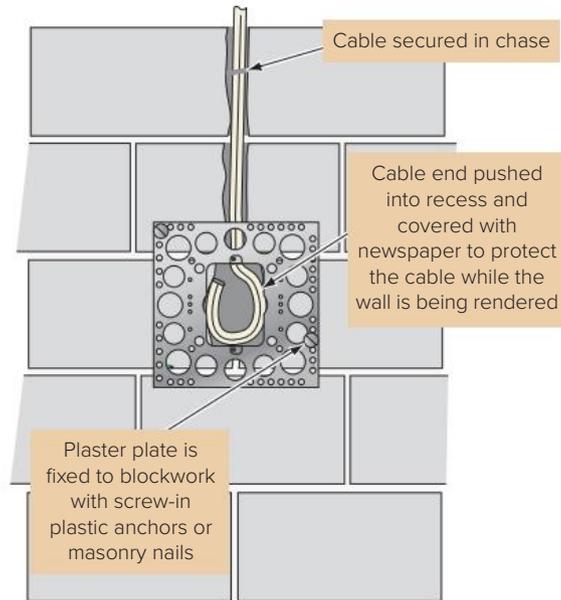


FIGURE 6.14 Examples and applications of plaster brackets

Plastic mounting blocks, like the one below, are used for flush-mounted accessories mainly with exposed surface wiring. They are also used where cutting of a wall box or plaster plate is not desirable. The mounting of accessories on wooden blocks as seen in old installations is generally redundant, but is sometimes used in the restoration of older buildings and houses.

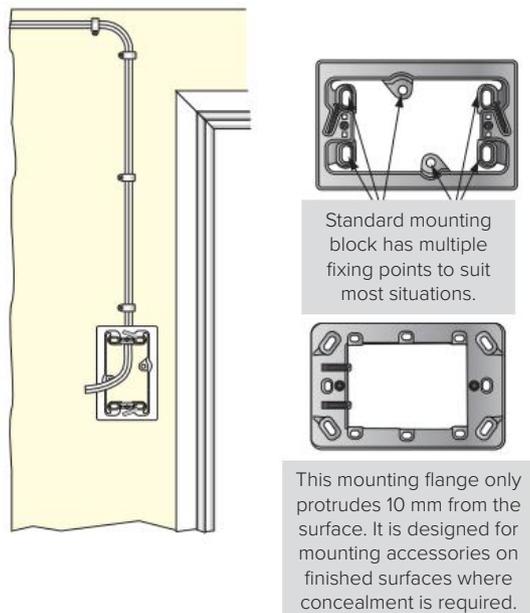


FIGURE 6.15 Examples and applications of mounting blocks



CHECK YOUR UNDERSTANDING

6. What would happen if the fixings holding an electrical accessory failed?
7. What device is suitable for securing the following accessories:
 - a. standard light switch on a lined framed wall
 - b. a standard socket-outlet on a rendered plaster single-brick wall
 - c. a socket-outlet on a rendered plaster double-brick wall separating different dwellings.
8. Name an installation where a fire-rated wall box would be used.
9. Where would you use a plaster plate?
10. Why would a mounting block that only protrudes 10 mm from the surface be used in an installation?

6.3 General switching, lighting and socket-outlet accessories

6.3.1 Switching devices

The most common accessories in an electrical installation are switching devices, which include all forms of devices that are capable of opening and closing the conductors in a circuit. These include manually operated switches and devices arranged for automatic operation, such as circuit-breakers, contactors and relays. Note that a circuit-breaker is a manually operated switch with a mechanism to trip open automatically if excess current flows in a circuit.

A switch must be capable of making or breaking a circuit without damage to itself, and of carrying its rated load continuously without overheating or deterioration. The basic switching action is illustrated in **Figure 6.16**.

All electrical installations must have switching devices to remove dangers and to control electrical equipment in accordance with *Clause 2.3*, which classifies switches by their intended purpose (*Clause 2.3.1*) as summarised in **Figure 6.17**. Before selecting and installing a switch, always ensure that it is suitable for a particular application. In addition to the switching purpose, the actual type of switch used will depend on the following factors.

Current rating and utilisation of switches

The factors affecting the current rating of a switch are:

- ▶ the current rating of the circuit in which it is installed
- ▶ whether it is required to switch underload and/or overload; and, if so:
 - ▶ the type of load it is to switch and how often the switch will be operated; and
 - ▶ whether it is to switch a.c. or d.c.

Functional switches must be capable of opening safely when a circuit is drawing maximum current, and emergency switches may be required to open under overload conditions. Accordingly, switching devices are categorised by their ability to switch various types of loads. This is termed the utilisation category, which is defined in the Standard for the manufacture of switchgear, *AS/NZS IEC 60947.3 Low-voltage switchgear and controlgear switches*. **Table 6.2** briefly shows how this applies.

Note that the *Wiring Rules*, *Clause 2.3.7.2* requires switching devices controlling loads with a low power factor (i.e. inductive loads) to be appropriately de-rated. An example of how this is applied in practice is illustrated in one manufacturer's test certification for a multiphase switch, which it rates at 63 A for AC21 utilisation but de-rates to 25 A for AC23.

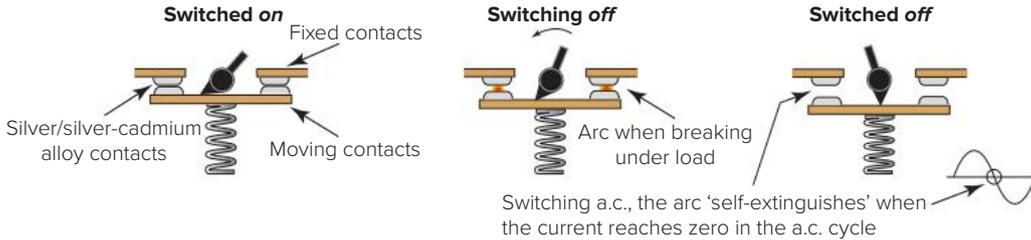
Note also that a switch rated for a.c. is not necessarily suitable for d.c. without substantial de-rating of its a.c. current rating.

Switching devices are designed with the following features:

- low-resistance contacts to ensure there is no voltage drop across the switch when it is switched on
- contacts that can withstand the heat from arcing when the contacts are opened
- a current and voltage rating and load type or utilisation.

Basic switching action

Shown by the contact mechanism of a manually operated switch



A switch normally used in a.c. circuits (sometimes marked a.c. only) is not suitable for a d.c. circuit of the same rating. Direct current, being steady and unidirectional, is not self-extinguishing like a.c. and so d.c. switch contacts must be *quick-break* and have a greater gap between contacts than an a.c.-rated switch when it is switched off.

Remember that a switch is in series with the load; accordingly, with the load connected and the switch off, the full circuit voltage is present across the switch contacts, the gap between which must be sufficient to prevent the voltage from conducting across it. The dual gap design in the above example allows for a more compact switch and is common among switching devices.



FIGURE 6.16 Basic capabilities of switches

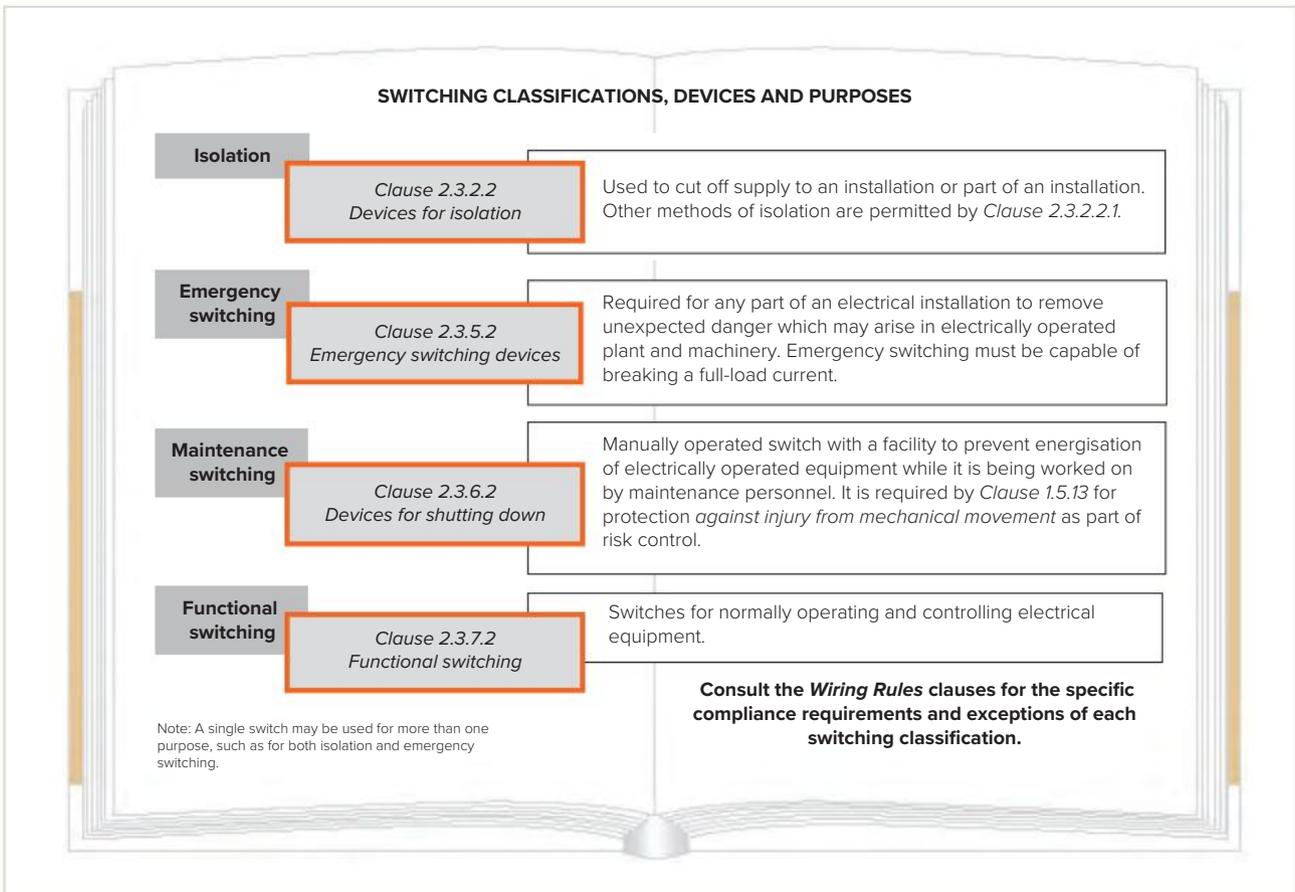


FIGURE 6.17 Switching classifications, devices and purposes

TABLE 6.2 Utilisation category applications

Utilisation category	Application
AC21/DC21	Switching of resistive loads including moderate overloads
AC22/DC22	Switching of mixed resistive/inductive loads, including moderate overloads
AC23/DC23	Switching of highly inductive loads

Voltage rating of switches

Switches are also rated for the voltage applied to the circuit in which they are to be installed. Typically for low-voltage a.c. circuits, single-phase switches are rated at 250 V a.c. while multiphase switches are rated at 500 V a.c.

Switch configurations

Switches are available in a variety of switching arrangements, from a simple single-pole on-off switch to multi-pole/multi-position switches used in control circuits. The most common switching configurations, where they are used and available examples are shown in **Figures 6.18** and **6.19**.

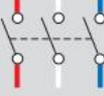
Switch configurations	Where they are typically used	Example
	Single-pole single-throw (SPST) or one-way switch. Simplest configuration used in switches for isolation and control (functional) of single-phase circuits such as lighting, water heaters and motors.	 A single-pole surface-mounted switch suitable for installation outdoors.
	Single-pole double-throw (SPDT) or two-way switch. The most commonly available switch configuration for lighting. As well as providing an on-off function, two switches can be used to control a light circuit from separate locations.	
	Intermediate switch. Typically used for switching a lighting circuit from more than two separate locations such as in a stairwell. Intermediate switches are installed in the circuit between the two-way switches.	
	Double-pole double-throw (DPDT) switch. Similar to an intermediate switch but with the switch side of each pole separated. Used in control circuits.	
	Triple-pole single-throw or on-off switch. Typical of three-phase circuits for isolation and switching for mechanical maintenance.	 Triple-pole switch in an IP 56 enclosure which protects against entry of dust and water (see Wiring Rules, Appendix G).
	Triple-pole double-throw or triple-pole changeover switch. Used for changing over to an alternative power supply or standby equipment such as a pump.	 Triple-pole changeover switch designed for panel or enclosure mounting. This switch has a centre 'o' position.

FIGURE 6.18 Common switching configurations and where they are used

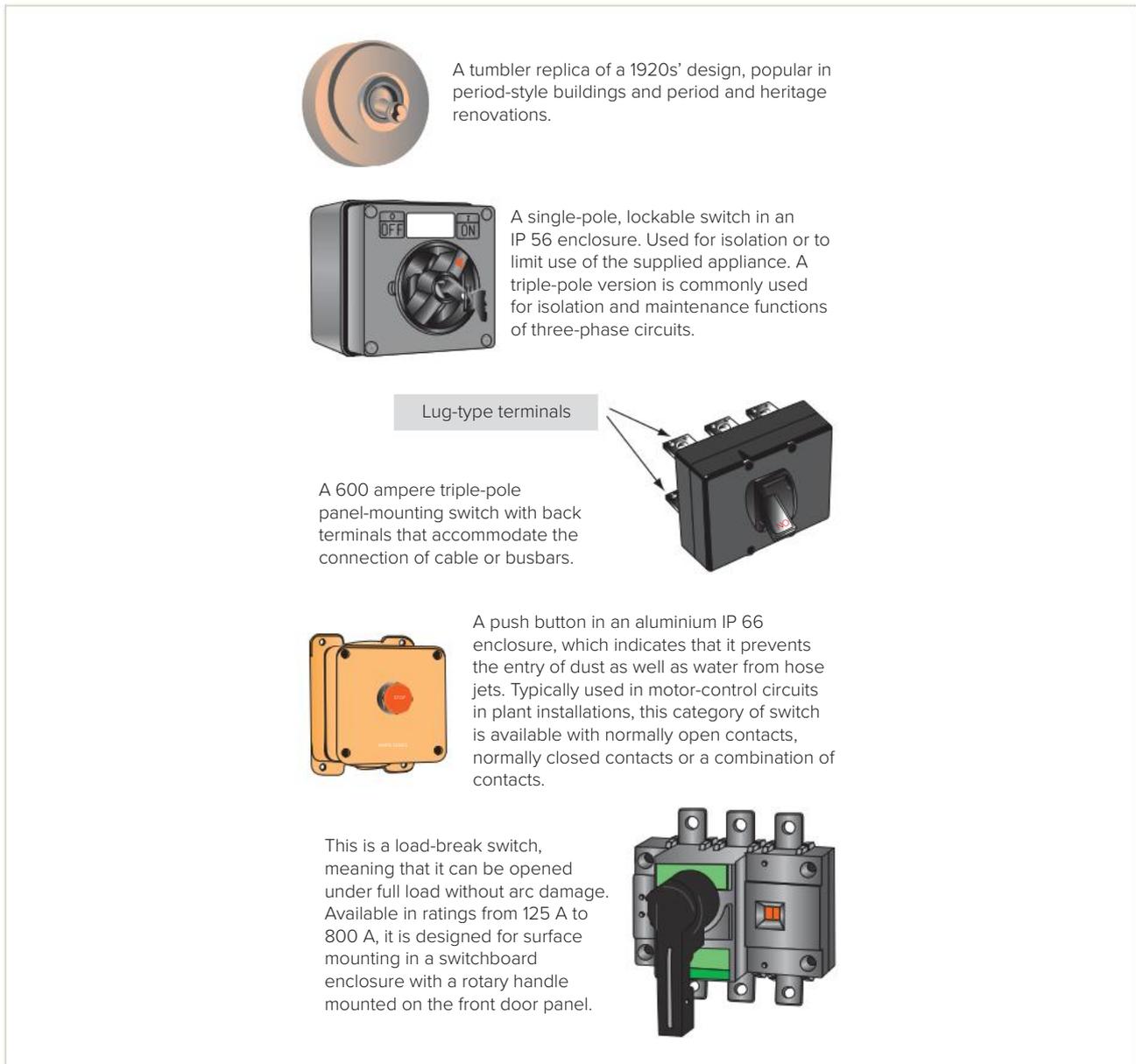


FIGURE 6.19 Examples of commercially available switches

6.3.2 Socket-outlets and plugs

The most common accessory for connecting low-voltage appliances is the socket-outlet and plug. With some exceptions, each socket-outlet is required by *Clause 4.4.4.1* to be controlled by its own switch. Socket-outlets are available in a large variety of pin configurations to connect extra-low voltage (ELV), single-phase and multiphase appliances, and for control applications. Some common examples are shown in **Figure 6.20**.

The reason for the various configurations is a safety provision to prevent insertion of a plug of higher current rating or of equipment intended to operate at a different voltage or frequency, and also to maintain correct polarity and phase sequencing. Other safety features include those for the prevention of contact with live receptacles and the pins of plugs as they are inserted and withdrawn. Examples are shown in **Figure 6.21**.

The term *socket-outlet* refers to the device into which a plug can be inserted (see *Clause 1.4.110*).



Surface-mounted socket-outlet commonly used for the final connection to current-using device controlled from a remote switch, such as luminaires in a suspended ceiling and exhaust fans.

The most common socket-outlet used in domestic and commercial installations is one that combines the socket-outlet with its controlling switch. The switched socket-outlet is often referred to as a GPO (general purpose outlet), power point or power outlet.



Single



Twin

Switched socket-outlets are available in single, twin and four gang in horizontal and vertical formats. Other types have special features, such as extra switch mechanisms, safety shutters, neon indicators and double-pole switches.



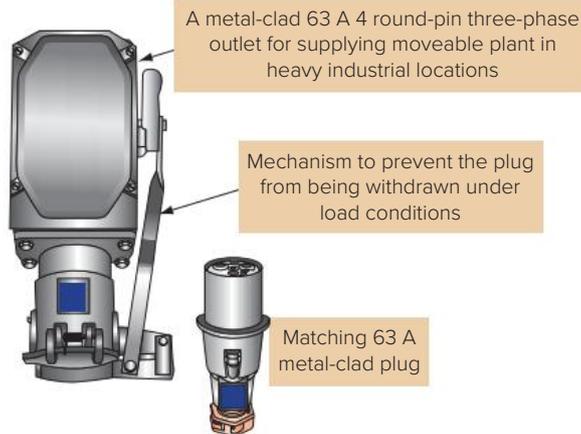
Multiphase socket-outlets come in a range of round pin types, such as three, four and five

Four-pin socket-outlets (three-phase and earth) are typically used for multiphase socket-outlets with industrial plant and equipment

Pendant socket-outlets are used in open manufacturing and process areas, where the layout of plant equipment may be altered from time to time or where there is no vertical surface to safely mount an outlet.



Pendant socket



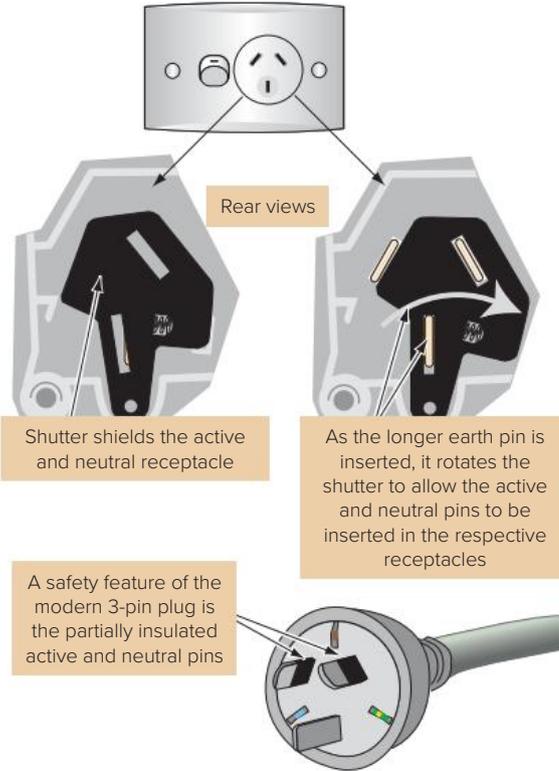
A metal-clad 63 A 4 round-pin three-phase outlet for supplying moveable plant in heavy industrial locations

Mechanism to prevent the plug from being withdrawn under load conditions

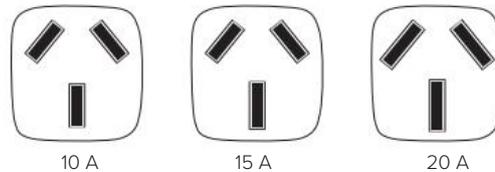
Matching 63 A metal-clad plug

FIGURE 6.20 Examples of socket-outlets

Some socket-outlets have safety shutters that shield the active and neutral contacts and do not open until the earth pin of the plug is inserted.

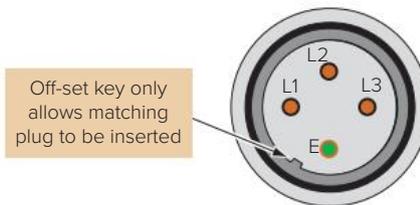


Another safety feature of the 3-pin plug and socket is that the earth pin is larger for each higher rating. This prevents a plug from being inserted into a lower-rated socket. For example, a 10 A plug may be inserted into a 15 A-rated socket, but it is not possible to insert a 15 A plug into a 10 A socket.



Earth pin and receptacle is larger in each higher rating

A similar technique of not being interchangeable is the reason for using different pin configurations and shapes; for example, for extra-low voltage (ELV) outlets in accordance with *Clause 7.5.10*.



A further example in industry is the provision of socket-outlets for high-speed power tools or those rated for high-frequency supply.

FIGURE 6.21 Examples of safety provisions incorporated into socket-outlet and plug design

Much thought has been given to the development of the standard 230 V a.c. socket-outlet combination for domestic and commercial use. The result is a variety of design features regarding both appearance and utility, and so a suitable type can be selected from a large range for practically any normal application. Although visible accessories such as socket-outlets and switches are usually selected by the consumer for their style and colour, the electrician should be ready to provide technical advice on the vast number of socket-outlets with added functions available in one accessory to suit most situations. Examples are shown in **Figure 6.22**.

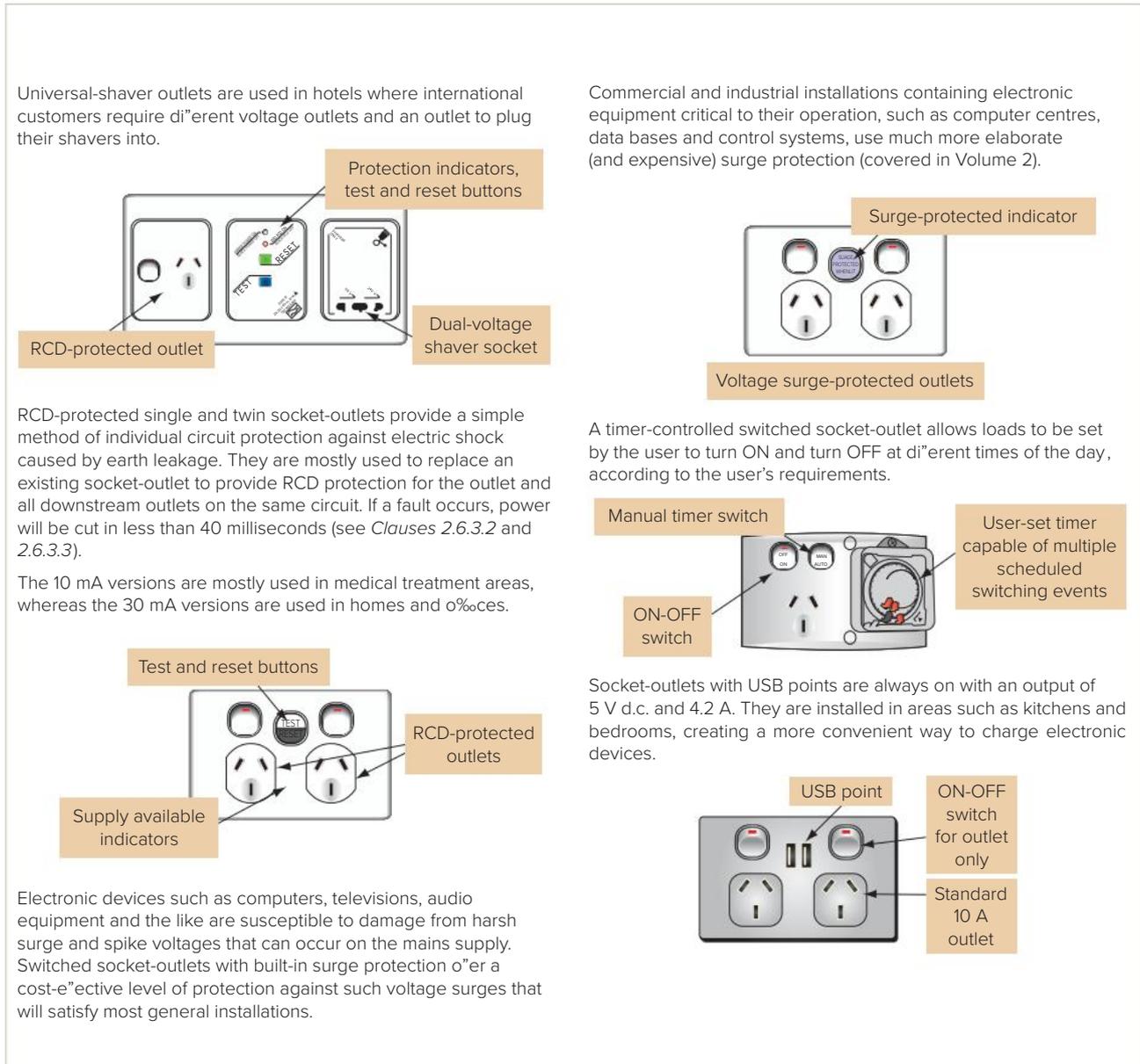


FIGURE 6.22 Examples of socket-outlet accessories with added functions

A special socket-and-plug assembly is available for the connection of cooking equipment such as cooktops and wall ovens as an alternative to connecting these appliances directly to the fixed wiring (**Figure 6.23**). The main advantage of this socket-and-plug assembly is that it enables an appliance to be installed just before the premises are handed over to their owner, reducing the risk of theft or damage to the appliance during construction. Another advantage is that it allows the appliance to be readily moved out of position for cleaning, servicing or wall painting.

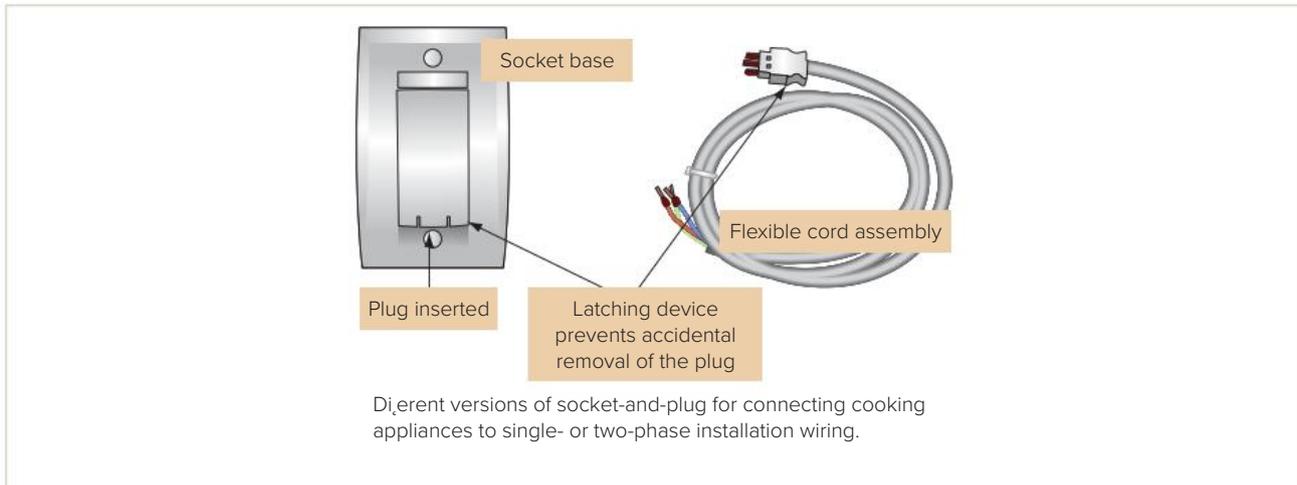


FIGURE 6.23 Cooking equipment socket-and-plug assembly

6.3.3 Lighting accessories

Remember from **Chapter 4** and **Section 6.1** of this chapter that lamps and luminaires are not included in the definition of an accessory; however, there are a number of devices associated with lighting that are considered accessories. These include the surface-mounted lamp holder called a batten holder, ceiling roses, cord-grip lamp holders and lamp extension sockets. Examples of these and their features are shown in **Figure 6.24**.

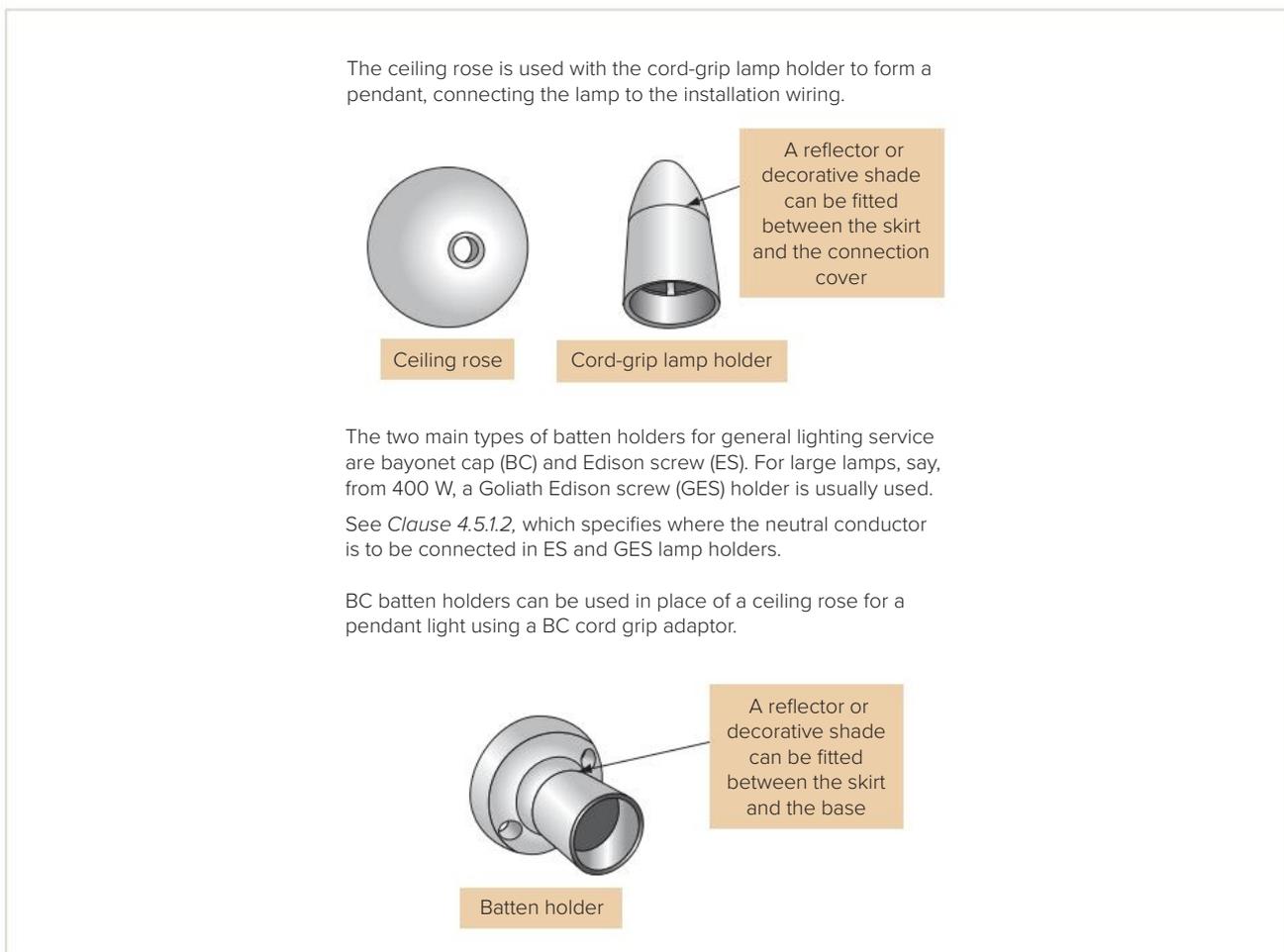


FIGURE 6.24 Examples of lighting accessories and their features



CHECK YOUR UNDERSTANDING

11. Describe the factors affecting the current rating of a switch.
12. What are the typical voltage ratings for a single a.c. switch and a multiphase a.c. switch?
13. Describe a typical application for a triple-pole on-off switch.
14. Which clause of the *Wiring Rules* states that a socket-outlet must be controlled by its own switch?
15. Name two common accessories associated with lighting installations.

6.4 Protection and control accessories

6.4.1 Protection accessories

There are a number of accessories that, when correctly selected and installed, fulfil the fundamental requirement of the *Wiring Rules* for protection against the danger and damage that may occur during the sensible use of an electrical installation. These protection devices are designed to provide protection against the following:

- ▶ electric shock when a fault current occurs (known as indirect contact with live parts)
- ▶ overload and short-circuit currents, which will overheat cables and other equipment
- ▶ overvoltage and undervoltage, which can cause damage to electrical equipment.

A single device (accessory) may perform more than one type of protection; such devices include circuit-breakers, fuses, residual current devices (RCDs) and motor starters.

Circuit-breakers

A circuit-breaker is a switch with built-in thermal-sensitive and magnetic-sensitive mechanisms that detect excessive current and automatically disconnect the supply to the circuit. Circuit-breakers are the most common device for protection against fault and overload currents, and are installed at the origin of a circuit at a main switchboard or distribution board. Being a switch, a circuit-breaker can be used as a convenient way to isolate a circuit.

Fuses

A fuse does a similar job to a circuit-breaker by automatically disconnecting the supply on detection of excessive current. However, the mechanism for this is different; the excessive current melts a fuse element and, as a result, opens the supply to the circuit.

You will come across semi-enclosed rewirable fuses in older installations, where the fuse element is a replaceable wire of sizes to suit the fuse current rating. Semi-enclosed rewirable fuses are no longer permitted (*Clauses 2.4.3 and 2.5.2*), mainly because they cannot handle the higher fault currents that have come with the need for higher capacity in the distribution network to supply electricity. Also, over-rated fuse wire might be used in replacing a blown element, raising the risk of overheating in the circuit. The *Wiring Rules, Appendix I* provides information concerning ratings of previously installed semi-enclosed rewirable fuses.

Residual current devices

Another form of circuit-breaker is the residual current device (RCD), which is specifically designed for protecting against electric shock from an earth fault. This has a mechanism that detects variations in current in the active

and neutral conductors, and disconnects supply to the circuit before it reaches a harmful level. Although RCDs are intended as additional protection, they are mandatory for a number of types of final subcircuits (*Clause 2.6.3*). RCDs are commonly available combined with a circuit-breaker in the one device. The *Wiring Rules, Clause 2.6.2.2.1* describes the different types of RCDs and their applications in the electrotechnology industry. This includes types such as AC, A, I, F, B and S. The *Wiring Rules* recommend the use of type A RCDs.

Examples of protection devices (accessories) are shown in **Figures 6.25** to **6.27**.

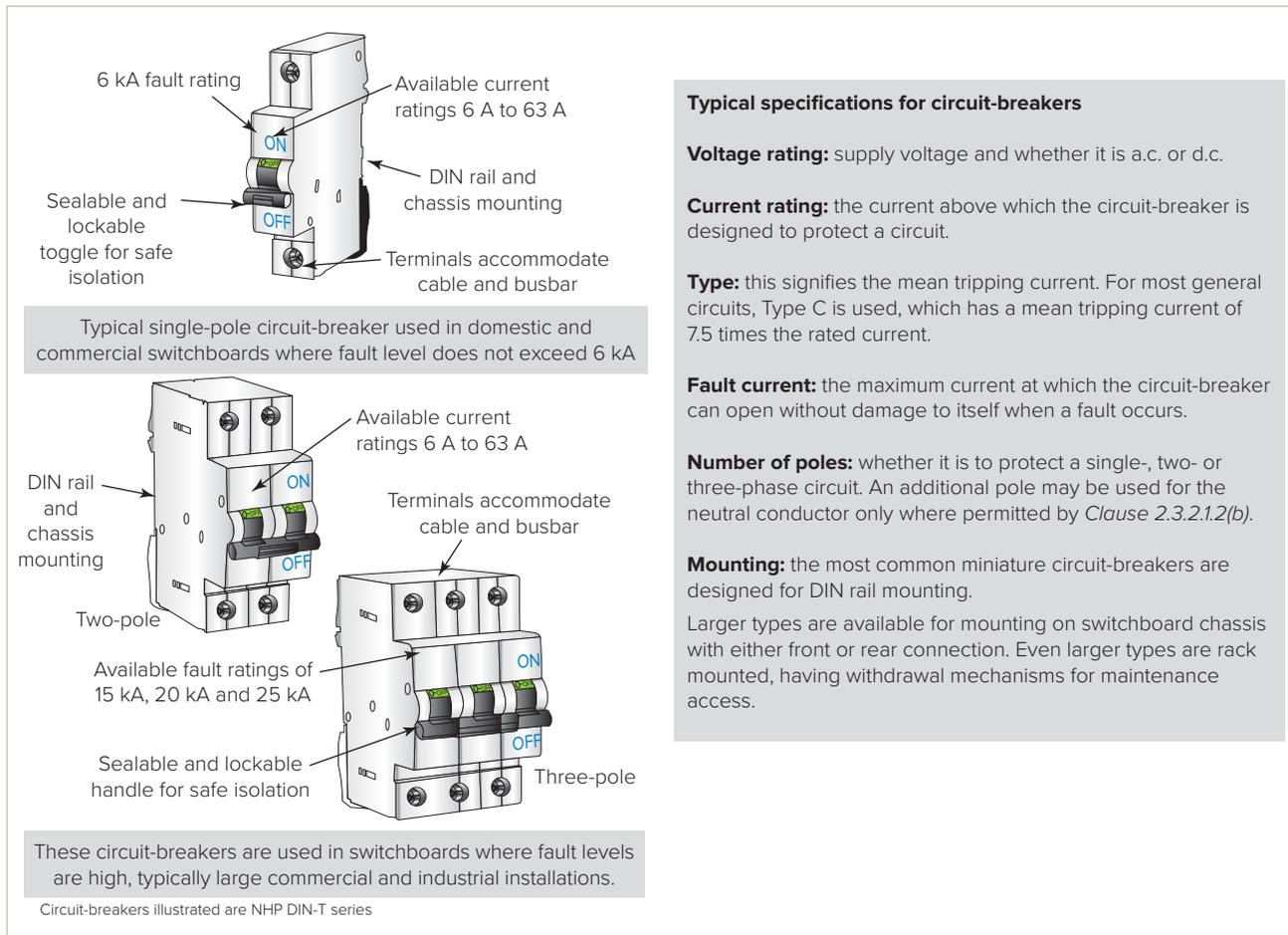


FIGURE 6.25 Examples and features of circuit-breakers

Motor overload protection and control

Probably the most important device in the use of electricity is the electric motor as the source of mechanical energy in appliances and for driving industrial equipment. Electric motors are very susceptible to overload, resulting in the motor overheating and possibly starting a fire. Because of this, *Clauses 4.13.2* and *4.13.3* of the *Wiring Rules* require motors above specified ratings to be protected against overload and overtemperature.

The switching of motors needs to be robust and fast acting, as when an overload occurs, breaking currents can be up to eight times their normal full-load current. In addition, for most applications, motors require some form of automatic control. The basic switching and overload accessories for doing this are the contactor, a magnetically operated switch, and thermal overload, a trip mechanism that operates from the heat created by overcurrent. In their basic arrangement, they are used in combination as a single accessory known as a direct-on-line (DOL) starter, as shown in **Figure 6.28**. There are many other types of motor protection and switching accessories and controls, and these are detailed later in the book.

As the name implies, the high-rupturing capacity or HRC fuse is able to interrupt high-fault currents without damage to itself. The fuse element is contained in a sand-filled ceramic cartridge, eliminating the risk of arcing when the element blows. They are often used as fault-current limiters for installations where the prospective fault current is higher than the rating of the circuit-protection devices.

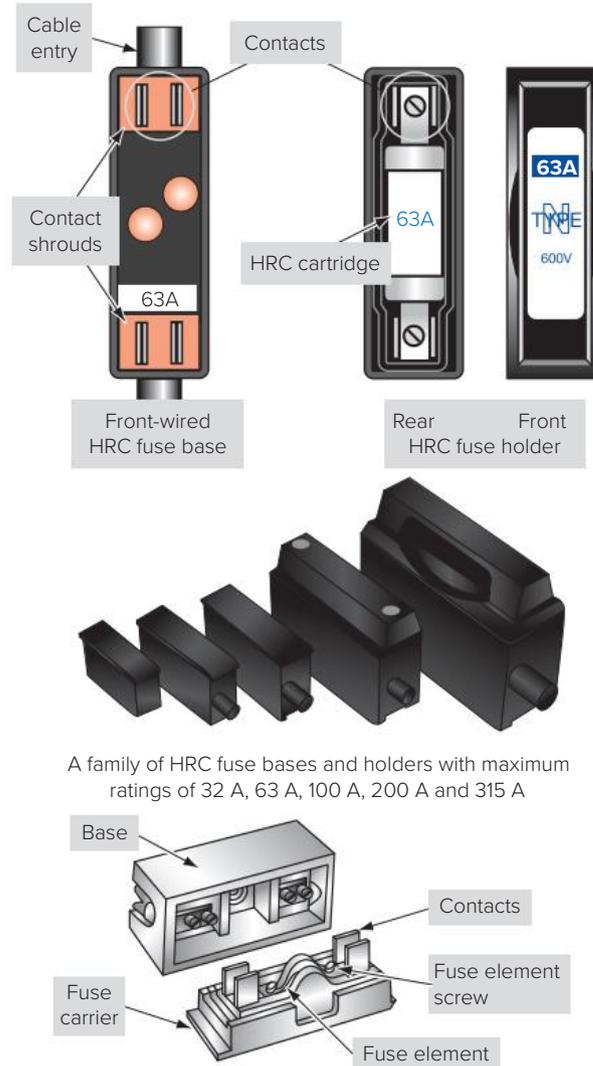


FIGURE 6.26 Examples and features of fuses

Other control accessories

There are many control accessories designed to react to specific physical changes such as temperature or pressure in order to control the operation of electrical systems. For example, in a refrigeration system, a thermostat detects when the minimum temperature is reached in the refrigerated area and switches the compressor off. Likewise, the thermostat switches the compressor on when the temperature rises. Other control accessories include devices for detecting proximity, movement and smoke, for measuring the flow of liquids in pipe systems, levels of moisture, quality of the electrical supply and energy use (as shown in **Figure 6.29**).

The residual-current device (RCD) is used for protection against the risk of shock from an earth fault. *Clause 2.6* mandates the use and types of residual-current rating of RCDs for particular circuits and installations. The most common type combines the functions of an RCD and a circuit-breaker to provide both earth leakage and circuit protection in a single device.

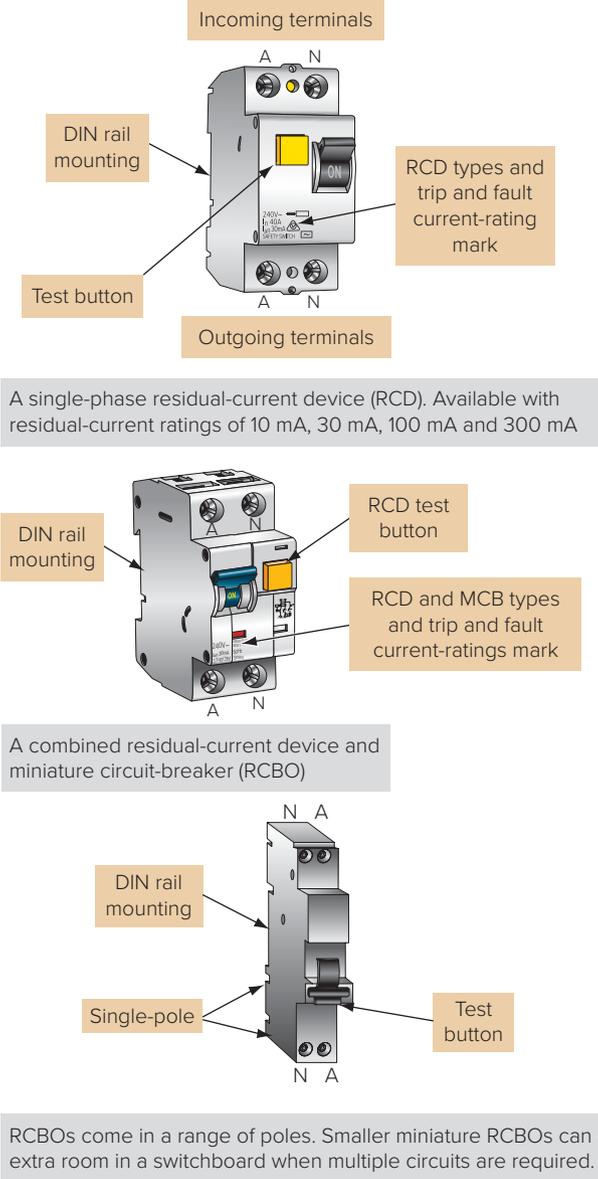


FIGURE 6.27 Examples and features of residual current devices

The electromagnetic relay operates in the same way as a contactor, but is used in conjunction with other control devices to automatically sequence switching in control circuits. The relay, like many control devices, is available as a solid-state device; many have the facility for programming a desired control sequence. Electronic accessories are used in systems designed to ensure the efficient use of energy in buildings through the control of lighting, air-conditioning and other energy-using equipment; these are covered in detail in **Chapter 8**. Nowadays most industrial processes are controlled by a programmable logic controller (PLC), a special computer designed for this purpose.

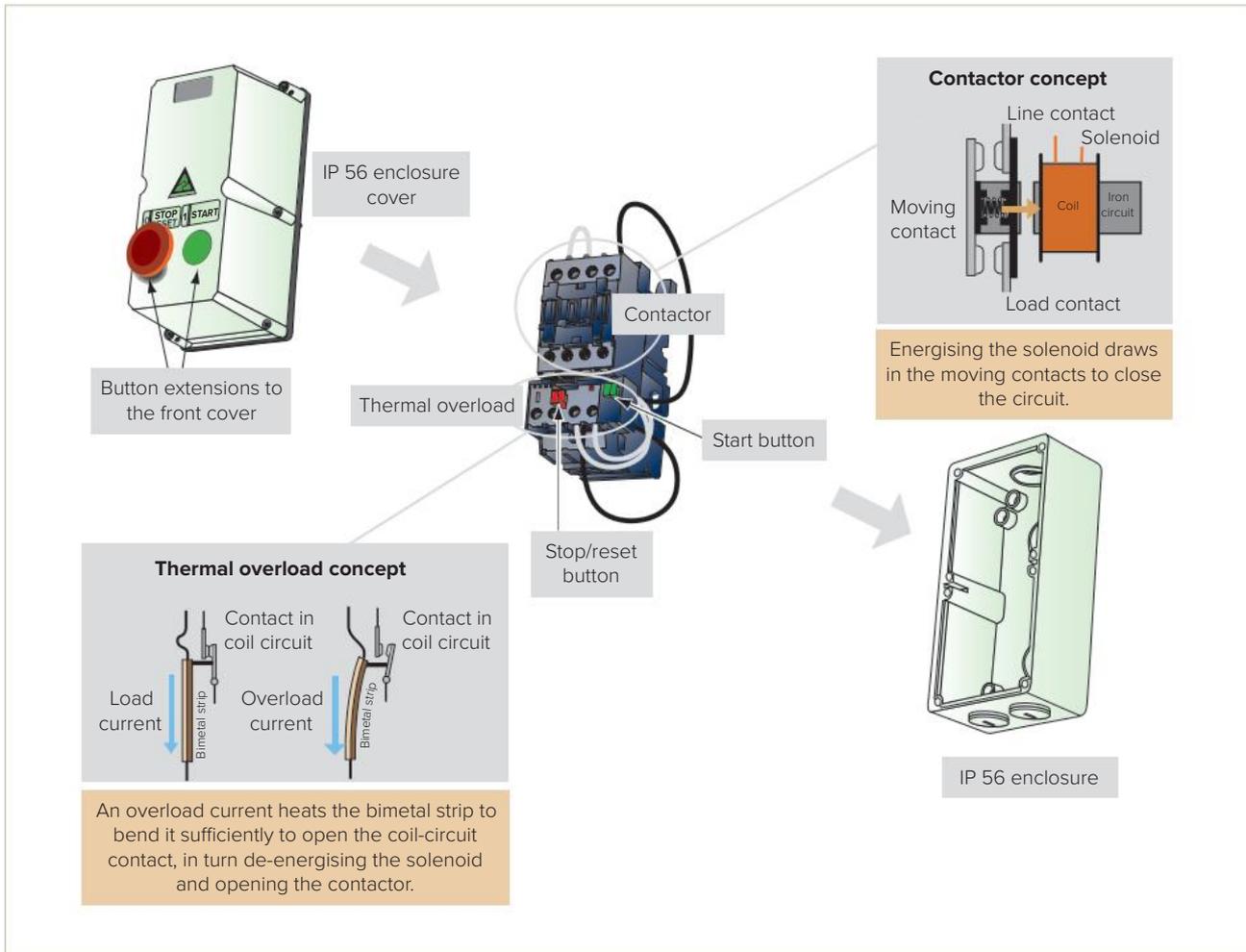


FIGURE 6.28 Examples and features of motor protection and control accessories

6.4.2 Electromagnetic compatibility

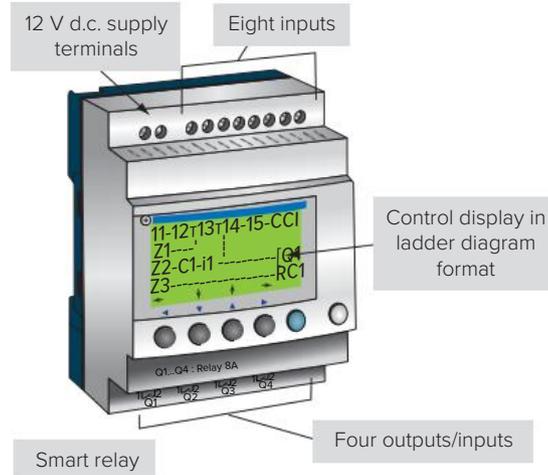
Electrical equipment emits some energy in the form of electromagnetic radiation (EMR), which can impact on the radio frequency spectrum (bandwidth) allocated for communications. This radiation is known as electromagnetic interference (EMI).

You may have experienced EMI as noise when using headphones that receive signals from an infra-red wireless transmitter connected to the audio output of a television or radio. Hearing aids are particularly prone to the EMI from mobile phones and fluorescent light fittings. A life-threatening example is when EMI from a mobile phone or other electronic device affects the electronic monitoring equipment in a hospital or the navigational aids in an aircraft.

The Australian Communications and Media Authority (ACMA) requires that all relevant manufacturers' products comply with the appropriate Australian and New Zealand Standards. Devices that comply are said to be electromagnetically compatible (EMC). Examples of products that are embraced by the regulations are lighting dimmers, time-delay switches, timers, passive infra-red motion detectors, switch mode power supplies and motor speed controllers.

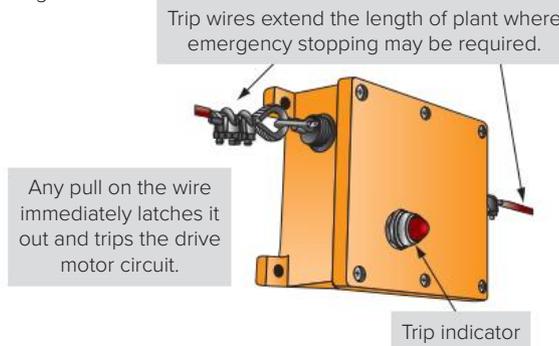
All products that are affected by the EMC regulations must be labelled with an approved compliance mark. A product that does not emit EMI, or emits EMI within specified limits and requires electrical safety compliance, carries the Regulatory Compliance Mark (RCM) shown in **Figure 6.30**.

Electronic smart relays are in many cases replacing electromagnetic relays because of their versatility and because they are programmable for any control scenarios requiring multiple inputs and outputs. They are basically a small programmable logic controller (PLC) with a program that can be backed up to a PC or removable EEPROM.



All types of switching devices are used to control industrial plant and machinery. For instance, limit switches are used to set the limits of the movement of mechanical parts such as the upper and lower travel of a hoist.

Another example is the trip-wire or pull-wire switch shown here that provides an immediately accessible emergency stop along the length of operating plant, such as a large conveyor or rolling mill.



Panel-mounted switches are common in control panels and switchboards for control of plant, switching operations and metering. They are usually of modular design and can therefore be ordered from the supplier in numerous configuration-switching arrangements and up to 12 switch positions.

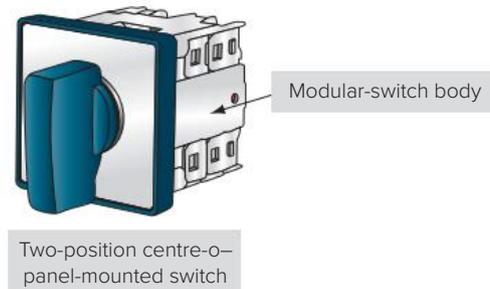


FIGURE 6.29 Examples and features of various control accessories



FIGURE 6.30 Regulatory Compliance Mark (RCM)

Australian Communications and Media Authority © Commonwealth of Australia



CHECK YOUR UNDERSTANDING

16. Explain the purpose of protection devices.
17. Why are semi-enclosed rewirable fuses no longer permitted for use as protection against fault and overload currents?
18. Name the components that make up a direct-on-line starter for an induction motor.
19. List three common types of control devices.
20. Give two examples of equipment that can cause electromagnetic interference.

6.5 Accessories for specific situations

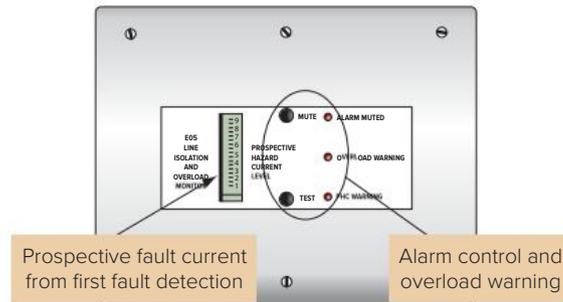
There are many situations and installations in wiring that require special treatment and accessories designed for a specific application. Typical of these are situations where water or steam are constantly present, high-temperature environments, situations where fires or explosions could occur, refrigeration chambers and high-voltage installations.

The wiring methods and accessories acceptable and safe for general wiring are not necessarily suitable for these special installations. For example, damp or wet situations where installations are exposed to wet weather need accessory enclosures commonly described as weatherproof or weather protected. These are broad terms; the International Protection (IP) rating of an enclosure more accurately describes the protection it provides. Refer to the IP ratings chart provided in **Chapter 18**.

The accessories for installations where an explosive atmosphere might be present are of various designs, some accessories being suitable for use in more than one type of location. All are specialised and expensive equipment. Examples of specific accessories are given in **Figure 6.31**.

Clause 7.8 of the *Wiring Rules* calls up a number of Standards covering the specific installations that generally make use of standard accessories, but where there are special precautions regarding their installation. Where a standard is not listed in *Clause 7.8.2*, the *Wiring Rules* will apply to the specific installation.

People receiving medical treatment are more vulnerable to leakage currents than the bulk of the population. In hospitals and medical centres line isolation and overload monitors (LIOM) are installed that enable the integrity of an isolated power-supply system to be continuously monitored. Unlike normal protection, an isolated supply requires two concurrent fault conditions to cause a hazard. The LIOM is able to detect when one fault occurs, and therefore is able to warn of a potentially hazardous situation before any fault current actually flows.

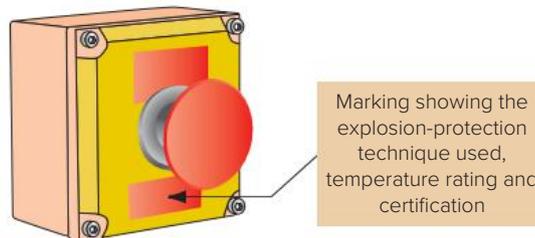


Clause 4.1.3 requires electrical equipment to be designed and installed to cope with the environment it is located in. To this end there are electrical accessories available for even the most harsh conditions. For example, one major manufacturer offers a range of IP-rated enclosures that are resistant against corrosive and industrial chemicals, animal fats, oils, solvents and lubricants. Selection is made easy by a colour code designating the chemical, impact-resistant or thermal properties an accessory provides.



A range of chemical and impact-resistant socket-outlets designated by colour code

A further example is equipment installed in areas where explosive gases or dusts may be present, known as hazardous areas. It is important that electrical equipment in these areas is designed to prevent sparks or heat from the electrical equipment initiating an explosion. The standards for such 'explosion-protected' equipment are called up under *Clause 7.7*.



Dust-proof ignition-proof (DIP) emergency stop button, suitable for installation where explosive dust may be present, such as a grain-handling facility

FIGURE 6.31 Examples of accessories for specific situations



CHECK YOUR UNDERSTANDING

21. Name three situations that require specifically designed electrical accessories.
22. Which *Wiring Rules* clause states that electrical equipment must be designed and installed so that it can cope with the environment in which it is used?
23. Name three standards covering specific electrical installations.

6.6 Data and communications accessories

Data and communications installations include telephone, internet/intranet, audio, cable and terrestrial television and security services. They can be quite complex, even in domestic installations. The most visible accessories for these services are the outlets for the connection of telephones, computers, and audio and video components. These outlets comprise a modular socket with escutcheon plates of the same size, shape and design as those used for power socket-outlets and switches; therefore they can be used with the same types of mounting accessories described in **Section 6.2**.

Local area networks (LANs), where access to internet services is required from a number of locations, are the norm for commercial installations and are not uncommon in domestic installations. Accessories in LANs include devices such as: patch panels for managing circuit distribution; switches—a common connection point for outlets; and switches and routers for directing incoming and outgoing data. A variety of enclosures and racking systems are available for mounting these devices.

Terrestrial television systems with multiple outlets include accessories for splitting the coaxial cable to accommodate a number of outlets and devices for optimising the television signal strength.

It is important to realise that the few examples mentioned or illustrated in this chapter represent only a very small fraction of an immense range of accessories available on the Australian and New Zealand markets. It is strongly suggested that you avail yourself of the many manufacturers' and suppliers' catalogues and technical information sheets to expand your knowledge of what is available.

As stated at the start of this chapter, always make sure that the accessories selected for an installation comply with the safety requirements of *Clause 1.7.3*. Electrical manufacturers can provide a wealth of technical and compliance information and advice on the intended use of their products. Before this information and advice can be given, however, the installing electrician must first decide for each installation what accessories are needed, including their electrical ratings, how they are to be used and the environment in which they are to be installed.



CHECK YOUR UNDERSTANDING

24. Name two data and communication installations.
25. List two accessories found in local area networks.
26. What is the function of a splitter in a multi-outlet terrestrial TV system?
27. Which *Wiring Rules* clause provides information on the safe selection of accessories to be used in an installation?

SUMMARY

- ▶ In the electrotechnology industry, accessories are used to fix materials such as timber, steel, sheet metal, concrete, brickwork and wallboards.
- ▶ Nails, screws, bolts, wall plugs and chemical fixings are all examples of fixings and fasteners.
- ▶ Fixings must be correctly selected and installed so that they suit the material they are being used with and support the weight of the accessory.
- ▶ Percussion tools are operated by powder or compressed gas and are a highly productive method of installing fixings.
- ▶ Hammer drills and tungsten-tipped drill bits are the most commonly used tools for drilling masonry and concrete.
- ▶ Stepper drills and hole saws are useful tools for electrical work.
- ▶ Chasing is the process of cutting channels or grooves in concrete and masonry surfaces to install conduits or cable.
- ▶ There are four basic types of mounting accessories: mounting brackets, wall boxes, plaster mounting brackets and mounting blocks.
- ▶ It is important to ensure accessories are securely mounted in order to reduce the risk of direct contact with live parts.
- ▶ Circuit-breakers, contactors and relays are common switching devices. They must break a circuit without damaging the device and carry its rated load continuously without overheating and deterioration.
- ▶ Switches must be selected according to their application and are categorised by their switching abilities.
- ▶ Socket-outlets are used to connect low-voltage applications and come in a variety of pin configurations.
- ▶ Lighting accessories include batten holders, ceiling roses, cord-grip lamp holders and lamp extension sockets.
- ▶ Protection devices such as circuit-breakers, fuses and residual current devices are designed to protect against electric shock, overload and short-circuit currents as well as overvoltage and undervoltage.
- ▶ Electrical equipment emits energy known as electromagnetic radiation, which impacts the radio frequency spectrum and is known as electromagnetic interference.
- ▶ Manufactured products affected by electromagnetic interference must comply with standards set by the Australian Communications and Media Authority.
- ▶ Devices that comply with those standards are electromagnetically compatible and are labelled accordingly.
- ▶ Accessories for the electrotechnology industry are designed for specific applications, such as in locations where water or steam are constantly present, high-temperature environments, fires, explosion, refrigeration and high-voltage installations.
- ▶ Data and communication installations include telephone, internet/intranet, audio, cable and terrestrial television and security services.
- ▶ It is important to always ensure accessories selected for an installation comply with the safety requirements of *Clause 1.7.3*.

REVIEW QUESTIONS

1. Name a fastening device used to fix accessories to the following:
 - a. timber
 - b. brick
 - c. hollow structures
 - d. concrete.

2. What type of anchor is best for securing a fixing in masonry near a corner? Give a reason for your answer.
3. List three accessories used with powder or gas fastening.
4. How would you secure the following items:
 - a. a mounting block on a masonry wall
 - b. a small non-metallic switchboard enclosure to the surface of a lined timber-framed wall
 - c. a floor-mounted switchboard to a concrete floor.
5. How is a masonry drill different from a standard twist drill?
6. What is the advantage of torque control on a hammer drill?
7. Why should chases in walls be planned in consultation with the builder?
8. List three hazards and control measures associated with fixing activities.
9. List the four basic types of mounting accessories.
10. What functions do the *Wiring Rules* state switches must perform in order to control electrical equipment and to eliminate dangers?
11. State the three precautions for preventing isolated electrical wiring from being inadvertently energised.
12. What are the *Wiring Rules* requirements for an item of switch gear required to disconnect all live conductors of a circuit?
13. What factors affect the current rating of switches?
14. Describe the switching applications of the three utilisation factors of switches.
15. What is the purpose of different receptacle/pin configurations in sockets and plugs?
16. Which clause in the *Wiring Rules* states the requirements for the connection of Edison screw-type lamp holders?
17. Name two devices used for the protection of fault currents.
18. What is the purpose of an RCD?
19. How are products affected by the EMC regulations labelled?
20. List three accessories common to voice and data installations in a customer's premises.

CHAPTER 7

Cables, connections and terminations

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ apply safety procedures to the handling, termination and connection of power and communications cables and conductors
- ▶ explain the difference between a conductor and a cable, noting their main features, construction, shape and form, and their function as determined by their insulation colours
- ▶ identify cable insulation types and characteristics from their designated codes and their applications
- ▶ apply the *Wiring Rules* requirements designating the functions of cable cores and terminating power cables and conductors
- ▶ list the features of aerial and overhead cables and applications of various high-voltage cables
- ▶ follow the correct process for terminating sheathed, armoured, old-type and new MIMS cables
- ▶ select and apply appropriate crimp and compression devices to a variety of conductors and make sound connections using a variety of accessories
- ▶ join conductors to form sound connections by soft soldering
- ▶ list the common types of copper communications cables, their applications, limitations and common arrangements in buildings
- ▶ explain the basic principles of optical fibre transmission, internal and external applications, terminating and joining in compliance with *AS/ACIF Wiring Rules*.

The transmission, reticulation and distribution of electrical energy from the power station to the consumer's equipment are carried out over great distances and sometimes through intricate and complicated circuits. This is achieved by the use of electrical conductors or cables interconnecting the various systems and eventually terminating at equipment that converts the electrical energy to some other form of energy that can be used by the consumer.

In the interests of efficiency, the conductors used for supply or interconnection of electrical equipment must offer minimum opposition to the flow of electric current; that is, their resistance must be low, otherwise an uneconomical power loss will occur within the conductors. The wiring of an installation is designed to have relatively low power loss and the aim is for almost all power conversion to take place within the consuming equipment.

To ensure the effective transmission of voice and data information, the cables used for communications must offer minimum interference to the information from cable characteristics such as impedance, electromagnetic radiation (EMR) and mutual inductance. The cabling of communications services is designed to have minimum loss or distortion of the information transmitted.

7.1 Conductors and cables



CAUTION

Connections and joints

Electrical workers must develop skills that prevent connections or joints from becoming weak links in the chain of electrical distribution or data communications. Particularly in the electrical system, a poor connection can result in loss of supply, property damage from fire or shock through breakdown in insulation.

In the *Wiring Rules* a *conductor* is regarded as a wire or other form of electrical conducting material for carrying current in a wiring system; a radiator element and the winding wire in a motor are not considered conductors within the scope of the *Rules* as defined by *Clause 1.4.35*. The definitions of cables and related terms in the *Wiring Rules* are used in a precise way throughout the trade; therefore *Clauses 1.4.21 to 1.4.27* and *Clauses 1.4.35 and 1.4.36* should be studied and well understood.

Figure 7.1 explains the basic definitions for a conductor and a cable. Other definitions related to cables are given in **Figures 7.2 and 7.3**.

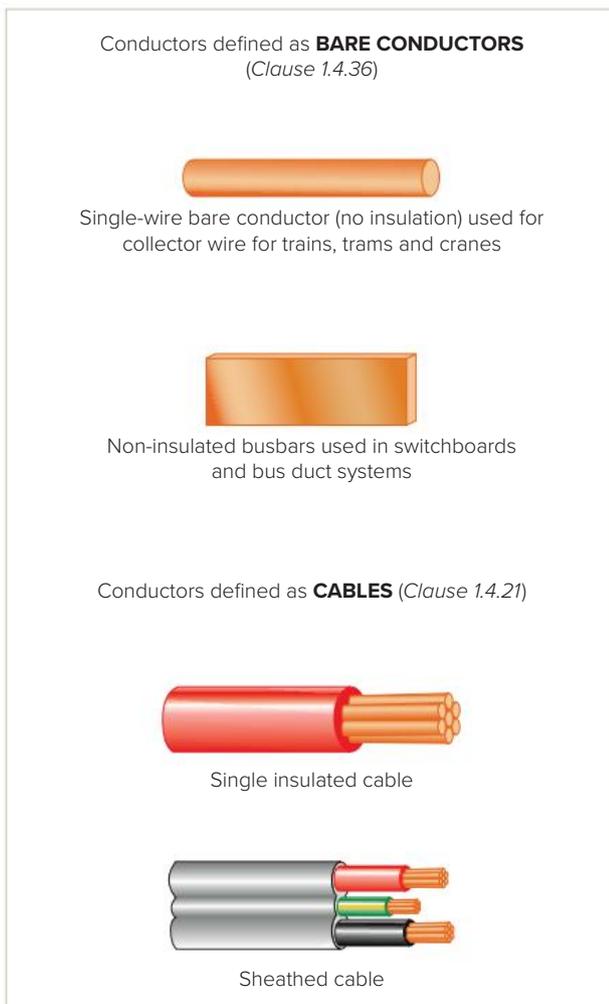


FIGURE 7.1 Conductor and cable definitions

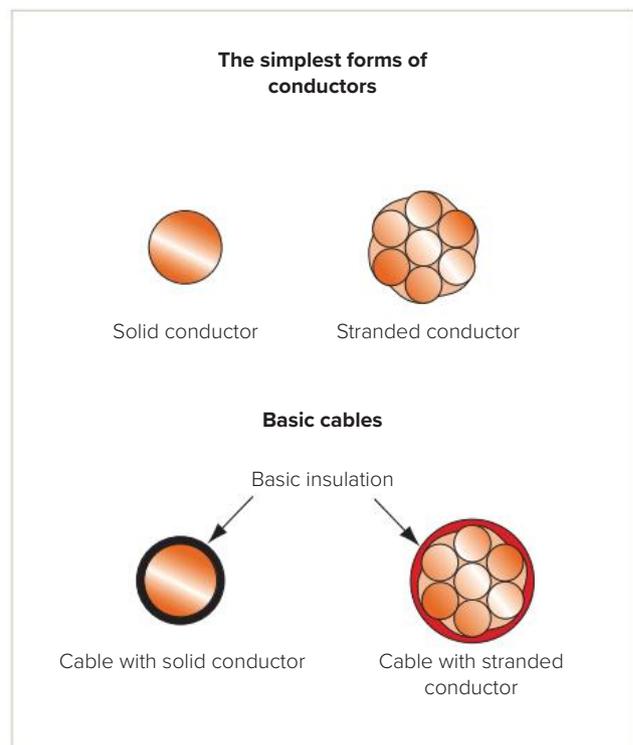


FIGURE 7.2 Basic conductors and cables

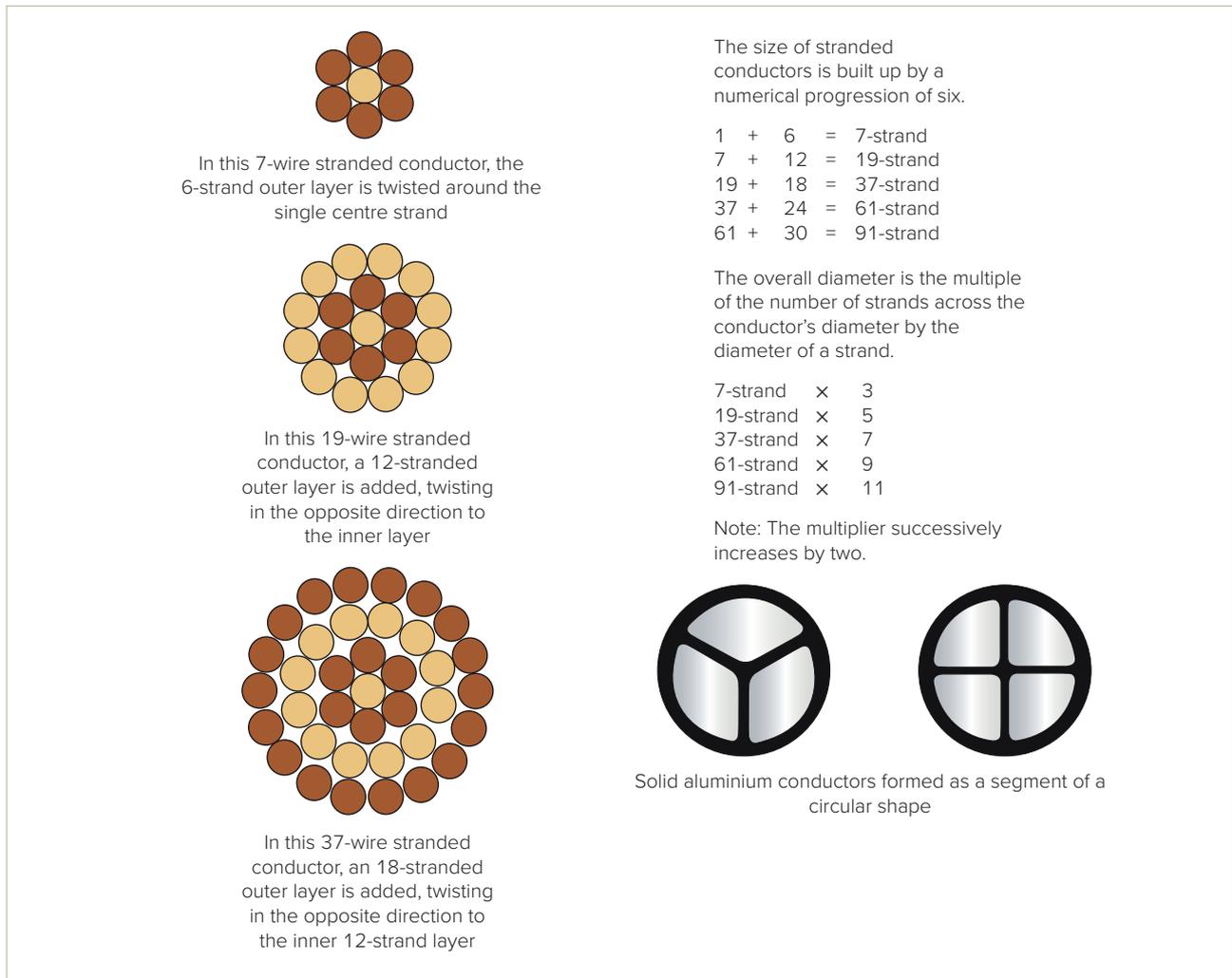


FIGURE 7.3 Conductor forms and structures

7.1.1 Conductor materials and applications

For power wiring, the two main materials used as conductors are copper and aluminium (see **Table 7.1**). Silver is the only metal with a marginally higher conductivity than copper, but it is too expensive for use in power wiring although it is used in switch contacts. Gold is quite often used for fine electronic components and other special applications due to its corrosion resistance.

The *Wiring Rules, Clause 3.5.1* and *Table 3.3* specify the minimum sizes for conductors for various types of wiring systems; *Exceptions 1 & 2 to Table 3.3* allows for smaller conductors provided that their selection is based on fundamental safety requirements. The minimum size of an aluminium conductor for aerial wiring is listed in the table as 16 mm^2 .

Many other conductors for general use will be encountered in practice, the most common being copper, with aluminium conductors used mainly in aerial and transmission lines.

7.1.2 Conductor forms or shapes

The form or shape of a conductor varies widely with the particular cable. The simplest shape is one conductor with a circular cross-section; this circular cross-section is the most commonly used for both single and stranded conductors in most of the smaller cable sizes (see **Figure 7.2**). Sections with other shapes are used mostly in the larger sizes for underground cables and for special-purpose conductors such as overhead collector wires and busbars.

TABLE 7.1 Comparison of copper and aluminium conductors

Features	Copper conductor	Aluminium conductor
Conductor material	Made with a high degree of purity (exceeding 99.5%)	
	Higher tensile strength than aluminium	One-third the weight of copper
Conductivity		Approximately 60% that of copper
Current-carrying capacity		About 80% that of copper for the same size conductor
Susceptibility to corrosion	Resistant to corrosion in unpolluted environments, but affected by ammonia and sulfur fumes	A surface oxide forms on aluminium that has a very high resistance
Joining and terminating	Can be easily soldered or mechanically joined without any special precautions	Surface oxide must be removed and prevented from forming between jointed surfaces with a neutralising paste; the high coefficient of expansion must be considered when joining and terminating
Application	The most commonly used conductor in general wiring	A much lighter metal than copper and so a popular conductor for aerial cables
Conductor size	For general wiring, size of a single-wire copper conductor is not more than 2.5 mm ² (1/1.78). Larger solid conductors used in mineral-insulated metal-sheathed (MIMS) cables and for busbars, some earthing conductors, trolley and collector wires	Used for solid conductors in large sizes as softer than copper and bends more easily

Conductors are manufactured to the Australian/New Zealand Standard *AS/NZS 1125 Conductors in insulated electric cables and flexible cords*, which specifies conductors by their cross-sectional area (CSA) and the number of wire strands that make up the conductor, as shown in **Figure 7.3**. For example, a 2.5 mm² cable can be a single strand of wire (often called *solid*) with a diameter of 1.78 mm, designated 1/1.78, or seven strands of wire (commonly called *stranded*), each with a diameter of 0.67 mm, designated 7/0.67, or a flexible conductor with many strands of thin wire. The conductor of a cable core can be single-strand or multistrand, while the cable itself can be single-core or multicore.

Both copper and aluminium cables use stranded-type conductors, although aluminium conductors are more commonly solid core, and are cheaper and easier to join but less flexible than stranded cables. Some large copper cables for special uses have their flexibility increased by bunch stranding or rope lay.

AS/NZS 3008.1 SERIES

Electrical installations—Selection of cables Part 1: Cables for alternating voltages up to and including 0.6/1 kV

This important Standard gives all the relevant information about cables and, together with the *Wiring Rules*, is used by electricians when planning electrical installation work. It is published as *Part 1.1* for Australian conditions and *Part 1.2* for New Zealand conditions.

Cables that are specifically manufactured for increased flexibility (*Wiring Rules, Clause 1.4.24*) are termed flexible cables, and their flexibility is achieved with a conductor of many small-diameter strands. For example, a 500 mm² conductor has 1403 strands, each 0.67 mm in diameter. A flexible cable with not more than five cores with a maximum conductor area of 4 mm² and a maximum wire (strand) diameter of 0.31 mm is classified as a flexible cord (*Wiring Rules, Clause 1.4.40*). In some very small flexible cords, to provide extreme flexibility metal tinsel is used as a conductor, but its use is restricted to the supply of low-current-rated appliances of not more than 0.5 A. Flexible cords used as installation wiring must comply with *Clause 3.9.7.4* of the *Wiring Rules*.



CHECK YOUR UNDERSTANDING

1. What is the difference between a conductor and a cable?
2. List the advantages and disadvantages of copper and aluminium conductors.
3. Describe the features of stranded cables.
4. What is a flexible cord? Refer to the *Wiring Rules*.
5. Explain the importance of *AS/NZS 3008.1*.

7.2 Types of cable insulation

The primary function of cable insulation is to withstand electrical pressure or voltage and thus to confine the current to the conductor without any leakage or deterioration in its properties, even after prolonged use. The most commonly used insulation materials are plastic materials and polymeric compounds including thermoplastic, elastomer and polyethylene groups. Additional insulation material is used as sheathing around one or more insulated cable core, to provide secondary insulation and to protect the insulation of the cable cores against physical damage. These are known as sheathed cables and they meet the definition of double-insulation (*Clause 1.4.73(c)*). Apart from the conductor material (copper or aluminium), cables are described by their permitted maximum normal operating temperature and a coded combination representing the type of insulation/sheathing material. Cables in common use are listed in this way in *Table 3.2* of the *Wiring Rules* and *Table 1* of *AS/NZS 3008.1 Electrical installations—Selection of cables*.

See **Table 7.2** for a guide to the coding of insulated cables that are in common use.

Cable manufacturers' catalogues cite additional coding for cable sheaths not listed in the *Wiring Rules*. For example, 3V is a thermoplastic polyvinyl chloride (PVC) designed for easier stripping than cables with 4V and 5V sheaths. Other sheath codes include GP for general purpose and HD for heavy-duty applications. Sheathed cables with cross-linked insulated cable cores often have PVC sheaths, as the sheathing is not in direct contact with the conductors.

NOTE: The specifications for polymeric cable insulation are contained in *AS/NZS 3808 Insulating and sheathing materials for electric cables* and the compliance Standard for cables with polymeric insulation is *AS/NZS 5000 Electric cables—Polymeric insulated. Part 1* of the Standard is for working voltages of 0.6 to 1 kV. *Part 2* covers insulation and sheathing for single-core and multicore cables to 16 mm² for working voltages of 475 to 750 V. These cables are popular for general lighting and power work because they are lighter and smaller in overall size compared with 0.6/1 kV insulated cables.

TABLE 7.2 General guide to coding of insulated cables in common use

Designated code	Insulant type	Characteristic	Typical application
Number e.g. 75, 90	All	Maximum operating temperature in °C of the conductor above which the insulation will deteriorate and eventually break down	Most common is 75 °C, while cross-linked insulants have ratings up to 110 °C; ratings of 150 °C and higher are available in fibrous, special polymeric (silicone rubber) and MIMS cables
V, TP, TPE	Thermoplastic compounds	Tends to flow and deform under pressure at higher temperatures	Most common for general wiring
R-	Cross-linked elastomer	Ability to maintain shape under mechanical pressure	Suitable for more severe conditions such as conductors that may operate at maximum current-carrying capacity or are subject to sustained overload
EP, CPE, CSP, S	Types of elastomer compounds		
X	Cross-linked polyethylene compounds		
HT		Properties of reduced smoke emission and flame propagation under fire conditions	Specified for areas where people are more vulnerable to smoke and spread of fire, such as in residential institutions and hospitals
HF		Free of compounds containing halogens such as chlorine that emit toxic gases at higher temperatures	Specified in locations where people are more vulnerable to exposure to smoke and toxic fumes, such as in underground rail systems
HFI		Properties of HF and HT	
UV		Suitable for exposure to UV radiation	Suitable for outdoor areas exposed to direct sunlight
MIMS (mineral-insulated metal-sheathed)	Magnesium oxide	Remains sound at relatively high temperatures; however, is hygroscopic (absorbs moisture, which diminishes its dielectric properties) and must be sealed from air	An alternative to HT and HF insulated cables but more expensive; used where cable must perform under higher temperatures

**CAUTION****When purchasing cables**

Although it is not usually necessary to consult cable compliance Standards, it is essential for electricians to ensure the cables they install comply with cable standards as required by the *Wiring Rules, Clause 1.7.3*. The standard that a cable complies with should be marked on the cable's insulation or sheath.

Table 1 of AS/NZS3008.1 lists Type-150 fibrous or polymeric insulated cables for temperatures up to 150 °C; however, higher temperature ratings are available. Braided fibreglass is common insulation for the internal wiring of heating and cooking appliances. The polymeric known as silicone rubber can be encountered in the internal wiring of luminaires and similar electrical installations for elevated temperature conditions. Processed fibrous insulation is used in special high-temperature situations, mainly as internal wiring for equipment such as furnaces. One manufacturer makes cables rated from 100 to 350 A that are fibreglass-braided and silicone-lacquered. These are primarily used for electric motors, for industrial heating equipment in plants such as aluminium smelters and foundries, for boilers and in factories where electrical cables are likely to be subjected to excessive heat.

Insulants, like most technologies, are under constant development and only the most common have been introduced here. Electricians can keep up to date by consulting manufacturers' technical manuals and the most recent Standards from Standards Australia and Standards New Zealand.



CHECK YOUR UNDERSTANDING

6. Explain the primary purpose of cable insulation.
7. Describe the characteristics of cables designated HT and HF.
8. What is the normal operating temperature of MIMS cable?
9. Where else would you find additional coding for cable sheaths not listed in the *Wiring Rules*?
10. Name a type of cable insulation suitable for internal wiring of equipment where the temperatures may rise to 150 °C.

7.3 Power cable classification

A power cable is known or classified by its components, as shown in the example of a sheathed multicore cable in Figure 7.4.

The description of three-core and earth cables from a cable manufacturer's catalogue:

3-core + earth, circular, V-90 insulated, PVC (3V90) sheathed to AS/NZS 5000, copper conductors, 90°C
 1.5 to 16 mm² 450/750V to AS/NZS 5000.2; 10 to 300 mm²
 0.6/1kV to AS/NZS 5000.1

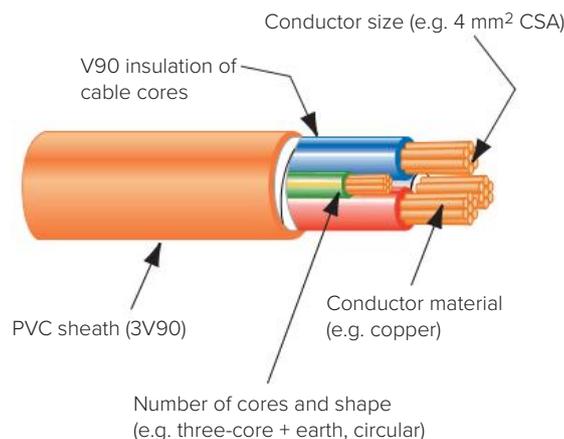


FIGURE 7.4 Example of how a power cable is classified

7.3.1 Identification of cables

The outer sheaths of cables are often coloured to identify their function. For example, orange sheathing identifies power cables and red-sheathed cables are used for fire-protection systems, while blue is commonly used for structured data communication cables.

7.3.2 Identification of cable cores

Clause 3.8.1 of the *Wiring Rules* stipulates that conductors must be identified to clearly show their intended function. This is usually shown by the colour of the conductor insulation, as **Figure 7.5** shows for both installation wiring and single-phase flexible cords. Clause 3.8.2 permits coloured non-conductive materials such as sleeving to be used at cable terminations to identify active and neutral functions of conductors; however, a conductor with green/yellow, green or yellow insulation may not be used under any circumstances as an active or neutral conductor.

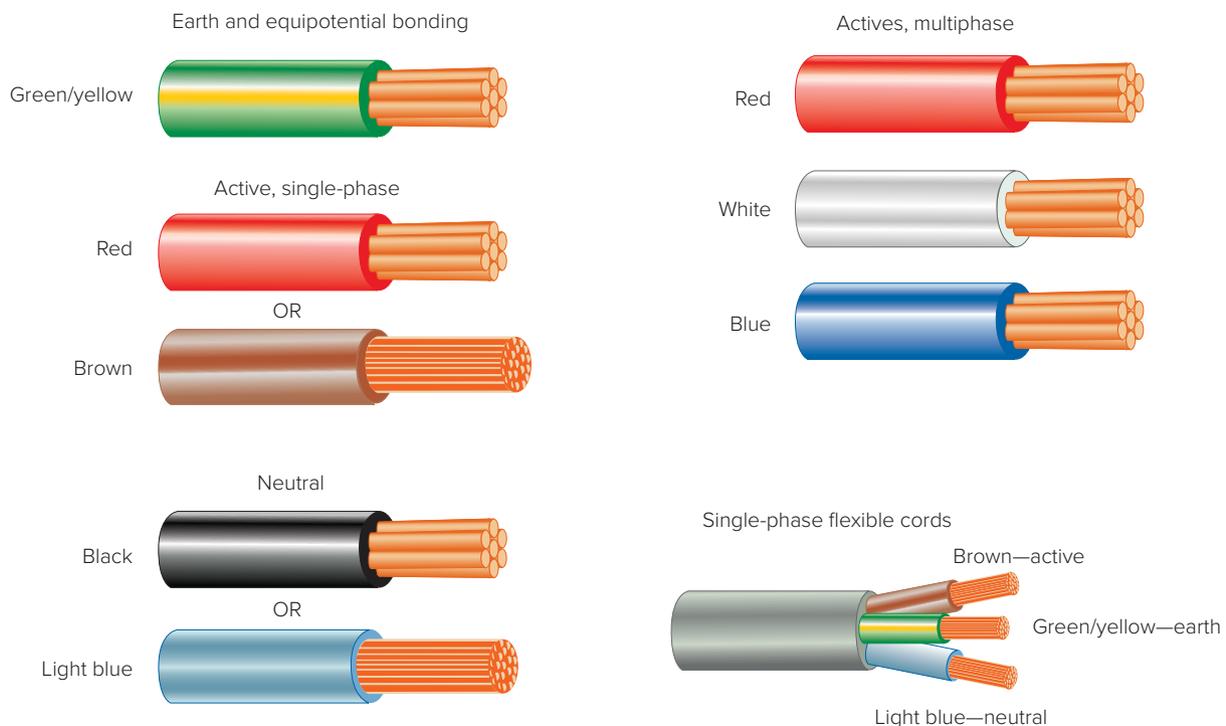


FIGURE 7.5 Power cable core identification

The numbering or lettering of active and neutral conductor cores of multicore cables is an acceptable means of identification (Clause 3.8.3.3) and is usually the method used where the type of insulation is difficult to manufacture in the required colours. The active and neutral cores of bare aerial conductors need not be coloured and a bare aerial earthing conductor must be identified at its termination points by the symbol \perp or the letter E (Clause 3.8.3.5).

Cables are manufactured in various configurations in accordance with relevant standards, including conductor identification colours complying with Clause 3.8.

The Australian/New Zealand Standard for conductor colours for multiphase flexible cords and cables is red, white and blue for actives (phases 1 to 3), black for neutral and green for earth. The *Wiring Rules*, Clause 3.8.3.4 points out that this contrasts with the International Electrotechnical Commission (IEC) requirements for multiphase flexible cords and cables, and in particular equipment wiring, and so care needs to be taken when connecting equipment that does not use the Australian/New Zealand conductor colour code.



TEST BEFORE YOU TOUCH

Do not rely on cable colours or markings as the only means of identification. Before connecting or disconnecting any cable, always follow safe testing procedures in order to know whether the cable is safe to work on and to confirm its function.



CHECK YOUR UNDERSTANDING

11. What are the main features of a sheathed power cable?
12. Why are the outer sheaths of cables coloured (e.g. red-sheathed cables)?
13. Which *Wiring Rules* table is used to define conductor colours for active, neutral and earth?
14. What symbol is used to identify bare aerial earthing conductors?
15. Which *Wiring Rules* clause identifies alternative and European cable colours?

7.4 Power cable types and applications

7.4.1 Cables in general wiring

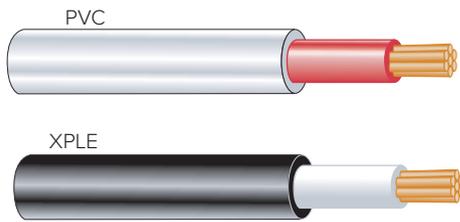
Thermoplastic sheathed cable (commonly known in the trade as TPS) is the most popular power cable where a protective enclosure is not required, because of its ease of installation. The conductors are PVC insulated, the cable cores are PVC sheathed and the cable is classified as having double insulation (see *Clause 1.4.73 (c)*), the outer sheath serving as both insulation and mechanical protection. TPS is manufactured as multicore flat cables in the 450/750 V voltage grade. Single-core circular TPS cable, more commonly known as SDI (single double-insulated), is available in both 450/750 and 0.6/1.0 kV voltage grades.

Multicore circular cables used for general wiring are manufactured in 0.6/1.0 kV voltage grades with PVC or XPPE (cross-linked polyethylene) insulation and a PVC sheath with or without steel wire armour (SWA). Although sheathed cables without armouring are sometimes installed in an enclosure such as conduit or trunking for convenience of installation, this is not a requirement of the *Wiring Rules* provided the cables are not subject to mechanical or other environmental damage. TPS, SDI and circular cables are suitable for underground wiring subject to the conditions of *Clause 3.11*.

Single-insulated cable (or building wire as it is commonly called) is manufactured in 0.6/1.0 kV voltage grades. Building wire must be installed in an enclosure, as required by *Clause 3.10*. Typically, the enclosures will be conduit or trunking. The use of building wire for general wiring has declined in recent years in favour of the convenience and lower overall cost of sheathed cables. Building wire is still commonly used in wiring between accessories in switchboards and in the final connection to an appliance such as a motor.

The cables shown in **Figures 7.6 to 7.12** are examples of those used in general wiring, along with typical cable specifications and where they are used.

Common name: Single double-insulated (SDI)



Where it is used

PVC SDI cable is used for general wiring in domestic, commercial and industrial installations where the cable is not subject to mechanical damage. May be installed unenclosed subject to *Clause 3.9* and is suitable for underground wiring subject to *Clause 3.11*. The same installation requirements apply to XPLE SDI cable; however, it is more typically used for heavier conditions in buildings and for industrial plants. It is particularly suitable for circuits in which overloads may occur.

Typical specifications for PVC cable

Compliance standards: *AS/NZS 5000.2* for 450/750 V grade with 1 mm² to 16 mm² copper conductors
AS/NZS 5000.1 for 0.6/1.0 kV grade with 1 to 400 mm² copper conductors

Insulation: PVC, V 90 black or red

Sheath: PVC, 3V 90 white

Normal operating temperature: 75 °C

Typical specifications for XPLE cable

Compliance Standards: *AS/NZS 5000.1* for 0.6/1.0 kV grade with 16 to 630 mm² copper conductors

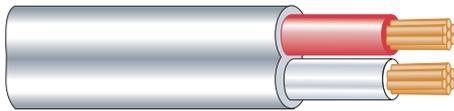
Insulation: XPLE, X-90, white

Sheath: PVC, 5V 90 black

Normal operating temperature: 90 °C

FIGURE 7.6 Power cable types and applications—single double-insulated (SDI)

Common name: TPS twin



Where it is used

Used for general wiring in domestic, commercial and industrial installations where the cable is not subject to mechanical damage. May be installed unenclosed subject to *Clause 3.9* and is suitable for underground wiring subject to *Clause 3.11*. A common application for cable with red and white cores is for active and switch wire in lighting circuits (see **Chapters 5 and 8**).

Typical specifications

Voltage: 475/750 V complying with *AS/NZS 5000.2*

Conductors: copper, 1 to 16 mm²

Insulation: PVC, V 90 red and white or red and black
Sheath: PVC, 3V 90 white for general wiring, red for fire alarm circuits

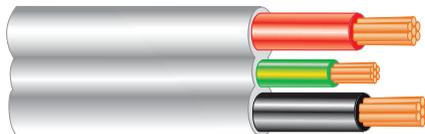
Normal operating temperature: 75 °C

FIGURE 7.7 Power cable types and applications—TPS twin

Common name: TPS twin and earth

Where it is used

Used for general wiring in domestic, commercial and industrial installations where the cable is not subject to mechanical damage. May be installed unenclosed subject to *Clause 3.9* and is suitable for underground wiring subject to *Clause 3.11*. A common application is for supply to light and power circuits looping at each point or switch (see **Chapters 5 and 8**).



Typical specifications

Voltage: 475/750 V complying with *AS/NZS 5000.2*

Conductors: copper, 1 to 16 mm²

Insulation: PVC, V 90 red, black and green/yellow

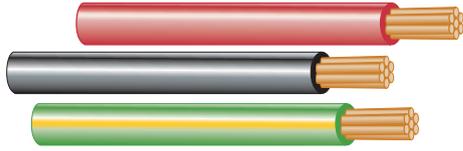
Sheath: PVC, 3V 90 white

Normal operating temperature: 75 °C

Note: Cables with similar specifications are available as three-core (red, white and blue cores) and three-core and earth (red, white, blue and green/yellow cores).

FIGURE 7.8 Power cable types and applications—TPS twin and earth

Common name: Building wire



Where it is used

Used for installation wiring, typically in non-domestic installations, and internal wiring of switchboards, control panels and electrical equipment. The cable must be installed in a suitable enclosure such as conduit or trunking as required by *Clause 3.10*. It is suitable for underground wiring subject to *Clause 3.11*.

Typical specifications

Voltage: 0.6/1.0 kV complying with *AS/NZS 5000.1*

Conductors: copper, 1 to 150 mm²

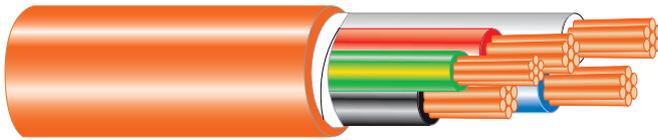
Insulation: PVC, V 90 all phase and neutral colours and green/yellow. Other colours may be available

Normal operating temperature: 75 °C

FIGURE 7.9 Power cable types and applications—building wire

Common name: Circular multicore cable

Cable types: PVC or XPLE two-, three- and four-core and earth (4-core and earth shown)



Where it is used

Circular cable is used for consumers mains, submains and final subcircuits in commercial and industrial installations where the cable is not subject to mechanical damage. It may be installed unenclosed subject to *Clause 3.9* and is suitable for underground wiring subject to *Clause 3.11*. The XPLE type is more typically used for heavier conditions in buildings and industrial plants where higher operating temperatures are likely. It is particularly suitable for circuits in which overloads may occur.

Typical specifications for PVC cable

Compliance Standards: *AS/NZS 5000.1*, 0.6/1.0 kV grade

Conductors: copper, 1.5 to 95 mm² for two-core and earth and up to 240 mm² for three- and four-core and earth

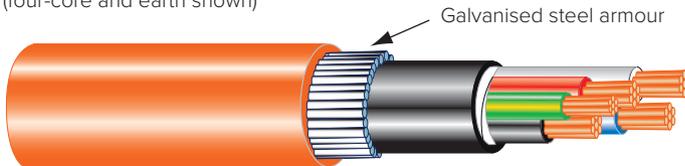
Insulation: PVC, V 90, phase, neutral and earth colours

Sheath: PVC, 5V 90 orange

Normal operating temperature: 75 °C

Common name: Steel wire armoured (SWA) multicore cable

Cable types: PVC or XPLE two-, three- and four-core and earth (four-core and earth shown)



Where it is used

SWA cable is used for the same types of circuits and installations as circular cable but in situations where mechanical damage may occur to a less protected cable.

Typical specifications for XPLE cable

Compliance Standards: *AS/NZS 5000.1*, 0.6/1.0 kV grade

Conductors: copper, 16 to 120 mm² for two-core and earth and up to 240 mm² for three- and four-core and earth

Insulation: XPLE, X-90, phase, neutral and earth colours

Sheath: PVC, 5V 90 orange

Normal operating temperature: 90 °C

FIGURE 7.10 Power cable types and applications—circular multicore and SWA

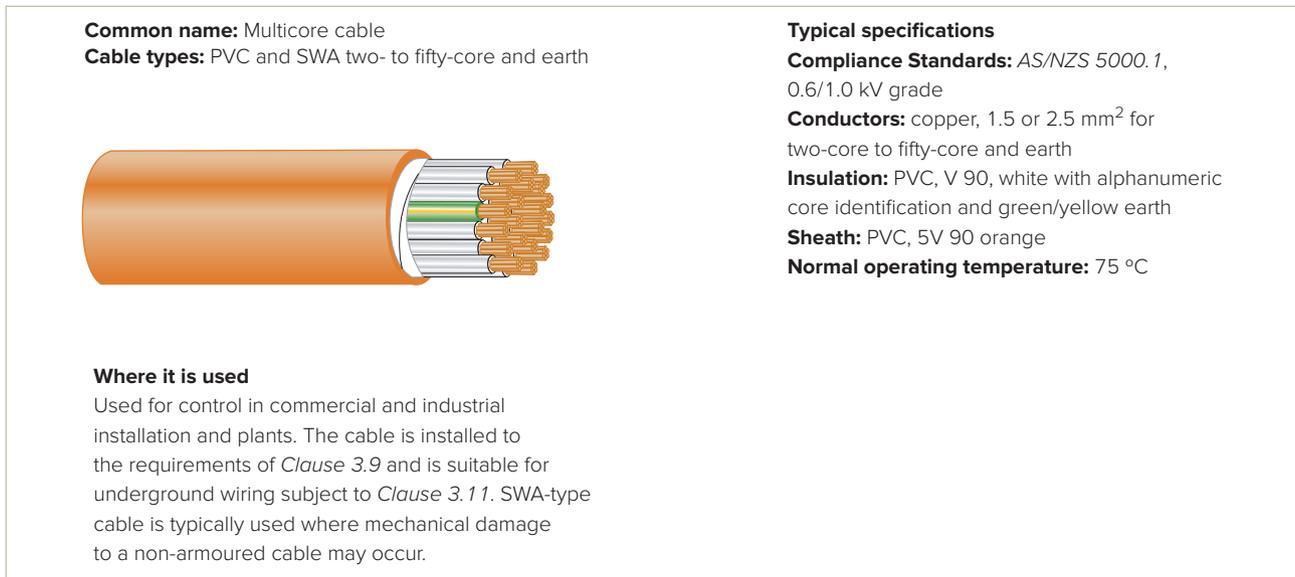


FIGURE 7.11 Power cable types and applications—multicore control

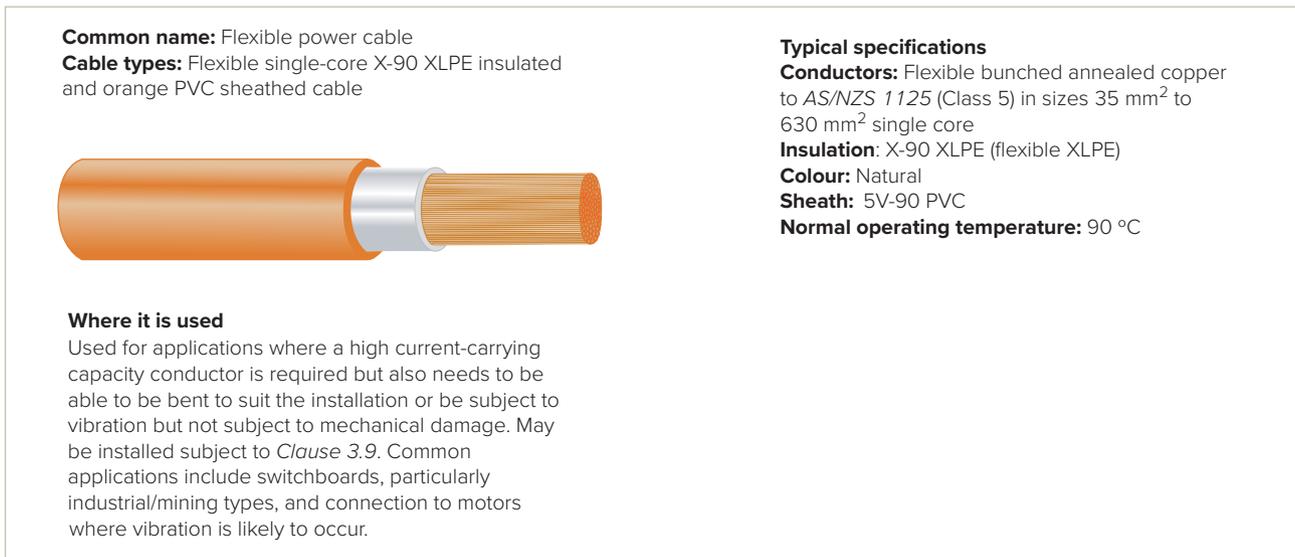


FIGURE 7.12 Power cable types and applications—flexible sheathed single-core

7.4.2 Fire-performance cables

The threat of fire is increased in places where fast evacuation of people is difficult. These places include high-rise office and residential towers, large public buildings such as shopping centres, museums, galleries and hospitals, and the underground areas of rail systems. In large modern installations, cables that minimise flame propagation and the emission of smoke and toxic gases are mostly used for general wiring. However, there is the additional need to maintain supply to some circuits for a period of time during a fire. These are the circuits that supply essential services such as fire pumps, emergency service lighting, passenger lifts, lighting to hospital operating theatres, and security control and communication systems.

Along with the general wiring requirements specified for the electrical installation in such areas, the fire performance of parts of the installation is specified by relevant standards. For example, *Clause 7.2.2.2.1* requires that the fire performance of wiring systems supplying fire and smoke control equipment, evacuation equipment and lifts (elevators) must comply with a particular WS (wiring system) classification specified by the Standard relevant to the installation of such equipment. The WS classifications are given in *AS/NZS 3013 Electrical installations—Classification of the fire and mechanical performance of wiring system elements*, which classifies wiring systems by their resistance to

the effects of mechanical impact, fire and water. Guidance for the application of this Standard is given in *Appendix H* of the *Wiring Rules*.

Fire-performance cables can be divided into two main groups:

- ▶ relatively low-cost halogen-free cables that do not propagate flame, emit very little smoke while burning and do not generate acid or corrosive gases, for use where circuit integrity in fire conditions is not required for essential services—these are intended for situations where cables must not emit dense smoke or corrosive gases
- ▶ cables that meet the above fire safety criteria and in addition continue to operate for an extended period during a fire—say, two hours or more—thus maintaining the operation of essential services such as fire and smoke control and evacuation equipment and fire pumps.

Non-metallic sheathed cables are the most common fire-performance cables used in electrical installations today. These cables use improved fire-performance polymeric materials for their insulation and sheaths, such as those designated HF, HT and HFI (see **Table 7.2**). Examples and specifications of these types of cables are given in **Figures 7.13 to 7.15**.



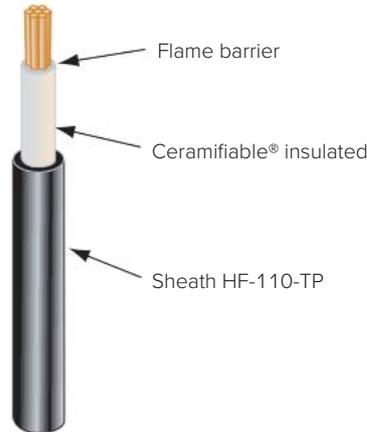
FIGURE 7.13 Fire-performance cables—Firestop circular



FIGURE 7.14 Fire-performance cables—Firestop flat

Another type of fire-performance cable that has been in use in electrical installations for many years is mineral-insulated metal-sheathed (MIMS) cable, as shown in **Figure 7.16**. This cable was originally developed in France in 1896 for use in oil tankers, passenger liners and submarines, and first manufactured in England in 1937 by Pyrotanax Ltd. Although the manufacturer of the cable has changed several times, it retains the name Pyrotanax. In recent years, the high cost of the cable and its complex installation have led to a preference for use of the less costly non-metallic fire-performance cables where less than the highest fire performance is required.

Proprietary name: Pyrolex
Cable types: single-core
Conductor: copper with maximum operating temperature of 110 °C
Conductor sizes: 10 to 630 mm²
Fire rating: WS52W, i.e. the cable met test criteria of maintaining integrity for two hours in simulated fire conditions and effects of moderate impact.

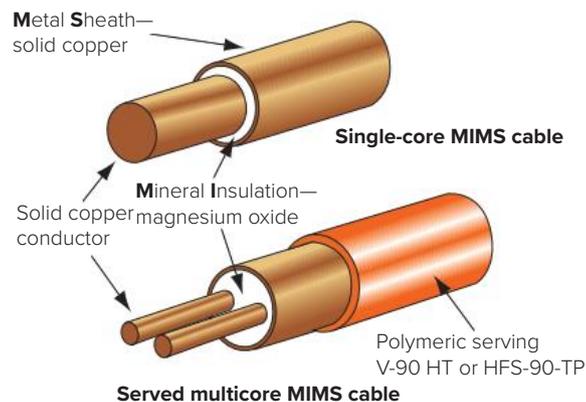


Where it is used

Used for essential power supplies and circuits such as mains and submains and smoke extraction fans, lifts and essential equipment in the event of a fire.

FIGURE 7.15 Fire-performance cables—Pyrolex

Common name: Pyro
Cable types: light-duty 500 V and heavy-duty 750 V grades single and multicore with and without serving
Conductor: solid copper with maximum sheath temperature of up to 250 °C
Conductor sizes: 1.0 to 2.5 mm² light duty, 1.0 to 400 mm² heavy-duty single-core



Where it is used

Used for essential power supplies and circuits such as mains and submains and essential equipment in the event of a fire. The non-served cable is used in high-temperature industrial situations such as around process heating and furnace equipment. Served cable is used in petrochemical plants, marine installations and is particularly suitable in hazardous areas.

FIGURE 7.16 Fire-performance cables—Pyrotenax

However, it is still in use, particularly where performance under higher temperatures is required, as it is permitted to operate with a copper sheath at temperatures of up to 250 °C under conditions specified in *Table 3.2 Note 5* of the *Wiring Rules*. The manufacturer successfully tested the cable for fire-survival qualities that re-created realistic fire situations by exposing the cable to extreme high temperature (950 °C) and simulating the effects of falling debris and water exposure from fire-fighting equipment. Pyrotenax has been used in many electrical installations in Australia and New Zealand in the past and, when these installations undergo refurbishment, it is often cost-effective to reuse the existing cables, requiring electricians to have the skills for its installation. Pyrotenax is manufactured overseas by Tyco Thermal Controls and is available in Australia through Pyrotenax Sales Pty Ltd and cable suppliers.

7.4.3 Aerial and overhead conductors and cables

Aerial conductors (bare) and cables (insulated) are cables strung between supporting poles or posts above the ground in an electrical installation in accordance with *Clause 3.12* of the *Wiring Rules*. Overhead conductors/cables generally refer to a distributor's low-voltage service lines or mains and medium-voltage (>1.0 kV <33 kV) cables installed on street poles, and medium-voltage and high-voltage transmission cables installed on steel towers.

Due to weight and cost factors, aluminium is the most common conductor material for overhead cables, although copper conductors are still available. Overhead transmission lines and many overhead distribution lines use bare aluminium conductors manufactured from high-purity electrical-grade aluminium or aluminium alloy. To sustain the tensile strength needed over long spans overhead, aluminium conductors incorporate steel reinforcing in various forms such as aluminium conductor galvanised steel reinforced (ACSR/GZ), as shown in **Figure 7.17**.

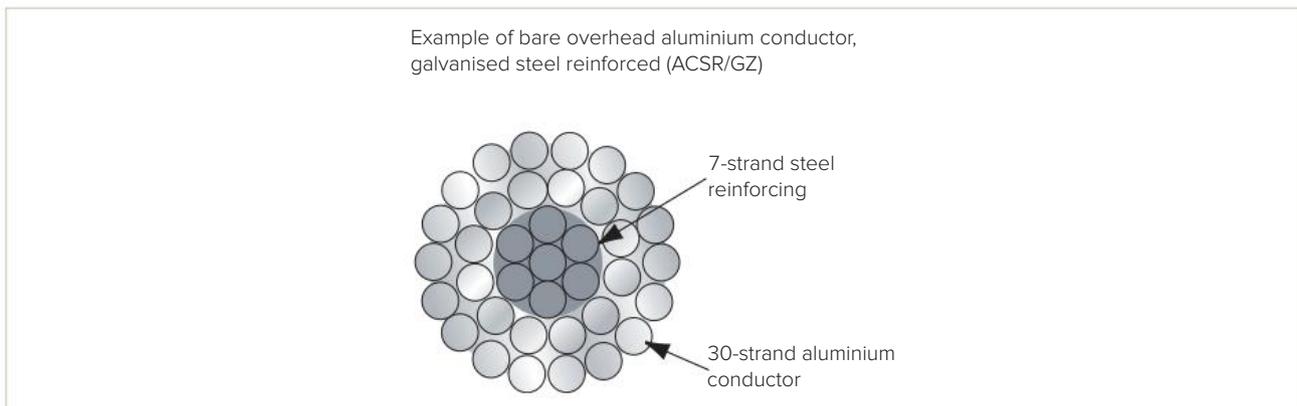


FIGURE 7.17 Aerial and overhead cables—bare overhead cable

Earth wires for transmission lines are usually ACSR/GZ or galvanised steel types and are now manufactured with the addition of optical fibres. For example, Prysmian Cables Pty Ltd supplies an optical ground wire (OPGW), as shown in **Figure 7.18**, that provides the means for internal line protection, transmission and distribution network communications and control, and also opens up the possibility of an additional revenue stream through leasing of optical fibre to third parties.

Copper and copper alloy conductors are now rarely used for bare overhead transmission or distribution, and find their main applications as collector wires for travelling overhead cranes and hoists, and for the contact wires on electric rail systems.

All the applications mentioned use bare conductors; the use of insulated overhead mains in a supply system is usually restricted to the aerial service line. Insulated aerials are in use mainly on the consumer's premises. However, low-voltage aerial bundled cable (LOBAC), as shown in **Figure 7.19**, is now commonly used in Australia for low-voltage distribution and service lines as an alternative to bare-conductor overhead mains.

Their advantages over bare conductors include:

- ▶ reduced necessity for clearance of trees in timbered areas
- ▶ elimination of the possibility of bushfires from the clashing of bare conductors in high winds
- ▶ cost savings in using shorter poles

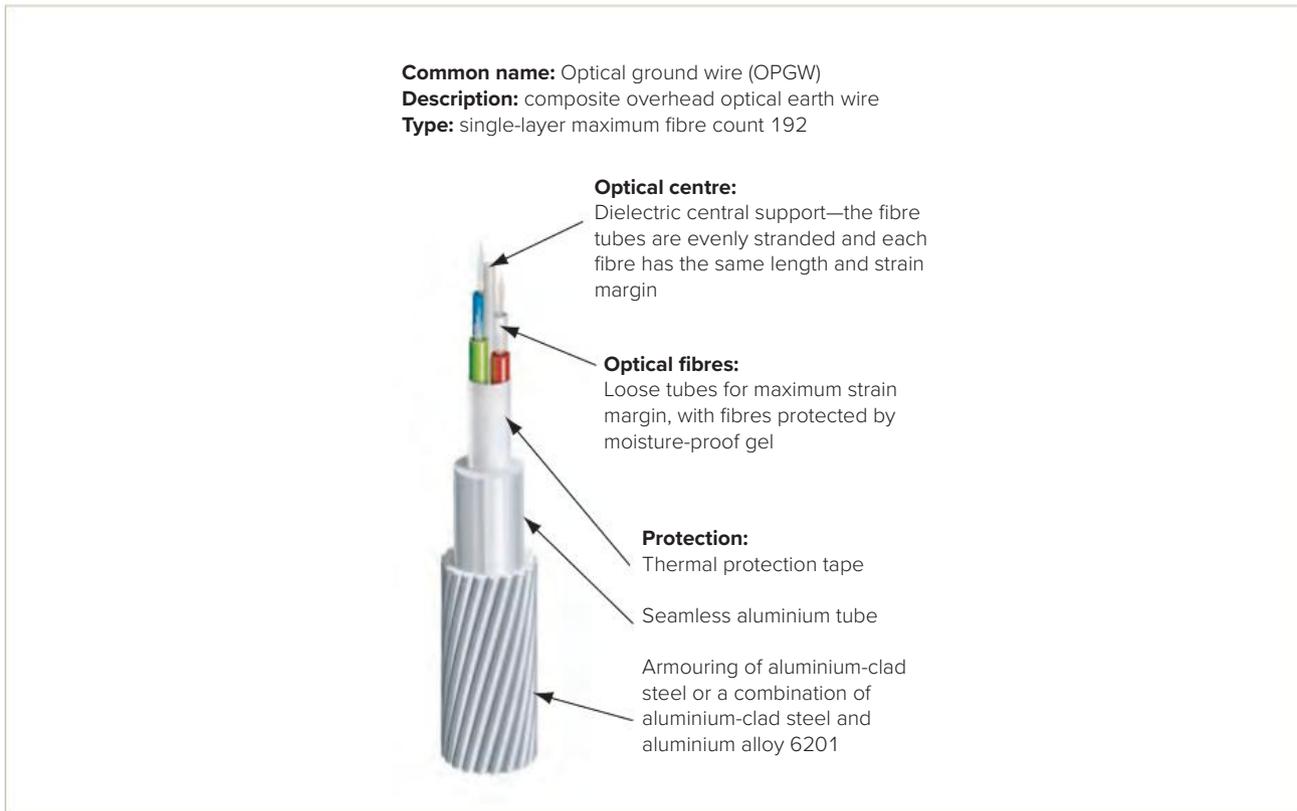


FIGURE 7.18 Aerial and overhead cables—optical ground wire

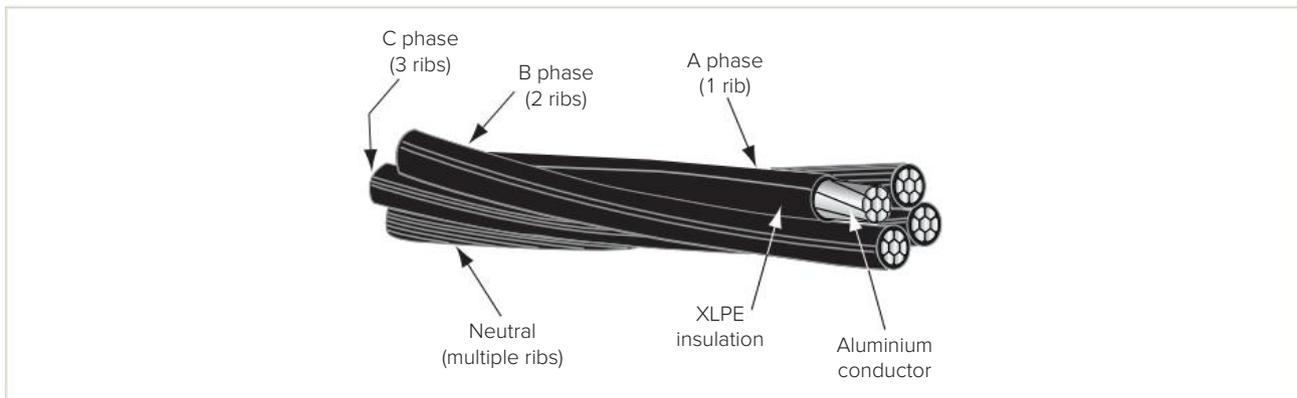


FIGURE 7.19 Aerial and overhead cables—low-voltage aerial bundle

- ▶ absence of phase-spacing requirements
- ▶ increased safety to line workers because service connections can be tapped off using special insulated piercing connectors and tools.

These cables are available as two-core, three-core and four-core systems. Other types of aerial conductors include single-core types and multicore types in flat and twisted sections, and single-core and multicore neutral screened cables.

7.4.4 Higher voltage and special-application power cables

Certain situations arise that require cables with particular performance requirements not applicable to general wiring. These include low-voltage, medium-voltage and high-voltage underground transmission and distribution cables, cables used in the mining and petrochemical industries, submarine cables and cables for variable-speed drives. Although electricians may not regularly deal with all these cables, knowledge of them is important, if only from a safety aspect.

Higher voltage power cable

Paper-insulated lead-covered (PILC) cable in medium- to high-voltage ($>1.0 \text{ kV} \leq 33.0 \text{ kV}$) power supply applications has given way to cross-linked polyethylene (XLPE) cables. These are available as light-duty or steel wire armoured (SWA) heavy-duty, both with either copper or aluminium conductors and copper wire screening. Cables with protection against termite and rodent attack are also available. An example and specifications of HV (used in the medium HV range) power cables are shown in **Figure 7.20**.



FIGURE 7.20 Example of higher voltage power cable

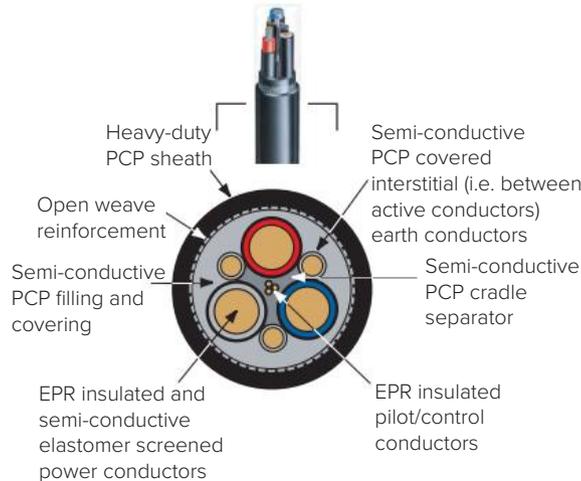
Mining cable

Mining activities involve the movement of high-powered electrical equipment, so the cables that supply them must be flexible and able to withstand rough mechanical treatment. The insulation materials used in mining cables are similar to those in MV cables, as most mining equipment is designed to operate at voltages above 1.0 kV. There is a large variety of mining cables available, each designed to meet the needs of specific mining equipment, safety, mechanical and electrical protection requirements. An example and specifications of mining cables are shown in **Figure 7.21**.

Cable for variable-speed drives

Cables that connect a variable-speed drive (VSD) to the motor it supplies have been developed to overcome problems with electromagnetic interference, high earth currents and reflected waves. The rotational speed of an induction motor is proportional to the supply frequency, normally 50 Hz. Modern VSDs vary the frequency by first converting (rectifying) the a.c. supply to d.c., then converting the d.c. to a quasi-sine wave through a fast-switching inverter. A quasi-sine wave is created by a series of pulses, the width of which can be modulated

Common name: HV flexible mining cable
Cable types: 245 (AS/NZS 1802) 1.1–6.6 kV semi-conductive screened flexible multicore cable
Conductor sizes: 50 mm² to 120 mm²
Conductor strands: 0.30 mm × 703 to 2146
Screen: Semi-conductive insulation screen ensures operation of the circuit-protection device in the event of insulation breakdown.



Where it is used

This mining cable is designed to supply a longwall shearer and the very flexible conductors allow for reduced bending radii.

FIGURE 7.21 Higher voltage cable—mining cable

to vary the frequency and hence the speed of the motor. VSDs are often referred to as variable-voltage variable-frequency (VVVF) drives because the impedance characteristic of induction motors requires the voltage to be adjusted when the frequency is changed.

Figures 7.22 and 7.23 outline the problems with VSDs and how these are solved by the design features of VSD cables.

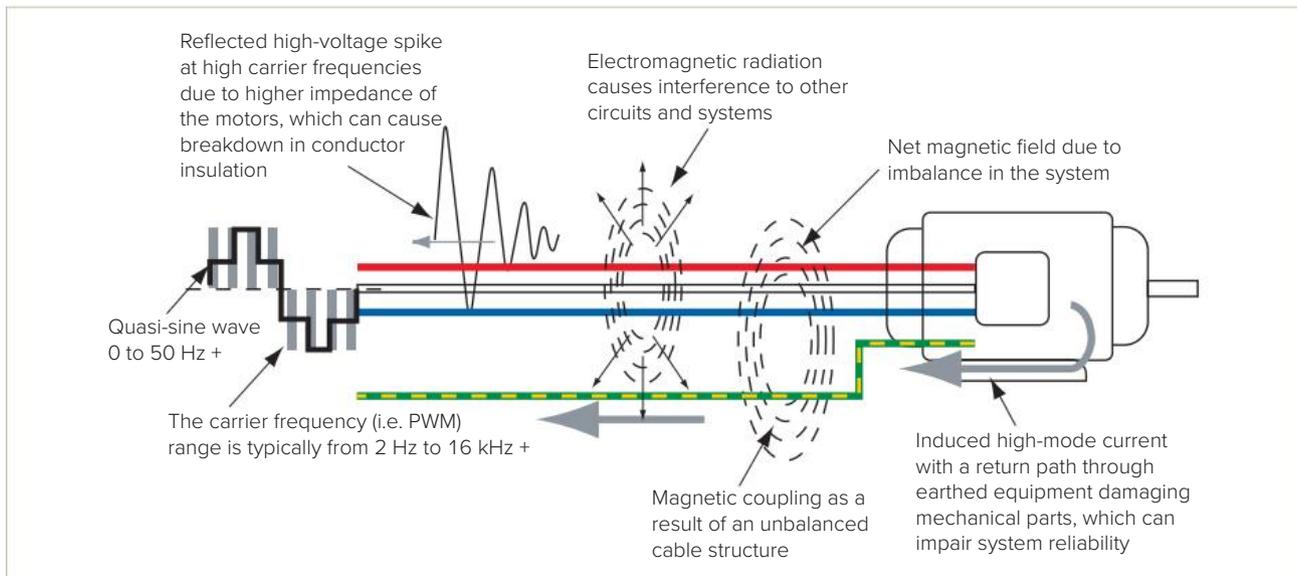
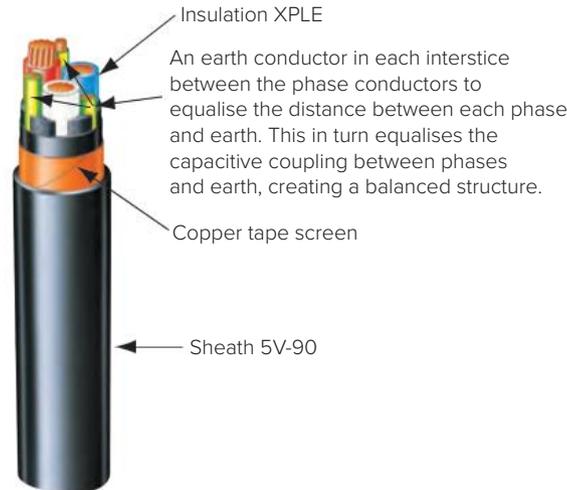


FIGURE 7.22 Variable-speed drives—why a special cable is needed

Common name: Variable-speed drive (VSD) cable
Cable type: symmetrical, copper screened XPLE
Conductor: stranded copper, typically 2.5 to 300 mm²
Maximum operating temperature: 90 °C



Where it is used

Used for installation wiring of the power circuit between variable-speed drives and motors to reduce EMI, high-earth currents and voltage spikes associated with the high carrier frequencies used in VSD technology.

FIGURE 7.23 Variable-speed drive cable



CHECK YOUR UNDERSTANDING

16. Explain why TPS is a popular cable for electricians to use.
17. What types of cables are used to supply essential services such as fire pumps and evacuation equipment?
18. Describe the main structural features of a MIMS cable. Tip: See **Figure 7.16**.
19. Describe the structural features of a typical bare overhead cable and a low-voltage aerial bundle.
20. Name situations in which an electrician would use HV cables. Tip: See **Figure 7.20**.

7.5 Power cable termination and conductor connection methods

The joining and terminating of cables are an integral part of wiring. A connection or joint must not represent a weak link in the chain of electrical distribution, and to prevent this, the following conditions must be met:

- ▶ The conductivity of the circuit must not be impaired by the inclusion of the joint and must be at least equal to that of the joined conductors.

- ▶ The insulating properties of the joined cables must be maintained.
- ▶ The inclusion of the joint in the wiring system must not weaken the system's protection against mechanical damage, fire, shock, chemical deterioration or other hazards.
- ▶ Where cables are joined or terminated at any type of terminal, the joint cannot have a smaller cross-sectional area (CSA) than the conductor being joined.
- ▶ The termination method must be adequate to prevent loose connections when the terminal is subject to vibration that might occur in service.

Clause 3.7 sets out the requirements for connections between conductors, and between conductors and equipment. Electrical connections must also comply with the requirements of *Clause 3.10 Enclosure of cables* and in particular *Clause 3.10.1.1*, which stipulates that insulated unsheathed cables must be enclosed along their entire length. This also applies to the single-insulated cores of sheathed cables (*Clause 3.10.1.2*). However, *Exception 2 of Clause 3.10.1.1* does permit 100 mm of unsheathed cable without enclosure in a wall cavity adjacent to the accessory at which the cable terminates.



DID YOU KNOW?

The most vulnerable components of an electrical installation are the electrical connections. For this reason, it is good practice to arrange an installation with as few connections/joints in the cables as possible, and those that must be made should be accessible.

7.5.1 Terminating cables

Before the conductor cores of a sheathed cable can be connected, the cable itself must be secured or terminated in a way that exerts no undue pressure on the connection after the connection is made (*Clause 3.7.1*). Termination of a cable is generally achieved either by fixing the cable adjacent to its entry into the enclosure where the conductors are to be terminated or with a cable termination device. Flexible cords are particularly susceptible to strain and must be properly secured, by either a tortuous path or cord grip device. *Clause 3.7.2.8* stresses that the knotting of cords as a means of securing them is not permitted.



SAFETY ALERT

Eye protection required

Use eye protection when cutting and trimming all cables, particularly steel wire armoured (SWA) and screening cables, as they can produce sharp flying particles.

Circular polymeric sheathed cable

The cable-termination device for circular polymeric sheathed cables is the cable gland, which is manufactured for all types of cables, cable sizes and installation requirements. For example, cable glands are designed to prevent the siphoning of water through the cable or wiring enclosures, or the seeping of moisture into connections and cable insulation, as required by *Clauses 3.7.2.1(f)* and *6.3.4.2*. Cable glands are available that maintain the earth continuity of cable armouring and screening (*Clause 5.5.4.3*) and for the stringent explosive-protection

requirements of hazardous areas in Standards called up by *Clause 7.7*. **Figures 7.24** and **7.25** show examples of terminating sheathed cables.

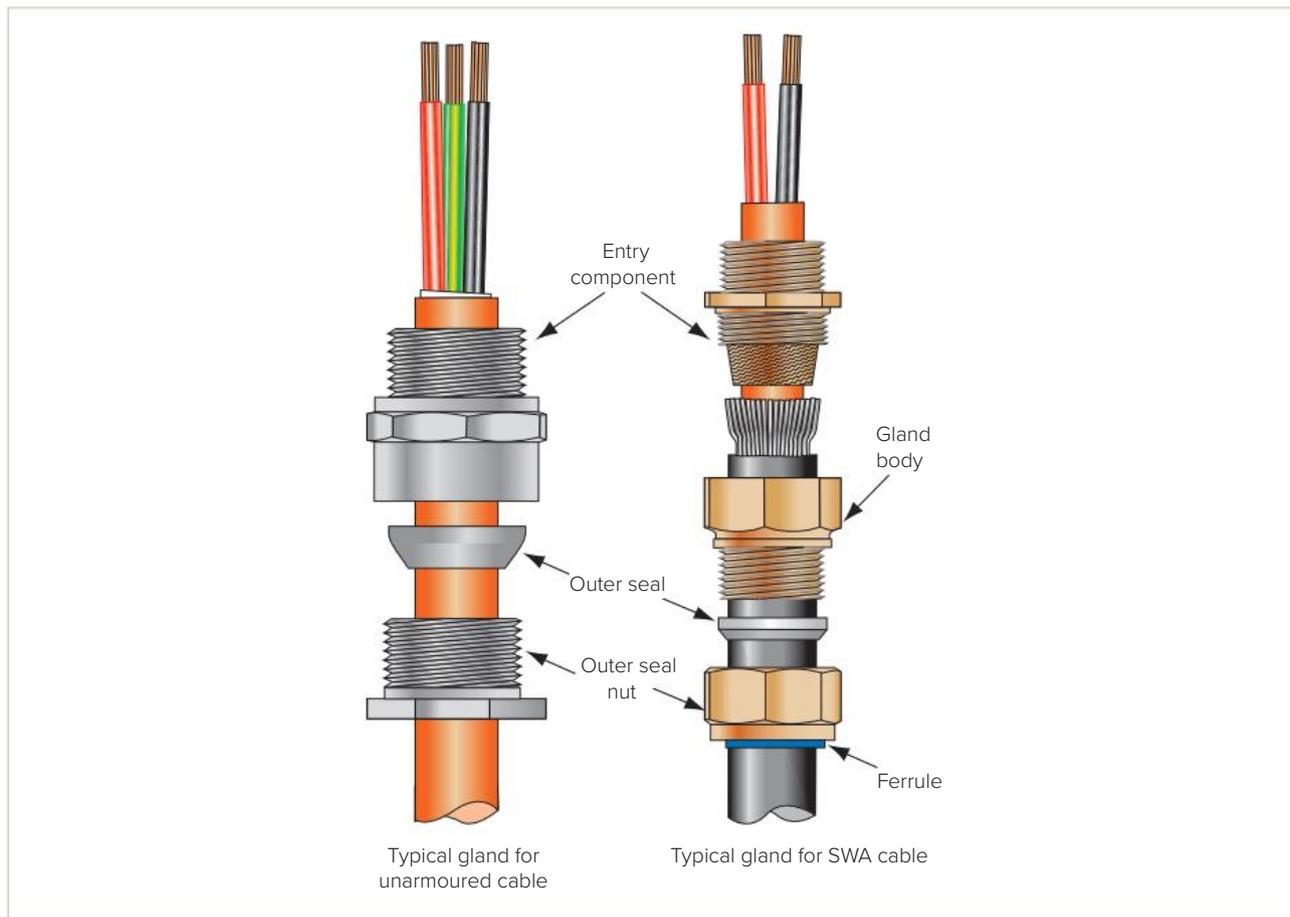


FIGURE 7.24 Basic cable glands

Mineral-insulated metal-sheathed (MIMS) cable

The magnesium oxide insulant used in MIMS cable is hygroscopic (it has an affinity for moisture) and in the past this required cable ends to be temporarily sealed and any moisture driven out by heat before final termination. However, in new MIMS cable the problem of low insulation resistance that this moisture caused has been eliminated by the use of an inorganic insulant that has a self-blocking characteristic, reducing the penetration of moisture in the cable to 100 mm from an unsealed end. This means that the precautions needed for working with old MIMS cable (Pyrotenax), as in a building refurbishment, and new MIMS cable are different, as shown in **Table 7.3**.

A cold screw-on pot-type seal suitable for temperatures up to 135 °C is the permanent termination for most applications and an earth-wire pot seal is also available if special earth continuity is required. The pot is filled with sealing compound and is provided with a moulded 'stub' cap with PVC or neoprene sleeving for the conductors. For temperatures exceeding 105 °C, PVC sleeving is replaced by silicone rubber sleeving or silicon elastomer-coated glass-braided sleeving, and a glassing flux is used instead of the pot-sealing compound.

In places where the seal may be in contact with oil, such as in petrochemical plants, the cold pot seal is used with a special oil-resisting compound, using the standard cap and standard PVC or neoprene sleeving. The minimum working temperature for all seals is -20 °C.

MIMS cable-terminating process

The process and sequence for terminating MIMS cable are given in **Table 7.4**, with illustrations of the terminating techniques in **Figures 7.26** to **7.36**.

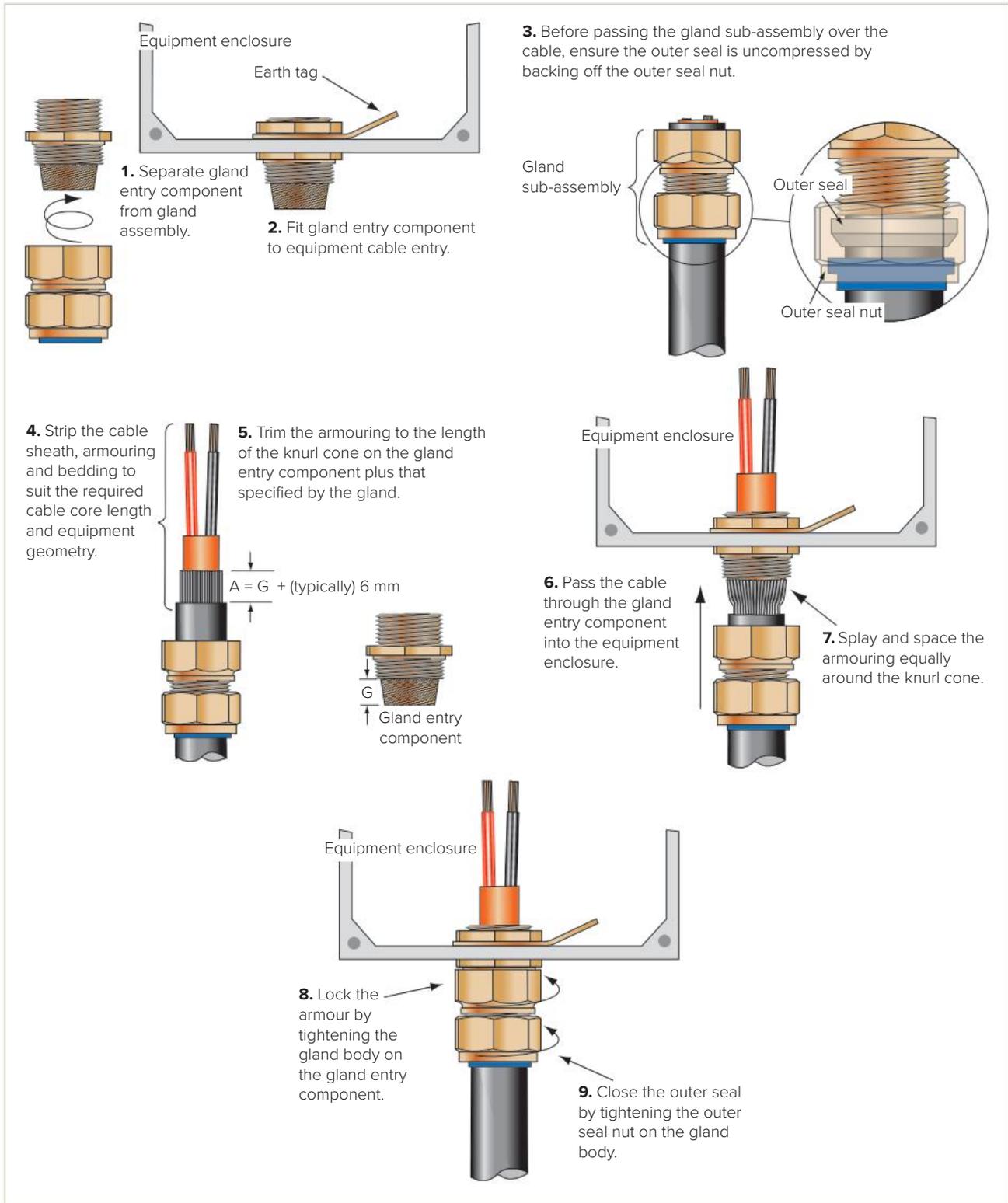


FIGURE 7.25 Terminating a steel wire armoured (SWA) cable

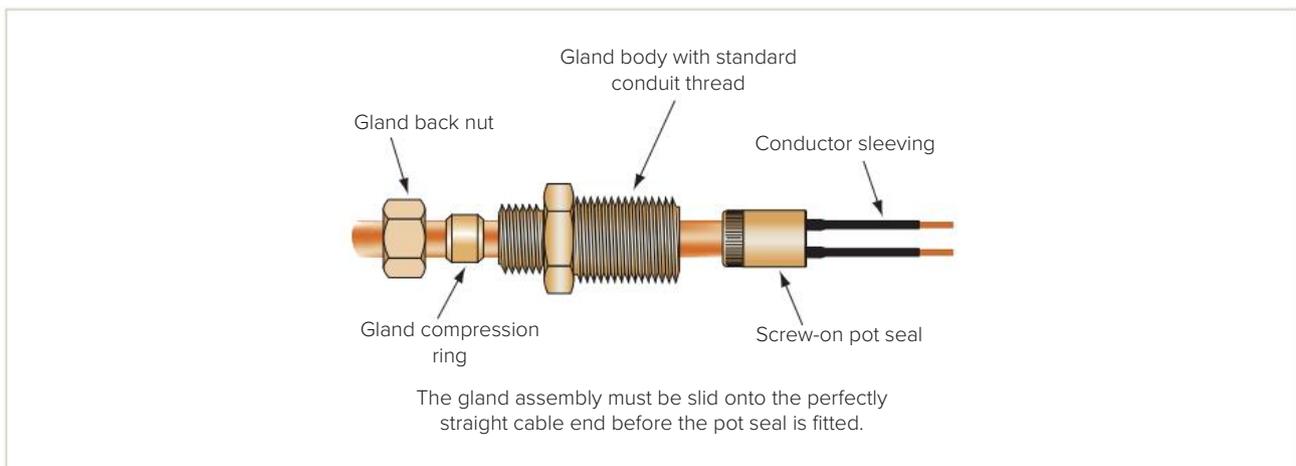
Screw-on pot seals are not used for sealing single-core MIMS cables. Two methods are available: taping and heat-shrink seals. Taping, using a special type of adhesive tape, is the most commonly used. In both cases, the portion of the sheath to be sealed should be cleaned using a non-metallic scouring pad (Scotchbrite or similar) and the conductor thoroughly cleaned with a clean, dry cloth to remove magnesium oxide powder. An insulation-resistance test must also be applied. Note that taped seals are superior to heat-shrink seals under fire conditions.

TABLE 7.3 Precautions for working with old and new MIMS cable

Old MIMS cable	New MIMS cable
Temporary seal of cable ends is required during storage.	Temporary seal of cable ends is not required during storage.
Installed cables require temporary seals pending termination.	Installed cables do not require temporary seals pending termination.
It may be necessary to allow extra length (a wasteful practice) for shortening of moisture-affected cable if cables have not been effectively sealed.	It is not necessary to allow extra length for shortening of moisture-affected cable.
Insulation should be tested before the cable is finally terminated.	Insulation is tested only after the cable is finally terminated.

TABLE 7.4 Process for terminating MIMS cable

Old MIMS cable	Figures	New MIMS cable	Figures
Strip the polymeric serving.	7.26	Strip the polymeric sheath.	7.26
Strip the copper sheathing.	7.27, 7.28 or 7.29	Strip the copper sheathing.	7.28 or 7.29
Clean the conductors.	7.30	Clean the conductors.	7.30
Fit the pot seal.	7.31	Fit the pot seal.	7.31
Test the insulation.	7.32	Fill the pot with sealing compound.	7.34
Drive moisture from the cable ends.	7.33	Fit the stub cap.	7.35
Fill the pot with sealing compound.	7.34	Insulate the conductors.	7.36
Fit the stub cap.	7.35	Test the insulation.	7.32
Insulate the conductors.	7.36		

**FIGURE 7.26** MIMS cable-termination techniques—cable gland assembly

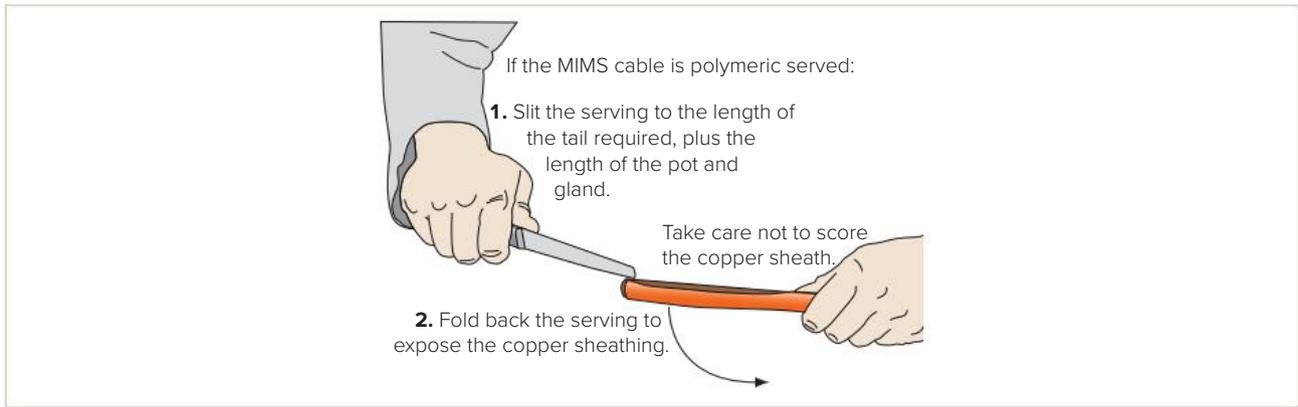


FIGURE 7.27 MIMS cable-termination techniques—stripping the serving

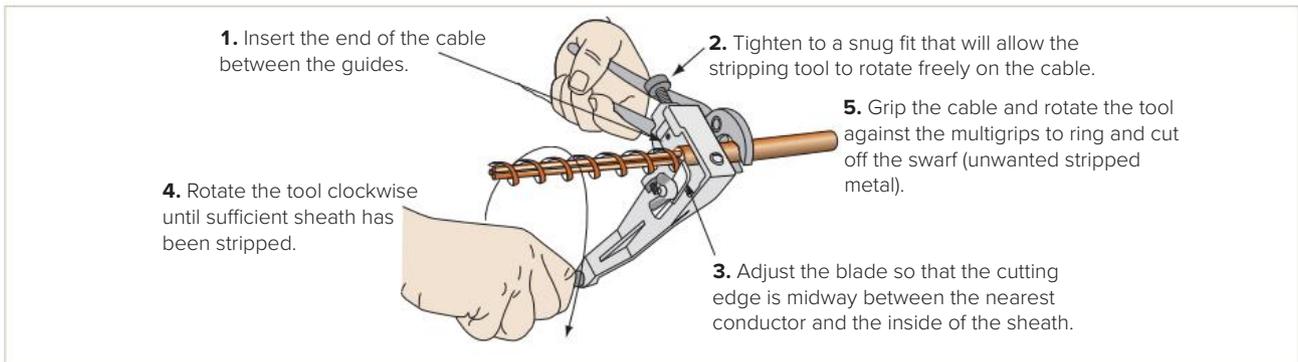


FIGURE 7.28 MIMS cable-termination techniques—stripping the sheath with a stripping tool

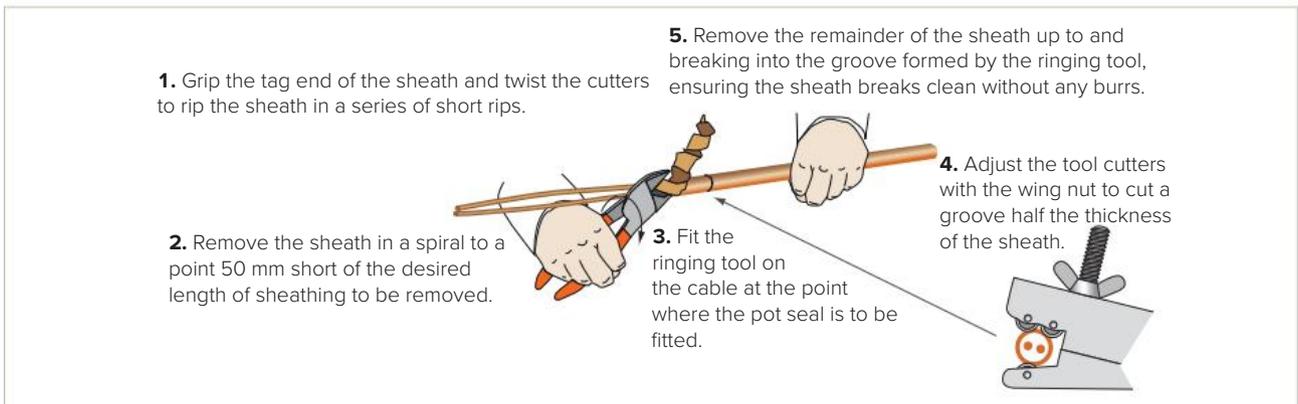


FIGURE 7.29 MIMS cable-termination techniques—stripping the sheath with a side cutter

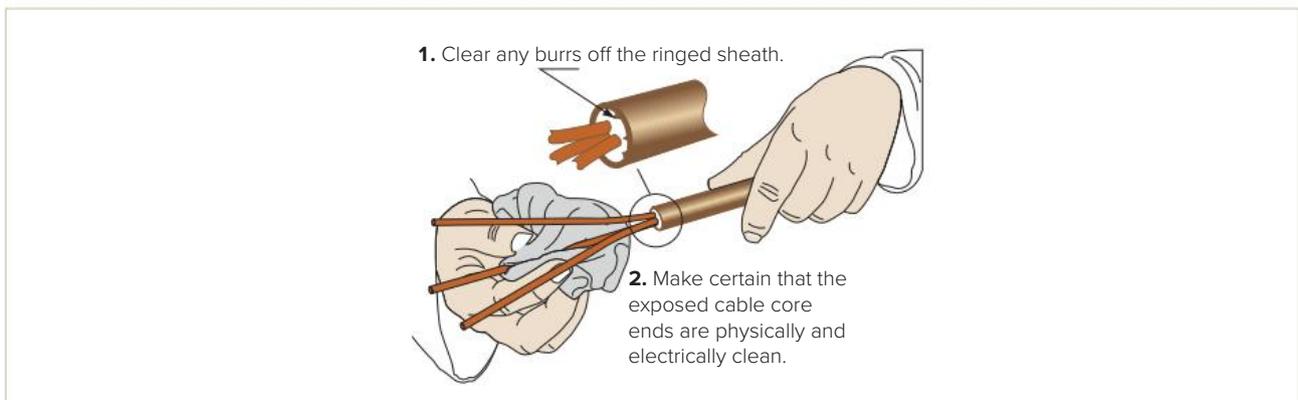


FIGURE 7.30 MIMS cable-termination techniques—cleaning conductors

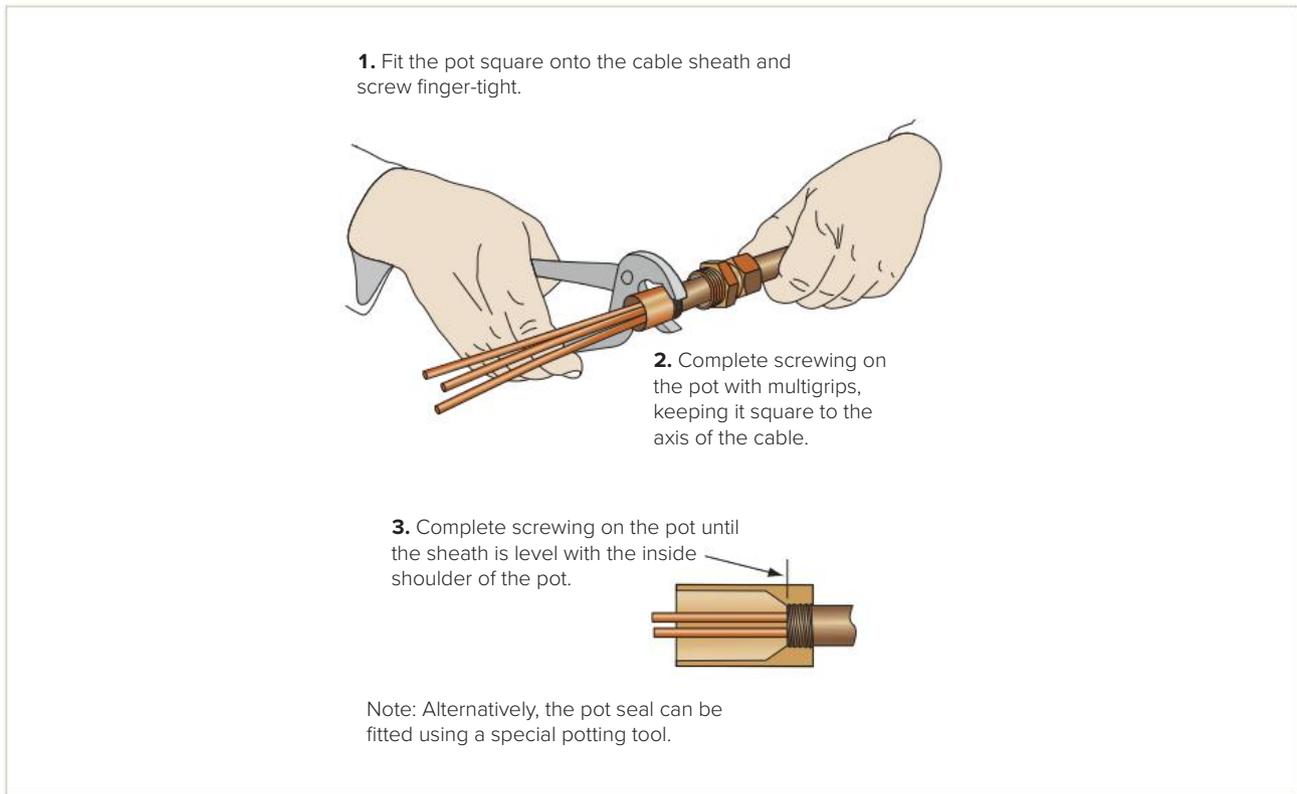


FIGURE 7.31 MIMS cable-termination techniques—fitting a pot seal

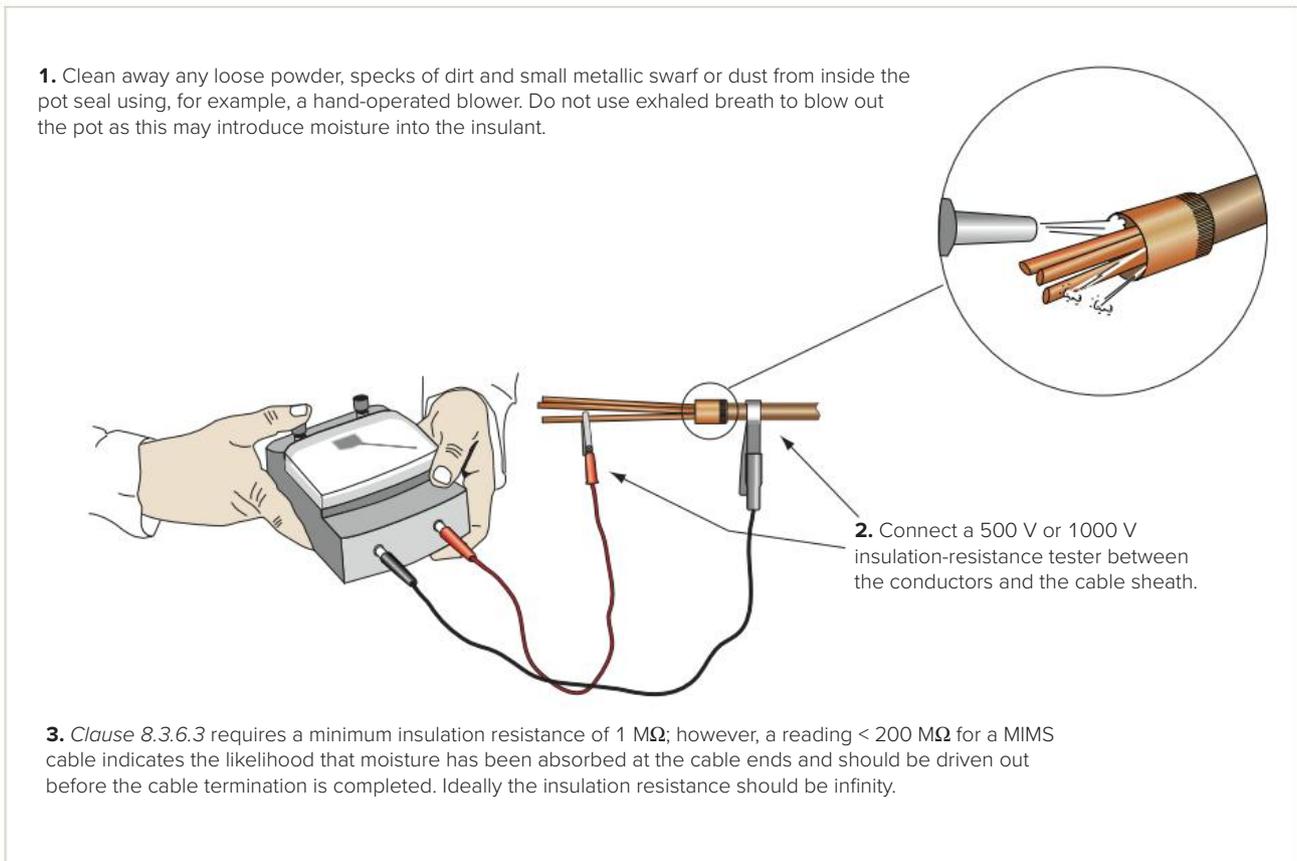


FIGURE 7.32 MIMS cable-termination techniques—testing insulation resistance

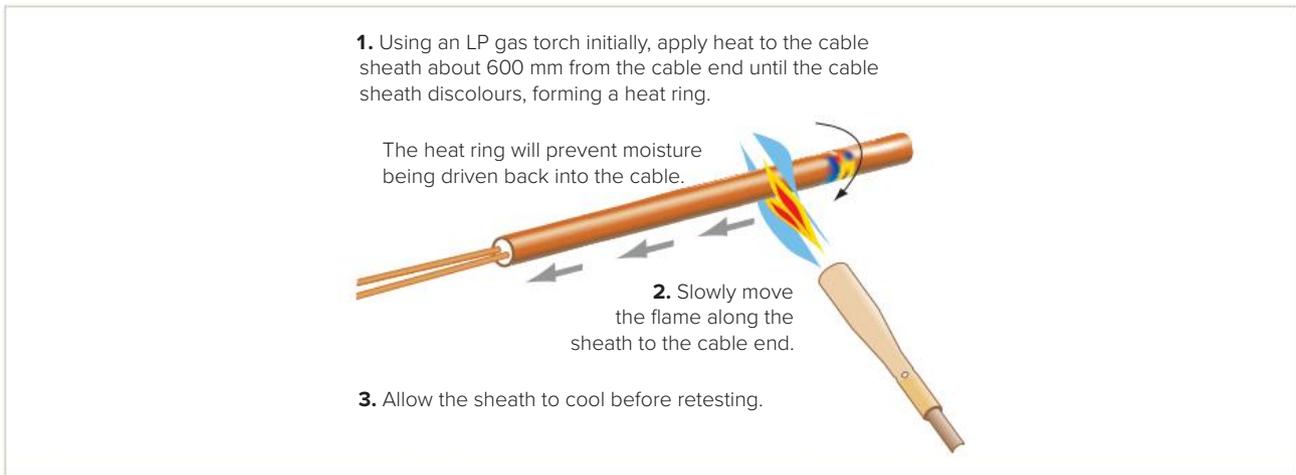


FIGURE 7.33 MIMS cable-termination techniques—driving moisture from the cable ends

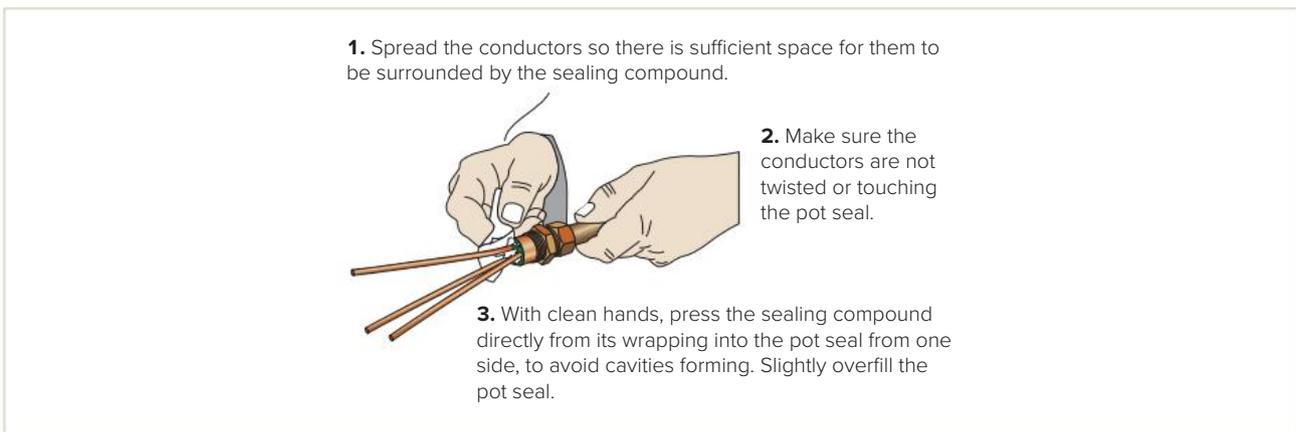


FIGURE 7.34 MIMS cable-termination techniques—filling the pot with sealing compound

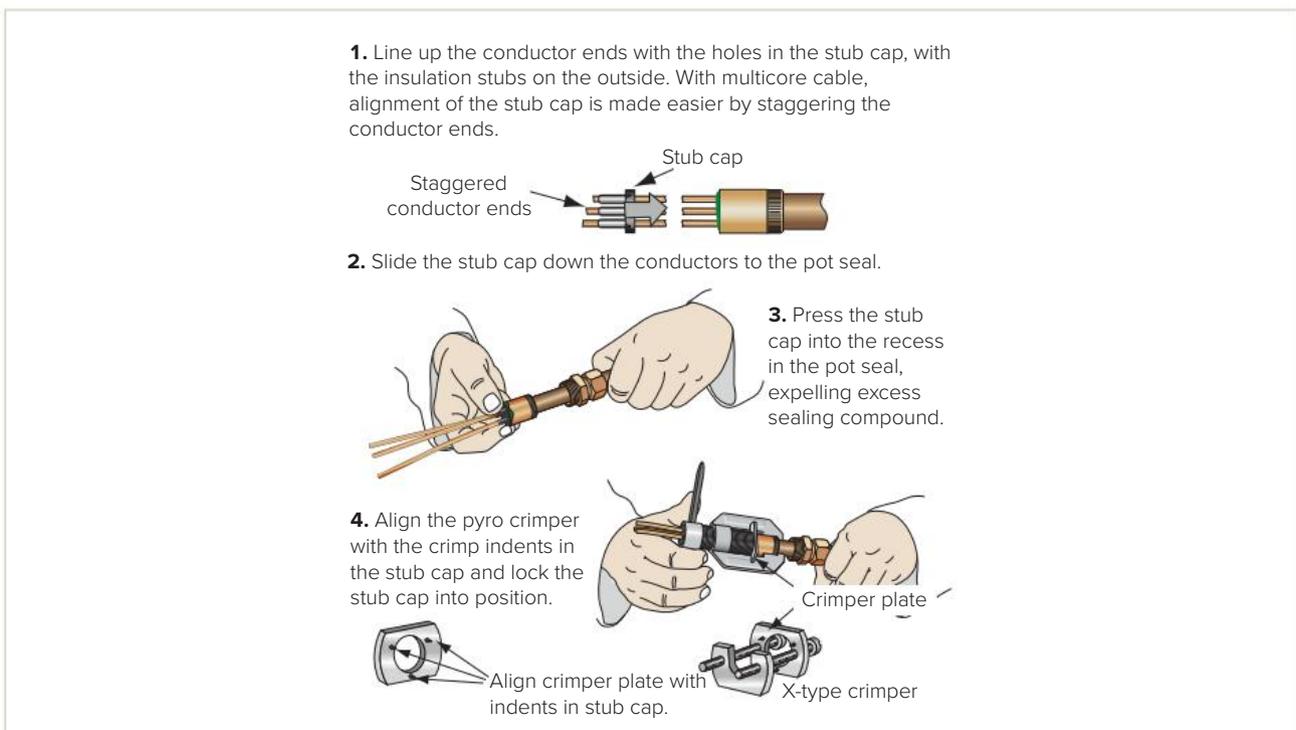
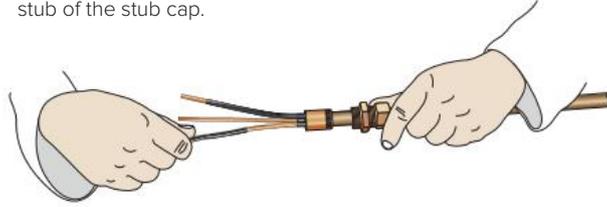


FIGURE 7.35 MIMS cable-termination techniques—fitting a stub cap

1. Select the insulation type and size specified by the manufacturer for the given cable and installation conditions.
2. Slide the insulation over the conductor and the insulation stub of the stub cap.



3. Test the insulation as shown in **Figure 7.32**.

FIGURE 7.36 MIMS cable-termination techniques—insulating conductors

7.5.2 Joining and connecting conductors

Terminating in accessories

Terminating and joining conductors are generally done by either clamping or crimping. In general wiring, most accessories have tunnel-type or screw-type terminals where the conductors are clamped by direct contact with either a plate or a screw. See *Clause 2.10.4.2* regarding tunnel-type terminals of bars and links in switchboards and *Clause 3.7.2.11(b)* for earthing conductors.

Figures 7.37 to 7.41 show typical terminals and connectors used in general wiring for copper conductors only. Accessories for general wiring that have insulation displacement terminals are now available.

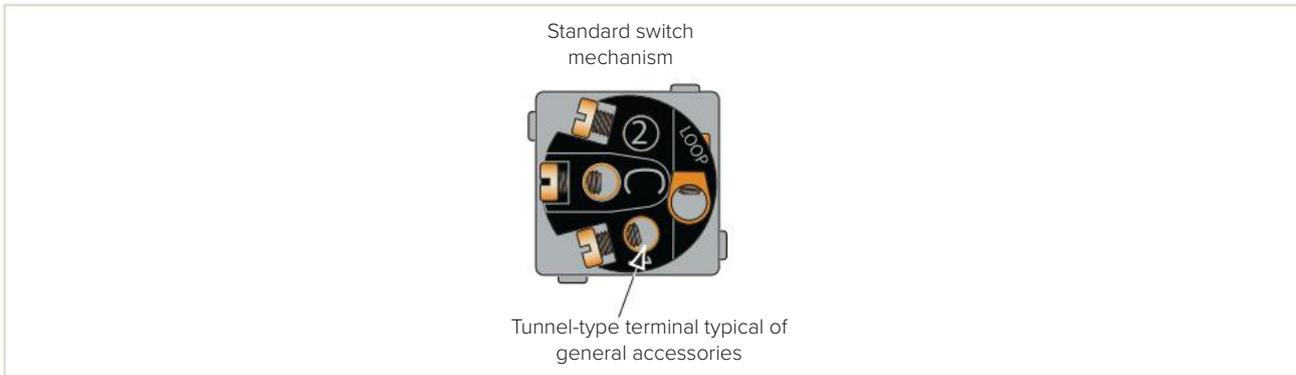


FIGURE 7.37 Conductor terminations and joining—accessory terminals

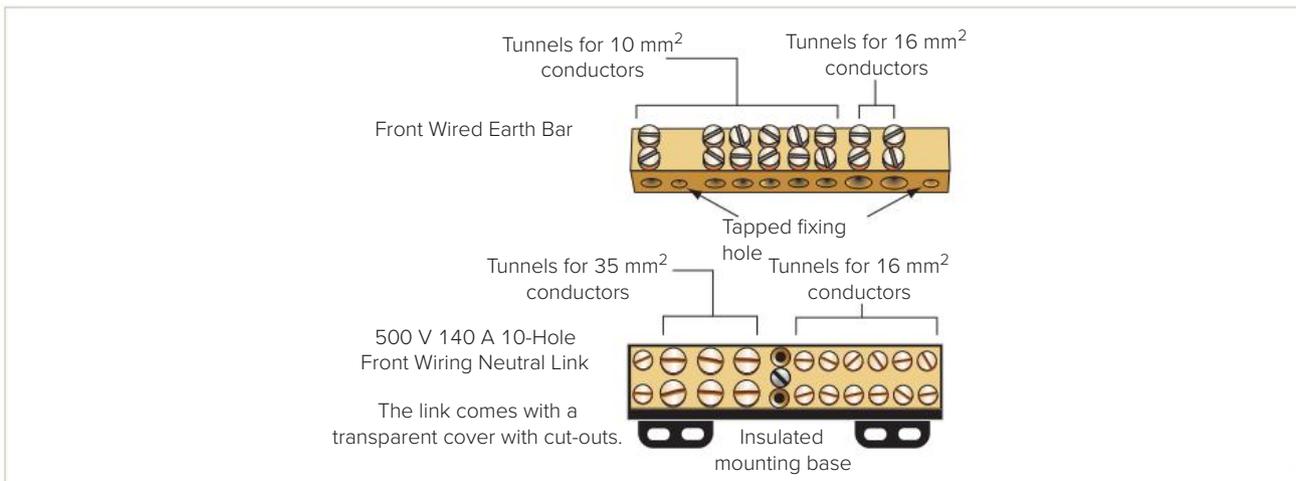


FIGURE 7.38 Conductor terminations and joining—bars and links

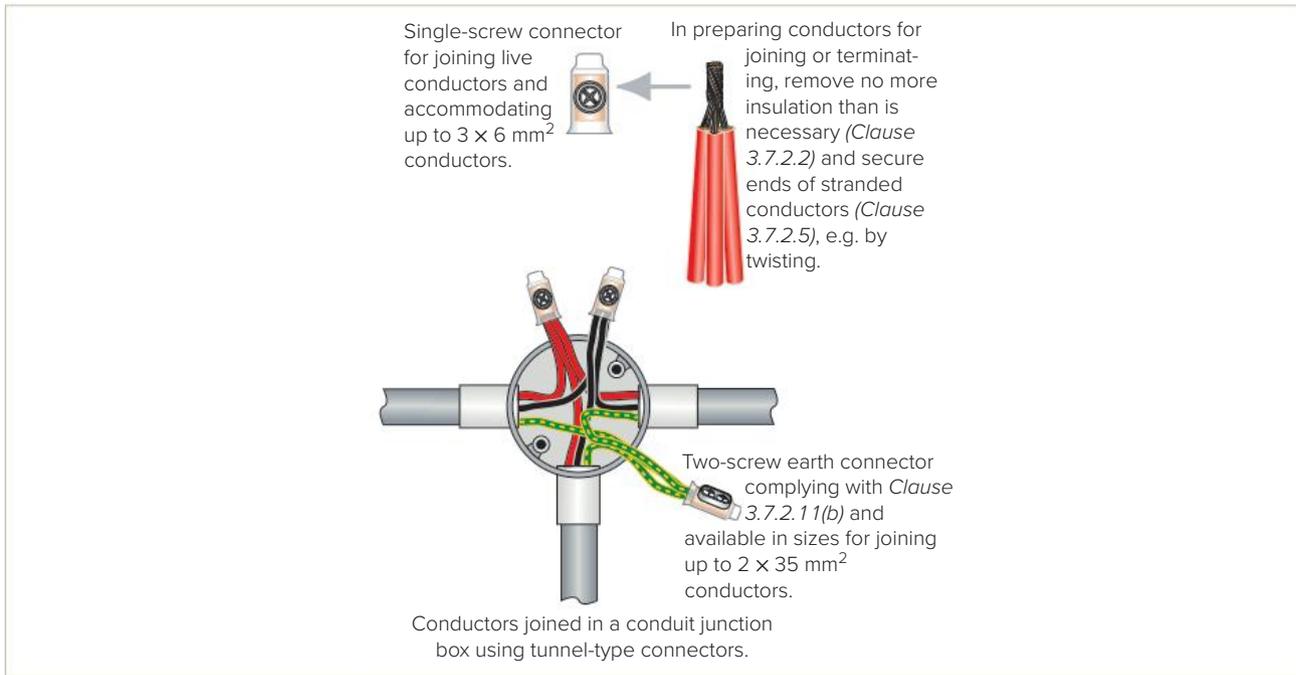


FIGURE 7.39 Conductor terminations and joining—tunnel-type cable connectors

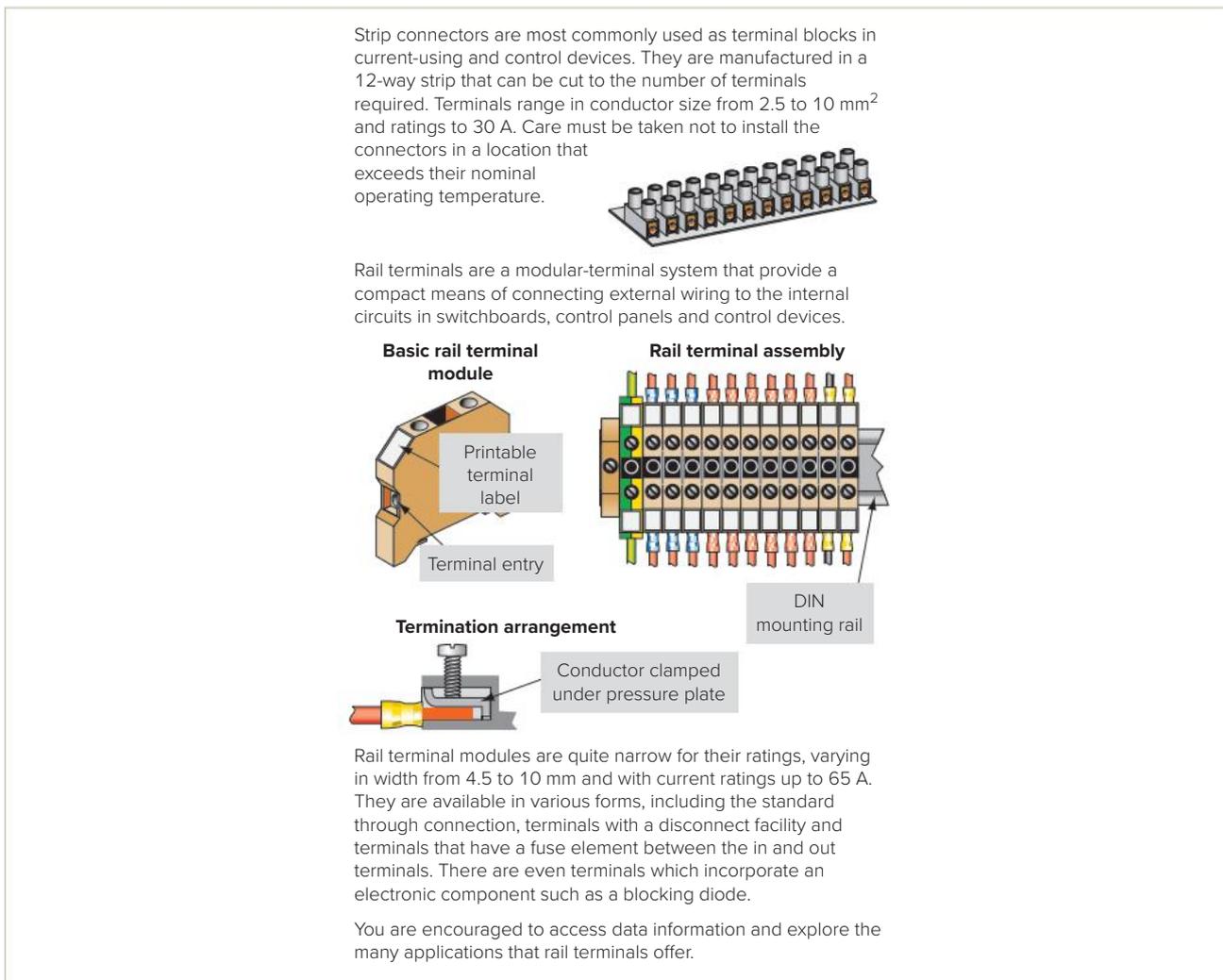


FIGURE 7.40 Conductor terminations and joining—terminal blocks

In this type of termination, precisely positioned blades pierce the insulation of the cable core to make the connection, removing the need to strip the core insulation.

How the termination works

Insulation clamping ribs hold the cable core securely and isolate the contact area from vibration and mechanical stress.



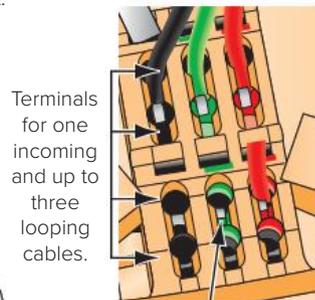
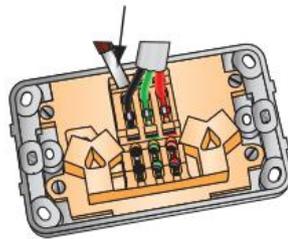
Contact tags at 45° across the axis of the cable core pierce the insulation, making a solid gas-tight connection.



Axial and torsional restoring forces maintain a durable connection.

Insulation displacement was developed for terminating telecommunications devices; shown here is its adaption to terminations in a socket-outlet.

After inserting the unstripped cable core into the terminal, a screwdriver is used to lever the terminal to lock in the connected position.



Terminals for one incoming and up to three looping cables.

Visual posts indicate the connected/disconnected positions.

FIGURE 7.41 Conductor terminations and joining—insulation displacement

Terminating conductors in tunnel-type terminals generally only requires stripping the end of the conductor core of insulation, taking care not to remove insulation beyond the metal tunnel component of the terminal (*Clause 3.7.2.2*) and twisting conductors where necessary to ensure cable strands are retained (*Clause 3.7.2.5*).

Crimping and compression terminations

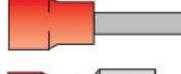
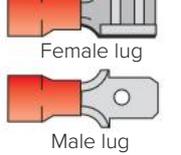
On the other hand, screwed and bolted terminals require the fitting of a cable lug to the conductor end. The most commonly used type of cable lug, the crimp or compression lug, is crimped under pressure to the bare conductor end to form a compressed solid with the conductor. Provided that the correct tools are used and the terminal type is the one recommended for the particular conductor, this method is speedy, economical and reliable. With certain precautions, this joining technique is applicable to copper, aluminium and copper-to-aluminium connections. Crimp lugs are manufactured in conductor sizes of 0.05 to 630 mm², in a variety of forms and for copper and aluminium conductors. Examples of types of crimp lugs, their features and applications are shown in **Figure 7.42**.

Care must be taken when joining aluminium cables, because of the film of aluminium oxide that forms on the surface of the conductor, the relative softness of the metal and problems that can arise due to corrosion. Also, the difference in the coefficients of expansion of aluminium and other metals when using bolted or clamped connections can result in unsatisfactory joints. Copper is the most common conductor in the small sizes used for lighting and power circuits; aluminium is restricted to a minimum size of 16 mm² and is more commonly used in aerial conductors and underground distribution. Copper does not present the same oxidation problems as aluminium, but this does not preclude the necessity of thoroughly cleaning copper conductors before terminating or joining them.

Figure 7.43 illustrates the techniques for fitting a crimp lug to a larger cable.

Crimp lugs are classified by whether they are insulated and the type of terminal connection they are intended for.

Examples of the pre-insulated crimp lugs for conductor sizes 0.2 mm² to 6.0 mm².

-  **Ring lug** for connection to screw or a stud-type terminal
-  **Spade lug** for connection to a stud-type terminal
-  **Flat blade lug** for connection in a tunnel terminal
-  **Quick connect lug** for use with corresponding fixed terminal
 - Female lug
 - Male lug

The lug insulation colour indicates conductor sizes that the lug is designed for.

Typical conductor sizes:

-  0.5 to 1.6 mm²
-  1.0 to 2.6 mm²
-  0.2 to 0.5 mm² (small)
2.5 to 6.0 mm² (large)

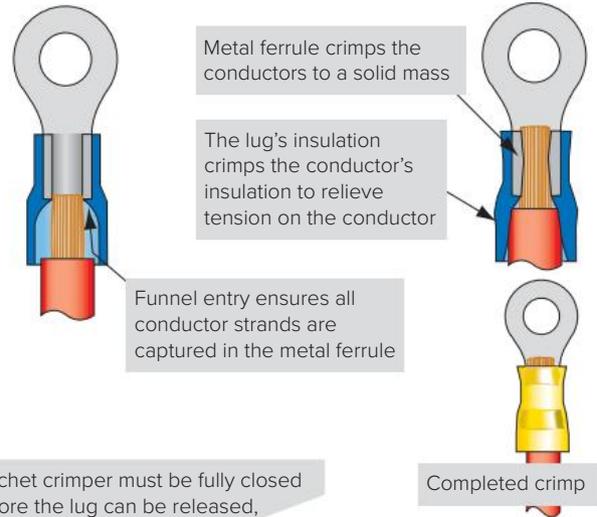
Using the wrong size lug may result in a poor connection.

-  **Bootlace pin** for use in tunnel terminals to ensure all conductor strands are contained and are not broken by terminal screws. Available in sizes from 0.25 to 120 mm². Colour coding is different to the standard pre-insulated lugs.

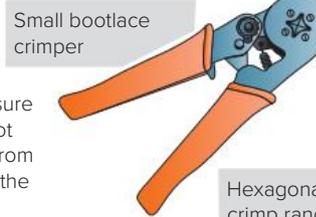
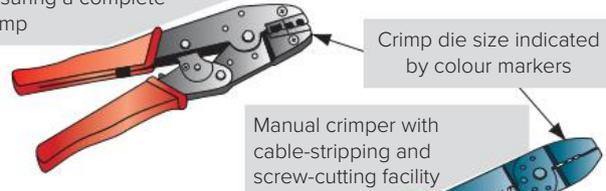
Uninsulated crimp lugs range from small (1 mm²) to large (630 mm² and above) conductors size, most being for the stud- or bolted-type terminals.

Examples include:

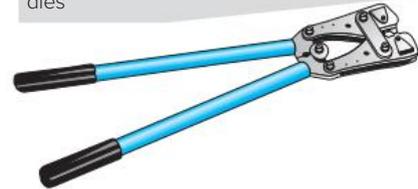
-  **Copper crimp link** used for extending cables typically in alteration at distribution boards
-  **Bi-metal lug** for terminating an aluminium conductor for connection to a copper terminal
-  **Reverse bi-metal lug** for terminating a copper conductor for connection to an aluminium terminal, such as an aluminium busbar
-  **Aluminium lug** for terminating an aluminium conductor. The sealing cap indicates that a lug is pre-filled with joint compound.



Ratchet crimper must be fully closed before the lug can be released, ensuring a complete crimp



Hexagonal copper lug crimper with crimp range 6 to 120 mm² conductors. It is equipped with self-contained rotating dies



Hydraulic crimper with die set of 16 to 300 mm². The tool exerts a crimping force of 13 tonnes at the die face

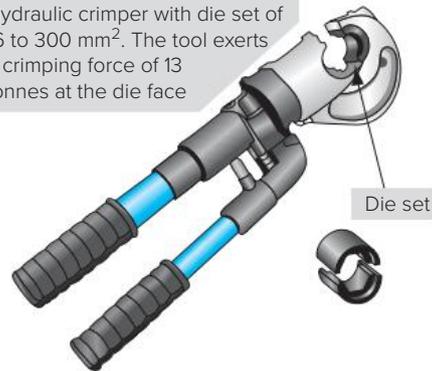


FIGURE 7.42 Examples of crimp lugs and crimping tools

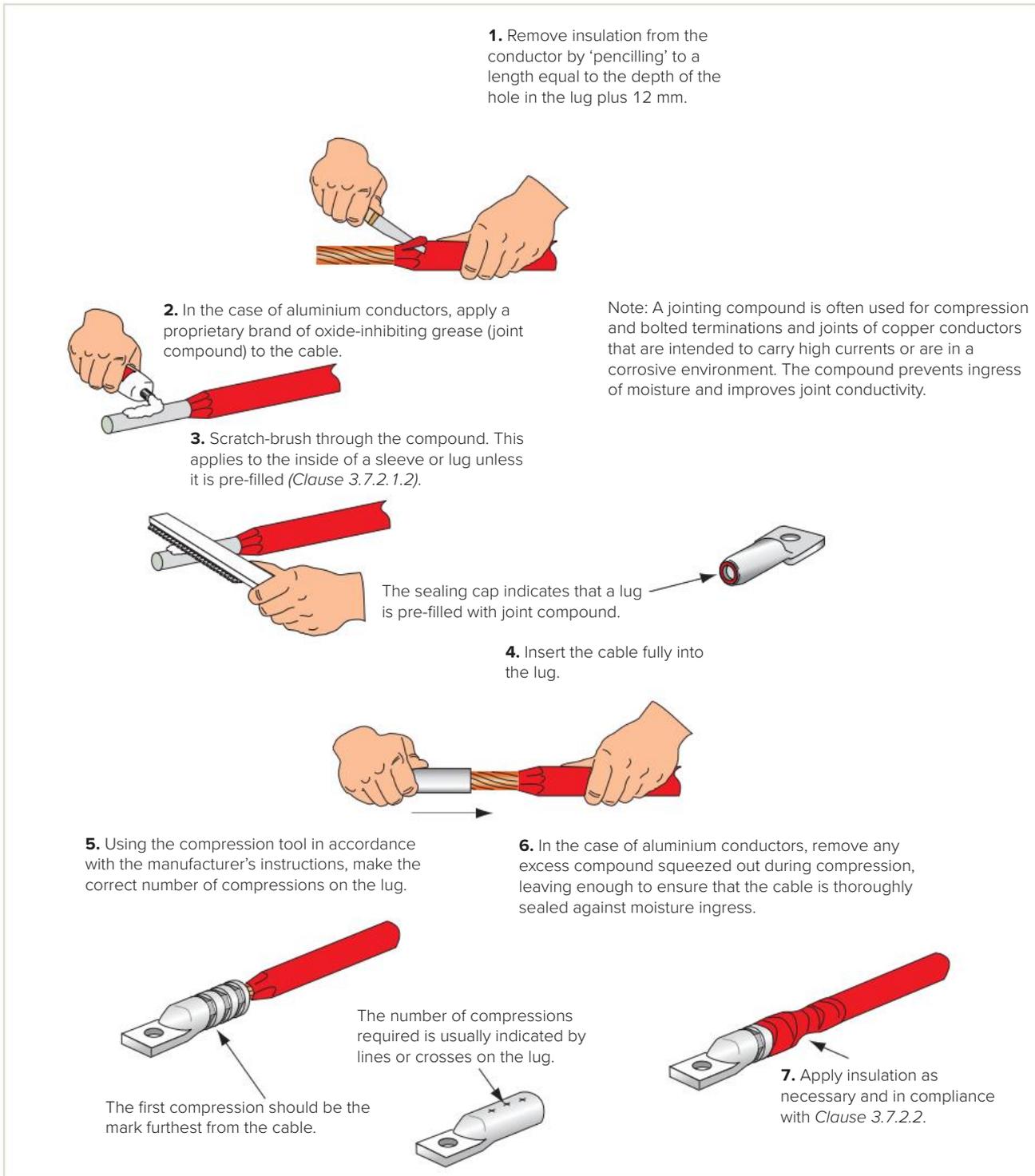


FIGURE 7.43 Terminating large conductors

Soft soldering

Although the now common use of crimping and compression fittings has meant less use of solder as a jointing medium, this method is still used in the field, for example in joining earth wires. Note that hard soldering, silver soldering, silver-alloy brazing and low-temperature brazing all describe a similar soldering process that is done within the temperature range 600 to 850 °C, using a silver-copper alloy solder or filler metal and usually carried out in repair workshops.

Soldering is a process where a fusible alloy (solder) is used to unite the surfaces of less fusible metals in a way that the metals are joined mechanically and electrically by the solder. The solder alloys unite with an extremely thin

surface layer of the metals being joined, so that for most purposes they act as one. Many soldering methods are used in workshops and in production, but in the field the usual methods of supplying heat to the metals to be joined are by open flame from liquid petroleum gas (LPG) or the hot tip of a soldering iron.



SAFETY ALERT

Soldering safety

Use personal protective equipment (PPE) to prevent the inhalation of fumes, contact with fluxes and contact with hot surfaces. The use of lead-based solders should be avoided. Correctly handle, use and store gas bottles and equipment and soldering irons.



CHECK YOUR UNDERSTANDING

21. Why is it important for electricians to develop skills in connecting and joining cables and conductors?
22. Explain step by step how to terminate an SWA cable.
23. Describe the differences between older-style MIMS cable and the newer MIMS cable. Tip: See **Table 7.3**.
24. Describe the process for making a sound connection in a tunnel terminal, stating the relevant *Wiring Rules* clauses.
25. Explain the differences between the three types of lug insulations.

7.6 Data and communications cable types and applications

Telecommunications encompass voice, data and video and audio transmission of entertainment and business information, fire and security, industrial process controls and intelligent building controls over media that include specialised copper cable, optical fibre cable, microwave and wireless. These telecommunications media must work without distortion or loss of information, and be able to be managed and accommodate further technical developments without the need for re-cabling.

To this end, telecommunications systems in buildings and premises, including the performance of telecommunications cables, must comply with the Australian adoption of international Standards. Because of electricians' expertise in installing power wiring in buildings, it is natural that many of them have become qualified to install telecommunications cabling as well. To carry out this work unsupervised, a person must have been assessed as competent to do so and be registered with an organisation accredited by the Australian Communications and Media Authority (ACMA).

7.6.1 Communications cable types

Copper cable

Communications cables with copper conductors transmit information encoded digitally in an analogue carrier signal (broadband) at frequencies from 10 to 600 MHz. They do not need the current-carrying capability of power cables and therefore have small conductors in the order of 0.4 to 0.9 mm².

Patch cables used for short connections between telecommunications outlets and equipment or for connecting parts of a cable system at patch panels, routers and switches have multistranded copper conductors, typically seven strands each of 0.2 mm diameter, that afford greater flexibility.

Communications cable design must take into account cable capacitance and inductance, both of which affect these cables' ability to transmit the relatively high frequencies of the carrier signal and their susceptibility to electromagnetic interference (EMI). Insulation and sheathing are generally made of the same polymeric compounds that are used in power cables.

The two main types of copper communications cable are the twisted pair cable shown in **Figures 7.44** and **7.45** and the coaxial cable shown in **Figure 7.46**.

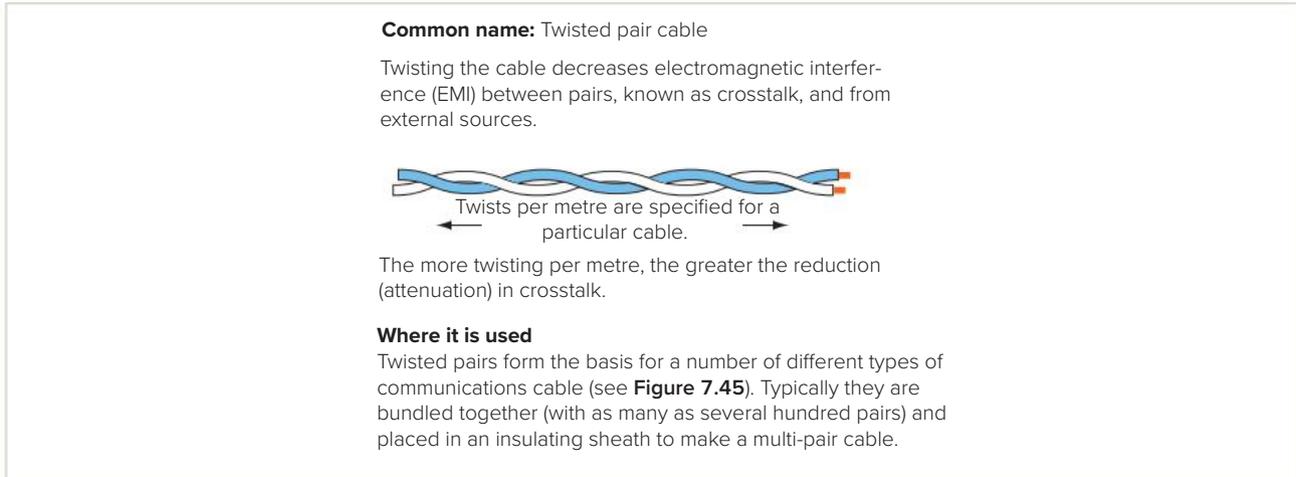


FIGURE 7.44 Communications cable types and applications—twisted pair cable

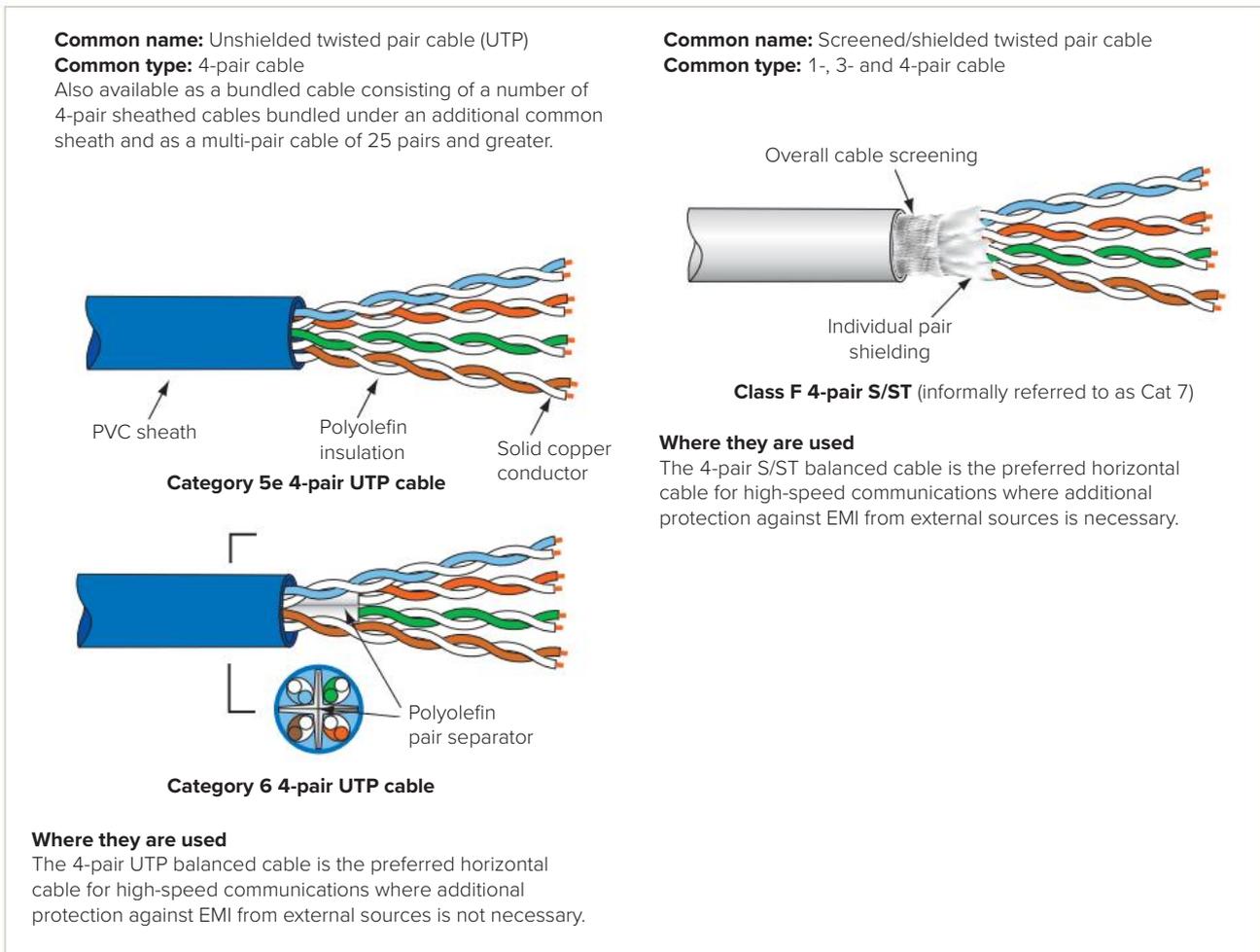


FIGURE 7.45 Communications cable types and applications—structured cable

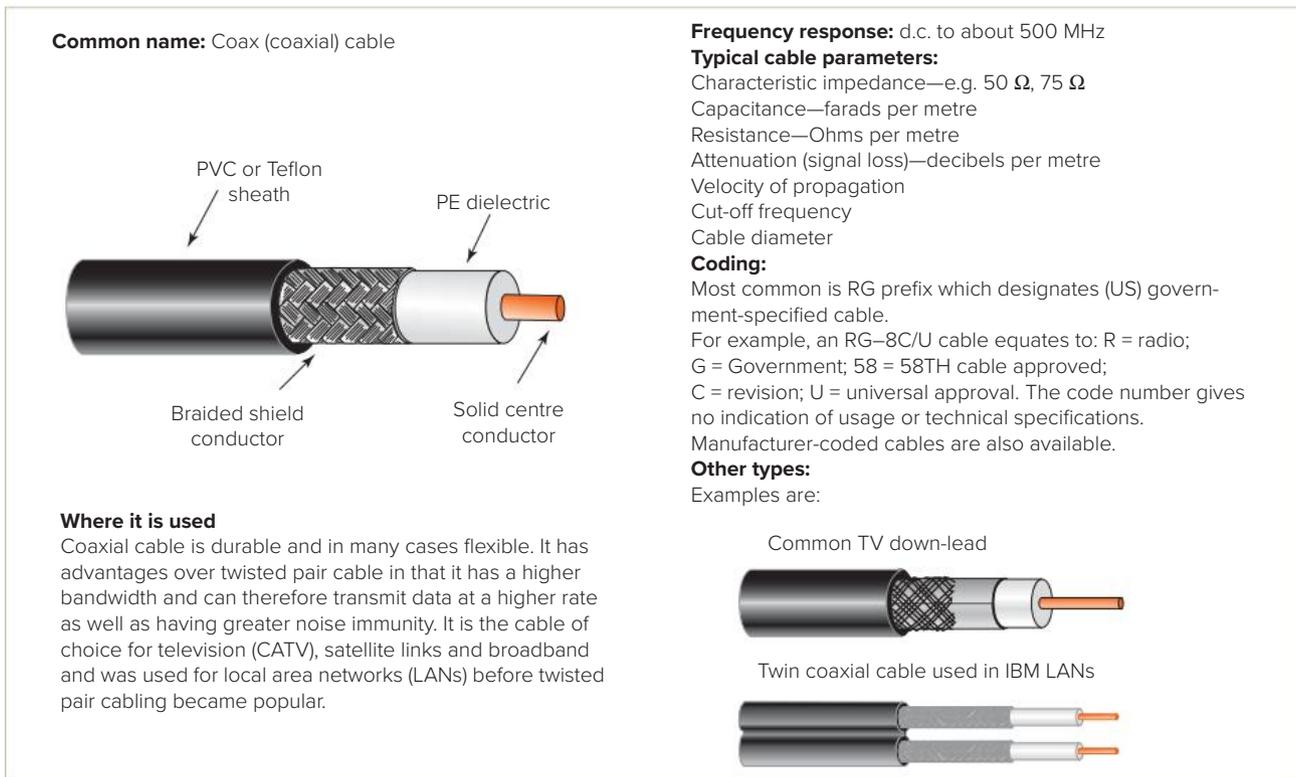


FIGURE 7.46 Communications cable types and applications—coaxial cable

An interesting communications cable designed for fire alarms and vital communications in potentially severe environments is a MIMS (Pyrotenax) twisted pair cable, as shown in **Figure 7.47**.

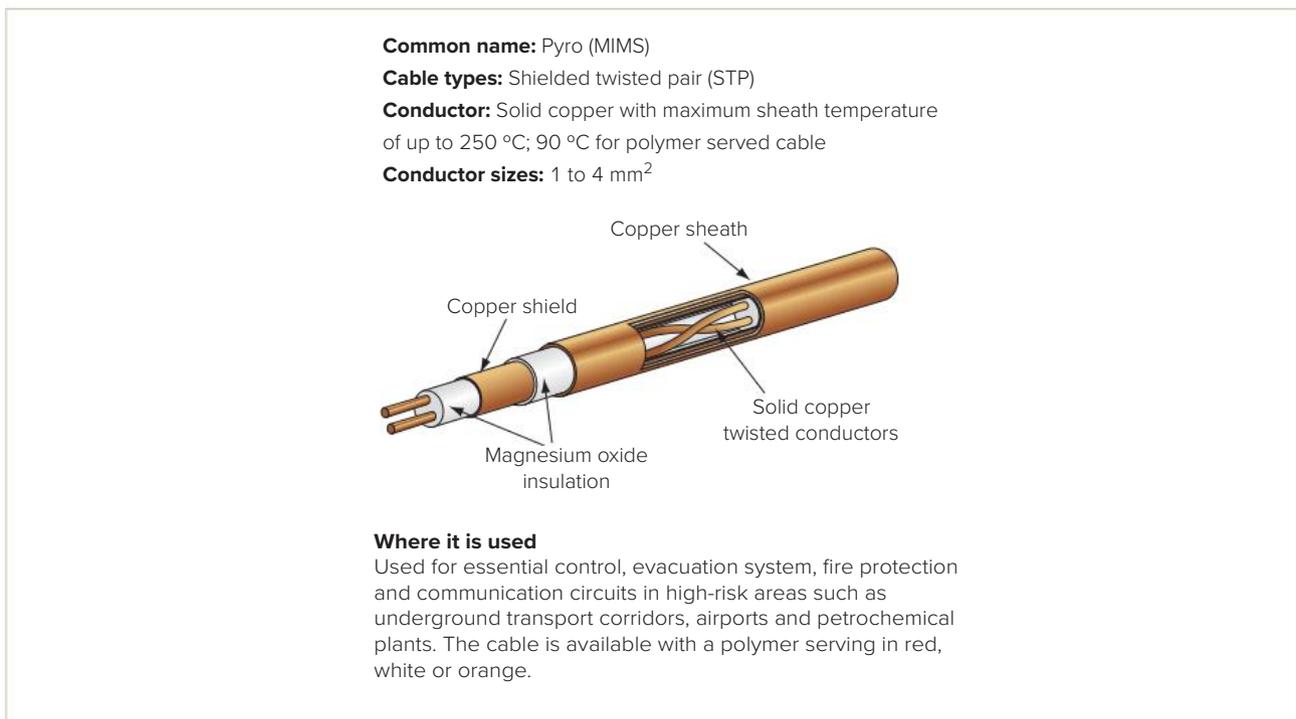


FIGURE 7.47 Communications cable types and applications—MIMS twisted pair cable

The performance standards for communications cables have been developed by various national and international consortiums and standards bodies around the world. The Australian/New Zealand compliance Standard is

AS/NZS 3080:2013 Telecommunication installations—Generic cabling for commercial premises, which is a modified adoption of the *ISO/IEC 11801* Standard, which sets the test performance standards for installed communications cables.

The cables are more commonly known as Category 3, 5, 5e, 6, 6_A, 7 and 7_A, with each higher number representing a more stringent specification for improved cable performance in terms of reliably transmitting and receiving data at high frequencies and in network applications. **Table 7.5** lists cables by classes and categories as specified by the international Standard *ISO/IEC 11801 Information technology—Generic cabling for customer premises*.

TABLE 7.5 Cable categories and performance

Class	Category of cable	Speed
A	1	100 kHz
B	2	1 MHz
C	3, 4	16 MHz
D	5e	100 MHz
E	6	250 MHz
E _A	6 _A	500 MHz
F	7	600 MHz
F _A	7 _A	1000 MHz

Cable specifications include characteristic impedance values of 100 Ω for twisted pair cable and 50 or 75 Ω for coaxial cable. The characteristic impedance, which is essentially the ratio of the cable inductance to its capacitance, is an important aspect of the cable's ability to transmit high frequencies. The specification also requires cable systems to be backward compatible, that is, a cable designed to an improved standard must be able to operate effectively within the same networks as previous cables.

Optical fibre cable

Optical fibre cables transmit voice data using a beam of light. In a data communications local area network (LAN), usually fibres are used in pairs, one for transmitting and the other for receiving. However, external networks such as the National Broadband Network (NBN) transmit and receive on a single fibre. Optical fibres are capable of carrying much more data and at much greater speeds than metal cables, and are immune to electromagnetic radiation (EMR). The basic principles of optical fibre transmission are illustrated in **Figure 7.48**.

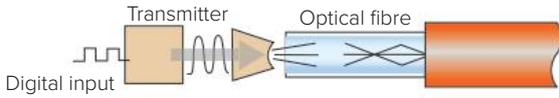
There are two basic types of optical fibre structures, the coated fibre and the tight-buffered fibre. Cables of tight-buffered fibres are mostly used for internal cabling; however, some are designed for external use. The cables most commonly used externally are of the loose-tube type, each tube containing a number of pairs of coated fibres. Optical fibre and cable structures are shown in **Figure 7.49** and examples of optical fibre cables in **Figure 7.50**.

7.6.2 Communications cabling arrangements

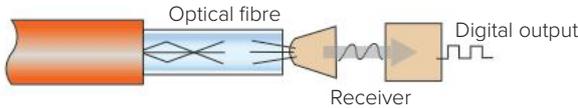
While the fundamental elements of communications cabling are fairly straightforward, their complexity lies in the number of lines entering a premises, the final number of outlets, their locations and the purpose of each one. To manage this complexity, as well as ensuring the safety and inter-operability of public telephone and internet networks, the telecommunications industry uses arrangements based on international Standards for the connection and distribution of services in buildings and premises. **Figure 7.51** shows the general arrangement of communications cables in buildings and premises.

Optical fibre cables are used in pairs; one fibre for sending and the other for receiving information. At the sending end of an optical fibre, information in the form of electrical pulses is converted into pulses of light, which is focused along the optical fibre transmitting the information to the receiving end. Here the light is converted back to electrical pulses.

Data in the form of voltage pulses is converted to light pulses and sent through the optical fibre.



Data in the form of light pulses is received and converted to voltage pulses for use in communications devices.



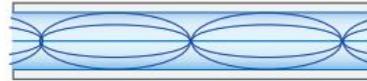
Optical fibres are classified by whether they support one or more transverse modes by which light can travel along the fibre. Transverse mode is derived by Maxwell's wave equation. A fibre supporting only one mode is termed a single-mode fibre and fibres supporting more than one mode are multi-mode fibres.



Light propagation in a single-mode fibre



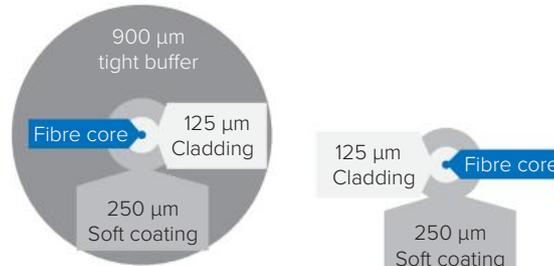
Light propagation in multi-mode step-index fibre in which the reflection of light off the fibre boundary is abrupt



Light propagation in multi-mode graded-index fibre in which the reflection of light off the fibre boundary is gradual

FIGURE 7.48 Basic principles of optical fibre transmission

Two basic fibre structures



Tight buffer fibre

Coated fibre

Core sizes:
single mode—9 µm; multi mode—50 µm or 62.6 µm

Optical fibre components

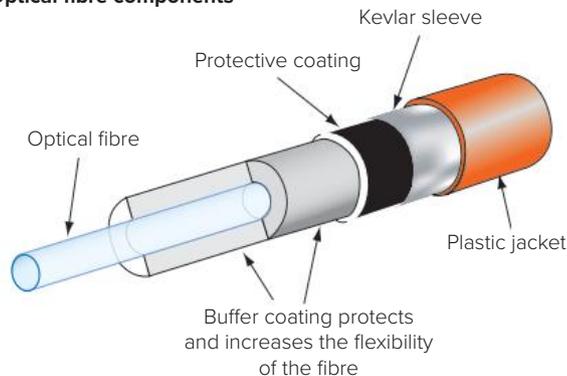


FIGURE 7.49 Examples of optical fibre and cable structures

Common name: Indoor/outdoor cable

Cable types: multi-mode OM1

Fibre: 6 and 12 core 62.5/125 μm



Where it is used

Used for outdoor connections between buildings, in campus installations or indoors as a riser between building floors.

Common name: Underground optical fibre cable

Cable types: single-mode OS1, multi-mode OM1 and OM3

Fibre: single-mode 6, 12 and 24 core 10/125 μm

multi-mode OM1 6, 8 and 12 core 62.5/125 μm

multi-mode OM3 6 and 12 core 50/125 μm



Where it is used

Used for underground installation in duct or direct buries in situations where water and termite resistance is required.

FIGURE 7.50 Examples of optical fibre cables

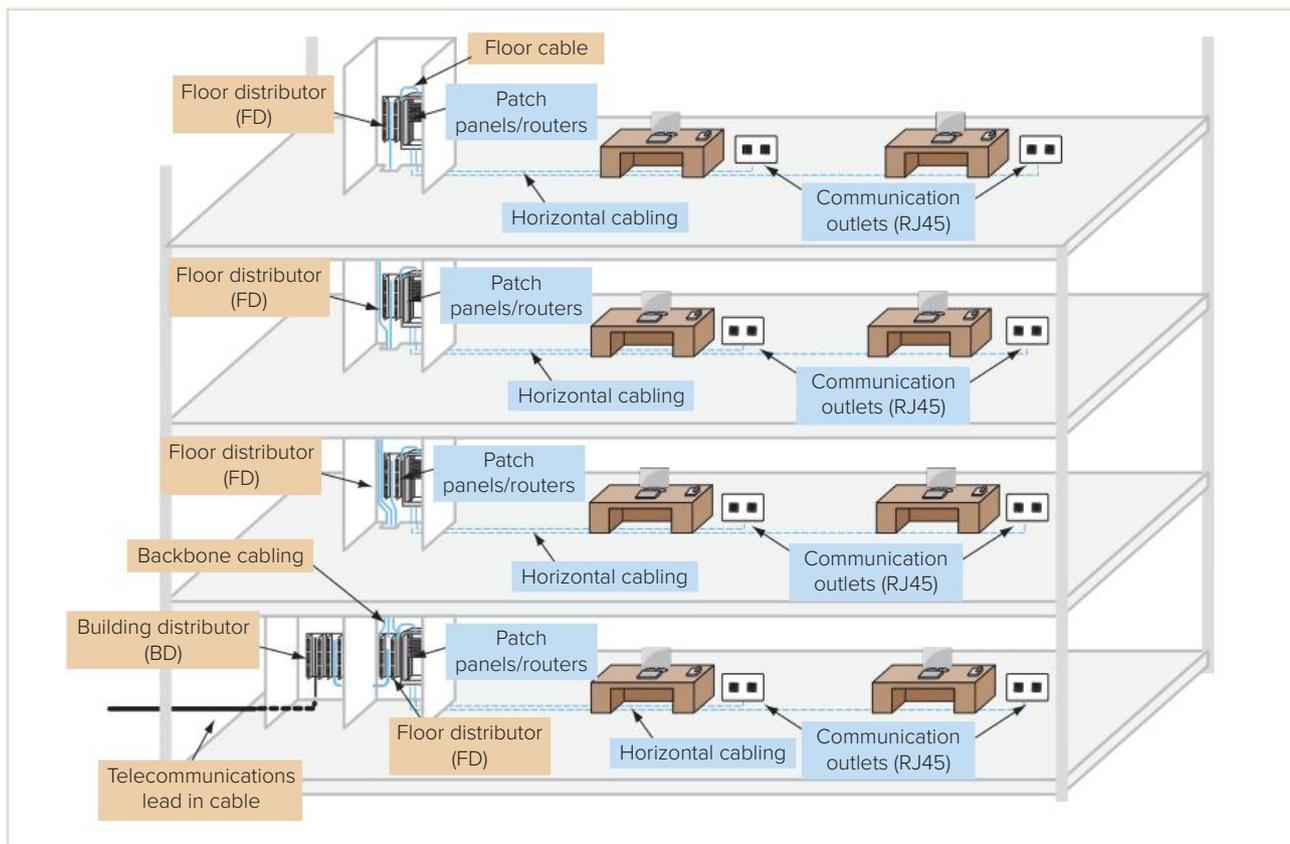


FIGURE 7.51 General arrangement of communications cables in buildings and premises

All cabling products must comply with *Technical Standard 008—Requirements for customer cabling products AS/CA 2008:2020*. This includes the hardware for distribution arrangements and the devices for terminating cables. Properly installed cabling hardware should provide:

- ▶ cross-connections as a means to connect various elements of the cabling system and customer equipment using cross-connects, patch cords and equipment cables
- ▶ identification of all cabling
- ▶ orderly cable management
- ▶ the ability to monitor or test cabling and active equipment
- ▶ protection against physical damage and ingress of contaminants that might affect continuity
- ▶ a termination density that is space efficient and provides ease of cable management and ongoing administration of the cabling system.

7.6.3 Communications cable terminations

Terminating copper cable

Like power cables, the most vulnerable parts of a communications cable installation are the terminations. The most common accessory used for copper cables is the modular socket/plug, in which the insulation-displacement termination and insulation-piercing termination are the most common. Although there are a number of proprietary systems available, they all comply with the common standard; examples are shown in **Figure 7.52**.

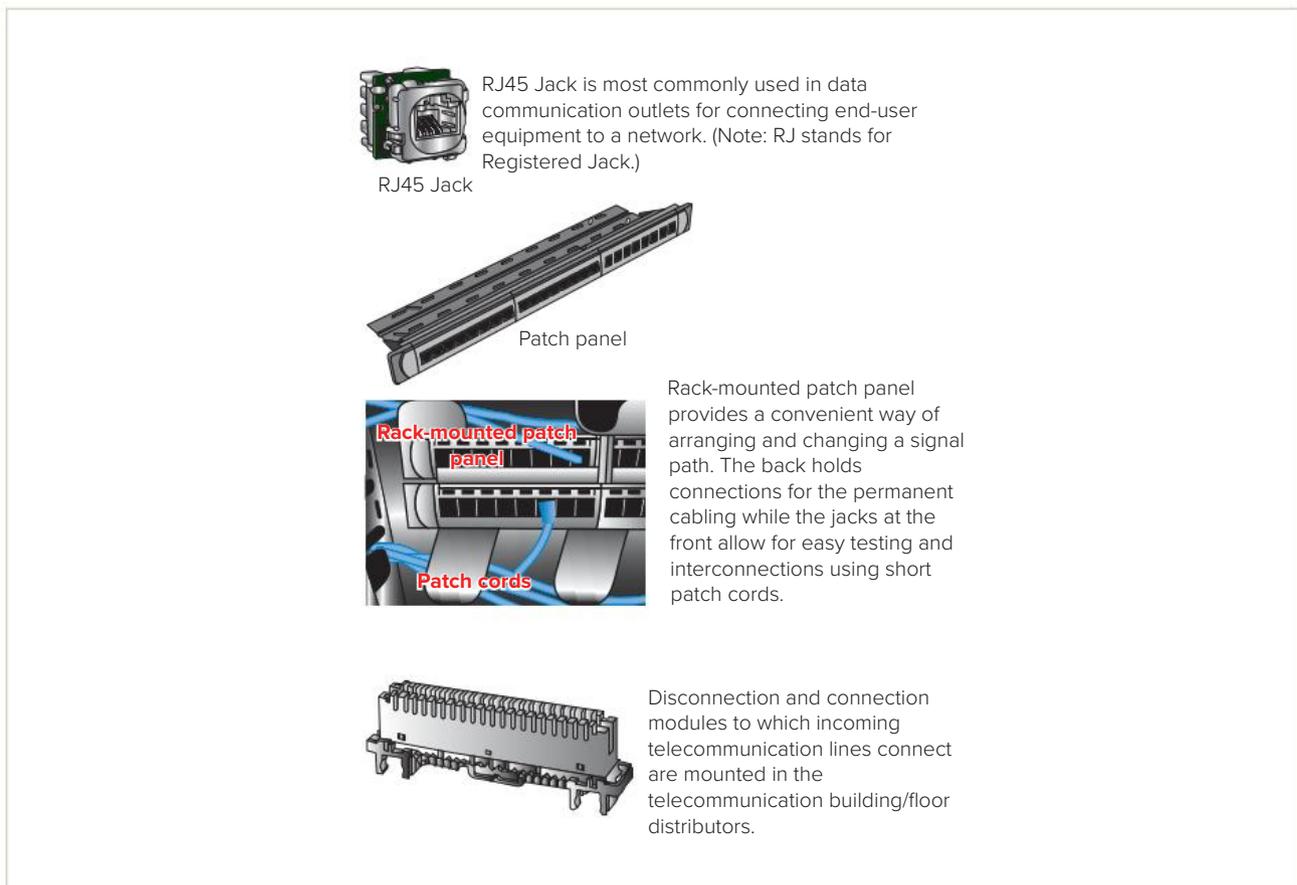


FIGURE 7.52 Examples of copper communications termination devices

Some of the parameters that characterise connector transmission performance are attenuation, near-end crosstalk (NEXT), return loss and d.c. resistance. While all of these parameters are sensitive to transmission discontinuity caused by connector terminations, NEXT performance is particularly susceptible to conductor untwisting and other poor installation practices that disturb pair balance and cause impedance variations. As well as signal degradation, improper termination practices can create loop antenna effects, resulting in levels of signal radiation that may exceed regulatory requirements for emissions.

Figure 7.53 shows the basics of terminating copper communications cables.

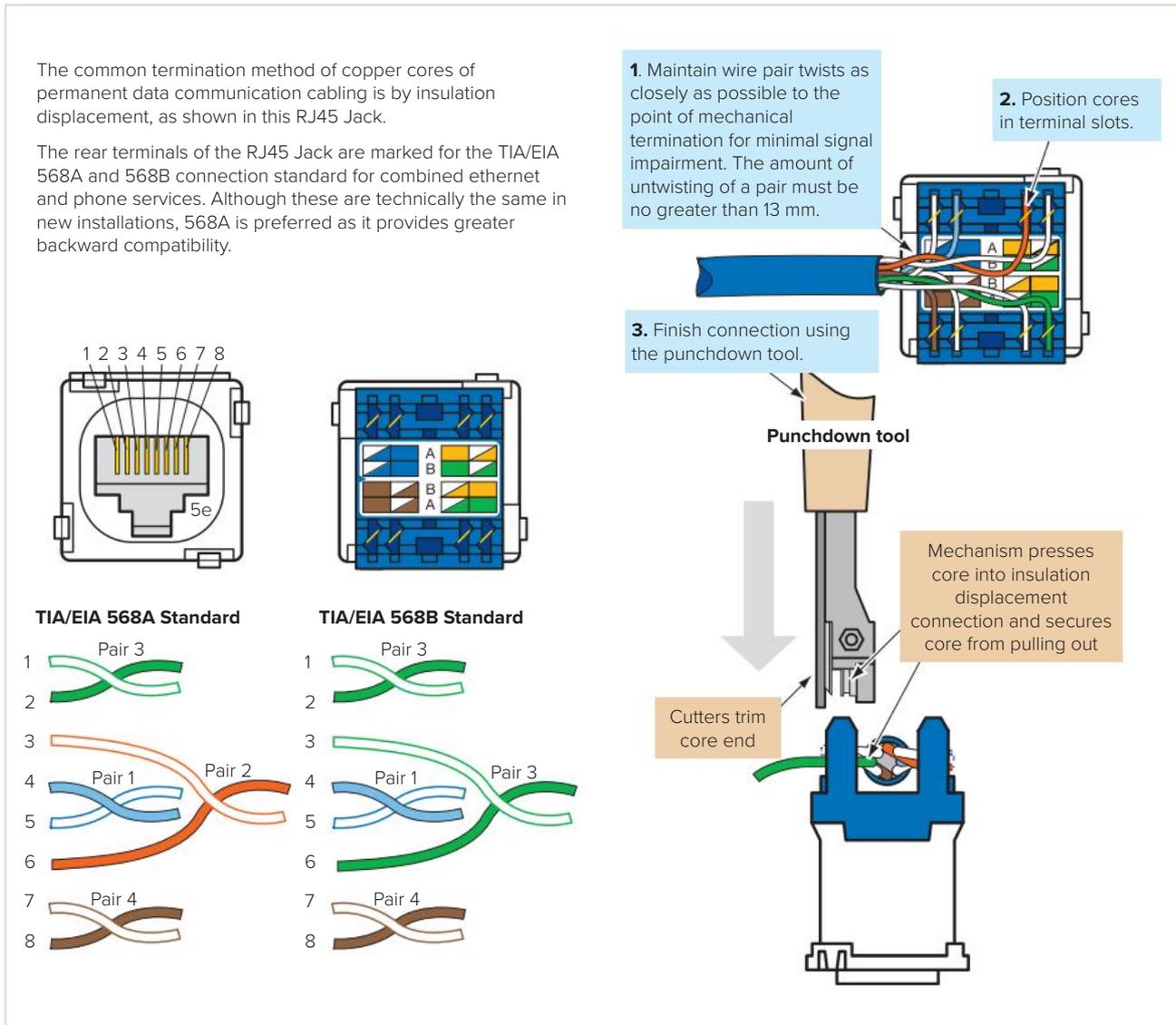


FIGURE 7.53 Basics of terminating copper communications cables

Terminating optical fibre cable

Splicing optical fibre cables is the term used for permanently melding the end of one cable to another. Optical fibre cable connectors are assemblies that secure the ends of the cables and precisely align one optical fibre with another to ensure the light signals pass from one to the next with minimal loss of light energy. Connectors used for terminating optical fibre cables align the optical fibre with a transmitting or receiving device. Whether splicing or terminating, you must protect yourself from the harm that can be caused by shards of waste fibre.

In addition to these safety precautions, terminating must be conducted in a thoroughly clean environment. Very small particles of dirt or dust contamination in a termination will greatly impair the performance of the cable.

The most common methods of connecting and terminating optical fibres are illustrated in **Figures 7.54** and **7.55**.

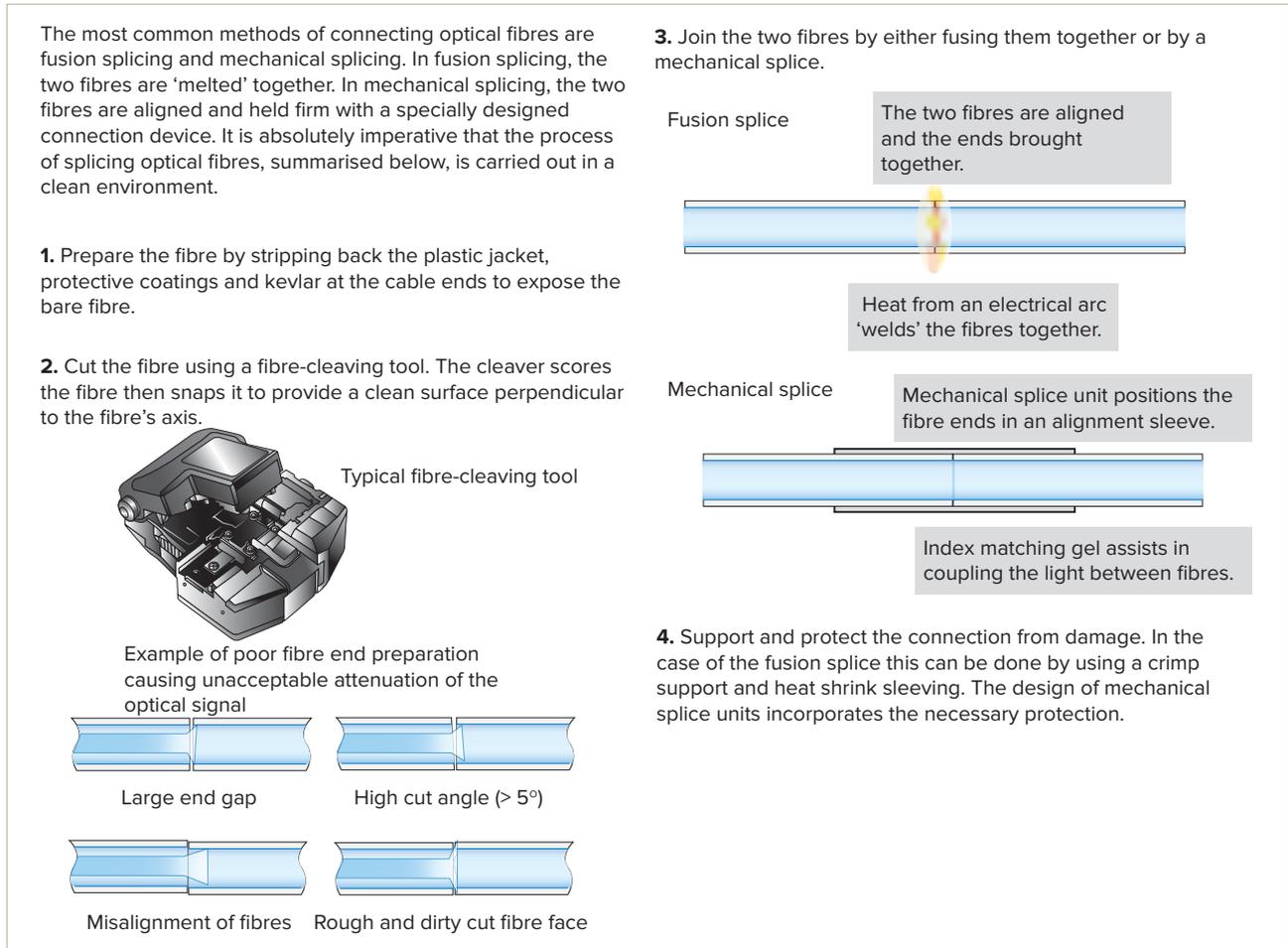


FIGURE 7.54 Optical fibre cable-termination process

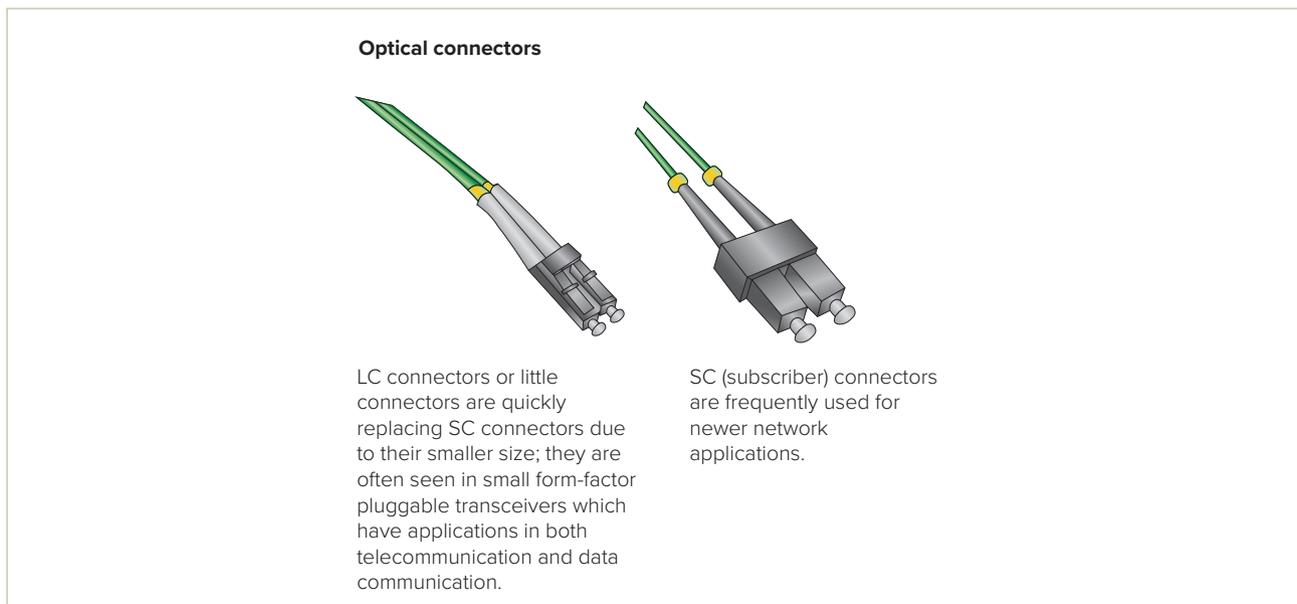


FIGURE 7.55 Optical fibre cable connectors



SAFETY ALERT

Glass fibre waste is harmful

Take every precaution to ensure that glass fibres:

- ▶ are not ingested
- ▶ do not become embedded in skin
- ▶ do not enter the eyes.

This means that you must:

- ▶ keep all food and beverages out of the work area
- ▶ wear disposable overalls to minimise fibre particles on your clothing
- ▶ wear safety glasses with side shields and also wear protective gloves
- ▶ put all cut fibre pieces into a sharps disposal container
- ▶ thoroughly clean the work area and wash your hands when the work is completed.



CHECK YOUR UNDERSTANDING

26. List three important functions of data and communications cabling.
27. Explain the principles of optical fibre transmission. Tip: See **Figure 7.48**.
28. Using appropriate safety procedures, terminate a Category 5e cable in a 8P8C modular socket. Tip: See **Figure 7.53**.
29. To maintain minimal signal impairment, what is the maximum length of untwisting that a pair of cables can have?
30. Name two methods for joining optical fibres.

SUMMARY

- ▶ *Clauses 1.4.21 to 1.4.27 and Clauses 1.4.35 and 1.4.36 of the Wiring Rules provide a definition for cable and related terms.*
- ▶ *Conductor form or shape varies widely depending on the cable, and copper and aluminium are the main materials used in conductors. All conductors must be manufactured according to AS/NZS 1125 Conductors in insulated electric cables and flexible cords.*
- ▶ *The function of cable insulation is to withstand voltage and to confine the current to the conductor without any leakage. The most commonly used insulation materials are plastic and polymeric compounds.*
- ▶ *Cables are described according to their conductor material and permitted maximum normal operating temperatures.*
- ▶ *Conductors have a designated code which can be found in the Wiring Rules and AS/NZS 3008.1.*

- ▶ The colour of a cable's outer sheath helps identify its function.
- ▶ Conductors must be identified to show their intended function, as stipulated in *Clause 3.8.1* of the *Wiring Rules*.
- ▶ Thermoplastic sheathed cable comes in multicore flat or single-core circular cable, is double-insulated and used when protective enclosures are not required.
- ▶ Single-insulated cable is often referred to as *building wire*. It is commonly used in wiring between accessories in switchboards and must be installed in an enclosure
- ▶ Fire-performance cables such as mineral insulated metal-sheathed cable are for use where there is an increased threat of fire.
- ▶ Aerial conductors (bare) and cables (insulated) are cables strung between supporting poles or posts above the ground. Aluminium is the most common conductor material used for overhead cables as it is lightweight and cost efficient.
- ▶ Joining and terminating of cables is an essential part of wiring and must not create a weak link in the electrical distribution.
- ▶ To install telecommunication cabling a person must be competent and registered with an organisation accredited by the Australian Communications and Media Authority.
- ▶ Communications cables are made of copper conductors and transmit information encoded digitally in an analogue carrier signal (broadband). The two main types are twisted pair cable and coaxial cable.
- ▶ *AS/NZS 3080:2013 Telecommunication installations—Generic cabling for commercial premises* sets the test performance standards for installed communication cables.
- ▶ *ISO/IEC 11801 Information technology—Generic cabling for customer premises* specifies cables by classes and categories.
- ▶ Optical fibre cables transmit voice data using a beam of light and are used in pairs, one for transmitting and the other for receiving.
- ▶ The arrangement of communications cables in buildings and premises depends on the number of lines entering the premises, the final number of outlets, their locations and the purpose of each.
- ▶ It is important to terminate communications cable correctly to limit signal degradation and loop antenna effects.
- ▶ Splicing optical fibre cables is the term used for permanently melding the end of one cable to another, and safety precautions must be followed when terminating or splicing these cables.

REVIEW QUESTIONS

1. Why must conductors used for the supply or interconnecting of electrical equipment have a low resistance?
2. What is the main feature of a flexible cable?
3. Name the types of cables that meet the definition for *double-insulation*.
4. What precaution should be taken when purchasing cables with respect to regulatory standards?
5. What determines the maximum normal operating temperature of a cable?
6. How can electricians be assured that the cables they purchase comply with the appropriate cable standard?
7. Identify the function of the conductors based on the following insulation colours:
 - a. green/yellow
 - b. black or light blue
 - c. red.
8. In **Figure RQ71**, show the colour and connection of the supply cables to an imported machine wired to the European colour code. Tip: See *Clause 3.8.3.3*.

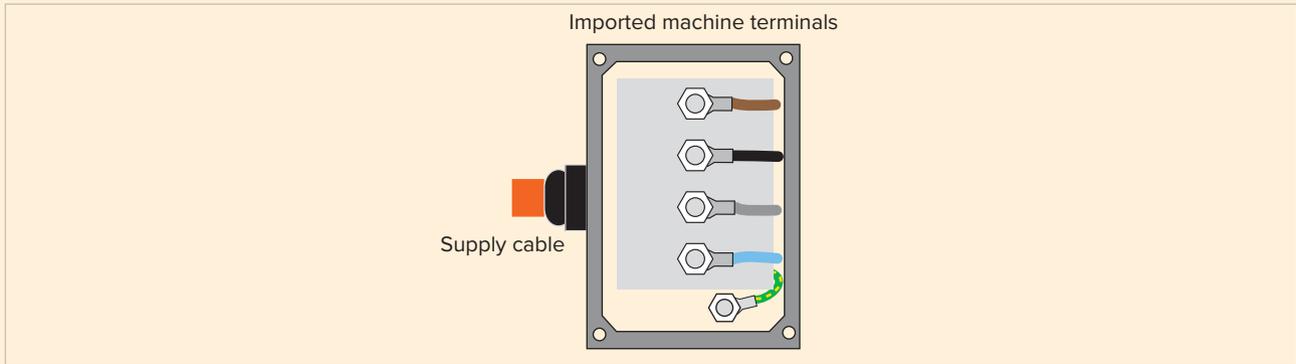


FIGURE RQ7.1

9. Before working on electrical equipment, how should the functions of conductors be identified? Give a reason for your answer.
10. Describe where the following cables would typically be used:
 - a. single double-insulated
 - b. TPS twin
 - c. TPS twin and earth
 - d. building wire
 - e. circular multicore and SWA
 - f. multicore control cable.
11. How must building wire be installed?
12. List the two main types of fire-performance cables.
13. What are the functions of an optical ground wire?
14. List two advantages of LV aerial bundled cable used for LV distribution and service lines over bare conductors.
15. Describe the specific features of a cable supplying a motor from a variable-speed drive and explain why such a cable is necessary.
16. Summarise the conditions that ensure cable terminations and conductor connections are sound and will not break down in use.
17. Name the particular hazards associated with terminating an SWA cable.
18. What are the requirements for a person to be able to carry out data and communication cabling work?
19. Using **Figure RQ7.2**, sketch and label the communication cabling arrangement.



FIGURE RQ7.2

20. List the particular risks and safety measures needed when terminating optical fibre cables.

CHAPTER 8

Lighting applications

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ understand the basic principles of light technology and the concepts of elementary lighting design
- ▶ identify different types of luminaires and understand their features and purpose
- ▶ identify test equipment used for measuring lighting levels
- ▶ explain how light is produced from various forms of light fittings
- ▶ understand how light-emitting diode technology is used in modern lighting applications
- ▶ compare various types of lighting technologies and understand their advantages and disadvantages
- ▶ identify common faults in luminaires and lighting circuits, and know which techniques fix such faults
- ▶ understand loop at the light and loop at the switch forms of thermoplastic sheathed cable wiring
- ▶ understand how to achieve single-way, two-way and intermediate light switching control
- ▶ describe the purposes and types of emergency lighting and their requirements as specified by the relevant standards
- ▶ list the components of smoke detector/alarm devices and their functions and usage.

Most lighting applications require some form of design or careful consideration. The objective of any lighting installation is to satisfy a visual need, and it is the nature of that visual need that determines which techniques are used. Lighting installations must also provide conditions that enable people to see in comfort. The techniques used in lighting vary according to the visual need.

Changes in technology create challenges for electricians. These challenges include correctly installing the electronics that play a major role in the technology behind new light sources and allowing for the use of computer and communication technologies in the development of intelligent lighting control systems. Technologies will continue to change rapidly for years to come. This change is driven by government policies that aim to better manage energy use, the economic advantages they allow and the technologies themselves. This underlines the importance of obtaining the details of new developments from manufacturers in order to keep up to date with the latest information.

The large number and types of light sources available for use in lighting installations are a major benefit for the user of lighting products and it is important to gain knowledge of all types of lamps and their applications. Light sources, or lamps, are selected for specific applications for a number of reasons. The final selection could be determined by size, colour, appearance, colour-rendering properties, life, operating costs and maintenance costs. This chapter covers a range of light sources and, although some are obsolete, the principles on which they operate continue to be relevant to newer versions.

The information in this chapter will help you to: choose the appropriate luminaires for the situation; perform simple lighting design tasks and calculations; understand control gear and circuits; and equip you to meet the demands of the modern user.

8.1 Basic lighting principles, terminology and units

The sensation that we call 'seeing' is produced by light entering the eye either directly from a light source or as a reflection off an object. Assuming there is no eye defect in the viewer, how well an object is seen depends on there being:

- ▶ sufficient light
- ▶ freedom from glare
- ▶ suitable contrast between the object and its background.

8.1.1 Nature of light and seeing

In common with radiation such as heat, radio waves and X-rays, light is a form of electromagnetic energy radiated or broadcast into space at a velocity of approximately 300×10^6 m/s. The electromagnetic spectrum and the human visual response are approximated in **Figure 8.1**. The fact that the eye sees yellow better than, say, purple or dark red of the same energy content influences the colour of fog lamps and contributes to the efficacy of sodium vapour lamps.

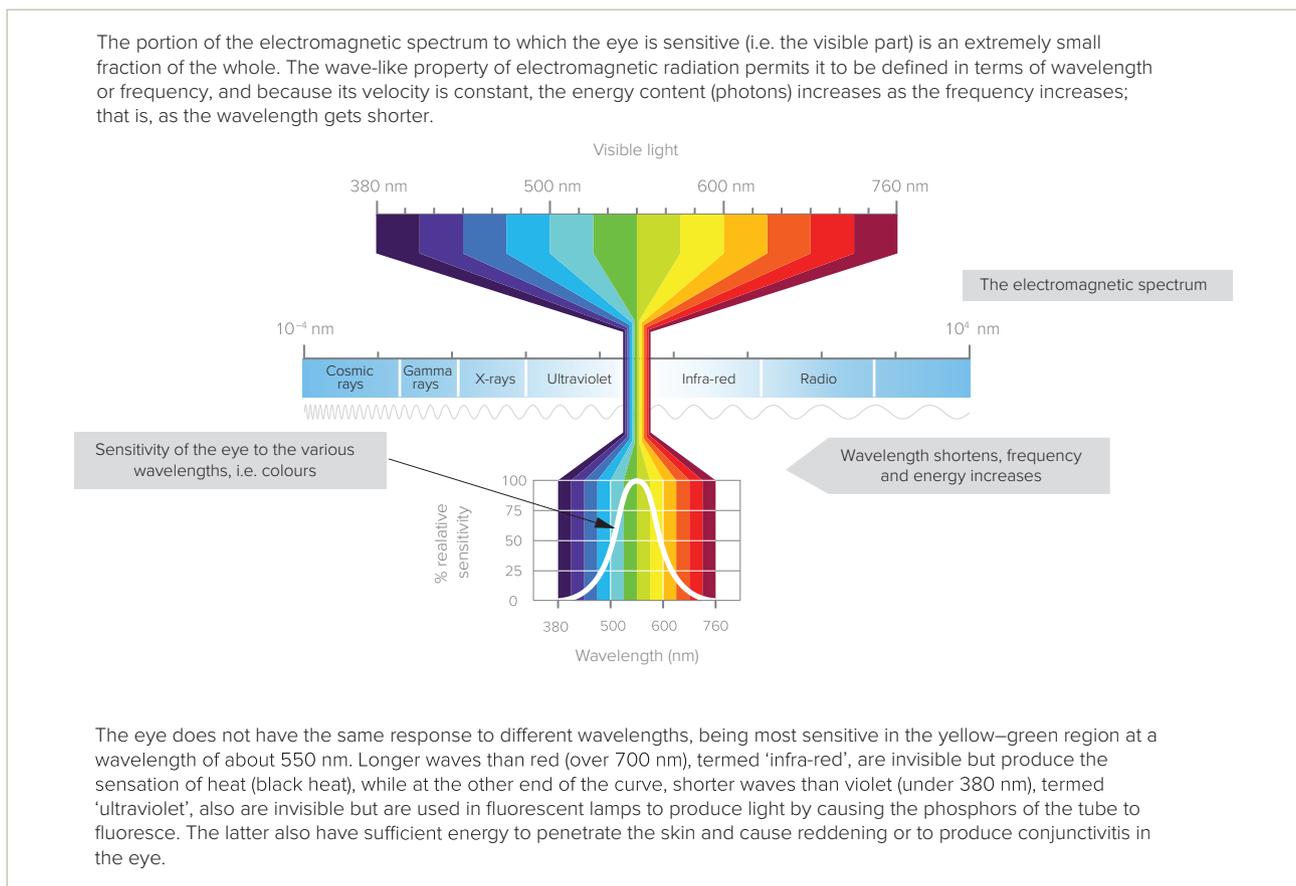


FIGURE 8.1 Electromagnetic spectrum and human visual sensitivity range

Although electromagnetic radiation (EMR) is wave-like, light is propagated in straight lines or rays and it is this concept of rays of light that makes possible the practical design of reflectors, diffusers and refractors, as shown in **Figure 8.2**.

Objects are seen by means of reflected light and what we know as white light consists of a combination of all the colours of the visible spectrum; so, if all colours are reflected by an object, it appears white. Where not all of the light rays are reflected, that is, where EMR of some wavelengths is absorbed by a surface, the surface appears as some

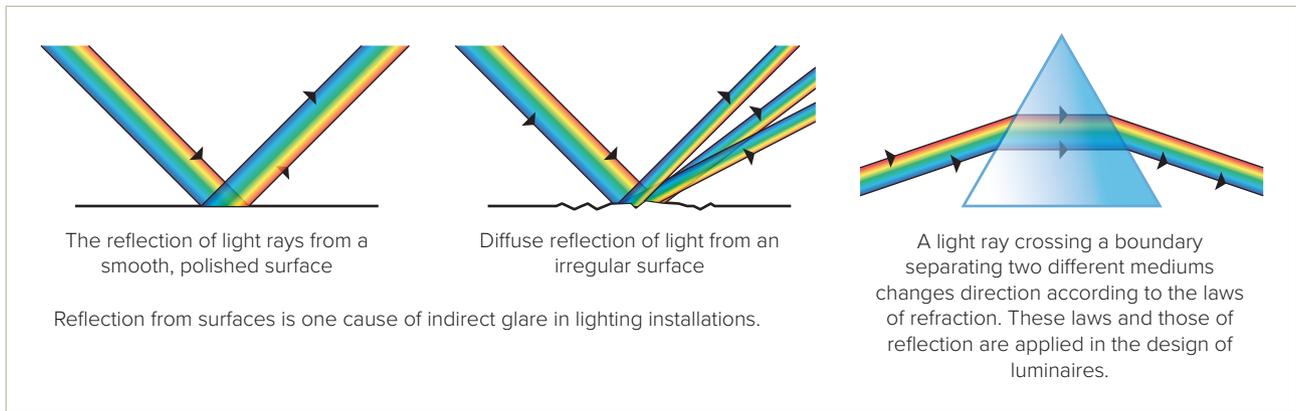


FIGURE 8.2 How light behaves—reflection, diffusion and refraction

other colour corresponding to the wavelength of the reflected light rays. Isaac Newton said: ‘Colours in the object are nothing but a disposition to reflect this or that sort of ray more copiously than the rest.’

These facts must be remembered when dealing with nearly all light sources. Light sources produce coloured light; that is, light rich in certain wavelengths (colours) while being poor in others. For example, incandescent lamps produce light rich in red, while sodium vapour (low-pressure) lamps produce an almost monochromatic yellow light. On the other hand, the colour of the light from a fluorescent tube depends on the properties of its phosphor coating. Hence, any object or visual task will appear to be differently coloured when lit by different sources of light.

8.1.2 Lighting terms and units

There are many terms and units associated with illumination. **Figures 8.3 to 8.7** show some common terms.

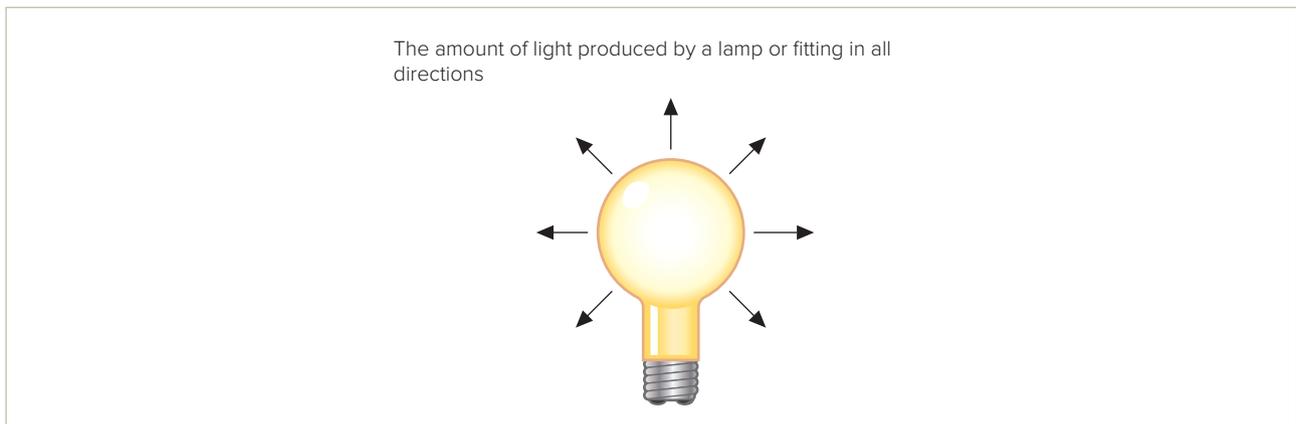


FIGURE 8.3 Luminous flux

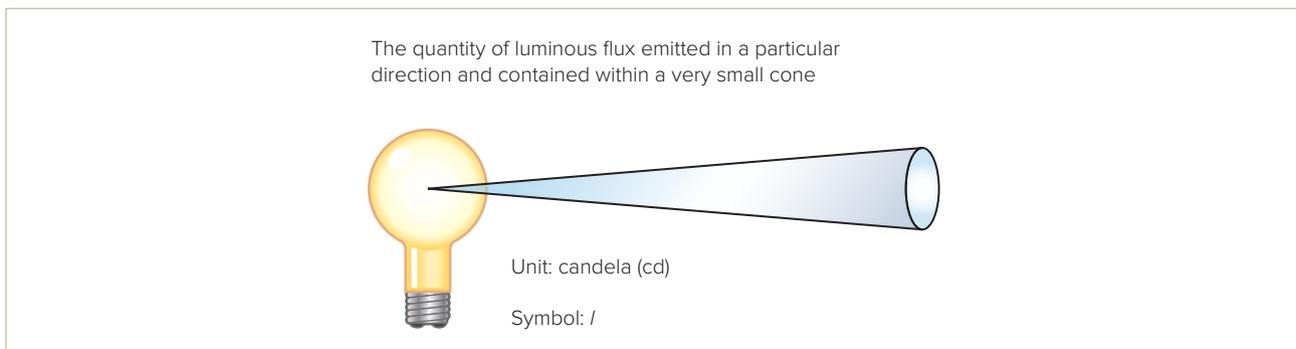


FIGURE 8.4 Luminous intensity

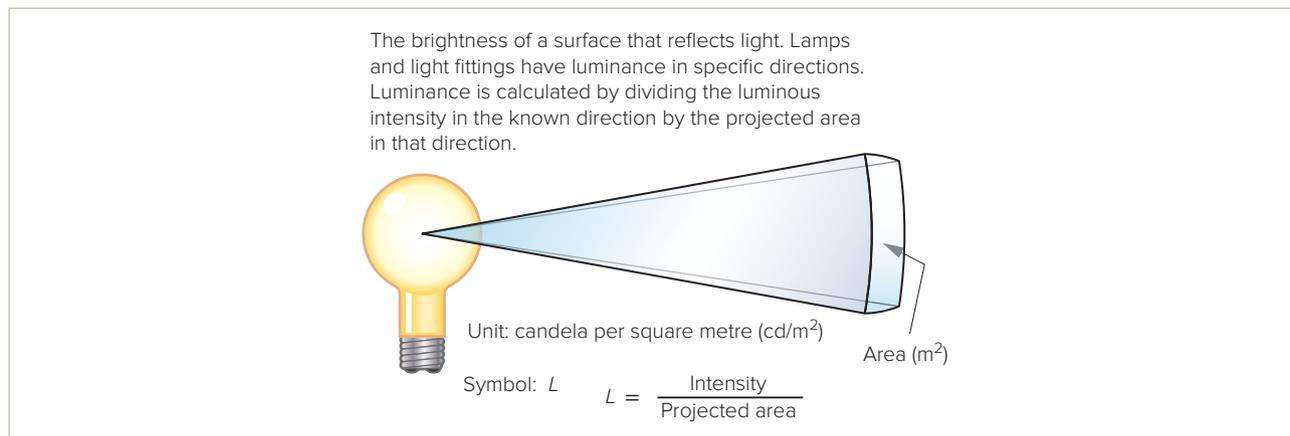


FIGURE 8.5 Luminance

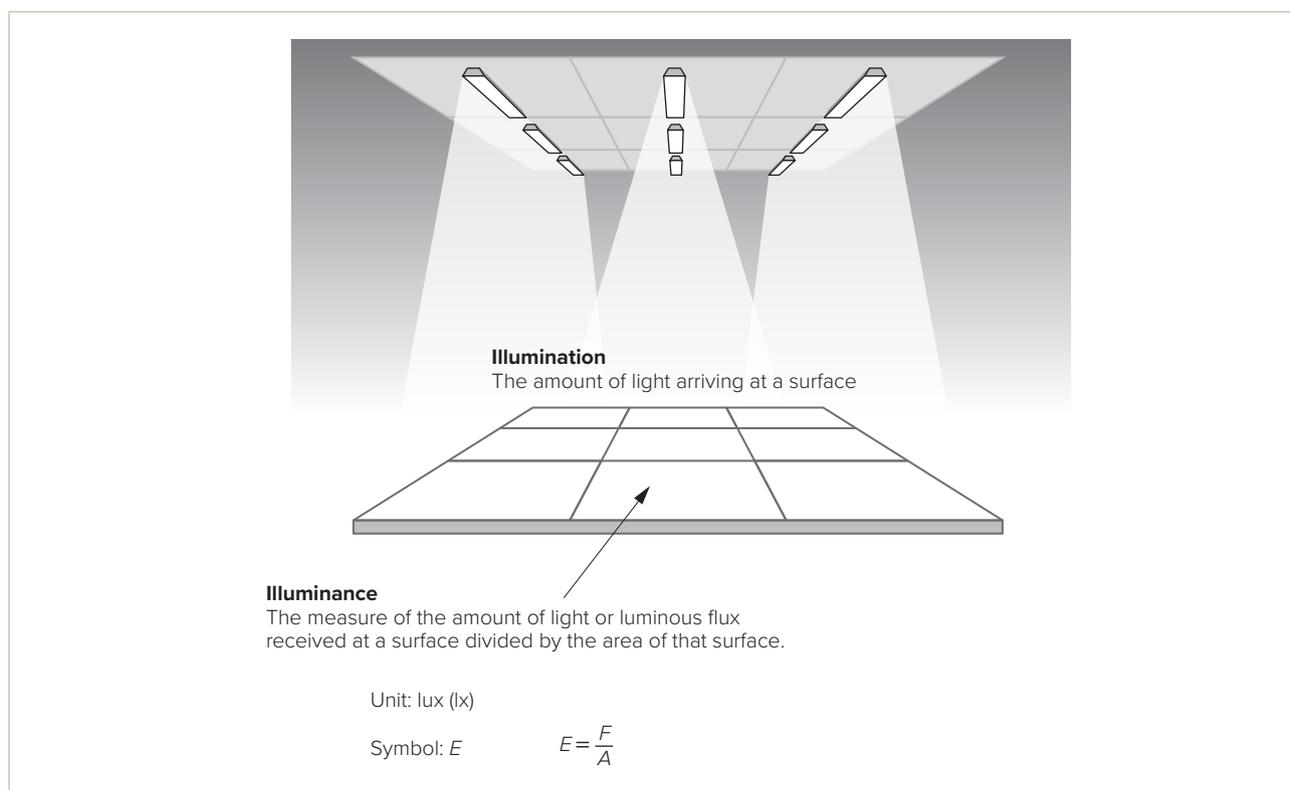


FIGURE 8.6 Illuminance

The light distribution of lamps and fittings is described in terms of luminous intensity and shown graphically in diagrams, as in the example in **Figure 8.8**.

Two important equations

First, by considering the definitions of luminous flux F and illuminance E , it is evident that, if the flux incident on the working plane is evenly distributed, then:

$$E = \frac{F}{A}$$

where E = illuminance in lux(lx)

F = total flux incident to the surface in lumens (lm)

A = (area of the working plane in square metres (m²))

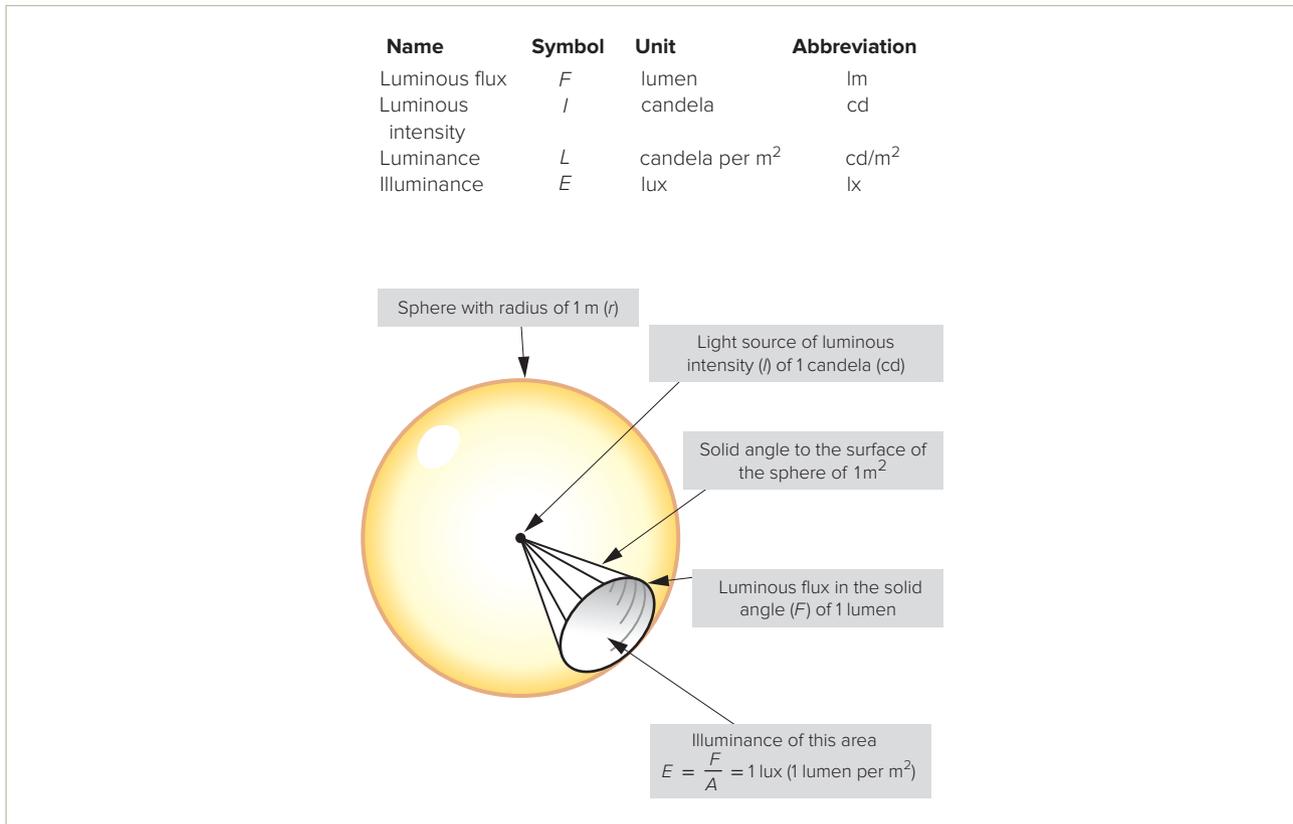


FIGURE 8.7 Relationship between luminous flux, luminous intensity and illuminance

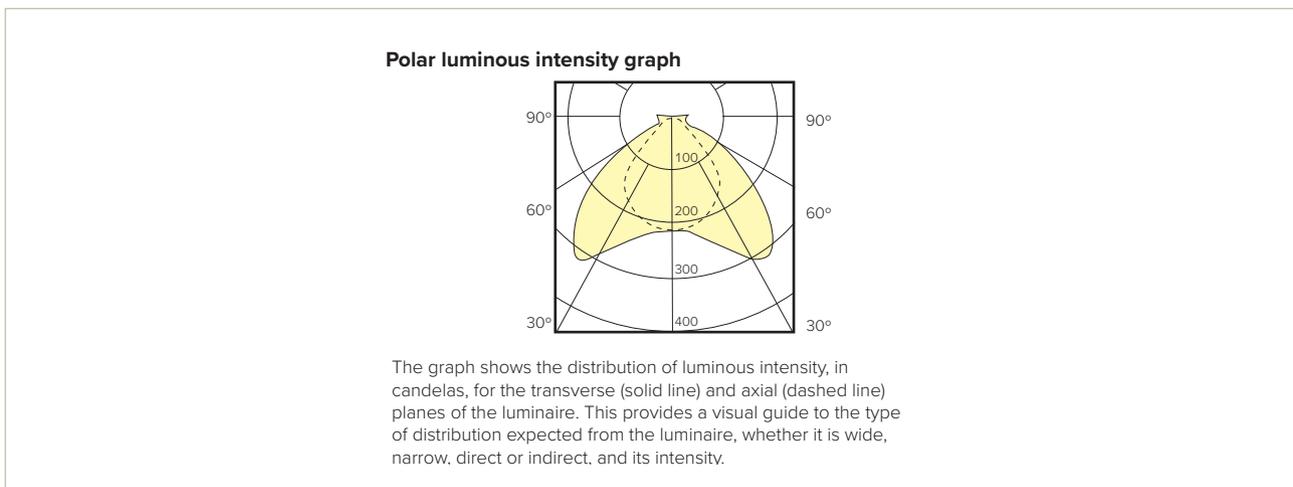


FIGURE 8.8 Typical form between light distribution from a luminaire

Second, because light travels in straight lines, if it is propagated from a point source the inverse square law applies: the illuminance on a surface is inversely proportional to the square of the distance from the source, as shown in **Figure 8.9**.

If the flux arrives at an angle to the surface, the value is reduced by a factor represented by the cosine of the angle. This occurs in a simple case, where it is assumed that the flux is normal to the surface. In practice, for a single bare incandescent lamp at a distance of, say, 2 m or more, this will give reasonably accurate results. However, this situation is rare because diffusers and reflectors usually redirect the light, and reflectance from walls and ceilings also affects the results.

The equation in **Figure 8.9** is used in the point-by-point method of determining the total flux required and, again, for practical light sources the illuminance produced by a number of sources may be assumed to be equal to the sum of the separate sources.

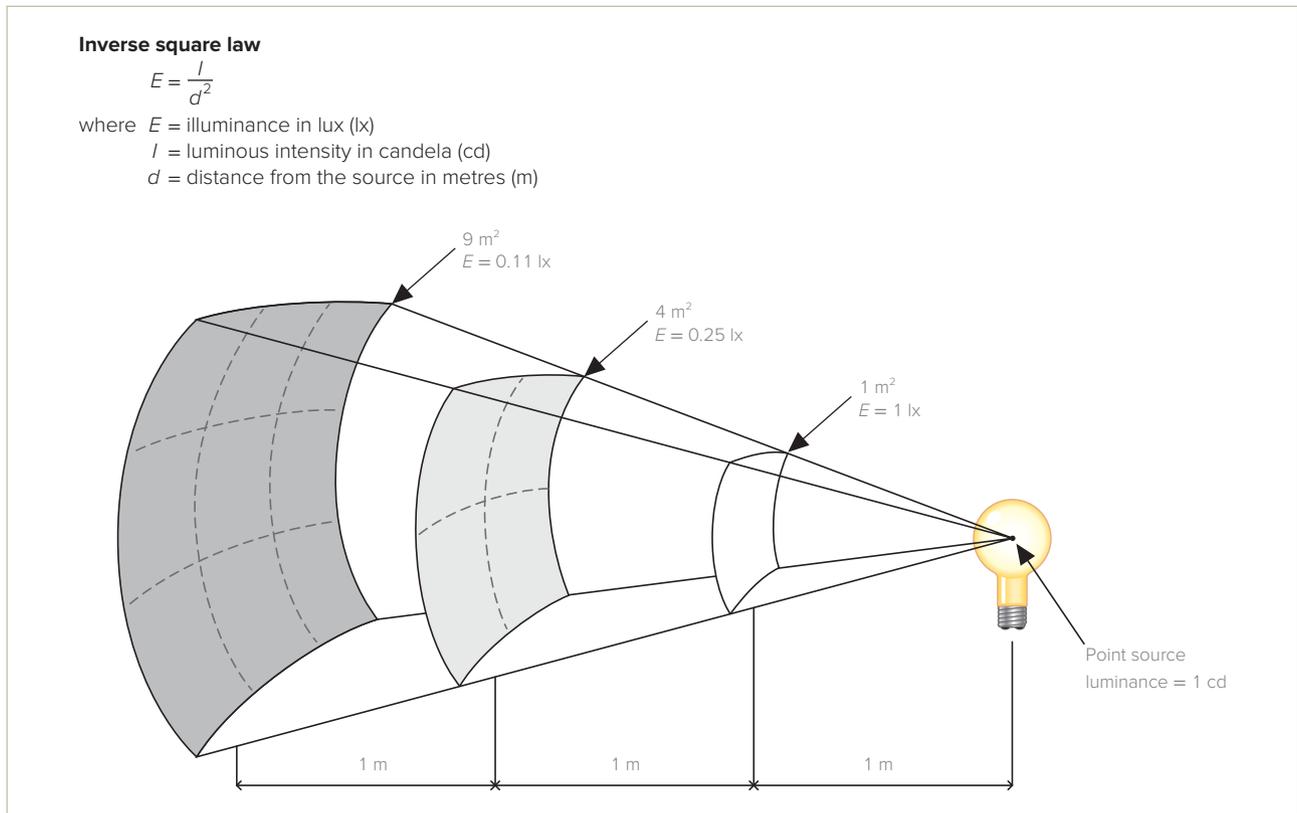


FIGURE 8.9 Law of inverse squares

Terms used in lighting design and maintenance are given in **Table 8.1** and some worked examples are given in **Examples 8.1** to **8.4**.

EXAMPLE 8.1

A total flux of 3500 lm falls uniformly on an area of 15 m².

Illuminance is given by:

$$\begin{aligned} E &= \frac{F}{A} \\ &= \frac{3500}{15} \\ &= 233.3 \text{ lx} \end{aligned}$$

EXAMPLE 8.2

The recommended maintained illuminance for the general working area of a bakery is 200 lx. If the working area is 300 m² the value of the useful flux incident on the working plane is given by:

$$\begin{aligned} F &= E \times A \\ &= 200 \times 300 \\ &= 60.000 \text{ lm} \end{aligned}$$

TABLE 8.1 Common lighting terms

Term	Definition
Visual task	The area requiring illumination for the performance of a task or job
Task area	The actual area where light is required
Average illuminance	The mean or average of the illuminance over a nominated work or task area
Initial illuminance	The average illuminance over an area that is achieved in a new lighting installation, when lamps are new and light fittings and room surfaces are clean
Maintained illuminance	The average illuminance that represents the minimum acceptable value to perform a task; at this point, lamps need to be replaced, and luminaires and room surfaces need cleaning
Working plane	The level at which the task is performed, usually horizontal, but can be any plane or working surface at which the task is carried out; the horizontal working plane in an office is considered to be 700 mm above the floor, and in an industrial application 850 mm above the floor
Direct and indirect glare	When a relatively bright object is seen against a dark background; glare can come directly from an offending bright source or indirectly by reflection from a glossy surface and, in most lighting installations where this occurs, discomfort from glare is experienced. Under these conditions, a task can be performed adequately but with a degree of discomfort. Values of luminance are important in the control of glare from light sources and luminaires
Shielding angle	The angle below the horizontal axis of the luminaire at which the lamp is first visible; it is the complementary angle to the cut-off angle
Reflectance	The amount of light or luminous flux reflected by a surface, divided by the amount of luminous flux reaching the surface; a white painted surface might have a reflectance of 80%, meaning 80% of the light reaching the surface is reflected by it
Unwanted reflection	Reflected light that reduces visual performance by reducing contrast
Luminous efficacy	The amount of light or luminous flux produced by a lamp, divided by the power consumed by the lamp; the efficacy is expressed in lumens per watt (lm/W). For example: What is the luminous efficacy of a 36 W fluorescent tube with an output of 3000 lm? Luminous efficacy = $\frac{3000}{36}$ = 83.3 lm/W

EXAMPLE 8.3

An illuminance of 200 lx is present at a distance of 3 m from a light source. If the inverse square law is applicable to the situation, what is the luminous intensity of the source?

$$\begin{aligned}
 F &= \frac{I}{d^2} \\
 I &= Ed^2 \\
 &= 200 \times 9 \\
 &= 1800 \text{ cd}
 \end{aligned}$$

EXAMPLE 8.4

At what height should a light source be mounted if its vertical luminous intensity is 5000 cd and it is required to provide an illuminance of 200 lx on the working plane?

$$\begin{aligned}
 F &= \frac{I}{d^2} \\
 d &= \sqrt{\frac{I}{E}} \\
 &= \sqrt{\frac{5000}{200}} \\
 &= 5 \text{ m}
 \end{aligned}$$



CHECK YOUR UNDERSTANDING

1. What three things determine how well an object can be seen?
2. The amount of light produced by a lamp or fitting in all directions is known as what?
3. What does the term *illuminance* mean?
4. Explain how the inverse square law affects the level of illuminance on a surface.
5. What does the term *luminous efficacy* mean?

8.2 Elementary lighting design

Lighting design is the domain of the lighting engineer, but the practising electrician should be aware of the basics, as discussed in the previous sections. The electrician should also be familiar with the main elementary principles employed in lighting design and be able to appraise a simple installation for the effectiveness and quality of the lighting.

8.2.1 Design requirements

The objective of a good lighting system is clearly to illuminate the task or work area in such a way that the work can be carried out with safety and visual comfort. This is achieved by:

- ▶ providing adequate illuminance on the task
- ▶ ensuring freedom from unwanted reflection
- ▶ producing the correct balance between luminance of the task and luminance of the surroundings
- ▶ avoiding excessive illuminance variation
- ▶ protecting against discomfort from direct glare from lamps and luminaires.

AS/NZS 1680.1—Interior and workplace lighting—General principles and recommendations defines maintained illuminance as ‘the defined level below which the average illuminance on any surface is not allowed to fall’. Typical values of maintained illuminance are given in **Table 8.2**.

TABLE 8.2 Maintained illuminance recommended for specific tasks

Task	Maintained illuminance
Circulation areas, corridors, walkways etc.	40 lx
Areas used periodically (e.g. storage areas, change rooms, cloakrooms, toilets)	80 lx
Areas occupied, but the task is not usually demanding (e.g. furnace rooms, foyers, stairs, escalators)	150 lx
Areas occupied, reasonably easy visual tasks (e.g. food preparation, semi-automatic production plants)	250 lx
Routine office functions, including screen-based activities, meeting and conference rooms	320 lx
Inspection of medium work (e.g. coil winding, car assembly)	400 lx
Areas with difficult tasks with fine detail (e.g. fine bench and machine work, drawing offices, spray booths)	600 lx
Areas with very difficult tasks (e.g. retouching paintwork, grading and matching leather)	800 lx
Extremely demanding visual tasks (e.g. colour reproduction and printing, woodwork inspection, hand sewing)	1200 lx
Tasks with minute detail (e.g. copper engraving, jewellery and watchmaking, instrument assembly)	1600 lx

The value of maintained illuminance will vary according to the visual demands of the task. Reference should be made to *AS/NZS 1680.1—General principles and recommendations* for specific values of maintained illuminance recommended for individual tasks.

General lighting and local lighting

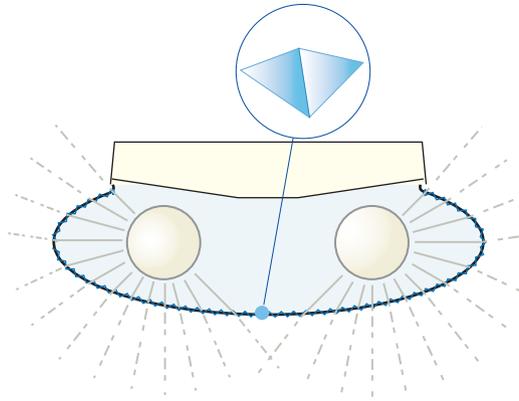
General lighting systems are those used in locations where a large space requires lighting over an area bigger than a single workstation. Local lighting systems are specifically designed for a particular task location. The task location can be as small as a watchmaker's field of view through a magnifier or as large as an industrial inspection station. The important point is that the lighting is designed specifically for the task in the location.

Freedom from glare

Uncomfortable glare from bare lamps can be reduced by housing the lamp in a luminaire, which will control the distribution of light. Unwanted reflections constitute indirect glare but, even if their brightness is insufficient to cause glare, the reflections may cause discomfort and prevent efficient viewing. Controlling the direction of the light and ensuring correct diffusion are essential: prismatic panels with suitable optical properties are widely used for this purpose (see **Figure 8.10**).

Manufacturers' data and lighting handbooks give performance characteristics for individual light fittings. The use of screen-based equipment in offices has resulted in the development of light fittings with low-brightness, high-quality

In the luminaire illustrated below, square-based conical prisms are used to control the light source and so give maximum illumination in the useful working area. At the same time, diffused linear refractors on the sides of the unit direct the light upwards for effective ceiling illumination.



Sharp shadows are also controlled by diffusers and by the correct spacing of luminaires to ensure that illuminance is reasonably uniform. For example, the spacing to mounting height ratio for general diffusing units and industrial trough reflectors is usually 1.5 to 1 or less.

FIGURE 8.10 Typical method for controlling light distribution and glare

aluminium louvres. These louvres have the effect of shielding the lamps from view and reducing unwanted reflection on screens. The *AS/NZS 1680* series deals with interior lighting and lighting specific to various work tasks, and should be consulted when dealing with the specific needs of those applications.

Suitable colour rendition for the job

Most tasks require some degree of colour discrimination, so the colour-rendering properties of lamps must be considered. Again, reference should be made to suitable tables, and it should be remembered that coloured walls and ceilings will reflect coloured light. If colour matching, for example, is involved, the illuminance will have to be at least 1000 lx and a daylight fluorescent can be used if the task is not too critical. Special blue filters are employed with filament lamps or colour-matching fluorescent lamps for more critical evaluation.

Uniform distribution of light over the task area

This requirement is mainly dependent on the correct spacing of suitable luminaires. The use of diffusers to spread the source of light can also contribute to uniform distribution and prevent shadowing.

Provision of local or special lighting where required

Local lighting is always supplementary to general lighting and should not be used as a substitute for it. Care should be taken to ensure that the luminaires used to provide this additional light are correctly positioned and do not cause visual discomfort.

8.2.2 Determining illuminance

There are two widely used methods to determine the illuminance on a working plane:

- ▶ The *point-by-point method* requires a calculation for each luminaire, making use of the inverse square law and cosine law where applicable; this method is rarely used on the average internal lighting job but is used

in applications such as floodlighting and street lighting—a detailed treatment of this method is beyond the scope of this book.

- ▶ The *lumen method*, which is the one considered here, has as its objective determination of the quantity of light flux in lumens that must be produced to provide the recommended illuminance in lux on the working plane, on the assumption that it is evenly distributed.

The lumen method

The total flux required is determined by first calculating the value necessary to give the required illuminance and then allowing for various losses. Once the number of luminaires has been decided, the flux or lumen output per luminaire and per lamp must be found. All the necessary factors that influence losses, such as room dimensions, reflectance values, light loss factor, luminaire types and so on, are tabulated for reference in the various lighting handbooks and/or manufacturers' data.

There are six steps in the calculation.

1. Reference to *AS/NZS 1680.1* or **Table 8.2** provides a value for the recommended value of illuminance in lux (*EAV*). In the examples that follow, *AS/NZS 1680.1* is used as the reference to give you practice in using the Standard.
2. The types of luminaire and lamp are chosen to suit the job, and mounting height and spacing are determined from a lighting handbook or the manufacturer's recommendation. This enables the number of luminaires to be tentatively determined.
3. The room dimensions (length and width) and the mounting height of the luminaire are correlated in reference tables under the title of 'room index'. The tables will give you a figure for this.
4. Knowing the room index from step 3, a figure for the overall utilisation factor, given by

$$U = \frac{\text{usable flux}}{\text{flux produced}}$$

is selected from another set of tables by cross-referencing the columns tabulated for the particular type of luminaire, the room index and the reflectance values of the walls and ceilings.

5. Another factor must be introduced to allow for depreciation of the lighting installation—the maintained factor (*MF*). This takes into account losses through:
 - ▶ lamp lumen depreciation
 - ▶ luminaire depreciation
 - ▶ room surface depreciation.

The product of all three gives the *MF*. *AS/NZS 1680.1* contains the information needed to arrive at an *MF* suitable for a particular set of circumstances. A typical *MF* for an installation of fluorescent luminaires in an air-conditioned office where lamps are regularly changed, and luminaires and room surfaces are maintained in a clean condition is 0.7.

6. The total required initial lumen output (*F*) can now be determined from the equation:

$$F = \text{average maintained illuminance} \times \text{area} \div \text{utilisation factor} \times \text{MF}$$

where

F = total initial lumens required

E = average illuminance in lux

A = area in square metres

U = utilisation factor

MF = maintenance factor

Thus:

Initial output per luminaire = $F \div \text{number of luminaires}$

Initial lumens output per lamp = $F \div \text{number of luminaires} \times \text{lamps per luminaire}$

EXAMPLE 8.5

Semi-direct fluorescent luminaires have been chosen for a library situated in a clean environment with dimensions of 12 m × 6 m and a ceiling height of 3 m. Reference to data provided by the manufacturer of the luminaires reveals that, if they are ceiling-mounted, the height is sufficient to eliminate glare and is within the luminance guidelines of *AS/NZS 1680.1*. Reference again to the manufacturer's data sheet shows that the spacing requirement is two rows, and the disposition of the library desks requires the luminaires to be fixed parallel to the length of the room (to view the lamps end-on and so reduce glare).

Reference to tables for semi-direct surface-mounted luminaires gives a utilisation factor (U) of 0.57 and an MF of 0.7. *AS 1680.1* prescribes a maintained illuminance of 400 lx:

$$\begin{aligned} F &= E \times A \div U \times MF \\ &= 400 \times 12 \times 6 \div 0.57 \times 0.7 \\ &= 72\,180 \text{ lm} \end{aligned}$$

If eight luminaires were used, arranged as shown in **Figure 8.11**, each would have to provide an initial output of:

$$72\,180 \div 8 = 9022.5 \text{ lm}$$

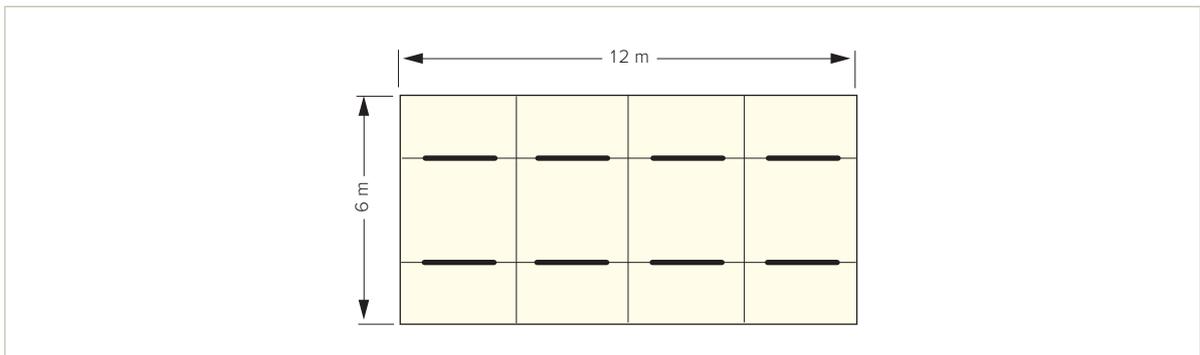


FIGURE 8.11 Lighting layout

This could be provided by 3 × 36 W white tubes, each tube giving approximately 3000 lm (initial lumens).

Alternatively, the designer might decide to install two rows of six luminaires, each containing 2 × 36 W tubes. The output required per luminaire in this case would be:

$$72\,180 \div 12 = 6015 \text{ lm}$$

Each tube would also provide approximately 3000 lm initially. This second scheme would provide a better light distribution and would be a little more efficient; a luminaire's efficacy falls slightly with multiple tubes because they tend to absorb one another's output. The light required here could be provided by 3 × 36 W white tubes, each tube giving approximately 3000 lm (initial lumens).

The lighting levels required in commercial and industrial installations, and which are commonly given in job specifications, may be higher than the Standards recommend. Completion inspections for an installation invariably include light level measurements using a light level meter or photometer similar to that shown in **Figure 8.12**. This instrument is useful when providing advice on lighting maintenance and updating a lighting installation.

This light meter measures the visible light from fluorescent, metal halide, high-pressure sodium or incandescent sources. It is a portable, easy-to-use digital light meter designed for simple one-hand operation, reading in lumen (lux) or footcandle (fc) units. The light meter is ideal for measuring interior illumination levels and for measuring or increasing the output level of luminaires. It is also ideal for reducing the energy burden of a building by significantly increasing the efficiency of its lighting system.



FIGURE 8.12 Example of a light level meter



CHECK YOUR UNDERSTANDING

6. What are the two methods used to determine the illuminance on a working plane?
7. What does the term *maintained illuminance* mean?
8. List some of the points required for good lighting design.
9. What is the difference between general and local lighting?

8.3 Incandescent lamps

Governments in Australia and New Zealand have embarked on a program to improve energy efficiency and reduce energy consumption in order to reduce greenhouse gas emissions and the effects of climate change, and also electricity costs to consumers. The mandatory regulation that applies to many common electrical appliances and lamps is the Minimum Energy Performance Standard (known as MEPS).

There are a range of requirements in MEPS and you should familiarise yourself with these requirements by reading the relevant documentation available online. There are also requirements for lumen maintenance (minimum of 80% measured at 75% of rated lamp life) and minimum lamp life (median lamp life of at least 2000 hours). The methods for measurement of efficacy, lumen maintenance and lamp life are set out in *AS/NZS 4934.1*.

NOTE: As a result of these efficiency measures, incandescent lamps have been almost completely removed from service. They have long been part of everyday life for many people and, while customers may ask for them, they should be educated about the modern alternatives.

Pilot lamps of 25 W and below and mains voltage reflector lamps including halogen (PAR, ER, R, etc.) are currently exempt from sales restriction.



DID YOU KNOW?

Efficacy is the correct term to use when discussing energy-efficient lighting. Efficacy is the measure of light output against the power input and is quoted in lumens per watt (lm/W), whereas energy efficiency is the ratio of energy output to energy input and is quoted as a percentage.

8.3.1 History

There are a number of claims about who first invented the incandescent lamp. Various patents were taken out in an effort to produce a lamp that could be used with the then-common gas light in which the filament would last a reasonable length of time. History accepts that the first commercial incandescent lamp was produced by Thomas Edison and Company in the United States. The basic principles of incandescent lamps are illustrated in **Figure 8.13**.

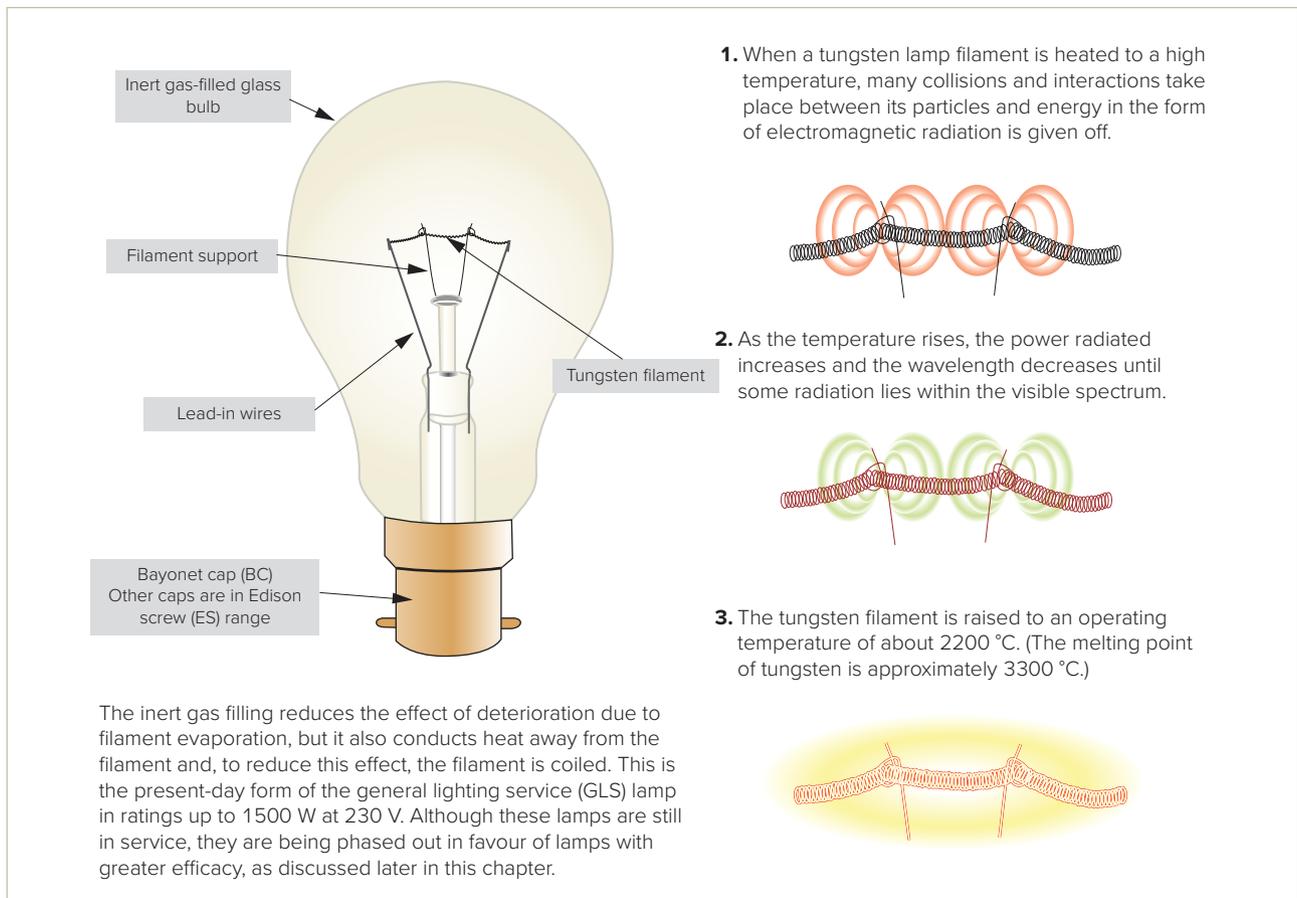


FIGURE 8.13 How incandescent lamps work

8.3.2 Development

For a limited range of incandescent lamps, luminous efficacy was further increased by coiling the helical coil filament on itself, but this was found to be a practical proposition only with ratings of 40 W, 60 W, 75 W and 100 W, mainly due to heat dissipation.

Lamp rating is expressed as power input in watts and light output in lumens. The effective life of an incandescent lamp is 1000 hours, but lamp life is seriously reduced by vibration or overvoltage. A 5% increase in operating voltage, say, from 230 V to 241.5 V, will halve lamp life; on the other hand, a 5% decrease will double it.

Lamp envelopes may be clear, pearl, inside frosted or inside silica-coated. The inside silica-coated type provides almost complete light diffusion. Lamps with inbuilt reflectors were also made.

Applications of GLS (general lighting service) incandescent lamps included:

- ▶ lighting situations where the initial saving in capital cost was greater than the saving in running costs of discharge lighting (e.g. infrequently used storerooms, toilets, lights used to supplement daylight where use was only on dark afternoons in winter, infrequently used outside lighting)
- ▶ local lighting mounted on machines (e.g. a drill or lathe)
- ▶ temporary installations
- ▶ outside or inside lighting where a strong directional light was required with a suitable reflector (e.g. display lighting)
- ▶ situations where a high value of light was required in restricted areas with perhaps dimming control (e.g. stage lighting)
- ▶ lighting installations that formed part of the decor (e.g. in a restaurant).

The incandescent GLS lamp has been phased out, as noted in **Figure 8.13**. Other, more energy-efficient lamps, such as compact fluorescents and LEDs, are now used as an alternative to incandescent lamps.

Tungsten halogen lamp

The tungsten-filament halogen lamp, sometimes termed quartz halogen or quartz iodine, is another type of incandescent lamp. This lamp has special design features, shown in **Figure 8.14**. These give rise to improved efficacy, with 15 to 35 lm/W being typical.

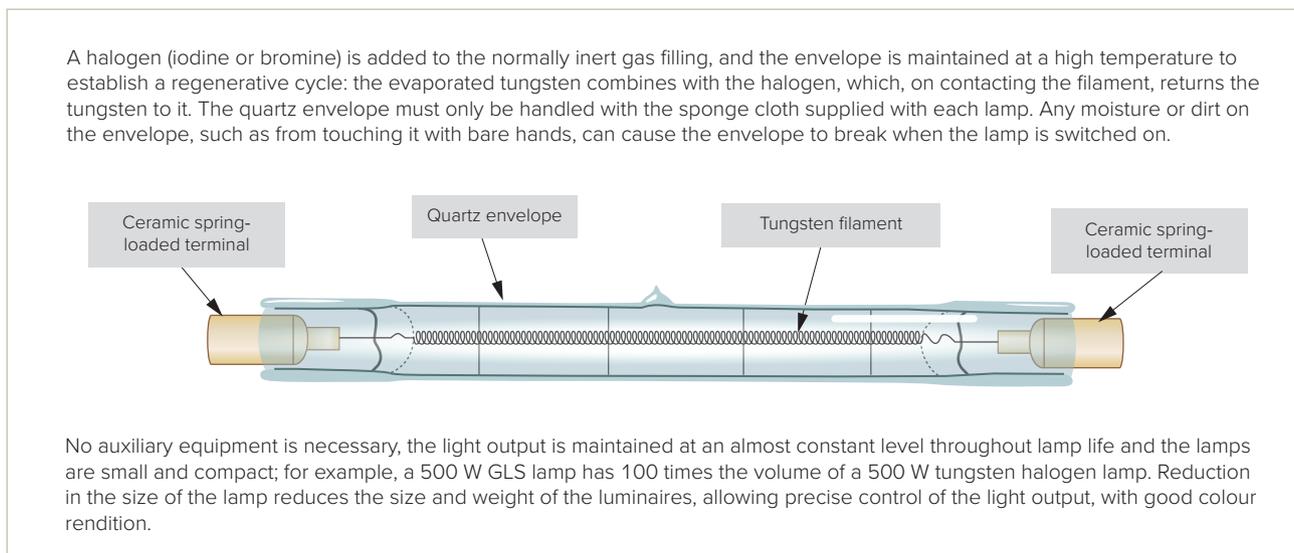


FIGURE 8.14 Features of tungsten halogen lamps

Applications of tungsten-filament halogen lamps included floodlighting, airfield lighting, projector lamps and film and television studio lighting. For the halogen cycle to operate correctly, the tube had to be installed within four degrees of the horizontal. The 500 W, 750 W, 1000 W and 1500 W sizes of this type of lamp were popular.

Low ratings were not made for general illumination but were obtainable in special types, such as the quartz iodine automobile lamp.



CHECK YOUR UNDERSTANDING

10. Governments in Australia and New Zealand have introduced what minimum standard for appliances to help reduce greenhouse gas emissions and energy costs to consumers?
11. What are the two GLS lamp caps or fittings commonly used throughout Australia and New Zealand?
12. List some of the applications for tungsten-filament halogen lamps.
13. Due to its hardness and ability to withstand high operating temperatures, which element is used as a filament in incandescent lamps?

8.4 ELV lamps

A modern application of the tungsten halogen lamp is the compact extra-low-voltage (ELV) tungsten halogen lamp; see **Figure 8.15**. The compact size of the lamp makes it suitable for use where a controlled beam is needed for effect, such as for display lighting. Another common application is for underwater lighting of swimming pools. Most miniature tungsten halogen lamps have their own reflector systems, providing a range of beam spreads: narrow, medium and wide. The dichroic reflector is very complex, not only reflecting lighting but also transmitting much of the infrared, therefore reducing heat in the forward beam and raising the colour temperature to 3000 K. 'Dichroic' refers to the coating inside the glass reflector. There are several layers of material, each layer with a different refractive index, that is, a different change of direction of the light in passing from one medium to another. The coating causes the multi-coloured appearance when viewed at different angles.

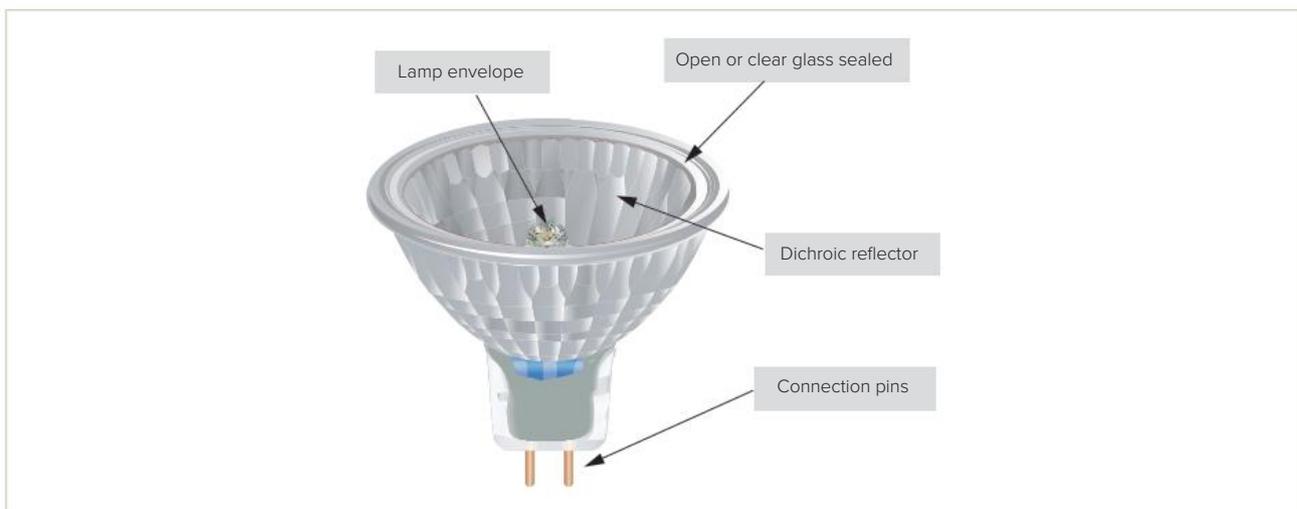


FIGURE 8.15 Compact extra-low-voltage (ELV) tungsten halogen lamp

8.4.1 Reason for extra-low-voltage design

The question is often asked: why ELV? The answer relates to incandescent lamp design. When the voltage is higher (230 V), the filament resistance needs to be higher for a given power dissipation than when the voltage is lower. The

lower resistance of an ELV lamp filament means that the filament can be thicker and shorter, and therefore more robust. A small filament results in a small lamp and a smaller reflector system for light control.

The energy-saving aspect of the lamp itself is related to the reflector design and its ability, through light control, to reduce waste light by precisely lighting the task. However, the use of the ELV lamp, together with the necessary isolation transformer, does not normally result in low operating costs for the ELV lighting system.

A comparison is often made with the 150 W PAR 38 lamp (PAR signifies parabolic reflector), which tends to scatter light and does not have the same control. The most common forms of ELV lamps are available in 20 W, 50 W and 75 W. The life of the lamps varies between 2000 and 3000 hours.

While ELV lighting has many advantages, the user and the electrician must be aware that there are differences between 230 V and 12 V systems. It should also be noted that high-heat and low-efficiency types of lighting such as ELV lamps are set to become increasingly unpopular in the future and will be replaced by their more efficient LED equivalents.



CHECK YOUR UNDERSTANDING

14. What does the term *dichroic* mean when applied to ELV lamps?
15. What was the main reason ELV lamps were developed?
16. What are the two main disadvantages of ELV lamps that are leading to their replacement by LED equivalents?
17. How is precise lighting control achieved with ELV lamps?

8.5 Gas-discharge lamps

In discharge lighting, radiation is produced by an electric discharge through a gas or vapour in the discharge tube. Gases and gas mixtures have been used for diverse applications for general illumination; the two vapours of mercury and sodium are outstanding, although experimentally almost every metal has been tried.

While incandescent lamps produce light containing all the frequencies of the visible spectrum, gaseous discharges produce a limited colour spectrum. Most are sources of coloured light that are characteristic of the gas used.

While there are a large number of gas-discharge light fittings left in installations, they are no longer installed to any significant degree. As time passes, these will all be replaced with more modern versions, most likely LEDs, which have much lower installation costs, reduced energy consumption and longer life spans.

How gas-discharge lamps work is detailed in **Figure 8.16**.

8.5.1 Lamp replacement

Gas-discharge lamps were available in a wide variety of shapes and sizes and, if you need to replace one due to special requirements, consult your supplier or electrical wholesaler.

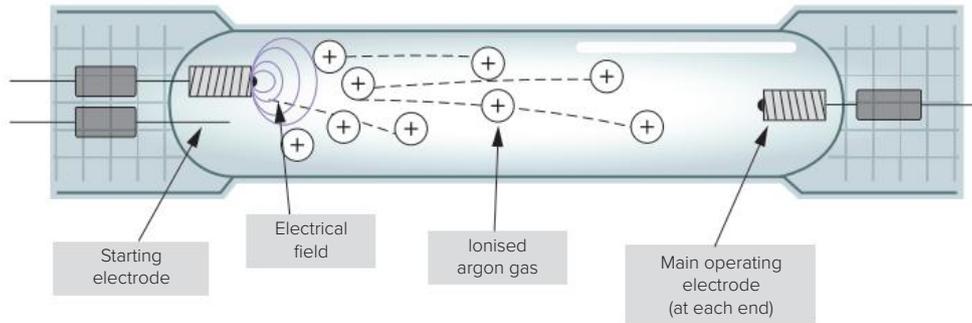
8.5.2 Types of lamps

Mercury vapour lamps

A typical mercury vapour lamp consists of the parts schematically illustrated in **Figure 8.17**. The outer bulb is filled with nitrogen, an inert gas. This maintains internal electrical stability to eliminate flashovers, provides thermal insulation of the arc tube and protects the metal parts from oxidation. **Figure 8.18** illustrates the effect of location of the power factor correction capacitor.

1. The column of gas in the discharge tube is an insulator until the arc is initiated and ionisation occurs.

2. In the ionisation process, the gas atoms assume an excited state, in which some electrons change energy levels and, in so doing, radiate energy of particular wavelengths peculiar to the gas employed.

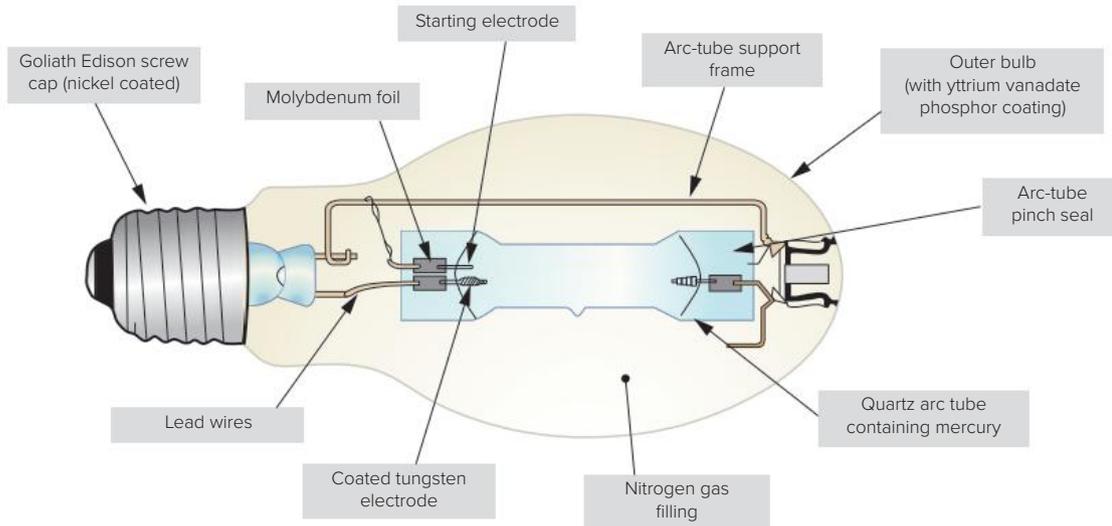


3. Once ionisation of the gas takes place, the current density increases rapidly and, in effect, the tube now becomes a short circuit.

4. To protect the lamp, which is now a short circuit, a ballast is incorporated in the circuit. The ballast has two functions: to limit the current to a predetermined value and to provide the necessary starting voltage across the discharge tube. A ballast consumes power, which must be added to the lamp wattage when calculating circuit currents.

FIGURE 8.16 Basic operation of a discharge lamp

The outer bulb is filled with nitrogen, an inert gas. This maintains internal electrical stability to eliminate flashovers, provides thermal insulation of the arc tube and protects the metal parts from oxidation. The quartz arc tube contains a precise amount of high-purity mercury and a starting gas, argon.



When the lighting circuit is energised, the starting voltage is impressed across the gap between the main electrode and the starting electrode. This voltage creates an argon arc between the starting electrode and the main electrode, and current is limited to a very low level by the starting resistor. The heat from this argon arc causes the mercury to begin to vaporise, and the resistance between the main electrodes drops. When resistance drops to a point where the voltage available from the ballast can establish an arc, the main arc strikes, vaporising more mercury. The resistance of the starting circuit is now high compared with that across the main gap, and the starting arc ceases. The main arc current is limited by a series-connected external ballast, as shown in **Figure 8.18**.

FIGURE 8.17 Construction and operation of elliptical mercury vapour lamp

Note that the capacitor should always be connected across the supply on the line side of the choke, because lamp operation is better on a low power factor. Should the capacitor be connected on the lamp side of the choke, current reversal in the lamp will be delayed, which may cause flicker.

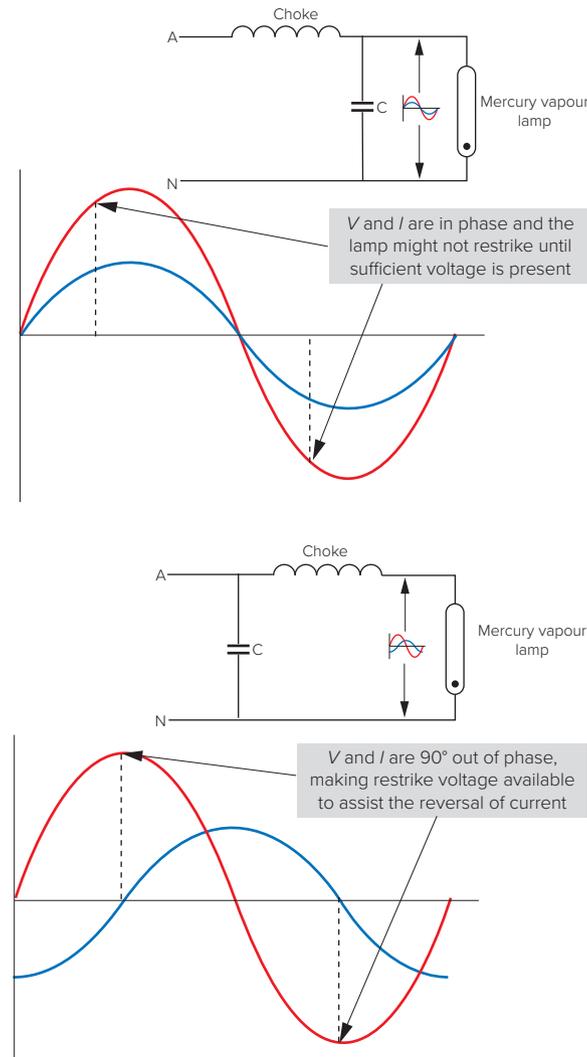


FIGURE 8.18 Effect of location of power factor correction capacitor

Metal halide lamps

Metal halide lamps are similar in design to mercury vapour lamps. The major difference is that metal halides are used in addition to mercury inside the arc tube. Their construction and operation are shown in **Figure 8.19**.

The metal halide lamp also differs from the mercury vapour lamp in that it requires a voltage higher than that of the mains supply to start ionisation. A typical circuit that is used to achieve the required starting conditions is illustrated in **Figure 8.20**.

High-pressure sodium lamps

High-pressure sodium lamps are constructed with two envelopes, as shown in **Figure 8.21**. Because of the arc tube's small diameter, a high-voltage high-frequency pulse is used instead of a starting electrode as used in the metal halide lamp (see **Figure 8.22**).

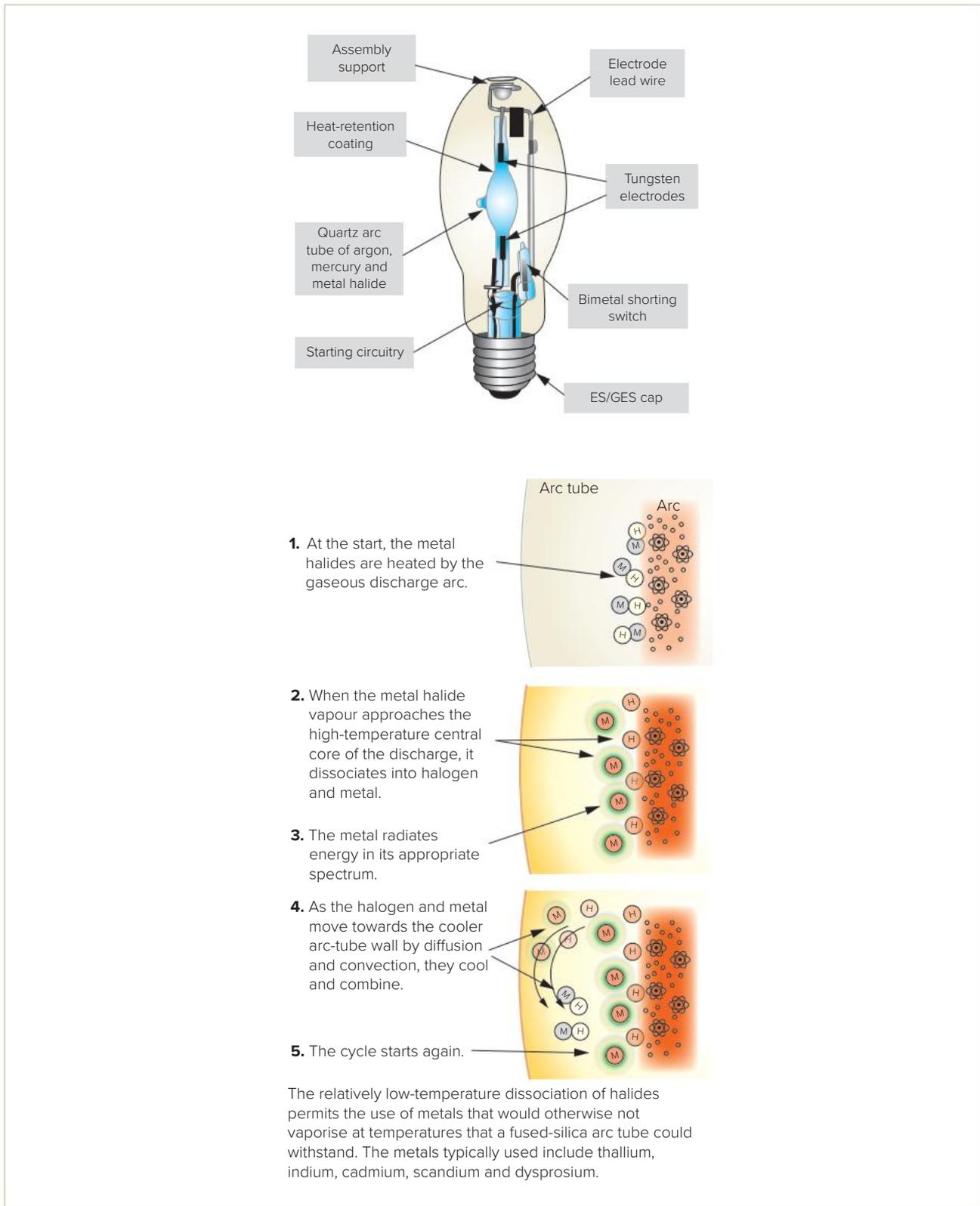


FIGURE 8.19 Construction and operation of metal halide lamps

Low-pressure sodium lamps

In low-pressure sodium lamps, the arc tubes are enclosed in a vacuum to maintain proper operating temperature (approximately 260 °C). Any deviation from that temperature can cause loss of lamp efficacy. These lamps range in size from 18 W to 180 W and have a rated life of approximately 18 000 hours (see **Figure 8.23**).

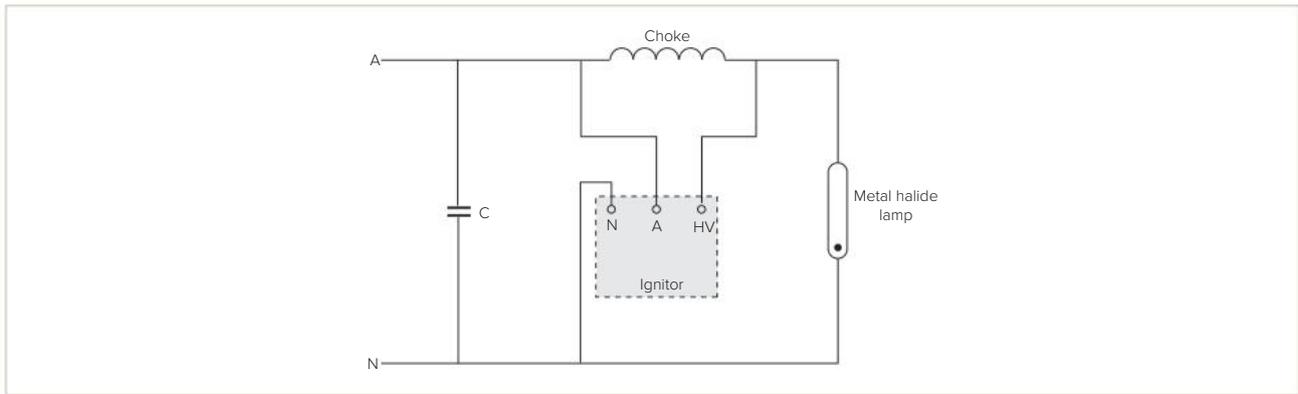


FIGURE 8.20 Basic metal halide lamp circuit

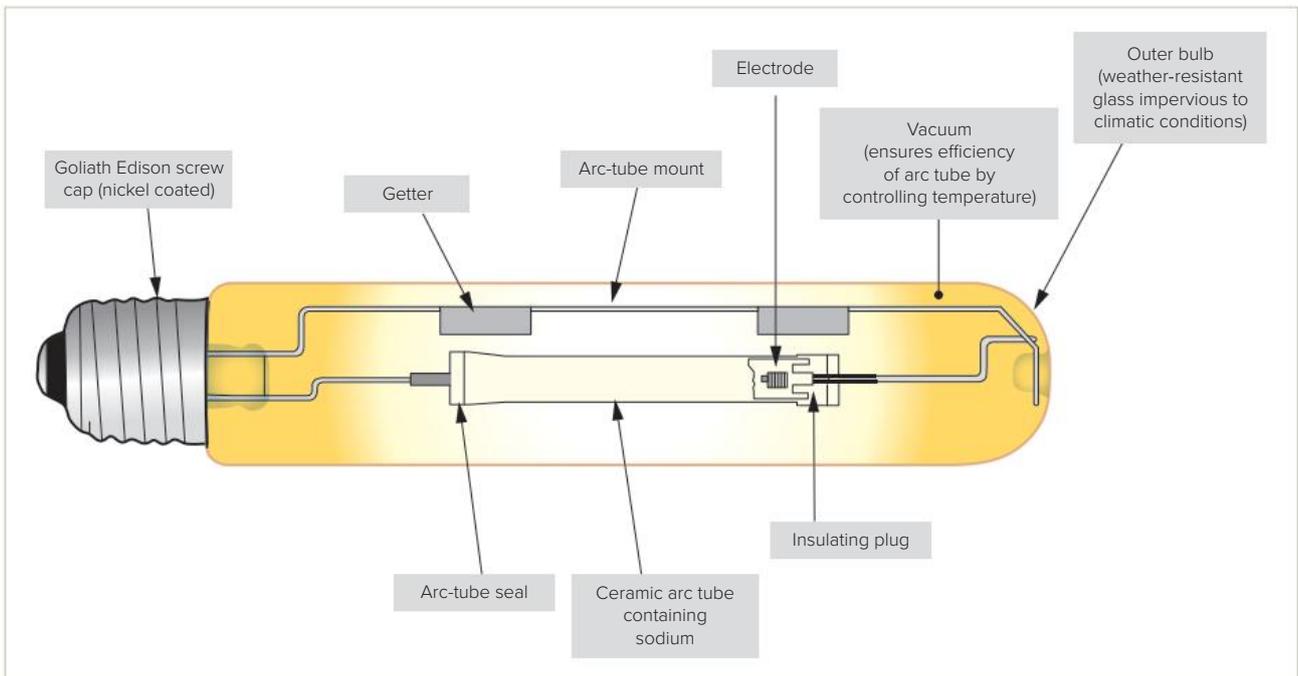


FIGURE 8.21 Typical high-pressure sodium lamp construction

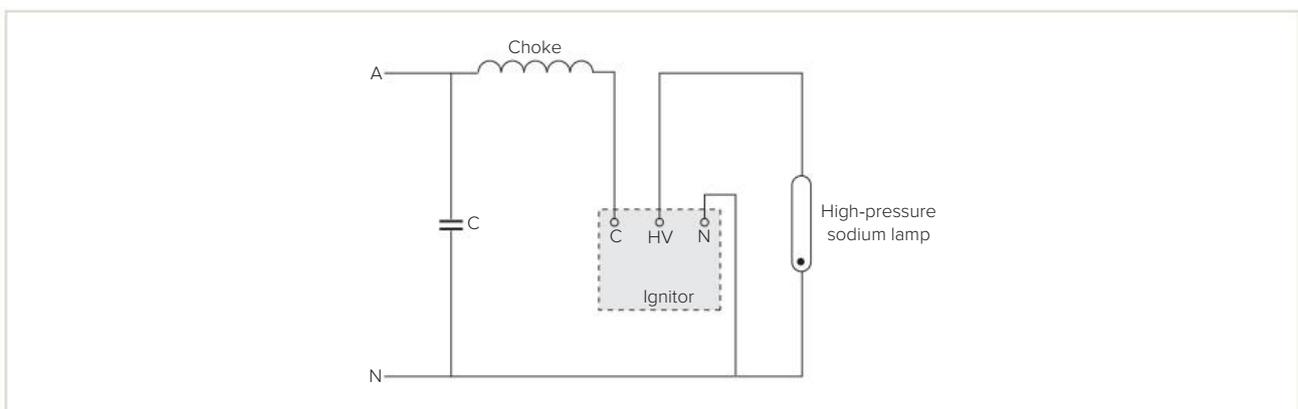


FIGURE 8.22 Basic high-pressure sodium lamp circuit

The circuit for a low-pressure sodium lamp includes a transformer, which is more accurately described as an auto-transformer (see **Figure 8.24**). It can take from 7 to 15 minutes before the lamp reaches operating stability, depending on the lamp type.

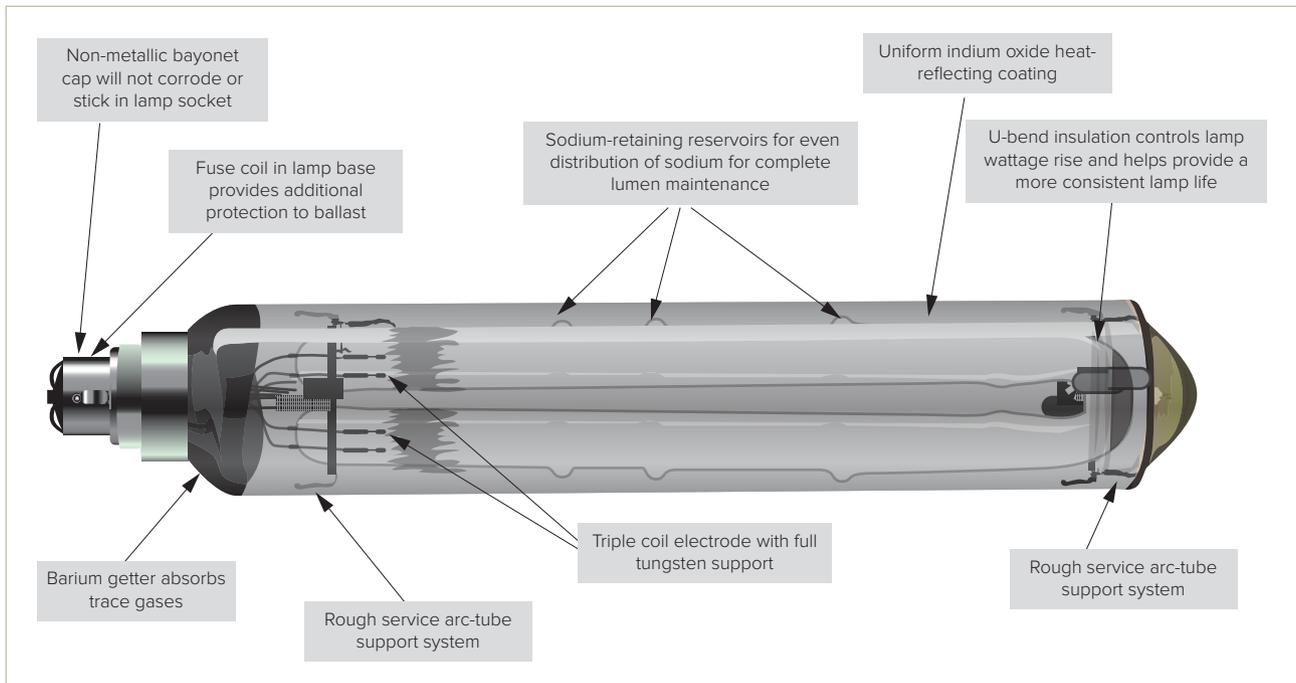


FIGURE 8.23 Low-pressure sodium lamp construction

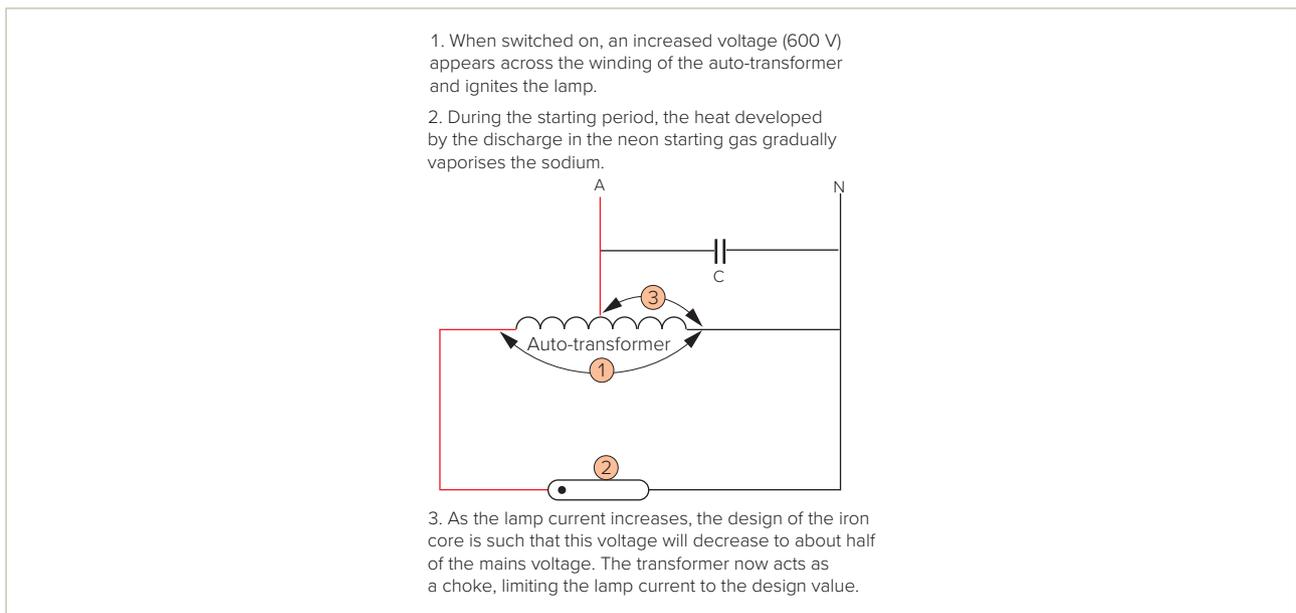


FIGURE 8.24 Basic low-pressure sodium lamp circuit



CHECK YOUR UNDERSTANDING

18. What two vapours are used for applications for general illumination?
19. What is the purpose of a ballast used in discharge lighting?
20. List the four common types of discharge lighting.
21. Describe how radiation is produced in a discharge lamp.

8.6 Fluorescent lamps

Fluorescent lamps were once the most widely used gas-discharge lamp. They basically consist of a glass tube containing an inert gas and a few drops of mercury with an electrode sealed in each end, as illustrated in **Figure 8.25**. The use of mercury is one of the reasons this type of lighting is being discontinued.

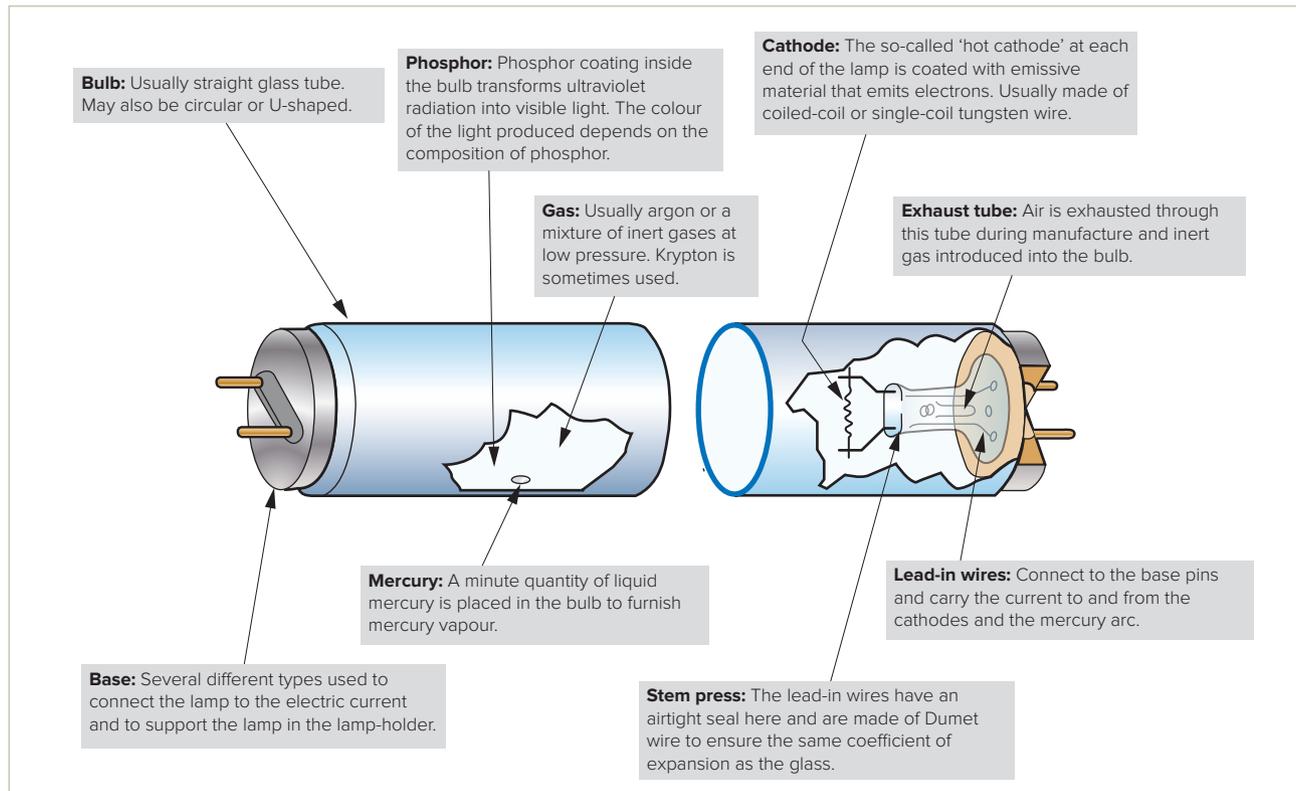


FIGURE 8.25 Construction and operation of a hot-cathode fluorescent lamp

This section helps you understand the function and connection of fluorescent lamps and fittings, but they are being phased out in favour of LED-type fittings and tubes. As there are so many of these types of light fittings still in existence, this will take quite some time, and so the repair and replacement of tubes will continue for a while yet.

Unlike the incandescent lamp, the objective of the fluorescent lamp is not to produce the maximum amount of light, but to efficiently generate short-wave ultraviolet (UV) energy and then employ fluorescent chemicals or phosphors to effectively convert that UV energy into visible light. A low-pressure mercury arc produces an abundance of one particular wavelength in the short-wave UV region, and phosphors are selected and blended to respond efficiently at this wavelength.

8.6.1 Operation of triphosphor lamps

In triphosphor lamps three fluorescent powders are used, each of which emits in a well-defined waveband: red, green, and blue. In this way, the near and far ends of the spectrum, for which eye sensitivity is very low, are cut out and a high proportion of the light is radiated in the region of maximum eye sensitivity, resulting in high luminous efficacy. The colour-rendering characteristic is the ability of a light source to reproduce the colour of various objects faithfully in comparison with an ideal or natural light source. The colour-rendering index (CRI) is a measure of this characteristic. The colour-rendering capability of triphosphor lamps is very good because the spectral wavelengths in which light is emitted coincide well with the three primary colours and produce accurate colour rendition.

There is an international system for identifying triphosphor fluorescent lamps. The designations 827, 830 and 840 are used by all manufacturers to identify the colour temperature (appearance) and colour-rendering ability of the

lamp. For example, an 840 lamp has a colour-rendering index of between 80 and 89 (85), indicated by the 8, and a colour temperature of 4000 K, indicated by the 40.



SAFETY ALERT

All fluorescent lamps contain mercury. Some contain up to 15 mg of mercury, a substance whose negative impact on the environment is well documented. Therefore, we need to protect our waterways from mercury originating from fluorescent lamps.

8.6.2 Compact fluorescent lamps

The versatility and improved performance made possible through the advent of the triphosphors were contributing factors to the introduction of compact fluorescent lamps. These lamps employ the same technology and operate in the same manner as the fluorescent lamps described above.

The compact fluorescent was originally designed to be used in applications where incandescent lamps had traditionally been used. The longer life of the compact fluorescent (up to 15 000 hours compared with 1000 hours) and the higher luminous efficacy result in reduced operating costs and lower maintenance costs. As already stated, the triphosphors used in the lamp make it possible to approach the colour appearance and colour rendering of an incandescent lamp.

As with the standard fluorescent lamp and fittings, compact fluorescent lamps are also being slowly phased out and replaced with LED-style lamps (see **Figure 8.28** later in the chapter), which provide a zero-mercury option along with the benefits of lower consumption of energy and extended lamp life.

8.6.3 High-frequency fluorescent lighting

High-frequency fluorescent lighting is now possible. The conventional operating frequency for a fluorescent lamp ballast, and hence the lamp, is that of the mains, 50 Hz. This is unfortunate, because a fluorescent lamp operates much more efficiently at higher frequencies; that is, it gives the same light for lower wattage. Moreover, the conventional 50 Hz ballast consumes energy and needs a compensation capacitor to increase the power factor. However, the sophistication of modern electronics has totally changed this situation. A high-frequency electronic ballast converts the 50 Hz mains into a high-frequency signal that drives one or two fluorescent lamps. Most good-quality high-frequency electronic ballasts incorporate harmonic filters and radio frequency interference (RFI) suppression, which limits the interference voltage (harmonics) to well below the specified limits.

Driving a fluorescent lamp at frequencies over 15 kHz produces a significant improvement in luminous efficacy. The human audio range stops at around 20 kHz and therefore a higher frequency (20–100 kHz) has been chosen for electronic ballast systems. At this higher frequency, the luminous efficacy is around 104 lm/W, as opposed to approximately 93 lm/W at 50 Hz. Thus, the same light level can be produced for significantly lower wattage at this frequency than at 50 Hz. This produces an energy saving of more than 10%. In addition, there is a further energy saving of more than 10% for the ballast, plus an improvement in the power factor. The energy savings in lamp and ballast together give an overall saving of 23% over a conventional installation with standard fluorescent ballasts.

8.6.4 Electromagnetic compatibility

Generally, fluorescent lamps are not suitable for use where electromagnetic interference might cause a problem. As explained in **Section 6.4.2 Electromagnetic compatibility**, with the rapid growth in the use of electronic systems and digital technology, it is becoming increasingly necessary to minimise electromagnetic interference. This can mean interference to electronic products such as televisions and radios, or disruption to aircraft or emergency communication systems.

Manufacturers and suppliers of lighting products are governed by legislation under the Australian Communications and Media Authority (ACMA). There are a number of international standards for electromagnetic compatibility

relevant to electrical lighting and similar equipment. Products that comply with the EMC requirements must be labelled as per the EMC framework. The C-tick mark ✓ signifies compliance with this framework.



CHECK YOUR UNDERSTANDING

22. What is the main reason for discontinuing the use of fluorescent lighting?
23. Describe how radiation is produced in a fluorescent lamp.
24. What are triphosphor lamps and why are they used?
25. What does the term *colour-rendering index* mean?
26. Why are high-frequency fluorescent light fittings used?

8.7 LED lighting

Lighting based on the use of a light-emitting diode (LED) has quickly become the most popular form of lighting across the world. Wherever lighting is required, LEDs have been introduced with great success. They now find applications in automotive, industrial, retail, street lighting, domestic and mining fields. LED lighting is set to be the dominant lighting source into the future.

A diode is the simplest semiconductor device, a material with a varying ability to conduct electrical current. The light-generation principle within an LED is similar to what happens in gas-discharge lamps, but now the discharge takes place in a solid-state material, as described in **Figure 8.26**.

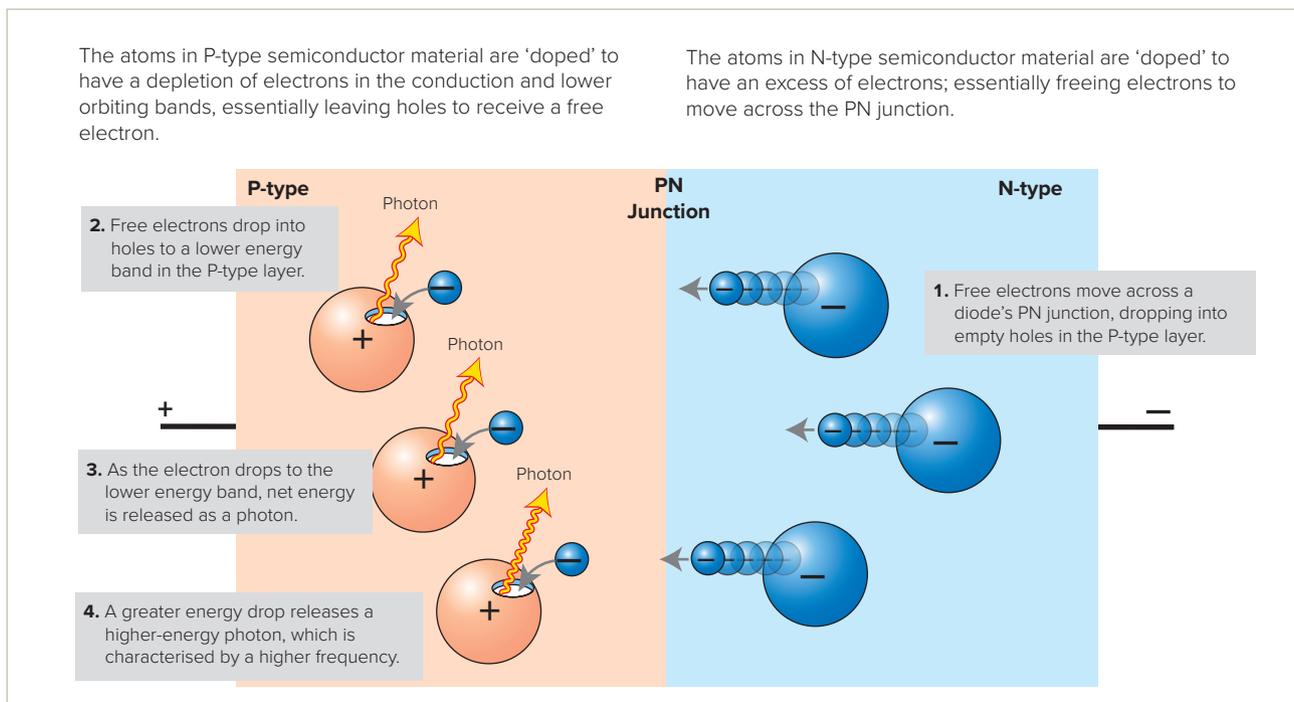


FIGURE 8.26 How a light-emitting diode (LED) works

While all diodes release light, it is not done effectively. In an ordinary diode, the semiconductor material itself absorbs a great deal of the light energy. LEDs are constructed to release a large number of photons outwards. Additionally, they are housed in a plastic bulb that concentrates light in a particular direction, as shown in **Figure 8.27**. Examples of LEDs that are replacing traditional lamps are given in **Figure 8.28**.

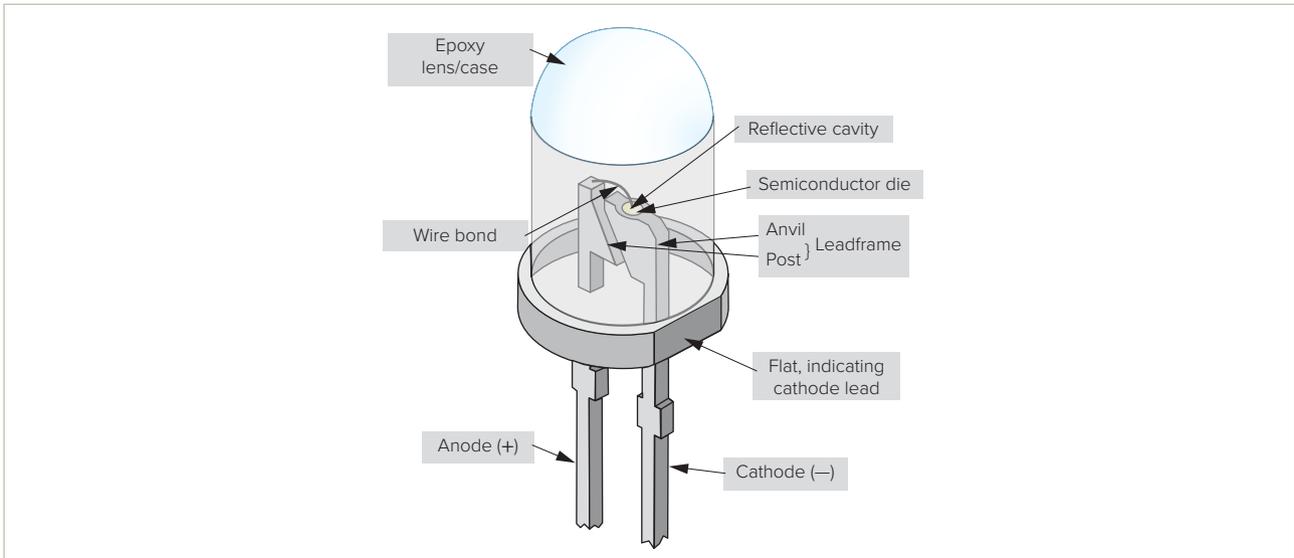


FIGURE 8.27 Basic construction of an LED



FIGURE 8.28 Examples of LEDs that are replacing traditional lamps

LEDs generate little or no infrared (IR) or UV but convert only 15–25% of the power used into visible light. The remainder is converted into heat and must be conducted from the LED die to the underlying circuit board and heat sink, housings or luminaire frame elements.

Manufacturers have been able to produce an LED with an efficacy equal to or better than those of traditional light sources. In general, the desire to produce more light results in higher junction temperatures and reduced life. Heat dissipation is an issue and is evident when observing the design of LED products.

In the production of LEDs, a single round wafer is coated with various materials to create the semiconductor which forms the heart of the LED. This is then sliced into extremely small rectangles. Wire bonds are inserted and the phosphor is added. The assembly is then encapsulated to form a finished white light LED package.

The coating processes create significant inherent variations that affect the lumens, colour temperature and voltage of the LEDs. In an effort to maximise yields, LED manufacturers sort their production into lumen, colour and sometimes voltage bins. This allows luminaire manufacturers to select only those LEDs that meet their acceptable performance range.

There are two main ways of producing high-intensity white light using LEDs. One is to use individual LEDs that emit three primary colours—red, green and blue—then mix all the colours to form white light. The other, now more popular method is to use a phosphor material to convert monochromatic light from a blue or UV LED into broad-spectrum white light, in much the same way as a fluorescent tube.

The specific wavelength or colour emitted by an LED depends on the materials used to make the diode. Red LEDs are based on aluminium gallium arsenide, blue ones are made from indium gallium nitride and green ones from aluminium gallium phosphide. White light is created by combining the light from red, green and blue (RGB) LEDs or by coating a blue LED with yellow phosphor.

8.7.1 LED luminaire types

LED luminaires—or lighting fittings as they are often called—are now as many and varied as the imagination. What were once only used as indicator lights in electronic equipment are now used in virtually every type and use of luminaire.

Advances in the way the light-source chip is manufactured mean that high light output with excellent colour rendition is available with a choice of colour temperatures.

Examples of where this style of light source is found are almost limitless. It is now not only being used to replace the light globes of traditional fittings such as domestic lamps, spotlights, floodlights, commercial lighting and industrial lighting, but is also being developed into luminaires that no longer look the same as traditional luminaires.

Table 8.3 gives a small selection of the variety of luminaires available. You should continue to ensure you are aware of new and exciting products as they emerge.

8.7.2 LED luminaire quality

The benefits and features of LED lighting have resulted in their domination of the lighting market. This popularity, however, has given rise to the manufacture of many poor-quality lamps and fittings. Poor-quality products can result in poor lighting performance, disappointed customers and unsupported warranty claims.

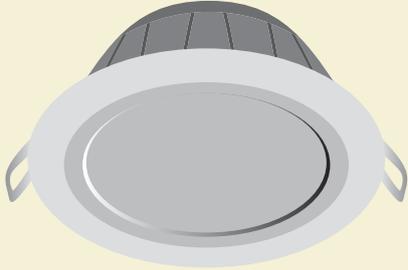
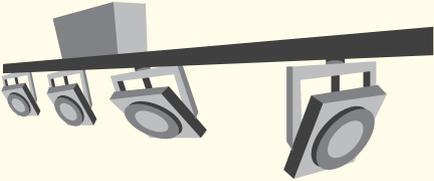
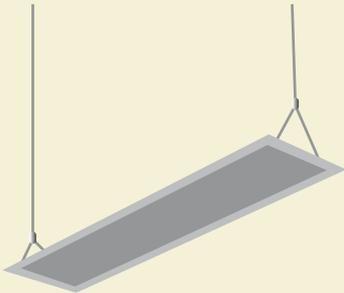
While price will always be one determining factor when purchasing supplies and equipment, it must be remembered that the price is not just the cost of the item, but the cost associated with the life cycle of the product. Well-known and properly tested brands will back up and support their products, unlike some online suppliers that are gone the next day!



CHECK YOUR UNDERSTANDING

27. How does an LED light work?
28. What are two main ways of producing high-intensity white light using LEDs?
29. LED replacements for halogen lamps can offer up to what percentage in energy savings?
30. List some domestic, commercial and industrial LED luminaires.

TABLE 8.3 LED lighting types and applications

Luminaire	Features	Typical application
<p>LED downlight</p> 	<p>Modern LED downlights allow the colour temperature to be selected, from warm white to daylight. They can also be controlled from smartphone apps and you can even tell if you have left your lights on from any remote location. They have features that include dimming and being switched on and off remotely and at different times of the day.</p>	<p>Applications are primarily for home and commercial use where a range of variable settings are required.</p>
<p>LED spotlights on a track</p> 	<p>LED spotlights are smaller and cooler. They can be rotated in almost any direction, providing flexibility and practicality. The low power consumption combined with 20 000+ hours of lamp life mean maintenance is greatly reduced.</p>	<p>These spotlights can be used in domestic and commercial applications, and are particularly suitable for lighting wall features such as art.</p>
<p>General office lighting</p> 	<p>LED troffer replacement luminaires come in both suspended and ceiling grid types. They offer excellent light and colour rendition, combined with economy and long life.</p>	<p>These are used for office and general commercial lighting applications where traditional fluorescent light fittings were previously used.</p>
<p>Highbay luminaires</p> 	<p>Modern highbay luminaires provide light quality, long service lifetimes, reduced energy consumption and less maintenance in the switch on/off (PSU) and DALI dimmable (PSD) versions. When the situation on a work floor changes, settings such as dimming levels and timing can be changed wirelessly by end-users themselves. Luminaires can be combined in groups across the layout and rezoning them does not require a hardware change.</p>	<p>These luminaires are mostly used in large factory or storage areas where a combination of flexibility, low maintenance and quality light is required.</p>

8.8 Comparison of light sources

The introduction of new energy-efficient lamps has made it easier to satisfy individual lighting needs. At the same time, the number and types of lamps now available can add confusion. Consequently, it is worthwhile setting some general guidelines for selecting a suitable light source.



DID YOU KNOW?

The term *accent lighting* describes the use of lighting to focus light on a particular area or object. Mostly used in domestic or commercial installations, it is good for lighting art or other artifacts.

Table 8.4 gives a historical comparison of lamps with varying performance characteristics. It should be noted that LED lighting has become the main source of illumination and these tables are for reference only.

TABLE 8.4 Lamp performance comparison chart

	Ceramic metal halide	Halogen	Compact fluorescent	Quartz metal halide	LED
Lamp efficacy lm/W	93	16	62	80	80
Lamp life (hrs)	12 000	3000	3000–12 000	9000	50 000
Colour rendering (Ra)	80–90	100	70–80	70–80	70–90
Accent lighting	Excellent	Excellent	Not suitable	Good	Good

Once the desired colour appearance is selected, the colour-rendering ability must be considered. The colour temperature of a lamp does not indicate its effect on colours, only the appearance of the light from the lamp itself. The colour-rendering ability of a lamp is quantified by its CRI. The method of determining the CRI is not discussed in this chapter, other than to say that it is an indicator of the relative colour-rendering ability of a light source and that, in the evaluation of a light source, the CRI must not be evaluated without reference to the colour temperature.

The choice of a light source with suitable colour properties depends on the nature of the visual task, the work environment and compatibility with other light sources in the work area, whether artificial or natural daylight. **Table 8.5** compares lamps with other light sources.

Note that the figures for lamp life quoted in the table vary from one manufacturer to another, depending on the criteria used for lamp tests. For example, Philips Lighting Industries quotes an average lamp life of over 5000 hours for its compact single-ended fluorescent lamp, based on a switching cycle of 3 hours (2 hours 45 minutes on, 15 minutes off).

Factors that affect the operating life of a gas-discharge lamp are its inbuilt characteristics, high mains voltage, low frequency, ambient temperature, shocks and vibrations and switching frequency. Incandescent lamps, which have a much shorter life than gas-discharge lamps, are also affected by ambient temperature, high mains voltage, burning position, and shocks and vibrations but they are less affected by switching frequency. Tungsten halogen lamps are more resistant to shock and vibration than other types of incandescent lamps, making them suitable for portable equipment. For this reason, they are often referred to as rough service lamps.

Under ideal conditions, such as street-lighting applications, where lamps are on for long periods without switching, lamp life is considerably increased; for example, a mercury vapour lamp could have a life in the range of 15 000 to 24 000 hours.

TABLE 8.5 Main range of lamps for general lighting purposes

Category	Type	Maximum efficacy (lm/W)	Economic life (hours)	Characteristic features	Typical application areas
Solid-state lamp	LED	70	50 000	Long life; no UV; no mercury	Virtually all modern applications
Fluorescent lamp	Tubular	104	7500	Wide choice of light colours; high lighting levels possible; economical in use	Currently installed in a wide range of applications
	Compact fluorescent	50–80	5000–8000	Energy-effective; direct replacement for incandescent lamps; compact; long life	Most applications where incandescent lamps were used previously; LEDs are slowly replacing these lamps
Gas-discharge lamp	Blended light/self-ballasted	28	5000	Long life; good colour rendering; easy to install; better efficacy than incandescent lamps	Direct replacement for incandescent lamps; small industrial and public lighting projects; plant irradiation
	High-pressure mercury	63	12 000	High efficacy; long life; reasonable colour quality	Residential area lighting; sportsgrounds; factory lighting
	Metal halide	94	6000	Very high efficacy combined with excellent colour rendering; long life	Floodlighting, especially for colour TV; industrial lighting; road lighting; plant irradiation
	High-pressure sodium	125	12 000	Very high efficacy; extremely long life; good colour rendering	Public lighting; floodlighting; industrial lighting; plant irradiation
	Low-pressure sodium	200	10 000	Extremely high efficacy; very long life; high visual acuity; poor colour rendering; monochromatic light	Many different application areas: wherever energy/cost-effectiveness are important and colour is not critical



CHECK YOUR UNDERSTANDING

31. When comparing lighting technology, which group of lighting has the best efficacy, colour-rendering index and lamp life?
32. What is a rough service lamp?
33. List some of the factors that affect the operating life of a gas-discharge lamp.

8.9 Luminaires and lighting circuits

While an incandescent lamp presents a closed circuit through its tungsten filament to the supply voltage, a gas-discharge lamp is an open circuit until the gas in the discharge tube can be ionised. As you have seen earlier in this chapter, additional components, often referred to as ancillary equipment, are also necessary. The ancillary equipment is first needed to start the lamp conducting, as it is an open circuit before the gas is ionised. Secondly, the circuit power must be limited to that of the lamp rating, because once it begins conducting, the lamp is nearly a short circuit. The basic components used to do this are:

- ▶ A source of voltage, higher than mains voltage, to ionise the gas and initiate conduction through the lamp, is usually supplied by the collapsing field in an electromagnetic ballast or the HV output of an autotransformer.
- ▶ A means of limiting the power to that of the lamp rating is achieved by a series-connected ballast or choke that has high inductance and low resistance, and limits the current to the lamp with minimal (I^2R) power loss.
- ▶ A third component, a power factor correction capacitor, is necessary to counteract the low power factor of the ballast or choke and reduce the current demand on the circuit.

Electronic controls are now incorporated in many ancillary equipment components for improved energy efficiency and lamp life, as well as reduced maintenance and automated control. This is a good exercise in the study of series and parallel circuit components for students of an electrical trades course.

Figure 8.29 illustrates the previously common hot-cathode low-voltage (230 V) fluorescent lamp circuit.

Power factor correction capacitors are essential in large installations, but most energy distributors do not require them in small isolated units, such as in a domestic installation. The effect of power factor correction on line currents is shown in **Table 8.6**.

Lamp performance varies according to brand. Refer to the manufacturer's data for actual performance figures. Circuit watts will vary when low-loss or electronic ballasts are used.

The 'inductor' shown in series with the capacitor in **Figure 8.29** is sometimes required by an energy distributor. This is to prevent interference with switching operations, if the mains are used as carriers for a signal injection system such as that used for the control of off-peak hot-water systems.

A fluorescent lamp operating on 50 Hz a.c. actually flickers at a frequency of 100 times per second. For most applications, the eye cannot detect the variation in the light output; however, when fluorescent lamps are used for illumination where rapid movement takes place (e.g. in the vicinity of rotating machinery), an effect can be produced where a moving part appears to be stationary. This is called the stroboscopic effect. It can be dangerous, but can be overcome in single-phase supply if a non-stroboscopic circuit is used. The circuit arrangement using an electromagnetic ballast is shown in **Figure 8.30**. In recent years, this problem has been overcome by the introduction of electronic ancillary equipment, as shown in **Figure 8.31**.

Electronic lamp circuits that operate on a high frequency overcome the stroboscopic effect, as well as providing other benefits such as instant starting, increased lamp efficacy and power factor correction as high as 0.95 without a capacitor in the circuit. Examples of these ancillary components and basic circuits are shown in **Figures 8.32** and **8.33**.

Compact fluorescent lamps designed as direct replacements for incandescent lamps have the ancillary equipment built into the lamp base. These lamps are commonly identified in their product number with the letter 'i'. Ancillary equipment is continually being developed and it is vital for electricians to keep up to date with these developments, if only to ensure that their work complies with requirements.

8.9.1 Installation of lighting

The installation of lighting must comply with the *Wiring Rules, Clause 4.5.2*, which requires that luminaires and ancillary equipment are installed so that they do not cause harmful temperature rises or ignite any material in their vicinity. Minimum clearance distances are given in the *Wiring Rules, Table 4.2*. An important requirement (which is

- When the circuit is first switched on, 230 V appear across the contact gap of the starter, ionisation takes place and the gas in the starter glows, giving it the name of *glow-type starter*.
- The energy dissipated in the gas warms the bimetal strip, which bends and makes contact with the other electrode to form a series circuit consisting of the ballast and the two filamentary electrodes.
- Current flowing through the filaments causes them to heat up and produce a cloud of electrons surrounding the filaments.
- After a short period, the bimetal strip in the starter cools sufficiently (as the glow discharge disappears when the bimetal strip closes) and breaks the circuit at the contacts.
- The sudden interruption of the current through the ballast causes it to produce a high induced (striking) voltage, which initiates the arc through the tube by ionising the argon gas it contains.
- The tube is now operating in series with the ballast, while the starter is in parallel with the tube. The voltage across the tube is low (about 100 V for a 36 W tube), and this voltage across the starter contacts is not sufficient to ionise the gas in the starter, so it remains open ready for the next start.
- The ballast, being in series with the lamp, now limits the power in the circuit to that of the tube rating.
- The ballast, which is highly inductive, causes a low power factor and hence an increase in supply current; the capacitor corrects this by improving the factor to an acceptable level.

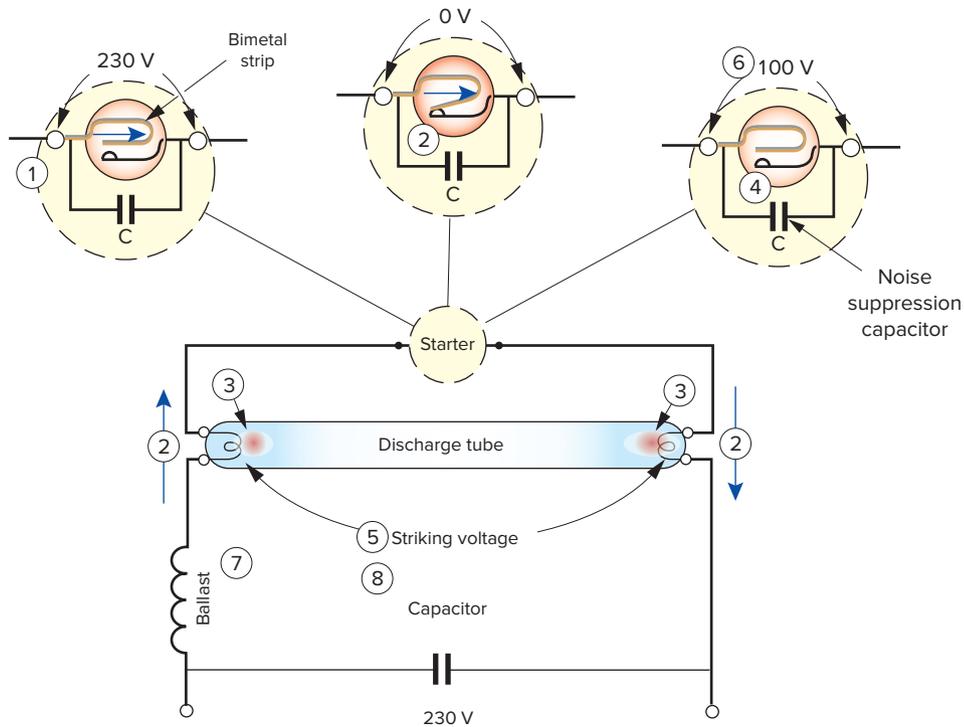
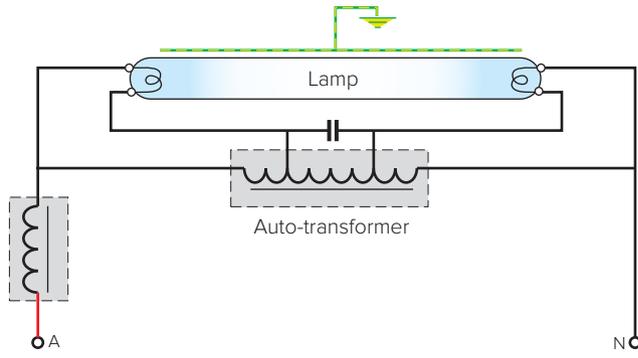


FIGURE 8.29 Previously common fluorescent circuit using electromagnetic ballast and glow-type starter

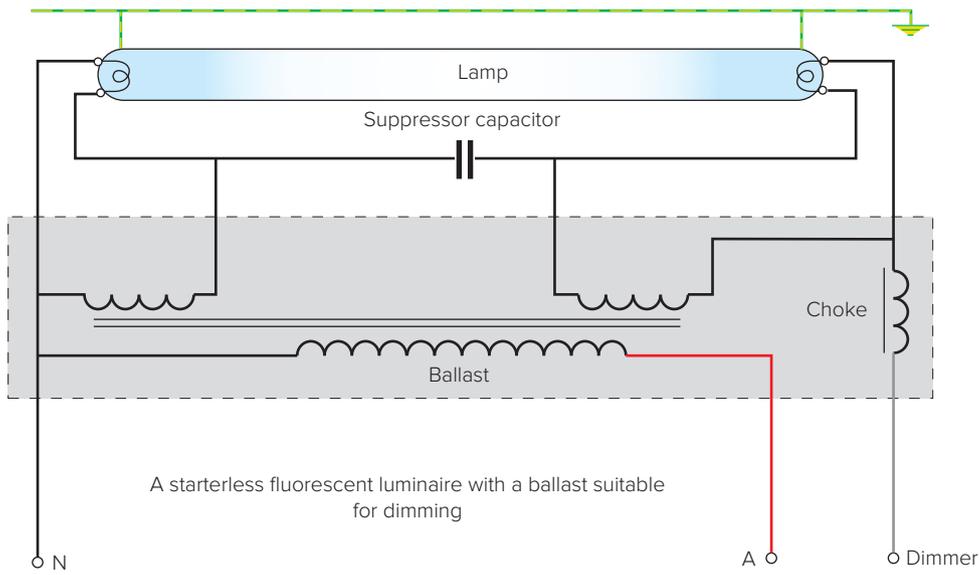
TABLE 8.6 Fluorescent lamp currents

Lamp watts	Circuit watts	Initial lumens	Line starting and running currents (A)			
			Not power factor corrected		Power factor corrected 0.8	
			Start	Run	Start	Run
18	26	1200	0.425	0.370	0.201	0.166
36	43	3000	0.625	0.415	0.422	0.261
58	67	4800	0.940	0.666	0.651	0.380

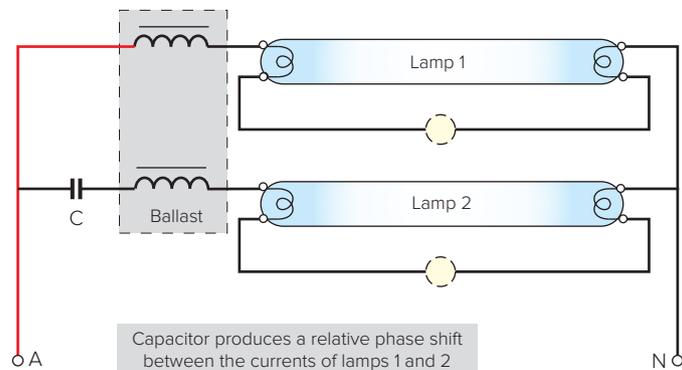
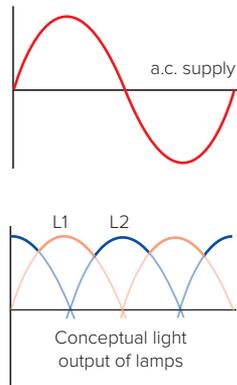


This circuit of a luminaire with the quick-start ballast was designed for use with the old T12 (38 mm) tubes. Note the earthed metal reflector needed for the lamp to strike.

They were more common in commercial installations because of their lower maintenance, but are not suitable for re-lamping with T8 tubes as they will not start.



A starterless fluorescent luminaire with a ballast suitable for dimming

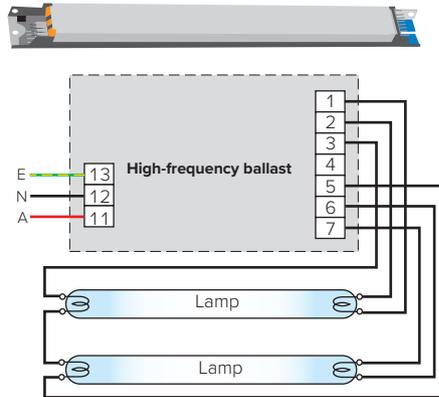


Capacitor produces a relative phase shift between the currents of lamps 1 and 2

The circuit arrangement using electromagnetic ballasts, above, causes the light emitted by each lamp to be displaced in time relative to the other. It can be seen that when one lamp is out or at minimum output the other is at full brilliance, thus producing negligible stroboscopic effect.

FIGURE 8.30 Examples of various fluorescent circuits using electromagnetic ballast

This high-frequency electronic ballast is designed for use with TL5 and TL5 Eco fluorescent lamps and is ideal for applications where high energy efficiency is required.

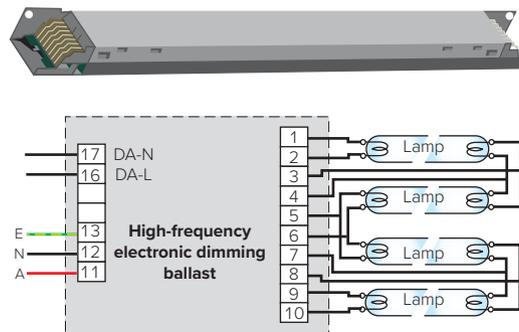


Features include:

- 50000-hour lifetime at maximum case temperature, combined with an unlimited number of switches on one lamp without reducing or affecting the useful lamp life.
- Programmed, flicker-free, pre-heated start (< 0.5 s) which allows the lamp to be switched on and off without reducing useful lamp life.
- Active power-factor correction to ensure constant light, irrespective of mains voltage fluctuations.
- The unit is protected against excessive mains voltage and incorrect connections.

FIGURE 8.31 Electronic ballast for a twin T5 fluorescent luminaire

These high-frequency electronic dimming ballasts have DALI (digital addressable lighting interface) or touch-and-dim push-button protocol for (compact) fluorescent lamps.



Features include:

- Programmed start for flicker-free ignition (0.5 seconds) and striation-free operation for no stroboscopic effects. Preheating the lamp electrodes enables the lamps to be switched on and off without reducing life.
- Smart power ensures constant light, independent of mains fluctuations and dimming from 1 to 100%.
- Stop circuit is activated within 5 seconds in the event of lamp failure (safety stop), and ballast resets automatically after lamp replacement.
- Protected against excessive mains voltages, incorrect connections and incorrect lamp use.

FIGURE 8.32 Dimmable DALI electronic ballast used for a four-lamp luminaire

This electronic control unit with impregnated or encapsulated electromagnetic ballasts is designed to control a range of high-efficiency discharge lamps. The unit ensures reliable starting and stabilises lamp power for optimum performance (minimum colour deviation).

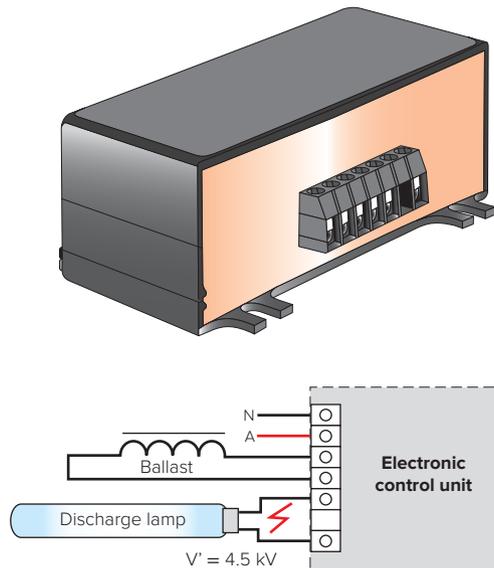


FIGURE 8.33 Electronic lamp controller

not always adhered to) is installing equipment in accordance with the manufacturer's instructions, as specified by *Clause 1.7.2 (b)* in general and *Clause 4.5.2.1(ii)*, which specifically refers to lamps and luminaires.

Classification of recessed luminaires

Standards Australia recently published a joint Australian/New Zealand Standard *AS/NZS 60598.2.2* that details the classification of recessed luminaires. This is in direct response to issues with heat and fires that resulted from incorrect installation. A clear pictorial guide is provided and the luminaires are classified by the ways they can be installed. It is essential that you understand this and ensure the luminaires you install are both compliant and safe.



SAFETY ALERT

Lamps must be disposed of responsibly through an accredited lamp-recycling service. All gas-discharge lamps contain mercury, which is extremely toxic and known to cause both chronic and acute poisoning. Sodium in discharge lamps is potentially explosive, and generates flammable hydrogen and caustic sodium hydroxide on contact with water.

8.9.2 LED luminaires and drivers

An LED driver is a self-contained power supply which has outputs that are matched to the electrical characteristics of the LED(s). They are available in many configurations and are usually sold to match the accompanying LED light source. The basic principle for most general installations is that the driver converts an a.c. input into a regulated d.c. output. This can be at either a constant current or constant voltage, depending on the application.

Constant current

Constant-current drivers power LEDs that require a fixed output current and a range of output voltages. The unit will specify an output current along with a range of voltages to suit the wattage of the lamp. This type of driver is most commonly used to supply downlights where a small number of LEDs are used in the design.

Constant voltage

Constant-voltage drivers power LEDs that require a fixed output voltage with a maximum output current. These drivers suit LEDs that have a resistor-regulated current in the LED module and provide a maximum current output. These are often used with LED strip lighting where the length of the strip determines the current rating of the driver. In most cases, the decision has already been made by the manufacturer, which has selected the most appropriate and reliable driver to suit the application.

Dimming

The dimming of compatible LED luminaires is generally achieved with a specially designed trailing-edge electronic dimmer using a TRIAC or a controlled voltage type. They are able to provide a 'soft start' for a smooth turn-on and prolonged lamp life. You should consult your lighting manufacturer or supplier to ensure the dimmers and the luminaires you are using are compatible. This type of dimmer switches the wave towards the end of the cycle, which suits the requirements of LED lighting and prolongs lamp life. Many manufacturers make what is known as a universal dimmer that will work for many other lamp types as well as LEDs.

Driver locations

The requirement for LED lighting to have a driver can present challenges when installing strip lighting or feature lighting. Illuminated stair treads typically do not have room for the control equipment and provision needs to be made during construction to house this equipment. Considerations include the heat rise of equipment and protection from environmental factors.

SMART CONTROL SYSTEMS

There are a range of proprietary smart control systems for LED lighting. These usually have a brand name associated with them and provide a range of flexible options. They can control individual fittings or groups, and vary both the brightness and the colour temperature.

Depending on the situation, an LED lamp and driver may be contained in a single luminaire or separately. This choice is based on the type and location of the luminaire, with considerations such as available space and maintenance.

The nature and principles of LED drivers are complex and continue to develop over time. They are what may be described as a black box and, once connections are made, they just work. The important considerations are what are found in the specifications of the driver unit. It should meet the voltage and current requirements of the LED it is connecting to, and should be of good quality and meet the relevant compliance requirements.

Figure 8.34 shows an example of an LED driver.

8.9.3 Maintenance of luminaires

Lamp replacement

Once a lamp reaches the end of its useful life, its light output begins to diminish. It is considered more economical to replace the lamp than to leave it in service with lowered efficacy and increased maintenance due to frequent failure. In large, well-maintained installations, group replacement schemes operate, which save on labour costs compared to the cost of making a maintenance call as each individual lamp fails. This is especially true where the luminaire has to be partly dismantled in order to replace a lamp. Also, the maintenance can be done after hours without interfering with production, while at the same time keeping the installation working at designed light-output values.

Tubular fluorescent lights are still a major modern indoor light source. They have a much longer life than incandescent lamps but tend to deteriorate more rapidly as they approach the end of their useful life. Discolouration

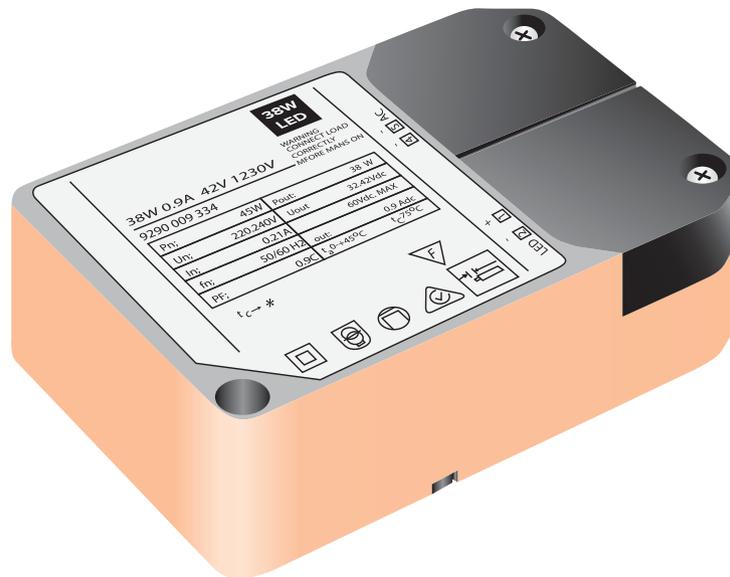


FIGURE 8.34 LED driver

at the ends of fluorescent tubes is an indication of lamp ageing and reduced efficacy. Their replacement with LED equivalents will see both a longer life and a more consistent light output.

Cleaning

Not long after being put into service, the usable light output from a luminaire begins to decrease, due to lamp ageing and the collection of dust and grime on the lamps and reflective surfaces. This also affects the light distribution characteristics. Regular cleaning is therefore necessary. The interval between cleaning periods will depend on the luminaire type and the working environment. The illuminance in lux on the working plane may be checked with a light meter for comparison with either the design figure or the recommended value in *AS/NZS 1680.1 Interior Lighting Part 1—General principles and recommendations*.

8.9.4 Lighting faults

Electrical faults

Lighting and lighting circuits are subject to similar faults to those that occur in other general electrical circuits. Much of the ancillary equipment used in traditional gas-discharge lighting presents issues with leakage currents, and open and short circuits. When these major faults occur in the control gear, it is advisable to consider entire replacement with a more modern form of lighting.

Lighting faults with modern LED lighting consist mainly of LED chip failure, which can only be dealt with by replacement, and failure of the electronic driver, which again will require replacement. It is very important to note that the excellent light output and long-lasting nature of LED lighting can only be enjoyed when high-quality and properly tested products are used.

Glare and reflection

When selecting and designing lighting installations, care should be taken to ensure that both unnecessary glare and reflection are minimised. The positioning of luminaires needs to consider the area and the intended usage in order to ensure correct location. The surfaces within the space and the direction of lighting both need to be considered. The use of reflection off ceilings and walls can be a way of reducing the glare associated with direct lighting.

8.9.5 Working with customers

For designing a lighting installation, we have covered a range of topics about lighting levels and positions of lighting. It is very important to include the customer, whether they are a homeowner, end-user or engineer, in the process

of lighting design. You should work with the customer to ensure the purpose or function of the area to be lit is understood, and the pros and cons of the chosen luminaires are explained.



CHECK YOUR UNDERSTANDING

34. Why are capacitors required in gas-discharge luminaires?
35. What does the term *stroboscopic effect* mean and why can it be dangerous?
36. What is an LED driver?

8.10 Lighting circuits

The common methods of lighting control by switching are:

- ▶ single-pole or one-way control from one position (see **Figures 8.35** and **8.36**)
- ▶ single-pole double-throw (SPDT) or two-way control from two positions (see **Figures 8.35** and **8.36**)
- ▶ two-way and intermediate switch (see **Figure 8.37**) control from any number of desired positions.

The circuit diagrams for each of these control methods are shown in **Figures 8.38** to **8.42**.

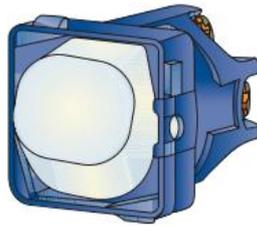


FIGURE 8.35 Front view of single-pole/two-way mechanism

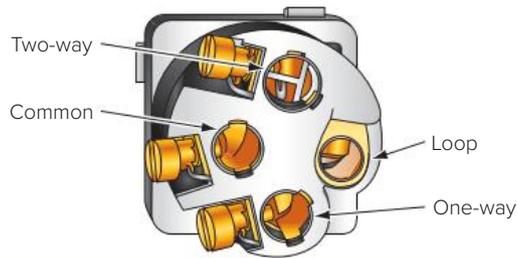


FIGURE 8.36 Rear view of single-pole/two-way mechanism

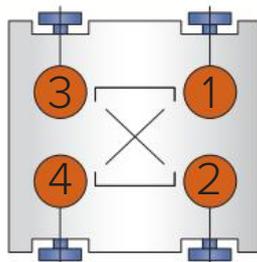
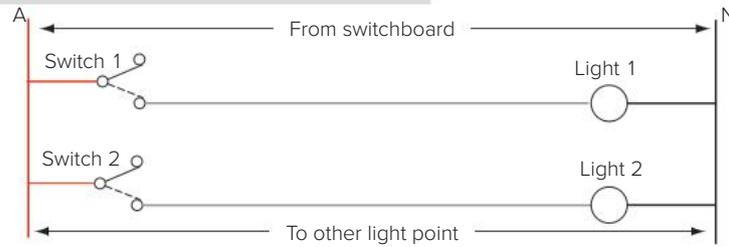


FIGURE 8.37 Rear view of intermediate mechanism. Note: refer to the manufacturer's guide as intermediate mechanisms may vary

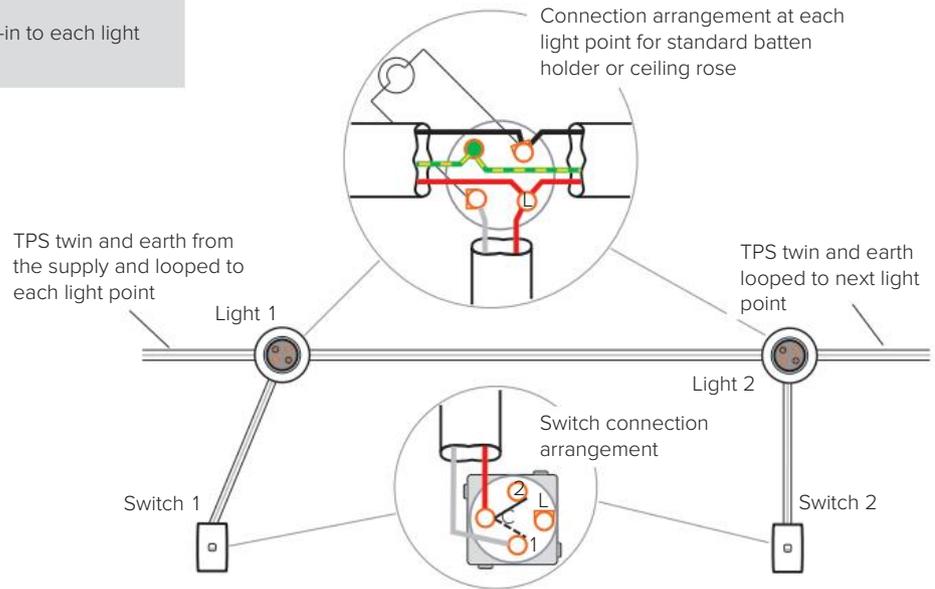
Circuit diagram

Light circuit with each light controlled by a one-way switch.



Wiring diagram

Using TPS cable and loop-in to each light point method of wiring.



Wiring diagram

Using TPS cable and loop-in to each switch position method of wiring.

This method has the advantage that most connections are done at ground level. TPS twin and earth are used throughout to maintain an earth at each light point as required by *Clause 5.4.3*.

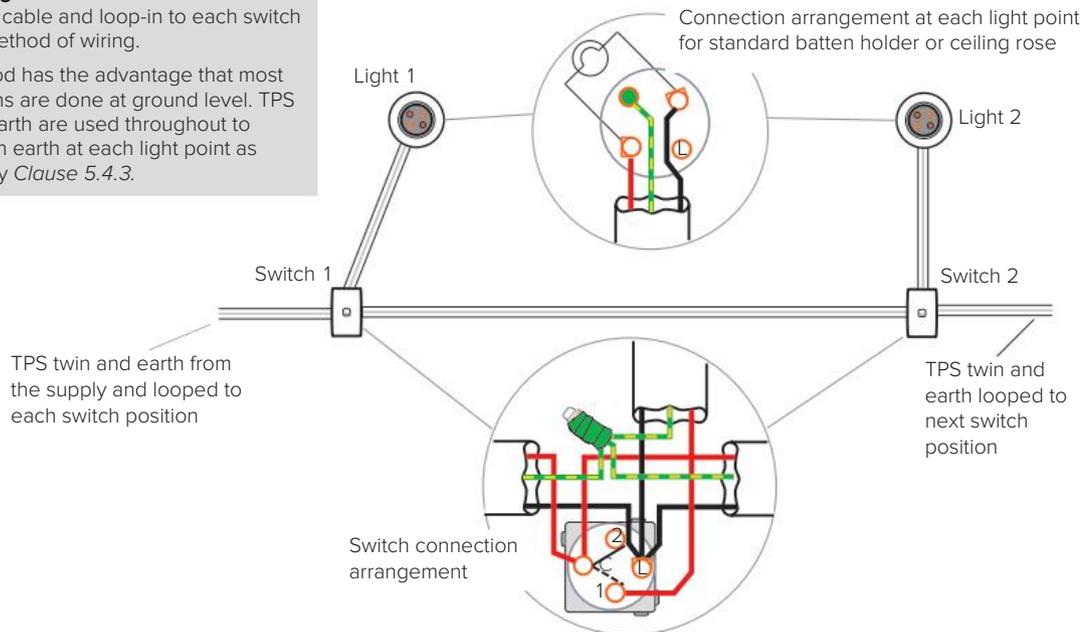


FIGURE 8.38 Circuit and wiring/connection diagrams for a light circuit with single-pole switches

8.10.1 Control from one position—circuit and wiring arrangements

The first and simplest type of control is from one position by one switch connected in series with one line or active conductor. The trade description for this switch is single-pole single-throw (SPST), but it is usually called a *single-pole* switch with the voltage and current rating specified; for example, a 250 V 10 A single-pole switch. There is a large variety of switch mechanisms available, from a basic single-pole on-off switch to a multi-pole multi-position type with a choice between spare or looping terminals. The most common switch mechanism is the one-way/two-way switch, which is *single-pole double-throw* (SPDT) and provides the convenience of both types in a single switch at little extra cost. Note that a switch marked ‘a.c. only’ is not suitable for d.c. operation and, if not specifically marked as suitable for fluorescent lighting, will need to be de-rated in accordance with *Clause 2.3.7.2*; therefore, take care when specifying the type of switch required.

For general wiring, the loop-in system is the normal wiring method, and most modern wiring accessories such as switches, ceiling roses and batten holders are provided with a spare looping terminal for this purpose. The loop-in system makes the joints of conductors accessible at common terminals in these accessories, maximising the use of multicore cables without the need for junction boxes. **Figure 8.38** contrasts the circuit diagram for a light circuit, where each point is controlled by a single switch, with the wiring/connection diagrams for two different loop-in cabling methods for the same light circuit.

Junction boxes are usually less accessible and take longer to install. The loop-in system is usually preferable, but sometimes it is expedient to use a junction box for cutting into the existing wiring. **Figure 8.39** shows an example where it may be more convenient to use a junction box rather than to loop at a light fitting to extend a circuit to an outside location.

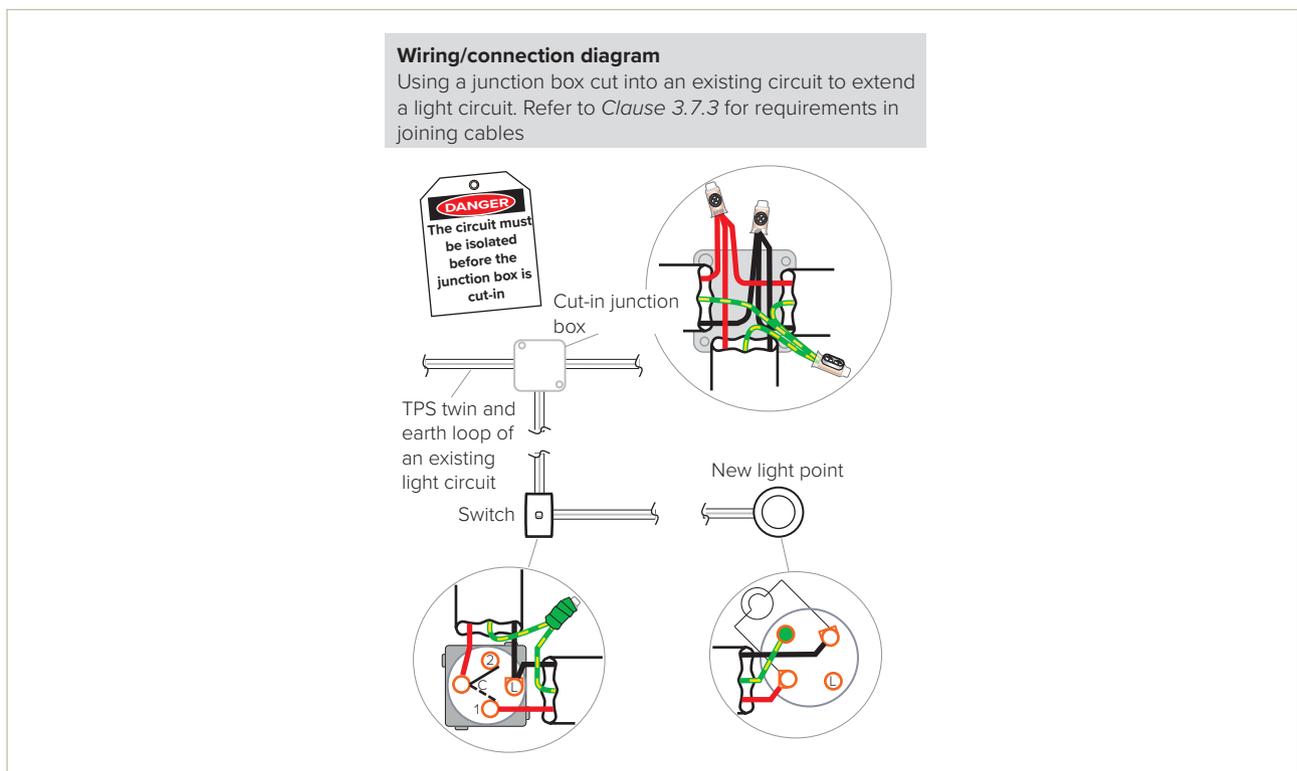


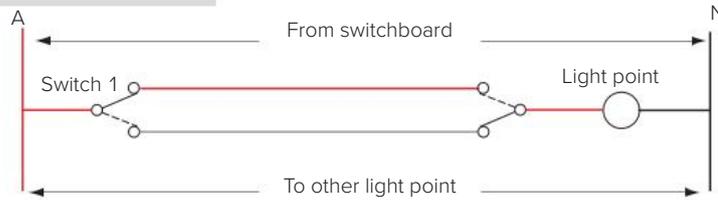
FIGURE 8.39 Cutting in a junction box to install an additional light point

8.10.2 Control from two or more positions—circuit and wiring arrangements

It is common for lighting to be controlled from two different positions, particularly where there are two ways of entering and exiting an area such as a living room. This is achieved by using two two-way switches connected in series with the light point. Although the basic two-way circuit arrangement remains unchanged, the way it is wired is an on-the-job decision based on the particular circumstances. Examples are shown in **Figures 8.40** and **8.41**.

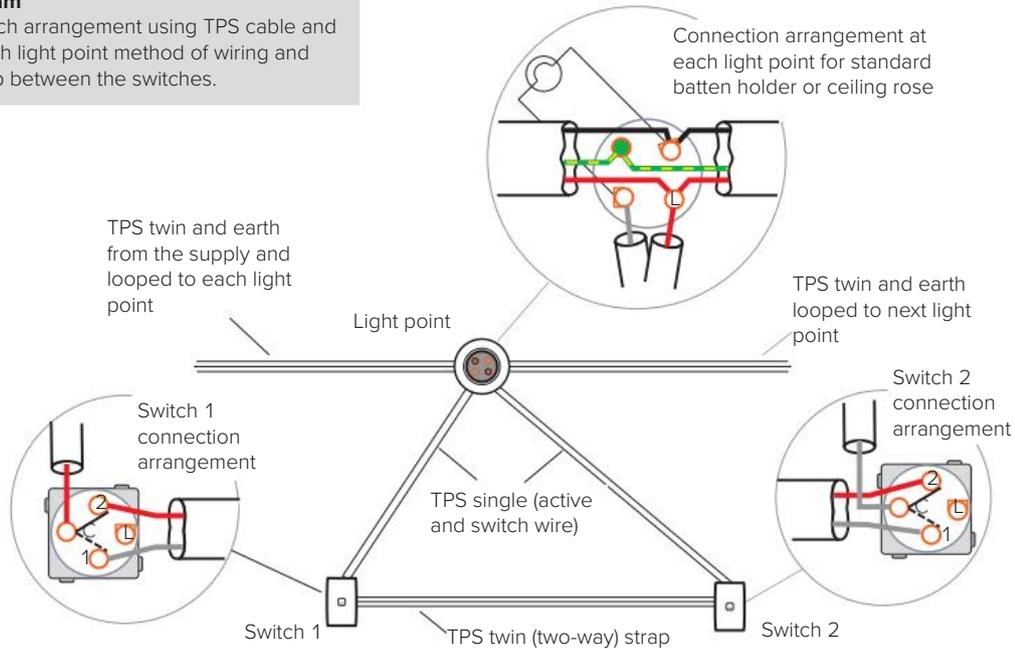
Circuit diagram

Light point controlled by two switches.



Wiring diagram

Two-way switch arrangement using TPS cable and loop-in to each light point method of wiring and TPS twin strap between the switches.



Wiring diagram

Two-way switch arrangement using TPS cable and loop-in to each light point method of wiring and a TPS three-core for switch wire and strap between the switches. This is commonly used in adding a second switch for an existing light point.

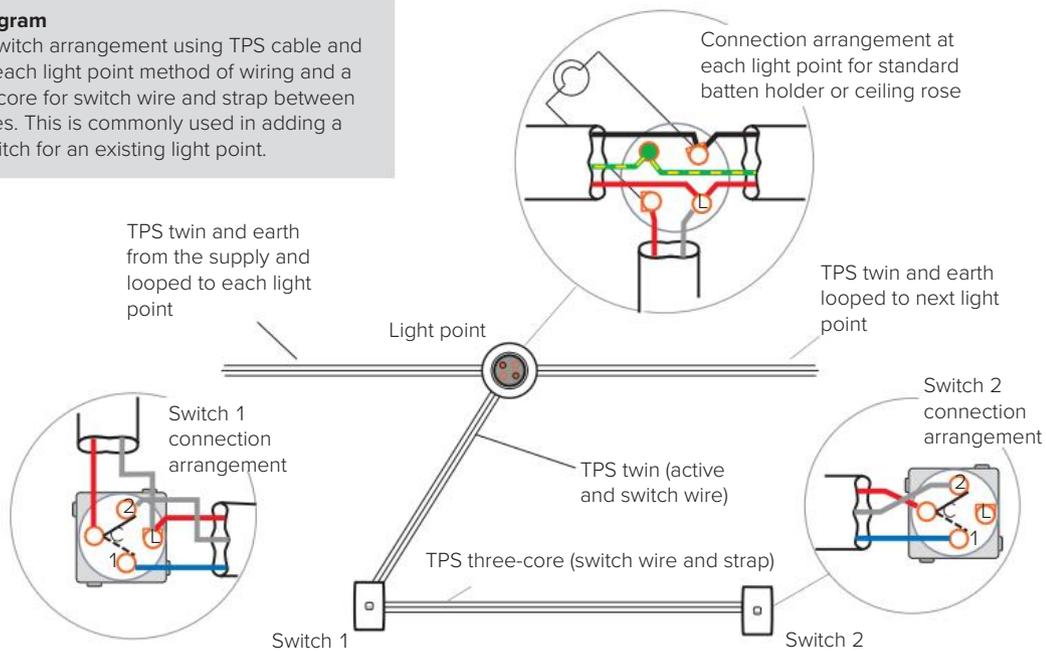


FIGURE 8.40 Two-way control of a lighting circuit

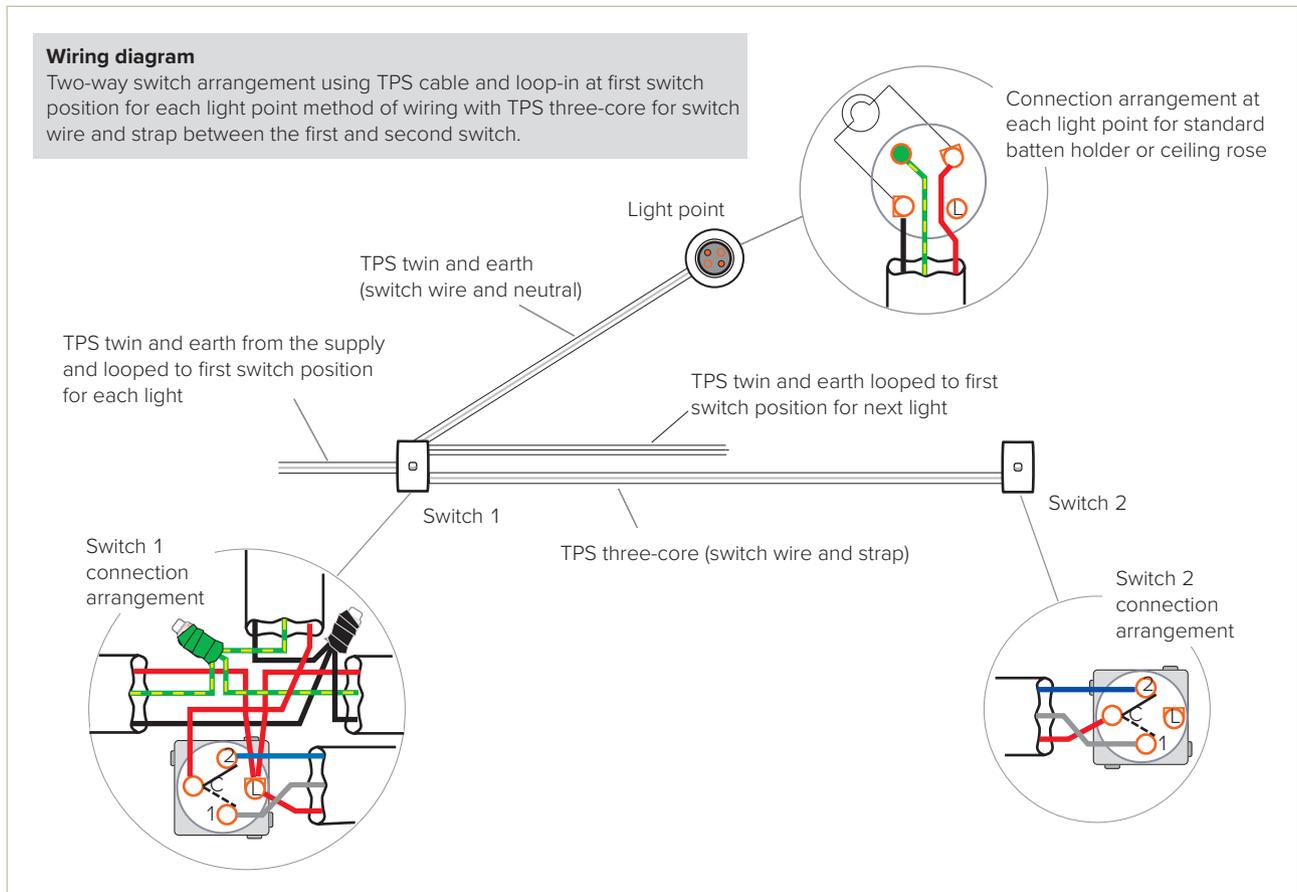


FIGURE 8.41 Two-way control of a lighting circuit looping at switches

Figure 8.41 includes a method of adding a two-way facility to an existing circuit in circumstances where it is either not desirable or impracticable to disturb the existing wiring. Again, it must be stressed that each job is a variation on the basic theme and that the way these basics are applied is an on-the-job decision.

Where switching from more than two positions is needed, two-way switches are used at each end of the control circuit in series, with as many switches at intermediate positions as required, there being no limit to the possible number of control positions. The type of switch necessary at the intermediate positions is logically called an intermediate switch and it has four connections or operative terminals. The wiring is the same for all types, irrespective of the internal bridging arrangements for the switches, which may vary between manufacturers. It is only when dealing with the conductors interconnecting the two-way switches (straps) to the intermediate switches that care must be taken to connect up correctly.

Figure 8.42 illustrates a typical circuit, showing multi-position control of a lamp using unsheathed insulated cable (building wire) in conduit. Multi-position switching of lighting is typically used in stairwells, where a switch is installed at each level and in areas with multiple entrances and exits.

The circuits illustrated in **Figures 8.38 to 8.42** are examples that show the importance of planning the wiring scheme.



CHECK YOUR UNDERSTANDING

37. List two common methods of lighting control using switching.
38. Draw a circuit diagram containing two lights controlled by a two-way lighting circuit and looped at the switch. Label the diagram.

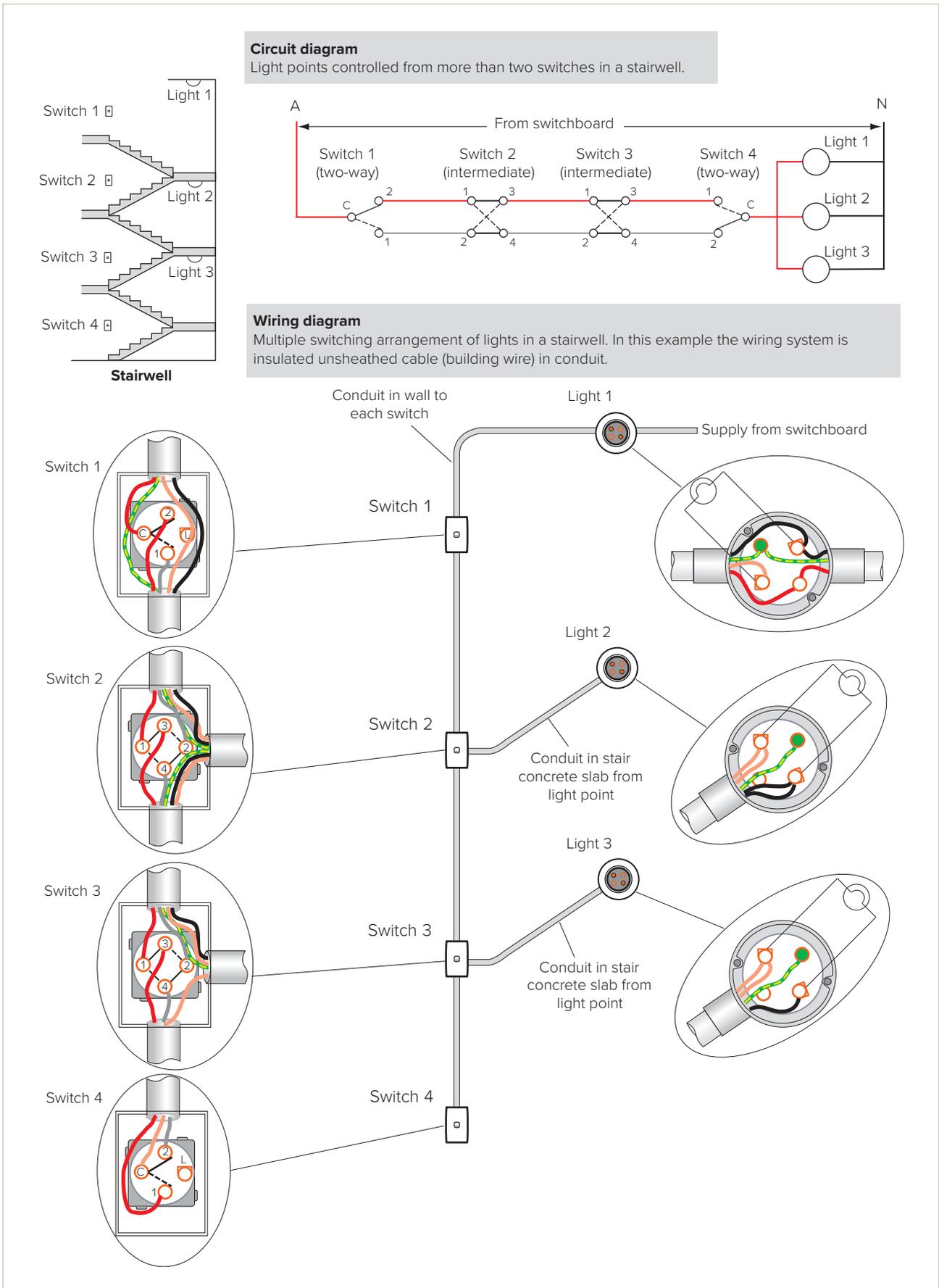


FIGURE 8.42 Multi-position control of a lighting circuit

8.11 Fire detection and alarm devices—residential premises

8.11.1 Smoke alarm requirements and types

Smoke-detector alarms (commonly called smoke alarms) are required in single domestic dwellings and buildings with residential facilities of a limited size and limited number of persons, such as boarding houses and guesthouses, as designated by building codes. In these buildings, smoke alarms, as shown in **Figure 8.43**, are commonly installed by electricians as part of general electrical installation work.

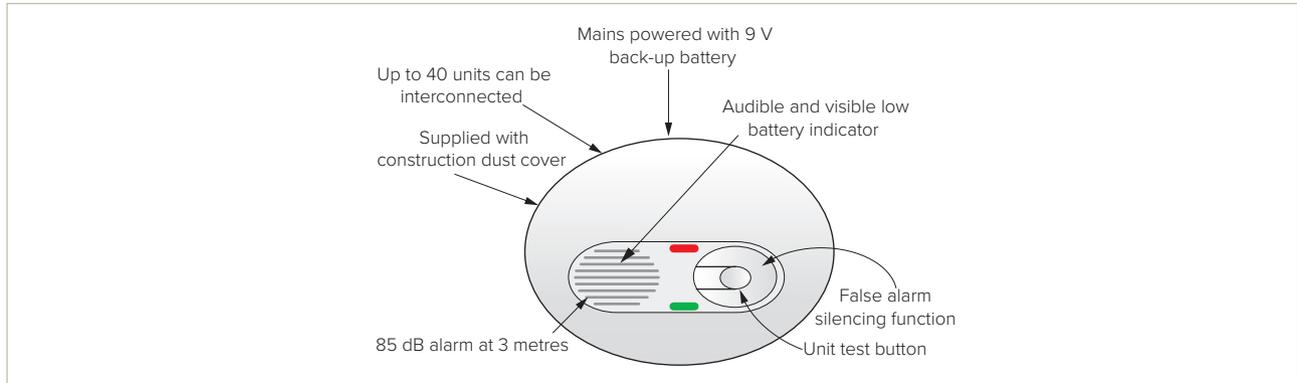


FIGURE 8.43 Typical smoke alarms used in domestic and small residential properties

The two most common smoke alarms and designated smoke-detection techniques are illustrated in **Figures 8.44** and **8.45**. Both types have built-in electronic sounders at a volume and frequency that will wake a sleeping person.

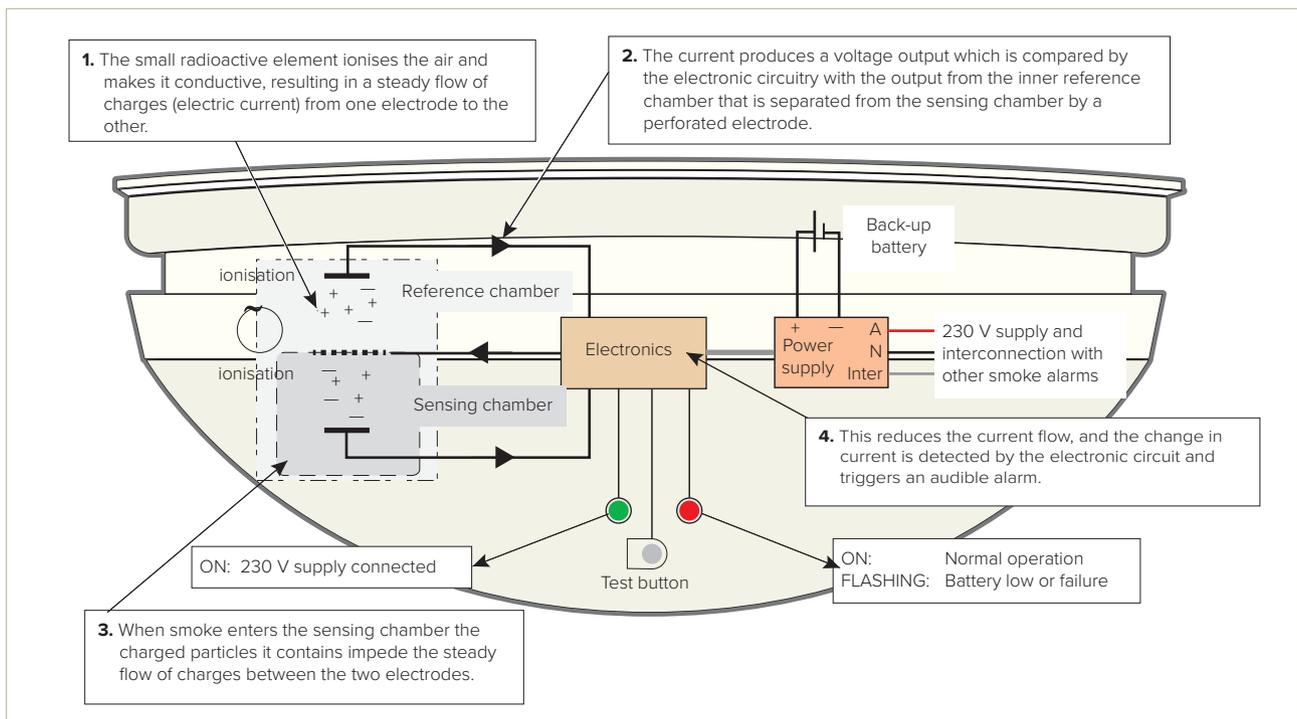


FIGURE 8.44 Ionisation-type smoke alarm

Consideration needs to be given to the type of smoke alarm and its location, to avoid the likelihood of nuisance alarms. Ionisation smoke alarms are more susceptible to smoke from cooking and prone to initiating false alarms, as

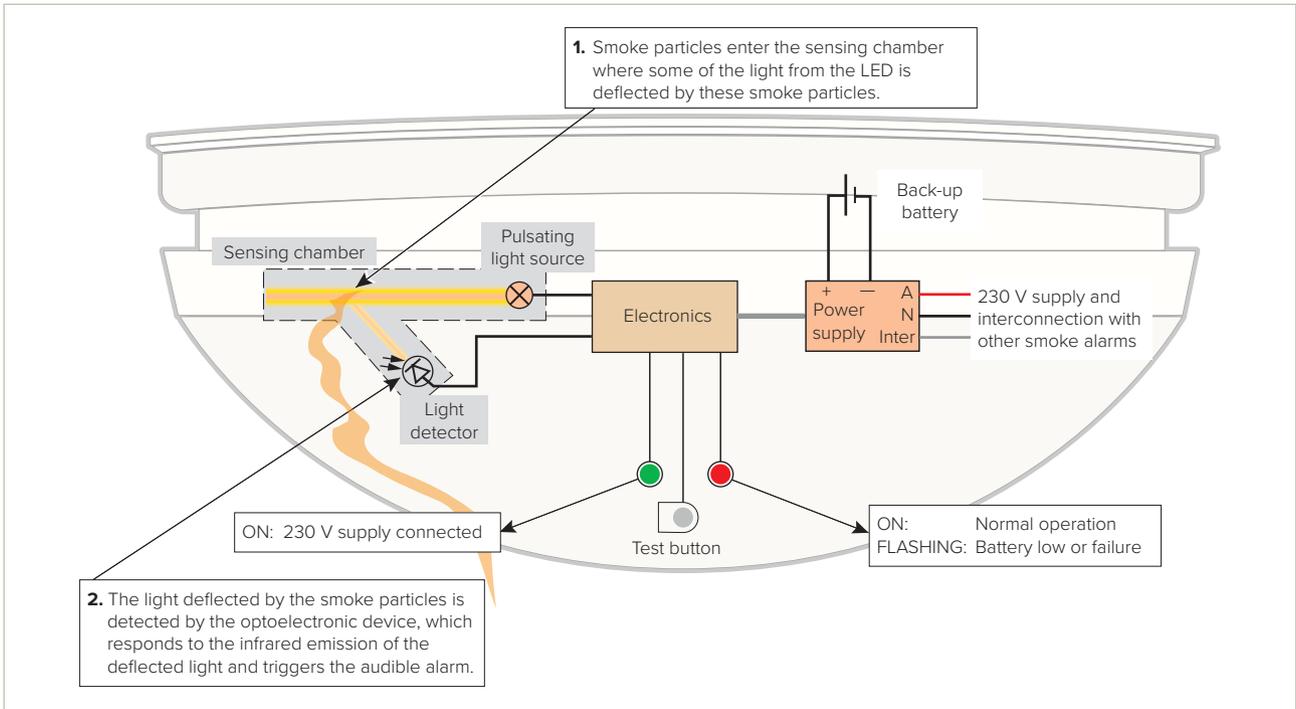


FIGURE 8.45 Photoelectric-type smoke alarm

shown in Figure 8.46. This has resulted in residents removing the alarm battery and forgetting to reinstall it after the cause of the alarm subsides, defeating the purpose of the smoke alarm. For this reason, local authorities advise that mains-connected photoelectric alarms should be installed. This is regulated in some jurisdictions.

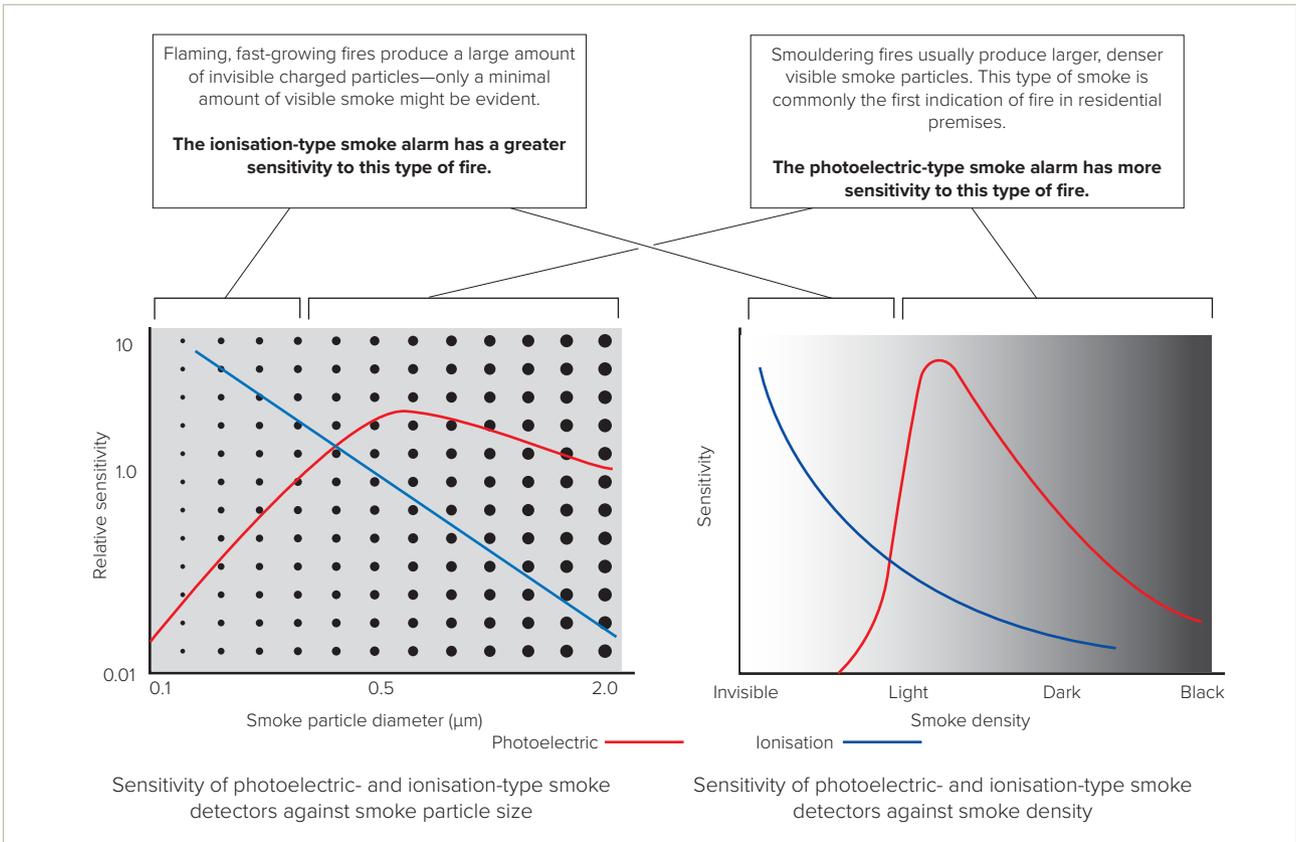


FIGURE 8.46 Sensitivity of photoelectric and ionisation smoke alarms

Special-purpose smoke alarms are available for hearing-impaired people. These special types may use strobe lights or vibrating devices to alert occupants of a dwelling who would not normally respond to an audible alarm.

8.11.2 Locating smoke alarms in domestic dwellings

When considering the location of smoke alarms, the main reason for installing them should be kept in mind. The sleeping areas of a building will be the main focus of location requirements because the object of installing a smoke alarm is to detect smoke before it reaches the sleeping occupants of a dwelling. The audible alarm triggered by smoke detection should awaken the occupants and give them time to evacuate the building.

The minimum requirements of the NCC are that a smoke alarm connected to the mains and with a standby power supply (e.g. a battery) must be installed on or near the ceiling on every storey of a new residential dwelling. Local building authorities may require mains-connected smoke alarms to be installed in existing tenanted dwellings (see **Figure 8.47**).

A high level of protection is provided by installing smoke alarms in every room of a residential dwelling except where combustion particles are normally present, such as kitchens and garages (see **Figure 8.48**).

Avoid installing smoke alarms in locations where air circulation is poor, known as dead air spaces, because the amount of smoke needed to trigger the alarm will not reach such locations until a fire is well established (see **Figure 8.49**).

Nuisance alarms can occur when a smoke alarm is installed in a location for which it is not designed. For example, the alarm may be triggered by cooking smoke from a kitchen or steam from a bathroom. To minimise the incidence of false or nuisance alarms, avoid installing smoke alarms in the locations shown and described in **Figure 8.50**.

8.11.3 Installing smoke alarms in domestic dwellings

Installation arrangements

Regulations dictate that mains-operated smoke alarms must be installed by a licensed electrician and connected to the mains supply in accordance with the *Wiring Rules*. The self-contained domestic smoke alarms described in this chapter are not deemed to be part of a system for fire detection and alarm. Therefore, their installation does not have to comply with the requirements for fire and smoke control equipment and evacuation equipment specified in *Clause 7.2* of the *Wiring Rules*. This means they do not have to be controlled by a main switch separate from the general installation main switch.

Smoke alarms may be:

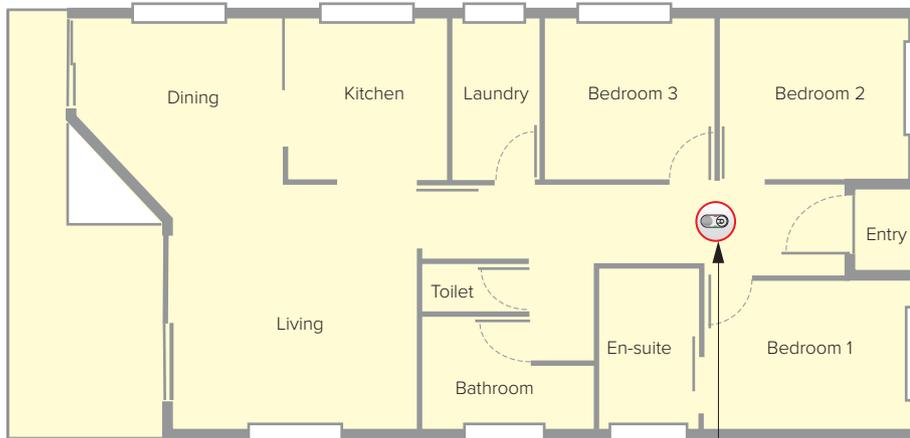
- ▶ supplied with their own dedicated circuit originating at the switchboard
- ▶ connected to a lighting circuit or
- ▶ connected to any other circuit that is energised 24 hours per day.

Connection to the nearest lighting circuit is often the best option for the following reasons:

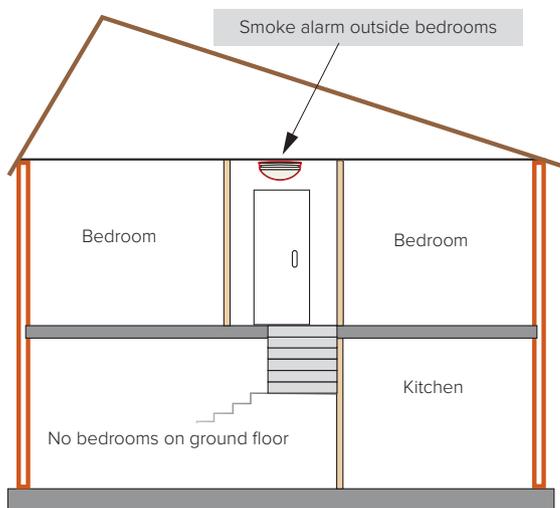
- ▶ If the lighting circuit is interrupted by switching off a circuit-breaker or a circuit fault tripping the circuit-breaker or RCD, the interruption to supply will be evident and the circuit will probably be restored promptly.
- ▶ Connection to a lighting circuit is the least costly option. Using an existing power circuit or installing a dedicated circuit will involve higher labour and material costs.

Most smoke alarms are designed for interconnection in parallel, and it is usually possible to interconnect ionisation and photoelectric smoke alarms. Up to 40 alarms may be connected together and they should always be connected on the one circuit.

Location of a smoke alarm outside the bedroom or bedroom area, such that it is in effect located between that area and the rest of the dwelling, will detect smoke before it reaches the sleeping occupants.



Smoke alarms should be located outside the entrance to each bedroom or in a common area or hallway; a distance of 900 mm from the doorway is recommended.



In a storey not containing bedrooms, the NCC suggest the location for a smoke alarm be the path of travel people will most likely take to evacuate the building. This will ensure that an alarm is raised before smoke makes the common exit path impassable.

Where a staircase leads to a basement, the smoke alarm should be installed at the bottom of the staircase. In both cases, the path of the smoke should not be obstructed by a door or any other structure.

FIGURE 8.47 Location of smoke alarms in a single dwelling

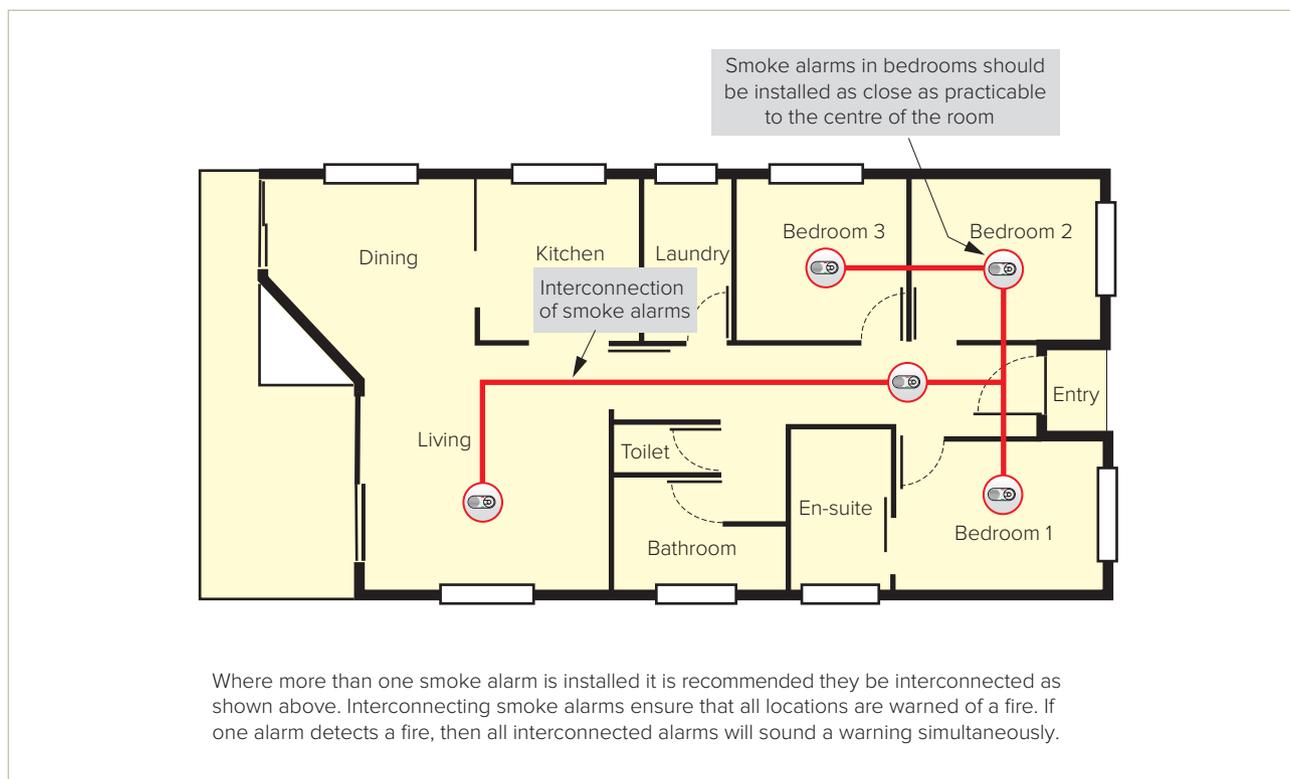


FIGURE 8.48 Smoke and fire alarm location for high level of protection

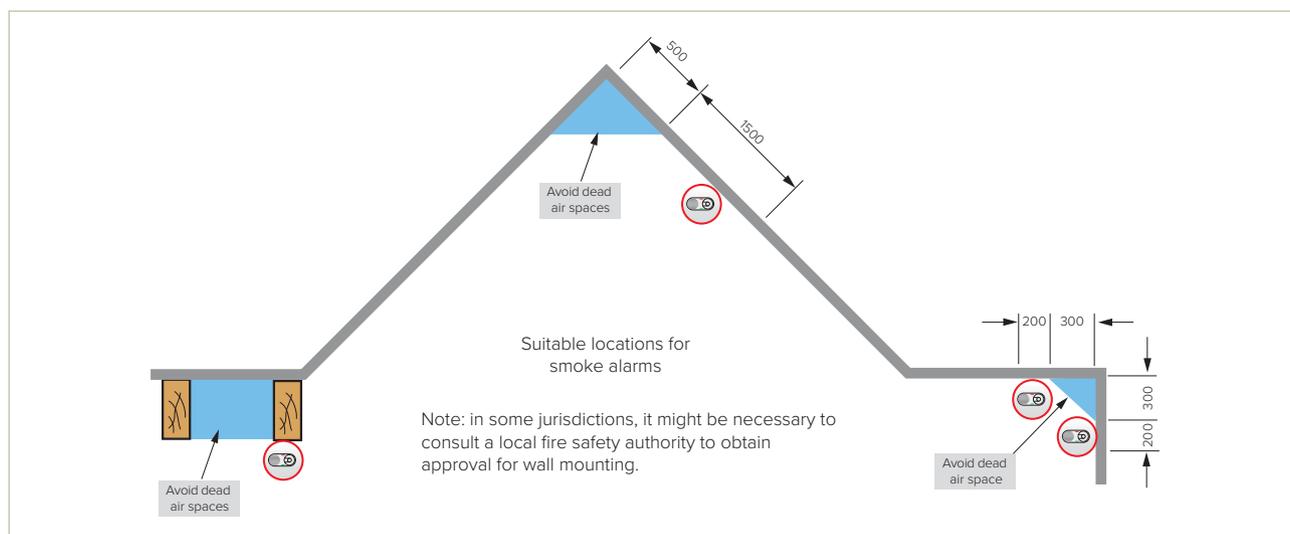


FIGURE 8.49 Avoiding locations where there is little air movement

For the purpose of determining the number of points in a final subcircuit, each alarm counts as one point. The alarm illustrated in **Figure 8.51** draws a current of 35 mA both in its quiescent (monitoring) state and when it is activated. The conductors of the final subcircuit supplying the alarms and all of the interconnecting conductors must be not less than 1 mm^2 in cross-sectional area, with 450/750 V grade insulation. Alternative wiring arrangements are shown in **Figure 8.51**.

On completion of installation of the wiring that alarms are to be connected to, the active, neutral and interconnecting or switch wires should be carefully checked before connecting the alarms into the circuit. Incorrect connections can cause damage to the electronic components in a smoke alarm.

Important note: Wiring should never be tested using an insulation-resistance tester if a smoke alarm is connected in the circuit, because damage to electronic components could result.

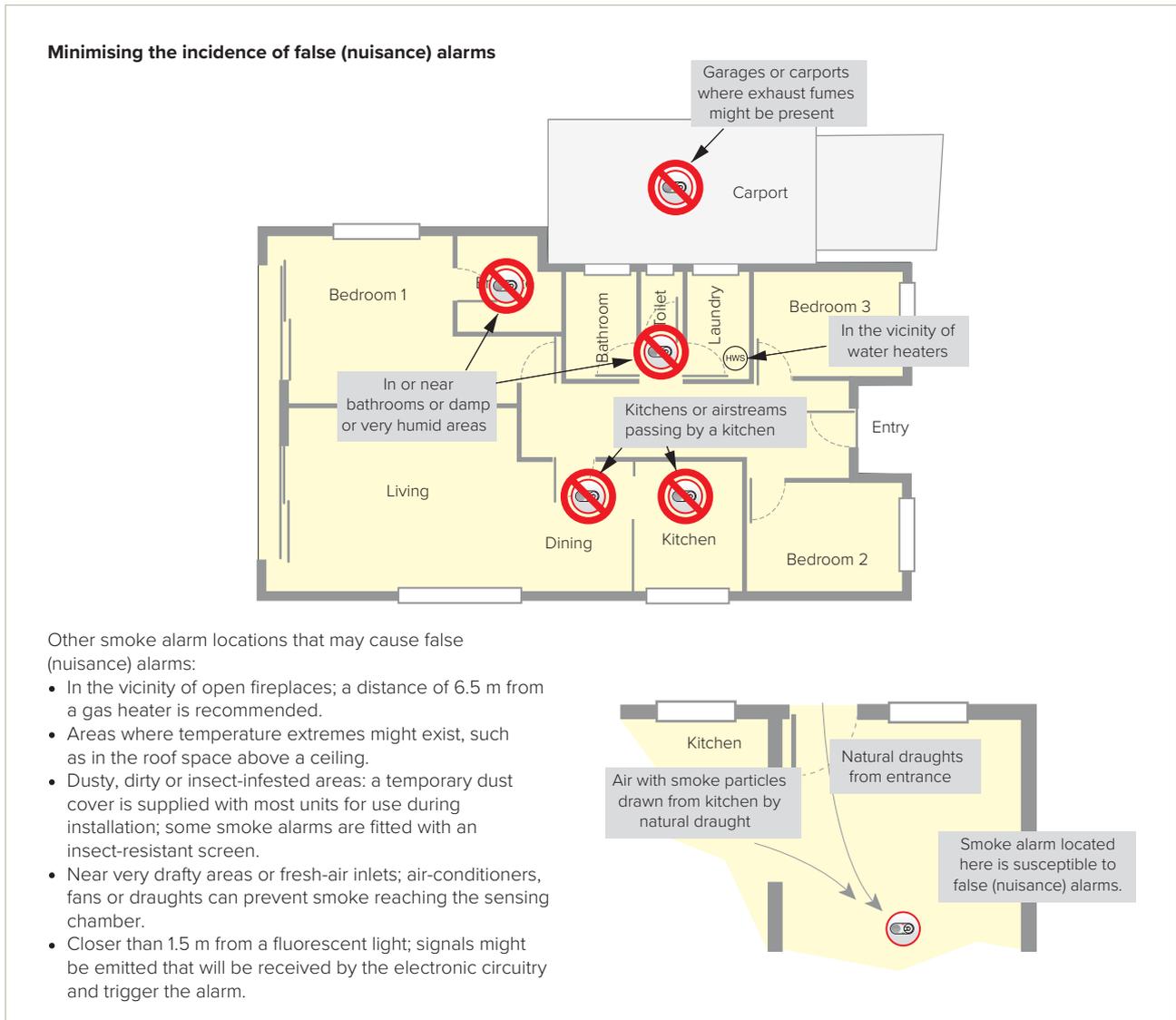


FIGURE 8.50 Avoiding incidences of false or nuisance alarms

Maintenance

In common with most electrical and electronic safety devices, smoke alarms need some minor maintenance and regular operation testing. The installing electrician should notify the householder of the advice given by the manufacturer. Typically this will include the following:

- ▶ **Cleaning:** Smoke alarms should be cleaned annually by careful vacuuming to remove accumulated dust, which may find its way into the sensing chamber and affect its operation. A slightly damp cloth can be used to clean the external surface of the unit.
- ▶ **Mains supply:** Regularly check that the mains supply is connected to the unit. Most smoke alarms have a power-on indicator light.
- ▶ **Operation:** Test-operate the alarm regularly, at least once a month. This is done by pushing the test button until the siren sounds.
- ▶ **Backup operation:** To check that the backup battery is working, switch off the circuit at the switchboard before pressing the button.
- ▶ **Battery replacement:** The majority of smoke alarms are supplied with a 9 V battery and these should be replaced with the correct type at intervals recommended by the manufacturer, typically at the same time each year.
- ▶ **Replacement:** It is recommended that smoke alarms be replaced every 10 years.

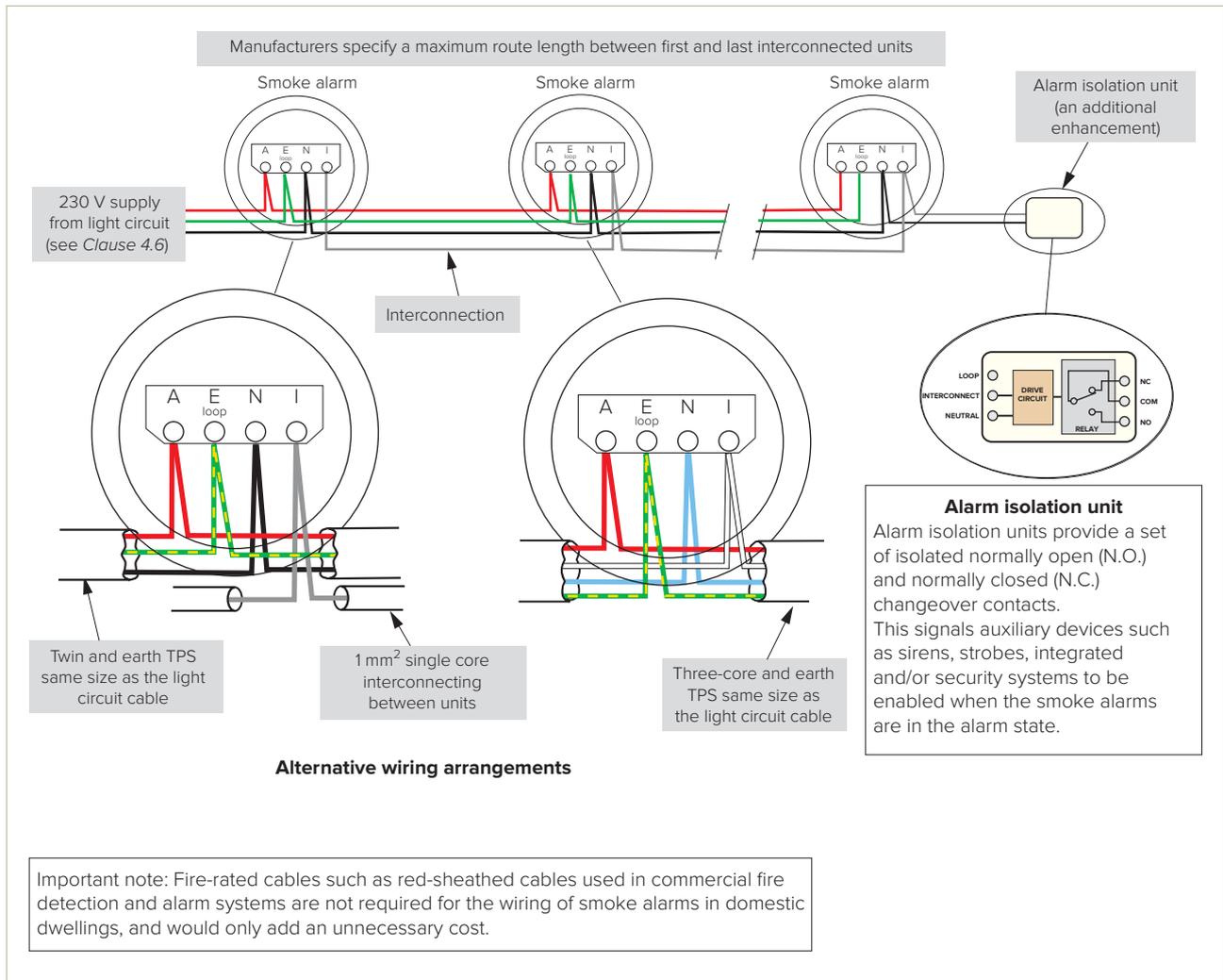


FIGURE 8.51 Wiring arrangement of domestic smoke alarm

CAUTION

Smoke alarm disposal

Although ionisation smoke alarms contain only an extremely small amount of radioactive material, if they are to be discarded they should be returned to the manufacturer or advice should be sought from local waste authorities. Photoelectric alarms do not contain any radioactive material and may therefore be disposed of in the normal way.

CHECK YOUR UNDERSTANDING

39. List two types of smoke detector alarms.
40. How can smoke alarms be adapted for hearing-impaired people?
41. When referring to smoke detector locations, what is a dead area?
42. Do mains-powered detectors have batteries?

8.12 Emergency lighting

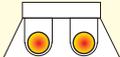
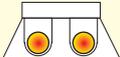
The purpose of emergency lighting is threefold: firstly, to clearly light the direction of exit from a building; secondly, to light the exit pathway. In particular situations, emergency standby lighting is necessary when a task must be completed; for example, in a hospital operating theatre or hazardous industrial situation, where health and safety are major concerns. Thirdly, emergency lighting must operate automatically in the event of a power-supply failure to the main lighting system.

There are two systems for emergency power supply: a self-contained or single-point system and a central battery system. The former is the most commonly used, particularly in small buildings. There are three basic types of luminaires that can be classified as self-contained or single-point systems:

1. non-maintained type—these fittings are not illuminated under normal conditions but are constantly on charge and only operate when the normal electrical supply fails
2. maintained type—these fittings have only one lamp, which is illuminated both under mains supply and when the mains supply fails; when the power fails, the battery provides power to the lamp, maintaining its light output in a blackout or emergency condition. This same lamp is illuminated under normal conditions when the normal electrical supply is on
3. sustained type—sustained emergency lights have two lamps in the fitting, with only one lamp illuminating in any given condition; one is for 230 V operation and is on under normal conditions, while the second lamp is only on when the normal electrical supply fails.

These operating modes are shown in **Table 8.7**.

TABLE 8.7 Operating modes of emergency luminaires

Luminaire type	Normal operation	Emergency operation
Non-maintained	 OR 	 OR 
Maintained	 OR 	 OR 
Sustained		

○ Non-energised

● Energised

The locations of emergency luminaires relate to the photometric performance (the quality and quantity of light) of the luminaire. Manufacturers' information will provide maximum spacing for a given range of mounting heights. The number and spacing of fittings should provide a minimum illuminance of 0.2 lx. (**Chapter 18** covers the basic principles of lighting and lighting design.) **Figure 8.52** shows specific locations within a building where it is necessary to provide emergency lighting.

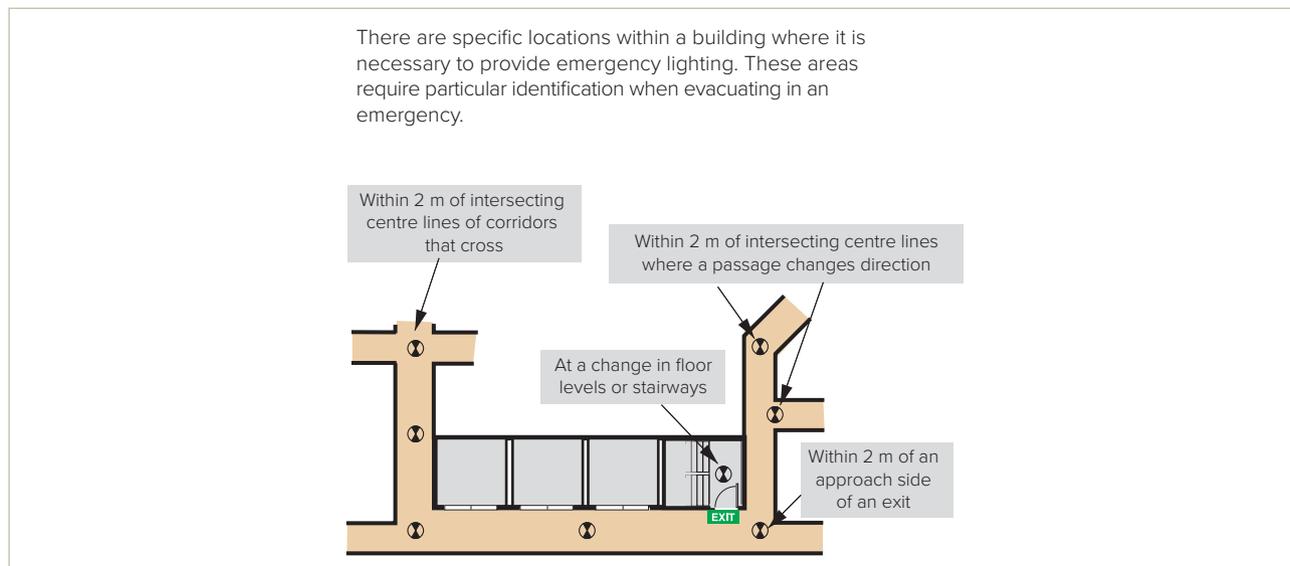


FIGURE 8.52 Specific locations for provision of emergency lighting

Most lighting manufacturers make a variety of emergency luminaires (light fittings) similar in style to their general range with the additional facilities for backup and testing as required by *AS 2293.3*. Exit lights include the international Standard *ISO 3864-1*, the running man pictographic that shows each exit or the direction to the nearest exit. Examples of emergency luminaires are shown in **Figure 8.53**.



LED exit light with international running man symbol showing the way to the nearest exit.



LED Firefly emergency light designed to light the egress path as shown in **Figure 8.52**.

FIGURE 8.53 Examples of emergency luminaires

(Top) Glow Images; (bottom) Signify

Inspection and maintenance of an emergency lighting system are essential if it is to function in the evacuation of a building in an emergency. *AS/NZS 2293.2* specifies requirements for six-monthly and 12-monthly inspection and

maintenance procedures for emergency lighting systems, which must be carried out by competent personnel and recorded in a logbook.

Computerised emergency lighting systems are designed to automate these procedures. In these systems, emergency luminaires and exit lights are equipped with addressable monitoring components that are connected to the system by a communications cable; some advanced systems use Powerline communications technology. The system constantly monitors and records a.c. power supply, battery life, battery charger status and emergency lamp operation, and records any remedial action taken, when it was taken and the provider of the service.



CHECK YOUR UNDERSTANDING

43. List the three main operating modes of emergency light fittings.
44. Why is emergency lighting an important feature of fire safety systems?

SUMMARY

- ▶ Sufficient light, freedom from glare and suitable contrast between the object and its background determines how well an object is seen.
- ▶ There is a range in the electromagnetic spectrum that the human eye is sensitive to and which allows objects to be seen.
- ▶ There are many lighting terms and units that are used to quantify and measure light.
- ▶ Good lighting design consists of:
 - ▶ providing adequate illuminance on the task
 - ▶ ensuring freedom from unwanted reflection
 - ▶ producing the correct balance between luminance of the task and luminance of the surroundings
 - ▶ avoiding excessive illuminance variation
 - ▶ protecting against discomfort from direct glare from lamps and luminaires.
- ▶ *AS/NZS 1680.1* sets out minimum lighting levels, in lux, for many tasks and should be consulted when installing lighting design.
- ▶ *Efficacy* is a term that means the measure of light output against the power input, and is quoted in lumens per watt (lm/W).
- ▶ Incandescent globes, where light is produced by passing a current through a filament, were the first type of globe developed but have now been phased out due to the development of more efficient technology.
- ▶ Halogen globes also use a filament-like incandescent but have a higher efficacy due to the fact the filament is made from tungsten enclosed in a quartz tube containing halogen gas.
- ▶ ELV halogen globes are a type of halogen that use extra-low voltage. By using ELV smaller, more robust filaments can be used. This, along with a small compact dichroic reflector inside the lamp, gives very good control over the light beam.
- ▶ High-intensity gas-discharge lamps include mercury vapour, metal halide and sodium vapour.
- ▶ Gas-discharge lamps use a technology where an arc is created between two electrodes enclosed in a tube of inert gas, with a mixture of either mercury, sodium or metal halides.

- ▶ Gas-discharge lamps have been used for many diverse applications and, like sodium vapour lamps, have outstanding efficacies but are now being phased out in favour of LED lighting.
- ▶ Low-intensity discharge lighting, such as fluorescent lighting, has been the most popular gas-discharge lighting technology used for some time.
- ▶ Fluorescent lighting creates light from a UV arc created between two filaments enclosed in a tube containing mercury and argon. The UV light is used to make the phosphor coating inside the tube glow and this produces light.
- ▶ Fluorescent lighting has many advantages such as electronic ballasts and compact fluorescent lamps but, due to the health and environmental risks of mercury, these lights are also being phased out.
- ▶ The colour rendering index (CRI) measures how accurately colours are displayed by the light produced by lamps. For example, halogens have the best CRI, producing light that shows colours at their best, whereas the monochromatic yellow light from sodium vapour lamps has a very poor CRI.
- ▶ LED lights use light-emitting diodes to produce light and are now the preferred option for most lighting applications due to their many advantages over other lighting technology.
- ▶ LED lighting is superior to every other lighting technology in almost every way. It can produce very bright light with excellent CRI, uses very low power and thus has high efficacy, produces little to no heat and lasts thousands of operational hours.
- ▶ Luminaires can either have all components of the lamp integrated into the single light fitting or they can have several external components, such as ballasts, transformers, drivers and so on. This must be considered when selecting luminaires as this can increase installation and maintenance costs and make fault finding with luminaires more difficult.
- ▶ The installation of lighting must comply with the *Wiring Rules, Clause 4.5.2*, which requires that luminaires and ancillary equipment are installed so that they do not cause harmful temperature rises or ignite any material in their vicinity. Always consult *AS/NZS 3000:2018* before commencing any wiring work that involves lighting circuits.
- ▶ There are three types of lighting control by switching: single-pole (one-way), single-pole double-throw (two-way), two-way and intermediate (three-way or more).
- ▶ Loop-in systems for lighting circuits include loop at the light and loop at the switch.
- ▶ There is a specific range of luminaires that are used to allow safe evacuation from potentially dangerous situations and they must be carefully selected.

REVIEW QUESTIONS

1. The objective of any lighting installation is to satisfy what?
2. Which concept of rays of light makes possible the practical design of reflectors, diffusers and refractors?
3. *AS 1680.2.4* recommends a minimum lux level for the general working area of an office as 320 lx. If the working area is 350 m², calculate the value of the useful flux incident on the working plane.
4. At what height should a light source be mounted if its vertical luminous intensity is 4500 cd and it is required to provide an illuminance of 150 lx on the working plane?
5. Identify two categories that luminaires are considered to fall into.
6. What condition could cause a premature failure of ancillary equipment needed to operate modern gas-discharge lamps?
7. What is the role of the dichroic reflector in an ELV lamp?
8. Describe the function of the internal reflective coating in an ELV lamp.
9. What test equipment is used for measuring light levels?
10. List three advantages of a compact fluorescent lamp over an incandescent lamp.

11. Research and compare the current drawn by a 30 W CFL and a comparably performing incandescent, e.g. 100 W.
12. List two primary ways of producing high-intensity white light using LEDs.
13. Identify five general benefits of using LED lighting.
14. Where would you expect the ancillary equipment controlling compact fluorescent lamps to be located?
15. What are the two main types of LED drivers?
16. What are two negative effects of purchasing poor-quality luminaires?
17. In difficult-to-access areas what is the main benefit of LED lighting?
18. In **Figure 8.40**, what switch mechanisms are required to install the two-way lighting circuit?
19. Describe the operation of an ionisation-type detector.

CHAPTER 9

Appliances—electric heating and motors

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ understand how various heating control devices operate, including thermostats and simmerstats
- ▶ understand heat energy, temperature, heat transfer, specific heat capacity, thermal conductivity and thermal stability
- ▶ explain how fixed electric heating appliances work, including space heaters and reverse-cycle air-conditioners
- ▶ explain the operation of electric water heaters
- ▶ list types of electric water heaters
- ▶ understand circuit diagrams used for common heating equipment and heating controls
- ▶ demonstrate how to test and perform fault finding on common heating equipment and heating controls
- ▶ explain the techniques for repairing/replacing faulty heating equipment components
- ▶ understand process heating and its applications
- ▶ understand the types of motors used in appliances and their installation requirements.

The most common forms of energy for which electricity is used are heat and motion. A device designed to do this is defined by the *Wiring Rules, Clause 1.4.9* as an *appliance*, which is:

A consuming device, other than a lamp, in which electricity is converted into heat, motion, or any other form of energy, or is substantially changed in its electrical character.

Electrical energy can be converted into heat by various methods: in resistive elements, through the action of a heat pump, by electric arc and by electromagnetic induction.

In wiring work, the heating effect due to current in the conductors is a disadvantage. It must be kept to a minimum because it represents a loss of energy and may lead to overheating of the material adjacent to the conductors. However, the heating effect of an electric current being passed through a resistive element is used in many heating appliances for domestic, industrial and commercial installations. Appliances also use other mechanisms for space and water heating, including collecting and transferring solar heat directly in absorbers, and the reverse-cycle process that transfers heat from the outside atmosphere to the interior of buildings to warm the space in winter and transfers heat from the room to the external atmosphere to cool the space in summer. Both of these heat-transfer processes use less

electrical energy for the delivery of a particular quantity of heat to be delivered to a load. Electromagnetic induction and electric arc are other methods of creating heat. Electrical energy can also be used to develop motion through the interaction of the magnetic fields produced by current flow.

This chapter deals with both these types of appliances and the installation requirements associated with them.

9.1 Appliances and accessories—installation requirements

Section 4 of the *Wiring Rules* sets out the minimum requirements for the selection and installation of appliances and accessories, as well as other electrical equipment not specifically covered in other sections. The overall outcomes of Section 4 requirements are that electrical equipment:

- ▶ functions as intended
- ▶ does not cause any adverse effects to the electrical installation
- ▶ operates safely
- ▶ does not present a danger of electric shock, fire, high temperatures or physical injury
- ▶ is installed as per the requirements in the *Wiring Rules*.

An overview of the compliance requirements that apply to heating appliances and motors is given in **Figure 9.1**.

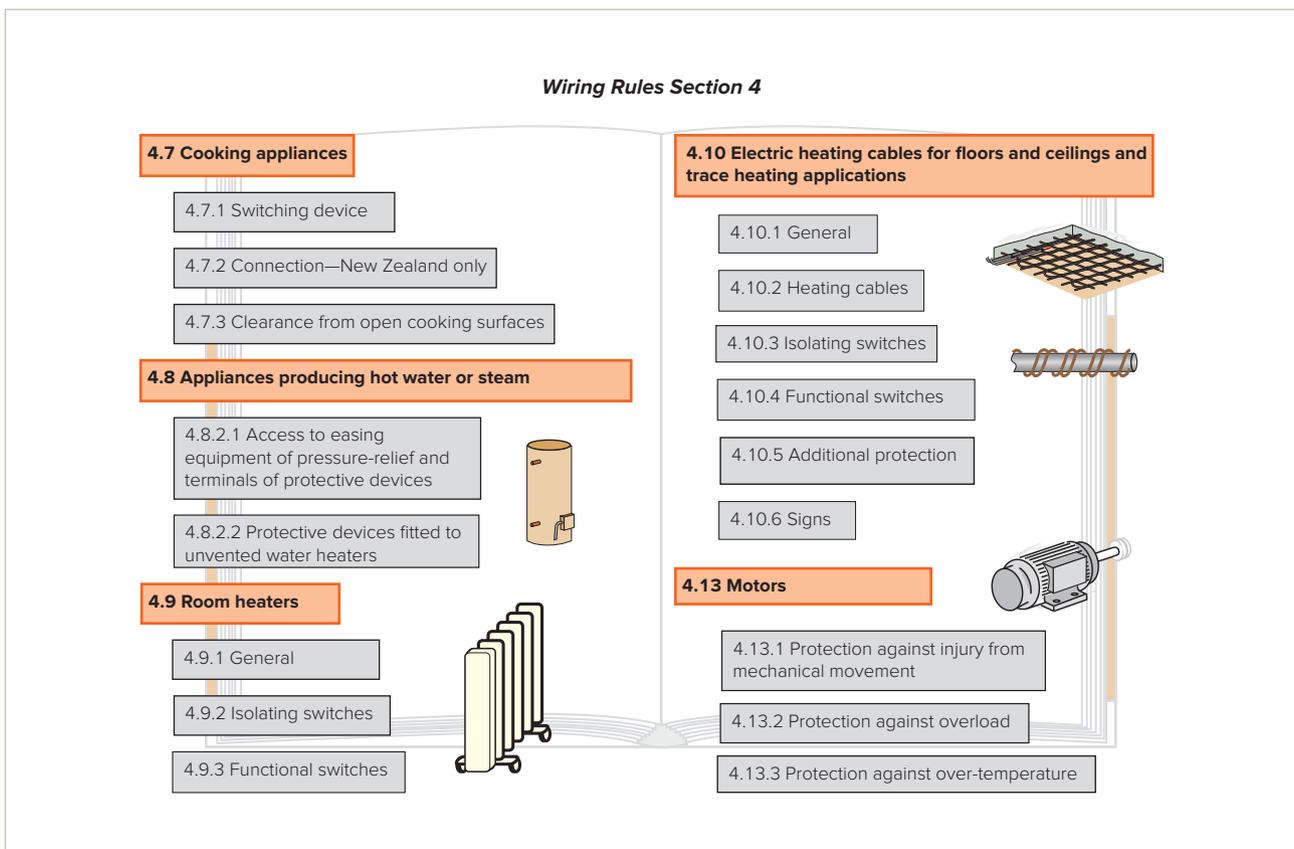


FIGURE 9.1 Installation requirements for appliances and accessories



CHECK YOUR UNDERSTANDING

1. Which section of the *Wiring Rules* sets out the minimum requirements for the selection and installation of appliances and accessories?
2. What is the *Wiring Rules* definition of *appliance*?
3. What are the two most common forms of energy derived from electricity?

9.2 Heating methods and control

9.2.1 Heat, temperature and heat transfer

In considering the use of heat energy, it is helpful to revise some basic theory relating to heat, temperature and heat transfer. Heat is a form of kinetic energy resulting from the movement of atoms and molecules in a substance, as illustrated in **Figure 9.2**.

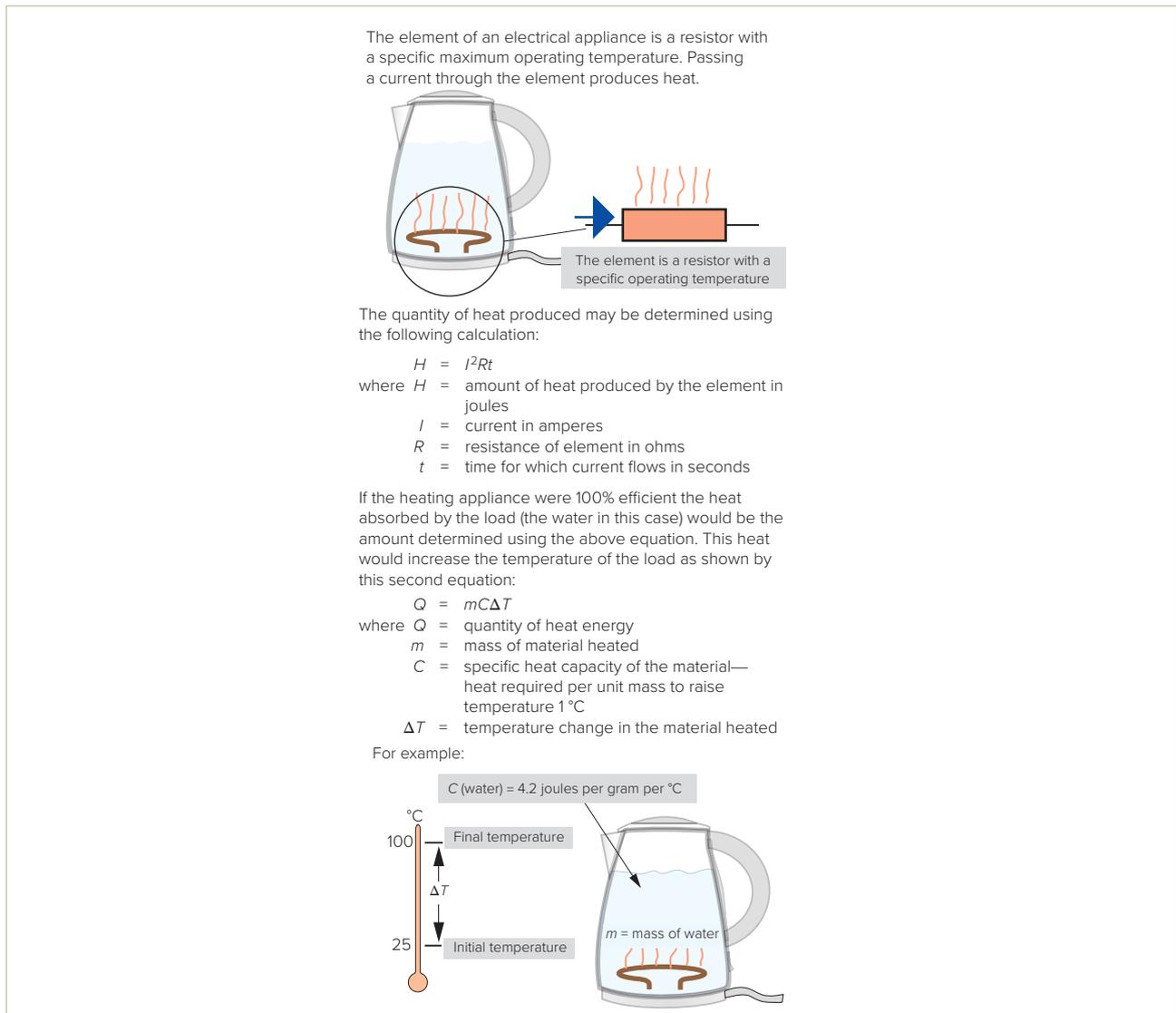


FIGURE 9.2 Heat

Temperature is illustrated in **Figure 9.3**. Heat energy transfer is illustrated in **Figure 9.4**.

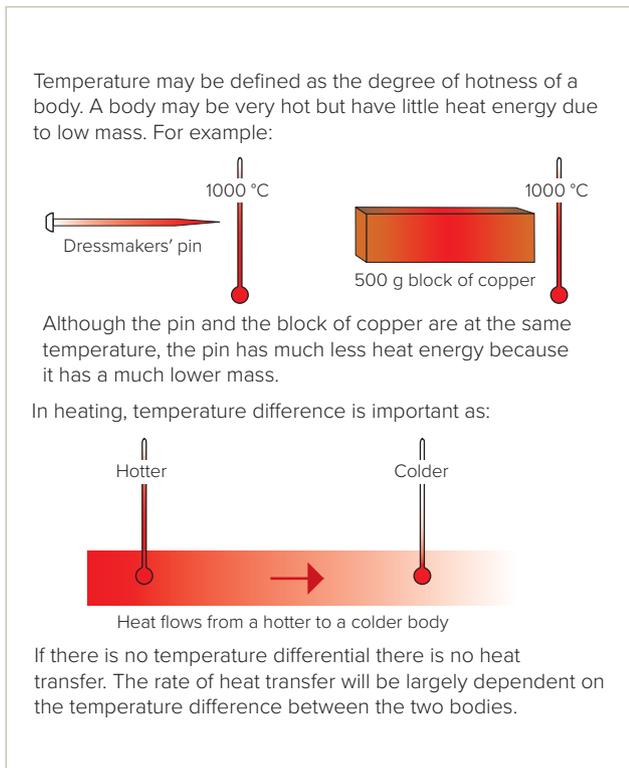
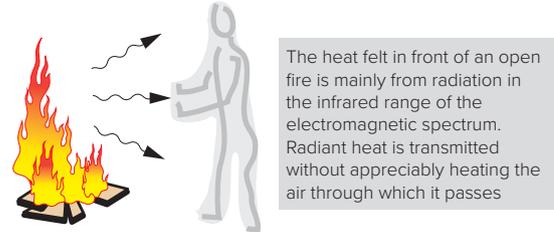


FIGURE 9.3 Temperature

Heat energy is transferred in three ways:

Radiation

Radiation is the transmission of heat energy from an object in a way that involves no material means of transfer. Heat is transferred as an electromagnetic radiation.

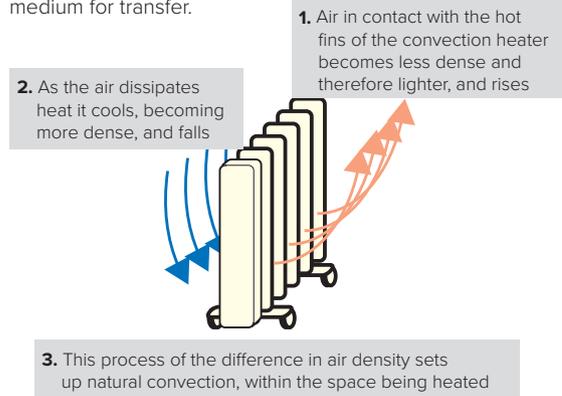


Because its transmission is in straight lines similar to light, it can be directed or focused by suitable reflectors.

A bright or polished surface reflects most of the radiant energy that falls on it, absorbing very little of that heat energy. A matt black surface is the best absorber and radiator of heat and the quantity of heat radiated rises rapidly as the temperature rises. These factors influence the design of radiant heating devices and systems.

Convection

Convection involves the transfer of heat by the circulation of a fluid; for example in space heating, air is the common medium for transfer.



If the heated air is made to move by a fan, the transfer is termed forced convection, and better heat distribution results.

Conduction

Conduction is transmission of heat directly from one body to another. Conduction is rarely used as a heating method in itself. However, it initiates heat transfer by convection.

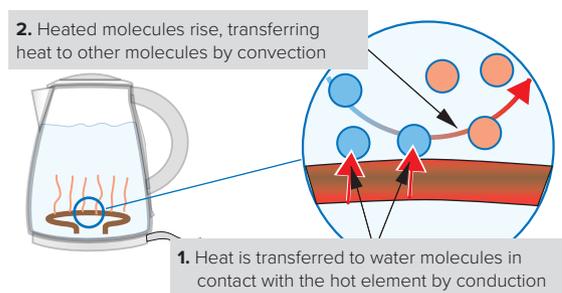


FIGURE 9.4 Heat energy transfer

9.2.2 Thermal conductivity

Thermal conductivity is illustrated in **Figure 9.5**.

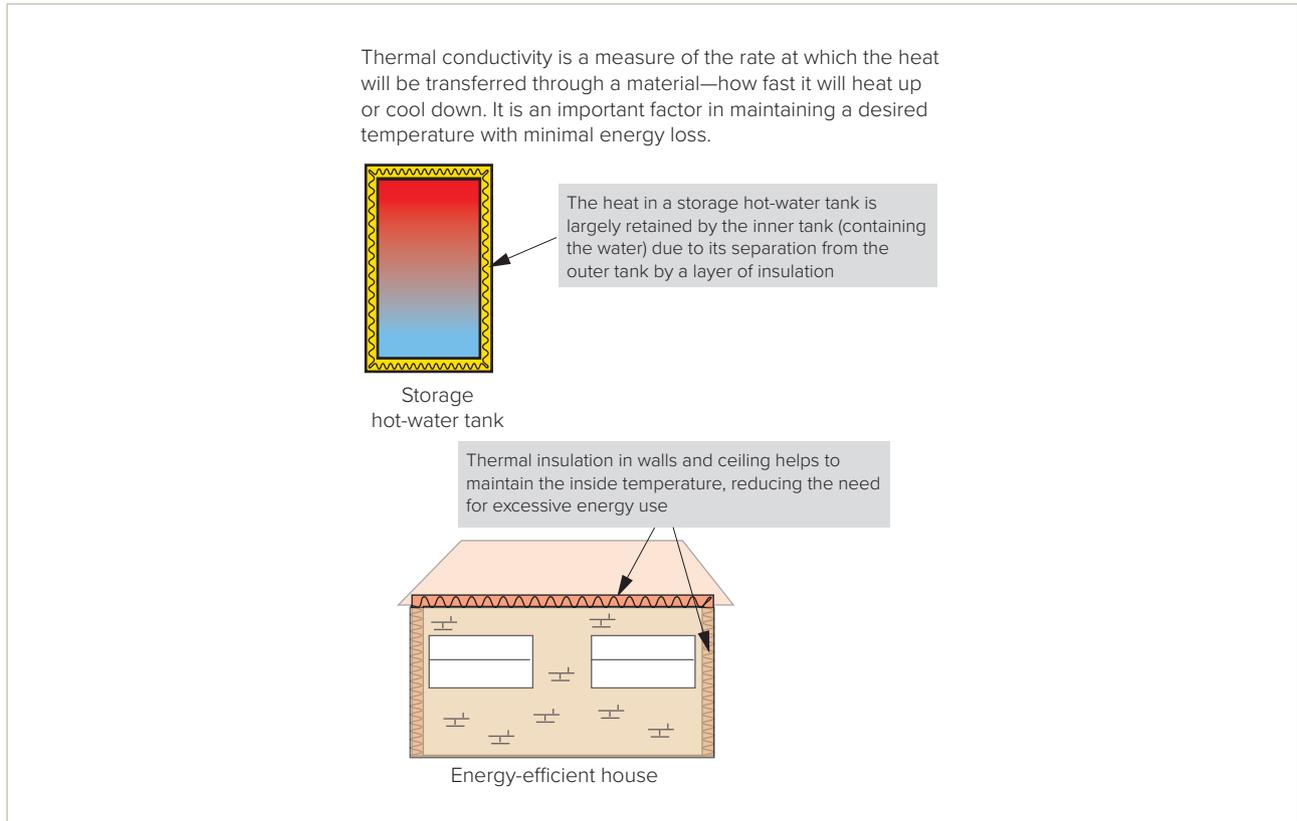


FIGURE 9.5 Thermal conductivity

9.2.3 Heating controllers

Principles of heating control devices

Most heating appliances need to have some measure of control over the temperature: for example, room temperature, oven temperature, incubator temperature and the temperature of an annealing furnace. The required control can be achieved:

- ▶ manually, by switching
- ▶ automatically, by some form of feedback or ‘averaging’ control device.

Manual control

The simplest form of manual control is the switch on a socket-outlet supplying a portable appliance such as a radiator, which is switched off when the appliance is not required. Portable heaters and small cooking appliances have multiple elements that are switched in various series and parallel configurations, as shown in **Figure 9.6**. This method provides simple levels of heat control suitable for these applications.

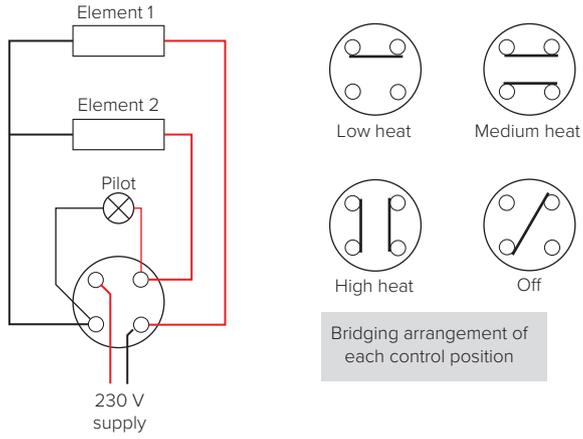
Some manual controls which are representative of the many types available are on/off and stepped-control types. Because they are manually set or controlled, control relies heavily on the judgment of the operator. However, because manual control is relatively simple and inexpensive, it is commonly used in many heating appliances. If more precise temperature control is required, automatic control devices are used.

Automatic control

Automatic temperature controls work on the principle of either switching the heating appliance on and off within a set temperature range or by proportioning the period of on/off control. Automatic temperature-control devices are

Three-heat switch

Low heat is obtained by connecting the two elements in series, medium heat by connecting one element only and high heat by connecting the two elements in parallel. The pilot light indication is bright for the high and medium switch positions but is dim in the low position.



Four-heat switch

Four-heat manual control on a convection room heater. An interesting exercise is to trace out the circuit to determine the manner in which the elements are connected, and calculate the power dissipated for each switch position.

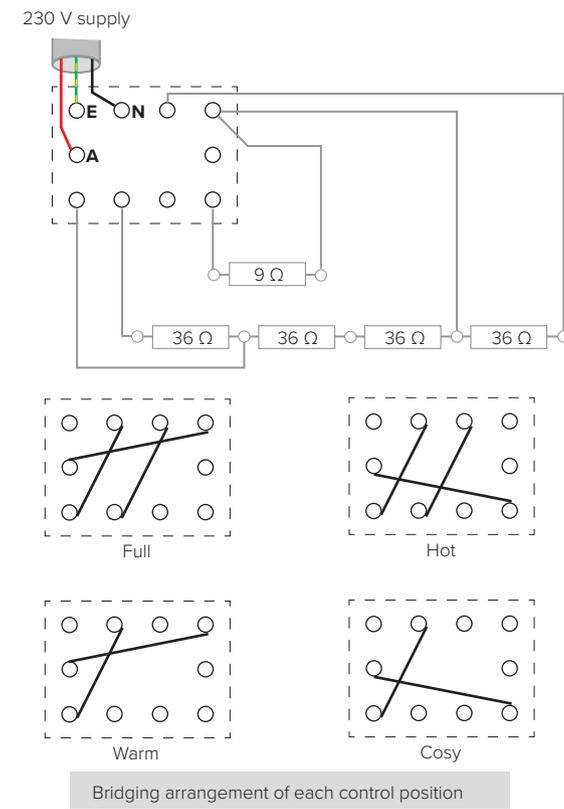
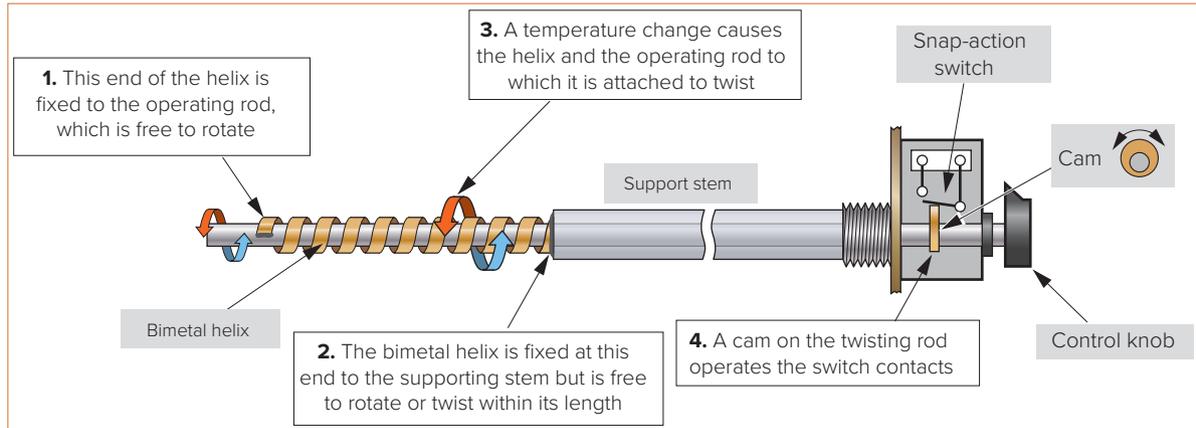


FIGURE 9.6 Manual heat level control

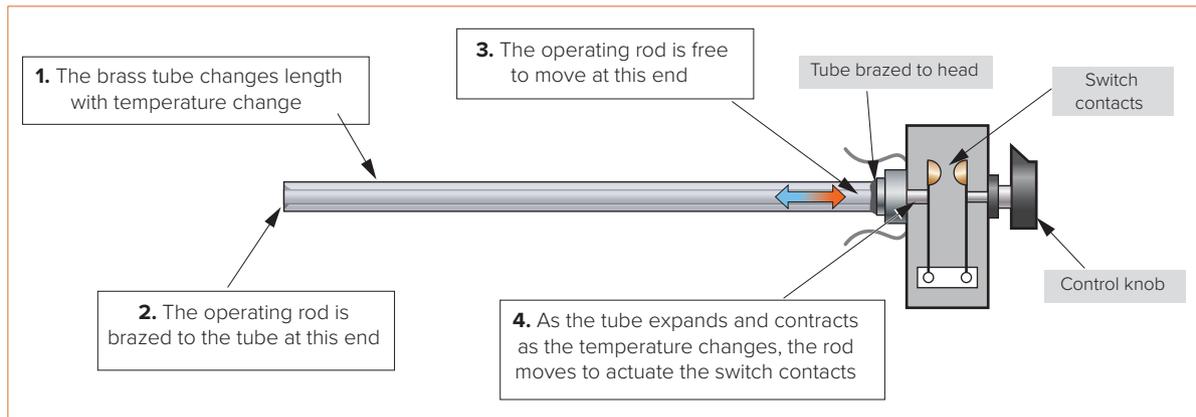
categorised by the method used to detect changes in temperature and then switch supply to a heating element or system. Examples are shown in **Figures 9.7, 9.8 and 9.9.**

Thermostats—electromechanical

Bimetal thermostat



Expanding tube thermostat



Vapour/liquid pressure thermostat

The advantage of this type is that the sensor (phial) and the control head may be some distance apart, as in an electric oven.

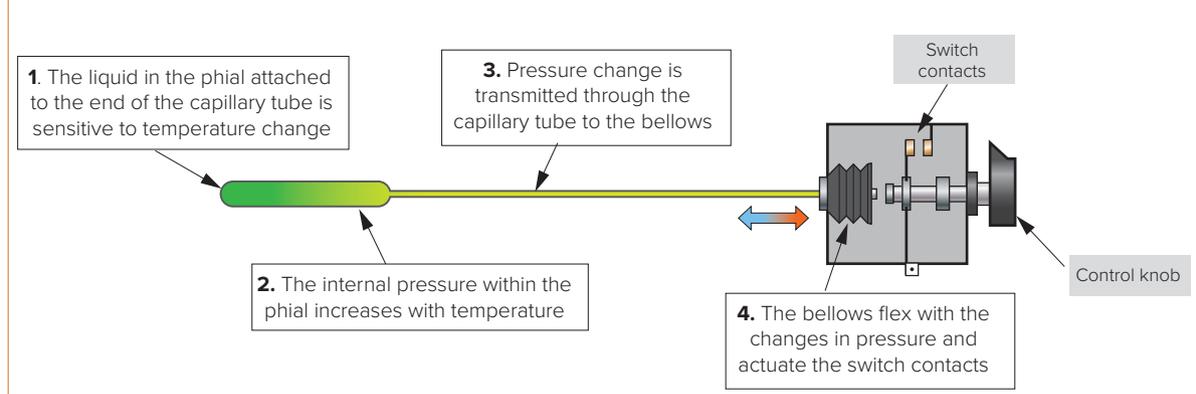
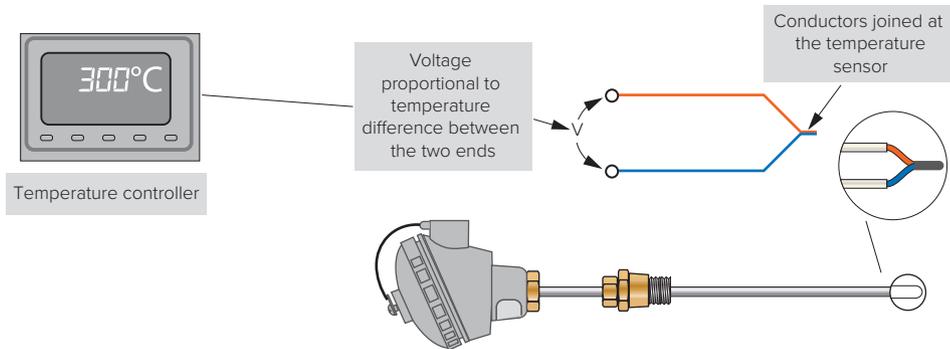


FIGURE 9.7 Thermostats—electromechanical

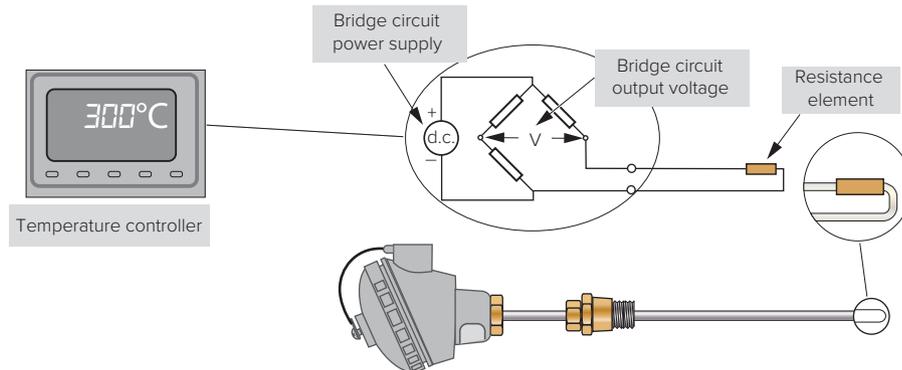
Thermostats—electronic

Thermocouples consist of two different metal alloy conductors joined at one end that produce a voltage proportional to the temperature difference between the two ends. This voltage is correlated to temperature.



Thermocouples are used in a range of industries, particularly in metal smelting where they are capable of measuring temperatures up to 2300 °C.

Resistance temperature detectors (RTDs) are used to measure temperature by correlating the resistance of the RTD element with temperature. Basically, the RTD element is connected as the variable resistance in a bridge circuit in which the output voltage is a measure of changes in resistance and therefore temperature.



Like thermocouples, RTDs are used in a variety of industries, and tend to be preferred for measurement and control of temperatures up to 600 °C.

There is a variety of thermocouples and RTDs available. The devices shown here are typical, having similar 'head' (terminal enclosures) and stems for insertion into a 'well' which is welded into a vessel or pipe at the location where temperature is to be measured.

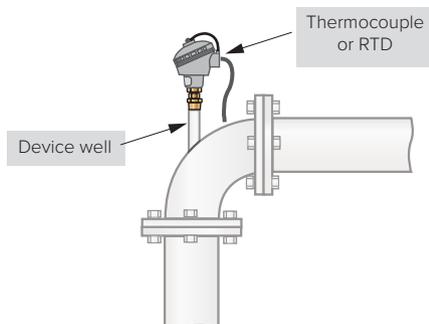


FIGURE 9.8 Thermostats—electronic

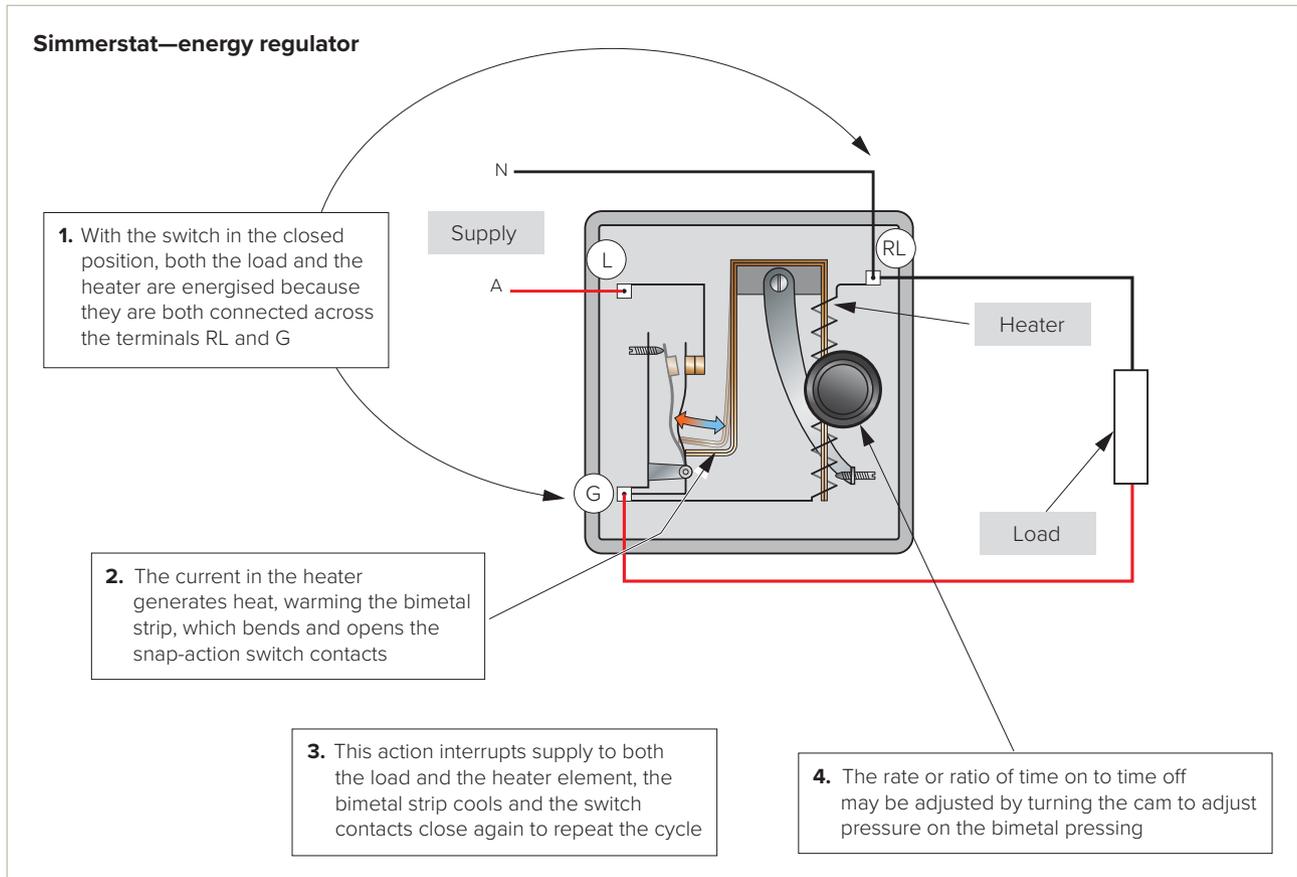


FIGURE 9.9 Simmerstat—energy regulator

There are many other controls used in association with heating. These include solenoid valves that operate to control the flow of hot water, temperature-sensing devices that operate fans for the control of hot air, and pressurestats that work on the air pressure in hot-air ducts. You may also encounter others.



CHECK YOUR UNDERSTANDING

4. What form of energy is heat?
5. Why is temperature difference important?
6. List the three methods of heat transfer.
7. What does the term *thermal conductivity* mean?
8. What are the two automatic temperature-control operating principles?

9.3 Water heating

The age-old need for hot water continues, whether it is for washing, cooking, storing heat or other processes requiring heat. Systems for producing hot water consist of one or more water heaters and the cold-water and hot-water plumbing that supplies hot water to one or a number of outlets. There are many types of water heaters, including:

- ▶ *instantaneous water heaters*, which do not store hot water but initiate the heating element when a hot-water tap is opened and the water flows

- ▶ *storage water heaters*, which hold a useful quantity of hot water in an insulated tank incorporating one or more heating elements
- ▶ *heat exchangers*, such as a calorifier, which use heat from another source to indirectly heat water; ‘waste’ heat, such as that from the exhaust of an engine-driven generator or the cooling system of a compressor, is used, thus improving overall energy efficiency.

This section focuses on systems that provide hot water for cleaning, washing, cooking and other direct uses. Before continuing, you should be aware of the risk of scalding and burns in the direct use of hot water, and the safety measures to protect persons from such risks.

9.3.1 Hot-water delivery temperatures

Regulations require hot water to be stored at a minimum of 60 °C to inhibit the growth of *legionella* bacteria. However, there is a high risk of severe scalding by water at this temperature and above, particularly for children and the elderly.



It is *not* acceptable to turn down the thermostat of a hot-water storage heater in order to limit the maximum delivery temperature, as this can lead to the growth of *legionella* bacteria.

The maximum hot-water delivery temperature applies to hot-water outlets in areas where people wash, such as bathrooms, showers and washrooms, and must not exceed:

- ▶ 45 °C for early childhood centres, schools, aged care homes and similar facilities
- ▶ 50 °C in all other facilities.

Compliance with these delivery-temperature limits is optional for kitchen sinks and laundry tubs. The requirements for hot-water temperatures and controls are contained in the relevant parts of the *Plumbing Code of Australia* (PCA) and the Standards series *AS/NZS 3500*, and are mandated in regulations.

The maximum delivery temperature is achieved by the use of a thermostatic mixing valve wherever constant and accurate delivery temperature, such as in an aged care home, is required. In other situations, a tempering valve is used. The valves are installed in the hot-water delivery line (obviously by a licensed plumber) in various arrangements that maximise energy efficiency and safety.

Delivery temperatures from instantaneous hot-water systems, whether gas or electric, are controlled electronically by built-in flow components and remote temperature-setting capabilities.

Tariffs for heating appliances

Under time-of-use pricing schedules distributors provide energy to hot-water systems and other suitable heating loads at three basic rates:

- ▶ *Off-peak rate 1* is commonly applicable to storage water heaters, thermal storage space heaters, underfloor heaters, pool heating and similar; under this rate, hot-water delivery is at not less than a specified rate.
- ▶ *Off-peak rate 2* is applicable to water heaters fitted with interlocked booster elements (i.e. non-simultaneous operation of the two elements) and other heating appliances under conditions set by the distributor. Conditions for off-peak rates include a minimum tank size and element rating for hot-water storage, such as 250 litre/4.8 kW; other eligible appliances must meet a specified aggregate power rating such as 3 kW.
- ▶ *The continuous rate* or *normal tariff* applies to all instantaneous-type heaters, small-capacity (continuous) storage units and larger storage units where the demand is intermittent and where it is impractical (e.g. due to a very cold climate) or uneconomical to store sufficient water for 24-hour demand.

9.3.2 Types of water heaters

Instantaneous water heaters

Instantaneous (electric) water heaters are switched on only when hot water is required. The water is heated as it passes through the heater, which is generally not on for extended periods. These heaters are usually arranged for supply at normal tariff rates.

Instantaneous water heaters are generally available as single-phase, two-phase and three-phase units. The single- and two-phase heaters are designed for single-outlet use, with wall mounting and above- and under-sink mounting options. Typical ratings range from 3.3 to 5 kW for single phase and up to 11 kW for two phase. The smaller units are popular in transportable homes, such as mobile homes and caravans. Three-phase units that are suitable for a single-bathroom small apartment are typically rated at 12 kW or 17.5 A per phase. Larger three-phase instantaneous heaters can be rated up to 27 kW or 39 A per phase.

Instantaneous electric water heaters are a viable alternative where there is little space for hot-water storage tanks and where other energy sources are not conveniently available. They have the advantages of limiting water waste and energy loss, as the unit only draws power when the water flows. However, they have a lower flow rate than storage mains pressure units and, because of the high demand on the supply system and the necessity for some to have a three-phase supply, an energy distributor may discourage their installation, preferring the installation of off-peak storage systems.

The major components of instantaneous electric water heaters are given in **Figure 9.10**. Note that instantaneous gas water heaters require an electrical supply, usually a socket-outlet, for their control system.

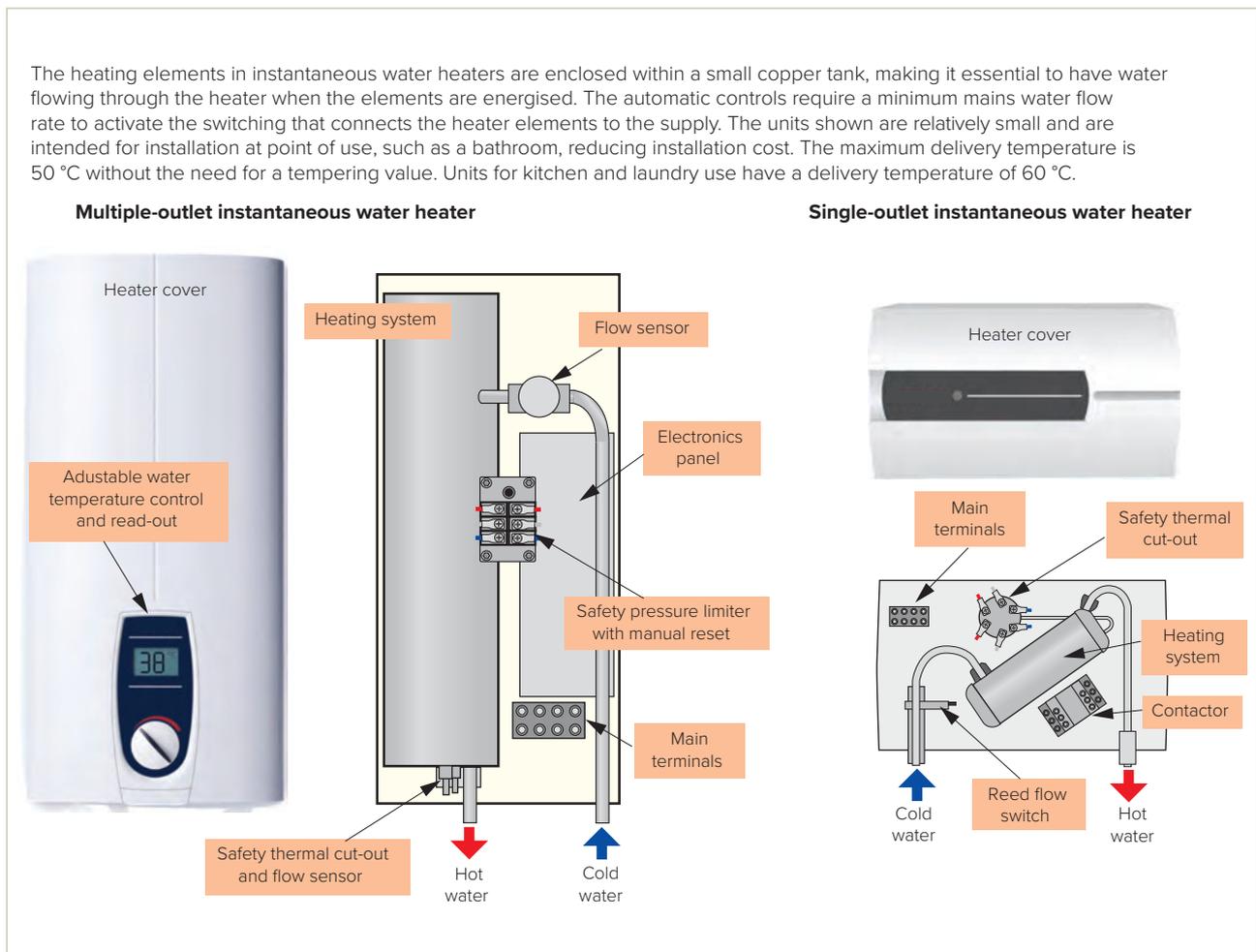


FIGURE 9.10 Examples of instantaneous electric water heaters

Storage water heaters

Storage water heaters come in various formats but have a number of common features: an inner tank that holds the water and the element, which may be either bare or sheathed; a layer of insulation surrounding the inner tank to minimise losses; and an outer metal casing, as shown in **Figure 9.11**.

Storage water heaters are commonly unvented—that is, they are not open to the atmosphere—and they deliver hot water at mains pressure. Older hot-water systems of the vented type, mostly installed in the 1950s to 1970s, rely on gravity for hot-water delivery pressure. These units are reaching the end of their lives and are being replaced mostly by unvented storage systems. **Figure 9.12** shows how the vented system works. A vented cold-water feed tank installed in an elevated position, such as in a ceiling space, is often used to increase delivery pressure to the hot-water storage tank when the normal mains pressure is low.

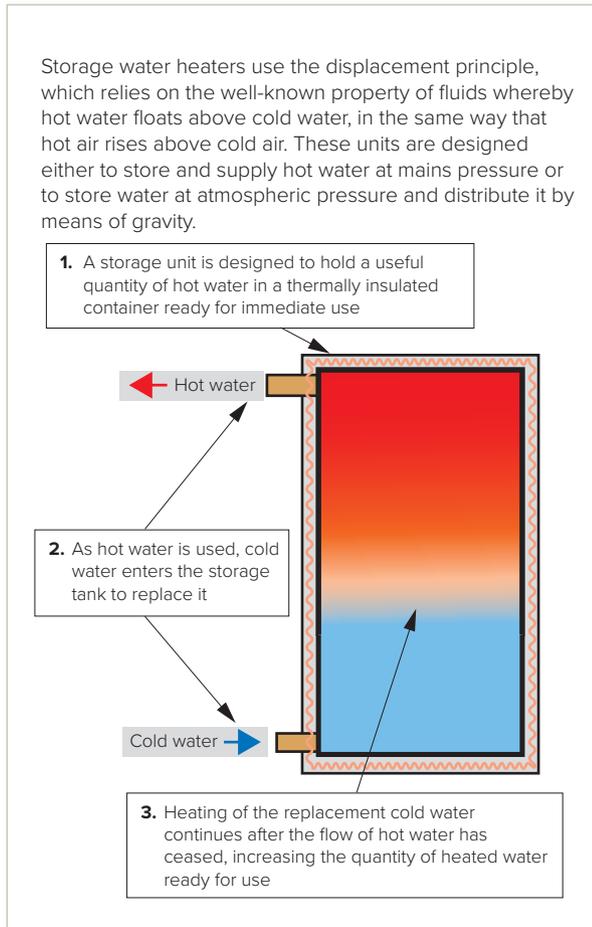


FIGURE 9.11 How storage water heaters work

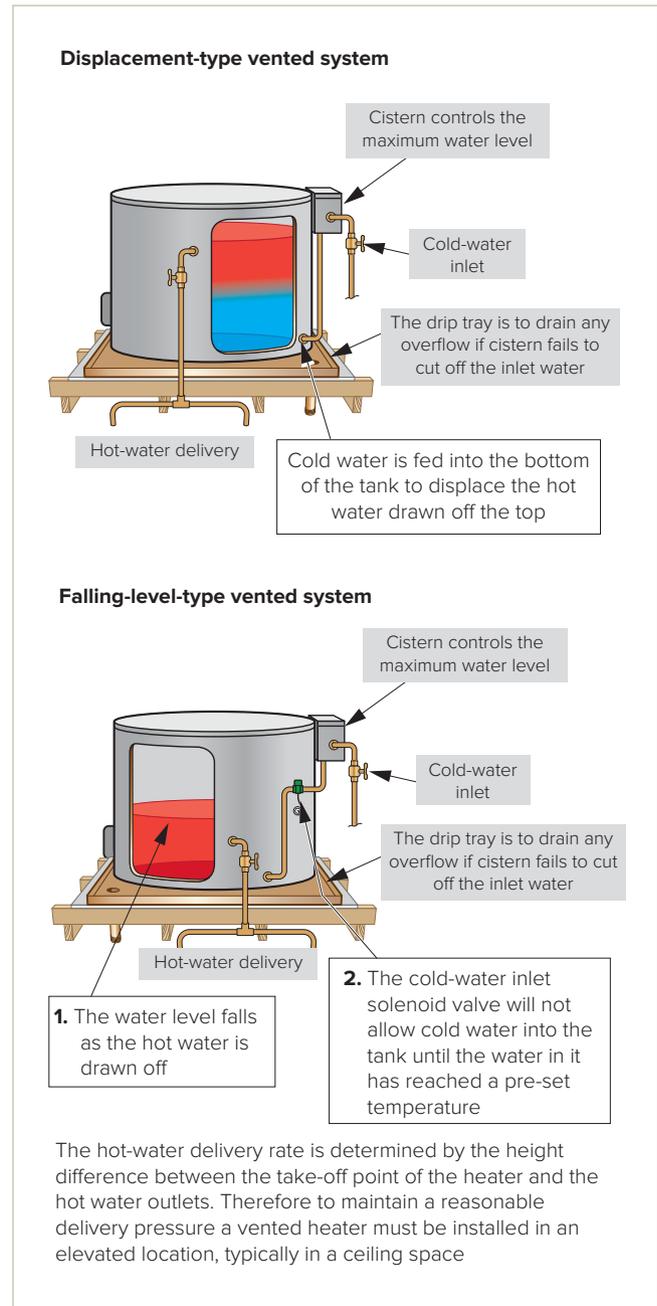


FIGURE 9.12 How vented storage hot-water systems work

The unvented electric storage hot-water system, more commonly referred to as a mains pressure system, is available in tank sizes from 25 to 400 litres, with power ratings of 3.6 and 4.8 kW. The off-peak rate is only available for units with a minimum storage capacity specified by the distributor, for example, 250 litres. Where there is a need for large amounts of hot water, such as for a large family, the larger capacity unit with a second booster element, similar to the one illustrated in **Figure 9.13**, is recommended.

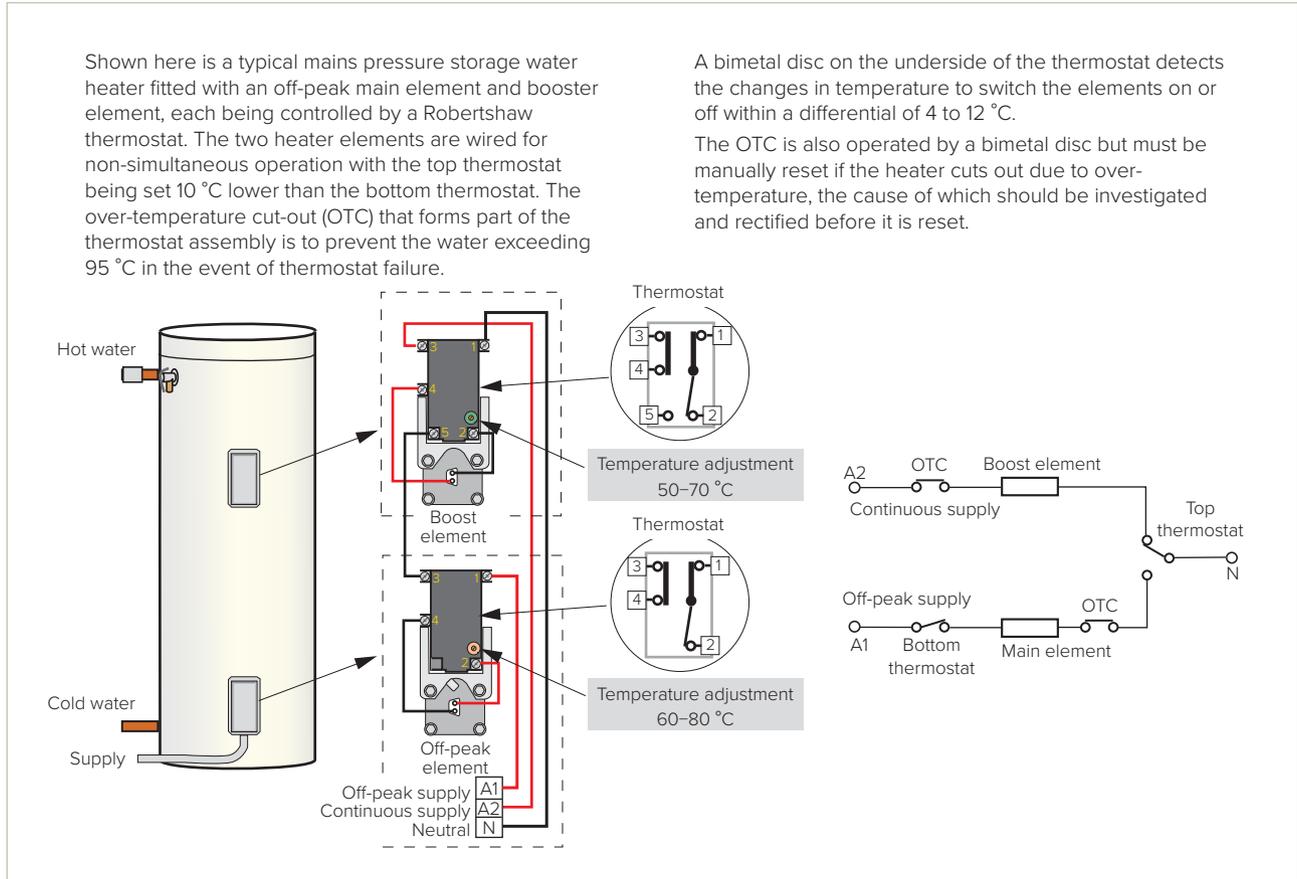


FIGURE 9.13 Mains pressure hot-water storage heater with booster element

Small-capacity storage heaters, of 80 litres or less, are referred to as continuous water heaters. They are in circuit continuously, as their name implies. Like the instantaneous type of water heater, they are supplied on normal tariffs.

The fitting of an OTC (overtemperature cut-out) is compulsory on all unvented storage hot-water heaters, as is the inclusion of a pressure relief valve in the hot-water outlet pipe. This valve opens when the pressure inside the tank increases beyond a pre-set value if the thermostat and OTC fail to open supply as the water approaches boiling point. **Figure 9.14** demonstrates the result of OTC failure.

The relief valve should be hand operated to release water through its outlet pipe at least twice a year to ensure it is not blocked in any way. A typical relief valve on systems with more than 180-litre capacity is set to operate if water pressure exceeds 1000 kPa.

Where mains water pressure is too high, a pressure-reduction valve should be fitted into the water inlet by a plumber. It is normal for some hot water to be released during the latter part of the water-heating cycle due to heat expansion, but if leakage persists, either the inlet water pressure is too high or the relief valve is faulty. In some jurisdictions, a cold-water expansion valve is fitted to the cold-water inlet and set to drip continually during the heating cycle.

As unvented systems operate at mains pressure, this type of heater has no need for the effect of gravity and therefore is most commonly installed at floor level. In small storage systems, the unit is located at the hot-water outlet to be supplied (in the kitchen sink or bath). In larger multi-point systems, the location should be as close as practicable to the outlet most often used. In a domestic installation, this is usually the kitchen sink.

The boiling point of water increases as the pressure increases and if the current is maintained to the element when it should have been shut off, the water reaches well beyond 100 °C. If the tank ruptures due to increased pressure, the water turns to steam as it is now at atmospheric pressure and boils at 100 °C. The resultant steam occupies much greater volume than the water, causing an explosion.

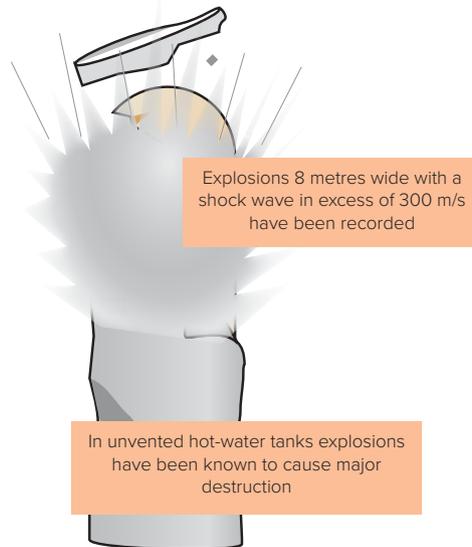


FIGURE 9.14 OTC failure

The storage hot-water systems discussed above are all used in domestic and other situations, the type used depending on the particular hot-water requirements. Common sizes used in domestic installations are 50, 80, 125, 160, 250, 315 and 400 litres. For controlled-load (off-peak) hot water, 250, 315 and 400 litre models are generally used. Mains pressure storage heaters are not manufactured above 400 litres in size, so in many commercial and industrial applications, where large quantities of hot water are used, multiple storage tanks are common.

A six-element 400-litre heater is manufactured for applications where there is high demand for hot water. Elements for this heater are normally rated at 6×3.6 , 6×4.8 or 6×6.0 kW each and arranged for star connection to a 400 V three-phase supply (see **Figure 9.15**).

9.3.3 Water heating from renewable sources

Governments in Australia and New Zealand have in recent years introduced financial incentives to encourage the use of renewable energy, as part of their efforts to lower greenhouse gas emissions and reduce the effects of climate change. This has resulted in large increases in the number of solar and heat pump hot-water systems installed. To appreciate the electrical aspects of these systems, it is necessary to understand the basic principles of how they work.

Solar systems

In solar hot-water systems, energy that radiates from the sun is captured in solar collectors and heat is transferred to the water. These collectors work best when exposed to direct sunshine, although radiation scattered through clouds and

A six-element 400 litre heater is manufactured for applications where there is high demand for hot water. Elements for this heater are normally rated at 6×3.6 , 6×4.8 or 6×6.0 kW each.

Note the star arrangement with two elements in parallel on each phase creating a balanced load, and there is no neutral current. Should an open circuit occur in any element the load will no longer be balanced and the neutral current will rise.

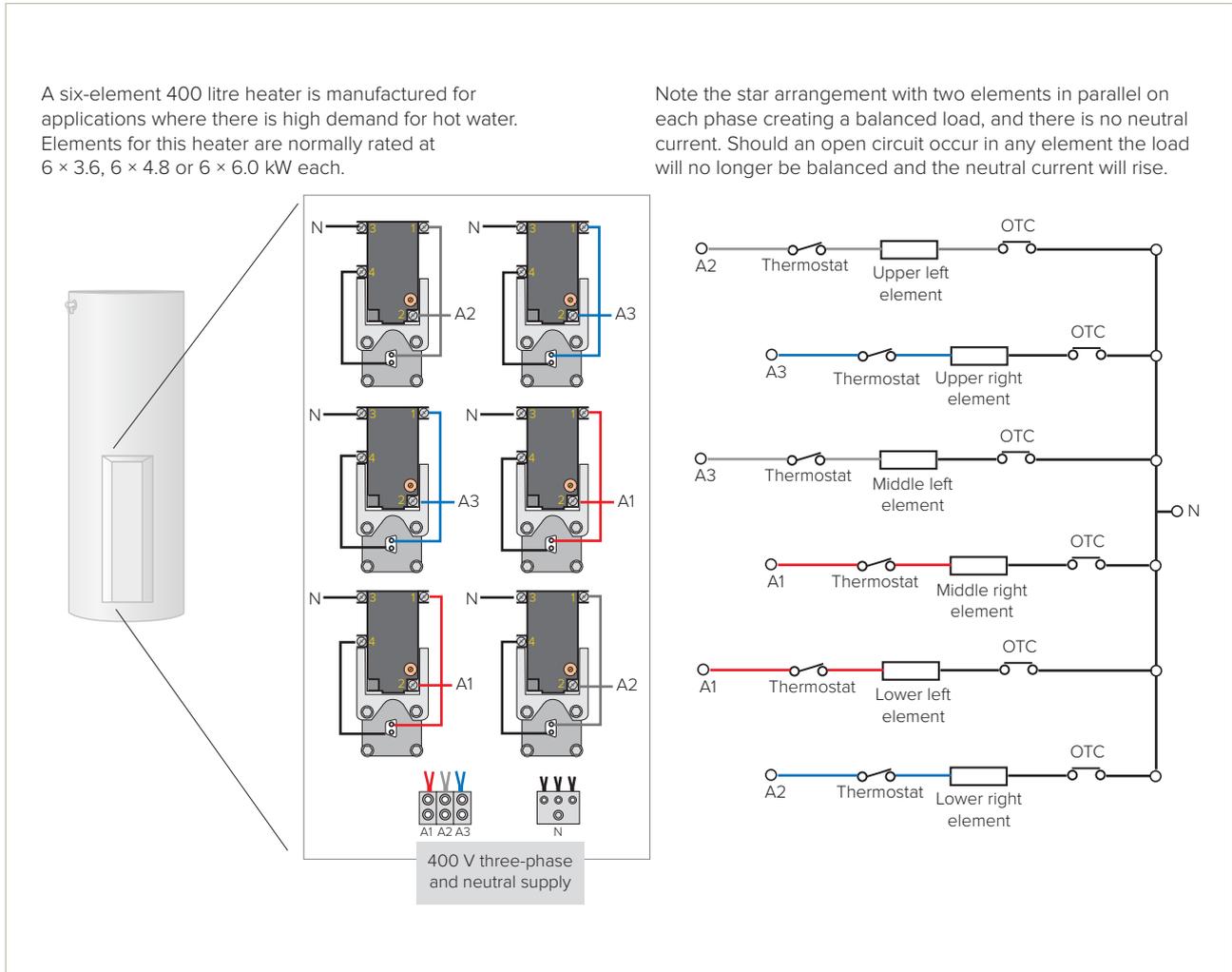


FIGURE 9.15 Example of a mains pressure storage heater bank

reflected off other surfaces is also captured. Depending on the latitude, useful solar energy is available in summer for between five and eight hours per day. When solar energy is not available (at night) or is not sufficient (on a cloudy day), an electric booster is used to maintain water temperature.

Most hot-water solar collectors are of the flat plate or evacuated tube type, varying mainly in the systems by which solar energy is captured and transferred to the water. The two systems for transferring energy to the water are:

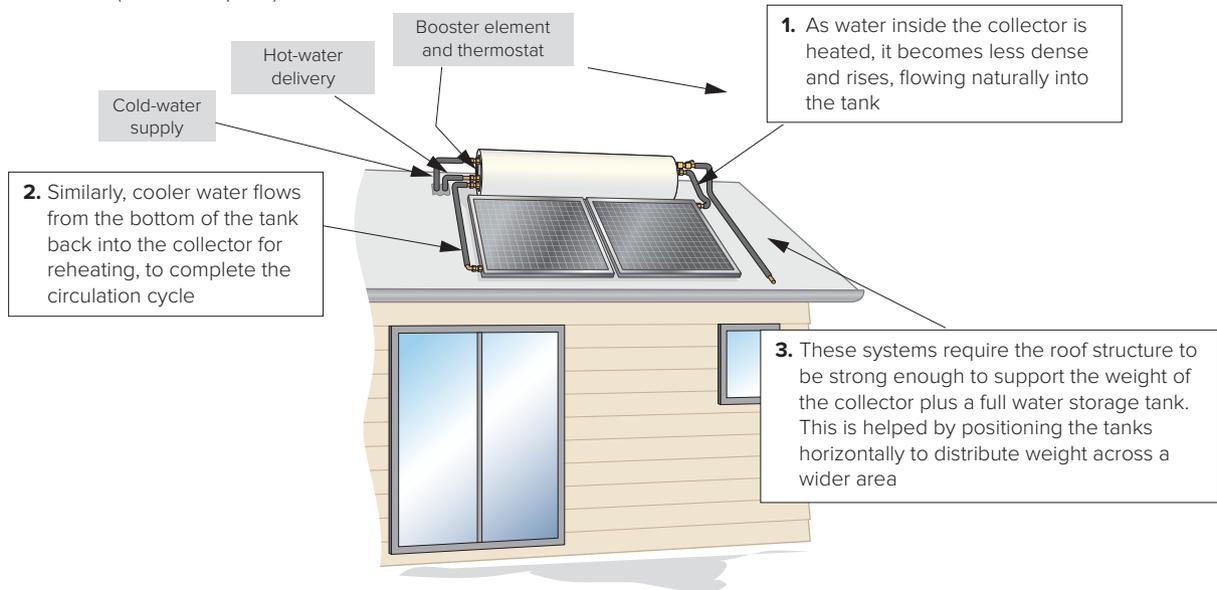
- ▶ the open-circuit system, which heats potable water directly through the collector; while typically lower in purchase cost, they cannot be used where freezing is a problem over sustained periods
- ▶ the closed-circuit system, which circulates an anti-freeze fluid through the solar collectors and then through heat exchangers which transfer the heat to stored water; these systems are suitable where freezing occurs over sustained periods.

The main components of solar hot-water systems—the collectors and storage tank—are installed as either a close coupled system or a split system, as shown in **Figure 9.16**.

A booster element is fitted to a solar hot-water system to provide an alternative source of energy when insufficient solar energy is available. Leaving the booster element on indefinitely would nullify the benefit of solar heating. A suitably rated timer control switch can be installed, which will help maximise energy savings with an electrically boosted connection to a continuous, time-of-use or extended off-peak (overnight and day) electricity supply. The circuit arrangement is shown in **Figure 9.17**.

Close coupled solar hot-water system

In these systems, where the tank is positioned above the collectors, water is moved through the system by natural convection (or thermosiphon).



Split solar hot-water system

These systems are used when it is impractical or aesthetically unacceptable to place storage tanks on the roof of a building. Since the collectors in this system are at the highest point, a small circulator pump is used to keep cold water or fluid moving up and forcing hot water or fluid down the piping. The circulator is typically controlled by a differential controller that operates the circulator whenever the temperature in the collectors exceeds the ambient water temperature by approximately 8 °C.

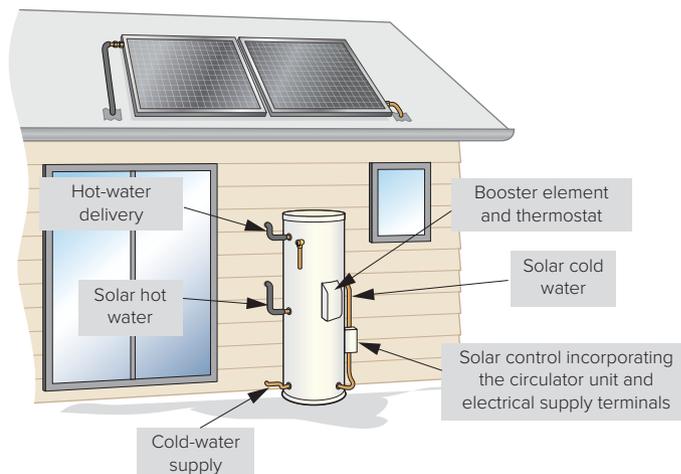


FIGURE 9.16 Solar water heater systems

Heat pump systems

In these hot-water systems, heat pumps transfer heat from one area to another and, since they do not produce this heat energy, they are capable of greater energy input to the stored water than the energy required to do the pumping. Heat pumps in hot-water systems collect solar energy from the heat of the ambient atmosphere and transfer it to the water. While not needing sunny conditions, they are not effective at temperatures below 5 °C. These systems may be either of a compact construction design or split as in other systems. An example is shown in **Figure 9.18**.

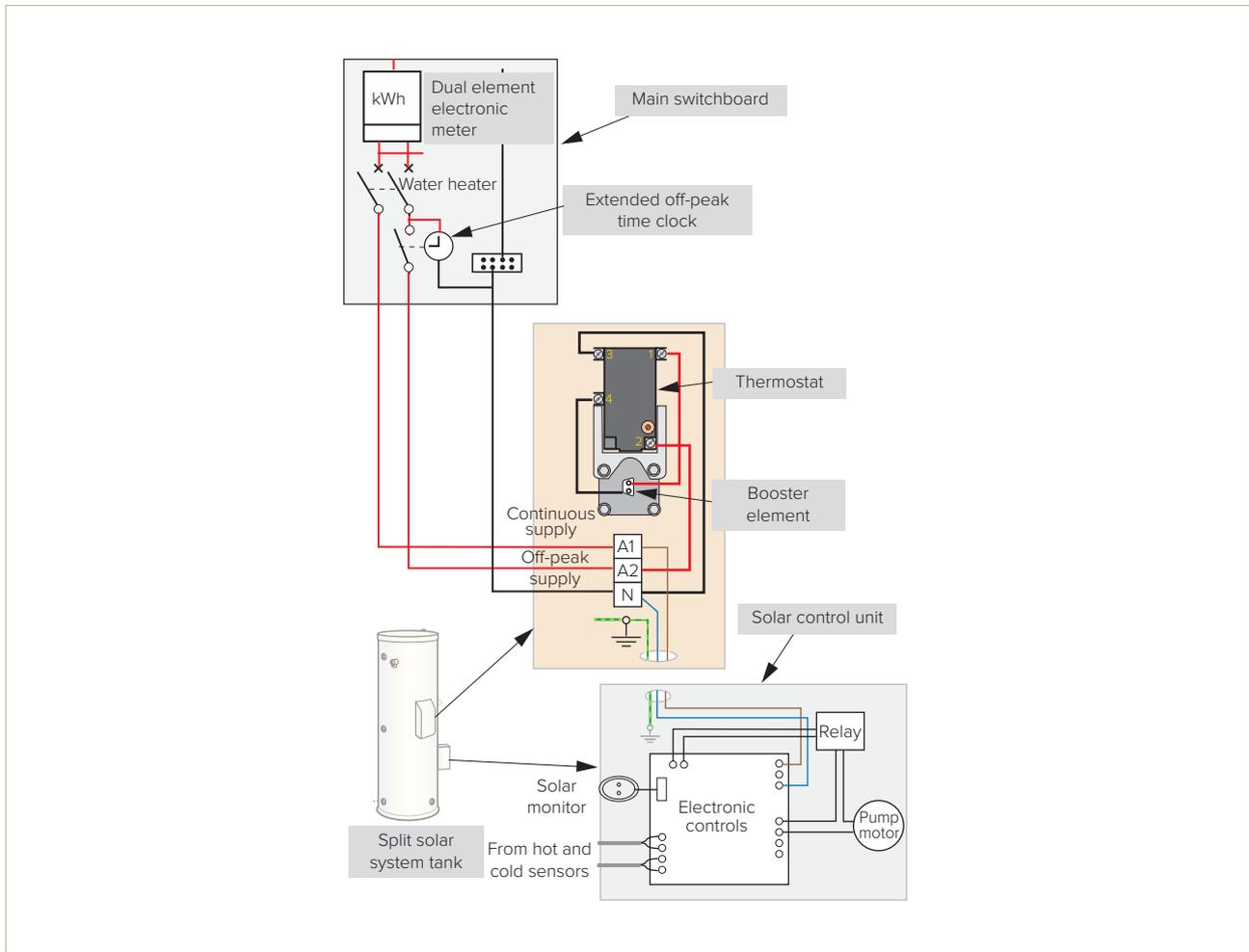


FIGURE 9.17 Example of circuit arrangements for a split solar hot-water system

An advantage of this type of system over the conventional solar water heater is that it can operate with or without sunshine; the collectors absorb heat under practically any weather conditions and even at night. Some power is, of course, used by the compressor motor (typically 300 to 700 W). The manufacturers claim that a booster element is not normally required. In common with other solar water heaters, the initial cost is considerably higher than for off-peak storage systems.



SAFETY ALERT

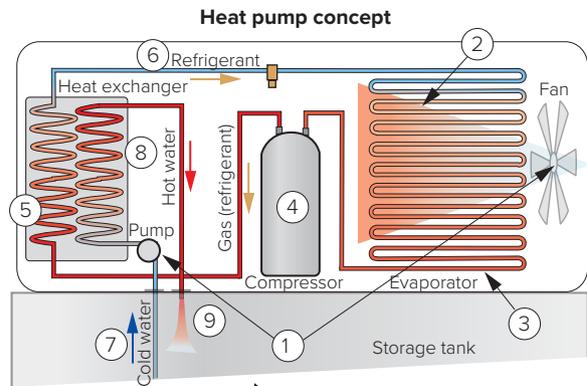
Isolate and lock out *all* supplies to the equipment to be worked on. Equipment connected to an off-peak control device should be expected to become live at any time, regardless of the time of day. Not applying this safety measure has resulted in a number of fatalities in the past.

Heat pump cycle

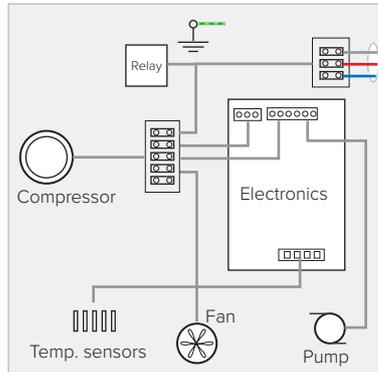
1. When hot water is required, the heat pump compressor and fan are started.
2. Ambient air is drawn over the evaporator by the fan and heat from the air is transferred to the refrigerant.
3. The refrigerant boils and changes phase to a gas which generates heat.
4. The refrigerant pressure and temperature is raised in the compressor.
5. The gas passes through a heat exchanger where the heat is transferred to the water.
6. As the refrigerant loses heat, it returns to a liquid and the process starts again.

Water-heating cycle

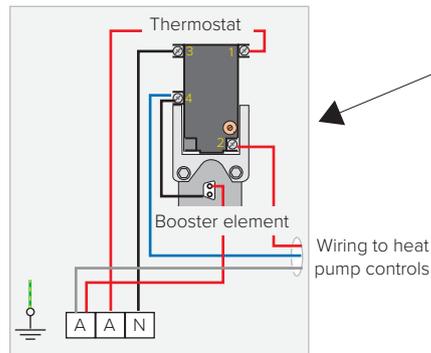
7. Cold water is drawn from the bottom of the storage cylinder via a pump and riser tube to the heat exchanger located in the heat pump module.
8. Heat is transferred from the hot refrigerant gas to the water and returned to the top of the storage cylinder.
9. The process continues from the top down until the contents of the tank are heated to the required temperature.



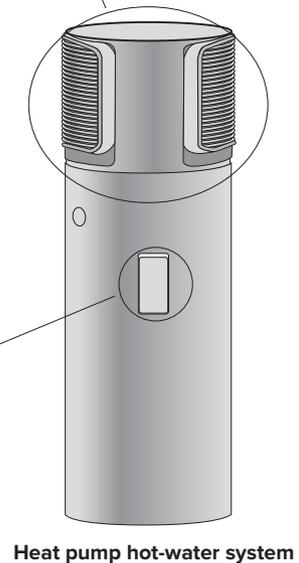
Clause 4.19 stipulates particular isolation arrangements for heat pump systems incorporating a compressor and split system air-conditioning units.



Basic arrangement of heat pump controls



Wiring to heat pump controls



Heat pump hot-water system

Booster heater

The heat pump will operate when the ambient air temperature is between a minimum of 3 °C to 5 °C and a maximum of 45 °C to 55 °C, even on cloudy days. The booster heating unit will operate when the ambient air temperature is outside this temperature range, if heating is required. The efficiency of the water heater increases as the surrounding ambient air temperature increases within the operating range of the heat pump.

When ambient temperatures approach zero, depending on the humidity, the water vapour in the air exiting the heat pump will begin to freeze, eventually blocking the evaporator surface and rendering the heat pump ineffective. When this condition is sensed, the heat pump is switched off and the booster element is energised to ensure sufficient hot water is available for consumption.

FIGURE 9.18 Heat pump hot-water systems and controls



CHECK YOUR UNDERSTANDING

9. What are the three common types of water heaters?
10. Why must hot water be stored above 60 °C?
11. What are the two safety devices included in sealed hot-water units?
12. What are the two types of solar hot-water systems?
13. What are the advantages of using a heat pump system over solar heating?

9.4 Heating systems

The term *heating system* describes a method of heating of space inside a building to provide a comfortable and healthy environment for people, and a satisfactory temperature for goods and equipment. Personal comfort depends on factors other than temperature, including air flow, pollution and humidity; however, as the name implies, space-heating equipment provides only heat.

Heating a space is usually achieved by radiation or convection and in most cases some combination of both, as explained in **Subsection 9.2.3**. Regardless of the energy source, heating systems and appliances have similar design features. While the focus here is on electrical heating, systems using other energy sources will have some electrical components for control, circulation or the like.

9.4.1 Types and applications

Heating systems and devices may be broadly classified into three main groups:

- ▶ portable heaters for heating persons or small rooms
- ▶ space heaters for heating large rooms and open-plan indoor areas
- ▶ central heating systems for heating a number of rooms.

Portable and fixed-space heaters

The most common portable heaters are radiant heaters, although the portable oil-column convection heater is also a popular choice. Portable heaters are relatively inexpensive and, while the running costs can be higher than with other systems, they are an ideal choice for people living in rented accommodation or where the cost of installing a fixed system is too high. Examples and features of portable heaters are shown in **Figure 9.19**.

Most space heaters are a radiant type but the heat is absorbed by solid bodies, such as hard furniture and flooring. This heat is transmitted to the air, initially by conduction and convection as the heated air rises. Space heaters, like portable heaters, are essentially used for comfort heating, whether in a domestic setting, at work or in places of leisure. The features of some of these are outlined in **Figures 9.20 to 9.22**.

Central air-conditioning systems

Ducted heating systems alone are not used in Australia to the same extent as in colder climates. Most large commercial buildings, however, have central plant ducted air-conditioning systems that provide either heated or cooled air (relative to the outside air temperature) to different areas of a building. They are designed to maintain an even pre-set temperature throughout the building while coping with the movement of people in and out of the building. Maintaining air temperature and humidity within a small range is an imperative in some manufacturing and commercial facilities, such as the server halls of data centres. Rather than using reverse-cycle methods, the trend in modern large central plant systems is to use waste heat for space heating and generation of electricity in a process known as co-generation. The basic concept of central plant systems is illustrated in **Figure 9.23**.

Radiant heater with infrared elements

This 2.4 kW heater with infrared radiant elements provides an effective mix of radiant and convection heat. The design includes stainless steel reflectors to ensure maximum heat output.



Fan-assisted radiant PTC heater

The ceramic elements in this portable heater have a positive temperature coefficient characteristic, meaning their resistance increases with temperature and thus reducing the load current. This makes them self-regulating to an extent and more efficient than conventional radiant heaters.

Available with a rating up to 2.4 kW, the design incorporates a fan and avoids the products of burnt dust particles, making the heater highly effective for those with respiratory illnesses or allergies.

LED display, touch control panel and electronic timer



Dry column convection heater



This column heater incorporates the patented element technology that results in greater heat output and a warm-up time up to eight times faster than traditional oil-filled column heaters.

Available with ratings from 1.5 kW to 2.4 kW, each with two heat settings, thermostatic control and electronic timer.

This type of heater has been shown to be more efficient than standard oil-filled column heaters.

Oil column convection heater

The common oil-filled column heaters range from 1.2 kW to 2.4 kW models, offering comfort for small to large rooms. The larger units include a fan to assist convection. All models typically incorporate a thermostatic control with overheat protection and are designed with multi-directional castors to make them easy to move from room to room.



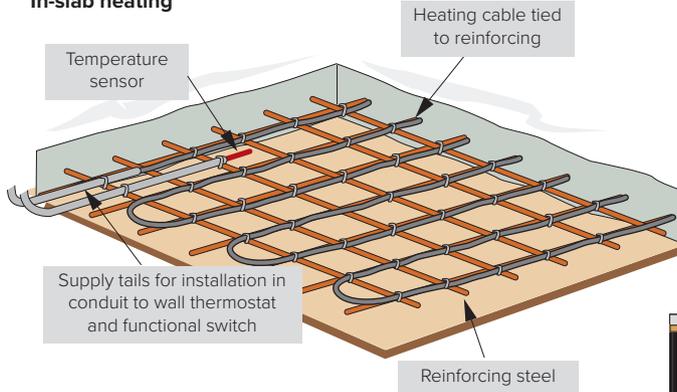
It is important to note that while equipment that bears the Regulatory Compliance Mark satisfies the relevant regulatory requirements for electrical safety, it does not necessarily satisfy the functional quality of an article.

FIGURE 9.19 Examples of portable heaters

Underfloor heating

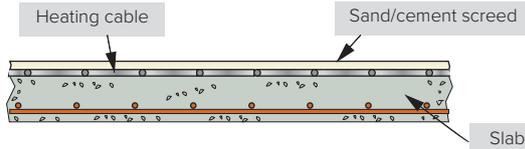
Underfloor heating provides a combination of radiant and convection heating. Heating is effected by cables designed to dissipate heat at a set rate along their length. They are available in set lengths and power outputs to suit a given area and room. The cable cannot be cut, so the required length needs to be carefully determined from manufacturers' data and recommendations. There may be differences between product brands.

In-slab heating



In-screed heating

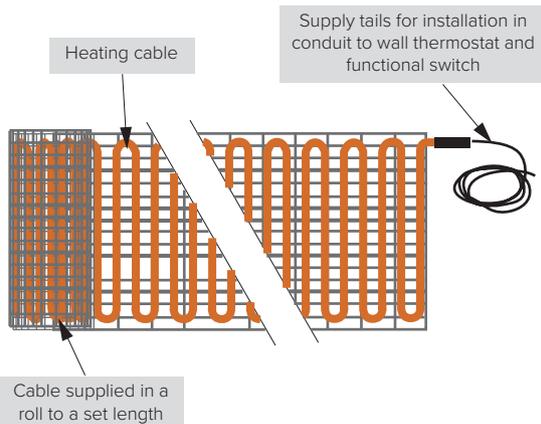
The heating cable may be laid directly on top of the slab and covered with the finishing screed.



Heating mats

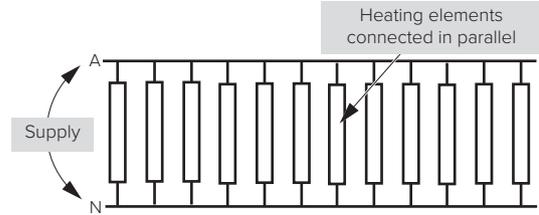
Heating mats are a heating cable bonded to a mat mesh designed for installation into thin adhesive beds, levelling compounds or thin screed beds beneath tiled floor finishes. Like the in-slab heating cables, the mats are manufactured to set lengths and power ratings and therefore cannot be cut. Again, required lengths are determined from manufacturers' data and recommendations.

Although the mat may be placed directly onto concrete floors, screed beds or fibre cement sheeting, manufacturers recommend placing floor insulation board underneath to minimise downward heat losses, improve heat-up times and reduce running costs.

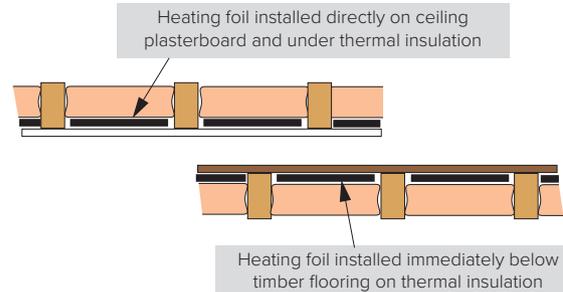
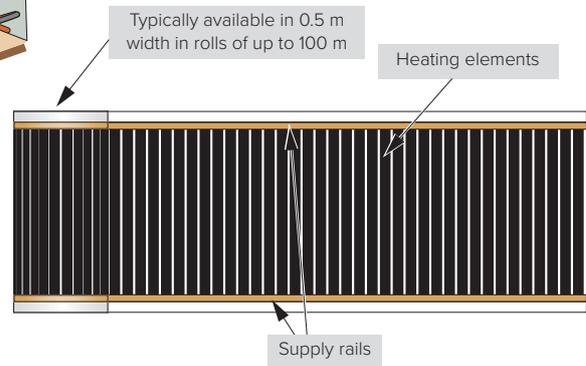


Heating foil

Heating foil is a radiant heater that consists of a thin carbon film heating element sandwiched between two layers of transparent high-temperature plastic laminate. The elements are connected in this circuit arrangement.



This circuit arrangement allows the foil to be cut to the required length without affecting the series resistance of the elements.



Radiant heating ceiling panels

The elements of radiant heating ceiling panels are sealed in metal enclosed with a white matt or satin finish. They provide localised comfort levels of heat and are particularly effective in difficult-to-heat areas. Typical applications are commercial offices, shops and store areas, commercial kennels, stables and farm buildings, industrial buildings and hospitals.

Ceiling panels vary in physical size, usually in 600 mm increments, with ratings from 300 to 3000 W

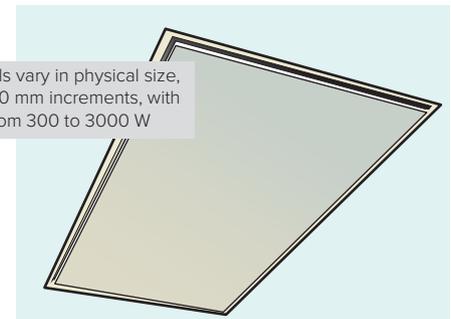
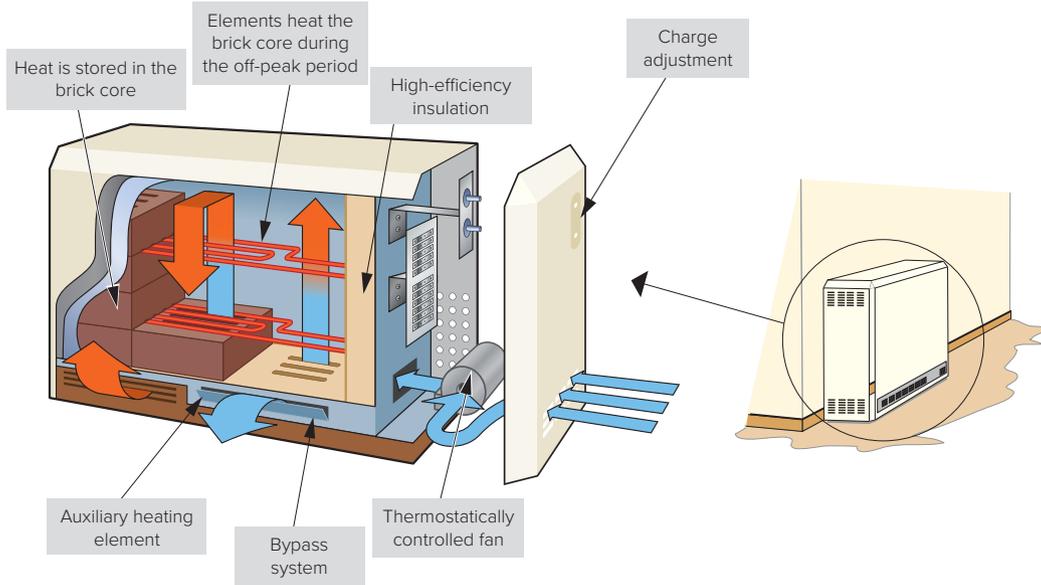


FIGURE 9.20 Types and features of underfloor and ceiling heating

This heat bank is designed to draw energy from the supply only during off-peak hours, while providing normal space heating as required at any time of the day or night. Heat is extracted by a fan, which is controlled by a room thermostat set to keep the area heated at the desired temperature.



With heat storage capacity of up to 50 kWh, this type of heater is designed to heat large areas in domestic, commercial and industrial situations. When the room is occupied and full heating is required, the slow-running fan forces air through the heater core and out into the room through a mixing damper, providing rapid uniform heat. As soon as the temperature reaches the pre-set level, the fans switch off. If needed, backup heating is provided by the auxiliary element.

FIGURE 9.21 Types and features of storage heaters

Reverse-cycle air-conditioning achieves heating and cooling by using a refrigeration system to exchange heat between the internal and the external air.

The principle of operation is similar to that of the heat pump hot-water system described in Figure 9.18. Changing the fluid to vapour and vice versa enables heat to be given out or absorbed by the fluid. Under certain conditions the heat output can be greater than the electrical input, for example 2 kW of (electrical) input energy might produce 3 kW of output (heat) energy, the extra heat being extracted from the ambient air.

The most common type of air-conditioning is the split system shown here, in which the noisy compressor unit is installed in an unobtrusive outside area. The wall-mounted indoor air delivery unit is designed to blend in with modern interiors.

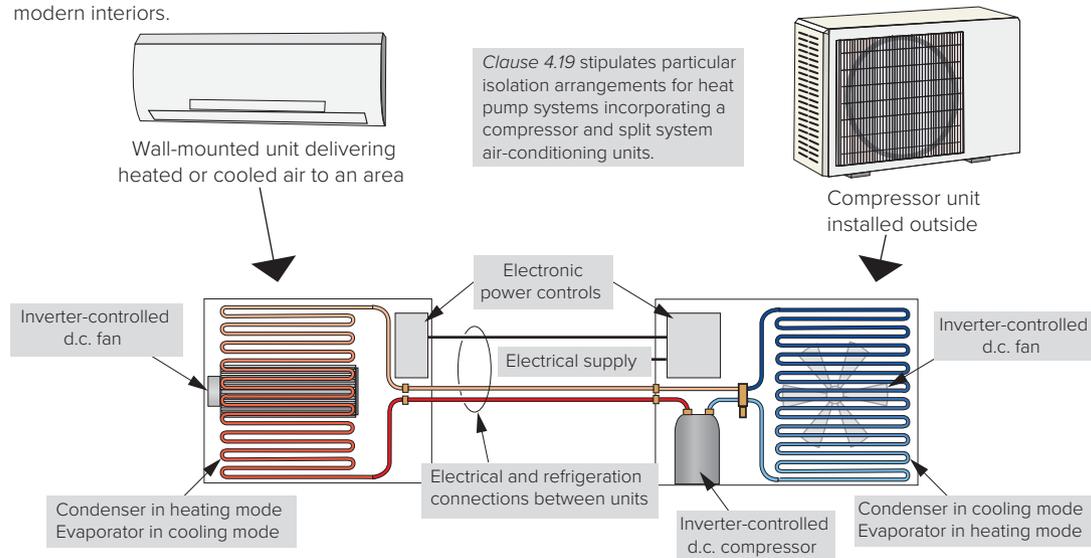


FIGURE 9.22 Features of reverse-cycle air-conditioning

The installation of electrical wiring and equipment in these plants is quite significant and complex, as the concept illustration suggests. For example, chiller compressor motors are typically rated in the hundreds of kW and use power electronic starting and control gear. To improve efficiency variable-speed drives are used for pumps and fans, with the control of the plant managed through programmable controllers. Instrumentation plays a part in monitoring temperatures and flows in the system and controlling actuators and motors.

Some electricians specialise in this work, which is a viable consideration for any apprentice in planning their career.

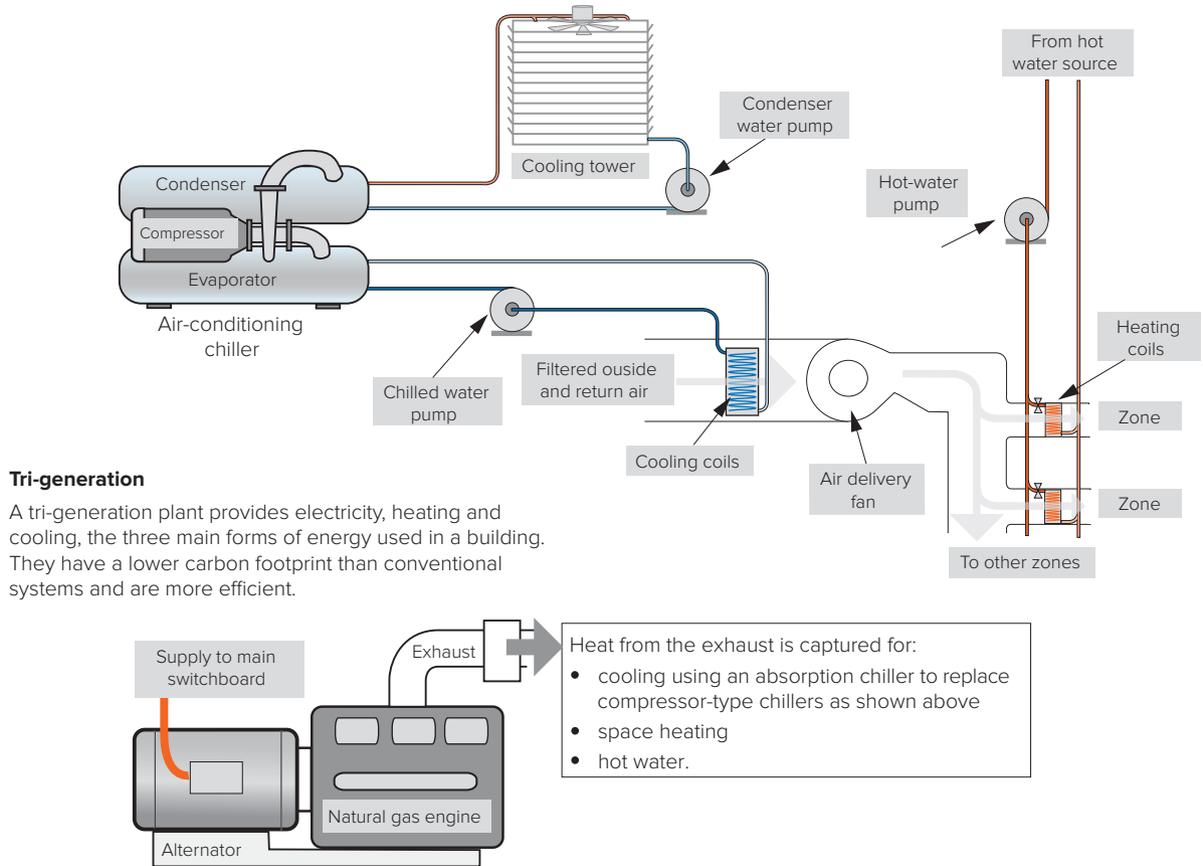


FIGURE 9.23 Central plant air-conditioning systems

Central ducted reverse-cycle air-conditioning for domestic dwellings is an extension of the split system that has become a viable alternative, particularly in new homes.

SAFETY ALERT

Air-conditioning and heat pump systems

Before carrying out any work, isolate and lock out supplies to *all* air-conditioning and heat pump units and ancillary equipment.

Wiring Rules, Clause 4.19

This clause stipulates requirements for the installation of isolating switches for air-conditioning and heat pump systems. These requirements include:

- ▶ location of switches
- ▶ extent of isolating function
- ▶ need for warning signs.



CHECK YOUR UNDERSTANDING

14. What three groups are heating systems broadly classified into?
15. What are the three types of air-conditioning systems available?
16. How is heat energy transmitted with space heaters?
17. What are some of the hard-wired heating products that can be incorporated into the building of a house?
18. Which *AS/NZS 3000* clause in *Section 4* contains requirements for air-conditioners and heat pump systems?

9.5 Process heating

The use of electrical means for producing the heat required in various manufacturing and industrial processes is widespread because it has the following advantages:

- ▶ Electrical heating is clean and makes for more conducive working conditions than other methods.
- ▶ With no open flames, the fire risk is lower.
- ▶ Precise temperature and automatic control of the heating processes are easily achieved.
- ▶ Electrical equipment is usually more compact than equipment using other fuels and so saves space.
- ▶ Automation is relatively easy.
- ▶ Higher temperatures and heating rates are obtainable.

In process heating, the methods used for the conversion and transfer of electrical energy to heat energy can be roughly classified as:

- ▶ resistance heating using some form of element
- ▶ trace heating used in a range of processes to maintain temperature and prevent pipe freezing
- ▶ infrared heating from a source of infrared radiation, such as lamps or strip heaters
- ▶ induction heating by inducing eddy currents in the work piece or the melt
- ▶ dielectric heating using an electric field to speed up molecular movement within the material
- ▶ arc heating using the heat generated in an electric arc.

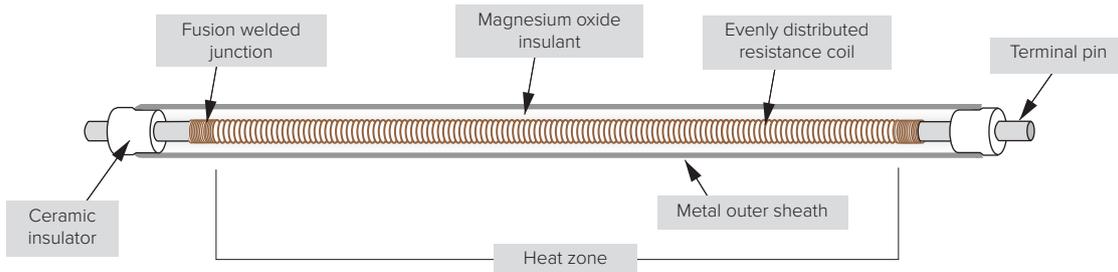
9.5.1 Resistance heating

Here the heat generated in an element is transferred to the material being heated by radiation, convection or conduction, depending on the application. Elements may be wire, strip or a solid such as silicon carbide. **Figure 9.24** shows some resistance heater types and where they are used.

In the past, exposed wire wound heating elements were used to provide heating in a range of processes; however, they have been largely replaced with sheathed or enclosed elements. Metal-sheathed elements, while very hot, do not have the added danger of being electrically ‘alive’ on the surface. Deterioration of the insulation of a sheathed element can result in the sheath becoming live. It is essential to earth the sheaths of these elements and ensure through insulation-resistance testing that the resistance to earth never falls below the *AS/NZS 3000* requirement of 10 000 ohms.

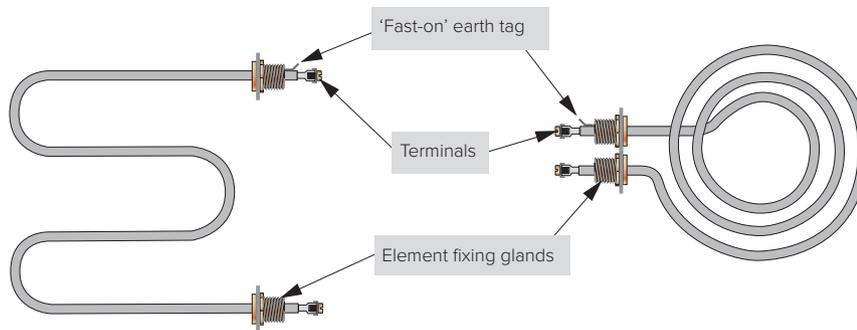
Calrod heating elements

Thermal tubular-calrod heating elements are the most versatile of all electric heating elements and are widely used as the main source of electric heat for domestic, commercial, industrial and scientific applications. Tubular elements can be immersed in liquids, cast into metals, clamped, placed in vessels and ducts to heat gases or simply used as radiant heaters for many processes. They are easy to install, require low maintenance and have excellent internal electrical insulation and heat conduction.



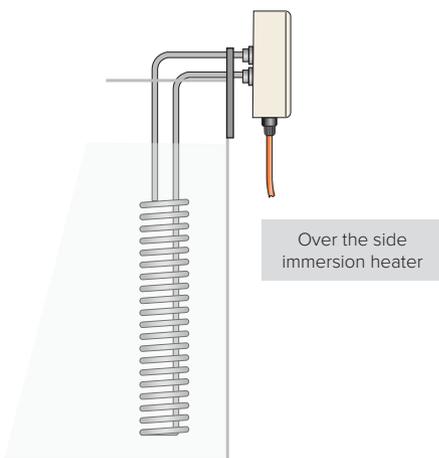
Commercial cooking elements

The elements shown here are examples of the wide range of heating elements manufactured for the commercial food industry. They are available in many shapes, voltages and power ratings to suit just about any food preparation appliance including one-offs for obsolete models.



Immersion heaters

These heaters are extremely useful in many applications. High heating efficiency and accurate control are maintained due to the heat being generated within the solution. These elements are easily installed and are often used to heat liquids, viscous materials and solids with low melting points. Some common substances include solvents, oil, water, plating baths, salts, wax, paraffin, asphalt and molasses.



Drum immersion heaters

These heaters are more efficient and economical than external heating and are used where the solution, liquid or material can be heated with the element being in direct contact.

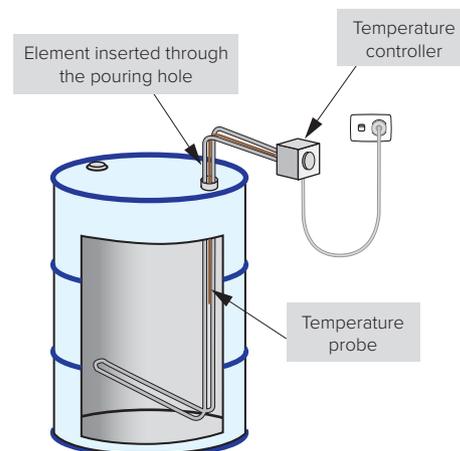


FIGURE 9.24 Examples of resistance heater elements and applications

Spot and seam welding are resistance welding techniques that use the direct-resistance heating method. However, where the work piece itself becomes the heating element, the direct-resistance method has been replaced in the main by induction heating technologies.

9.5.2 Trace heating

Trace heating comprises specially designed cables and tapes that are installed around pipelines, valves and vessels to maintain the flow temperatures of crude oil or petroleum by-products. It is also used to provide frost protection, particularly for pipes carrying water. In the food and confectionery industry, trace heating is used to keep ingredients such as chocolate, toffee and syrup in liquid form in pipes, tanks and nozzles. There are several types of resistance trace heating and systems using dielectric techniques, as illustrated in **Figure 9.25**.

In the design of a trace-heating system, two important factors must be considered: heat loss compensation and attaining and maintaining the required temperature in the product. Remember: heat loss is related to the temperature difference between the pipe and the atmosphere it exists in and the surface area the heat is passing through; the greater the area, the greater the loss. For example, a long pipeline dissipates more heat to the surrounding atmosphere than does a short one and heat loss is also affected by pipe diameter and the number of flanges and valves in the line. In addition, it is essential to provide sufficient heat to raise the temperature of the material to the required level to enable the industrial process to be effective.

The heat loss and respective heat required are determined in watts per metre, and then matched with a heating cable with this watt-per-unit output or higher. Manufacturers and suppliers of trace heating make product technical advice and comprehensive data on the design of a trace-heating system readily available by way of tables, graphs and formulas to be used in assessing an installation's requirements. Also available are comprehensive installation guides. Some of the basic techniques are given in **Figure 9.26**.

9.5.3 Infrared heating

This form of heating does not require a medium between the heater and the material to be heated. There are several types of infrared devices, each operating at different filament temperatures/wavelengths, and it is important to match the type of heater to the load. The most common form is quartz-tungsten: a tungsten element encased in a quartz bulb or tube, usually incorporating a reflector. Manufacturers' data sheets should be referred to in selecting a heater for a particular application; for example, shorter wavelength units are not suitable for evaporating water in drying applications. An example is shown in **Figure 9.27**.

Commonly used in textile manufacturing, metal finishing and food processing, a large number of emitter shapes and wavelengths in the infrared range are available. Manufacturers' data sheets should be referred to in selecting a heater for a particular application, as different material responds best to a particular wavelength and intensity. For example, water evaporates more readily under a medium wavelength heater in drying applications.

9.5.4 Induction heating

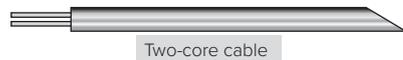
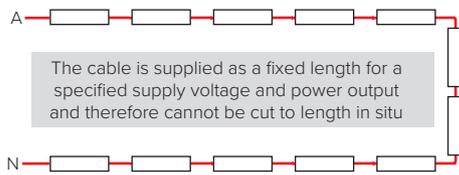
Induction heating is used in metal forging, casting, heat treatment, production welding, plastic moulding and similar processes, replacing previously used methods such as resistive heating, oil-fired furnaces, gas torches and the like. In this method, currents are inducted in the metal work piece to heat it to the required temperature. The basic principles and typical applications are shown in **Figure 9.28**.

A more recent adoption of induction heating is in domestic cooktops, where the induction element heats ferrous-based cookware, which then heats the food by conduction. As the cooktops are not heated themselves, they provide a high degree of safety. While much more efficient than resistive elements, they cannot be used with non-ferrous cookware.

Constant power series heating cable

Series heating cable is a simple resistive material conductor insulated with a thermally conductive material. A typical example is the mineral-insulated metal-sheath (MIMS) heating cable used extensively for high-temperature maintenance, high-temperature exposure and/or high-watt-density applications which exceed the limitations of thermoplastic insulated cables.

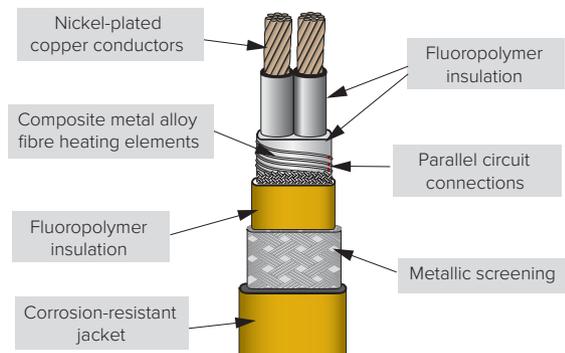
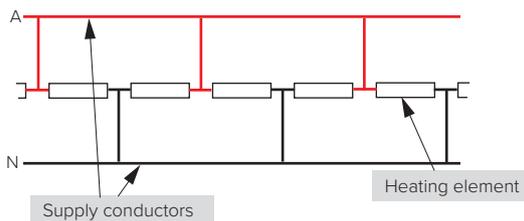
The cable presents as a series circuit of linear resistance



Parallel resistance (zone) heating cable

This is a heating cable that contains short parallel independent heating elements along its length. Localised damage will cause only a partial loss of heating. Watt-per-unit length output is relatively unchanged by variations in circuit length up to several hundred metres. Commonly referred to as cut-to-length, parallel cables are easy to size because circuit lengths (within limits) do not have to be considered.

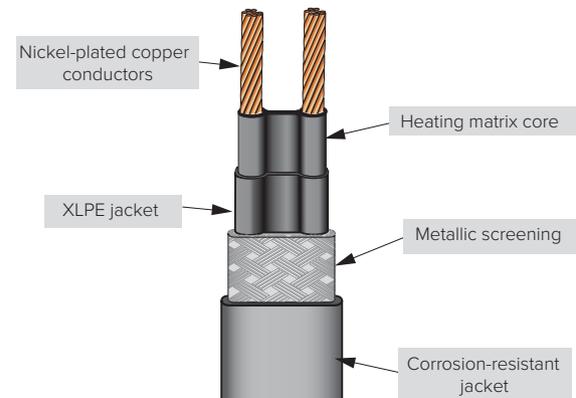
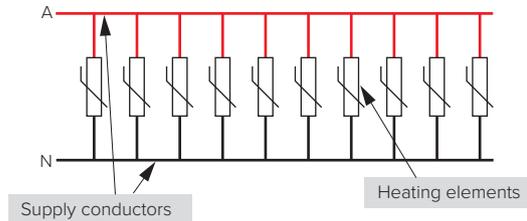
The cable presents as a multiple-path parallel resistance circuit



Self-regulating heating cable

Self-regulating cables have a conductive polymer heating element where resistance exhibits a positive temperature coefficient (PTC) characteristic; that is, the resistance of the element increases with temperature. As the temperature increases, the cable power output approaches zero. At this temperature the cable effectively shuts off. Being a parallel construction, the self-regulating heating cable can adjust its power output for local conditions along its length.

The cable presents as a multiple-path parallel PTC resistance circuit



Power-limiting heating cable

Power-limiting cables have PTC characteristics like the self-regulating type. However, they provide higher power output at higher temperatures, and as the temperature increases power-limiting cables do not reach a shut-off temperature.

Skin effect trace heating system

The system generates heat in the ferromagnetic heat tube by the return electrical current flowing through the impedance of the inner skin of the heat tube. There is no voltage or current on the outer skin of the heat tube. Skin effect systems are used for trace heating pipes up to 25 km long from a single supply source.

Trace heating power and control

Trace heating cables are commonly designed to operate from 230 V a.c. supply. Switchgear must be suitably rated to cope with initial inrush current, as may occur with some types of systems. Trace heating can be controlled by any of the electromechanical or electronic thermostats, covered in **Section 9.2**. For more precise control, electronic controllers integrated into a process control system are used. In some cases a thermostat may not be needed where self-regulating heating cables are used.

FIGURE 9.25 Types of trace heating

Only the basic techniques for installing trace heating are covered here. In the field the manufacturers' and suppliers' installation instructions should be followed as required by the *Wiring Rules, Clause 1.7.2*. Before, during and after installation the cables' resistance should be tested with at least 500 V d.c., although some manufacturers recommend a test voltage of 2500 V d.c. for polymer-insulated cables. The insulation resistance of the heating cable should not be less than 20 MΩ.

Trace heating cables should be installed only after the pipe work is completed, installed, tested and finished and prior to the installation of thermal insulation. The basic installation techniques are shown below.

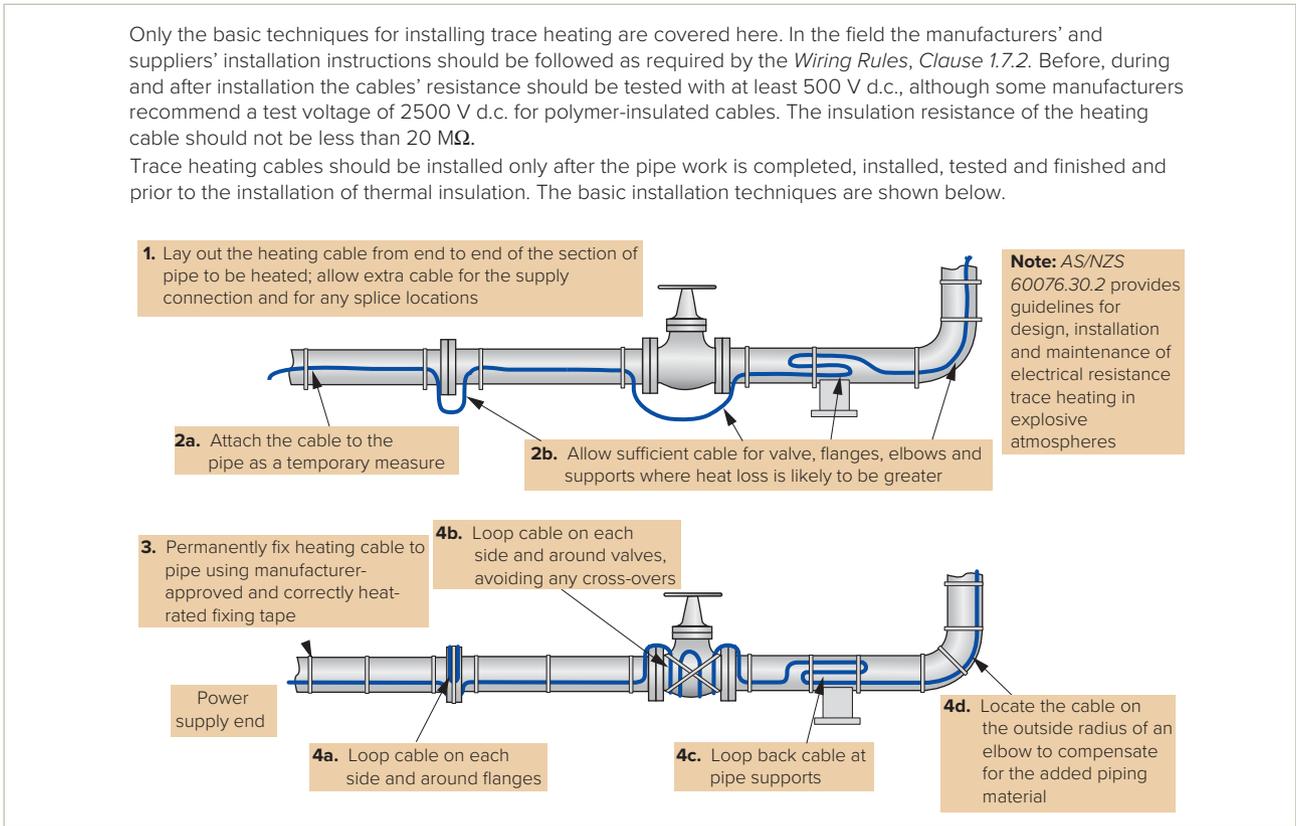


FIGURE 9.26 Basic techniques for installing trace-heating cables

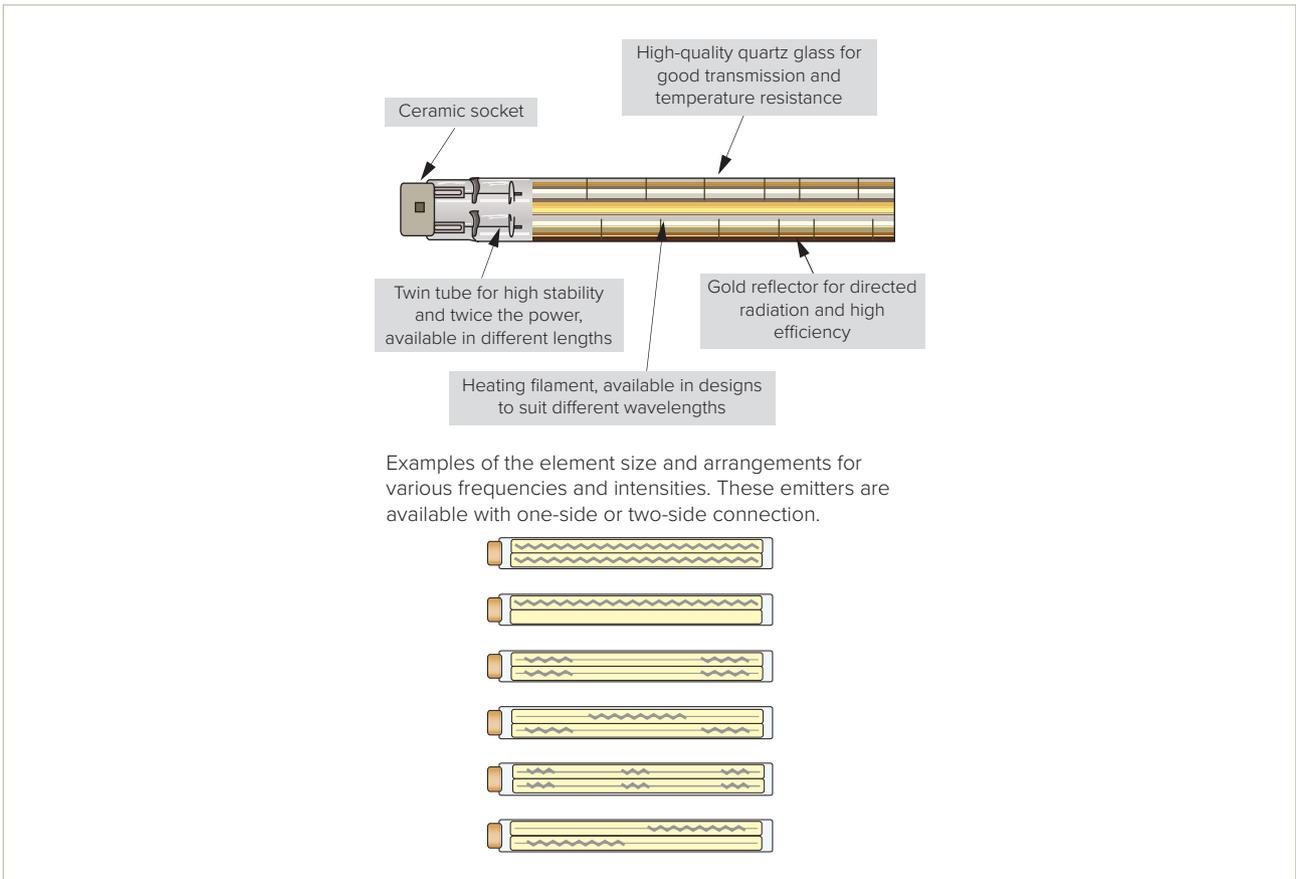
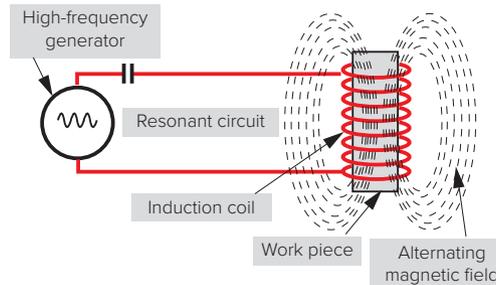


FIGURE 9.27 An example of infrared heating lamps and their applications

Induction heating uses a high-frequency alternating magnetic field to heat materials that are electrically conductive. The magnetic field is produced by a high-frequency generator in a resonant circuit. The passage of current through an induction heating coil generates a very intense and rapidly changing magnetic field in the space within the work coil. The work piece to be heated is placed within this intense alternating magnetic field.

Induction heating is a non-contact heating process and is very efficient as the heat is actually generated inside the work piece.

Basic induction heating circuit



Example, metal tempering

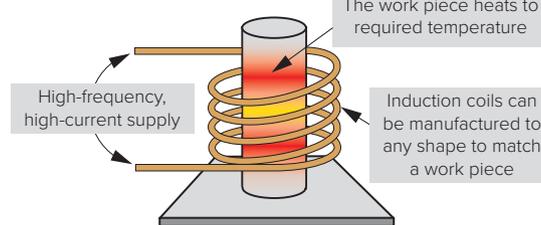


FIGURE 9.28 Basic principles and typical applications of induction heating

9.5.5 Dielectric heating

Non-conductive materials (known as *dielectric* materials) are heated when subjected to an oscillating electrical field due to a hysteresis effect within the material being heated, similar to the hysteresis effect in magnetic materials. The principle is illustrated in **Figure 9.29**.

This method is used extensively for the heating of thermosetting synthetic glues, the welding of plastics and the preheating of moulding powders and pellets. Dielectric heating is also used in the foodstuffs industry for defrosting, sterilisation and disinfecting, and for the drying of breakfast cereals, dog biscuits and similar tasks. There are many other applications for this type of heating in industrial processes.

Microwave heating

Microwaves are a form of dielectric heating. The main differences are: microwave frequency is much higher (over 2 GHz); microwaves are more effective at obtaining uniform temperature distribution; there is no need for physical contact with the load; and power ratings are lower. The common applications are vulcanisation of rubber, and commercial and domestic cooking.

9.5.6 Electric arc heating

A familiar use of arc heating is in welding, where an electric arc between an electrode and the base material melts the metals at the welding point to create a secure joint. Arc welding is done using either a d.c. or a.c. power supply with consumable or non-consumable electrodes.

The material to be heated is placed between two electrodes that act as capacitor plates and form the dielectric component of a capacitor. A high-voltage, high-frequency oscillator is applied to the electrodes to heat the dielectric material.

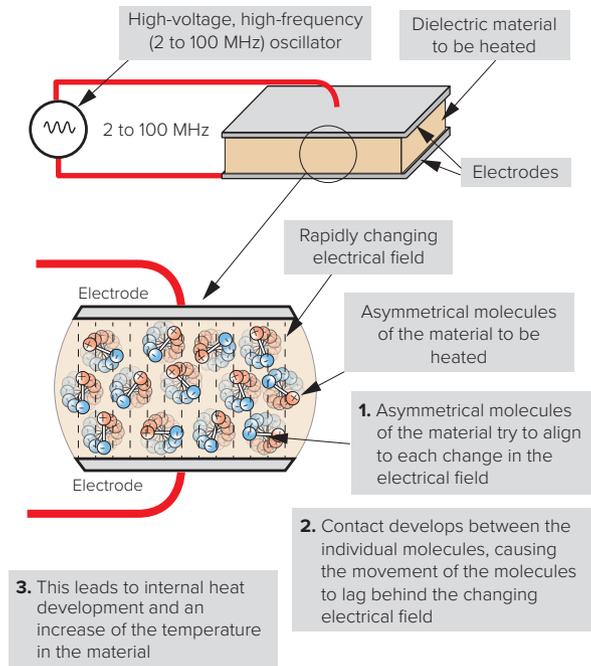


FIGURE 9.29 Principles of dielectric heating

Large industrial furnaces can melt hundreds of tonnes of steel per batch and require high power and very high current input (tens of thousands of amps is common). Graphite rods carry the current to the iron load via an arc that generates intense heat. Temperatures of about 1800 °C are reached in large industrial units and small laboratory units can achieve 3000 °C.

The direct type of electric arc furnace, as shown in **Figure 9.30**, mainly uses scrap steel as feed stock. A medium power furnace will typically produce 100 tonnes of molten steel ready for tapping in about 70 minutes.

The indirect-arc type, or rocking arc furnace, heats the charge by an arc established between horizontally opposed graphite electrodes connected to a single-phase supply. Heat transfer is mainly by radiation. These are mainly used for nonferrous metals with loads up to 100 tonnes.

When working on or around arc heating equipment, safety measures against the risks of burns, arc flash, toxic fumes, noise and overheating must be followed.

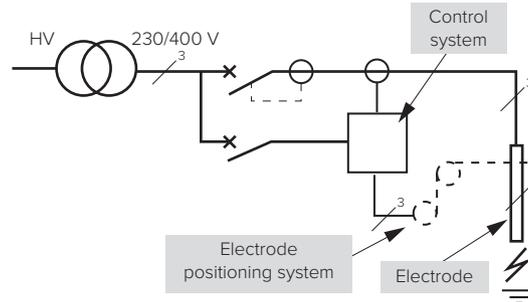


CHECK YOUR UNDERSTANDING

19. What is trace heating?
20. How does induction heating work?
21. How does electric arc heating work?

An electric arc furnace is most commonly used for recycling steel scrap, which is a far more energy-efficient method of making steel than manufacturing it from base materials, as is done in a blast furnace. Arc furnaces are the source of steel for a mini-mill, which may make bars or strip product.

Basic arc furnace circuit



Energy requirements

Typically steel manufacturers using electric arc furnaces aim for a tap-to-tap time of less than one hour. With energy of 440 kWh needed to melt 1 tonne of scrap steel, the supply demand for a 50 tonne furnace would be 22 MVA. The arc current could be as high as 32 kA, depending on the secondary voltage tapping used.

The dynamics of the arc furnace load cause disturbances such as flicker and harmonic distortion in the power supply system. This requires the addition of filter systems, capacitor banks and other measures to maintain the quality of power for other customers.

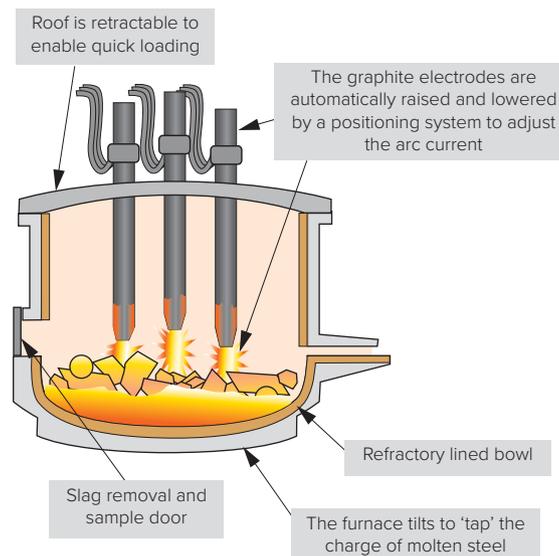


FIGURE 9.30 Basic concepts of a direct-type electric arc furnace

9.6 Motors

A range of a.c. and d.c. electric motor types are built in as an integral part of many appliances. They are not part of electrical installation work but are the domain of specialised service trades. For example, d.c. motors with electronic commutation use applications to improve their efficiency and, for the benefit of consumers, their star rating.

By far the most common freestanding electric motors are single-phase and three-phase squirrel-cage types. These motors drive most equipment that requires mechanical effort; pumps, fans, conveyors, lifts, overhead cranes and traction equipment are all driven by an electric motor, in most cases a squirrel-cage motor.

The advent of standards for motor efficiency and of more reliable and cost-effective electronic power control systems, such as soft starters and variable-voltage variable-frequency (VVVF) drives, has maintained the preference for squirrel-cage motors.

9.6.1 Induction motor overview

The main difference between the two types of three-phase induction motor is the structures of their rotors, which are either:

- ▶ a slip-ring rotor for connection to an external circuit or
- ▶ a short-circuit rotor, more commonly called a squirrel-cage rotor.

The slip-ring rotor has windings similar to that of the stator, with a structure of brushes on a slip ring at one end of the rotor for adding resistance to the rotor circuit in order to control motor starting torque. These motors are expensive to manufacture and the slip-ring gear needs periodic maintenance.

The squirrel-cage motor is made of a rotor with bars short-circuited at both ends, making a very sturdy, low-maintenance rotor circuit that is simple to manufacture and cost-effective. The structural components of these motors are shown in **Figure 9.31**.

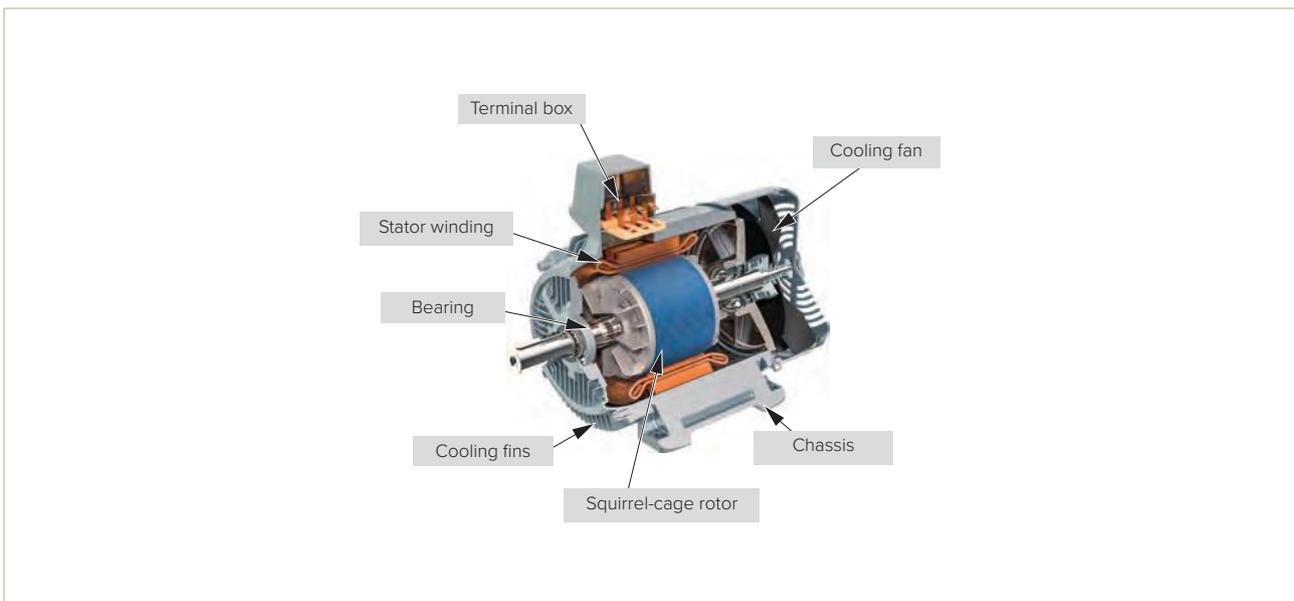


FIGURE 9.31 Components of a three-phase squirrel-cage motor

natatravel/Shutterstock.com

In basic single-phase motors, being only one phase, a rotating magnetic field is not naturally created at standstill. So to develop a starting torque, they are designed with a more resistive start winding to create a rotating magnetic field.

The start winding is disconnected once the motor is running. Variations in design include the switching of capacitors in the starting and running winding circuit to improve torque. The most vulnerable component of single-phase induction motors was the centrifugal switch arranged to switch the starting winding and capacitors. Centrifugal switches have been replaced by built-in electronic switching relays, resulting in wider use of the single-phase squirrel-cage motor.

As mentioned, power control electronics have enabled the use of squirrel-cage motors in place of d.c. and slip-ring motors where speed and torque regulation are needed for operational or efficiency improvements. Squirrel-cage motors are used to drive control pumps, fans, compressors, conveyors and in many other industrial applications.

Modern squirrel-cage motors are highly efficient and available in power ratings from 60 W up to 2+ kW in single phase and up to megawatt output in three phase.

9.6.2 Installing motors

It is not the role of the electrician to select a motor for a particular job. This requires mechanical engineering design skills and is usually done by the manufacturer or supplier of the equipment to be driven, such as a pump or fan. The electrician is, however, required to comply with the *Wiring Rules* (and any job specification) in selecting and installing the circuit protection, cable types and size, starting and control equipment and isolation, motor protection and starting devices. **Figure 9.32** illustrates how these are applied.

Before installing the circuit and controls for a motor as presented on a job, it is worthwhile checking that its nameplate details align with any specification on which the installation was quoted. These include:

- ▶ *rated voltage, number of phases and frequency*—these have been a problem particularly when a motor is supplied with imported equipment
- ▶ *power and current rating*—if not as planned, this may impact the cable sizes, protection and switchgear ratings
- ▶ *IP rating*—the intended environment when the job was planned may be different from the actual site classification, and if the motor and associated equipment are in a hazardous area, its certification must align with the zone and location specifications.



DID YOU KNOW?

Torque is developed by interaction between the rotating magnetic field developed by the stator winding and the magnetic field induced in the rotor circuit. The rotor circuit field is only maintained by the difference in its rotational speed and the synchronous speed of the rotating magnetic field of the stator. For example, the synchronous speed of a four-pole motor on a 50 Hz supply is 1500 rpm, while the full load rotor speed is typically 1440 rpm. For this reason, these are technically described as asynchronous motors.



CHECK YOUR UNDERSTANDING

22. What are the most common types of motors?
23. What are the two different types of induction motor rotor construction?
24. How is starting torque developed in a single-phase motor?
25. What are the three main clauses in *AS/NZS 3000:2018* that specify requirements for motor installation?
26. Before installing a motor, what properties of the motor need checking?

The three main *Wiring Rules* requirements for the installation of motors are stated in clauses:

4.13.1 Protection against injury from mechanical movement

4.13.2 Protection against overload

4.13.3 Protection against mechanical movement

The requirements apply to all types of motors, with some exceptions and alternative methods of compliance.

The following provides a snapshot of where the clauses apply.

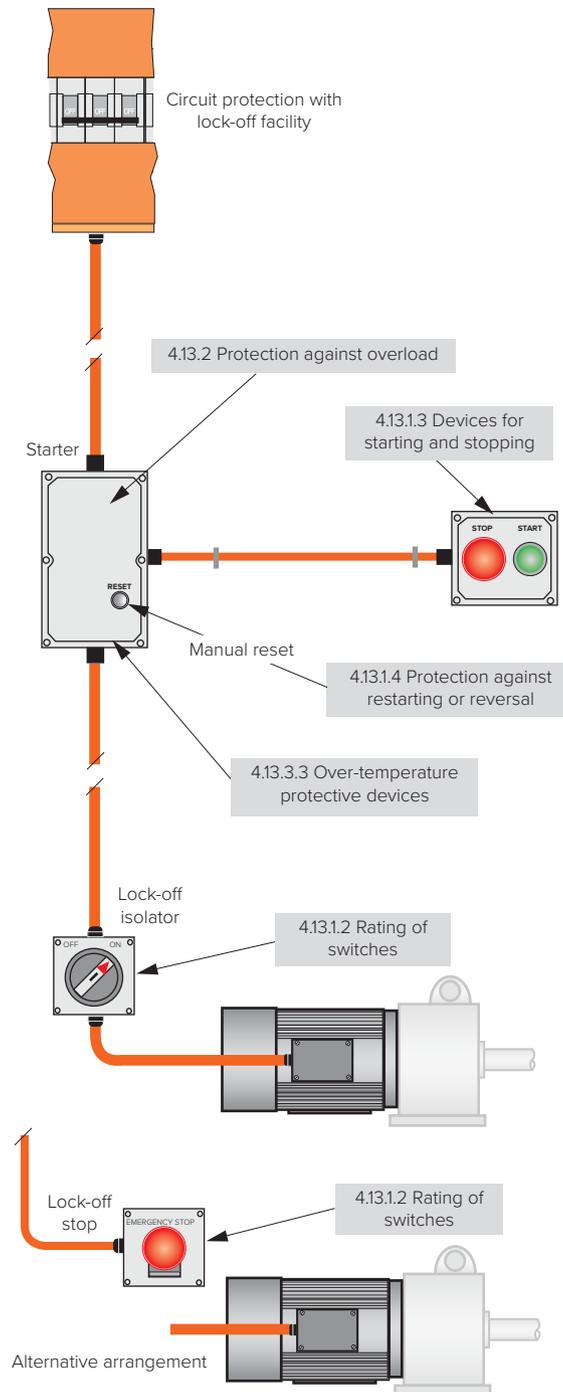


FIGURE 9.32 Installation requirements and practices for motors

SUMMARY

- ▶ Heat and motion are the most common forms of energy for which electricity is used.
- ▶ Electricity can be converted into heat in many ways but the use of a resistive load, such as an element, is the most common method.
- ▶ Electricians need a good understanding of *Section 4* of the *Wiring Rules*, which sets out the minimum requirements for the selection and installation of appliances and accessories.
- ▶ Heat is a form of kinetic energy produced by the movement of molecules in a substance.
- ▶ The three methods of heat transfer are conduction, convection and radiation.
- ▶ Temperature is a measure of the hotness of a body and is related to the amount of heat energy in the body and the body's mass.
- ▶ Heat energy can be controlled electrically using heat controllers, which can be controlled either manually or automatically.
- ▶ Automatic heat controllers need a form of feedback on the temperature of the process—this is obtained from thermostats, which can be either electromechanical or electronic devices.
- ▶ Electrical heating is widely used for water heating—the main types of water heaters are instantaneous water heaters, storage water heaters and heat exchangers.
- ▶ Water heating can also be achieved from renewable resources such as solar and heat pump systems.
- ▶ Heating systems can be broadly classified into three main groups: 1) portable heaters for small areas or small rooms; 2) space heaters for large areas or large rooms; 3) central heating for several rooms.
- ▶ The main technology used in portable, space and central heating systems is either radiant heat or air-conditioning systems.
- ▶ Heating is used extensively in various manufacturing processes due to its many advantages, which include its clean processes, lack of open flames, precise temperature and automatic control and compact equipment.
- ▶ Process heating uses resistive elements, trace heating, infrared heating, induction heating, dielectric heating, microwave and electric arc.
- ▶ Many appliances use motors and the most widely used motor is the a.c. induction motor.
- ▶ The a.c. induction motor is used in two configurations: 1) wound rotor with slip-ring connections; 2) short-circuit, squirrel-cage rotor.
- ▶ When installing a motor an electrician needs to consider all electrical and mechanical requirements, such as supply voltage and frequency, power rating, IP rating and required torque, and they must adhere to all requirements for motor installation as specified in the *Wiring Rules*.

REVIEW QUESTIONS

1. List four methods by which electrical energy can be converted into heat.
2. Explain how heat is created in a substance.
3. Define the term *temperature*.
4. List two ways that temperature control can be achieved.
5. List three types of automatic temperature control.
6. List three common types of thermostatic control devices.
7. Which water-heating device initiates the heating element only when the hot-water tap is opened and water flows?

8. Should you turn down the thermostat of a water storage heater below 60 °C? Explain your answer.
9. Which off-peak rate would you apply for if you had a water heater fitted with interlocked booster elements?
10. List three classifications for water heaters.
11. Give an example of where you would use an instantaneous hot-water system.
12. Excluding special conditions, is it permissible to connect an 80-litre unvented storage heater to off-peak supply?
13. Define the term *space heating*.
14. What system would you commonly use to provide heated or cooled air throughout a large commercial building?
15. List five forms of process heating.
16. Heating food by conduction is achieved by which type of heating?
17. Which type of heating is used in the foodstuff industry for defrosting, sterilisation and disinfecting?
18. What is the most common free-standing electric motor?
19. List the main difference between the two types of three-phase induction motors.
20. What should be identified on the nameplate and checked against the specification prior to the installation of a motor?

CHAPTER 10

Electrical installations for safety services—fire protection and evacuation equipment

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ explain how construction and building codes and the *Wiring Rules* provide safety services to buildings
- ▶ describe the two main purposes of fire-detection and alarm systems
- ▶ identify detectors suitable for use in non-domestic buildings
- ▶ understand the relationships between the components of fire control and indicating equipment
- ▶ demonstrate understanding of the *Wiring Rules, Clause 7.2 Safety services*
- ▶ show, with the aid of a diagram, the locations of fire alarms in a domestic dwelling for the minimum required protection and the maximum possible protection
- ▶ interconnect smoke alarms to a lighting circuit in compliance with the *Wiring Rules* and manufacturers' instructions.

Ever since humans discovered the usefulness of fire for heating and cooking, we have had to live with the ravages it causes when it becomes uncontrolled. History records many fires that started small—from, perhaps, the sparks of an open fire, an overturned candle, a spilt oil lamp—but escalated rapidly, causing deaths and the destruction of not only buildings but also large parts of cities. The Great Fire of London in 1666 started in a baker's shop and spread to most of the city, destroying some 600 houses. The industrial age, with its widespread use of heat and fuel, witnessed the advent of the factory fire. The introduction of gas and then electricity in buildings as an energy source in the nineteenth century added another dimension to the risks posed by fire.

During those times of somewhat ad hoc building standards, insurance underwriters began to demand that buildings meet a minimum standard in order to be insured against fire and other catastrophes. From these beginnings evolved the building standards we have today: the National Construction Code (NCC) in Australia and the Building

Code in New Zealand (NZBC). These codes establish the minimum level of performance that the various aspects of a building design must meet, including requirements for fire-detection and warning systems, means of egress from the building and means of controlling the spread of fire.

The *Wiring Rules* requirements for electrical installations for these safety services (*Clause 7.2*) are concerned with ensuring supply to fire-detection, warning, control and evacuation systems, but not the systems themselves. These are covered by technical standards referenced by national construction and building codes or local authorities.

This chapter focuses on the *Wiring Rules* requirements and the fire-detection systems encountered in general electrical work, and outlines the fire systems that are installed and maintained by specialists in the field.

10.1 Fire safety in buildings

To appreciate the importance of fire safety during the electrical installation of safety services, it is helpful to have some understanding of the nature of fires and the less obvious hazards they produce. Yes, they can cause severe burns and fatalities, but the most harmful hazard is smoke and the toxic gases it contains. Smoke causes irritation of the upper and lower respiratory tracts, and this affects the speed at which a person can move and, therefore, their ability to escape a fire. Extended exposure to smoke can cause asphyxiation (and death).

The gases contained in smoke depend on the fuels feeding the fire. For example, carbon-based fuels produce carbon monoxide and carbon dioxide. Other fuels such as those containing chlorine, nitrogen or hydrocarbons produce a variety of gases, some of which are highly toxic and potentially explosive.

Here we are concerned with fires in enclosed spaces such as rooms, offices or other divided spaces in a building, where the spread of fire and its by-products are affected by:

- ▶ the transfer of fire heat around enclosed spaces, which causes fire to spread
- ▶ the movement of smoke and gas around an enclosed space
- ▶ different structures within an enclosed space
- ▶ explosions that contribute to spreading the fire.

The development of a fire in an enclosed space progresses through five major phases over time, as illustrated in **Figure 10.1**. The common measures to prevent a fire starting, and to get people out safely if one does start, are shown in **Figures 10.2, 10.3 and 10.4**.



CHECK YOUR UNDERSTANDING

1. What does the acronym NCC stand for in relation to construction standards?
2. What is the most harmful hazard to a person in a fire?

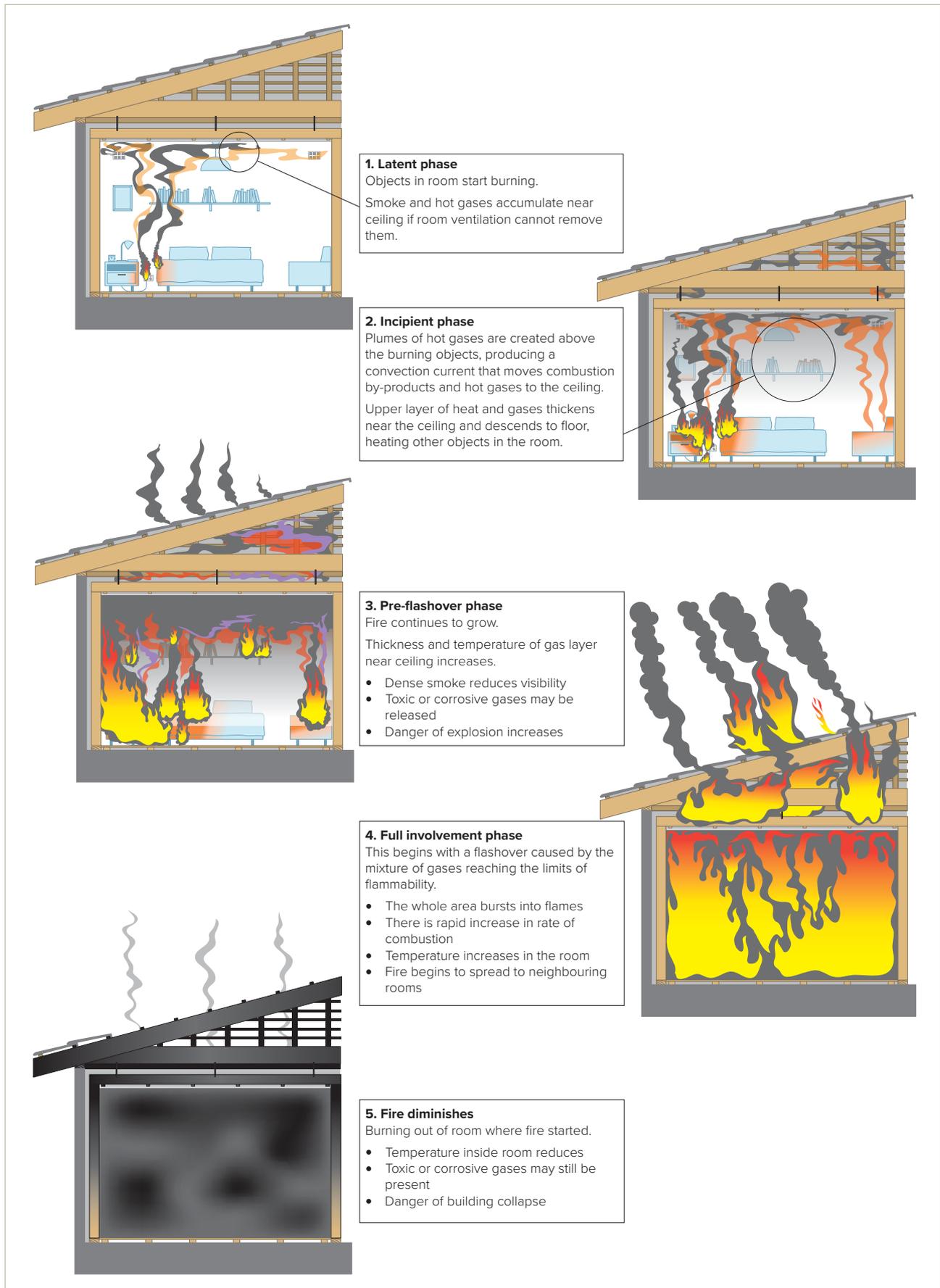


FIGURE 10.1 How a fire propagates in an enclosed space



FIGURE 10.2 Impression of fire safety in a single domestic residence



FIGURE 10.3 Impression of fire safety in a building with residential facilities

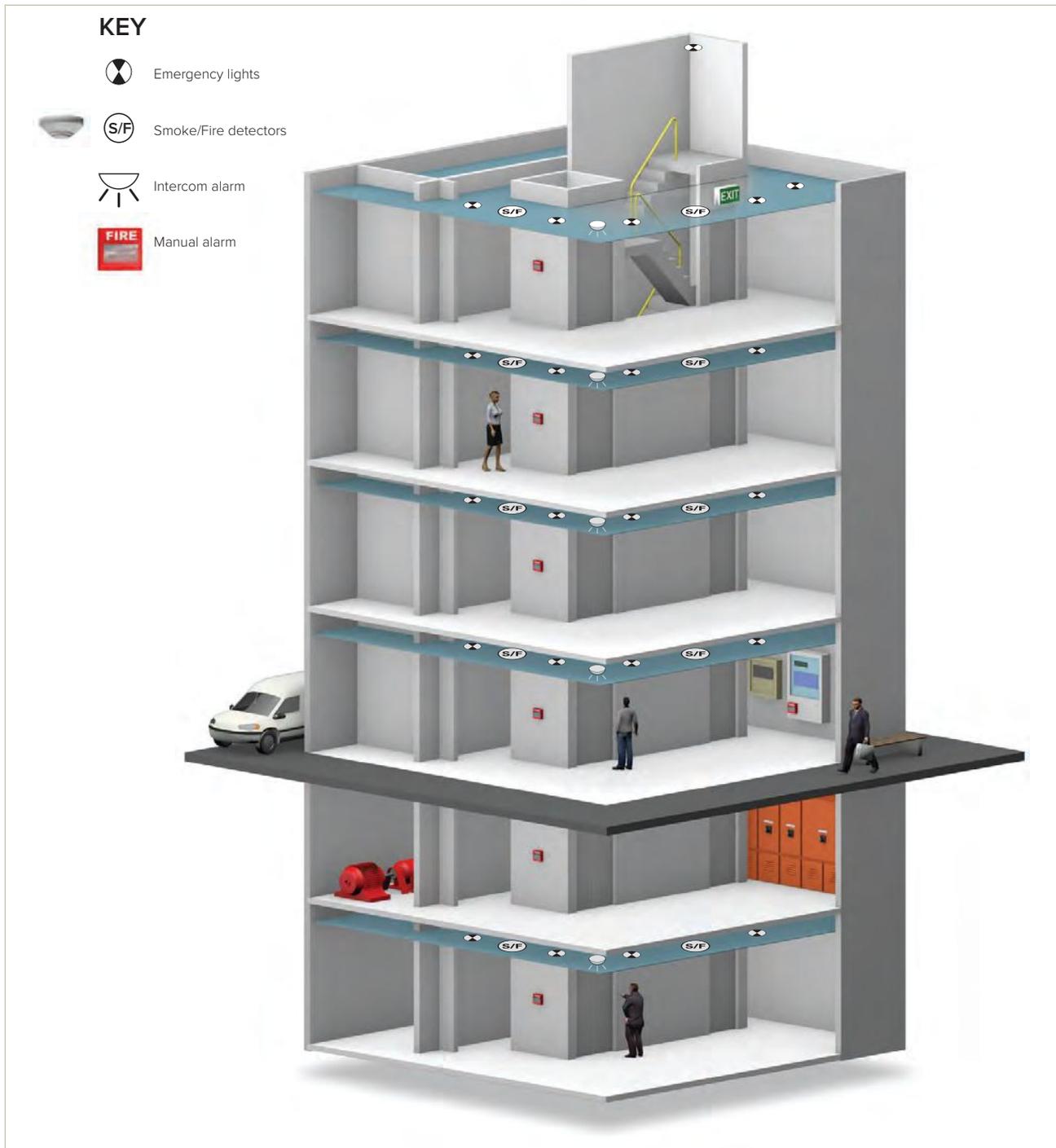


FIGURE 10.4 Impression of fire safety in larger buildings

10.2 Fire safety standards, regulations and systems

There are a range of regulations, standards and systems that provide guidance for electricians installing fire safety systems. They outline the minimum requirements and provide diagrams and references to ensure fire safety systems function as intended.

The design considerations for fire safety systems must take into account the building type in which the system will be used, as well as the protection of both property and persons. A more detailed explanation of these requirements and standards can be found in **Chapter 8**.

10.2.1 Fire safety standards and regulations

The fire safety requirements for buildings are contained in the National Construction Code (NCC), which has been adopted by, and forms part of, the building regulations for all states and territories. The code is produced and maintained by the Australian Building Codes Board (ABCB) on behalf of the Australian federal, state and territory governments, and provides performance provisions for the design and construction of buildings. The purpose of the NCC is to achieve nationally consistent minimum required standards for health, safety (including structural safety and safety from fire), amenity and sustainability. The New Zealand Building Code (NZBC) has a similar purpose and relationship with regulations. Neither code prescribes construction methods but gives guidance on how a building and its components must perform, rather than how the building must be designed and constructed.

The *Wiring Rules* requirements for electrical installations for safety from fire (*Clause 7.2*) are concerned with ensuring supply to fire-detection, warning, control and evacuation systems (see **Figures 10.5** and **10.6**) but not the systems themselves. The systems are covered by technical standards referenced by the respective codes or local authorities. See **Figure 10.7**. For further information on the NZBC, visit the New Zealand Department of Building and Housing at www.dbh.govt.nz/index.

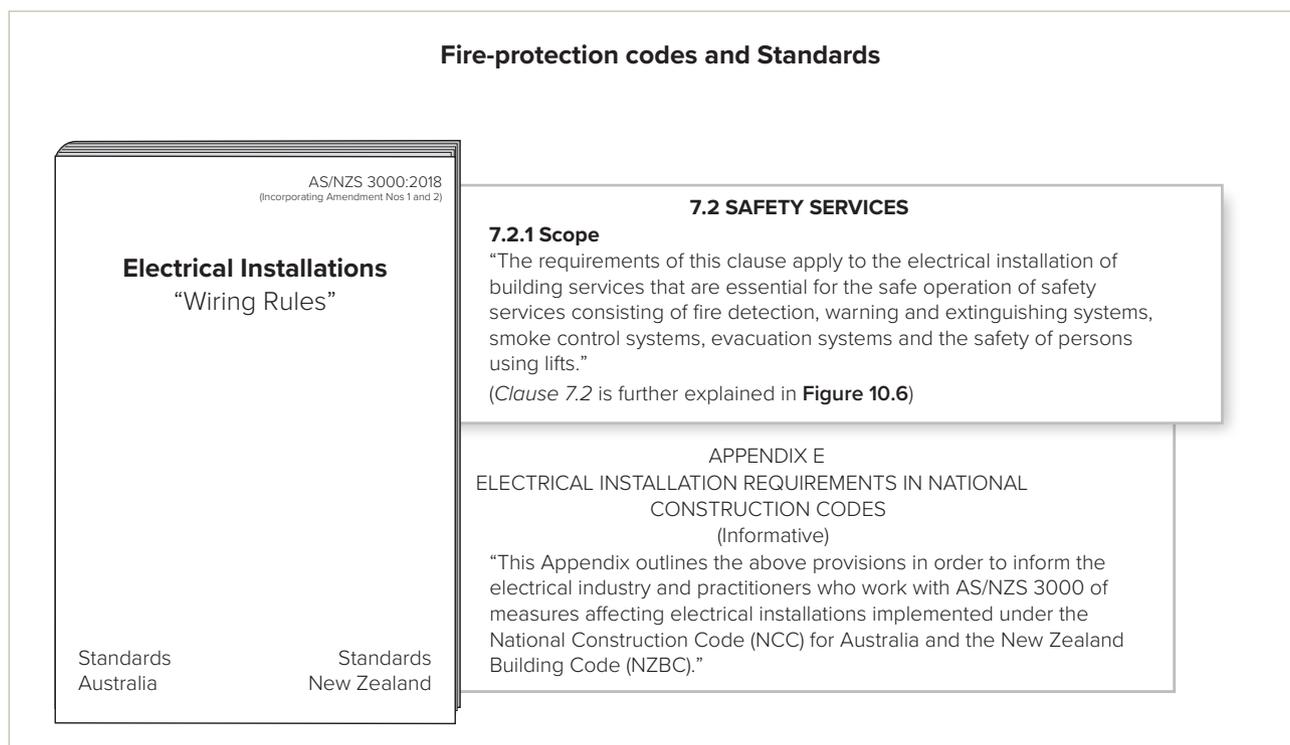


FIGURE 10.5 Extracts from *Wiring Rules—safety services in buildings*

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10.2.2 Fire safety systems

The extent to which the fire safety performance requirements apply depends on the building classification. The NCC lists 10 classifications of buildings or structures, each with a number of sub-classifications and broadly based on building function and size. The primary requirement—life safety—is applicable to all occupied buildings.

Life safety—fire-detection alarm and evacuation systems

These systems focus on protecting the safety of occupants. An awake person is able to detect the by-products of fire using their senses of sight, smell and sound. Fire-detection systems mimic these human senses and provide warnings to building occupants and remote monitoring centres of fire danger. The people most vulnerable to a fire in a building are those who are asleep, and therefore early detection of fire and audible warnings are vital. Detection

Safety services (fire safety)—installation requirements

The *Wiring Rules* essentially cover the requirements to ensure the integrity of supply to these safety (emergency) systems and equipment but not the systems and equipment themselves. Requirements for these are given by other standards and codes as outlined in **Figure 10.7**. **Figure 10.5** shows the main sub-clauses under *Clause 7.2 Safety services* and the functions to which they apply to assist the reader in understanding the *Wiring Rules* requirements. Each clause should be read carefully as there are a number of exceptions, keeping in mind that other standards specify the requirements for each part of the safety (emergency) services themselves.

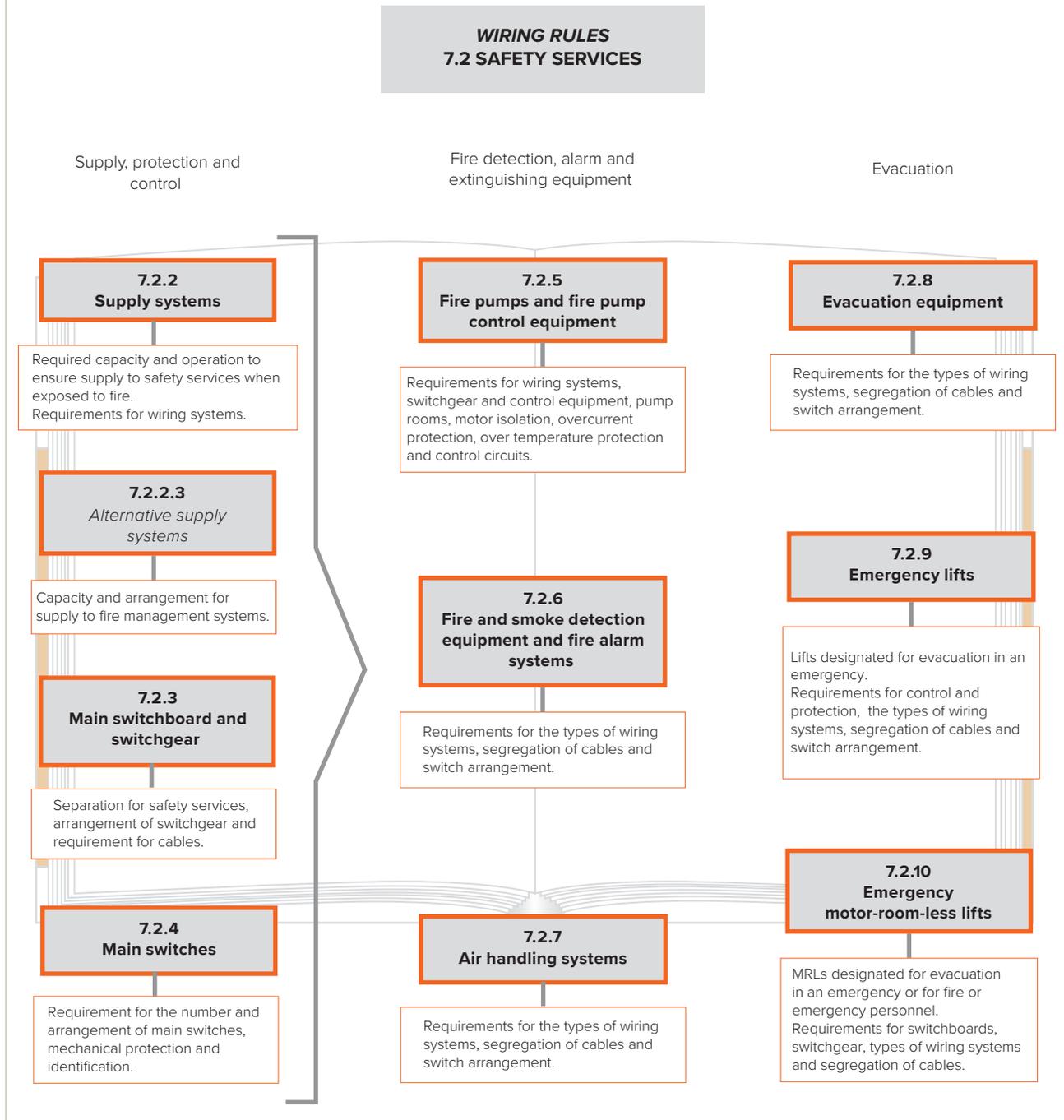
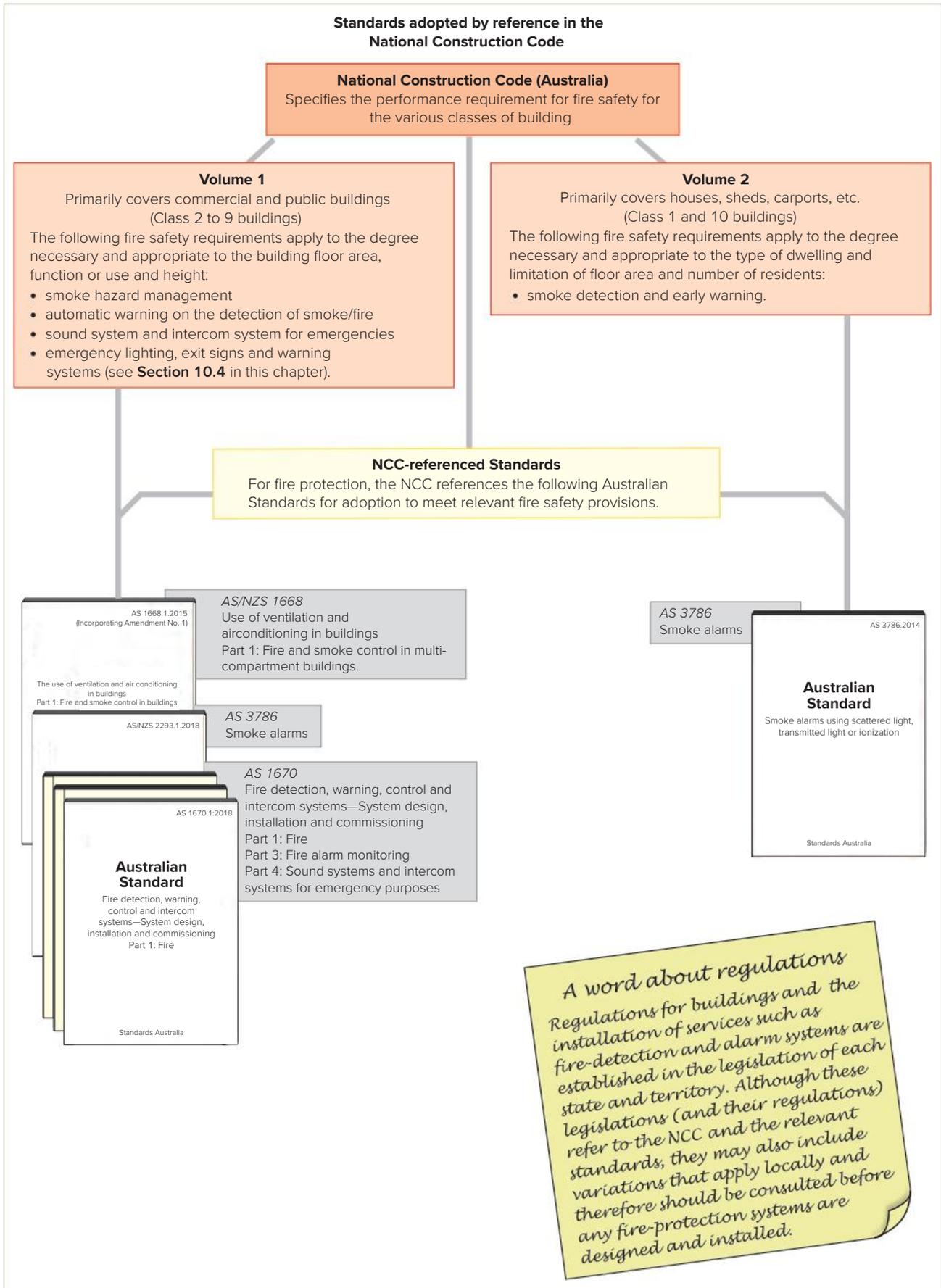


FIGURE 10.6 *Wiring Rules*—installation arrangements and requirements for emergency (safety services)

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A word about regulations

Regulations for buildings and the installation of services such as fire-detection and alarm systems are established in the legislation of each state and territory. Although these legislations (and their regulations) refer to the NCC and the relevant standards, they may also include variations that apply locally and therefore should be consulted before any fire-protection systems are designed and installed.

FIGURE 10.7 NCC-referenced Standards applicable to safety services

and warning systems in hospitals, aged care facilities and the like are designed to alert nursing staff and carers of the impending danger so they can assist with evacuating the occupants. Evacuation systems include emergency lighting that leads the way to safe exits and designated emergency lifts.

Property protection—fire-detection alarm systems

These systems are designed to protect buildings and the equipment inside them where the buildings are often unoccupied by people.

Fire-control systems

Integrated with life safety and property protection are modes in the ventilation and air-conditioning systems to control the smoke, sprinkler and deluge systems in order to suppress the spread of fire.



CHECK YOUR UNDERSTANDING

3. What is considered the primary requirement of fire safety systems?
4. How is a property protection system defined?

10.3 Fire-protection systems—non-domestic premises

Installations of fire-detection and alarm devices must take into account the type of premises to be protected and the most suitable devices with which to do this. The correct location of such devices is essential for the systems to be effective and allow for safe egress.

This section is concerned with fire-protection systems for use in non-domestic premises. **Chapter 8** provides information on appropriate fire safety systems for residential buildings.

10.3.1 Alarm systems and devices

Fire-detection and alarm systems essentially used in non-domestic premises are the province of specialists in the field of fire protection. Electricians competent to work in this field have completed a national qualification, currently the *Certificate IV in Electrical—Fire protection control systems (UEE40820)*. The following is a brief outline of the main fire-protection system components involved in this work.

Smoke-detector alarms

Types of smoke detectors that generally fall into the category of commercial devices (i.e. non-domestic) are shown in **Figure 10.8**, while **Figure 10.9** presents the principles behind some specialised smoke alarms.

Aspirating smoke detectors operate in the high to very high sensitivity range. Air is drawn through sample points to a sensing chamber, where it is analysed for smoke particles. The two main types of technologies used are:

- ▶ Light scattering, where a stream of sampled air is continually passed through a high-energy focused laser light source within a detection chamber. Light is scattered by any smoke particles present in the sample and the amount of light scattering is analysed by a solid-state receiver at the other end of the laser light.
- ▶ Particle counting, where a stream of sampled air is drawn through a laser beam. These devices count particles of smoke and ignore other particles in the air. They are very sensitive to small numbers of smoke particles.



FIGURE 10.8 Typical smoke detector used in commercial and public buildings

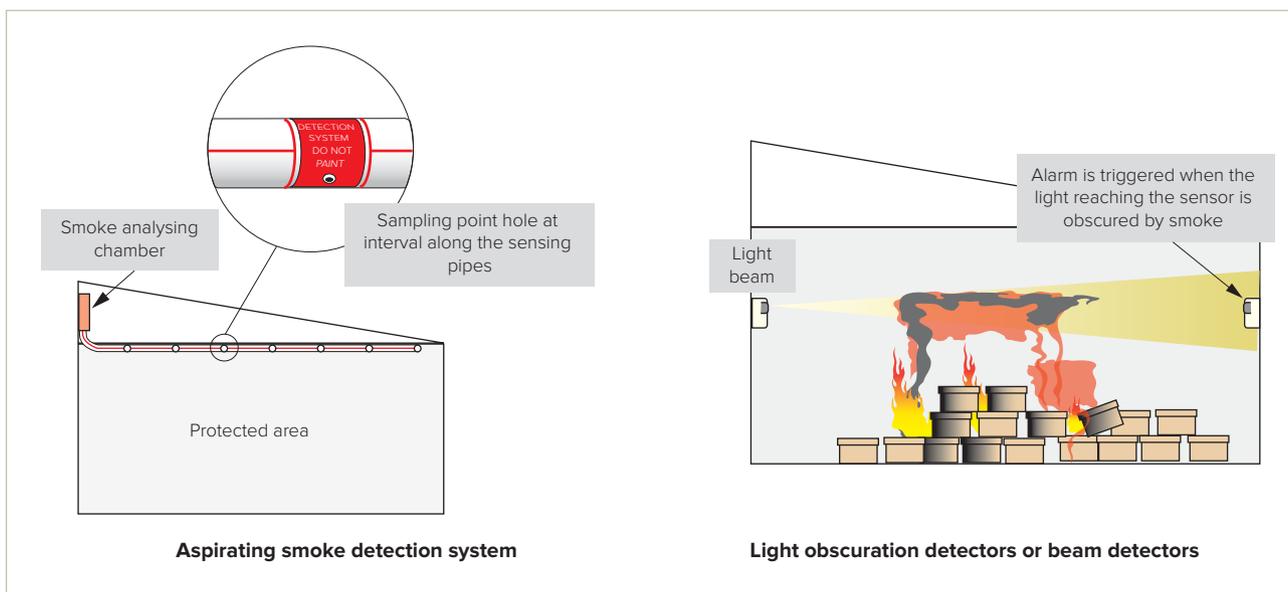


FIGURE 10.9 Principles behind some specialised smoke detectors

Duct-mounted smoke detectors are installed in the air-duct system. They operate by sampling the air flowing through the system and detecting smoke particles.

Light-obscuration smoke detectors (also called beam detectors) operate on the light-obscuration (light-blocking) principle and are a line-of-sight type. These detectors normally consist of a light source and light sensor. They are designed to protect large, open areas where it would be both difficult and expensive to install point-type smoke detectors. Normally the light source is installed at one end of the area to be protected and the light sensor is installed at the other end.

Carbon monoxide and multi-sensing detectors

Carbon monoxide (CO) fire detectors detect carbon monoxide gas in the air. These point-type devices require CO to enter the detector housing and reach the gas sensor chamber. See **Figure 10.10** for an example of this type of fire detector.

Multi-sensing detectors combine different sensors in the one housing (multi-point criteria) to detect smoke, CO or heat. Multi-sensor detectors may use two or more different types of sensor to collect information about a fire and generate an alarm.

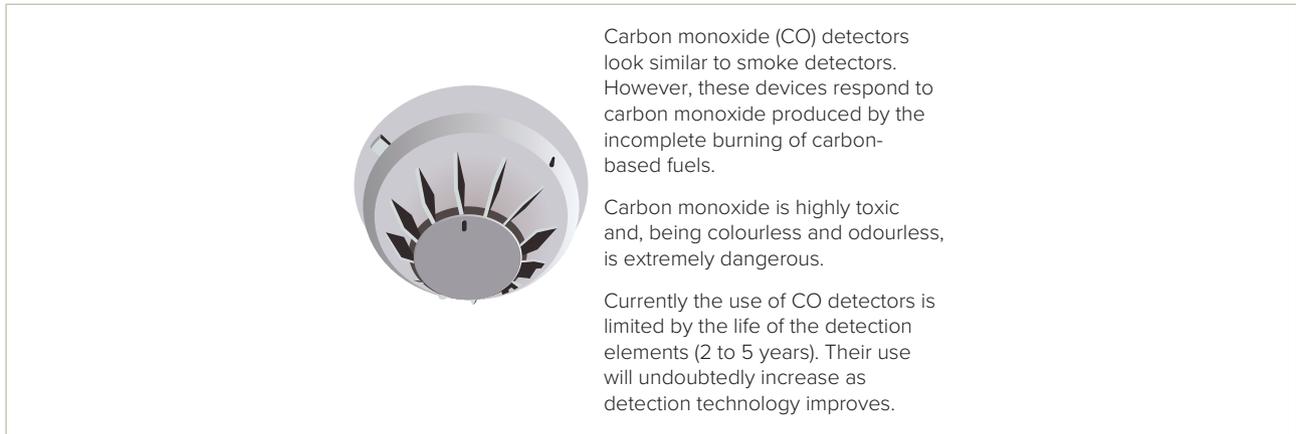


FIGURE 10.10 Example of a carbon monoxide (CO) detector

Heat and flame detectors

Heat detector alarms monitor the atmospheric temperature by reacting to either abnormally high rates of temperature change or a rise to a specific pre-set temperature. The older point-type heat detector alarms use a bimetal strip, which bends when heated to make or break an electrical circuit and so sounds an alarm. Another type uses eutectic solder elements, which melt when the specified temperature is reached, causing the circuit to close and signal an alarm.

Newer point-type heat detectors use a thermistor heat-sensing element and are able to respond to a variety of fixed temperature settings and to a rate of rise. These include:

- ▶ Probe types react to thermal expansion or contraction of the outer casing of the detector, which closes or opens the electrical contacts to send an alarm signal during a fire. These detectors have a fixed-temperature sensing element set to a specified temperature, or both rate-of-rise and fixed-temperature sensing elements.
- ▶ Linear-type heat detectors can detect heat along any portion of a cable. Some linear-type heat detectors are conductor cables encased in temperature-sensitive insulation. When the temperature reaches a pre-set point, alarm is sent to the fire indicator panel (FIP).
- ▶ Optical fibre sensor cables measure temperature via optical fibres that function as linear sensors. Laser pulses are sent down the cable and they measure temperature and locations. These measurements are compared and, if a rapid increase in optical loss is detected, an alarm signal is generated.

AS 1670.1 specifies the types of heat detectors to use in different locations. See **Figure 10.11** for an example of a heat detector.

Flame detectors contain electro-optical sensors that are sensitive to light of different wavelengths, so they can detect light that is not visible to the human eye such as:

- ▶ UV (ultraviolet) light—radiation
- ▶ IR (infrared) light—radiation.

Figure 10.12 illustrates the principles behind flame detectors.

Manual alarms

The familiar ‘break glass’ alarms seen in the public areas of buildings allow the manual actuation of the system by an occupant who has detected a fire. **Figure 10.13** illustrates a manual fire alarm.

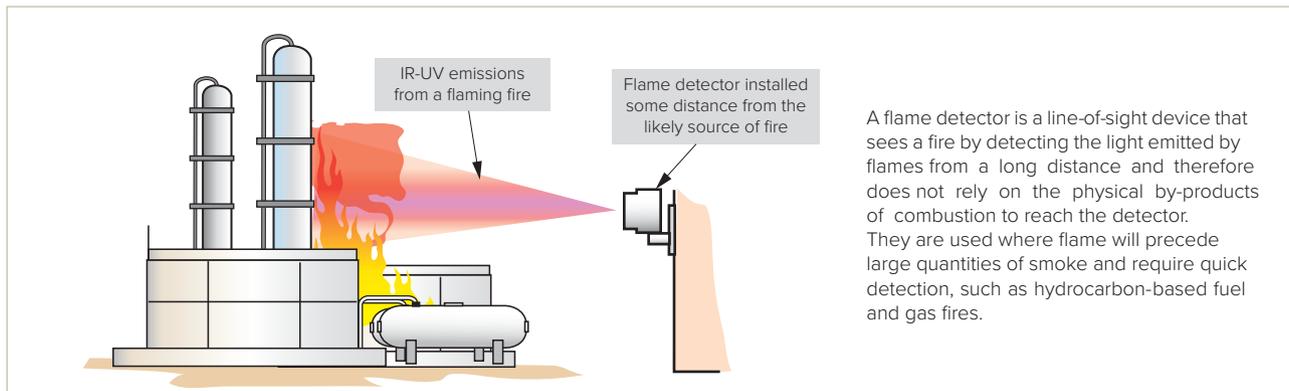
Alarm and warning systems

The best type of warning system to install in a building depends on the use, size and height of the building and the relevant BCA life-safety objectives for such a building. A warning system can simply consist of alarm bells spaced throughout the building, electronic sounders or a complex speaker arrangement. **Figure 10.14** describes some warning devices.

Thermistor heat detector

The most common element used in heat detectors is the NTC thermistor. The Tyco Type A detector shown here uses fixed-temperature (60 °C) sensing thermistors to readily track the local ambient temperature. Comparison is made with the responses of a thermally delayed operation to determine the temperature rate of rise. This also triggers an alarm condition.

The heat detector has an epoxy-encapsulated electronic design with a visible alarm LED. A remote indicator may be connected to the base assembly.

FIGURE 10.11 Example of a heat detector**FIGURE 10.12** Principles of flame detectors

Activating the break glass alarm sends a detection signal back to the fire indicator panel (FIP). On receiving this detection signal, the FIP initiates the system's programmed response.



In more complex fire-detection systems there may be white or red break glass alarms (manual call points) in each evacuation zone, near the fire exits. White break glass alarms allow the occupant to activate the emergency sound system by breaking the glass. Red break glass alarms are connected to the fire-detection system as an activating device. When the glass is broken, the control and indication equipment (CIE) sends a signal to the fire brigade or remote monitoring centre.

FIGURE 10.13 Manual fire alarm

Buildings built prior to 1980 which have had no major renovation undertaken have a warning system consisting of one alarm bell mounted at the front of the building. Currently, the building standards and subsequent Australian Standards still allow options for warning system components, but bells are no longer one of these options.

The simplest warning system consists of electronic sounders operated from the fire indicator panel. These devices (dispersed throughout the building) sound the evacuation signal when a warning system output signal is generated by the fire indicator panel.

Dedicated sound systems for emergency purposes are commonly used in larger buildings and public buildings.

These systems can have separate warning zones for each evacuation area, produce the evacuation signals and instruct the occupants to evacuate the building.



Visual warning devices (VWD) are often installed to provide a visual indication in high-noise areas as well as for areas occupied by hearing-impaired personnel. They can also be used to alert occupants of an early fire condition prior to a full fire alarm.

FIGURE 10.14 Warning devices

Fire control and indicating equipment

The fire-detection devices used in non-domestic premises are equipped to be addressable in a central system of fire control and indicating equipment (FCIE). These devices are commonly connected by a four-core cable: two for the extra-low voltage (ELV) supply and two for communications in the system, in a daisy-chain topology up to a limited number of devices typically 40.

Fire indicator panels (FIP) are the main part of the system of fire detection and control. They receive, indicate and control the detection, alarm and warning functions of the complete system. Should a fire alarm be raised by a fire-detection and warning system, the FIP is the starting point when the fire brigade attends a callout. FIPs are often located at the designated entry point to a building, such as in the main entrance (lobby), or the fire control room for large buildings. They are often contained in a large cabinet along with other fire-protection equipment, such as a local control station for a gaseous fire-suppression system. One or more remote panels can be connected to the main FIP to provide remote indications and sometimes controls as well.

Figure 10.15 illustrates the role of fire control and indicating equipment.

10.3.2 Evacuation and fire control

The imperative of the alarms and warning systems discussed in the previous subsections is the fast and safe evacuation of persons from an area where a fire may have started. The warning systems have an extended role in that they can be used for any type of threat or emergency. Once warned of an imminent threat, people must be able to identify the safe exits from the area and the egress paths should be lit.

Getting people out

Commercial and public buildings (Classes 2 to 9) are required by the BCA to have emergency evacuation lighting, with a deemed-to-satisfy provision referring to the Australian Standard series *AS 2293*, as shown in **Figure 10.16**.

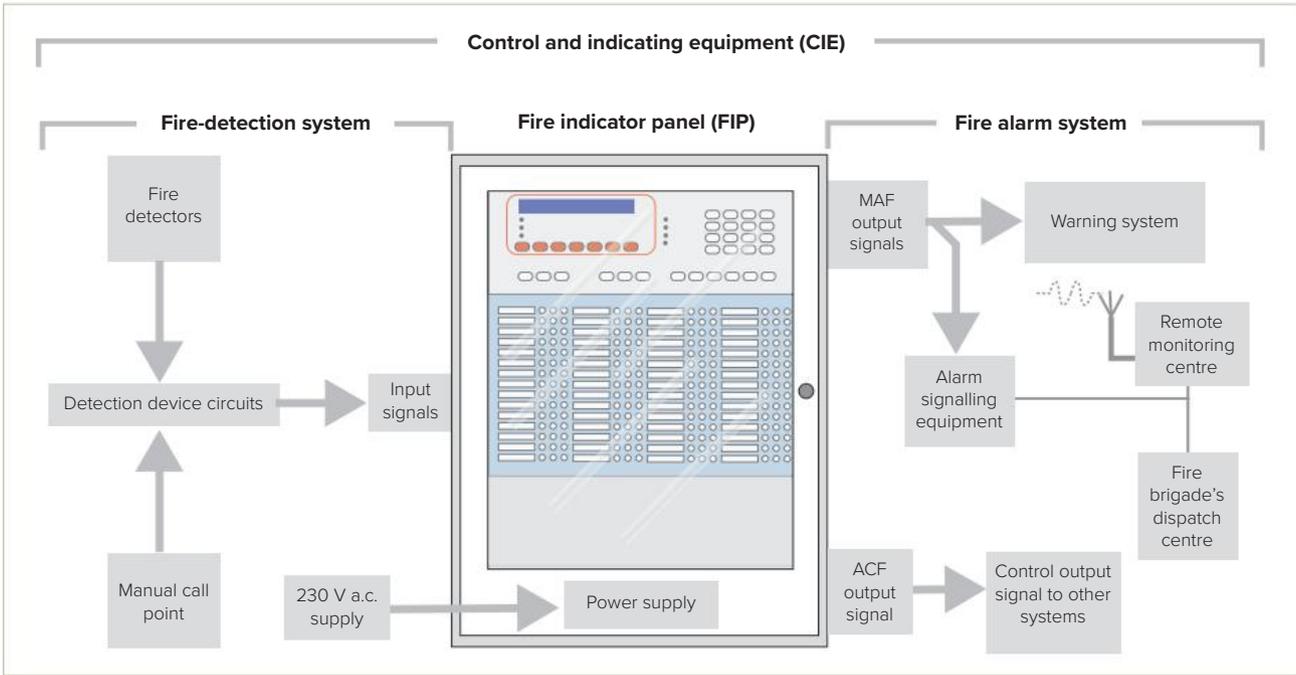


FIGURE 10.15 Role of fire control and indicating equipment

NCC-referenced Standards

The NCC reference the following Australian Standards for adoption to meet relevant fire safety provisions for the safe exit of persons.

AS/NZS 2293.1:2018

Australian/New Zealand Standard™

Emergency lighting and exit signs for buildings
Part 1: System design, installation and operation

Standards Australia
Standards New Zealand

AS 2293
Emergency escape lighting and exit signs for buildings
Part 1: System design, installation and operation
Part 2: Inspection and maintenance
Part 3: Emergency escape luminaires and exit signs

FIGURE 10.16 Emergency lighting regulations and Standards

Emergency lighting

The provision of emergency lighting in an installation is to ensure that once fire or other danger is detected there is sufficient light to safely egress. This is particularly relevant when the electrical supply to the installation has been cut by the event or by emergency workers. Further details concerning *AS/NZS 2293* requirements for emergency lighting can be found in **Chapter 8**.

Controlling smoke and fire

So, a fire alarm sounds, the mains power trips and the emergency lighting takes over, all working as it should—except for the main hazard in exiting a building fire: the smoke. To deal with this hazard and limit the spread of fire, smoke-control

elements are installed in buildings as a requirement under the NCC. Included in the design of the ventilation and air-conditioning systems are methods for limiting smoke from spilling into egress paths, such as fire-isolated exits, ramps, passageways and public corridors leading to a safe place. The designs include the maintenance of a different pressure between compartments to keep smoke out, and the use of fire/smoke curtains, fire dampers and the like.

What about the fire itself? Fire sprinkler systems, deluge and suppression systems are installed to limit the spread of fire and assist the fire brigade, which takes charge of these events.

To reiterate, installing and maintaining the systems for controlling smoke and fire are the province of other trades. The responsibility of the installing electrician is to comply with the requirements of *Clause 7.2 Safety services* to ensure the integrity of the supply to the emergency service systems and equipment for when they are needed.



CHECK YOUR UNDERSTANDING

5. Describe how a light-obscuring/beam detector operates.
6. What type of manual alarm is used in buildings?
7. What is the purpose of a fire indicator panel?

SUMMARY

- ▶ The development of a fire in an enclosed space progresses through five major phases: 1) latent phase; 2) incipient phase; 3) pre-flashover phase; 4) full involvement phase; 5) fire diminishes.
- ▶ Fire safety standards, regulations and systems have been designed to promote life safety, property protection and fire control.
- ▶ There are a variety of fire-detection methods available and it is vital to select the method that meets the particular building's requirements.
- ▶ The *Wiring Rules* detail requirements regarding the safe installation of fire safety systems in electrical installations.
- ▶ It is vital to correctly maintain and test fire-protection systems to ensure their effectiveness.
- ▶ The selection of the correct detector is important to ensure effectiveness and reduce nuisance tripping and unwanted alarms.
- ▶ Each installation is designed according to the required specifications in order for it to function correctly and ensure compliance with requirements.
- ▶ There are different requirements for domestic and commercial fire safety installations.
- ▶ Each fire safety installation will require evacuation equipment to ensure safe and efficient egress from buildings.

REVIEW QUESTIONS

1. List three of the aspects of building design for which the NCC establishes minimum levels of performance.
2. What role does *AS/NZS 3000* play in the area of fire detection, warning control and evacuation systems?

3. List the five phases of the development of fire in an enclosed space.
4. Briefly explain the difference between the NCC and *AS/NZS 3000* in relation to fire safety.
5. Life safety fire-detection and alarm systems are focused on protecting what?
6. Identify a type of smoke detector alarm you could install in a large, open commercial area.
7. Describe how a light-obscuring/beam detector operates.
8. Define the role of a fire indicator panel.
9. Identify the Standard responsible for evacuation lighting.
10. Describe the intentions of *AS/NZS 3000* in relation to safety services.

CHAPTER 11

Renewable energy and other alternative supply installations

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ identify types and principles of renewable energy generators and briefly discuss their applications
- ▶ understand the output of common renewable energy generation systems and the factors that affect their performance
- ▶ identify the Standards and regulations that relate to renewable energy power systems
- ▶ outline the purposes of grid connected and standalone power systems
- ▶ recognise the requirements of AS 3000 with regard to generation systems
- ▶ summarise the components of standalone power systems and their purposes
- ▶ understand the purposes of stand-by and standalone generators and their applications
- ▶ recognise that additional training and certification are required for an electrician to work with renewable energy and alternative energy systems
- ▶ define and recognise uninterruptible power systems
- ▶ describe the arrangement and application of battery systems.

The creation and consumption of electricity have changed significantly and will continue to change in future years. The methods of generation have also changed, with traditional coal-fired generation being replaced with more sustainable and cleaner technologies.

This chapter introduces a range of these generation technologies and their applications, as well as providing a basic understanding of their installation.

The changes present challenges to electricians in keeping pace with the emerging technologies and their applications. New rules and Standards are also being introduced, and will continue to be introduced, to accommodate these changes in order to ensure the ongoing safety of electrical installations.

In some cases, specialised training and competencies regarding the design and layout of these systems are required that are not included in this book.

11.1 Renewable energy sources within a consumer installation

Electricity can be generated via a variety of methods and technologies. Some of these are described later in the chapter; however, there will continue to be new and emerging methods that will affect the ways we work and undertake installations. What was, until quite recently, considered expensive and complex is now cheap and easy to install, with the availability of packaged products ready for installation.

These installations must comply not only with *AS/NZS 3000*, but also with a range of additional Standards that relate to electricity systems, and include the following:

- ▶ *AS 4777 Grid-connected energy systems via inverters*
- ▶ *AS/NZS 3010 Electrical installations—generating sets*
- ▶ *AS/NZS 4509 Standalone power systems*
- ▶ *AS 3011 Battery systems*
- ▶ *AS/NZS 5033 Installation and safety requirements of photovoltaic (PV) arrays.*

National training packages define a range of competencies that are applicable to these types of installations and which are continually being updated as required to cover this dynamic area of electrical work. There are peak bodies like the Clean Energy Council (CEC) that provide national guidance and recommendations for the accreditation of electrical workers based on these national competencies. The CEC provides recommended accreditation for rebates and renewable energy credits, promotes the use of clean alternative energy, and supports installers, retailers and government departments.

11.1.1 Engine-driven generators

The engine-driven generator has been around for a very long time and formed the initial basis of electricity production. Engine-driven generators were often localised and provided basic supply to an area around the generator. As consumption increased, these were replaced by power stations, which still used the same principle of electrical generation but on a much greater scale and distributed to a power grid.

Today, engine-driven generators are used for more specific applications:

- ▶ backup supply to the grid for installations such as hospitals and telephone exchanges
- ▶ remote-location and isolated-area power generation
- ▶ temporary power during installation and maintenance work
- ▶ maintaining data processing, sewerage pumping and other vital services
- ▶ supplying electricity to ships and other isolated systems.

Types of engines

The methods of driving these generators vary depending on the size, location and local requirements. Small units often use a small petrol-driven engine to provide the rotation. Larger skid-mounted units are more likely to be powered by diesel motors for greater fuel efficiency and reliability. There are also a range of gas turbine-driven generators available that are capable of producing high thermal efficiency in excess of 60 per cent.

Figure 11.1 shows a small portable generator, **Figure 11.2** shows a larger skid-mounted generator and **Figure 11.3** shows a gas-turbine generator.

Selection and use of the appropriate generator are determined by many factors, including output required (normally measured in VA), location, portability and fuel source. When required for short-term applications, generators are often hired, due to their high cost. There are many suppliers that can provide support when you are required to install this type of equipment.



FIGURE 11.1 Small portable generator
yevgeniy11/Shutterstock.com



FIGURE 11.2 Skid-mounted generator
stefan11/Shutterstock.com

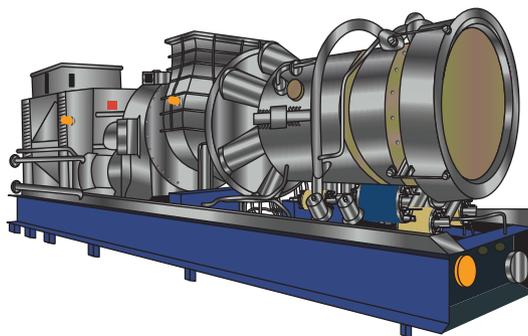


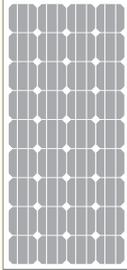
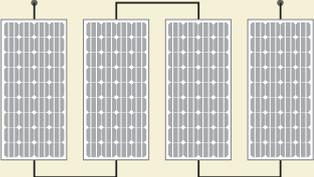
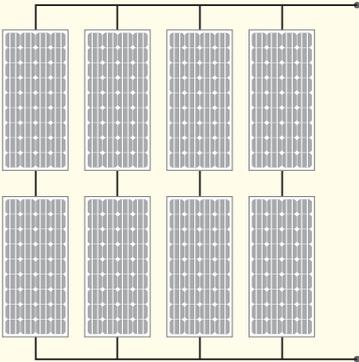
FIGURE 11.3 Gas-turbine generator

11.1.2 Photovoltaic (PV) arrays

Photovoltaic (PV) devices use semiconductor materials to convert energy (light) from the Sun directly into electricity. The most common type of semiconductor is silicon, which is the technology this chapter discusses. This technology was commercialised in the 1970s and has been supported at state and federal levels by a succession of governments and policies. It is now common practice for a new residence to have a PV array installed during construction.

Photovoltaics is a modular technology that can be expanded from a single cell of approximately 3 watts to solar arrays hundreds of megawatts in size. **Table 11.1** shows how PV devices can be scaled up in size via technology.

TABLE 11.1 Increasing scale of photovoltaic devices

Name	Image	Description
Solar cell	 <p style="text-align: center;">Cell</p>	<p>The building blocks of a PV array are the PV cells. A PV cell, or solar cell, is a thin sheet of silicon that has been treated so that when sunlight hits the silicon, it produces electrons. These electrons are harnessed so that the cell produces a voltage and current, resulting in useable electrical power.</p>
Solar module	 <p style="text-align: center;">Module—cells in series</p>	<p>Each solar cell produces only a small amount of power, so they are connected in series and in parallel to form a solar module, which will typically be rated at 150 to 400+ W. Solar modules are the building blocks of every PV array.</p>
String	 <p style="text-align: center;">String—modules in series</p>	<p>Solar modules connected in series are known as strings. Connecting solar modules in series increases the voltage of the string. Some strings in PV systems operate above 500 V d.c.</p>
Array	 <p style="text-align: center;">Array—strings in parallel</p>	<p>A PV array is a collection of solar modules connected together to increase the power output of the array. A single string of solar modules is the most basic array; however, strings of modules are often connected in parallel form to obtain higher output currents and increase array power.</p>
Farm	 <p style="text-align: center;">Praethip Docekalova/Shutterstock.com</p>	<p>Extremely large PV systems may be many megawatts in capacity and cover very large areas.</p>

Solar module/array performance

Solar arrays generate direct current (d.c.) electricity. A single solar module or panel will generate between 12 and 100 volts depending on the technology and the module size, and it may produce upwards of 8 amps. When solar modules are connected together to form a solar array, the combined output can be hundreds of volts, so great care should be taken when working with or around solar installations.

The output of a solar module is normally described using the nominal power rating or peak power rating. This is the amount of power the module will produce if it is operating under the standard conditions used for testing the module, which are 25 °C and 1000 W/m². When a module is actually installed it will not be exposed to these conditions very often, due to changes in temperature during the day and variations in the amount of sunlight falling on the module throughout the day and the year. **Figure 11.4** shows how the output from a solar array varies over the course of a typical day.

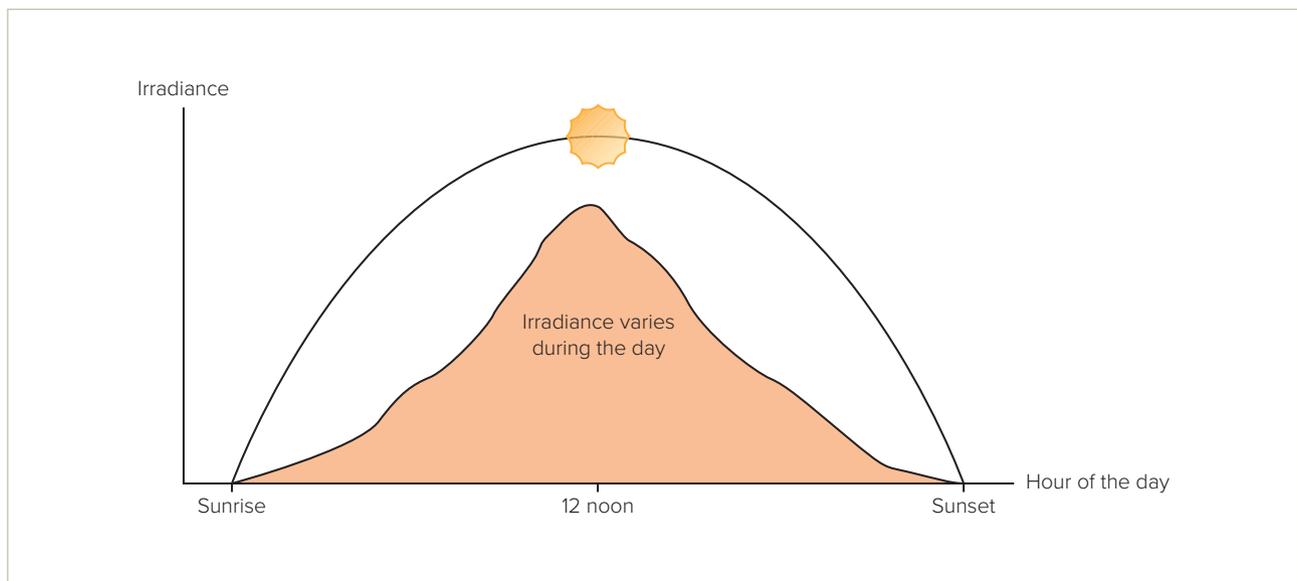


FIGURE 11.4 Typical daily generation profile of a solar array

Solar module/array actual output

To account for a solar array's output variation, solar designers have to calculate the adjusted output of solar arrays. In most cases, the output of the solar array has to be de-rated (reduced) for the actual operating conditions, some of which are shown in **Figure 11.5**. It is common to use a percentage figure to indicate the adjustment/de-rating figure applicable. For example, if a de-rating of 5 per cent is to be applied to an array, this means the array output is reduced by 5 per cent. Therefore the remaining output will be $100\% - 5\% = 95\%$. This gives a remaining efficiency for the solar module/array of 0.95, or 95 per cent. Typical efficiency figures used in solar designs are shown in **Table 11.2**.

In most PV systems, all of these de-rating losses will need to be applied in order to correctly estimate the output of the solar array over a year. When considering multiple de-rating losses for one system, all the de-rated efficiency factors must be multiplied together, using the method shown in **Figure 11.6**.

Solar cells have the advantage that they do not produce any emissions while operating. This means they do not produce any greenhouse gases (GHG) such as carbon dioxide (CO₂) or any other gases that are harmful to the environment.

The amount of power used to manufacture a solar module is expected to be recovered by the power produced by the module in two to three years, depending on the technology used.

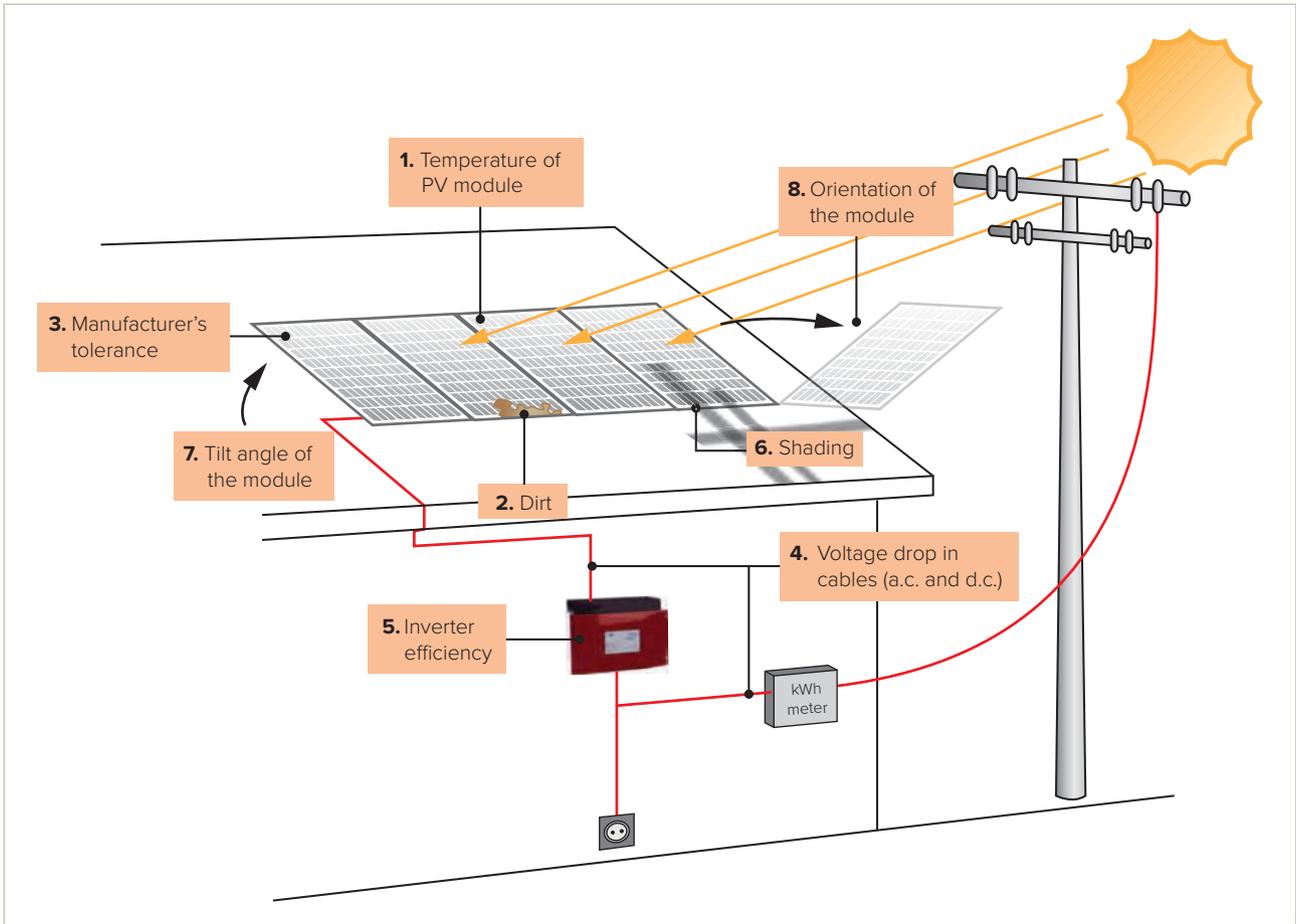


FIGURE 11.5 De-rating factors that affect a solar array's output

TABLE 11.2 Typical de-rating factors for a solar array

Factor influencing array yield	Percentage loss/de-rating	De-rated efficiency factor
Dirt	5–10%	0.95–0.9
Module mismatch*	Maximum 5%	0.95
Voltage drop	1%	0.99
Shading	5% (site-specific and selected by designer)	0.95 (or as appropriate)
Orientation and tilt	5% (site-specific and selected by designer)	0.95 (or as appropriate)
Temperature	0.5% per 1 °C (in Australia a temperature difference of 25 °C is not uncommon)	0.875 (or as appropriate)

* Module mismatch is used to allow for differences in the output of solar modules that may result from manufacturing effects like small variations in the current output of individual cells.

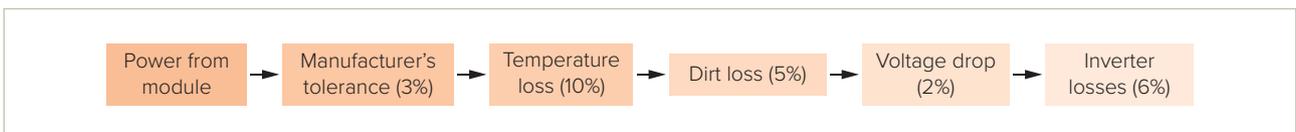


FIGURE 11.6 Method for determining total de-rating of a solar module before determining energy yield

11.1.3 Fuel cells

Fuel cells are devices that convert a fuel, typically natural gas or hydrogen, into electricity and heat. Unlike an internal combustion engine, which burns the fuel to create mechanical energy that is then converted back to electricity, a fuel cell uses chemical reactions to create electricity directly. This process is highly efficient and produces low emissions.

The five basic steps of fuel-cell operation are shown in **Figure 11.7** and described below:

1. Methane from natural gas enters the fuel cell and reacts with high-temperature water vapour to form carbon dioxide and hydrogen.
2. Hydrogen enters the cell through the anode; the anode oxidises the hydrogen, removing the electrons from the fuel.
3. The electrons travel through the anode and into the electrical load circuit.
4. The oxidised fuel passes through the electrolyte, a special membrane that allows only the oxidised fuel through.
5. The oxidised fuel reacts with oxygen at the cathode and the electrons returning from the load circuit. This by-product constitutes the exhaust emissions.

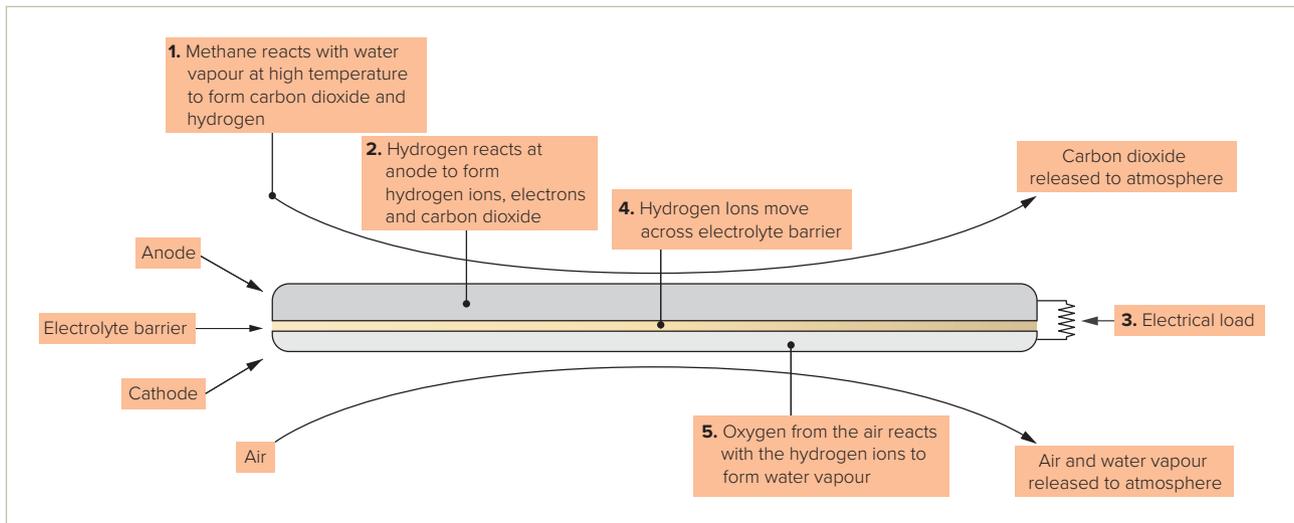


FIGURE 11.7 The five basic steps of fuel-cell operation

While there are many different types of fuel cell on the market, the biggest difference between technologies is in the fuel that they use to produce electricity. The two most common types are hydrogen and natural gas.

Hydrogen fuel cells cause hydrogen gas to react with oxygen. This process was first demonstrated more than two hundred years ago and is a well-known and well-understood technology. Hydrogen fuel cells have the advantage that they can be turned on and off quickly, can operate at fairly low temperatures and produce only water as an emission. These advantages make them popular for use in vehicles.

Natural gas fuel cells take in either bottled or mains natural gas and use the major component of the gas, methane, as fuel. Natural gas fuel cells have the advantage over hydrogen technology that natural gas supply networks are well established around the world. The disadvantages of natural gas fuel cells are that they operate at high temperatures, take a longer time to start and emit carbon dioxide as an exhaust gas.

Output

The output of a fuel cell is direct current (d.c.) electricity. Some fuel-cell units include an integrated inverter (d.c. to a.c. converter, discussed in **subsection 11.1.6**), while others will require an additional inverter if the aim of the installation is to connect to the electricity grid or to supply a.c. loads.

Fuel cells also generate heat as part of the generation process. Many units are designed so that this extra heat can be used to heat water, particularly in domestic applications. If this is the case, it is important to ensure that a

sufficiently large hot-water reservoir is connected to the unit and that all plumbing work is completed by a suitably licensed person.

11.1.4 Wind generators

Wind generators are a highly visible form of renewable energy generation. Wind generators harness the energy of the wind to turn the blades of a turbine. The mechanical energy then creates electrical energy in the turbine. For a wind turbine to be economical, it requires a reliable wind resource and thorough consideration of both the chosen site and tower height. It should also be noted that, unlike photovoltaics and fuel cells, wind turbines require regular maintenance due to their many moving parts.

There is a vast range of wind turbines available worldwide, with more and more options regularly reaching the market. This constantly changing product choice can make comparing different products difficult, because there are very few standard references used to rate wind turbines. However, some of the most common points of comparison are the power rating, whether the blades are upwind or downwind of the turbine, how the turbine turns to capture the wind (yawing), the way the turbine protects itself from extremely high winds (furling) and which axis the turbine spins around (horizontal or vertical axis).

Wind turbines vary greatly in size, shape and complexity (see **Figure 11.8**). The most common design is the horizontal axis wind turbine (HAWT), a category split into upwind and downwind generators. Upwind generators are units where the turbine itself is forward of the mounting pole relative to the direction of the wind, whereas downwind generators have the turbine aft of the pole. Depending on its size, profile and number of blades, the turbine can be optimised for different wind speeds.

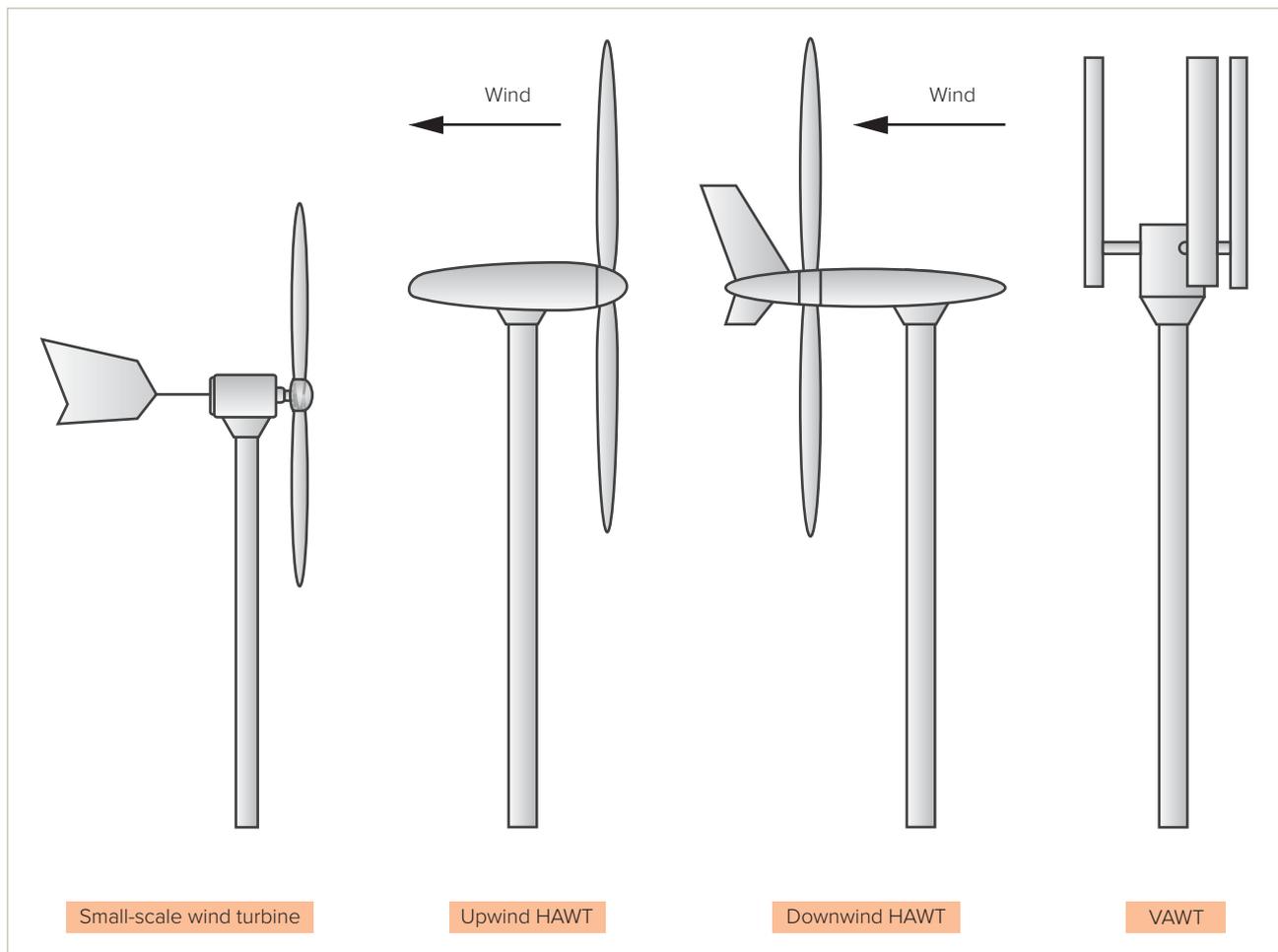


FIGURE 11.8 Types of wind turbine commonly seen in industry, including horizontal axis and vertical axis machines

Vertical axis wind turbines (VAWTs) are a more recent development. These turbines come in a range of forms, from vertical blades or cups that spin about the mounting pole to large rotating helixes. These turbines offer simplicity; they do not require yawing or furling systems. Despite their advantages, these turbines rarely perform at the same efficiency as HAWTs. *Yawing* refers to the ability of a wind turbine to pivot on its support to face the wind. This functionality is essential in all areas without a highly prevalent wind direction, as the turbine's efficiency is greatly reduced when it is not facing the wind.

While larger turbines are usually controlled electronically, with a motor to turn the turbine into the prevailing wind as shown in **Figure 11.9**, smaller scale units incorporate a sail at the rear of the device to point the device into the wind (see first turbine in **Figure 11.8**). This sail also acts as a furling device.

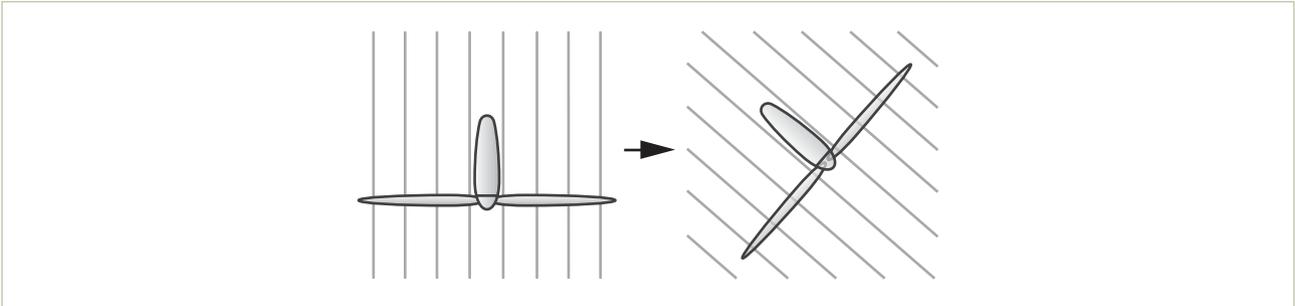


FIGURE 11.9 Yawing turns a wind turbine so it faces the oncoming wind and so can generate as much energy as possible; many wind turbines have a mechanical yawing system

Furling describes a mechanism utilised in small-scale wind turbines to reduce the potential for damage to the turbine during periods of high wind. The turbine's tail is adjusted to point the turbine at an angle to the wind, as shown in **Figure 11.10**, reducing its effectiveness but limiting the likelihood of damage due to excessive blade-tip speed. The tails of smaller units require manual adjustment, although medium-sized turbines can detect dangerous wind speeds and adjust automatically.

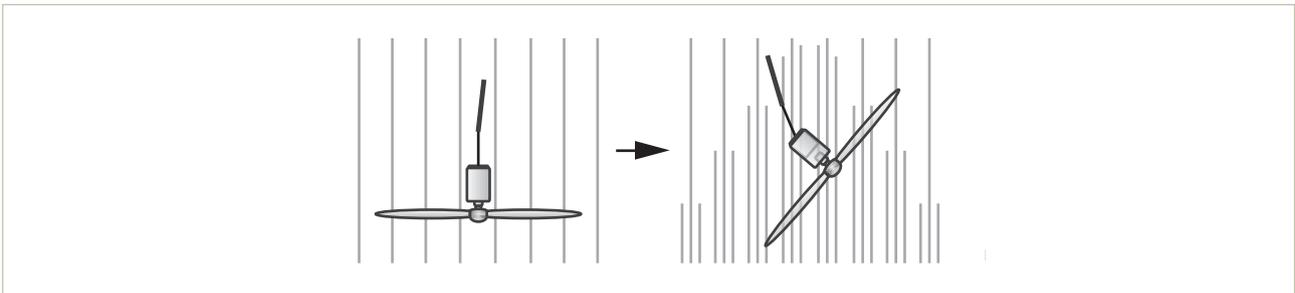


FIGURE 11.10 Furling turns wind turbines away from oncoming wind that is too strong. The left image shows an unfurled turbine operating in normal wind conditions with the tail running directly out behind the turbine. In the right image, the stronger wind has furling the turbine (pushed its tail to the right), directing the blades away from the wind

The furling mechanism fitted to wind generators means that the generator can be positioned slightly out of the wind so that:

- ▶ it will not be damaged
- ▶ it will still be able to produce power.

Wind generators without any furling mechanism may have to pull completely out of the wind for self-protection during periods of high winds. These generators will produce no power until the wind speed decreases and they are able to reposition themselves safely.

Large-scale turbines achieve the same effect by regulating the blades themselves. A blade's effectiveness is related to the angle made with the wind, so rotating the blade can reduce the force transferred to the hub. This in turn reduces the rotational velocity of the unit and avoids dangerous blade-tip speeds.

Output

Wind generators' output can be either d.c. or a.c. depending on their design; however, a.c. output turbines are the most common on the market. Although the output is a.c. it is not typically a grid-quality sine wave. For this reason, it is necessary to modify the output so it is a useable grid-quality a.c. supply. This a.c. output is either fed into a rectifier to convert the a.c. to d.c. for d.c. battery charging, or fed through a converter to match the wind generator's output to the grid specifications. Wind turbines produce no emissions when they operate.

11.1.5 Micro hydroelectric generating systems

Micro hydroelectric generating systems make use of water to produce localised electricity generation for particular situations. They use the flow and fall of a nearby water supply to produce a low-maintenance and emission-free source of energy. These systems can be used to supply energy to nearby installations or to provide water pumping from the river or stream to nearby properties. **Figure 11.11** shows a micro hydroelectric generator.



FIGURE 11.11 Micro hydroelectric generator
Boutique Power

Given the nature of these systems and their locations, they tend not to be used for more than local applications. With the significant and ongoing reduction in the cost of PV systems, micro hydroelectric has had a steep decline in popularity in recent years.

11.1.6 Inverters

Inverters are used to convert direct current (d.c.) electricity derived from PV arrays, batteries and other d.c. sources to alternating current (a.c.) electricity. They have undergone significant improvement and development in recent years and are now lighter and cheaper than ever before, and continue to improve. They make use of solid-state power electronics to produce, from a variable d.c. supply, a quality and stable a.c. sine wave that can be used directly to power an installation or sent back into the grid for broader consumption.

Inverters are not generators themselves, but are used to convert the energy derived from other generating sources like PVs or battery systems. A more comprehensive explanation of inverter operation and usage will be detailed in **Section 11.4**.

11.1.7 Batteries

While batteries have been around since electricity was first discovered, they have made significant progress in the last 10 years and continue to produce advances in materials and methodologies. Traditionally batteries were considered primarily for cars and portable devices, but they are now being installed widely to provide mainstream electricity requirements for homes and businesses.

Major types of storage batteries include:

- ▶ lead acid (see **Figure 11.12**)
- ▶ lithium-ion (see **Figure 11.13**)
- ▶ zinc bromide (see **Figure 11.14**)
- ▶ sodium nickel chloride (see **Figure 11.15**).



FIGURE 11.12 Lead acid battery



FIGURE 11.13 Lithium-ion storage battery

Malp/Alamy Stock Photo

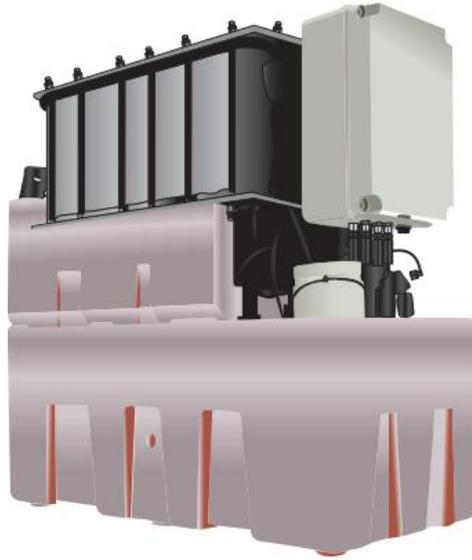


FIGURE 11.14 Zinc bromide flow battery



FIGURE 11.15 Sodium nickel chloride battery

Many battery systems are now sold as complete systems that require only an electrical connection and physical installation. They contain the necessary monitoring and system-output electronics and associated safety systems.

Great care should still be taken with storage battery systems, as they can contain very high energy and voltages and so produce significant fault currents. These precautions and further details are provided later in the chapter.

11.1.8 Regulations

There are many regulations and Standards covering renewable energy and alternative energy supply systems. These Standards relate to safety, design and system performance. In addition, almost all alternative supply systems are designed to take advantage of government incentives, which often place additional best practice requirements on the system.

All electrical systems, grid connected or otherwise, must comply with the *Wiring Rules, Electrical installations* and must be installed according to work health and safety (WHS) and safe work practice requirements. Some of the applicable Standards that must be observed during alternative energy installations are:

- ▶ Grid connection—*AS 4777: Parts 1, 2 and 3: Grid connection of energy systems via inverters*
- ▶ Solar arrays—*AS/NZS 5033 Installation of photovoltaic (PV) arrays*
- ▶ Standalone systems—*AS/NZS 4509 Parts 1 and 2: Standalone power systems*
- ▶ Battery banks—*AS 4086 Parts 1 and 2: Secondary batteries for standalone power systems*
- ▶ Lightning protection—*AS/NZS 1768 Lightning protection*
- ▶ Wind loading—*AS/NZS 1170.2 Structural design actions—wind actions*
- ▶ Generating sets—*AS/NZS 3010 Electrical installations—generating sets*
- ▶ State and local government regulations—Local environmental plans etc.

This is not comprehensive and shows only some of the applicable Standards. Any single installation may fall into any or all of these categories and it is the responsibility of licensed tradespeople, accredited designers and installers to remain up to date with the current requirements of their work practices.

Additional guidelines for the installation of alternative energy systems are provided by the Australian Clean Energy Council (CEC) design and installation guides for grid connected PV systems and standalone power systems. The CEC also manages the design and installation accreditation for alternative energy systems, which electricians require in order to be eligible for government funding and incentives.

Figure 11.16 shows the relationships between a renewable energy system and the Standards, regulations, guidelines and compliance activities that may be needed. Note that this is a representation only and each system will have individual needs and compliance requirements.



CHECK YOUR UNDERSTANDING

1. What is the smallest part of a solar photovoltaic array?
2. List three de-rating factors affecting photovoltaic installations.
3. Name three types of storage batteries.
4. What is the Australian Standard applicable to grid connected solar installations?

11.2 Alternative supply systems

When an alternative supply system is incorporated into an electrical installation, there are a range of implications that need to be considered. *AS 3000 Section 7.3* provides details and requirements for the connection of alternative supply systems. The *Wiring Rules* detail selection of a system and other applicable Standards, isolation and overcurrent protection of alternative supplies, and the requirements of earthing systems. **Figure 11.17** shows the *AS 3000* connection diagram for an alternative supply to a switchboard with a local MEN connection.

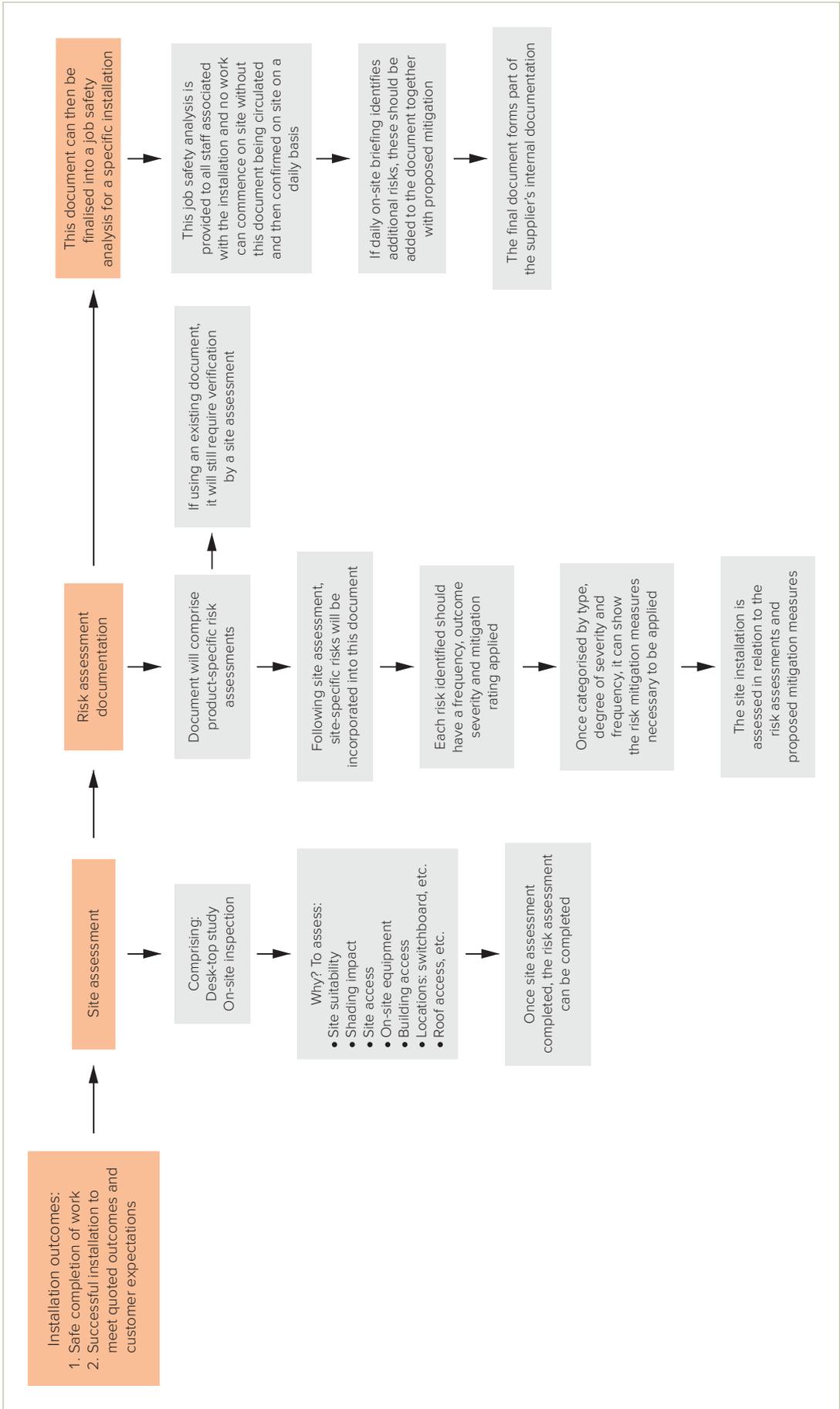


FIGURE 11.16 Flow chart of Standards, regulations and compliance requirements related to renewable energy power systems

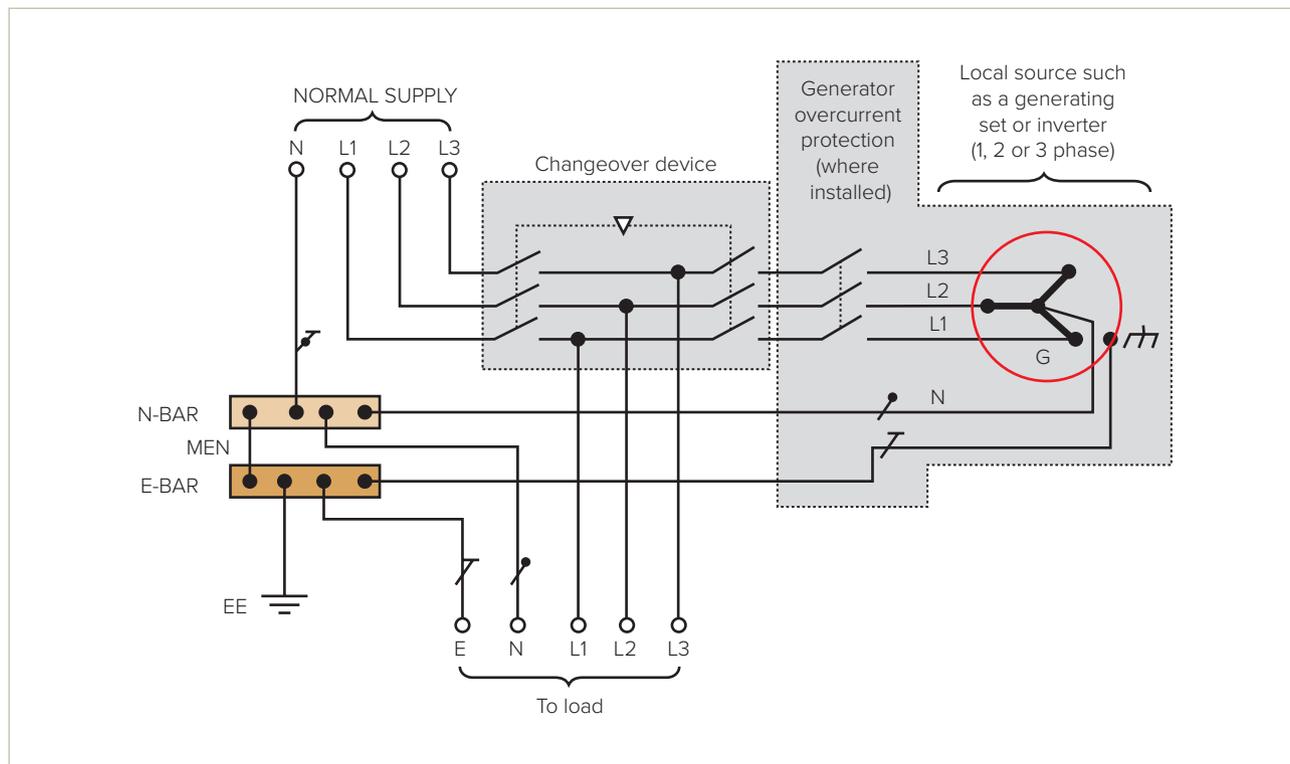


FIGURE 11.17 Example of connection of an alternative supply to a switchboard with a local MEN connection (three-pole/three-pole changeover)

Graphic created using information from the *Wiring Rules* © Standards Australia Limited. Copied by McGraw-Hill with the permission of Standards Australia and Standards New Zealand under Licence CLE0722MGH

11.2.1 Earthing requirements

It is important to understand the earthing system requirements for the installation of alternative supply arrangements. *AS 3000 Clause 7.3.6* provides guidance based on MEN system requirements for how to ensure that all parts are effectively and safely earthed.

11.2.2 Changeover switches

When connecting alternative supplies to a mains-supplied installation, it is vital to ensure there is an electrical separation between the two systems by means of a changeover-switch arrangement. This is to prevent the two supplies being simultaneously connected, as their voltages, frequencies and phase positions may be different. These changeover mechanisms must incorporate a mechanical interlock that physically prevents the two supplies being connected at the same time. The changeover switches can be manual or automatic types and in some cases incorporate the circuit-breaker protection as part of their design.

The major points to note from *AS 3010* when installing a three-pole/three-pole automatic transfer switch (ATS) are:

- ▶ main switchboard contains a MEN link and ATS
- ▶ mains and generator neutrals are not switched
- ▶ mains supply neutral is connected directly to MEN link
- ▶ generator supply neutral is connected directly to MEN link
- ▶ generator overcurrent protection has three-phase protection, no neutral protection.

The ATS can be based on a circuit-breaker or load-break switch. **Figure 11.18** shows a load-break automatic transfer switch, while **Figure 11.19** shows a circuit-breaker automatic transfer switch.

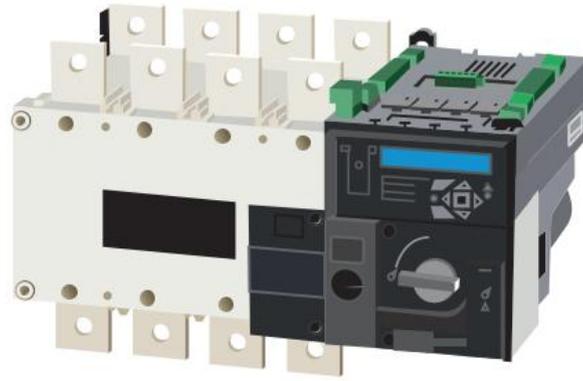


FIGURE 11.18 Load-break automatic transfer switch



FIGURE 11.19 Circuit-breaker automatic transfer switch

11.2.3 System requirements

Consideration needs to be given to the nature of the load that an alternative supply system is required to support. When a power outage creates the need for the alternative supply to be connected, often only essential services are supplied.

In hospitals, for example, there is a range of life-saving equipment that must be maintained, as well as lighting and ancillary loads that can be shed in the event of a power failure. In these sorts of installations, distribution boards are divided into the essential and non-essential services.



CHECK YOUR UNDERSTANDING

5. Which section of the *Wiring Rules* contains information concerning the requirements for connecting alternative supply systems?
6. Why must a changeover mechanism be used when connecting an alternative supply to a mains-supplied installation?
7. Should the neutral and earth from a generator be switched? Why or why not?
8. Can a load-break switch be used as a changeover switch?

11.3 Standalone power systems

As the name suggests, standalone power systems are those that do not have a connection to a grid supply and the local generation forms the only source of energy. These installations need to comply with the requirements of *AS/NZS 3000* and a range of other Standards to ensure safety.



SAFETY ALERT

There is a popular public misconception that, because an installation is not connected to the grid, *AS/NZS 3000* rules and regulations do not apply: this is not true!

An example of the method of connection of a standalone system is provided by *Figure 7.6, AS/NZS 3000*. This method of installation is very similar to the connection to a street supply with an earth electrode, main switch and distribution. The neutral is connected to the star point of the generator and the earth to the chassis of the standalone generator.

11.3.1 Types of standalone systems

In the past, standalone systems were primarily engine-driven generators. The use of a petrol-driven or diesel-driven motor to rotate an electrical generator or alternator provided the required power for the installation. This, however, has a few drawbacks, as the system needs to be sized for the peak load and either run all the time or started repeatedly, creating waste and wear.

It is not uncommon for a standalone system to incorporate multiple sources of generation. In **Figure 11.20**, we see an example installation that incorporates a solar array, battery storage and a backup generator.

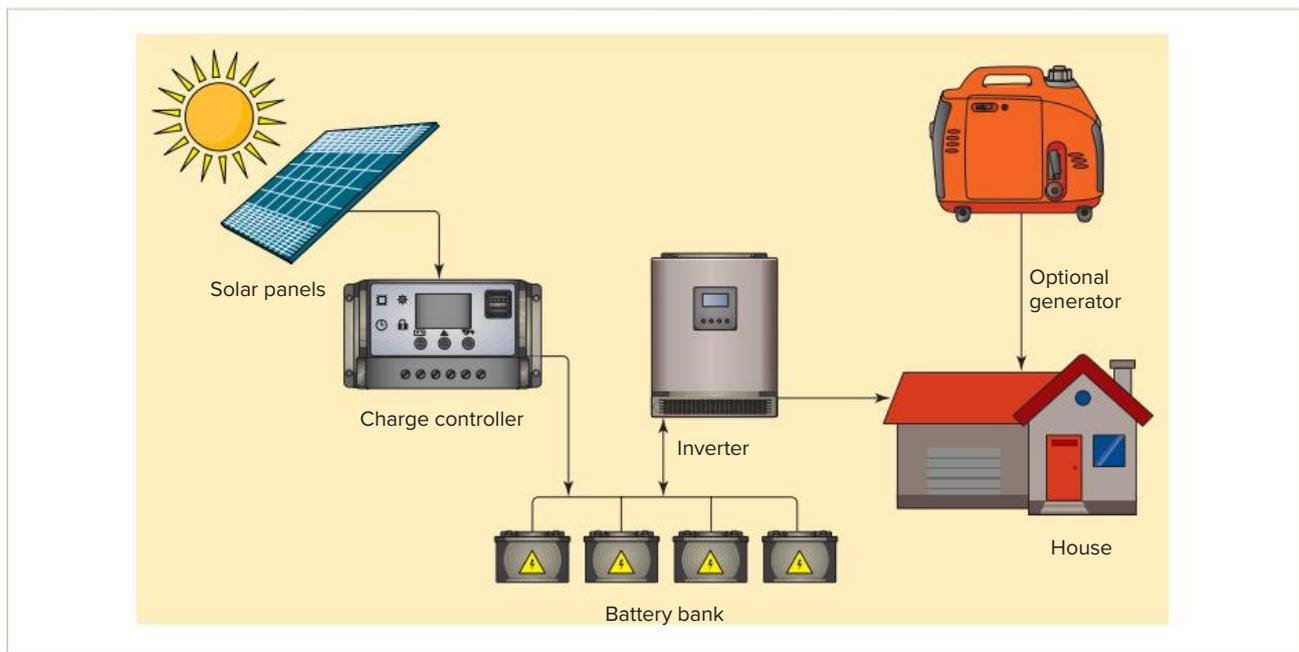


FIGURE 11.20 How standalone power generation systems work

11.3.2 Design of standalone power systems

When considering the design of a standalone system, there are a range of variable conditions to be considered. A site assessment should be undertaken in order to better understand the requirements of both the loads and the available

alternatives for generation. A high wind area may allow for very effective wind generation, or a nearby river or stream may bring micro hydroelectricity into the mix.

Design of such complicated systems is usually undertaken by specialists in the field due to the many complex factors. Considerations such as oversizing form part of the design process. Oversizing means that a system should have enough capacity to allow for variances in system output due to ambient conditions or system tolerances. Australian Standard *AS/NZS 4509.2* details that an oversizing factor between 1.3 and 2.0 should be included in system calculations to ensure continuity of supply and prevent system failure.

11.3.3 Standards and regulations

Low-voltage standalone power systems are required to be installed so they meet a range of existing and potential new Standards. Current Standards that need to be considered include, but are not limited to:

- ▶ *AS/NZS 3000 Wiring Rules*
- ▶ *AS/NZS 3010 Electrical installations—generating sets*
- ▶ *AS/NZS 4509 Standalone power systems*
- ▶ *AS/NZS 5033 Installation of photovoltaic arrays*
- ▶ *AS/NZS 4777 Grid connection of energy systems via inverters*
- ▶ *AS/NZS 5139 Electrical installations—safety of battery systems for use with power conversion equipment.*



CHECK YOUR UNDERSTANDING

9. Define a standalone power system.
10. List three items you might find in a standalone power system.
11. What sizing factor should be applied when designing a standalone system?

11.4 Inverter systems

An inverter is a device that is used to convert direct current (d.c.) to the more commonly used alternating current (a.c.) for use in distributed systems. This process is undertaken by power electronic components that take the steady flat-line d.c. output of batteries and photovoltaic arrays, and convert or ‘invert’ it to a sinusoidal waveform, as shown in **Figure 11.21**.

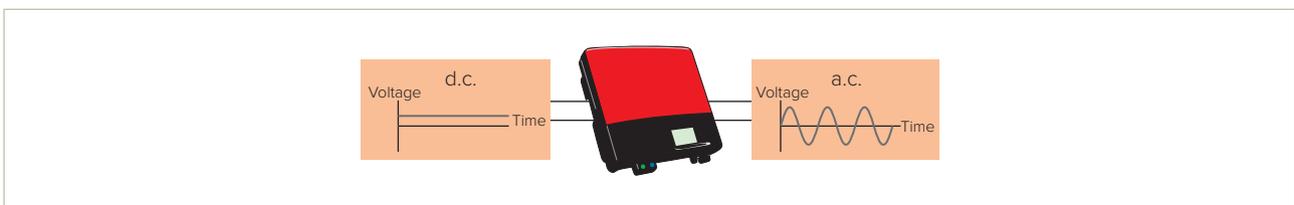


FIGURE 11.21 Inverters convert direct current electricity to grid-quality alternating electricity using power electronics

Most of the loads in a modern domestic installation use a.c. electricity and this will most likely continue for some time. Electricity from PV arrays and batteries, however, is d.c. and so needs to be converted for use in the installation.

11.4.1 Types of inverters

Standalone inverters

Standalone inverters range in size from around 100 watts to many kilowatts. You may be familiar with small-scale inverters that plug into 12 V sockets in cars for charging phones and other low-energy devices. Portable inverters up to 2.4 kW are available for camping and other outdoor activities, and connect to either batteries or portable PV arrays.

Standalone inverters have two types of outputs: modified sine wave and true sine wave. Modified sine wave inverters generally produce a sine wave that is poorly shaped and thus not suitable for many applications. It can supply switch-mode power supplies and lighting fairly well, but cannot be used for motors, transformers or voltage-sensitive equipment.

Figure 11.22 shows a small standalone inverter, while **Figure 11.23** shows a large standalone/multi-mode inverter.



FIGURE 11.22 Small standalone inverter

Selectronic Australia Pty Ltd



FIGURE 11.23 Large standalone/multi-mode inverter

Selectronic Australia Pty Ltd

For any standalone situation, you must ensure that a true sine wave inverter is used and that it can provide an output to match the installation, typically 230 V at 50 Hz. These inverters may be rated in one of two ways: maximum continuous output and peak output. The peak output can meet the requirements of the starting load and initial inrush current of some devices like motors.



Standalone inverters cannot, and must not, be connected to the a.c. grid!

Grid connected inverters

Grid connected inverters, as the name suggests, are designed to be connected to the electricity supply grid. They are designed not to function unless they first establish a connection with an existing grid supply. Once the supply is detected, the inverter will match its output characteristics to those of the supply and then begin to function. If the grid supply is lost for any of several reasons, the inverter will immediately shut down and stop producing an output. Once supply has been restored, the inverter will reconnect after a programmed period of time. This process is known as anti-islanding and it is a requirement of the Australian Standard *AS 4777* and should be tested regularly. **Figure 11.24** shows a grid connected inverter.



FIGURE 11.24 Grid connected inverter
Selectronic Australia Pty Ltd

When an inverter is supplying to the grid, it must conform to *AS 4777* and have the following characteristics:

- ▶ grid voltage = 230 V single-phase line to neutral
- ▶ power factor ranging from 0.8 leading to 0.95 lagging, although most inverters operate at a power factor of 1 only
- ▶ voltage tolerance of +10% to -6%
- ▶ frequency = 50 Hz
- ▶ total harmonic distortion less than 5%.

Multi-mode inverters

Multi-mode inverters are designed to be able to provide a grid connected solution as well as an off-grid solution. They offer the flexibility to import and export electricity depending on installation needs, as well as providing a complete standalone system when coupled with an energy-storage system. This flexibility can also allow the unit to provide the installation with an uninterruptible power supply and load-shifting adjustable export control. The connection to a multi-mode inverter can be via both alternating current (a.c.) or direct current (d.c.) and the device has onboard software that allows many configurations of use.

The installation of grid connected inverters with associated PV arrays may be subject to specific rules and regulations, depending on the local supply authority, and may require individual inspection. This may also apply to the associated metering that allows both the import and export of energy associated with the grid connection. There are currently a series of national units of competency associated with the installation of grid connected inverters and PV arrays in order to receive the associated rebates and government incentives.

11.4.2 Energy exporting

Most of us are familiar with the purchase of electricity from a supply authority or, more recently, an energy retailer. With the popularity of both PV and battery systems, it is now possible for average domestic installations to become an 'energy retailer' themselves. When either energy is generated that is in excess of the installation needs or stored energy is not needed, it can be sent back into the grid and payment received. This payment varies based on location, time, government policies and energy retailer rates.

Specialist metering is also required for the import/export and this is being rolled out throughout the country as part of the smart meter programs (see **Figure 11.25**). These meters can be programmed with various tariff rates and can calculate the value of usage based on whether the installation is importing or exporting.

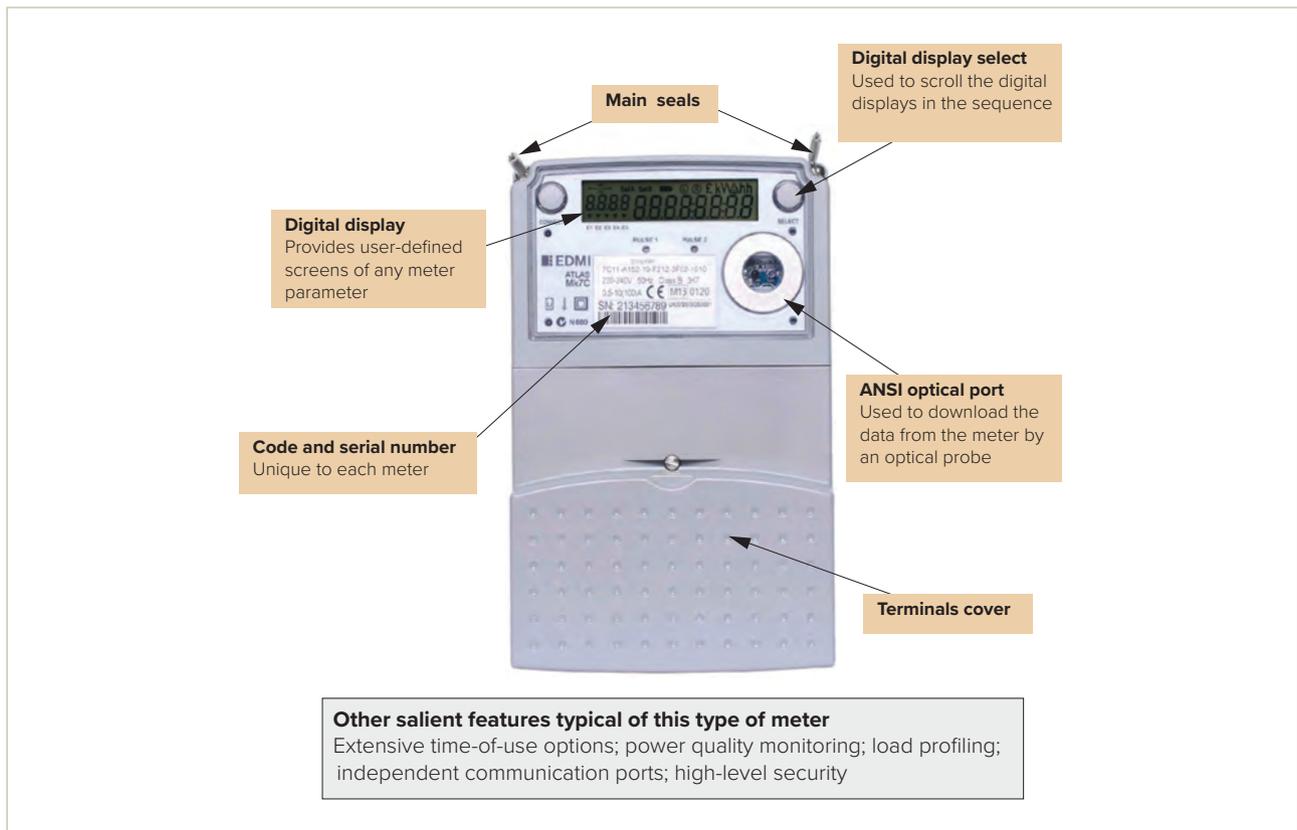


FIGURE 11.25 Example of a whole current, single-phase smart meter

EDMI Pty Ltd

11.4.3 AS/NZS 3000 requirements for inverters

The *Wiring Rules* have a range of requirements for the installation of inverters to ensure their safe and effective installation. *Section 4.12* details a range of requirements with regards to selection, control, isolation, overcurrent protection and earthing. Further direction for the installation of inverters is contained in *Section 7.3* of the *Wiring Rules* and this details the requirements for inverters as energy-generation systems. The installation of inverters must also comply with the requirements of *AS 4777* for grid connected and *AS 4509* for standalone systems.



CHECK YOUR UNDERSTANDING

12. What is the function of an inverter?
13. Is it possible to export excess energy from a home?

11.5 Battery systems

Battery systems are used for the storage of electrical energy for use at a later time. Recent developments in both battery types and their large-scale production have resulted in a rise in capacity and a reduction in cost. Even as you read this chapter, new and emerging battery technologies are being produced. The ability to effectively store energy made from renewable sources is vital as we move away from fossil fuel and other non-renewable or polluting sources of energy.

11.5.1 Types of batteries

The most popular types of batteries that are currently available for use are lead acid and lithium-ion. This will almost certainly change, with flow-style batteries becoming more popular and emerging technologies such as sodium nickel making progress. In some publications, the term *battery* is being replaced with *energy storage* as the technologies evolve and the methodologies to store energy evolve also.

11.5.2 Battery safety and hazards

Electrical installations contain a range of hazards, many of which we have already discussed. Batteries and battery banks present a new and significant safety hazard in themselves that needs special consideration. Most battery storage systems have the ability to deliver very high current if a high demand or short circuit is placed on them. While this is a feature of the batteries and very handy for fluctuations in load, it can also result in currents that can cause damage, fire and personal injury.

Older installations have long contained lead-acid battery systems and these are found where backup power was required for installations like telephone exchanges, emergency lighting and other essential services. Hazards of these systems include hydrogen gas discharge, acid spillage and burns, and potential short circuit of the terminals. The installation rooms usually contained safety equipment such as appropriate PPE, safety showers and emergency procedures. Modern battery installations are less hazardous, but still contain the potential for serious harm and so should be approached with caution and knowledge of how to safely work with them.

Lithium-ion batteries have been associated with fires in both aircraft and mobile devices. Their temperature and current need to be monitored to prevent dangerous overheating. Good-quality lithium-ion cells have protection built in for both overcurrent and overtemperature to ensure failure does not occur.

AS 3011 provides guidance for the installation of battery systems and new Australian Standards are also currently being produced to deal with the emerging technologies.

11.5.3 Classification of battery systems

Self-contained systems

The installation and selection of battery systems can be complex and very technical to ensure the correct mix of function, viability and safety. As a result, there is a large and ever-increasing range of self-contained or complete

battery systems available for purchase and installation. These systems take into consideration both the technical and physical aspects of a battery system, and are able to be installed both quickly and without a significant amount of training. This combination, coupled with the appropriate approvals and safety, makes this sort of system preferred by most installers.

Each self-contained system provides the consumer/installer with all the technical specifications regarding the amount of storage, depth of discharge, preferred location of installation and likely performance results. **Figure 11.26** shows a self-contained battery system.



FIGURE 11.26 Self-contained battery system—Tesla Powerwall 2

Stephen Dwyer/Alamy Stock Photo

Partially engineered systems

There are battery systems that have been pre-manufactured and contain the majority of the requirements and Standards that need to be considered. They may require the installation of d.c. interconnections and interfacing with new or existing inverters. Installers will need to consider a range of system data to ensure that the system installed meets both customer and safety requirements.

Bespoke systems

These systems are normally designed from the ground up to suit a particular installation, and the selection of all the equipment is part of the design and installation process. In these types of systems, there is a fundamental requirement that the persons involved are appropriately trained, accredited and capable of making these equipment selection and installation decisions.

11.5.4 Major installations

As the technology used in battery systems improves and costs are reduced, large-scale battery systems are becoming more popular and economical. South Australia recently installed a lithium-ion battery storage system that can provide over 100 MW to create additional grid capacity during high demand and, at the time of publication, is one of the biggest in the world. It is pictured in **Figure 11.27**.

11.5.5 Standards, rules and regulations

The Standard *AS IEC 62619—Secondary cells and batteries containing alkaline or other non-acid electrolytes—Safety requirements for secondary lithium cells and batteries for use in general applications* has been adopted for use in Australia and covers safety requirements for secondary lithium cells and batteries for use in stationary and mobile applications. This Standard can also be used for residential and commercial battery systems.



FIGURE 11.27 South Australian large-scale 100 MW battery storage system

Lincoln Fowler/Alamy Stock Photo

Batteries can be dangerous and consideration must also be given to the transportation of batteries and battery systems with regard to hazardous goods and associated legislation. The Standard *IEC 62281 Safety of primary and secondary lithium cells and batteries during transport* provides important guidance around the safe transportation of batteries.

It is anticipated that upcoming battery installation Standards will recognise the differences between self-contained, partially engineered and bespoke systems, and apply the requirements accordingly.



CHECK YOUR UNDERSTANDING

14. What is the main use of batteries in the application of renewable energy?
15. What is the easiest battery system to install?

11.6 Uninterruptible power systems

11.6.1 Purpose

An uninterruptible power system (UPS) is similar in composition to a SAPS (standalone power system) but, instead of using on-site renewable energy sources to charge the batteries, energy from the grid is used for battery charging. Occasionally photovoltaics are used as a supplementary energy source for battery charging under these conditions, as shown in **Figure 11.28**.

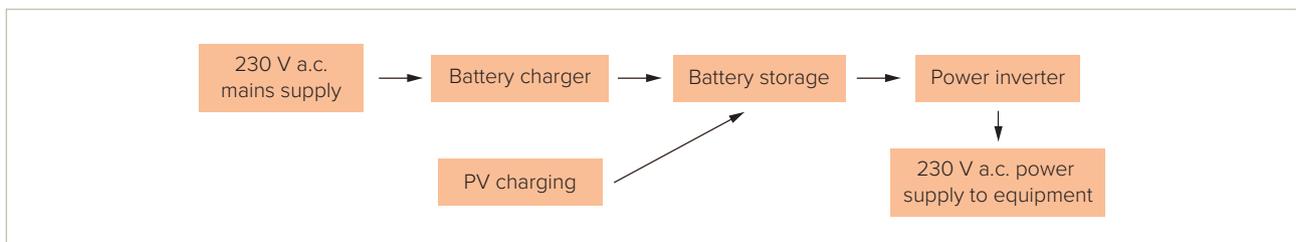


FIGURE 11.28 Typical energy flows in a UPS system

A UPS is used to provide power to essential appliances when the grid fails or when the power supply is affected in some way; for example, the supply voltage has variances that make it unsuitable to operate standard 230 V a.c. appliances. Depending on the UPS used, it can give appliances sufficient time to properly shut down and/or it can be used to run a load during a grid outage until power is restored.

Important considerations when choosing a UPS include:

- ▶ the switching or changeover time, that is the time that elapses between when the grid fails and when the UPS is ready to provide power to the load; this switching time (i.e. the delay) must suit the a.c. loads to be supported
- ▶ the UPS's operating time, that is the length of time that the system can sustain power to a load of a certain wattage
- ▶ the power quality required and how closely the UPS can replicate the characteristics of the power available from the grid.

Matching these criteria to the individual loads is a critical element of UPS selection and sizing.

11.6.2 Types and applications

There are many topologies of UPS available that provide differing levels of power quality, protection time, sensitivity and complexity. The simplest UPS are in-line systems, as shown in **Figure 11.29**. They use a battery charger to provide power to the battery bank (d.c.) before being inverted back to grid-comparable a.c. by an inverter. In this system, the a.c. power supported by the UPS is always supplied through the UPS equipment. For this reason, this type of UPS is also used where a power filter is required for an a.c. supply or the a.c. equipment being used must be operated as a 'no break' system.

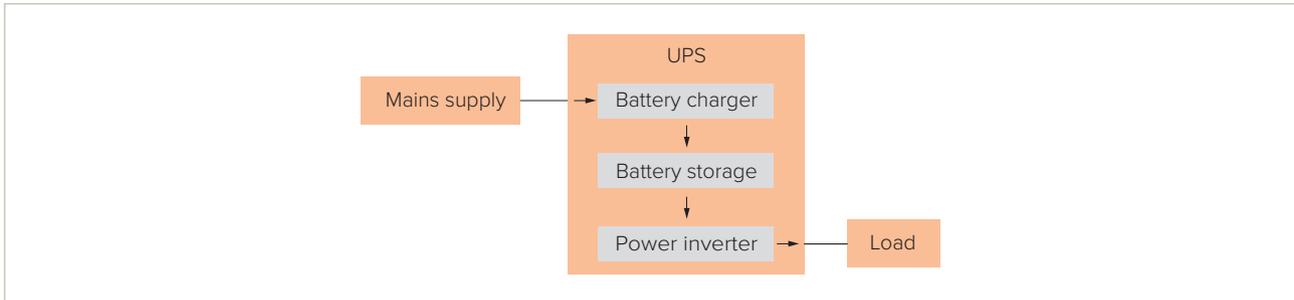


FIGURE 11.29 Energy flows through an in-line UPS device; all energy supplied to the load comes from the batteries in the UPS regardless of whether there is a blackout

Switched systems are similar; however, they switch to inverter power once the grid has failed, meaning that this type of system operates as a backup power supply. These systems are sized and typed according to the equipment to be backed up and will only be activated when the grid power has failed. These more simple UPS are common in small businesses to maintain a server or small medicine fridge.

Flywheel UPS utilise a spinning disc attached to a generator. The spinning disc provides energy to an alternator and the energy required to start the generator should the grid fail. These flywheel systems are rarely smaller than 10 kVA and provide power for large loads such as hospitals and commercial server rooms.

11.6.3 Installation arrangements

It is essential that UPS are installed according to the Standards and service rules, so that circuits of the installation and the electricity grid cannot unintentionally be live in the event of a grid failure. When designing a UPS, it is important to pay detailed attention to which loads are to be connected to the UPS and how the wiring of the

installation is configured in order to ensure that cables and components with the potential to be live during a grid failure or when the main switchboard has been disconnected are not mistaken for a conventional circuit.

When installing a UPS, all components should be suitably housed to protect them from the environment and protect users from electrocution, especially around battery banks. **Figure 11.30** gives an example of a large UPS installation. To ensure safety, any grid-protection devices installed for a UPS must *not* isolate the neutral or earth circuits. **Figure 11.31** shows a typical installation arrangement for a UPS based on *AS 4777*.



FIGURE 11.30 UPS battery system

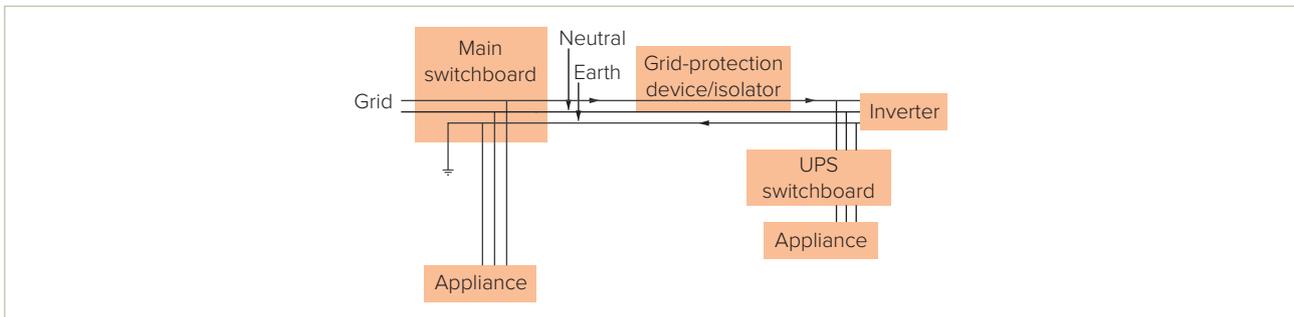


FIGURE 11.31 Typical connection method for a UPS on a grid connected installation

AS 4777.1 and *AS 4777.3* identify additional requirements for UPS, beyond those of standard grid connected inverter systems. These requirements include that a UPS must supply an identifiably separate set of circuits and that, where possible, these circuits should be in a separate switchboard or load centre. It is also essential to provide warning signs at the main switchboard and any other relevant boards to indicate that some circuits may be live when the main switchboard has been isolated, and that this may include any neutral or earth circuit in the installation.



CHECK YOUR UNDERSTANDING

16. Provide examples of loads that may require a UPS.
17. What characteristics should be considered when selecting a UPS?

SUMMARY

- ▶ The selection and use of an appropriate engine-driven generator are determined by factors such as size, location, local requirements and fuel source.
- ▶ Photovoltaic devices use semiconductor materials such as silicon to convert light energy directly into electricity.
- ▶ Fuel cells are used to produce electricity, with the only significant by-product being water.
- ▶ Wind generation is achieved by placing wind turbines in a windy environment and harnessing the generated electricity.
- ▶ Small-scale hydroelectric generation can be used in small standalone systems, usually to feed into battery storage.
- ▶ Batteries are the primary method of electrical energy storage and allow for later use of this energy.
- ▶ A number of rules and regulations apply to enable renewable energy systems to be effective and safe.
- ▶ *AS/NZS 3000* provides methods and diagrams associated with alternative supply systems and their connection.
- ▶ Standalone electrical power systems require careful design to ensure they meet both the relevant rules and regulations as well as intended function.
- ▶ Inverters are used to convert d.c. to a.c. for use in immediate loads and to feed the surplus back into the grid.
- ▶ To ensure the uninterrupted supply of electricity to essential and emergency services a variety of uninterruptable power supplies are used.

REVIEW QUESTIONS

1. a. A number of PV modules connected in series are known as what?
b. A number of strings connected in parallel are known as what?
2. What is a fuel cell?
3. What is the by-product (emission) of a hydrogen fuel cell?
4. What electricity output does a fuel cell create?
5. What is the most common design for wind turbines?
6. What is the electrical output of most wind turbines?
7. List three Standards that should be observed when installing a grid connected system via inverters.
8. List two hazards relating to battery banks.
9. What is an inverter?
10. Where would a grid connected inverter be electrically installed in a PV system?
11. Which Standard outlines the requirements for standalone inverters?
12. *AS 4777* states that an inverter must be able to be isolated from two things. What are they?
13. List three important features to be considered when selecting a UPS.
14. What care should be taken when designing a UPS system?
15. Provide three situations where engine-driven generators would be used.
16. List five Australian Standards that relate to renewable energy systems.
17. List four considerations when designing a standalone hybrid system.

CHAPTER 12

Protection—earthing and protective methods

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ understand the reasons for having an earthing system
- ▶ list the different types of earthing systems in use
- ▶ understand the hazards and risks in an electrical installation
- ▶ understand how the earthing system provides protection against indirect contact
- ▶ describe parts of an earthing system and the purpose of each
- ▶ understand the MEN earthing system as used in Australia and New Zealand
- ▶ list the devices used for automatic disconnection of supply
- ▶ identify the correct size earthing conductors and connection methods required for an electrical installation
- ▶ describe the faults that may occur within an installation that affect the earthing system and the hazards that can occur
- ▶ describe the application arrangements of SELV and PELV circuits.

Although the earthing system does not affect the actual operation of appliances or equipment, it is the most important part of the installation in its protective role against the risk of electric shock and fire hazard when a breakdown of insulation occurs.

In an effective earthing system, exposed conductive parts are electrically connected to the general mass of earth, that is, to the earthing system network in a distribution area. Remember, exposed conductive parts are those that could become live if a single layer of insulation fails (*Clause 1.4.73*). An effective earthing system usually ensures that, should a fault occur in an appliance, sufficient current flows to earth to operate a circuit-breaker or fuse so as to disconnect the appliance from the supply. Leakage currents to earth are small and insufficient to operate the fuse or circuit-breaker, in which case a residual current device (RCD), where installed, will detect the leakage current and disconnect the circuit. (These devices are covered in detail in **Chapter 16**.)

To understand how an earthing system operates, you should know the basic principles of the earthing systems described in this chapter and be familiar with the requirements of *Section 5* of the *Wiring Rules*. Low-voltage installations in Australia and New Zealand incorporate an earthing system to fulfil these requirements.

12.1 Reasons for an earthing system

A fundamental safety principle of electrical installations is the protection of persons and livestock against, as *Clause 1.5.5.1* puts it, ‘the danger that may arise from contact with exposed conductive parts which may become live under fault conditions’. The principal method used is the automatic disconnection of the supply (*Clause 1.5.5.2(a)*), of which the earthing system is an integral part.

Going about our normal day-to-day activities, we are in constant contact with the Earth’s conductive surface, so any rise in voltage between the Earth and exposed or extraneous conductive parts, such as the metal case of a washing machine, places a person who touches the metal case at risk of electric shock (see **Figure 12.1**).

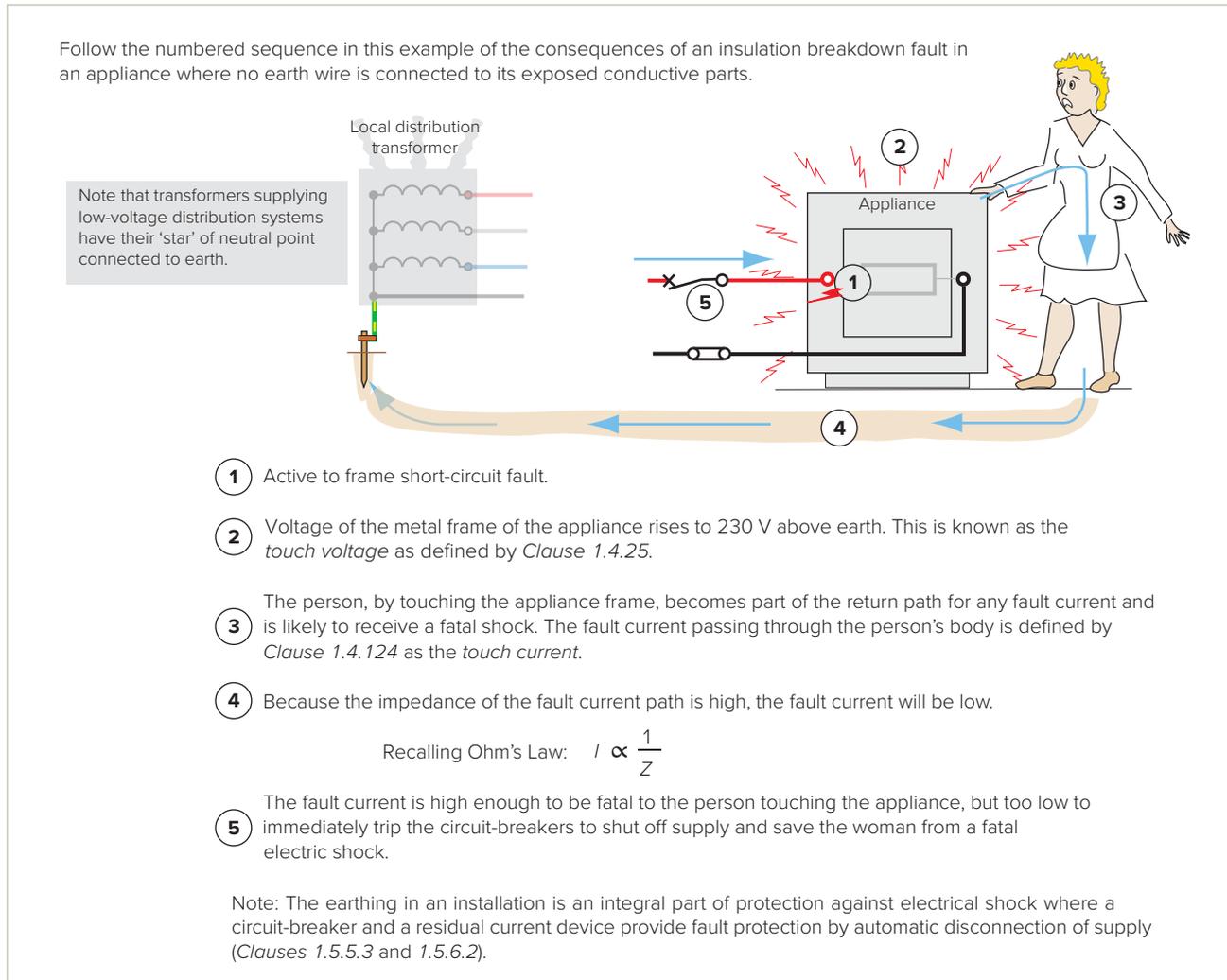


FIGURE 12.1 Consequences of not having an earth wire connected to exposed conductive parts

Even when all materials for an installation are carefully selected and then carefully installed to comply with strict specifications and *Wiring Rules* requirements, the possibility of insulation failure in the wiring or equipment is ever present. The failure of insulation immediately introduces hazards to life from electric shock and hazards to property from an electrically initiated fire.

12.1.1 Shock hazard

The consequence of not having an earth wire connected to exposed conductive parts, such as the metal frame of an appliance when a breakdown in insulation occurs, is illustrated in **Figure 12.1**.

12.1.2 Electrically initiated fire

The heat that develops in an electrical fault is sufficient to start a fire and is commonly cited in news reports as a possible cause of fires. The example given in **Figure 12.2** is for a short circuit to earth fault that introduces no further impedance in the fault current path; it is as if the active conductor was bolted to the appliance frame and is therefore known as a bolted fault or more commonly a dead short circuit. However, short-circuit faults occur where the impedance of the fault path prevents sufficient fault current from flowing to trip the protective device in the prescribed time. This type of fault is often referred to as a partial short circuit.

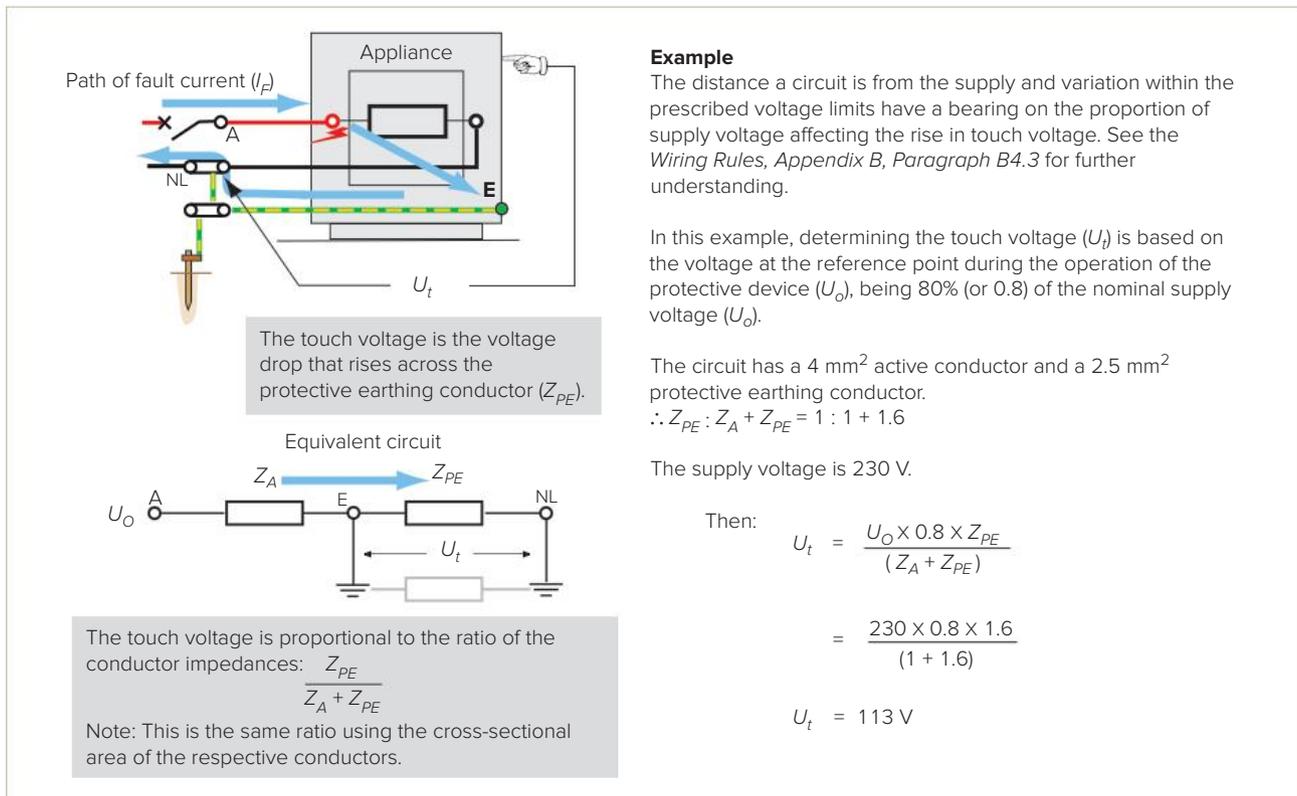


FIGURE 12.2 Limiting a rise in touch voltage

A fire caused by a fault, whether a dead short circuit or a partial short circuit, is an ever-present hazard owing to the heating effect of the fault current, as shown in **Figure 12.3**.

12.1.3 Voltage stability

Another reason for earthing is to ensure that the supply active and neutral are maintained at a fixed and stable potential with respect to earth. This condition is not obtained in an unearthed system, where a fault or standing leakage current could cause the potential of the earthing system to ‘float’ or vary in value relative to other parts of the system. Consider one type of fault that might occur, as shown in **Figure 12.4**, in an unearthed system as compared with an earthed system.

12.1.4 Functional earthing

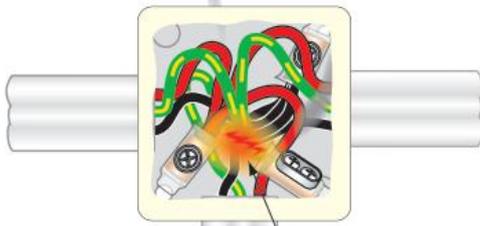
The earthing necessary for the correct functioning of some types of electrical equipment, and not for the operation of overcurrent-protection devices, is defined as a functional earth by *Clause 1.4.66*. Equipment such as that used for entertainment, communications and instrumentation is often affected by stray currents in an earthing system and exposed conductive parts of this equipment.

If fault current is present for even a short period, a fire hazard exists owing to the heating effect of this current. The heat developed is proportional to the duration of the fault current and the resistance, but it varies as the square of the current value:

$$H = I^2 R t$$

where H = heat developed in joules
 I = fault current in amperes
 R = resistance in ohms
 t = time for which fault current flows in seconds.

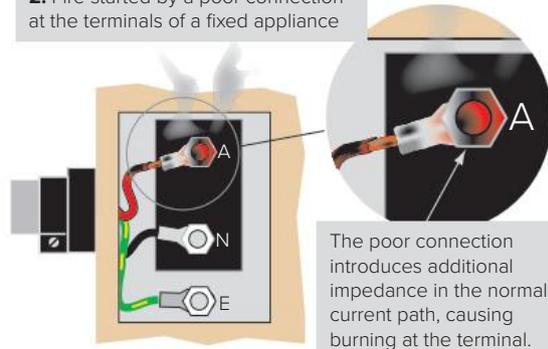
1. Fire started by a short circuit in a TPS junction box



A short circuit between active and earth connectors caused by moisture and dust accumulation in the junction box.

The short circuit in this example is likely to be a bolted fault and will trip the circuit-protective device quickly, isolating the fault and preventing further damage.

2. Fire started by a poor connection at the terminals of a fixed appliance

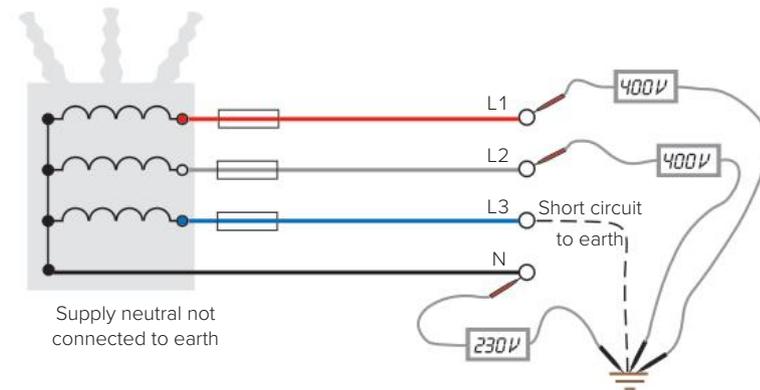


The poor connection introduces additional impedance in the normal current path, causing burning at the terminal.

The burnt terminal in this example will likely result in a partial short circuit to earth that will reduce the chance of the circuit-protective device quickly tripping. In this case a residual current device (RCD) would act immediately to isolate the fault. RCDs are illustrated later in this chapter and are covered in more depth in **Chapter 9**.

In these examples, effective earthing minimises the danger of fire hazards by ensuring that, should a fault occur, sufficient current will be present to operate a protection device (i.e. circuit-breaker, fuse or RCD) and quickly isolate the fault before a fire can start or gain a hold.

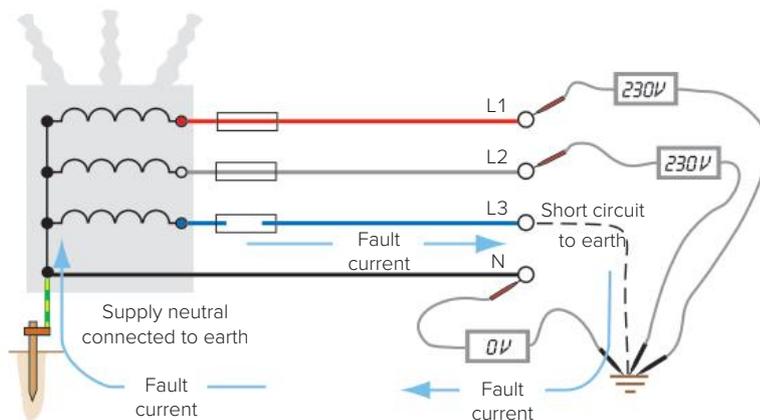
FIGURE 12.3 Limiting the risk of fire



Supply neutral not connected to earth

The short circuit raises earth to the same potential as L3 as shown by the voltages measured from the site of the short circuit. The voltages will be shown to vary from these values when measured from other points to earth.

Although this is a serious fault, the circuit-protection fuse will not operate as no current flows due to the fault.



Supply neutral connected to earth

Fault current

The low-voltage supply systems in Australia and New Zealand are earthed systems, the nominal voltages of which are:

- L1 to L2 = 400 V
- L1 to L3 = 400 V
- L2 to L3 = 400 V
- L1, L2 or L3 to N = 230 V
- N to Earth = 0 V

The short circuit here does not disrupt the stability of the voltages due to the neutral being earthed at the supply.

The fault current ensures that the circuit-protection fuse will operate, isolating the fault.

FIGURE 12.4 Stabilising earth potential in the supply system

These currents can induce voltages in the electrical circuits of the equipment, causing interference with its normal function. For example, unwanted noise in an entertainment system could be the result of poor functional earthing; some types of residual current device (covered in **Chapter 13**) use a functional earth.

The goal of functional earthing is to eliminate any potential difference in the earthing system or conductive parts associated with this equipment that may carry a current in normal use. Often a star system of earthing is used where all equipment is earthed at one point, so that there is no closed circuit within which a stray earth current could flow. Advice on the need for functional earthing should be obtained from equipment manufacturers; however, the requirement for protective earthing takes precedence over any functional earthing (*Clause 5.2.3*).

Figure 12.5 shows an example of functional earthing used to suppress or eliminate noise in the telecommunications equipment in a customer's premises.

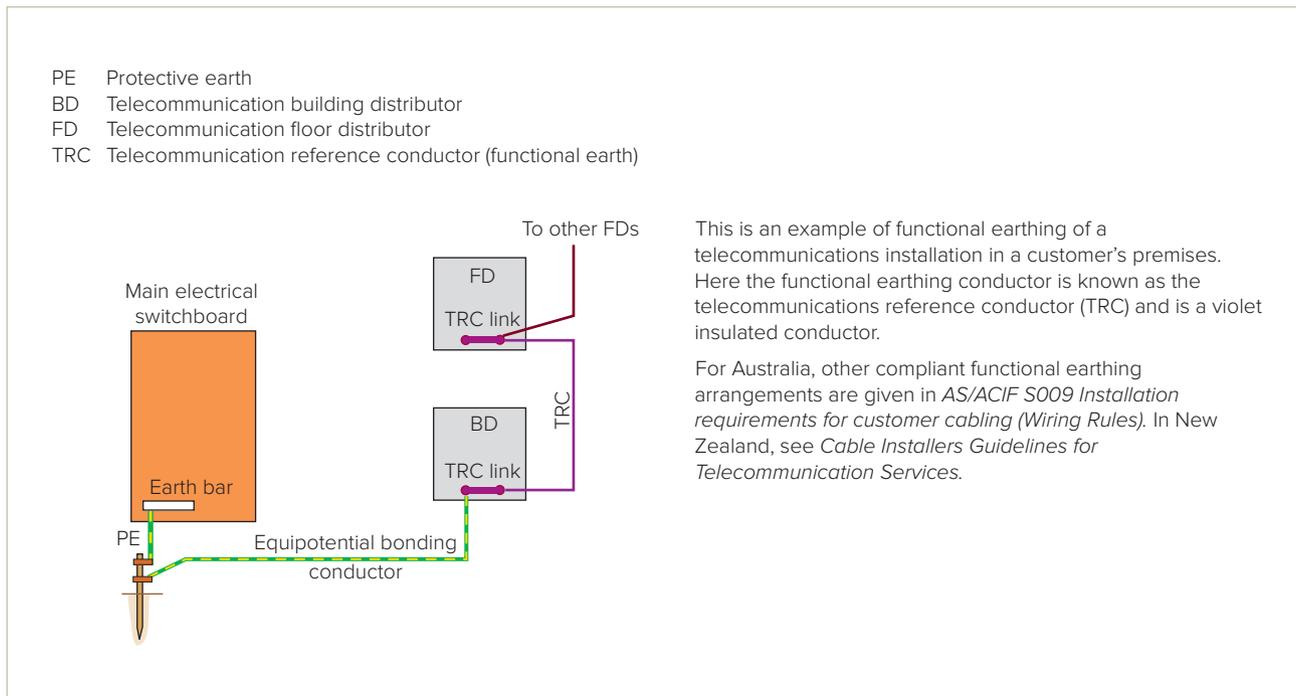


FIGURE 12.5 Example of functional earthing



CHECK YOUR UNDERSTANDING

1. How does an earthing system provide safety against electrical shock hazards?
2. What is the main hazard associated with high fault currents?
3. How does a system of earthing improve system voltage levels?
4. What is functional earthing?

12.2 Earthing systems

As can be seen from **Section 12.1**, the earthing system plays a major role in protection against electric shock, prevention of damage by electrically initiated fires and the functioning of some equipment. There are several earthing and protection schemes used in different parts of the world and, although the standardised distribution

systems in Australia and New Zealand use one particular scheme, other arrangements are permitted according to the *Wiring Rules Part 1* and *Clause 5.1.4*. The International Electrotechnical Commission (IEC), of which Australia and New Zealand are members, categorises three distribution schemes by the coding systems shown in **Figure 12.6**.

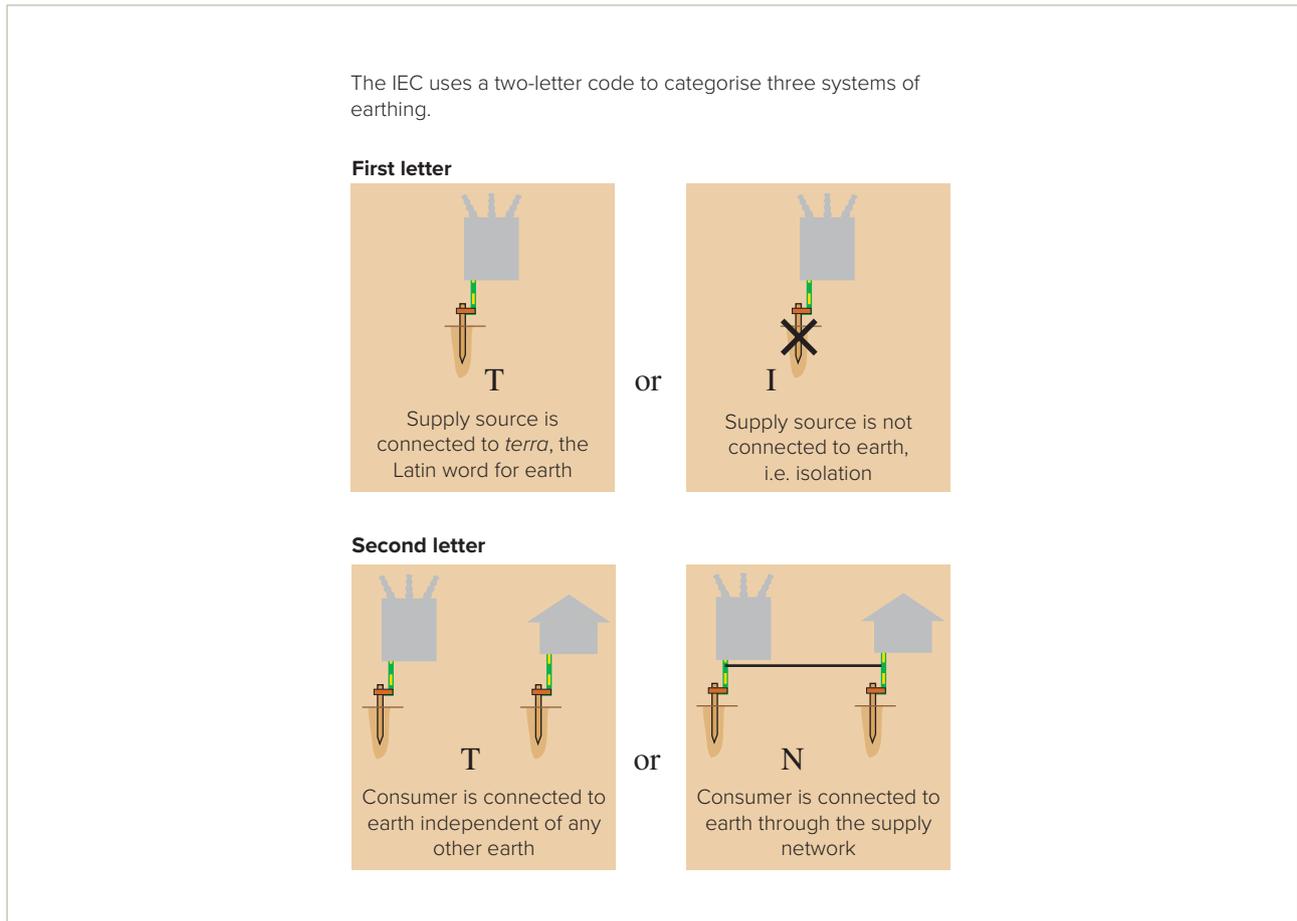


FIGURE 12.6 IEC distribution system code

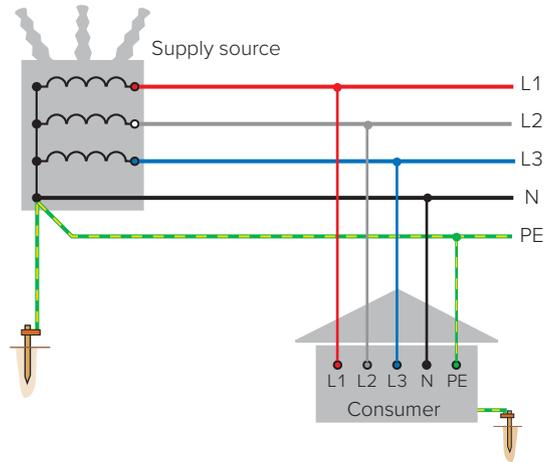
The most common earthing and protection scheme, the TN system, is explained in **Figure 12.7**. The TN-C-S variant is the one used in Australia and New Zealand as the multiple earthed neutral (MEN) system. The other arrangements recognised by the IEC are the TT and IT systems, shown in **Figure 12.8**.



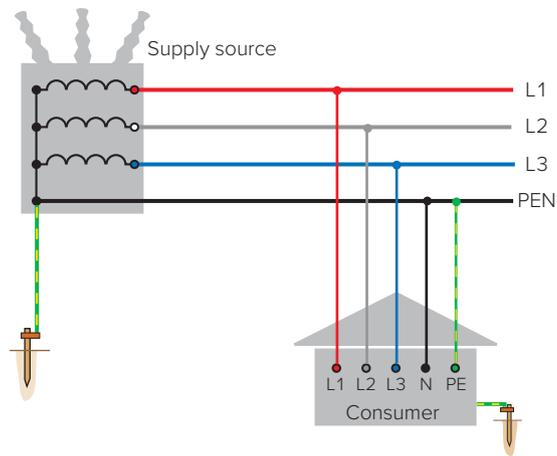
CHECK YOUR UNDERSTANDING

5. Briefly explain the TN system, the most common earthing and protection system.
6. What TN variant system is used in Australia and New Zealand?
7. What are two other earthing arrangements recognised by the IEC?

The *TN-S earthing system* uses separate protective earthing (PE) and neutral (N) conductors from the supply source to the consumer and within the installation.



The *TN-C earthing system* uses a combined protective earth-neutral (PEN) conductor from the supply source to the consumer and within the installation.



The *TN-C-S earthing system* uses a combined protective earth-neutral conductor (PEN) from the supply source to the consumer's main switchboard, but uses separate protective earth (PE) and neutral (N) conductors within the installation.

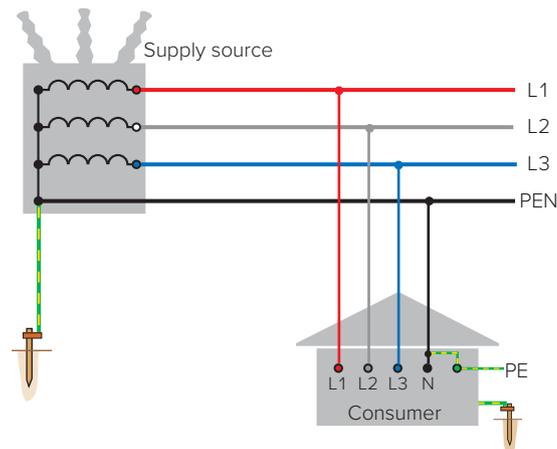
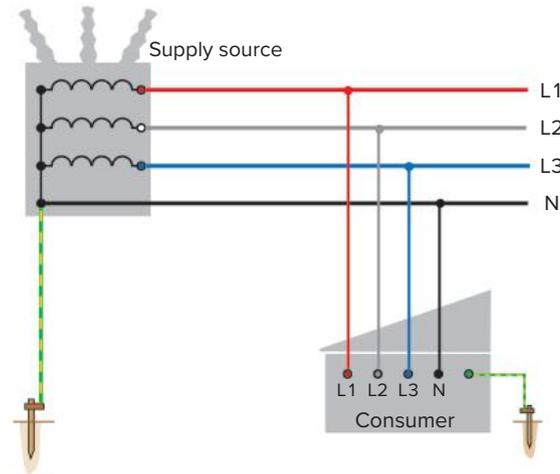


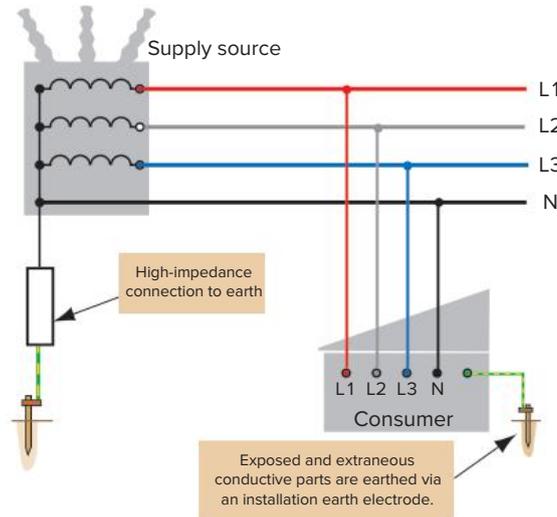
FIGURE 12.7 TN earthing system

In a *TT earthing system*, the consumer's protective earthing is provided by a local connection to earth, independent of any earth connection at the supply source.



An *IT distribution system* does not rely on a low-impedance earth fault to operate protective devices as it has no direct connection to earth at the supply. Insulation breakdown in one line is not likely to pose a danger to a person as the fault current is very low. A second fault on a different phase will raise touch voltage to a dangerous level.

The system includes permanent monitoring of the insulation to earth coupled with an alarm signal to operate in the event of a first fault to initiate its location and repair. If a second fault should occur, a protection arrangement will operate to switch off supply.



The advantage of the IT system is continuity of supply, for example in some mining applications where supply interruption may pose a hazard.

FIGURE 12.8 TT earthing system and IT distribution system

12.3 MEN earthing system

The *Wiring Rules* requirements for protective earthing are centred on the multiple earthed neutral (MEN) distribution system. In the MEN system, the parts of each installation that are required to be earthed are connected to the general mass of earth and connected within the installation to the neutral conductor of the supply. In addition, the neutral conductor of the supply is connected to earth within the distribution system and at the low-voltage distribution transformer (*Clause 5.3*). This multiple earthing of the neutral has given the system its name, multiple earthed neutral, or MEN for short. It is essentially a TN-C-S system.

12.3.1 Components and connections

Figure 12.9 shows a typical arrangement of MEN earthing in an installation; a brief description of each component and its purpose is given in **Table 12.1**.

12.3.2 How the MEN system works in providing fault protection

The MEN system is a current-operated system to protect against a fault between an active conductor or exposed conductive part, commonly described as an earth fault. The purpose is to limit the rise in touch voltage (*Clause 1.4.125*). The system operates to isolate an earth fault by ensuring the fault current rises quickly to operate the circuit-protective device; that is, to trip the circuit-breaker or rupture the fuse.

If the impedance of fault current path, known as the earth fault loop, is too high the fault current might be too low to operate the circuit-protective device. Referring to **Figure 12.10** and applying Ohm's Law, $V = IZ$, it can be seen that high impedance coupled with low current will result in a dangerous rise in potential between a fault, say the frame of an appliance, and the general mass of earth, say a concrete floor. For example, a current of 1 A, not high enough to rupture a fuse, would produce a voltage drop of 200 V across a return path of 200 Ω . The requirements set out in the *Wiring Rules* contain measures to ensure that the impedance of the path taken by a fault current is as low as possible.



DID YOU KNOW?

Impedance is the combined effect of resistance and reactance in an a.c. circuit:

$$Z = \left(\sqrt{R^2 + X^2} \right)$$

For cables up to 120 mm² the resistance is more than 10 times the cable reactance, and therefore the reactance can be regarded as negligible.

Note that additional protection by residual current device (RCD) protection is required for designated circuits (*Wiring Rules, Clause 2.6.3*). These use a different principle of operation (see **Figure 12.14** later in the chapter). Note that RCDs are additional protection and therefore a requirement for a low earth fault loop impedance still applies.

Clauses 1.5.5.3 and 5.7.4 require that, if a fault of negligible (i.e. 0 Ω) impedance occurs between an active conductor and earth or exposed conductive parts, causing the touch voltage to exceed 50 V a.c. or 120 V d.c., the supply must be automatically disconnected within a specified time. The disconnect time specified for 230/400 V supply voltage is not more than 0.4 seconds for circuits supplying socket-outlets up to a 63 A rating or earthed handheld and portable equipment. For other circuits, the disconnect time is not more than 5 seconds (see *Clause 5.7.2*).

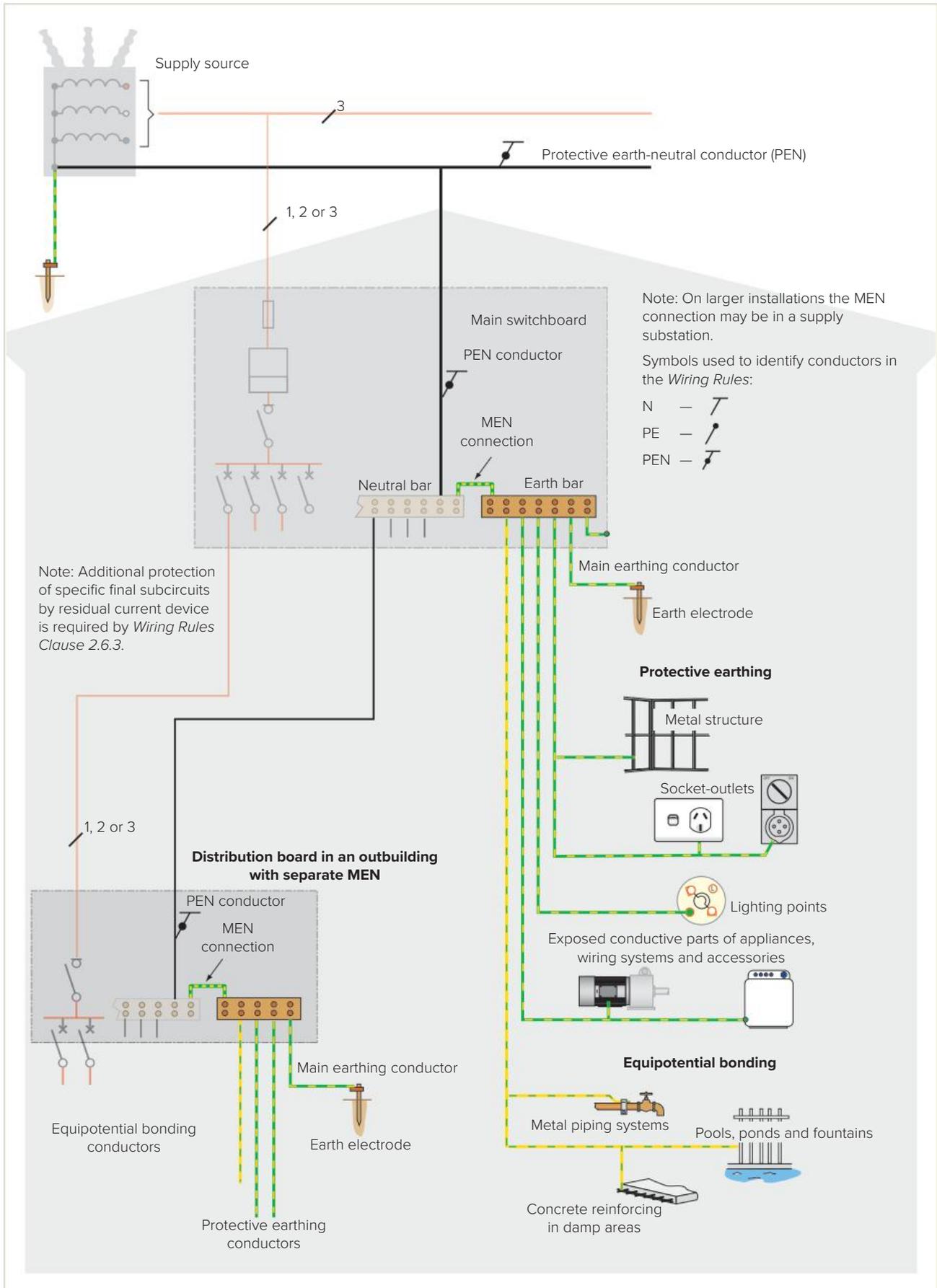
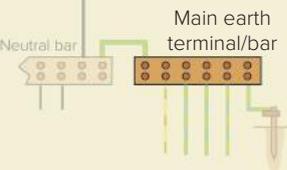
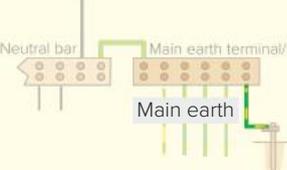
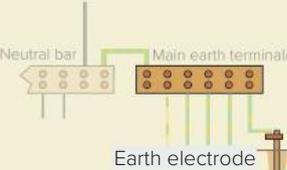
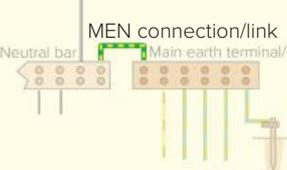
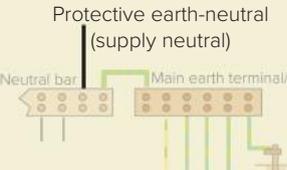
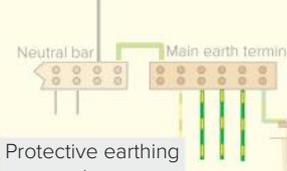
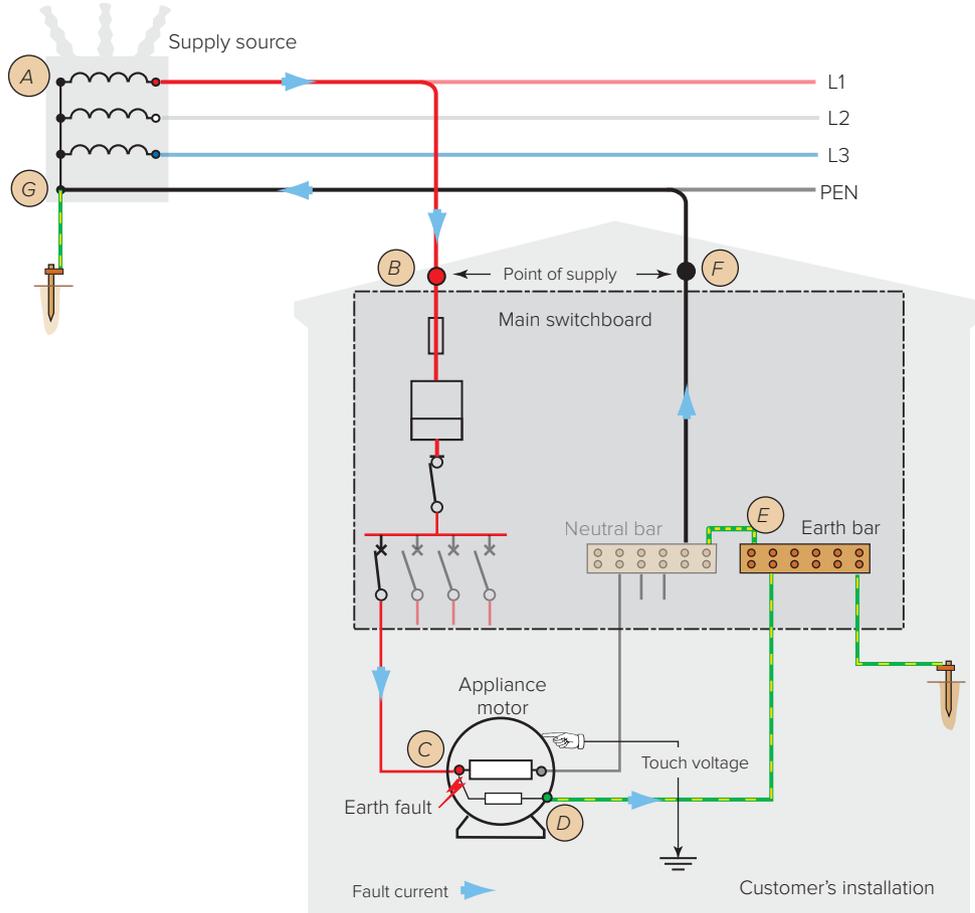


FIGURE 12.9 Multiple earthed neutral (MEN) distribution system

TABLE 12.1 Components of a MEN earthing system

Component	Function	Wiring Rules reference
 <p>Main earth terminal/bar</p> <p>Neutral bar</p>	<p>The main earth terminal is the point where all parts required to be earthed are connected to earth, via the main earthing conductor and earth electrode. The main earth terminal may be a soldered connection, a single terminal or a terminal at an earth bar.</p>	<p>Clause 5.3.4</p>
 <p>Main earth terminal/bar</p> <p>Main earth</p> <p>Neutral bar</p>	<p>The main earthing conductor connects the main earth terminal at the main switchboard to the earth electrode, and thus to the mass of earth.</p>	<p>Table 5.1 Clause 5.3.3.2 Clause 5.5.1.2 Clause 5.5.1.3</p>
 <p>Main earth terminal/bar</p> <p>Earth electrode</p> <p>Neutral bar</p>	<p>The earth electrode is a rod, cable or metal strip embedded in the earth as a means of connecting to the general mass of earth the parts of the electrical installation that are required to be earthed. The most common earth electrode consists of a copper-sheathed steel rod driven into the ground. A number of alternatives are acceptable, such as a metallic strip buried horizontally in a trench or a concrete footing or floor slab buried directly in the ground.</p>	<p>Clause 5.3.6</p>
 <p>MEN connection/link</p> <p>Main earth terminal/bar</p> <p>Neutral bar</p>	<p>The MEN connection or link is a conductor (generally a green-and-yellow insulated cable) that connects the main earth terminal to the neutral bar. At this point, the separate protective earthing conductors and the neutral conductors in an installation are combined with the supply neutral to become a protective earth-neutral conductor. Most commonly the MEN link is at the main switchboard, but for a larger installation it could be in a substation.</p>	<p>Clause 5.3.5</p>
 <p>Protective earth-neutral (supply neutral)</p> <p>Main earth terminal/bar</p> <p>Neutral bar</p>	<p>The supply neutral acts as a protective earth and neutral conductor. It carries both the out-of-balance return current from the installation under normal use and the fault current when an earth fault occurs.</p>	<p>Clause 5.1.3</p>
 <p>Protective earthing conductors</p> <p>Main earth terminal/bar</p> <p>Neutral bar</p>	<p>Protective earthing conductors, commonly green-and-yellow insulated cable, are provided with each circuit to connect the associated exposed conductive parts to the main earth terminal/bar and subsequently the main neutral and the mass of earth. A protective earthing conductor is generally required for every final subcircuit, for example, at each socket-outlet, lighting point and fixed appliance. A protective earthing conductor is not always a cable but may be a metallic wiring enclosure such as steel conduit, or metallic cable sheath or armouring.</p>	<p>Clause 5.3.2 Clause 5.3.3 Table 5.1 Clause 5.5.2</p>
 <p>Equipotential bonding conductor</p> <p>Main earth terminal/bar</p> <p>Neutral bar</p>	<p>Equipotential bonding conductors connect conductive parts that are not part of the electrical installation, but that might be in contact with earth (known as extraneous conductive parts), to the earthing system of the installation. The reason for this is to eliminate any potential difference that might occur between the extraneous and exposed conductive parts. A metal water pipe and a metal pool fence are examples of extraneous conductive parts.</p>	<p>Clause 5.6</p>



Impedances in the earth fault-loop

Z_{AB}^1 The impedance of supply source and active conductors in the distributor's network to the point of supply.

Z_{BC}^2 The impedance of the consumer's main active conductor plus the final subcircuit active conductor.

Z_{CD} The impedance of the fault itself. Can vary from zero to a higher value, dependent on the severity of the breakdown; for a bolted fault the impedance is 0Ω .

Z_{DE}^2 The impedance of the protective earthing (PE) conductor.

Z_{EF}^2 The impedance of the consumer's main protective earth-neutral (PEN) conductor.

Z_{FG}^1 The impedance of the protective earth-neutral (PEN) conductor in the distributor's network from the point of supply to the supply source.

Note:

1. A characteristic of the distribution network and therefore cannot be changed.
2. Dependent on the route length of the cables and the conductor size and is therefore influenced by the cable size selected in the planning stage of an installation.
3. High-impedance return path through other local earth electrodes and MEN connections has little effect in the fault current path.

Equivalent circuit:

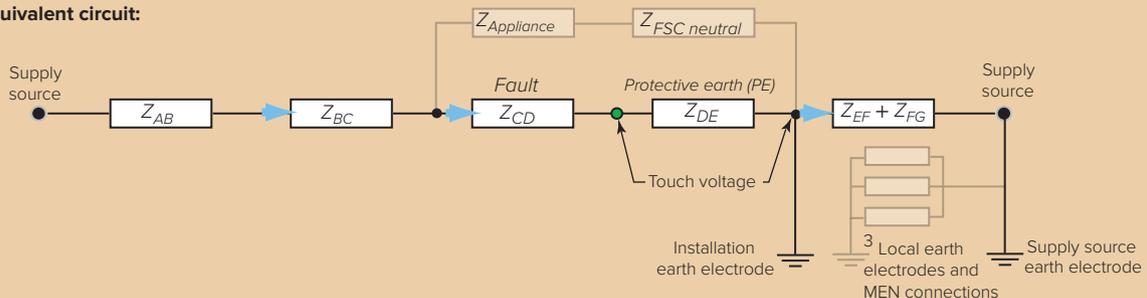


FIGURE 12.10 Impedance that makes up the earth fault-loop

12.3.3 The role of protective devices

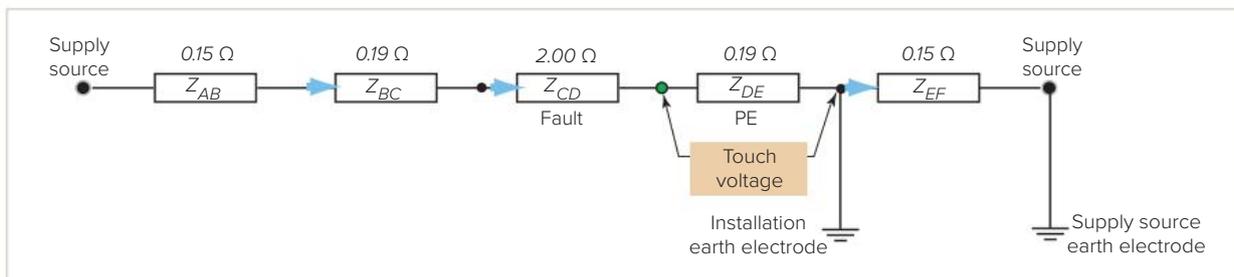
The MEN system, together with a type of protective device listed under *Wiring Rules, Clause 2.4*, is integral to limiting the rise in touch voltage of exposed conductive parts when a fault occurs. The other requirement for protective devices is protection against overcurrent that could cause injury or damage because of excessive temperatures or electromechanical stresses (*Wiring Rules, Clause 2.5*), which is covered in detail in **Chapter 13**.

The focus here is on the fault protection aspect of protective devices. Now consider the impedances in the earth fault-loop, as shown in **Figure 12.10**, that affect the magnitude of the fault current.

Following on from **Figure 12.10**, the importance of earthing is illustrated in the following examples of rises in touch voltage when a fault occurs and the actions of the circuit-protective device to disconnect the circuit. *Appendix B* of the *Wiring Rules* advises that the voltage available at a fault can vary between 1.0 where the fault is close to the source of supply and 0.6 where the fault is the maximum distance from the supply. In **Examples 12.1** to **12.3**, the complete fault-loop is considered; therefore full-phase voltage (230 V) is used.

EXAMPLE 12.1: PROTECTION AGAINST EARTH FAULTS

In this case, the fault itself has an impedance of 2.00Ω .



EXAMPLE 12.1

The impedance of the fault path (Z_S) is:

$$\begin{aligned} Z_S &= Z_{AB} + Z_{BC} + Z_{CD} + Z_{DE} + Z_{EF} \\ &= 0.15 + 0.19 + 2.00 + 0.19 + 0.15 \\ &= 2.68 \Omega \end{aligned}$$

Hence, the magnitude of the fault current is:

$$\begin{aligned} I_F &= U_o \div Z_S \\ &= 230 \div 2.68 \\ &= 85.8 \text{ A} \end{aligned}$$

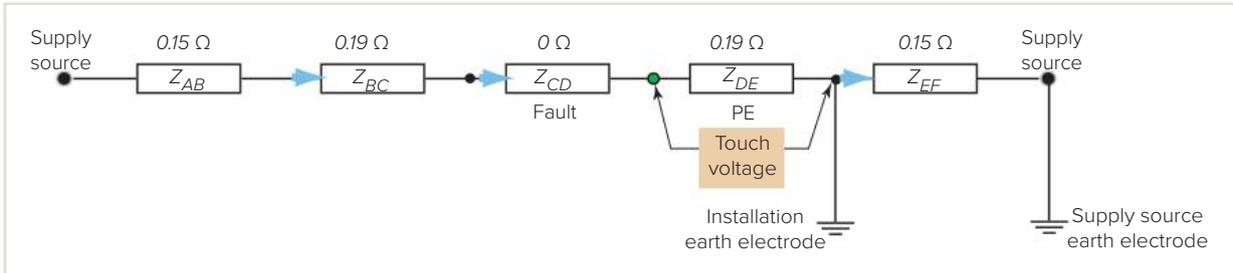
Therefore, the touch voltage is:

$$\begin{aligned} U_T &= I_F \times Z_{PE} \\ &= 85.8 \times 0.19 \\ &= 16.3 \text{ V} \end{aligned}$$

This value of current is high enough to operate the 16 A protection device but not necessarily within the prescribed time, particularly if the appliance is supplied through a socket-outlet. Incidentally, a C-type circuit-breaker needs 7.5 times its rated current (i.e. 120 A) to trip within the prescribed time when a fault occurs. However, the breaker will trip fairly quickly and, until it does, the touch voltage has not risen above 16.3 V, well under the limits stipulated by *Clauses 1.5.5.3(c)* and *5.7.4*.

EXAMPLE 12.2: PROTECTION AGAINST EARTH FAULTS

What is the rise in touch voltage with a dead short circuit, that is, when the impedance of the fault is 0Ω ?



EXAMPLE 12.2

The impedance of the fault path (Z_S) becomes:

$$\begin{aligned} Z_S &= Z_{AB} + Z_{BC} + Z_{CD} + Z_{DE} + Z_{EF} \\ &= 0.15 + 0.19 + 0.00 + 0.15 \\ &= 0.49 \Omega \end{aligned}$$

Then the magnitude of the fault current is:

$$\begin{aligned} I_F &= U_O \div Z_S \\ &= 230 \div 0.49 \\ &= 469.0 \text{ A} \end{aligned}$$

Therefore, the touch voltage rises to:

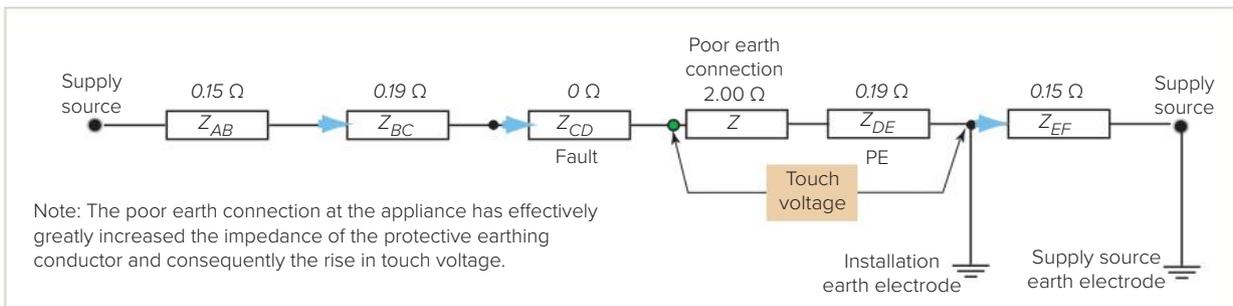
$$\begin{aligned} U_T &= I_F \times Z_{PE} \\ &= 469 \times 0.19 \\ &= 89.1 \text{ V} \end{aligned}$$

This is above the limits stipulated by *Clauses 1.5.5.3(c)* and *5.7.4*. However, the circuit-breaker will disconnect the supply as intended; typically within 10 milliseconds for, say, a 16 A C-type circuit-breaker.

These examples show how, when a fault occurs, the touch voltage is limited by a low-impedance earthing system, thus reducing the risk of injury by electric shock.

EXAMPLE 12.3: PROTECTION AGAINST EARTH FAULTS

However, if under a dead short circuit condition a poor earth connection introduces, say, 2.00Ω into the earth fault-loop, the result is different.



Note: The poor earth connection at the appliance has effectively greatly increased the impedance of the protective earthing conductor and consequently the rise in touch voltage.

EXAMPLE 12.3

The fault current is the same as in **Example 12.1**; however, the poor earth connection effectively increases the impedance of the protective earthing conductor a hundredfold. Then the touch voltage rises to:

$$\begin{aligned} U_T &= I_F \times Z_{PE} \\ &= 85.8 \times 2.19 \\ &= 187.9 \text{ V} \end{aligned}$$

Here a 16 A C-type circuit-breaker will take at least 2 seconds to trip and disconnect the fault, which is much longer than specified by the *Wiring Rules*, given that the appliance is likely to be connected through a socket-outlet.



CAUTION

Example 12.3 emphasises the care that must be taken when connecting earthing conductors, and this is one of the reasons why mandatory testing, which is dealt with in **Chapter 15**, is necessary.



CHECK YOUR UNDERSTANDING

8. What system of protective earthing is used in Australia and New Zealand?
9. How is a MEN system connected to the general mass of earth?
10. How does the MEN system provide fault protection?
11. What table in *AS/NZS 3000* is used to determine the size of the protective earth conductor for a given final subcircuit?
12. What is the maximum disconnect time for final subcircuits supplying socket-outlets up to a rating of 63 A?

12.4 Earth faults

In studying this section, you will gain further understanding of the purpose of the earthing system and some common causes of earth faults. Faults that affect the operation of an electrical installation can occur:

- ▶ on the electricity supply system to the installation
- ▶ on an adjacent installation
- ▶ in wiring or accessories in an installation
- ▶ within electrical apparatus.

12.4.1 Electricity supply system faults

If an earth fault occurs in the supply system, ideally it will operate the supply protection, leaving the consumer's installation unaffected or, at worst, produce a temporary interruption to supply. Occasionally, however, faults that

affect the consumer's earthing system do occur, and in this regard the MEN system is particularly vulnerable due to the interconnection between the supply neutral and the consumer's earthing system. Supply system faults are most often due to either:

- ▶ an open circuit of supply neutral
- ▶ reversed polarity of supply.

12.4.2 Open circuit of supply neutral

As previously stated, in the MEN system the supply neutral on the distribution side acts as both the protective earthing conductor and the neutral conductor. That is, it carries the out-of-balance or return current under normal operating conditions and the fault current when an active-to-earth fault occurs in an installation. As such, the protective earth-neutral (PEN) conductor is the most vulnerable part of the MEN system. A poor connection or open circuit in the PEN conductor can place the supplied electrical installation in a potentially dangerous condition, as shown in **Figure 12.11**.

The distinguishing feature of the MEN system, whereby the neutral supply line and the consumer's earthing system are connected at the neutral link, must always be kept in mind when testing or working on the system. Any supply fault that causes a voltage rise in the neutral will result in this voltage appearing on the earthing system.



SAFETY ALERT

Work health and safety (WHS) authorities alert plumbers and associated workers to the hazard of serious or fatal electric shock that could be present when removing water meters or cutting through or disconnecting metallic water pipes to a customer's water service. The hazard arises when there is an open circuit or poor connection in the electrical system's PEN conductor, as illustrated in **Figure 12.11**. The recommended work procedures include attaching a large bridging conductor across the section of water service on which work is to be done and engaging an electrical contractor to investigate any suspected earth fault.

At this point you might well ask, 'Why use the MEN system of earthing?' Further study will show that its obvious advantage of limiting touch voltage and its role in disconnecting the supply when an earth fault occurs outweigh its disadvantages. This is particularly the case when coupled with the mandatory use of residual current devices (covered in **Chapter 13**) on the most vulnerable circuits to ensure disconnection of supply even under conditions of earth current leakage.

12.4.3 Reversed polarity of supply

Consider the effect of a supply connection error in which the active and neutral connections have been reversed, say, at the point of supply, as shown in **Figure 12.12**. Note that this is totally avoidable and should not occur; however, it does emphasise the need for care when making connections and the importance of testing.

12.4.4 Mistakes in wiring

Carelessly installed wiring or wiring accessories can cause exposed conductive parts such as metallic wiring enclosures to become live. For example, the covers of equipment and luminaires must be fitted carefully so that they do not ruin

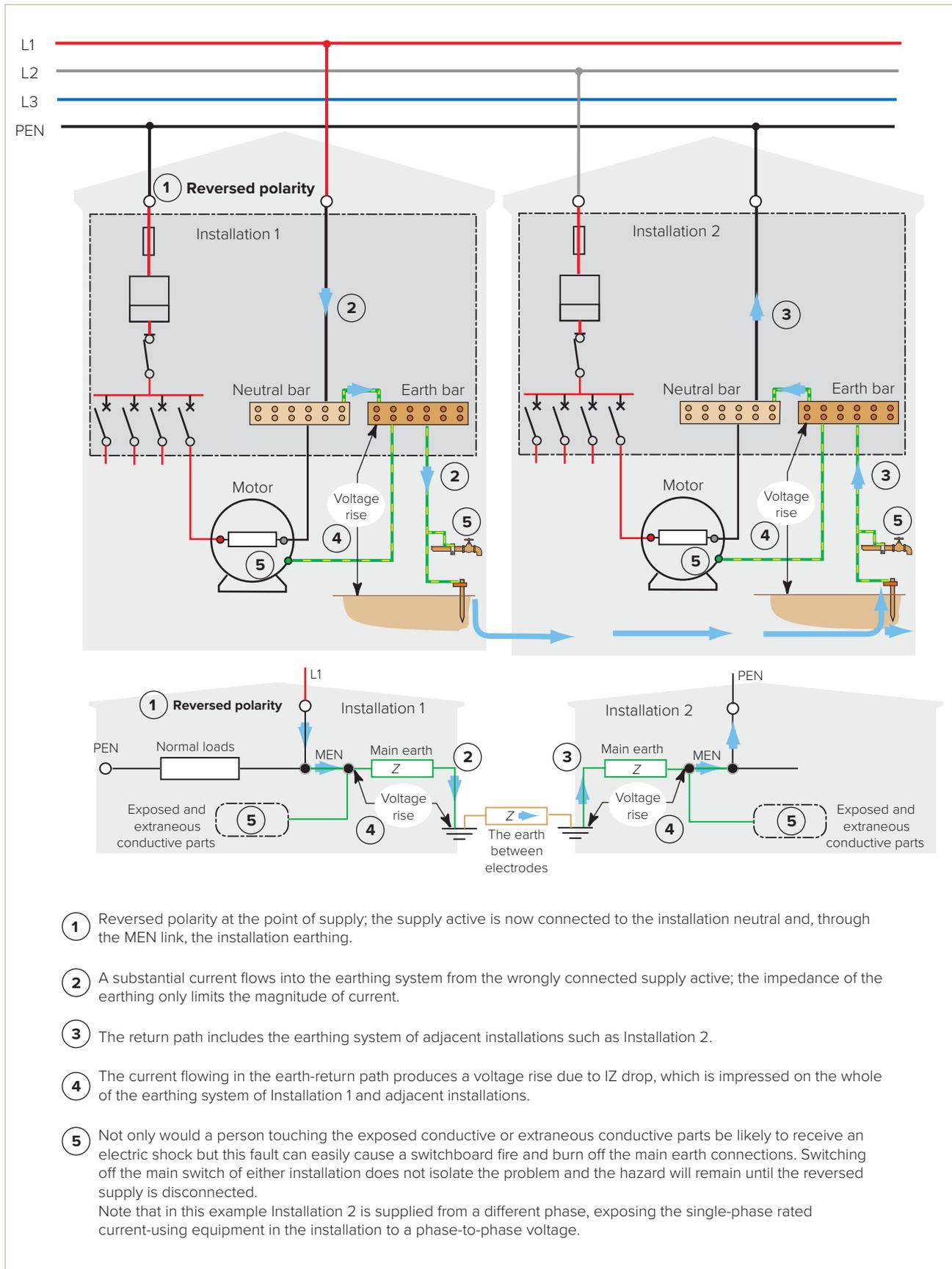


FIGURE 12.12 Reverse polarity of the supply

the internal wiring. As previously pointed out, wrong connections (incorrect polarity) should not occur if due care is given to the connection of accessories and appliances. The consequences may not be immediate but the hazard is still present, as shown in **Figure 12.13**.

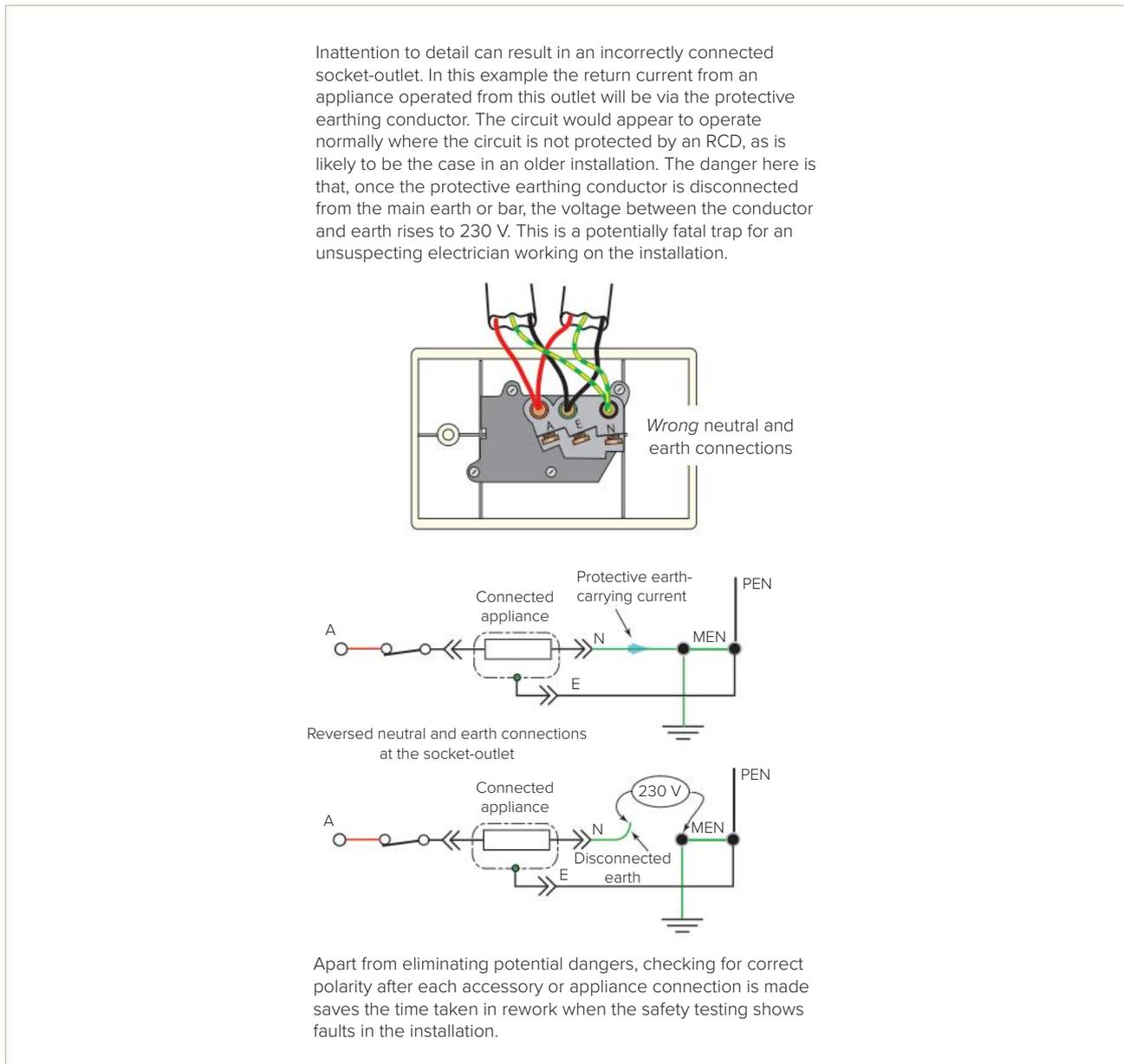


FIGURE 12.13 Examples of mistakes in wiring

12.4.5 Neutral-to-earth breakdown

In the earthing system described in this chapter, breakdown of the neutral-to-earth conductor constitutes another fault condition; but, because neutral and earth are normally at the same potential, this fault is less likely to occur than an active-to-earth fault. If breakdown of the neutral does occur, the hazard is similar to that described for mistakes in wiring where the protective earth is carrying current. Protection from this type of fault is provided where a residual current device (RCD) is installed, which is briefly explained in **Figure 12.14**; in-depth coverage of RCDs is given in **Chapter 13**.

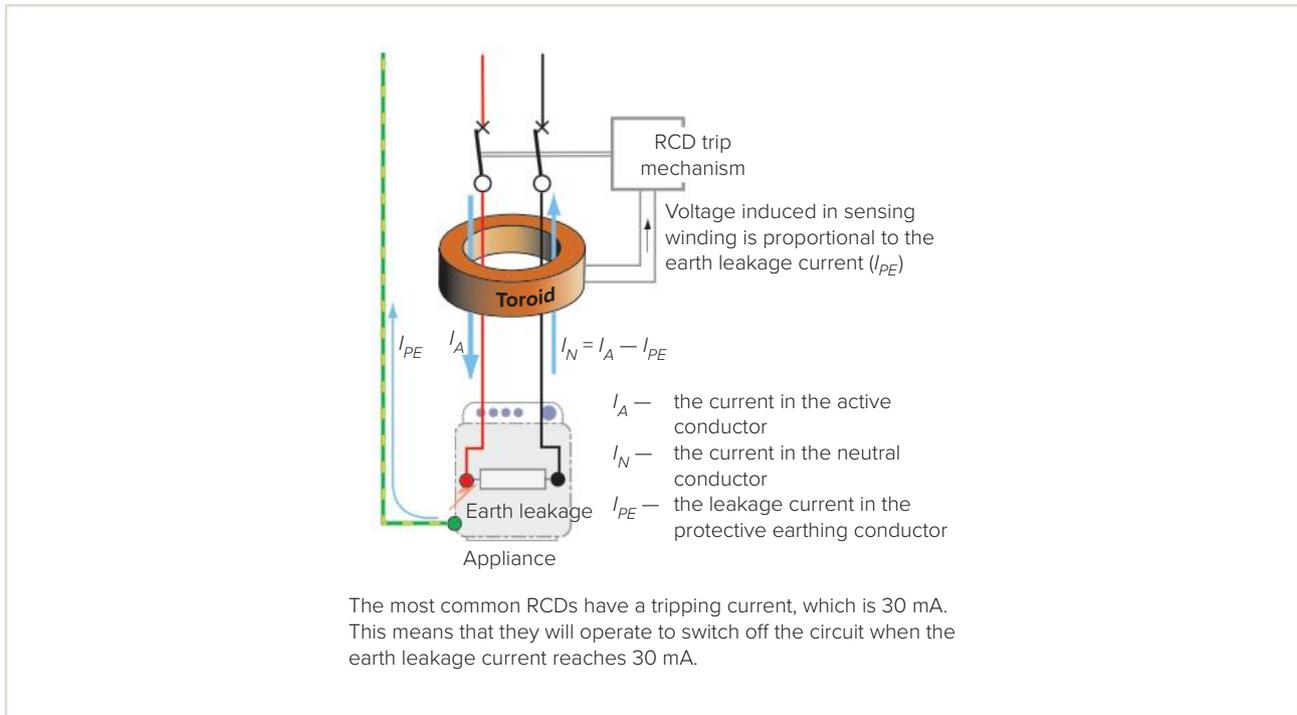


FIGURE 12.14 Protection against insulation breakdown between live conductors and earth and risk in a rise of touch voltage



SAFETY ALERT

Disconnecting main and protective earthing conductors

In an installation, the breakdown of insulation between neutral and conductive parts, or an open circuit or poor connection in the PEN conductor, can result in the earth acting as the return path for the load current instead of the neutral, without an immediate indication of the fault.

- ▶ Do not disconnect the main earth in an energised installation.
- ▶ In a de-energised installation, test that the main earth is not carrying current from another faulty installation before disconnecting it.
- ▶ Before disconnecting a protective earthing conductor, isolate the supply to the circuits when a test shows that the protective earthing conductor is carrying current.



CHECK YOUR UNDERSTANDING

13. List four locations where an earth fault can affect the operation of an electrical installation.
14. List the two most common supply system faults.
15. What is the purpose of a PEN conductor?
16. What fault will occur if a neutral-to-earth insulation breakdown occurs?

12.5 Earthing system—selection and installation

Having studied the reasons for earthing, the principles involved and the effects of an earth fault, you now know that the function of the earthing system is mainly for protection. You will also realise that, to achieve an adequate degree of protection, the earthing system must be installed in an efficient and electrically sound manner.

Section 5 of the *Wiring Rules* describes the MEN earthing system and sets out requirements for protective earthing in that system in the logical manner shown in **Figure 12.15**; the basic philosophy is to earth all metal that can be touched and that might become live due to insulation failure.

12.5.1 Earthing conductor selection

Clause 5.3.3 relates earthing conductor sizes to the size of the largest active conductor protected by the earthing conductor, and the appropriate sizes are listed in *Table 5.1* of the *Wiring Rules*.

There are stringent requirements around the use of aluminium protective earthing conductors, due to the care needed in terminating them and protecting them against corrosion. For an aluminium main earthing conductor, the minimum size is 16 mm² and for all other earthing conductors they must be a solid conductor up to 10 mm² (*Clause 5.3.2.1.2*). Note that a minimum of 6 mm² applies to copper aerial earthing conductors, the size of which is governed by considerations of mechanical strength, as required by *Clause 3.12.2.2* and *Table 3.9*. Incidentally but importantly, *Clause 3.8.3.5* requires aerial earthing conductors to be identified at each end by the letter E or the earthing symbol \perp .

The current-carrying capacity of earthing conductor sizes specified in *Table 5.1* of the *Wiring Rules* is obviously intended for very short periods, while at the same time allowing sufficient time for the protective device to operate. **Figure 12.16** shows the minimum protective earthing conductor sizes and **Figure 12.17** explains the reasons for the size of protective earthing conductors.

For example, although the sizes given in *Table 5.1* will satisfy most situations, *Clause 5.3.3.1.2* allows selection of the protective earthing by calculation. This calculation takes into account the energy let-through and maximum permissible temperature that a cable can sustain within the specified tripping period without permanent damage to the conductor material or insulation. Maximum permissible temperatures for conductor, insulation and sheathing materials are given in *AS/NZS 3008.1 Electrical installations—Selection of cables, Section 5*.

A factor to consider when selecting protective earthing conductors is the resistance, which increases with the route length of the circuit. This in itself is dependent on the maximum fault-loop impedance permitted for each circuit. Remember, the impedance of the fault-loop is that of the series circuit formed by the active conductor and protective earthing conductor. In some cases, a protective earthing conductor larger than that specified in *Table 5.1* can be used to keep the resistance of the fault-loop below its permitted maximum, because of the route length of the circuit. This is a matter for the electrician (or engineer) to decide when designing the installation.

12.5.2 Earth electrodes and main earth

The minimum size for a main earthing conductor is 4 mm² for copper. The main earthing conductor size is generally selected from *Table 5.1* of the *Wiring Rules* in relation to the cross-sectional area (CSA) of the active-phase conductor of the consumer mains. This can be varied in relation to maintaining double-insulation of incoming and outgoing cable, and where voltage-drop limitations require an increase in the CSA of the consumer mains (see *Clause 5.3.3.2*).

The *Wiring Rules* specify two types of electrodes (*Clause 5.3.6.2*): the vertical type, which is driven into the ground; and the strip type, which is buried horizontally in a trench. Acceptable electrode materials, their CSA dimensions and surface treatments are given in *Table 5.2*; for example, a common vertical type is a 12 mm diameter steel rod clad with 250 μm of copper. A typical vertical electrode in situ is shown in **Figure 12.18**.

It is necessary to install a driven electrode in a position that is outside the building and exposed to the weather. This exposure to the weather requires the earth-bonding clamp to be protected from deterioration, such as by painting it with an exterior-grade paint. *Clause 5.3.6.2* permits the use of conductive reinforcement of a concrete foundation

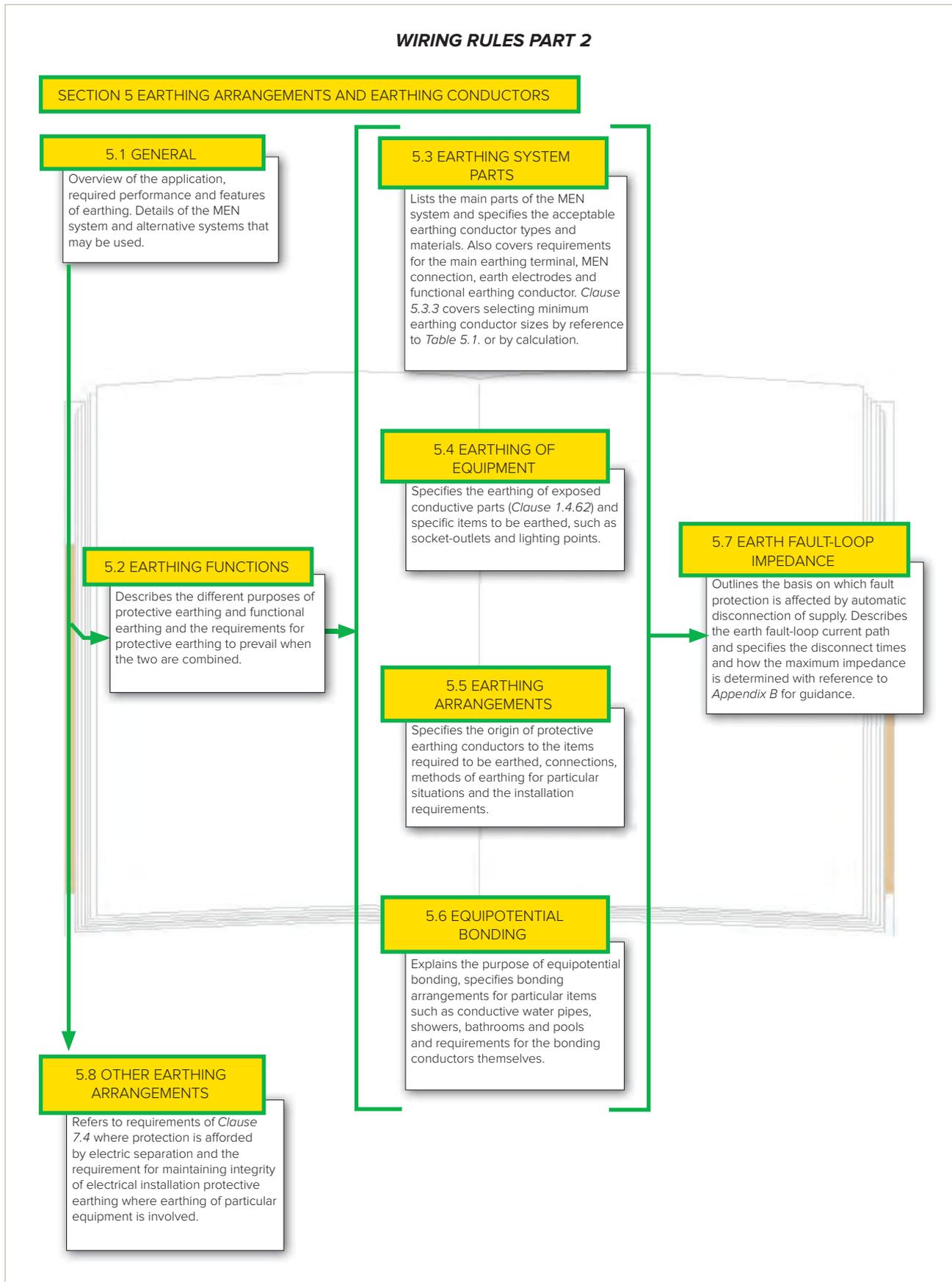
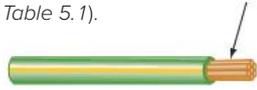


FIGURE 12.15 Summary of *Wiring Rules* earthing requirements

The minimum permissible size for a single-insulated copper earthing conductor is 2.5 mm² (see Clause 5.3.3.1.2 and Table 5.1).



The protective earthing conductor may be 1.0 mm² or 1.5 mm² when incorporated in multicore cable or flexible cord with active conductors of that size (see Clause 5.3.3.4 and Table 5.1).

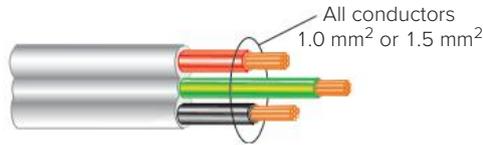
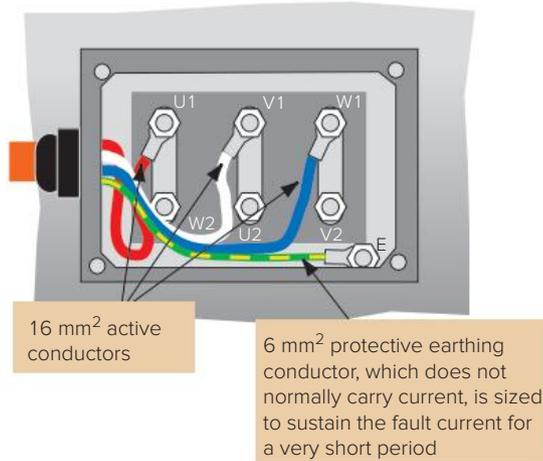


FIGURE 12.16 Minimum protective earthing conductor sizes

In the cable for this motor circuit, the current-carrying capacity of 6 mm² is 40 A while the 16 mm² active conductors have a current-carrying capacity of 63 A in the same cable, according to *Wiring Rules, Appendix C, Table C6*.



The protective earthing conductor and active conductors are in the same fault path:

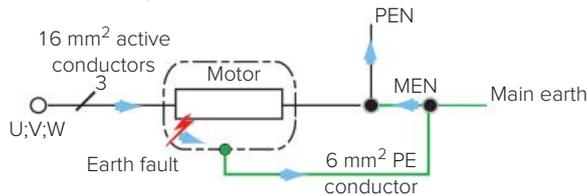


FIGURE 12.17 Reasons for size of protective earthing conductors

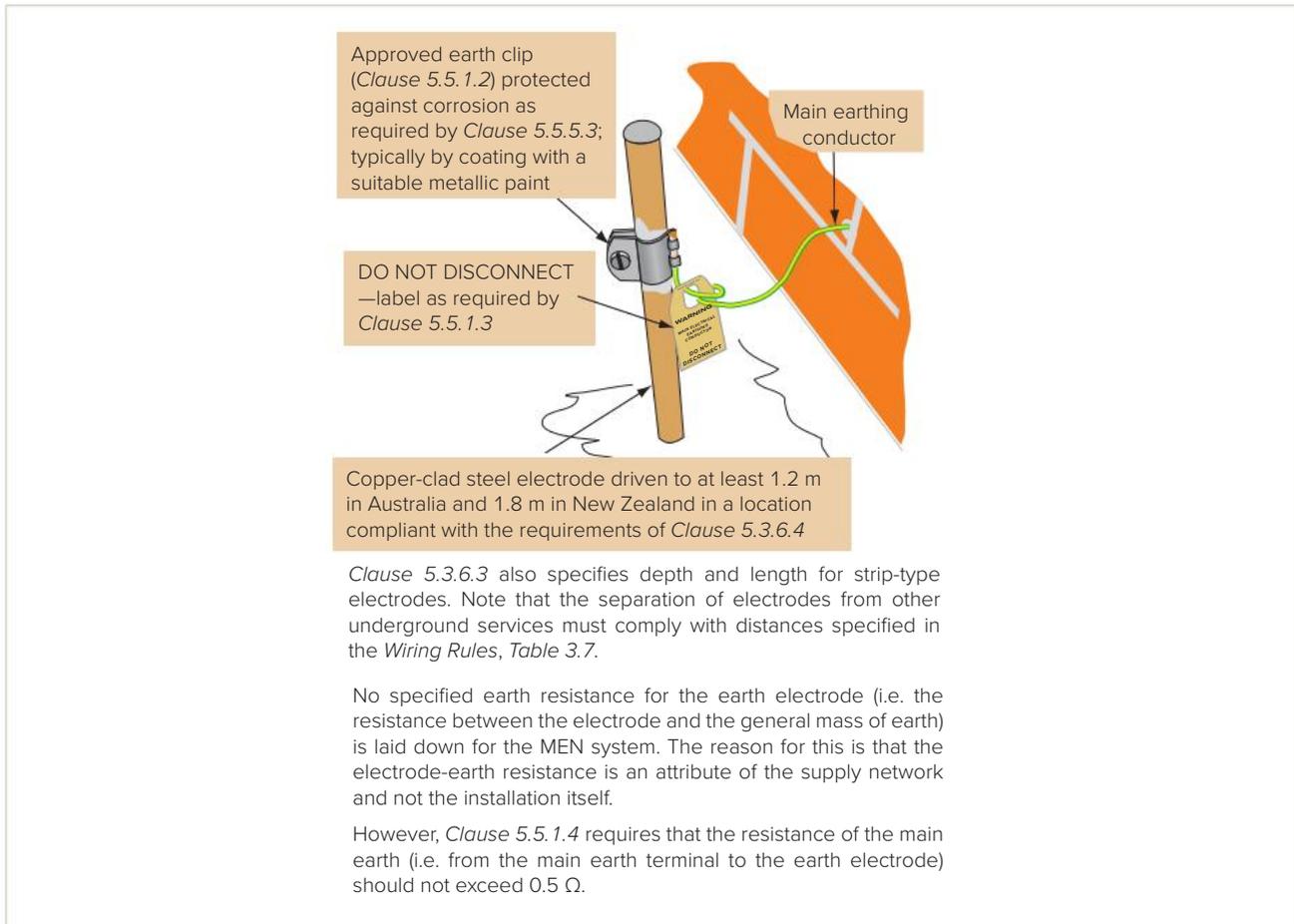


FIGURE 12.18 A typical vertical electrode in situ

or slab as an earth electrode. However, current building trends towards energy efficiency and the use of thermal insulation under on-ground structures probably make this arrangement unsatisfactory.

12.5.3 Earthing of equipment

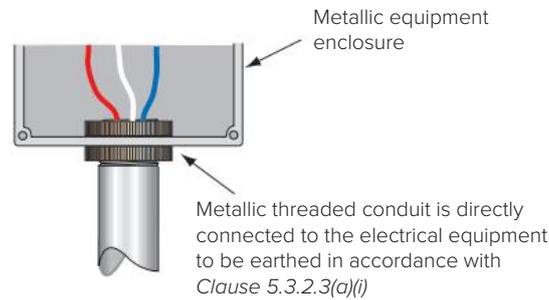
In general, the earthing of equipment is achieved by direct connection of a suitable earthing conductor, but there are some circumstances where other earthing mediums are permitted (see **Figure 12.19**). For example, a common framework earthed by connection of a protective earthing conductor can itself be considered a protective earthing conductor for equipment fixed to and in electrical contact with the framework (Clause 5.3.2.3(c)(i)). In practice, this would require that there is no material between the equipment and the framework, such as paint, that might form an insulation barrier and introduce a high resistance of the earth fault current path.

The *Wiring Rules* in Clause 5.4 require specific accessories and equipment to be earthed; some examples are shown in **Figure 12.20**.

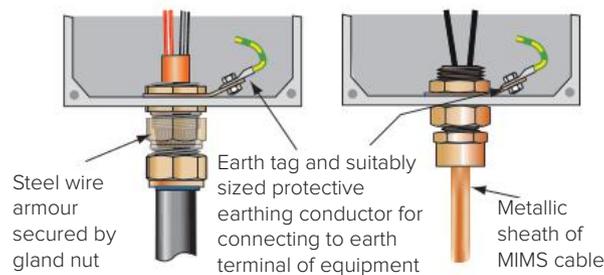
Further to the examples shown in **Figure 12.20**, Clause 5.5.2.1 and the *Wiring Rules*, Figure 5.3 show that protective earthing conductors are arranged to originate from the main earth terminal or bar at the main switchboard, or from an earth terminal or bar at the same distribution board as the active conductors of the circuits they protect. Note that the use of a common protective earthing conductor is acceptable.

The conditions under which structural metal work and conductive building materials are to be earthed and the methods for satisfying these requirements are specified by Clause 5.4.6.1.

Example of a metallic conduit used as the protective earthing conductor (*Clause 5.3.2.2*); it must be installed to maintain both mechanical and electrical continuity in accordance with *Clauses 3.10.3.3 and 5.5.4.2*.



Examples of cable armour and conductive cable sheath used as a protective earthing conductor as permitted by *Clause 5.3.2.2*.



The protective earthing conductor in the multicore cable can only be used to earth equipment supplied by the live conductors in the same cable as restricted by *Clause 5.5.2.2.1*. This is also the case with the above examples.

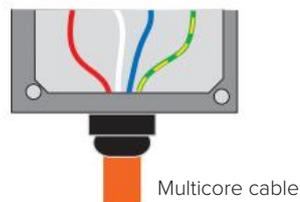
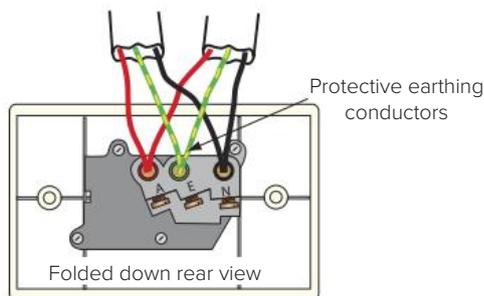


FIGURE 12.19 Examples of other earthing mediums

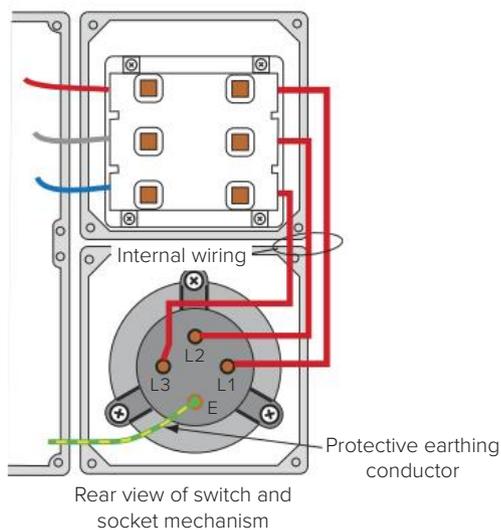
12.5.4 Separate MEN

A detached portion of a premises, say another building, which is called an outbuilding in the *Wiring Rules*, might be regarded as a separate MEN installation, as shown in **Figure 12.9**. In this case, a study of *Clause 5.5.3.1* reveals several points of safety that must be observed. Firstly, the outbuilding must have only one MEN connection at one distribution board, which is to be treated as a main switchboard. Secondly, it must not be possible to disconnect the submain neutral supplying the distribution board at any point in its route. **Section 12.4** discusses the potential dangers of an open circuit in the supply neutral in a MEN system. Finally, there should be no parallel circuits created with the supply neutral by protective earthing or equipotential bonding within the whole installation.

The earth pin of all socket-outlets must be earthed in accordance with *Clause 5.4.2*.



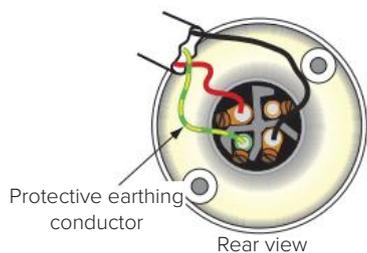
Single-phase three-pin socket-outlet



Three-phase four-pin socket-outlet

An earthing conductor, suitably terminated, must be provided at every lighting point (*Clause 5.4.3*). Accessories for terminating wiring at light points, such as batten holders, are provided with an earth terminal.

A batten holder has no exposed conductive parts but is likely to be replaced at some time by a luminaire that does have exposed conductive parts. Hence the requirement for a protective earthing conductor at each light point, although it may not be needed at the time of installation. Note that *Clause 5.4.4* requires exposed conductive parts of a luminaire to be earthed. The exception is a double-insulated type or one which operates at extra-low voltage.



Standard batten holder

FIGURE 12.20 Example of items required to be earthed

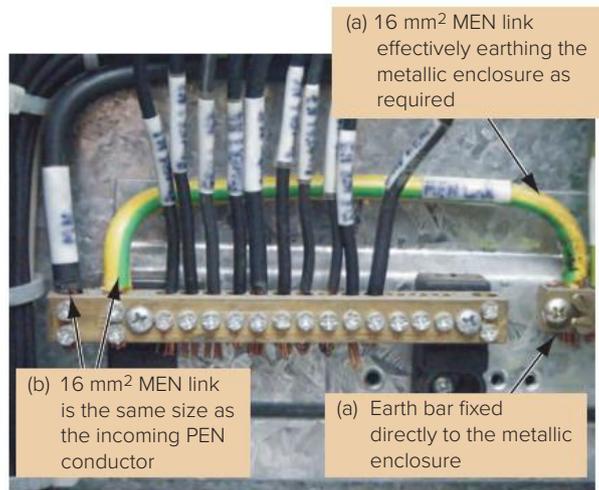
12.5.5 Unprotected consumer mains

The only position for interconnection of the main earthing conductor and the main neutral conductor (i.e. the MEN link) is at the main switchboard or at a substation (*Clause 5.3.5*). Where the MEN link is at the main switchboard, some energy distributors might prefer it under seal in their link.

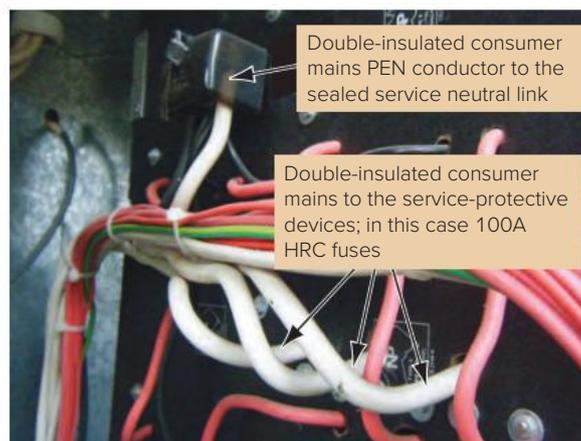
Figure 12.21 shows examples of alternative arrangements for dealing with exposed conductive parts associated with consumer mains that are not protected on the supply side against short circuits.

In the arrangement below, the exposed conductive parts of the switchboard enclosure are earthed by a conductor with the same current-carrying capacity as the main neutral. It also fulfils the role of the MEN link.

Either of these arrangements (a) or (b) satisfies *Clause 5.5.3.5*.



The arrangements shown above are not required if double-insulation of the consumer mains is maintained to the service protection device that provides short-circuit protection, as shown in the example below.



The requirement also applies to all exposed conductive parts associated with unprotected consumer mains such as aerial supports, wiring enclosures and accessories.

FIGURE 12.21 Examples of earthing exposed conductive parts associated with unprotected consumer mains

12.5.6 Earth connections

Connection methods and joints in earth wires are restricted to those outlined in *Clause 3.7.2.11*. For example, connections between an earthing conductor and an electrode, water pipe or metallic sheathing of underground supply cables must be accessible and protected from damage (see **Figure 12.22**).

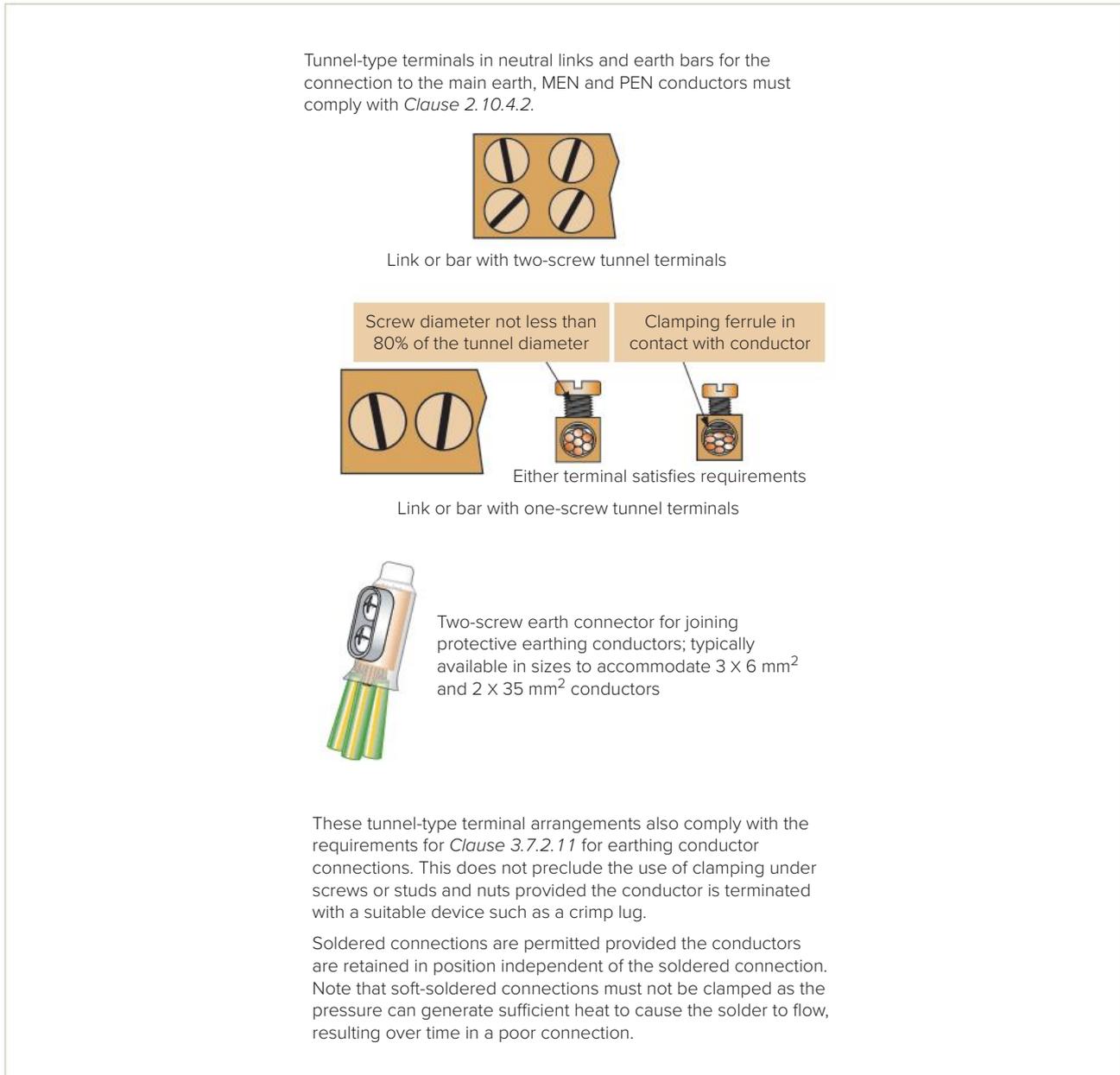


FIGURE 12.22 Earthing connections

12.5.7 Equipotential bonding

A very important part of earthing in an installation is the bonding of extraneous conductive parts to the earthing system, to reduce the risk of a rise in potential between them. Extraneous conductive parts are not part of the electrical installation but may be at local earth potential (see *Clause 1.4.63*). Differences in potential can arise from currents in the earth resulting from such events as faults in the supply network, lightning discharges and the like.

Clause 5.6.2 details the requirements for bonding conductive water pipes and those for other services, conductive cable sheaths and wiring enclosures, conductive reinforcing of concrete floors of showers, bathrooms, concrete

swimming pools, spas and other extraneous parts in pool zones and telecommunications earthing systems. Subject to the requirements of *Clause 5.6.3*, a 4.0 mm^2 bonding conductor is sufficient, except for telecommunications systems, where the bonding conductor must be not less than 6.0 mm^2 . Identification is the same as for protective earthing.

12.5.8 Examples of earthed situations

If you have any doubt about whether the exposed conductive of a particular item of equipment should be earthed, apply the definition for an earthed situation, *Clause 1.4.48*. Examples are provided in **Figure 12.23**.

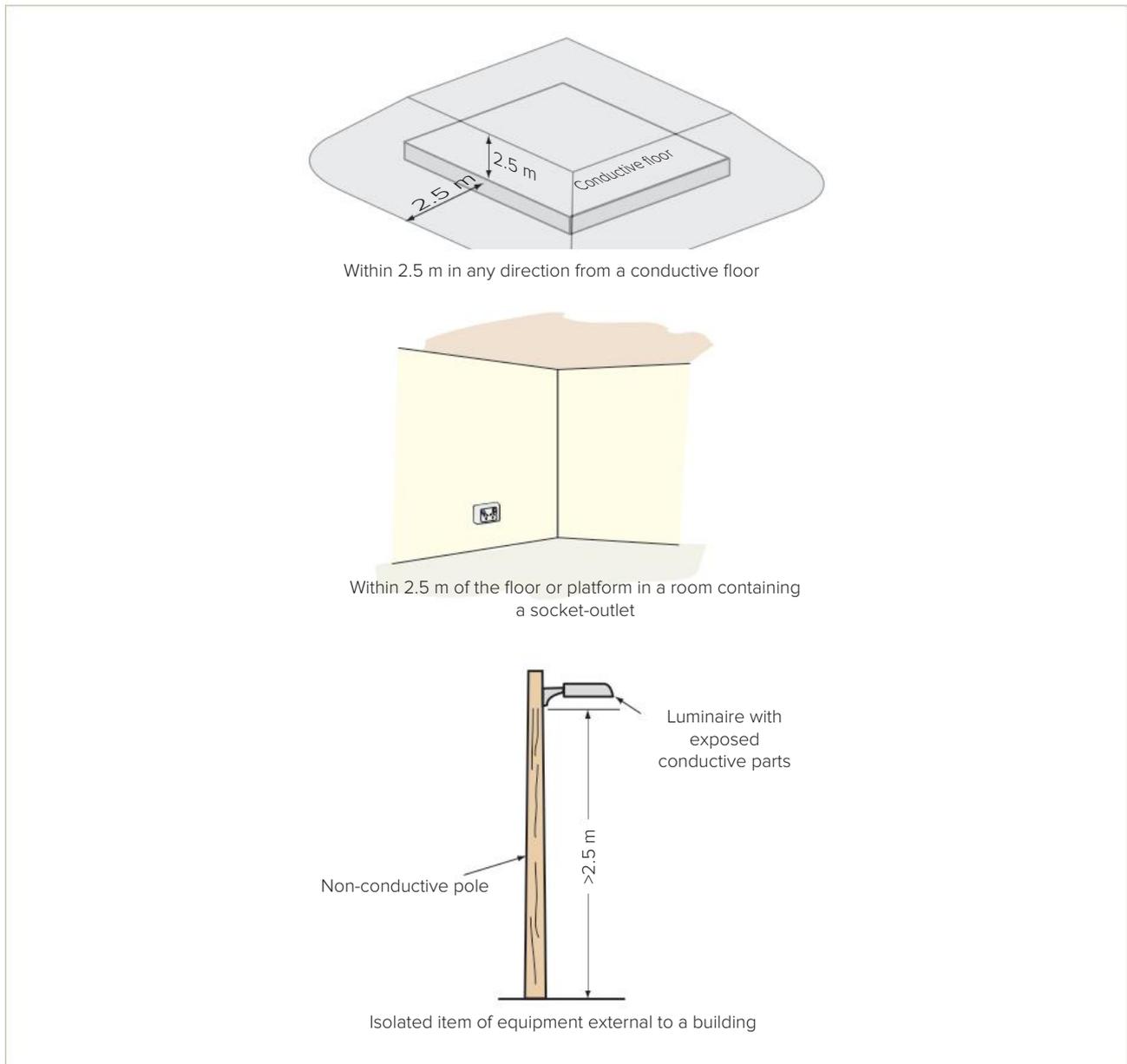


FIGURE 12.23 Earthed situations

Manufacturers of protective devices such as circuit-breakers and fuses expend much effort and cost to ensure that these operate within the prescribed times to disconnect faults, should they occur. As the protective devices rely on an effective earthing system, this must be installed so that it functions as a protective system, as required by the *Wiring Rules*, and in a manner that ensures it will continue to do so in service. This is clearly the responsibility of the electrician.



CHECK YOUR UNDERSTANDING

17. What is the minimum size for the main earth conductor?
18. What is the minimum size for protective earth conductors?
19. What are the two types of earth electrodes specified by *AS/NZS 3000*?
20. What is the purpose of an equipotential bond?
21. What are the earthing requirements for an outbuilding?

12.6 Other protective methods

Section 12.3 in this chapter dealt with earthing as an integral part of protection against indirect contact with live parts by means of the automatic disconnection of the supply. However, there are other acceptable methods of providing this protection. They are by the use of:

- ▶ electrical separation
- ▶ extra-low voltage
- ▶ Class II equipment.

Some involve earthing and bonding, and others do not.

12.6.1 Electrical separation

This method of protection uses a supply from an isolation transformer, motor generator set, uninterruptible power supply (UPS) or the like. The output of the supply must be separated from the input by double-insulation; that is, the supply devices have two electrically separate windings or circuits, which ensures that there is no potential difference between the secondary supply terminals and earth or the primary supply, making shock hazard remote (see *Clause 7.4.2*).

An example of the use of protection by separation is given in **Figure 12.24**, which should be studied in conjunction with *Clause 7.4* and *Wiring Rules, Figure 7.8*.

This system of an unearthed supply appears attractive but it cannot be used on an extensive system, say for supply distribution, due to leakage paths, as discussed in **Section 12.3**. It is used to some extent in some closed systems, such as in a mine, where earth leakage relays continuously monitor leakage current.

12.6.2 Extra-low voltage systems

As we covered in **Chapter 2**, the severity of an electrical shock has much to do with the level of current passing through the body and, as you know from Ohm's Law, current flow is dependent on the resistance of the current path and the applied voltage. By reducing the voltage to an extra-low level, hazards associated with electric shock are greatly reduced. Extra-low voltage (ELV) is not greater than 50 V a.c. or 120 V d.c. (*Clause 1.4.128(a)*).

This is not to say that these voltages are safe in all situations. Protection against direct contact is required for ELV operating above 25 V a.c. or 60 V d.c. In situations where large-area contact with the human body is expected (e.g. in a swimming pool), equipment within the pool is restricted to not more than 12 V a.c. or 30 V d.c. (*Clause 6.3.4.5*).

Figure 12.25 illustrates the two ELV systems covered by the *Wiring Rules*.

The ELV supply can come from a safety isolation transformer complying with *AS/NZS 61558*, a battery, an engine-driven or motor-driven generator or an approved electronic device. As with all supply sources, separation from

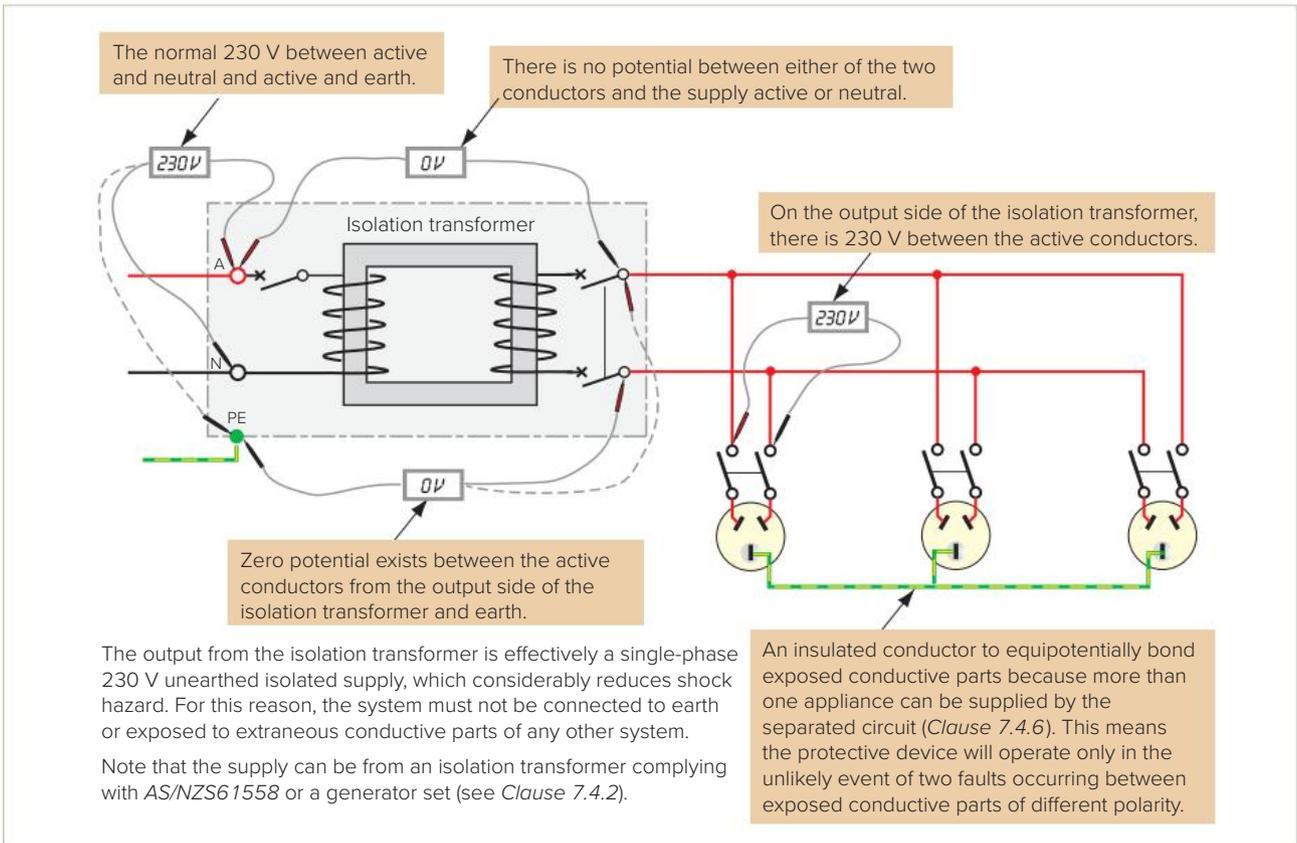


FIGURE 12.24 Example of protection by electrical separation

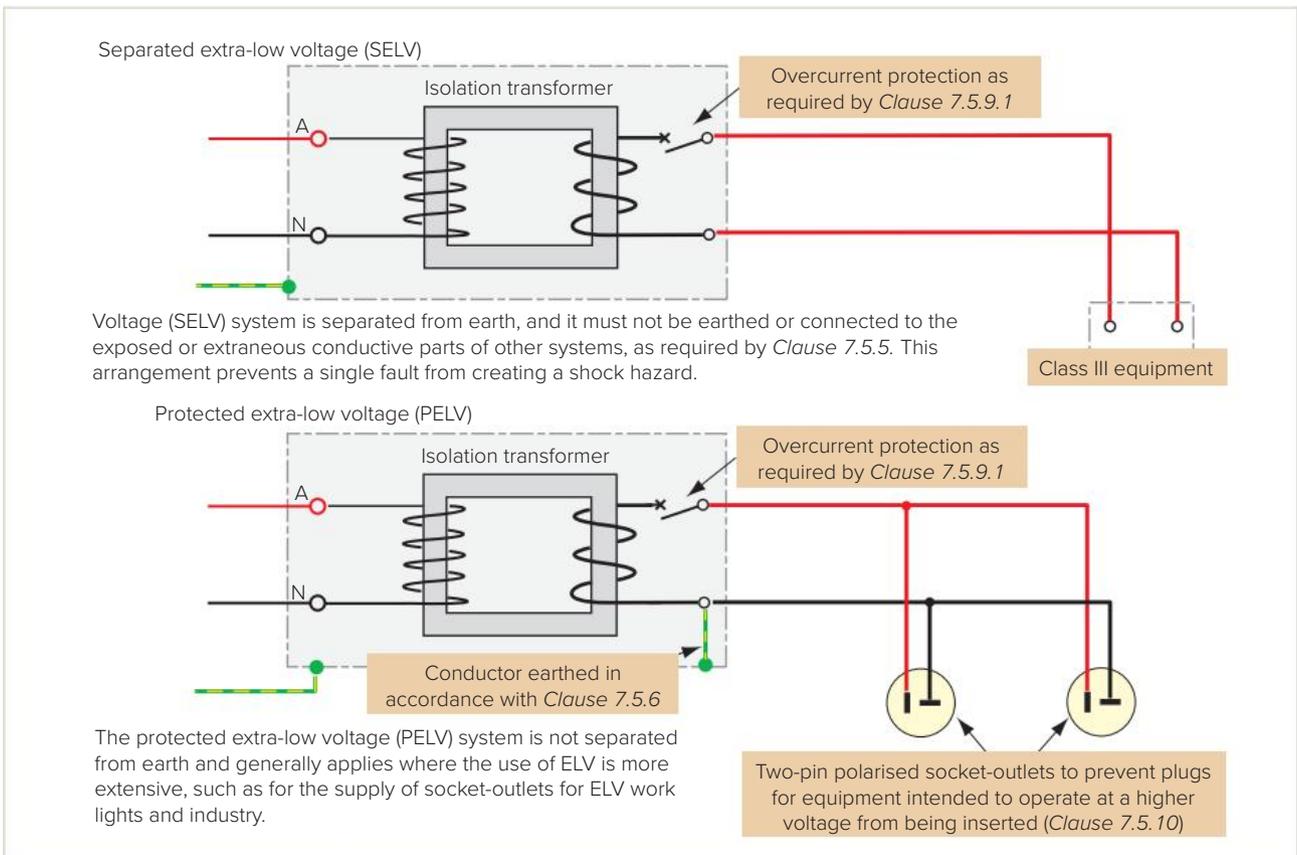


FIGURE 12.25 Extra-low voltage systems

higher voltages is a prime factor in their compliance (*Clause 7.5.3*). Another important requirement is that the live conductors of SELV and PELV circuits must be separated from one another and from other higher voltage circuits. This can be achieved by the use of double-insulated cables or separate compartments in the same enclosure.

Typically, a SELV system is used to supply a single item of equipment such as an ELV luminaire, where the output rating of the transformer is limited and protection is afforded by the protective device of the primary supply. A requirement for a current-using device to be designated ‘Class III equipment’ is that it must be operated from a SELV supply. The PELV system generally applies where the use of ELV is more extensive.

12.6.3 Use of Class II equipment

Class II equipment essentially protects against insulation breakdown either by encasing all metal parts in insulation, or by interposing two separate layers of insulation (double-insulation) between the live parts and any external metal so that both sets of insulation would have to break down to constitute a hazard. Classes of equipment are defined by *Clauses 1.4.31 to 1.4.33*.

Recall that the first section of insulation adjacent to the live parts is known as the basic insulation and the second insulating barrier, between the first and the external metal parts, is termed the supplementary insulation. The same principle is used with double-insulated cable, say, thermoplastic-sheathed (TPS), with the internal single insulation of the conductor providing the basic insulation and the external sheath providing the supplementary insulation (see *Clause 1.4.73*).

Many current-using devices are double-insulated, such as kitchen appliances and larger capacity power tools. They are manufactured to comply with Standard approval and test specifications, and are marked ‘DO NOT EARTH—DOUBLE-INSULATED’ or with the symbol that indicates an appliance is of the double-insulated type. (See **Figure 12.26** for examples.)

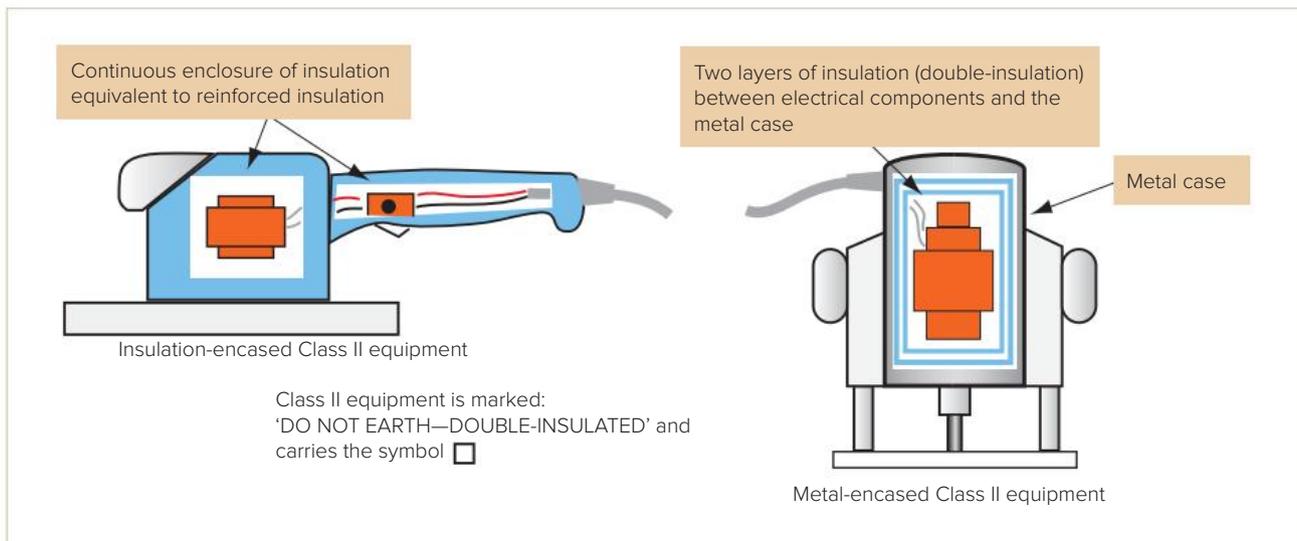


FIGURE 12.26 Different types of Class II equipment

Warning: On no account must this instruction not to earth be disregarded, because any earthing of external parts would actually introduce a hazard by creating an earthed situation wherever the equipment was used. In addition, there would be extra stress on the insulation when the external metal was earthed.

Flexible cord supplying this equipment must be of the two-core double-insulated type, instead of the three-core type. Particular care must be taken to maintain the double-insulation protection where the cord enters the appliance, and conductors within equipment should be secured so that they cannot come into contact with accessible metal (see *Clause 5.4.1 Exceptions*).



CHECK YOUR UNDERSTANDING

22. Other than automatic disconnection of the supply, what are the three acceptable methods of protection against indirect contact?
23. Why are unearthed, electrically separate systems, such as SELV, not used in large extensive systems?
24. What voltage levels are used in ELV systems, and why are such systems useful as a means of protection against indirect contact?
25. What is Class II equipment?

SUMMARY

- ▶ The earthing system is the most important part of the electrical installation as it protects against the risk of electric shock and fire hazard if a breakdown of insulation occurs.
- ▶ An effective earthing system usually ensures that, should a fault occur in an appliance, sufficient current flows to earth to operate a circuit-breaker or fuse to disconnect the appliance from the supply.
- ▶ Earthing systems remove shock hazards, prevent electrically initiated fires, ensure voltage stability and ensure correct operation for some electrical systems.
- ▶ The IEC has a coding scheme to categorise different earthing systems in use throughout the world. Australia and New Zealand use the TN-C-S system:
 - ▶ T—the supply source is connected to earth or *terra*.
 - ▶ N—the supply source is connected to earth through the supply *network*. This is achieved by having the neutral in the consumer mains connected to earth at the supply, at various points through the distribution network and at the consumer main switchboard.
 - ▶ C-S—the earthing system uses a *combined* protective earth-neutral or PEN from the supply to the consumer and within the consumer's installation but uses separate protective earth (PE) and neutrals (N) within the installation.
- ▶ The TN-C-S earthing system is also known as the multiple earthed neutral system or MEN. In the MEN system, the parts of each installation that are required to be earthed are connected to the general mass of earth and connected within the installation to the neutral conductor of the supply.
- ▶ The components of the MEN earthing system are:
 - ▶ main earth terminal—point where all earthing conductors are terminated
 - ▶ main earth conductor—connects the main earth terminal to the earth electrode
 - ▶ earth electrode—a rod, cable or strip embedded in the earth as a means of connecting the earthing system to the general mass of earth
 - ▶ MEN connection—bonds the earthing system to the supply neutral at the main switchboard. Also called the MEN link
 - ▶ PEN—or protective earth-neutral. The supply neutral in a MEN system where the neutral carries normal neutral return current and earth fault current back to the supply
 - ▶ protective earth conductors—conductor provided for all final subcircuits to allow exposed conductive parts associated with the final subcircuit to be connected to earth

- ▶ equipotential bond—conductors provided to connected conductive parts that are not part of the electrical installation to earth to ensure that if there is any fault current flowing in the earthing system there will be no potential rise between the conductive parts and the mass of earth.
- ▶ If an earth fault occurs, a low-impedance return path for the fault current, known as the earth fault-loop, ensures high current flow and thus ensures the circuit protection operates in the required time to automatically disconnect the supply and limit the rise in touch voltage.
- ▶ For earth faults with high impedance and/or small leakage currents, the circuit's protection may not operate in the required time. RCDs will operate with small leakage currents and thus are now mandatory on most circuits to offer protection for small level earth faults.
- ▶ Faults in the earthing system, such as broken PEN conductors, reversal of the supply and insulation breakdown, can result in very dangerous situations where the earthing systems of both the installation and neighbouring installations become energised, resulting in a shock hazard.
- ▶ Other protective methods such as electrical separation, SELV and PELV systems and the use of Class II appliances can be used to provide protection against shock hazards in an electrical installation.

REVIEW QUESTIONS

1. Does earthing affect the normal operation of an appliance?
2. Describe the fundamental safety principles of an electrical installation for protecting against electrical hazards.
3. What is the principal method used in protecting against electrical hazards when a fault causes exposed conductive parts to become live?
4. Describe the consequences of an insulation breakdown fault in an appliance where no earth wire is connected to its metal frame.
5. How could an earth fault initiate a fire?
6. In a TN-C-S distribution system, what is the role of the PEN conductor?
7. Explain the purpose of the MEN connection.
8. Describe the path of fault current when there is a breakdown of insulation in an installation.
9. When is a circuit-protective device required to disconnect the supply to a fault within a prescribed time?
10. Determine the rise in touch voltage when a bolted fault occurs in an appliance supplied by a 25 A circuit where the active conductor has a resistance of 0.2Ω and the protective earthing conductor has a resistance of 0.5Ω . (Use $0.8 U_0$ at the fault.)
11. What could be the likely cause of reported shocks off the water taps in an installation?
12. Explain the reasons for the safety measures a plumber should take before cutting into a metallic water pipe system.
13. Briefly explain how a residual current device works.
14. Why might an electrician select a protective earthing conductor that is larger than that required by *Wiring Rules, Table 5.1*?
15. Why is it permitted to have an earthing conductor smaller than the circuit active conductors when they both carry the same current when a fault occurs?
16. What is the minimum required depth in the ground of a vertical-type rod electrode in Australia? What is the minimum depth in New Zealand?
17. What is the maximum permitted resistance between the main earth terminal and the earth electrode?
18. Why is no specific resistance between the earth electrode and the general mass of earth required by the *Wiring Rules*?
19. Describe the purpose of equipotential bonding.
20. How do SELV and PELV systems differ?

CHAPTER 13

Electrical protection and protective devices

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ apply the *Wiring Rules* to identify overcurrent protection requirements and ensure compliant installations
- ▶ understand how circuit and control arrangements are made in an electrical installation
- ▶ explain the difference between direct and indirect contact and the protection requirements required for each
- ▶ understand the differences between overloads and short circuits and the protection requirements for each
- ▶ list the devices used for protection in an electrical installation
- ▶ understand prospective short-circuit current and calculate the value for an installation
- ▶ understand what a residual current device is and their installation requirements
- ▶ explain basic types of motor protection
- ▶ understand overvoltage and undervoltage and the devices used to protect against each
- ▶ arrange circuits for the requirement of discrimination.

The immense energy available in the modern electrical distribution system poses a great risk of damage to property and death or injury to persons; hence the importance of *Clause 1.5 Fundamental safety principles* of the *Wiring Rules*. This specifies requirements to ensure an electrical installation is protected against the detrimental effects of current, dangerous fluctuations in voltage and hazards of electric shock. In practice, this means using circuit-breakers or fuses to protect circuits against overload and short-circuit currents, and to limit touch voltage when an earth fault occurs; using devices for protection against voltage surges and excessive voltage reduction; and using residual current devices (RCDs) for additional protection to limit the rise of touch voltage when an earth fault occurs.

Although these protection requirements have been mentioned in previous chapters, it is now appropriate to learn more about the causes and consequences of overcurrent, overvoltage and undervoltage, and the effects of current on humans. The principles of how each protective device works and, importantly, how they work together in an installation are explained.

13.1 Protection against overcurrent

There are many rules that, after consideration of various limiting factors, specify maximum safe working currents for wiring; these are covered in **Chapter 16**. If these specified current limits are exceeded and there is no protection, or the protection is either inadequate or ineffective, the resulting abnormal conditions could produce overheating of conductors, subsequent insulation failure (see **Figures 13.1 to 13.6**) and a possible rise in touch voltage (*Clause 1.4.125*).

NOTE: Doubling the current increases the heat fourfold. For example, 2.4 kW is added to a circuit, doubling the load:

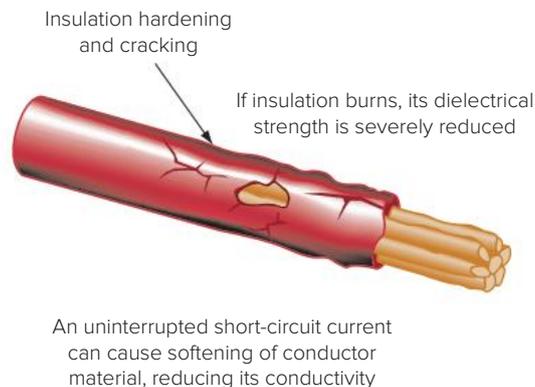
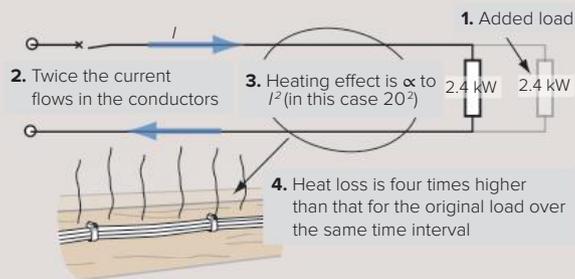
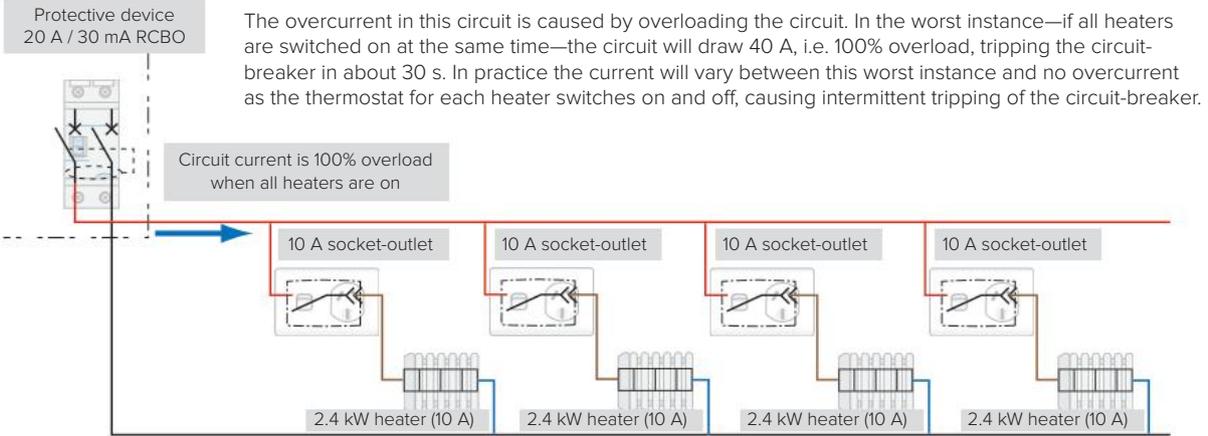


FIGURE 13.1 Effect of overcurrent on cables

It is common for the combined rating of the socket-outlets on a power circuit to be greater than the rating of the circuit-protection device, on the assumption that all outlets will not be used at the same time or, if they are, will not have heavy loads connected to them.



The circuit in this example highlights the care that needs to be taken when planning the circuit arrangements for an installation. (Installation planning is covered in **Chapter 13, Section 13.2.**)

FIGURE 13.2 Causes and consequences of overcurrent by overload—too much connected load

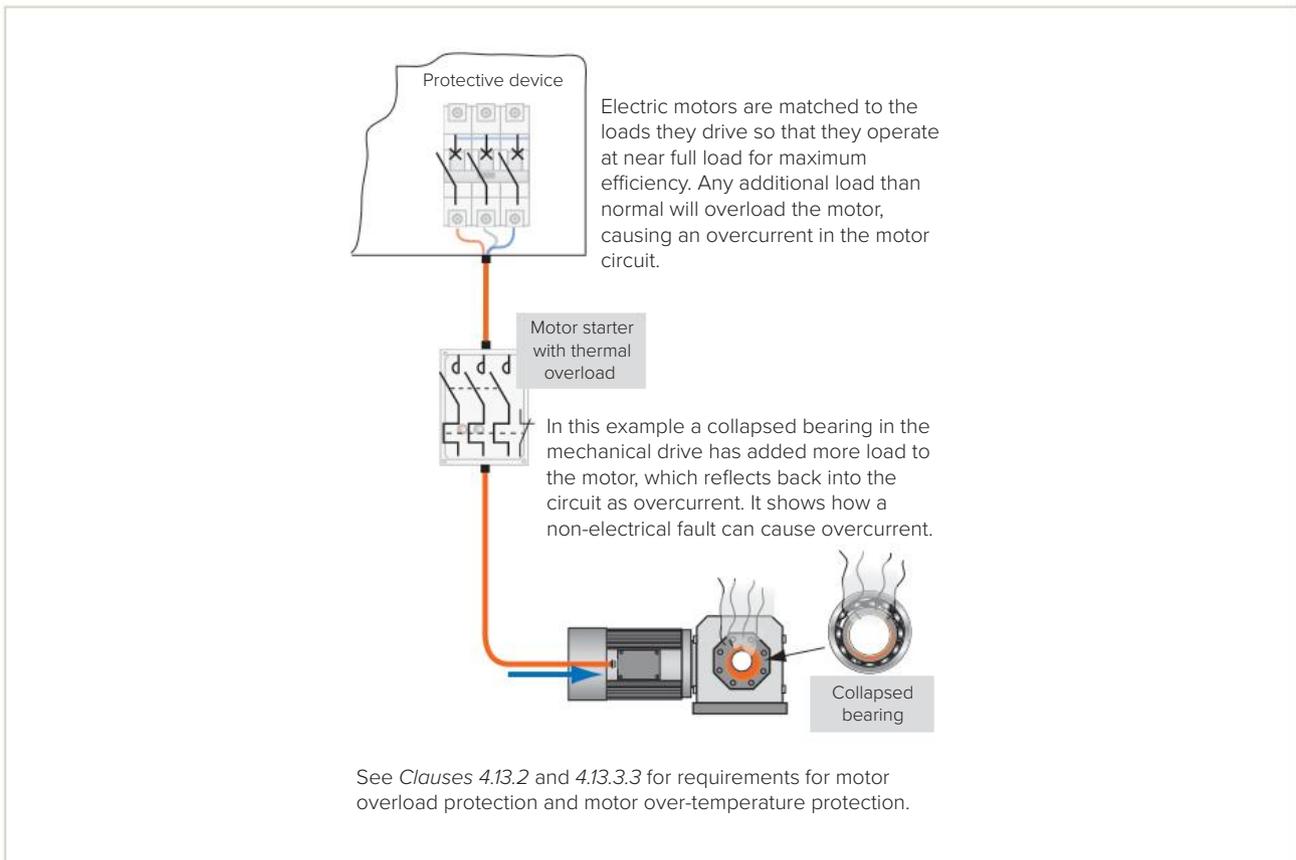
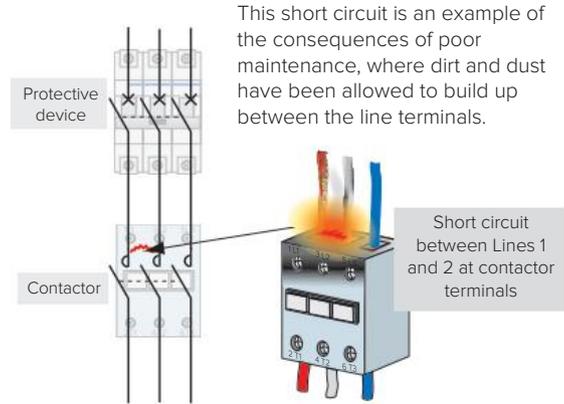


FIGURE 13.3 Causes and consequences of overcurrent by overload—faulty load e.g. motor

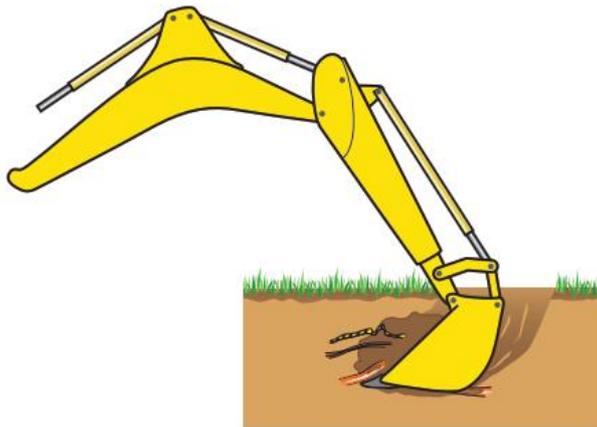
Overcurrent can be in the thousands of amperes when caused by a short circuit and can be very damaging. A common place for short circuits to occur is at the terminals of equipment as illustrated here.



Other causes of short circuits at equipment terminals are transient high-voltage spikes from lightning strikes or rapid switching of inductive loads generally described as arc-faults. Requirements for arc-fault current protection in heavy-current switchboards is covered in **Chapter 3**.

FIGURE 13.4 Causes and consequences of overcurrent by short circuit—line fault

An unfortunate occurrence from time to time is the damage caused to cables during excavation work, resulting in undetected damage to insulation, exposure of live conductors or a short circuit. This has happened even when a cable is identified with marker tape as required by *Clause 3.11.4.5*.



The safety consequences are injury or death from electric shock. The costs of repair and loss of supply disrupting production are likely to be high.

Note that marking the route and recording of underground cables is required by *Clause 3.11.4.6*.

FIGURE 13.5 Causes and consequences of overcurrent by short circuit—earth fault

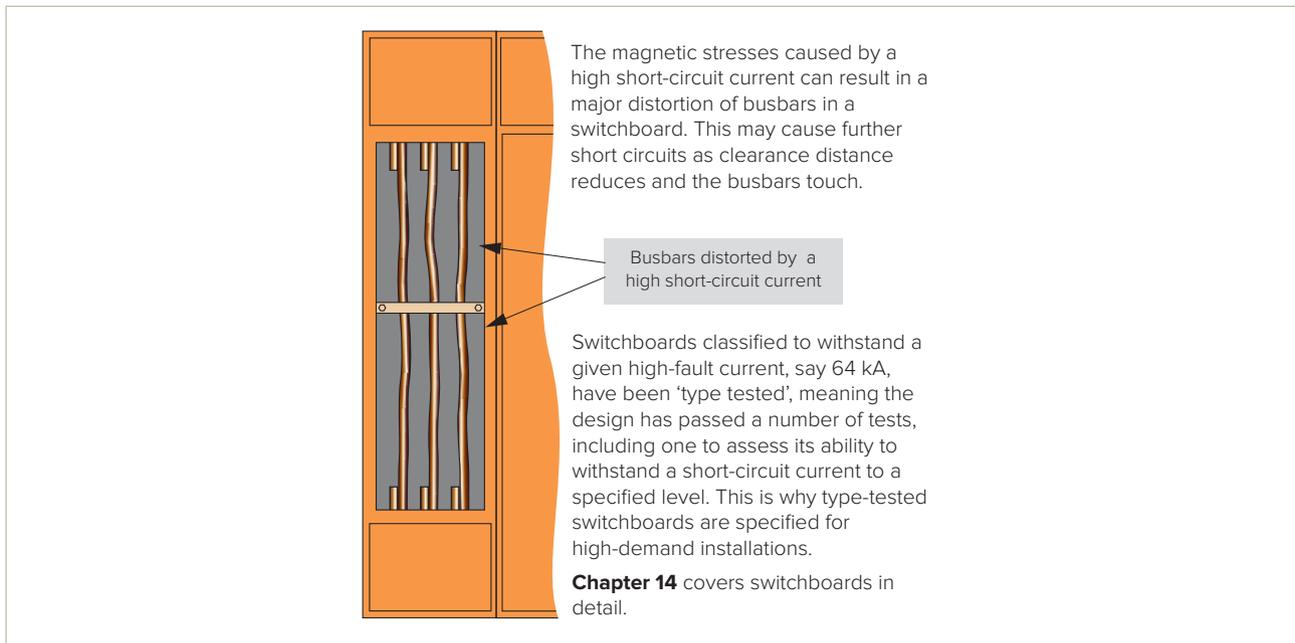


FIGURE 13.6 Causes and consequences of overcurrent by short circuit—electromagnetic damage from a short circuit on busbars

Remember that the heating effect is proportional to the square of the current and is determined by:

$$H = I^2 R t \text{ joules}$$

where

H = heat produced in joules

I = conductor current in amperes

R = resistance of conductor in ohms

t = time for which current flows in seconds.

The heat dissipated in the conductors results in heat loss in the system, contributing to inefficiency in energy use and deterioration of cable insulation if cable temperature rises above its rated value.

DANGER

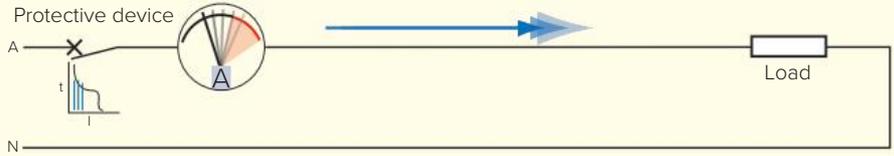
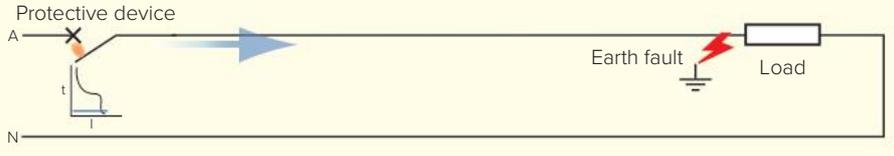
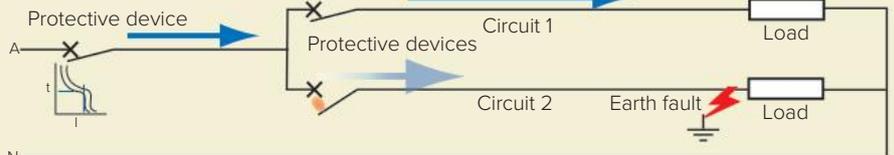
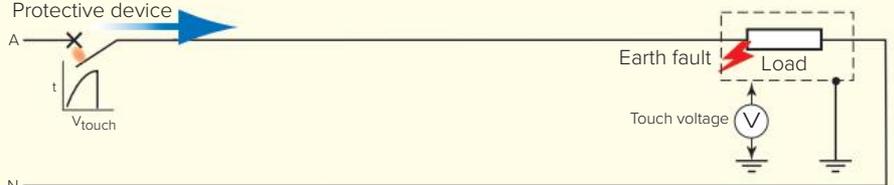
The danger of not complying with the principle of overcurrent protection is that the high value of energy dissipated might cause excessive and destructive damage to wiring and equipment. Associated heating and arcing present a high fire risk and, more importantly, a person working close to an arc produced in an uncontrolled release of energy could sustain a fatal injury. There is always the possibility of shock hazard due to leakage current causing potentials above earth on parts of the installation that are normally at earth potential or isolated from earth.

13.1.1 Causes and consequences of overcurrent

Electrical protective devices (i.e. circuit-breakers and fuses) have three distinct functions, two of which merge because both are dependent on overcurrent; yet they are distinct in that each requires different design considerations for its successful operation. Residual current devices (RCDs) used for additional protection against a rise in touch voltage

(Section 13.3) depend on an imbalance in the delivery and return current in a circuit. **Table 13.1** illustrates the basic concepts behind these functions.

TABLE 13.1 Functions of protective devices

Function	Application
<p>Operate normally</p>	<p>The fuse or circuit-breaker should be capable of carrying its rated current continuously without overheating or deterioration.</p> 
	<p>Small overloads of short duration should not cause the protection to operate.</p> 
<p>Protect wiring</p>	<p>The protection must operate, even on a small overload, if the overload persists long enough to cause overheating of the circuit conductors.</p> 
	<p>The protection must open the circuit before damage caused by fault currents can occur.</p> 
<p>Discriminate</p>	<p>Protection must be discriminative in that only the faulty circuit is isolated, and other circuits remain operative and unaffected.</p> 
<p>Limit rise of touch voltage</p>	<p>The protection must open to limit the rise in touch voltage of exposed conductive parts when an earth fault occurs.</p> 

Clause 2.5 of the *Wiring Rules* specifies an extensive number of requirements for protection against overcurrent, as summarised in **Figure 13.7**. The purpose of these requirements is to protect the active conductors by automatically disconnecting the supply before an overcurrent attains a magnitude or duration that could cause injury to persons or livestock, or cause damage because of excessive temperatures or electromechanical stresses in the electrical installation.

Overcurrent protection cannot be expected to protect connected appliances that, where required, have protection incorporated into the appliances themselves or included within the associated control device.

13.1.2 Overload protection

Overload currents in circuit conductors must be cut off by a protective device before the overload currents cause a temperature increase that might damage joints, insulation or other material surrounding the conductor. The *Wiring Rules* stipulate that, in the event of an overload, a protective device (circuit-breaker or fuse) must disconnect the supply before the temperature rise caused by the excess current damages the cable insulation, circuit connections or adjacent cables. To do this without the inconvenience of nuisance tripping, *Clause 2.5.3.1* of the *Wiring Rules* requires coordination between conductors and protective devices, as shown in **Figure 13.8**.

The requirements for overload protection in the *Wiring Rules* are intended to limit heating of cables to acceptable limits. The note to *Clause 2.5.3.1*, however, warns that the requirement does not protect against the longer-term deteriorating effects on cable insulants of small overloads (less than I_2) of long duration. Circuits should be designed according to all expected operating conditions.

The protection should also be immune to causes of nuisance tripping, such as an overload of short duration, but must fully protect the wiring against overloads that could cause damage if allowed to continue.

13.1.3 Short-circuit protection

So far only overload current has been considered, where a measure of the overload is usually known or assumed. Using normal full-load or maximum demand current as the base, an overload is expressed as twice the rated current, or 150 per cent overload. However, in the case of a short circuit, the only limit to the value of current present is the impedance of the faulty circuit and the available short-circuit energy, with no component of the load having an effect.

Prospective short-circuit current

The interrupting capacity of the protective device (circuit-breaker or fuse) must be adequate to enable the interruption of the highest value of current available at the point of installation of the protection (*Clause 2.5.2*). This value of current is known as the prospective short-circuit current (PSC). The protection will be located at the commencement of the circuit, which is usually at the main switchboard or at a distribution board and must operate to interrupt the short-circuit current before the temperature of conductors reaches the admissible limit. Temperature limits for cables under short-circuit conditions are given in *AS/NZS 3008.1* series *Section 5*.

Clause 2.5.4.1 stipulates that the PSC must be determined at every relevant point of an electrical installation, the relevant points being mainly where protective devices are installed. The PSC decreases as the distance from the point of supply increases, due to the impedance of the circuit conductors involved.

NOTE: The approach to PSC in this chapter is intended to provide an understanding of the basic parameters that determine short-circuit currents. Calculating PSC requires data that is not always available to the electrician when planning an installation. In practice, a fairly safe estimate of PSC can be made using the chart or table provided by the manufacturer of the protective device.

Energy distributors usually declare a minimum PSC at the point of supply, which may be higher than the actual value, to allow for future upgrades to the distribution network. For large or complex installations, the energy distributor (and client) will require input from and confirmation by an engineer.

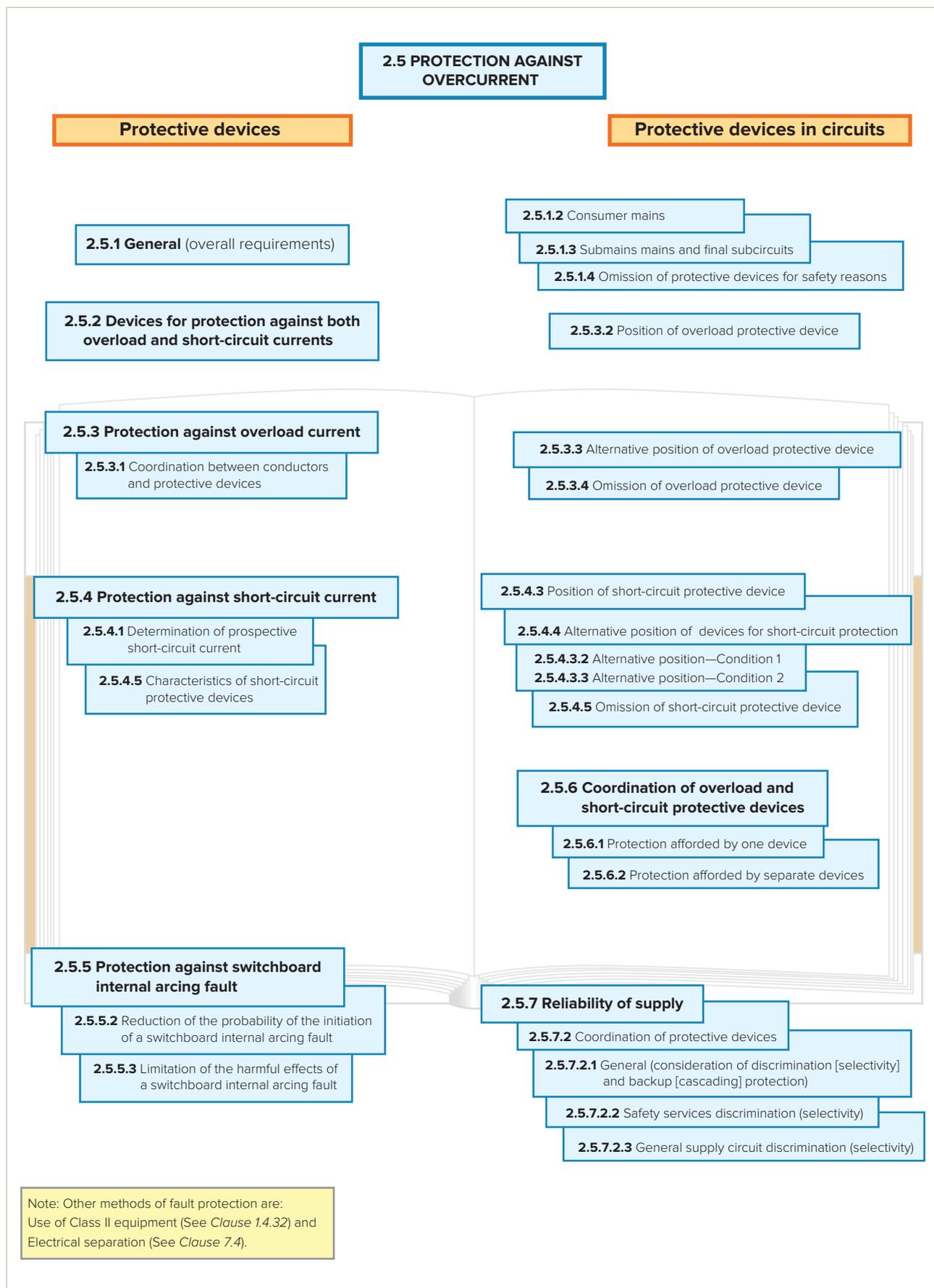
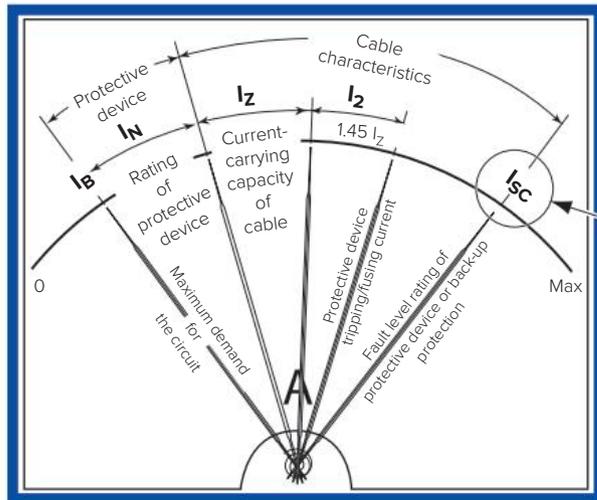


FIGURE 13.7 Summary of *Wiring Rules* for protection against overcurrent

Coordination of cables and protective devices



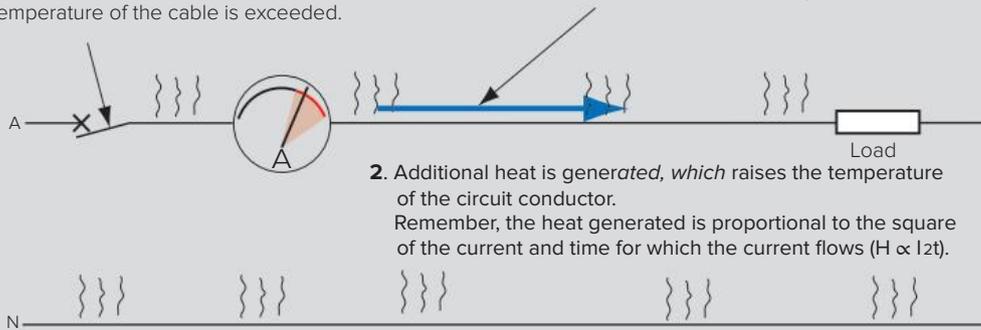
Conductors must be protected against the higher temperatures caused by short-circuit currents as required by Clause 2.5.4.

In order to comply with the requirements of $1.45 I_N$, fuses should be de-rated to $1.45/1.6$; that is, 90%. (See Clause 2.5.3.1.)

When an overload occurs:

3. The protective device must operate to open the circuit before the maximum-permitted operating temperature of the cable is exceeded.

1. A current higher than the normal-rated current is present in both the circuit wiring and the series-connected protective device.



2. Additional heat is generated, which raises the temperature of the circuit conductor. Remember, the heat generated is proportional to the square of the current and time for which the current flows ($H \propto I^2t$).

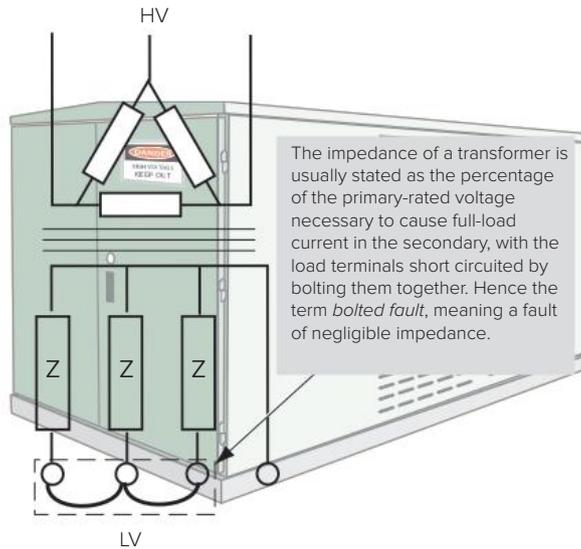
FIGURE 13.8 Overload protection requirements

Determining prospective short-circuit current

The current that flows when a short circuit occurs is only limited by the impedance of the supply source, usually a substation transformer or group of transformers and the cables up to the point where the short circuit occurs, as shown in Figures 13.9 and 13.10.

Any estimation of fault level must commence at the source of supply using first principles, Ohm's Law, $I = \frac{V}{Z}$, remembering that $Z = \sqrt{R^2 + X^2}$. The resistive components and the reactive components of conductors to the relevant points in the electrical installation must therefore be added separately to arrive at an accurate value of impedance and hence the prospective fault current. This is illustrated in the following examples.

NOTE: The total impedance to the point where the PSC is to be determined is a vector sum of all the individual impedance values in series to that point. Simply adding the individual impedance values algebraically will give a higher total impedance than is really the case and therefore result in a lower PSC than would otherwise be determined.



For example, if 5% of supply voltage produces full-load current, then, with secondary short circuited and normal supply voltage of 100%, 20 times the full-load current will be present ($100 \div 5 = 20$).

Common transformer impedance values are in the range of 4 to 6%.

Take a 750 kVA 230/400 transformer where the full-load current is:

$$I_{FL} = \frac{S}{\sqrt{3} \times V_L} = 1083 \text{ A}$$

then with an impedance of 5% prospective short-circuit current (PSC):

$$I_{SC} = I_{FL} \times 20 = 21.66 \text{ kA}$$

So the equivalent impedance is:

$$\begin{aligned} Z_{SC} &= \frac{V}{I_{SC}} \\ &= 400 \div 21.66 \times 10^3 \\ &= 0.01847 \, \Omega, \text{ for a short circuit between phases} \\ &= 230 \div 21.66 \times 10^3 \\ &= 0.01062 \, \Omega \text{ for a short circuit between a line and neutral} \end{aligned}$$

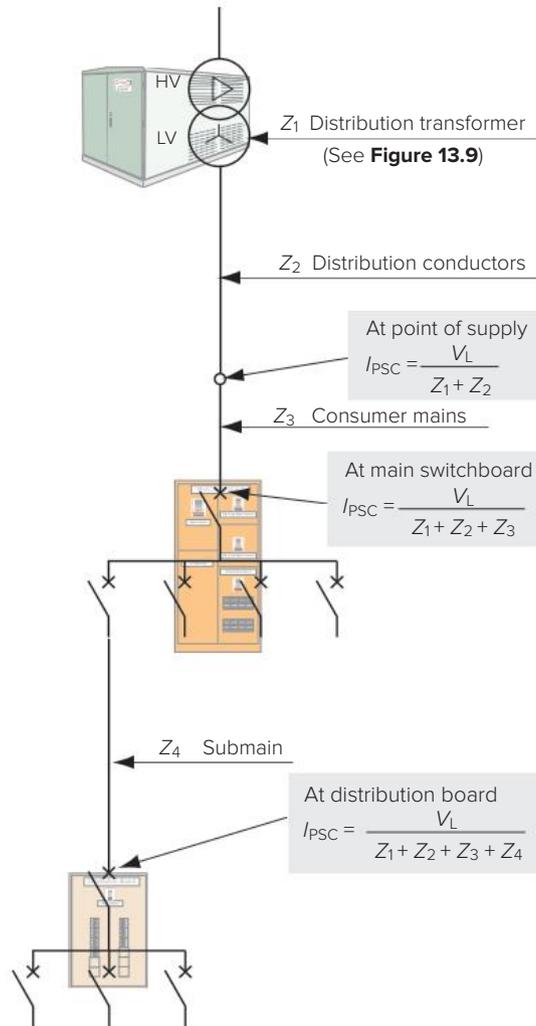
In order to estimate the prospective fault current at relevant points in electrical installations supplied by the transformer, the R/Z ratio (i.e. $\cos \theta$) must be known and can be taken as between 0.2 and 0.3.

FIGURE 13.9 Factors limiting short-circuit current of a distribution transformer

A short circuit to earth in the multiple earthed neutral (MEN) system is the equivalent of a phase to neutral fault. However, the current would be further reduced owing to the impedance of the earthing system between the fault and the neutral link.

Engineering calculations for large and complex installations are commonly done using dedicated engineering software. However, it is important that the user of such software has an understanding of the electrical theory and processes involved so their output design can be trusted.

Switchboard manufacturers also need to consider fault levels and other requirements for switchboards to pass type approval tests. Venting and modular design are commonly used to contain explosions caused by high-fault currents. Any equipment mounted on a switchboard must have full short-circuit capacity for the fault level at that point. (See **Chapter 14** for more detailed coverage of switchboards.)



Recalling that $Z = \sqrt{R^2 + X^2}$, the values of R and X for common conductor types and sizes, cable types and temperatures are given in AS/NZS 3008 Tables 30 to 39.

Note that the fault level at any point in an installation decreases the further it is from the supply due to the additional impedance of the circuit conductors.

FIGURE 13.10 Factors limiting short-circuit current in an installation

EXAMPLE 13.1

A factory complex is supplied directly from a supply transformer. Estimate the prospective fault current at the main switchboard, given:

Transformer rating: 500 kVA 11 kV 400/230 V with an impedance of 4%

Consumer mains: $3 \times 400 \text{ mm}^2 + 1 \times 150 \text{ mm}^2$ V-75 single-sheathed cables installed in underground duct and route length of 14 m.

1. Determine the maximum fault-current impedance of the transformer, given $\cos \phi$ 0.25.

$$I_{FL} = \frac{S}{(\sqrt{3} \times V_L)} = \frac{(500 \times 1000)}{\sqrt{3} \times 400} = 722 \text{ A}$$

$$I_{(SC)} = I_{FL} \times \frac{100}{(Z\%)} = \frac{(722 \times 100)}{4} = 18.05 \text{ kA}$$

$$Z_{(TX)} = V_L \div I_{SC} = \frac{400}{(18.05 \times 1000)} = 0.0222 \Omega$$

Express this impedance in the resistive and reactive components:

$$R_{TX} = Z \cos \phi = 0.0222 \times 0.25 = 0.0056 \Omega$$

$$X_{TX} = Z \sin \phi = 0.0222 \times 0.9682 = 0.0215 \Omega$$

2. Determine the reactance and resistance of the consumer mains from the tables in *AS/NZS 3008*. Note that the values given are Ω/km .

From *Table 30*, the reactance of 400 mm² PVC single-sheathed cable is 0.0829 Ω/km . Then the reactance of the consumer mains (assuming trefoil arrangement) is:

$$X_{CM} = \frac{X_{(\Omega/1000)}}{1000} \times L_{CM} = \frac{0.0829}{1000} \times 14 = 0.0011 \Omega$$

From *Table 34*, the resistance of 400 mm² V-75 single sheathed cable is 0.0620 Ω/km . Then the resistance of the consumer mains is:

$$R_{CM} = \frac{R_{(\Omega/1000)}}{1000} \times L_{CM} = \frac{0.0620}{1000} \times 14 = 0.0009 \Omega$$

3. Determine the impedance of the supply network at the main switchboard.

$$\begin{aligned} Z_{MSB} &= \sqrt{(R_{TX} + R_{CM})^2 + (X_{TX} + X_{CM})^2} \\ &= \sqrt{(0.0056 + 0.0009)^2 + (0.0215 + 0.0011)^2} \\ &= 0.0266 \Omega \end{aligned}$$

4. Determine the PSC at the main switchboard.

$$I_{(MSB SC)} = \frac{V_L}{Z_{MSB}} = \frac{400}{0.0266} = 15.05 \text{ kA}$$

It can be seen that the reactance components of the transformer impedance and the large size of the consumer mains are significant in calculating the prospective fault current.

EXAMPLE 13.2

Following on from **Example 13.1**, determine the PSC at a distribution board supplied from the main switchboard by a four-core 50 mm² V-75 sheathed cable with a route length of 95 m.

1. Determine the reactance and resistance of the submain from the tables in *AS/NZS 3008*. Again, note that the values given are Ω/km .

From *Table 30*, the reactance of 50 mm² PVC multicore cable is 0.0797 Ω/km . Then the reactance of the consumer mains is:

$$X_{(SM)} = \frac{X_{(\Omega/1000)}}{1000} \times L_{SM} = \frac{0.0797}{1000} \times 95 = 0.0076 \Omega$$

From *Table 35*, the resistance of 50 mm² V-75 single-sheathed cable is 0.471 Ω/km. Then the resistance of the consumer mains is:

$$R_{(SM)} = \frac{R_{(\Omega/1000)}}{1000} \times L_{SM} = \frac{0.471}{1000} \times 95 = 0.447 \Omega$$

2. Determine the impedance of the supply network at the distribution board.

$$\begin{aligned} Z_{DB} &= \sqrt{(R_{TX} + R_{CM} + R_{SM})^2 + (X_{TX} + X_{CM} + X_{SM})^2} \\ &= \sqrt{(0.0055 + 0.0009 + 0.0447)^2 + (0.0247 + 0.0011 + 0.0076)^2} \\ &= 0.0610 \Omega \end{aligned}$$

3. Determine the PSC at the distribution board.

$$I_{(DBSC)} = \frac{V_L}{Z_{DB}} = \frac{400}{0.061} = 6.6 \text{ k}$$



CHECK YOUR UNDERSTANDING

1. What is the danger of not complying with the principle of overcurrent protection for conductors?
2. What are the necessary functions of protective devices?
3. What does the term *prospective short-circuit current* mean?
4. What electrical properties limit prospective short-circuit current?
5. What is one method for determining the PSC at the main switchboard?

13.2 Overcurrent protective devices

Overcurrent protection of a whole installation, submains, final subcircuits and appliances themselves is performed by circuit-breakers or fuses, and in some cases both.

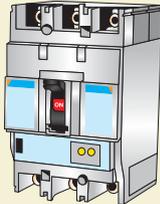
13.2.1 Circuit-breakers

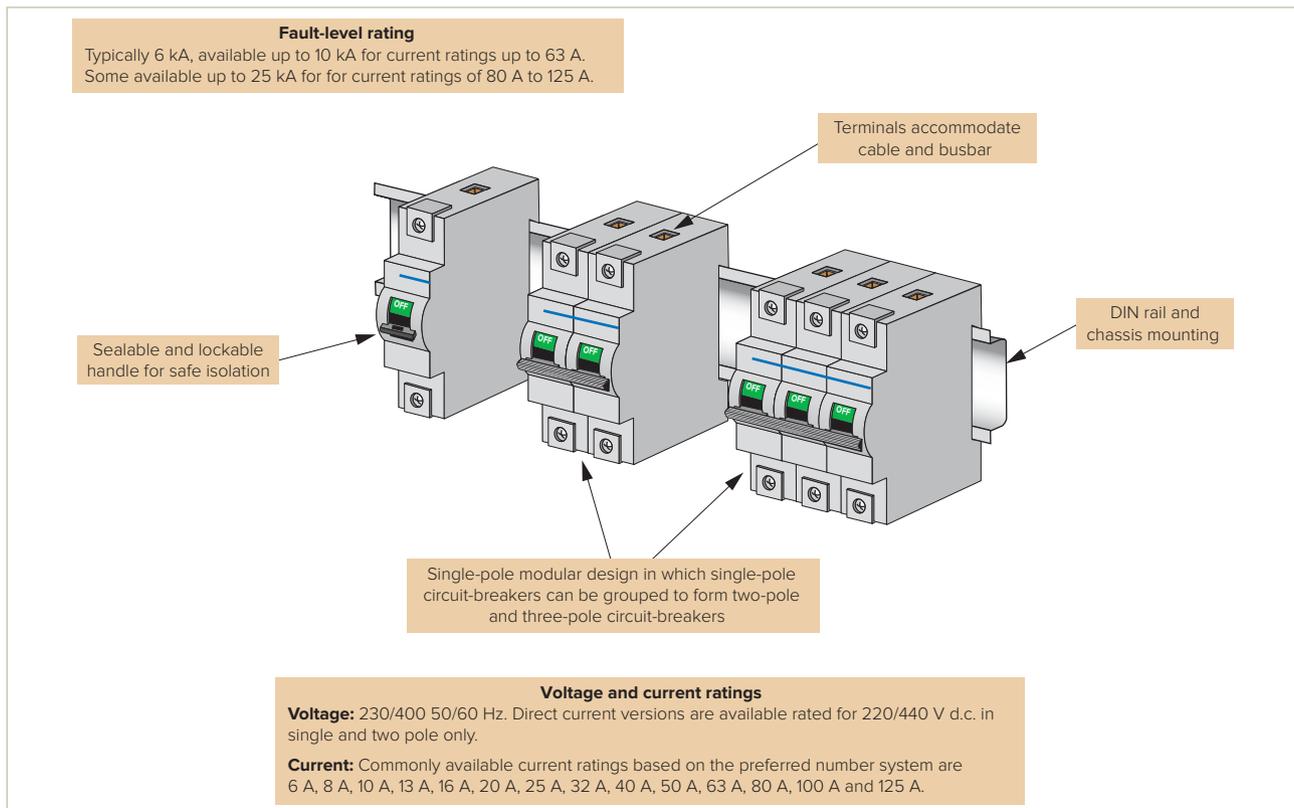
The primary function of a circuit-breaker as defined by *Clause 1.4.30* is protection, although it also provides a switching facility. Circuit-breakers are widely used to provide protection in their own right but may be used in conjunction with fuses, depending on the service duty required. The most commonly used circuit-breaker for rated currents up to 125 A is the miniature circuit-breaker (MCB) that complies with *AS/NZS 3111 Approval and test specification—Miniature overcurrent circuit-breakers* and *AS/NZS 60898 Electrical accessories—Circuit-breakers for overcurrent protection for household and similar installations—Circuit-breakers for a.c. operation*. These Standards specify the mean tripping currents and tolerances for classifying these circuit-breakers by type, as shown in **Table 13.2**.

Moulded-case circuit-breakers (MCCBs) that comply with *AS 60947.2 Low-voltage switchgear and controlgear Part 2: Circuit-breakers* are used for protecting circuits in commercial and industrial installations where higher fault conditions and demands exist. Larger air circuit-breakers (ACBs) are used in similar types of installation for high fault current limiting of incoming supply, large feeders (mains and submains) and load switching.

The major features of circuit-breakers are shown in **Figures 13.11, 13.12 and 13.13**.

TABLE 13.2 Circuit-breaker types and applications

Type		Application
Miniature circuit-breaker (MCB)		Miniature circuit-breakers are most commonly used for overload and short-circuit protection of submains and final subcircuits in domestic and light commercial installations.
Moulded-case circuit-breaker (MCCB)		Moulded-case circuit-breakers are most commonly used for protection of submains, heavily loaded circuits and final subcircuits in commercial and industrial installations. They are available with built-in protective relays providing selectable overcurrent settings.
Air circuit-breaker (ACB)		Air circuit-breakers are used in distribution networks and large installations as main switches for feeders/submains. They commonly have built-in protective relays providing a range of selectable protective and monitoring functions.

**FIGURE 13.11** Major features of MCBs

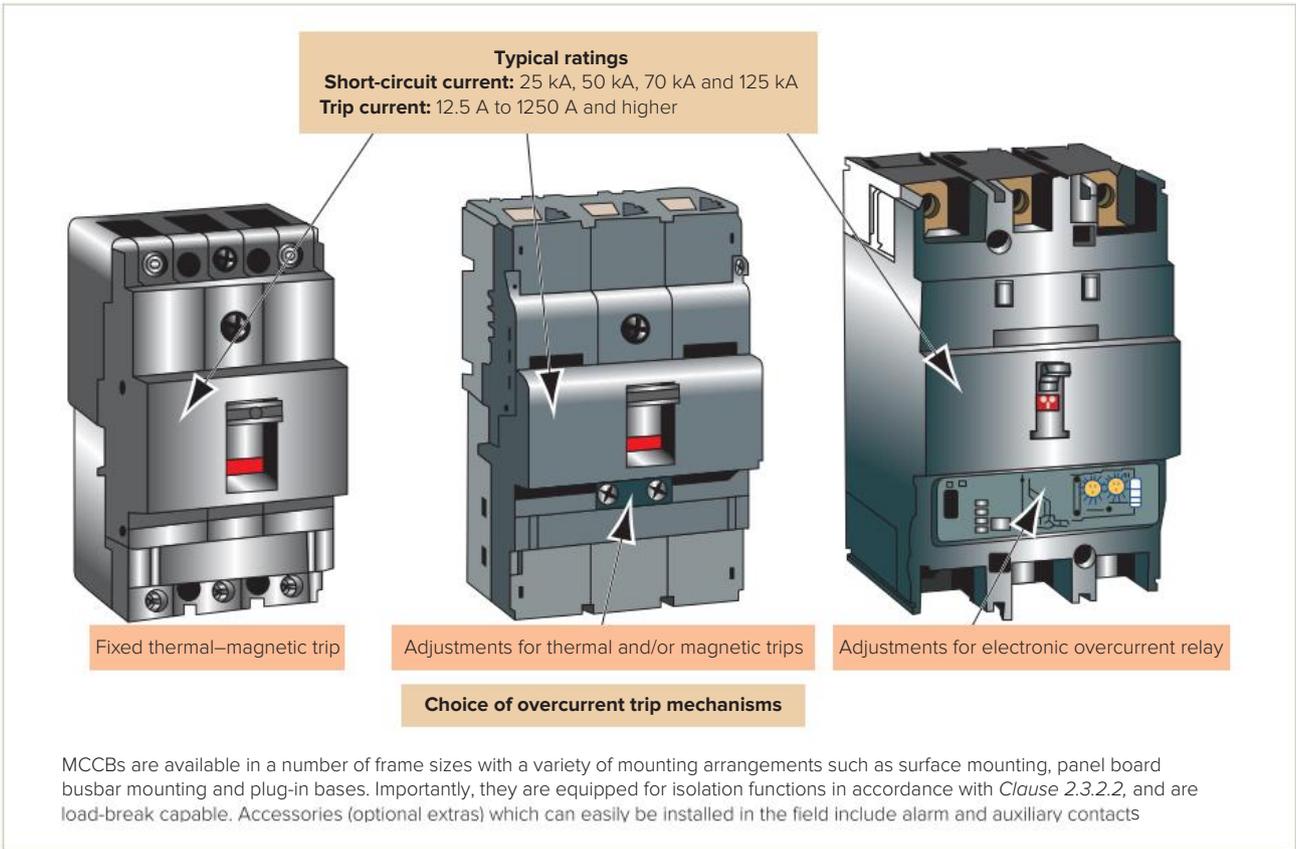


FIGURE 13.12 Major features of MCCBs

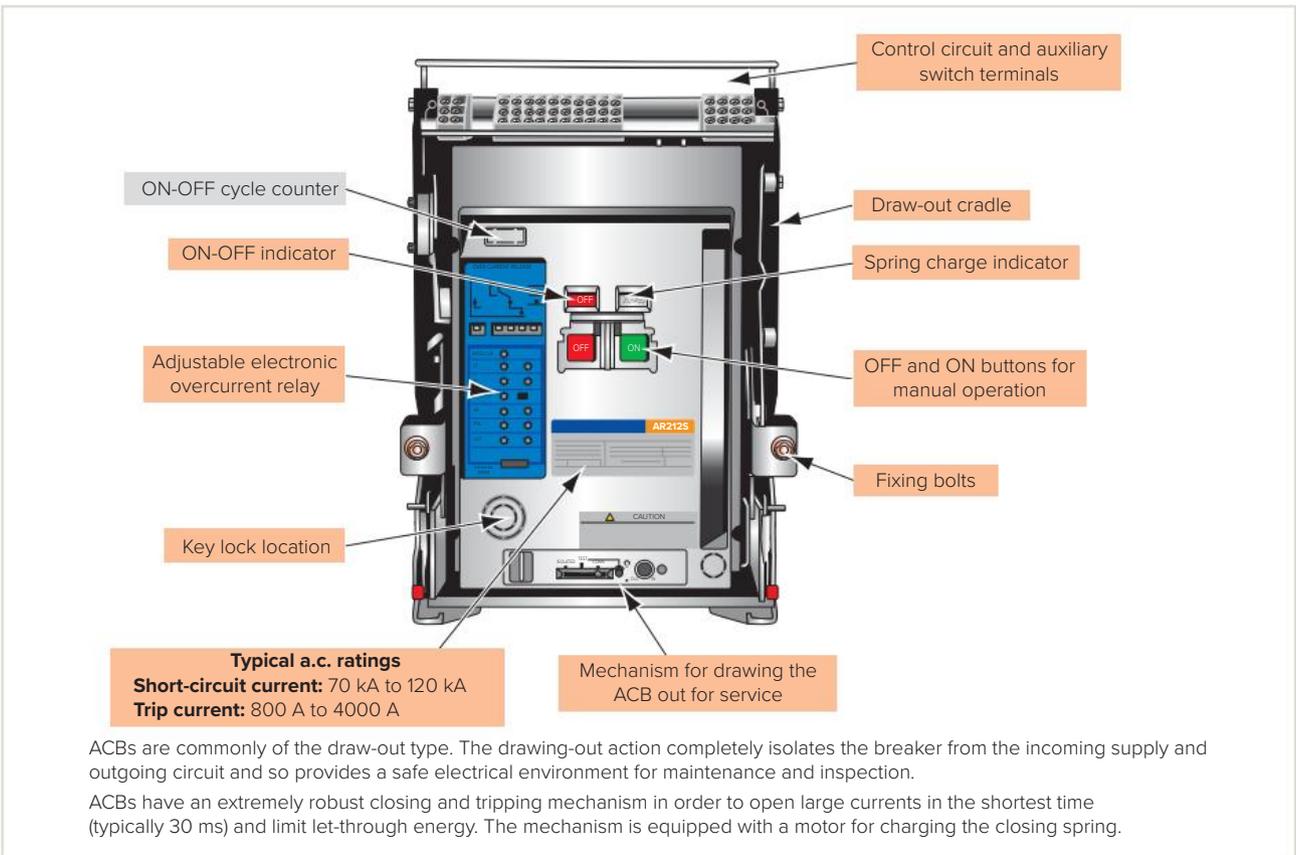


FIGURE 13.13 Major features of ACBs

Circuit-breaker operating mechanisms

Protection by a circuit-breaker is achieved by automatically opening the circuit (commonly called tripping) in response to an overcurrent due to either an overload or short circuit. Modern circuit-breakers are thermal-magnetic devices, that being a reference to the two tripping elements employed. The thermal element causes a time-delayed trip of the circuit-breaker on detection of overload current, while the magnetic element causes an almost instantaneous trip of the circuit-breaker on detection of a high inrush current, as is the case with a short circuit. The concepts behind this arrangement are illustrated in **Figures 13.14 to 13.16**.

Temperature de-rating

If the circuit-breaker is installed in the same ambient temperature conditions as the protected circuit, the time to trip will reduce because the ambient temperature of the protected cables will also have risen. The time lag of the thermal trip ensures that overloads of short duration do not cause tripping; but should these continue, the cumulative heating effect will eventually trip the breaker in time to avoid exceeding the temperature rise limits of the cable.

MCBs are designed and calibrated to carry their rated current and to operate within their designated thermal time/current zone at 30 °C in free air conditions. If the circuit-breaker is required to operate in a higher ambient temperature than 30 °C then it will require progressively less current to trip within the designated time/current zone.



DID YOU KNOW?

What is a shunt trip?

A shunt trip is an additional trip solenoid fitted to a circuit-breaker that allows the breaker to be tripped from an external switch, button or control device. The shunt-trip solenoid activates the mechanical trip release in the same way that the internal thermal and/or magnetic protection units in the breaker cause it to trip. Shunt trips are usually available as an accessory (optional extra) to MCCBs and are a standard feature of ACBs.

In practice, if it is in an ambient temperature higher than its rating—or even in an enclosure or grouped with other equipment where the temperature will exceed its free air temperature rating—an MCB must be de-rated. One manufacturer provides temperature-correction tables and a factor of 0.9, 0.85 and 0.8 applied, respectively, for groupings of 2 to 4, 4 to 6 and greater. For example, a 63 A circuit-breaker in an enclosure grouped with more than six other circuit-breakers would have its rating reduced to 50.4 A. And a further reduction in rating would apply if the ambient temperature was higher than 30 °C.

Circuit-breaker characteristics

The two main protection functions of a circuit-breaker are to protect wiring from overcurrent from either an overload or a short circuit—each requires a different time response. When a short circuit occurs, *Clause 1.5.5.3* specifies that the protective device must disconnect the supply within 0.4 s for final subcircuits supplying socket-outlets rated up to 63 A, hand-held Class I equipment and portable equipment intended for manual movement during use. A maximum disconnect time of 5.0 s is specified for circuits such as submains, final subcircuits and those supplying fixed or stationary equipment. As mentioned in **Section 13.1**, *Clause 2.5.3.1* of the *Wiring Rules* requires coordination between conductors and protective devices, as shown in **Figure 13.17**.

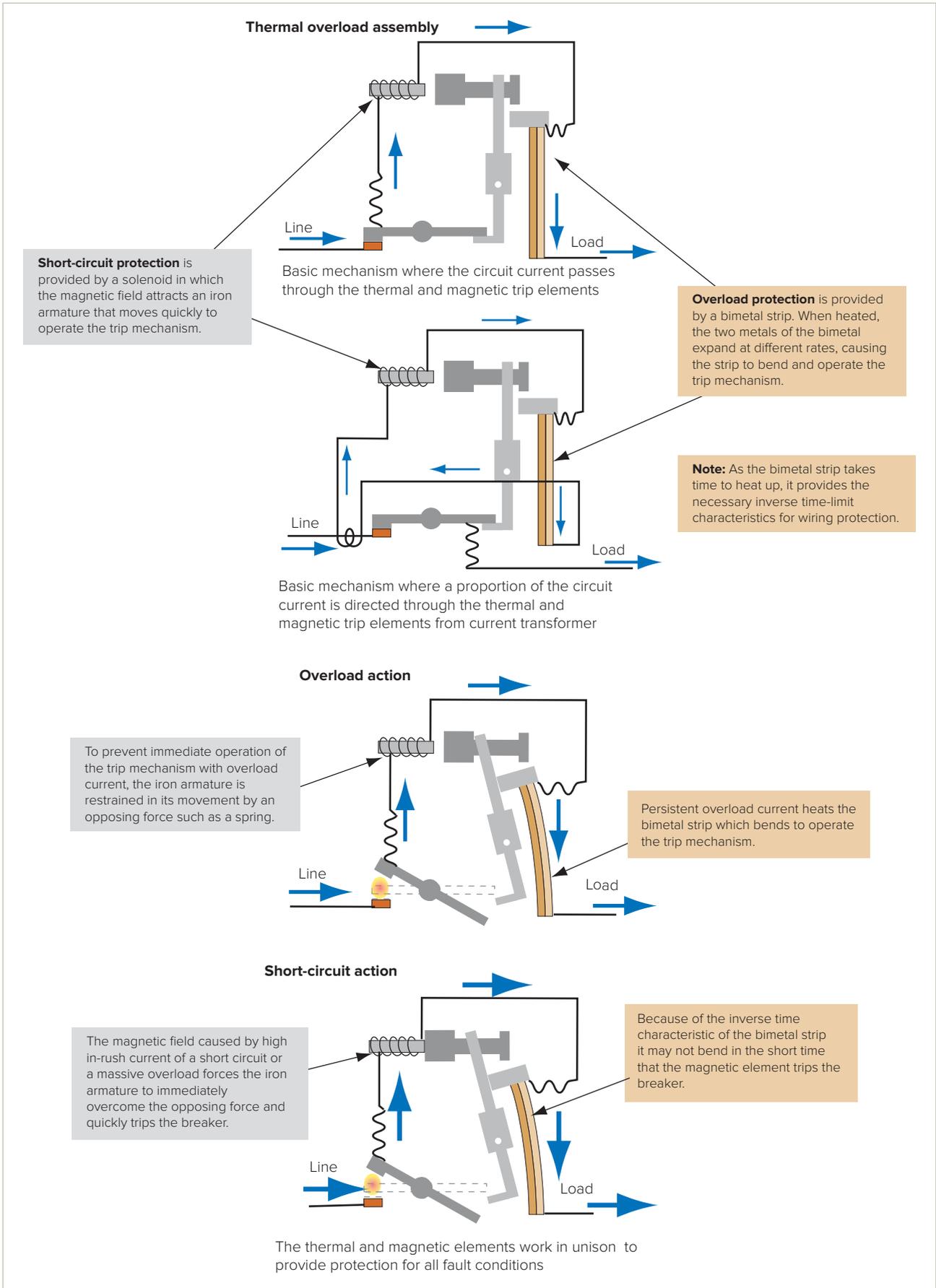
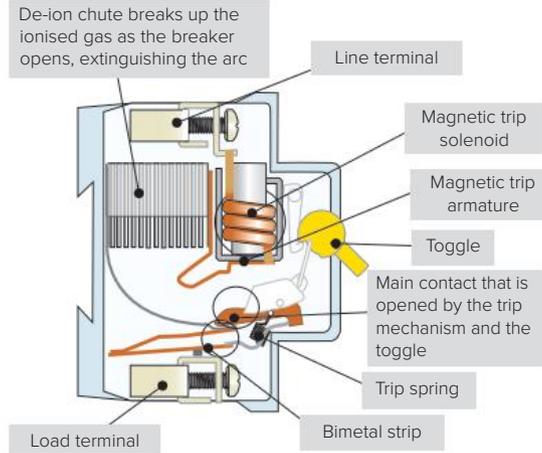


FIGURE 13.14 How overcurrent elements in thermal–magnetic circuit-breakers work



Although the mechanism shown above is of an MCB, thermal–magnetic MCCBs have the same components. The addition of a current-transformer circuit is used in circuit-breakers rated for high currents.

Important design features of large circuit-breakers, like ACBs, are the switching arrangement shown below. These features aid breaking of high currents, reduction of arcing and incorporate integral isolation to ensure electrically safe servicing and inspection.

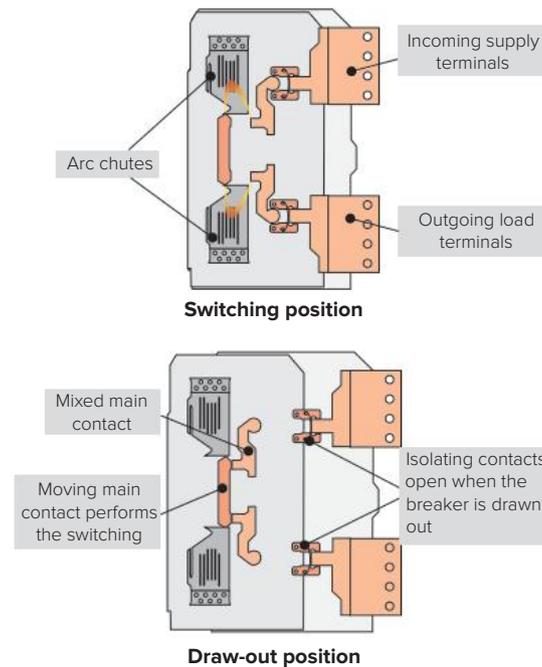


FIGURE 13.15 Typical circuit-breaker mechanism

The short-circuit and overload protection functions of circuit-breakers are represented in the graphs in **Figure 13.18** showing their time–current characteristic curves. Fixed-setting circuit-breakers (typically MCBs) are intended to protect wiring against both overloads and short circuits in domestic or commercial wiring where operation (switching on or off or resetting) is possible by an un instructed person. They are designated by their instantaneous time–current characteristic curves, which classify these circuit-breakers into three types, as shown in **Figure 13.18**.

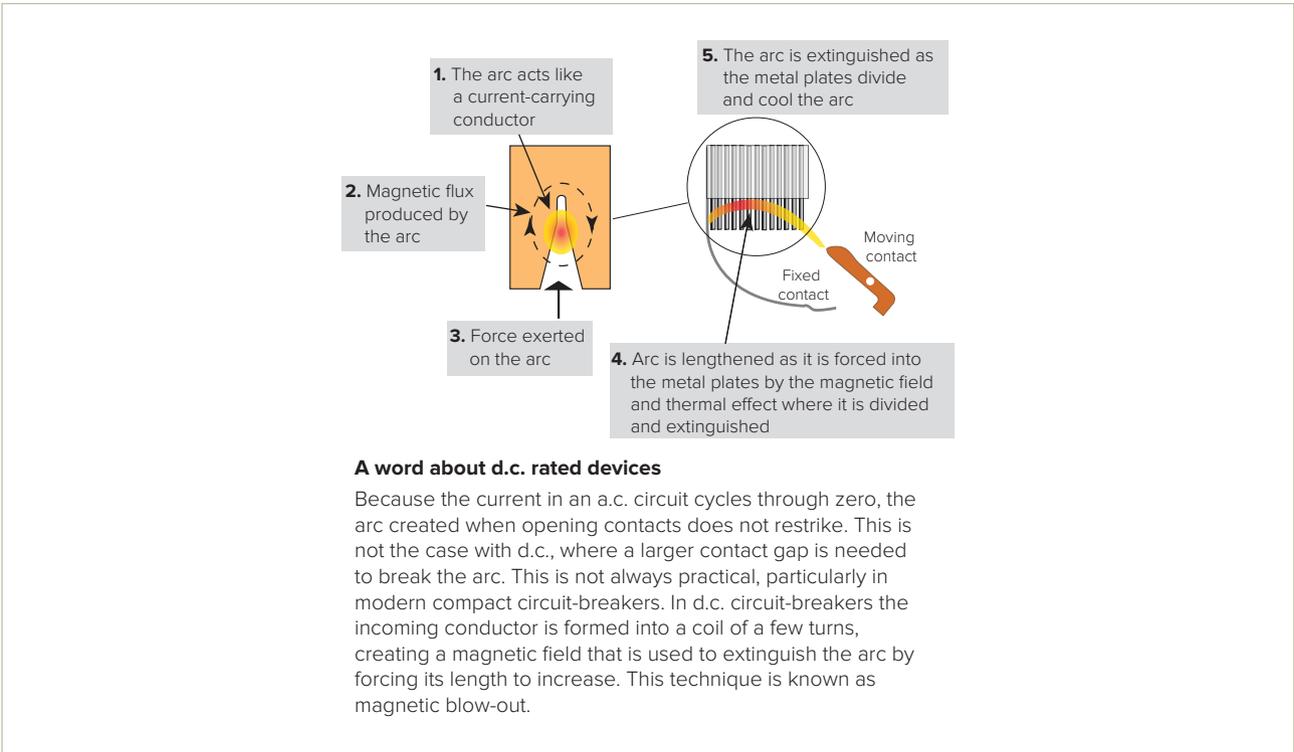


FIGURE 13.16 How de-ion arc chutes work

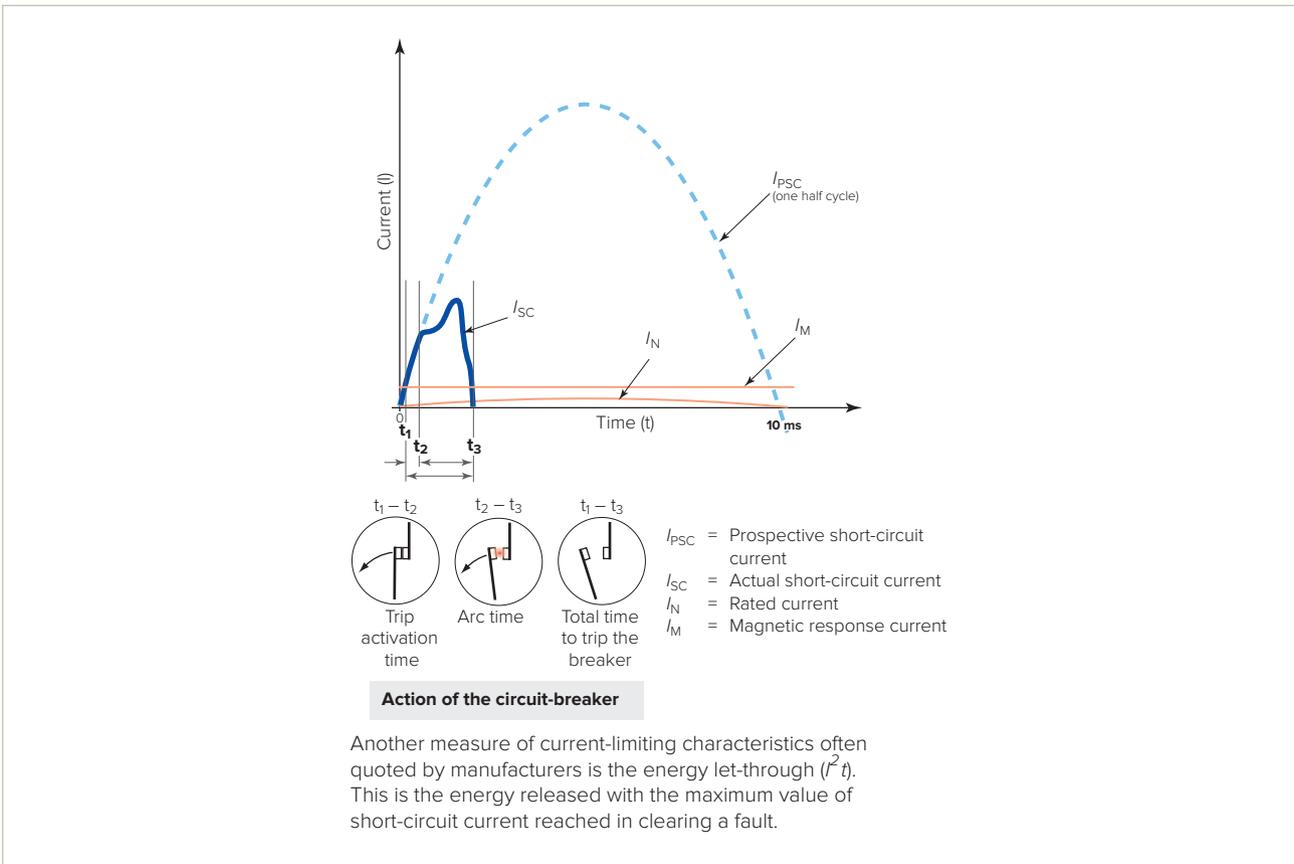
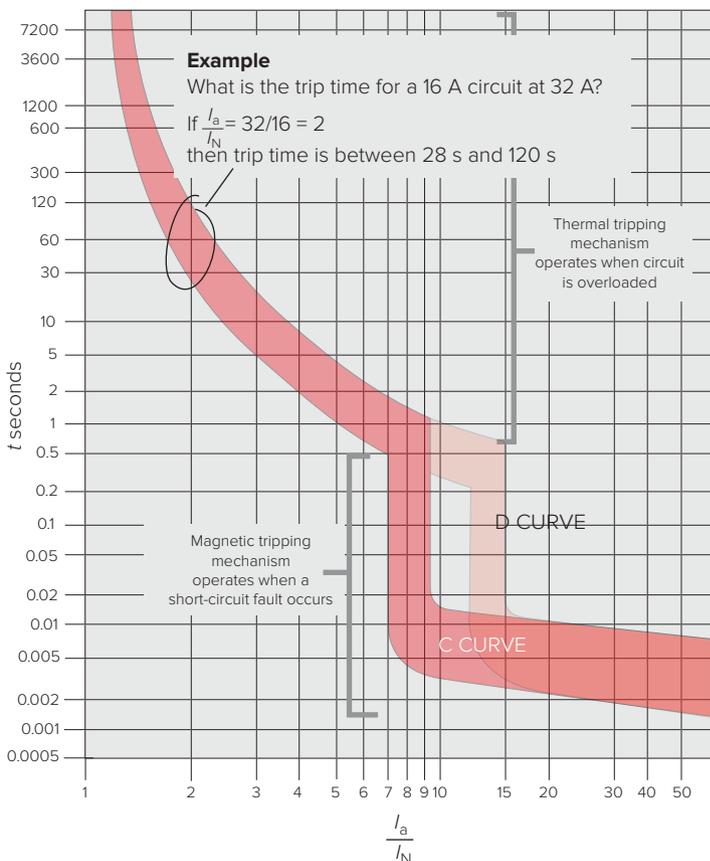
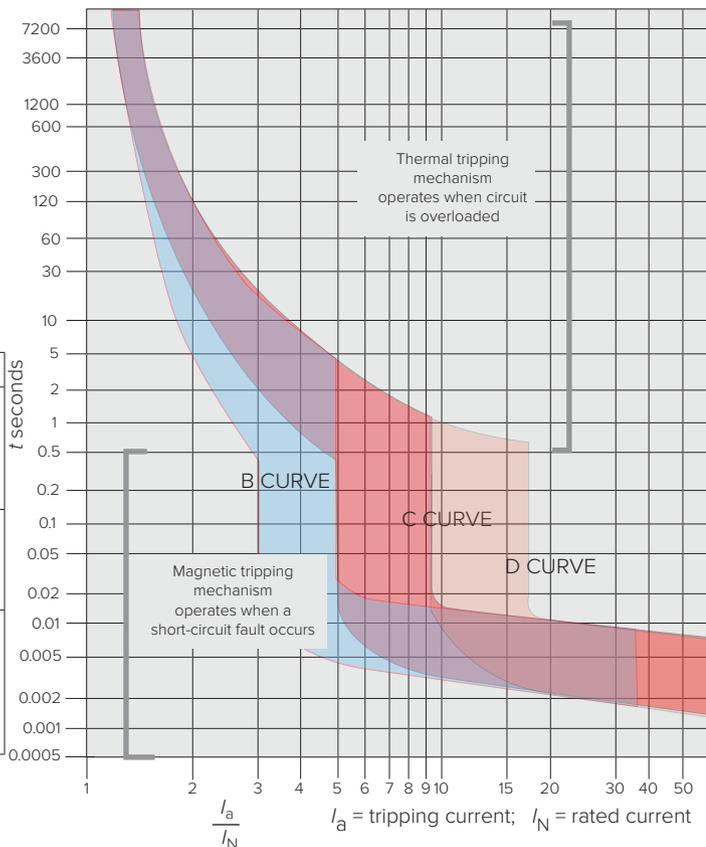


FIGURE 13.17 Current-limiting characteristics of a circuit-breaker

The range of instantaneous trip currents within which each type of circuit-breaker shall operate is specified by Standards. Most circuit-breakers are manufactured with a trip characteristic closer to the mean value.

Note: The mean tripping current is used for determining fault-loop impedance when selecting cables and suitably rated circuit breakers.

Type	Tripping current	Application
B	3 to 5 times rated current; that is, a mean tripping current of 4 times rated current	Only for resistive loads such as electrical heating, water heaters, ranges/ovens
C	5 to 10 times rated current; that is, a mean tripping current of 7.5 times rated current	Most common loads such as lighting, socket-outlets and small motors
D	Varying within 10 to 50 times rated tripping current; therefore circuit-breakers with mean tripping currents for particular applications are available	Loads with transient inrush currents such as larger motors



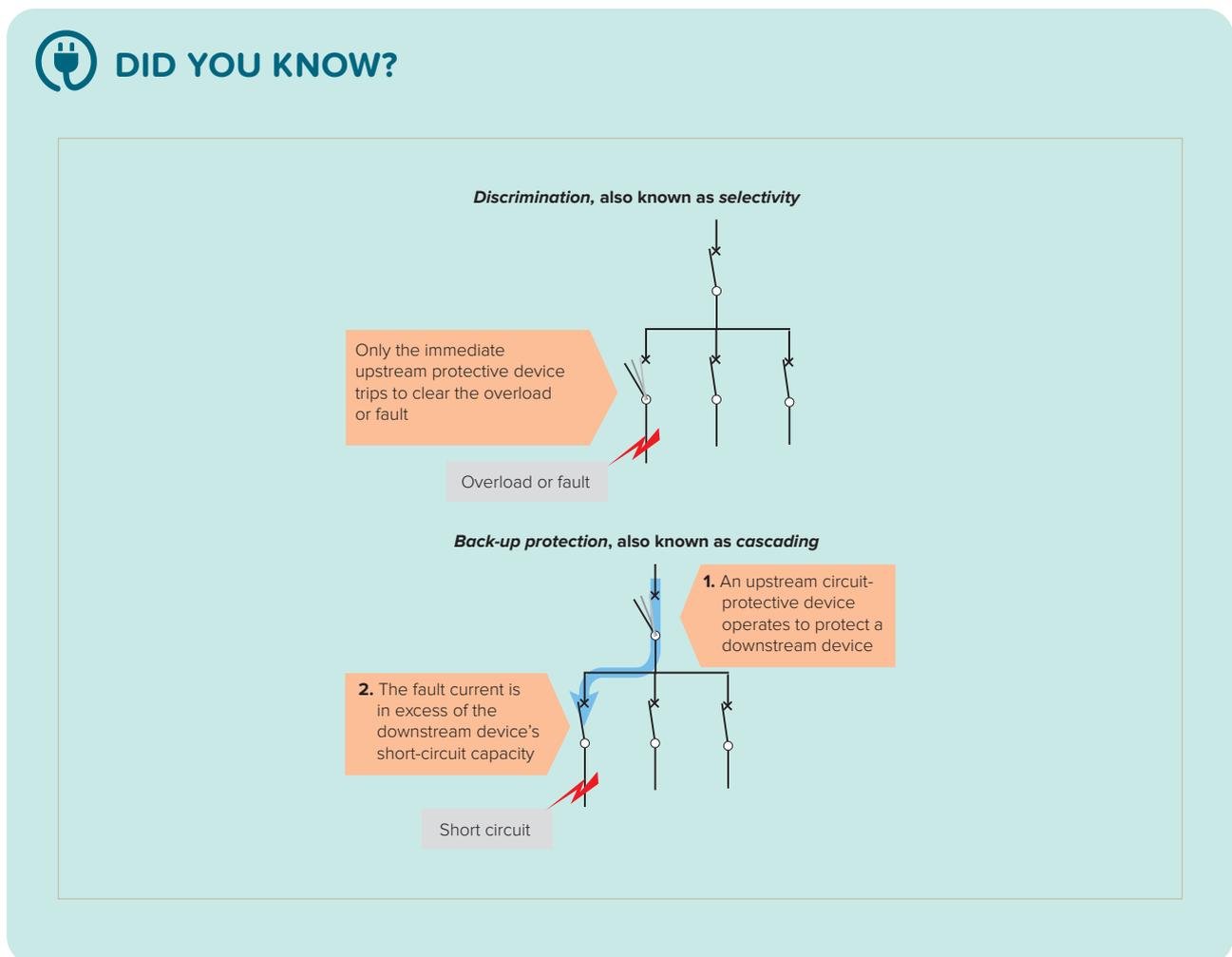
The application of the overload function of a typical C type MCB. The C type is the most commonly used.

FIGURE 13.18 Typical time–current characteristics of fixed-setting circuit-breakers

It is worth noting that the short-circuit function of the modern circuit-breaker is a current-limiting characteristic similar to that of an enclosed fuse link (**Figure 13.18**).

Overcurrent protection relays (OCRs)

Adjustable overcurrent protection relays (OCRs) are normally included as a component part of moulded-case and air circuit-breakers. They provide adjustment to their tripping characteristic for coordination of discrimination with upstream and downstream protection, and motor-overload protection. Electronic overcurrent-protection devices use a microprocessor to monitor and initiate trip circuits and alarms.



Figures 13.19 to 13.21 illustrate overcurrent relays and typical time–current characteristics of adjustable circuit-breakers.

13.2.2 Fuses

The fuse was the first device developed to protect electrical wiring, and dates back to the early telegraph systems of the late 1800s. Since then, the modern fuse, with its current-limiting characteristics, has become the first line of defence against high short-circuit currents and provides protection for sensitive components.

The example of an overcurrent protection relay shown here is typical of those incorporated in an MCCB. The selectable predetermined characteristic curves reduce the number of misunderstood variables that need to be specified. This enables users to set the characteristic for the particular load application.

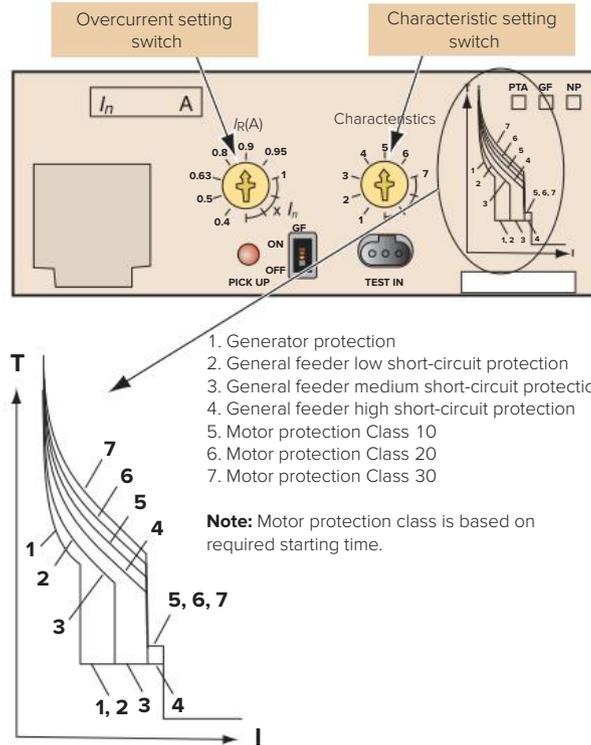


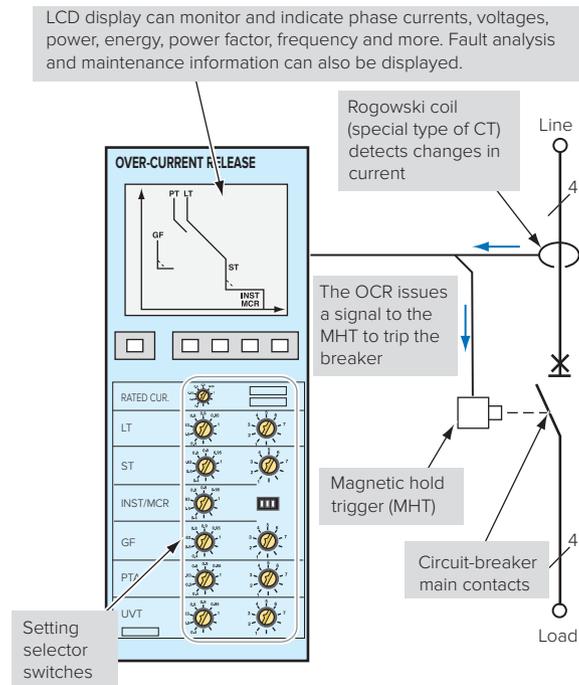
FIGURE 13.19 Example of MCCB overcurrent relay

More recently developed circuit-breakers with similar current-limiting characteristics have caused a major decline in the use of fuses for the protection of most common circuits. Add to this the convenience of resetting a circuit-breaker against the need to replace a blown fuse element.

Nevertheless, fuses are still considered an important component in circuit protection. They are used extensively in distribution networks and as fault-current limiters to back up downstream circuit-breakers that do not have the prospective fault-level capacity required in particular situations. They are incorporated in switches that provide an isolation function similar to circuit-breakers. In circuits where the likelihood of a fault current is low but they require a high degree of reliability, fuses have an advantage because they have low initial and ongoing costs.

Figure 13.22 illustrates how a fuse works.

The modern high-rupturing capacity (HRC) fuse is manufactured to the Standards series *AS 60269:2005: Low-Voltage Fuses* based on the *IEC 60269-1* Standard of the reference number. The Standard has a number of parts covering general requirements, fuses for households and similar applications, fuses for industrial applications and fuses for the protection of semiconductor devices such as SCRs.



Summary of typical functions available in electronic overcurrent relays

Overload protection

Adjustable from 40–100% of rated current.

Reverse power trip function

Provides additional protection when paralleling generator for generator protection with the reverse power trip function.

Pre-trip alarm function

Can be used to monitor and switch on additional power back-up to feed critical circuits.

N-phase protection function

In 3-phase, 4-wire systems the N-phase protection function prevents the neutral conductor from sustaining damage or burnout due to large third-harmonic components in the neutral.

Undervoltage trip function

Available as a fixed type or with adjustable voltage pick-up and adjustable time delay and 3-phase and single-phase failure protection.

Earth leakage trip function

Used in conjunction with an externally mounted zero-phase current transformer (ZCT), this function provides protection against leakage to earth of very small levels of current.

Contact temperature monitoring function

Monitors the temperature of the ACB's main contacts. An alarm indicates when the temperature exceeds set point.

Remote communications protocol

Supports common protocols such as modbus, enabling transmission of various data via networks. Types of data include energy measurement, fault analysis and history, and maintenance information.

FIGURE 13.20 Example of ACB overcurrent relay

Adjustable setting thermal–magnetic circuit-breakers provide a convenient means of applying discrimination between the upstream and downstream protection devices, as required under *Clause 2.5.7*.

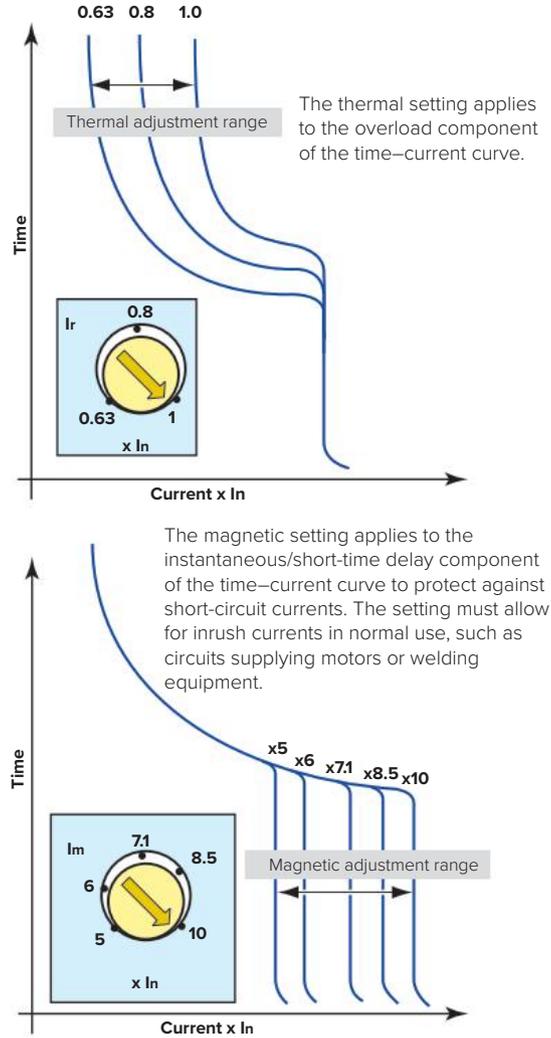


FIGURE 13.21 Typical time–current characteristics of adjustable circuit-breakers

Clause 1.6.68 defines a fuse as ‘a device for protecting a circuit against damage from an excessive current flowing in it by opening the circuit on the melting of a fuse element by such excessive current’.

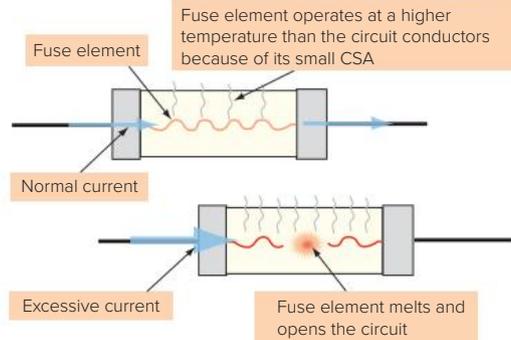


FIGURE 13.22 How a fuse works



DID YOU KNOW?

A switched fuse is a switch containing a fuse, usually mounted in a carrier. The fuse (and carrier) physically move when switching occurs. The circuit symbol is:



A fused switch is a switch in series with a fuse in a single housing. The fuse and the switch are essentially separate. The circuit symbol is:



This device is commonly referred to as a combination fuse switch (CFS).

When referring to a fuse it is usually the fuse link that is meant; that is, the ceramic enclosure that carries the fuse element. In addition to the fuse link, which comes in various physical sizes, forms and characteristics, there are devices for holding the fuse link and connecting incoming and outgoing circuit conductors. Examples are shown in **Figures 13.23** and **13.24**.

As the name implies, the high-rupturing capacity or HRC fuse is able to interrupt high-fault currents without damage to itself. They are often used as a fault-current limiter for installations where the prospective fault current is higher than the rating of the circuit-protective devices.

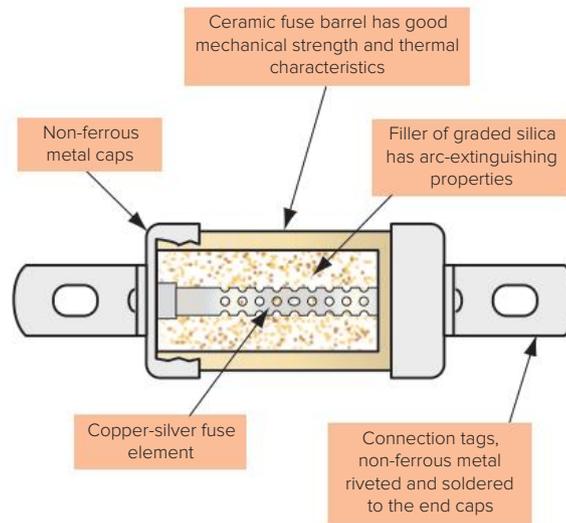


FIGURE 13.23 Basic features of common fuse links

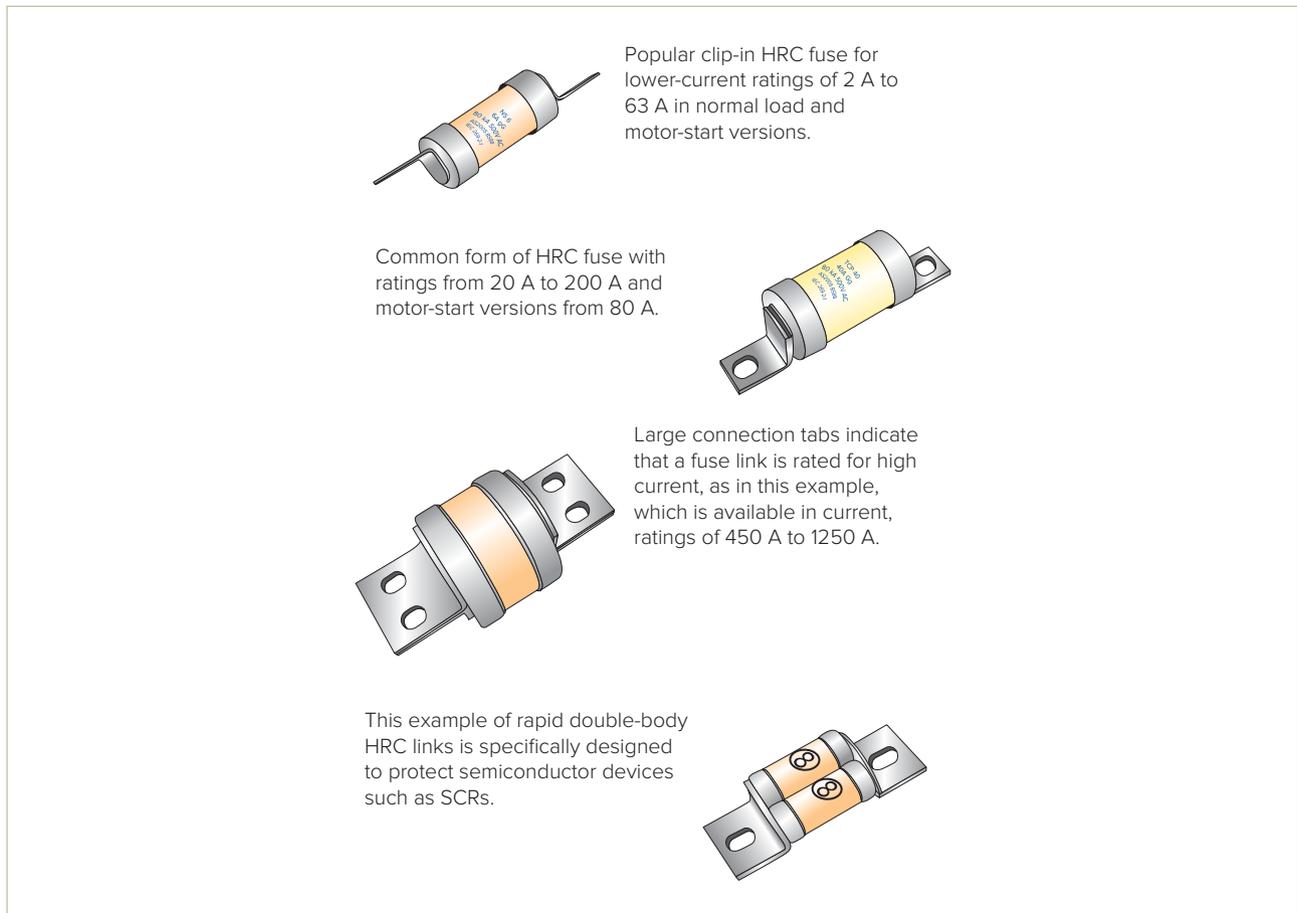


FIGURE 13.24 Examples of fuse link types

Fuse applications

Fuses derived from IEC Standards are marked with symbols denoting their particular application or characteristic, known as the *utilisation category*, as shown in **Table 13.3**. **Figure 13.25** shows common fuse types and fuse holders.

HRC fuse links have many advantages, the most important being:

- ▶ They are able to safely interrupt high values of fault current; that is, they possess high rupturing or breaking capacity.
- ▶ Their high operating speed is sufficient to ‘cut off’ the rising fault current and thus limit short-circuit energy that could produce electrical and mechanical damage.
- ▶ They are non-deteriorating in service, so their characteristics are constant and their performance is consistent.
- ▶ Their discrimination is reliable when properly graded.

The HRC fuse is a current-limiting device with a characteristic similar to that of a current-limiting circuit-breaker. Time-current characteristics of fuses do not, however, exhibit the same differential between overload and short-circuit function as do circuit-breakers, as shown in **Figure 13.26**.

Replacement of fuse links

A fuse link must be replaced only by one of the same utilisation category and rating, assuming that the original was of the correct type and rating. This is of vital importance, because the category of the fuse in terms of current, rating, voltage, characteristics and category of duty is the only assurance that it will provide full protection, discrimination and successful interruption of supply to the circuit on both overloads and short circuits.

TABLE 13.3 Fuse link types and applications

Utilisation category	Application/characteristic
gG	Full-range breaking-capacity fuse for general application, mainly used for cable and line protection
aM*	Partial-range breaking-capacity fuse for short-circuit protection of motor circuits
gR	Full-range breaking-capacity fuse for protection of semiconductor devices (quicker than gS)
aR	Partial-range breaking-capacity fuse for short-circuit protection of semiconductor devices
gPV	Full-range breaking-capacity fuse for protection of photovoltaic systems
gS	Full-range breaking-capacity fuse for protection of semiconductor devices for increased line utilisation; combines gR and gG performance Semiconductor protection against short circuits via gR characteristic combined with cable protection against overload via gG characteristic
gB	Full-range breaking-capacity fuse for mining applications
gTr	Full-range breaking-capacity fuse for transformer protection, rated in transformer apparent power (kVA) instead of rated current (A)
gM	Full-range breaking-capacity fuse for motor-circuit protection, dual rated (widely used in UK, Australia and South Africa)

* Partial-range breaking capacity is 4 × rated current and not suitable for overload protection below this value.

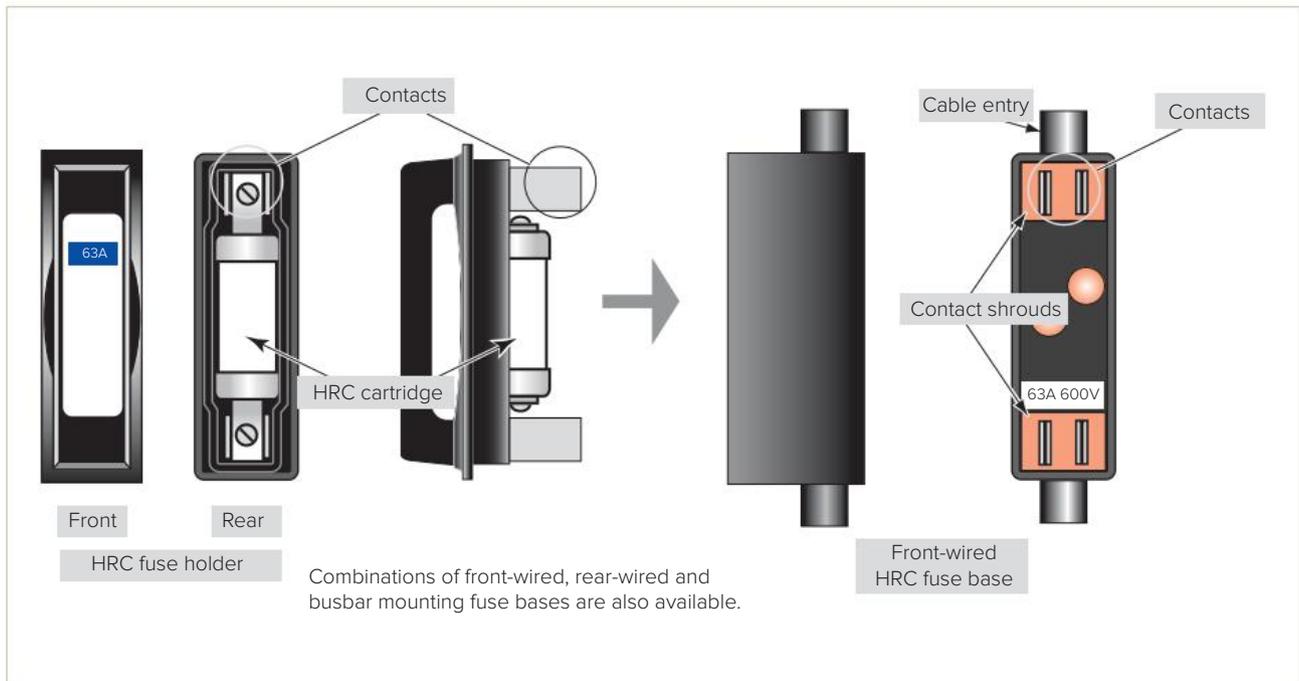
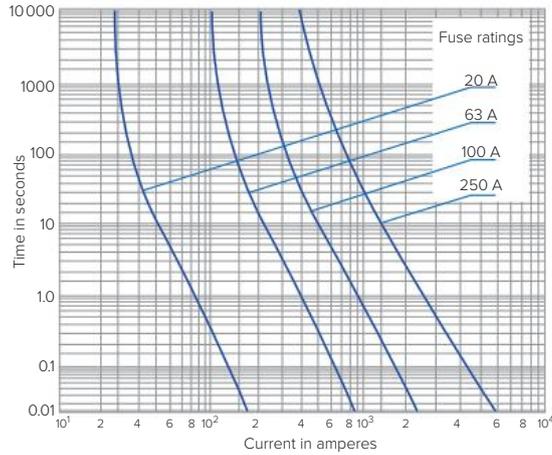
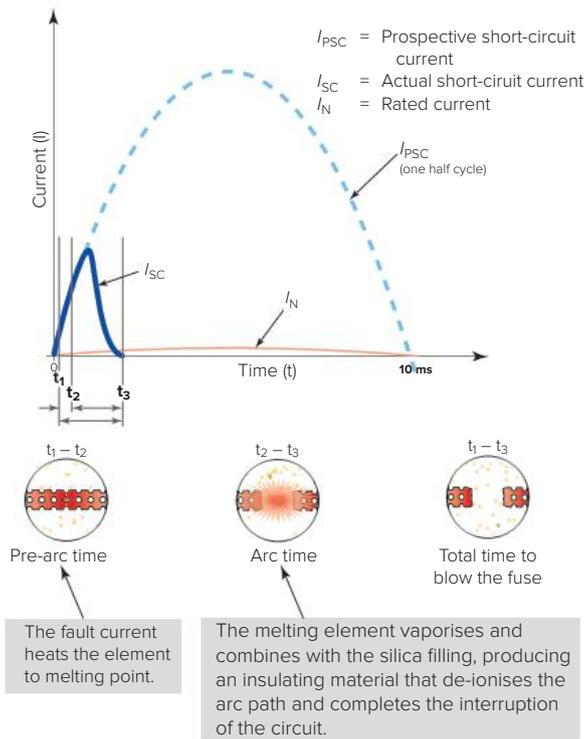


FIGURE 13.25 Fuse types and fuse holders



Example of HRC fuse time–current characteristics



Action of the fuse element

As with circuit-breakers, another measure of current-limiting characteristic often quoted by manufacturers is the ‘energy let-through’ (I^2t). This is the energy released with the maximum value of short-circuit current reached in clearing a fault.

FIGURE 13.26 Characteristics of fuses

For example, motor-protection fuses are designed to withstand large inrush currents in multiple start-up situations. Some fuses only protect against short circuits, while others also protect against overloads. There are many differences. Choosing the wrong fuse could potentially cause serious damage by under-protecting or could cause excessive downtime due to nuisance-blowing.

Semiconductor devices such as rectifiers, SCRs and power transistors are extremely sensitive to current fluctuations and require special protection. Semiconductor fuses belonging to the utilisation categories aR, gR and gS are rapid-acting fuses specifically designed to protect semiconductor devices. They are often referred to as solid-state fuses or rectifier fuses and are able to open the circuit (blow) much faster than other fuse types, so it is extremely important that they are replaced with direct equivalents when required.

In common use until about 20 years ago, installation of semi-enclosed rewirable fuses is no longer permitted (*Clause 2.5.2*). The increased capacity of distribution networks to supply the increase in electricity use and the need for improvements in safety have made them redundant. The semi-enclosed rewirable fuse is, however, still in use in many older installations.

13.2.3 Motor-overload protection

Electric motors are mechanically robust and electrically reliable. As such, they require very little maintenance if protected throughout their life by correct and adequate wiring along with suitable circuit protection. This assumes that the motor type used is suitable for the load working conditions and the working environment. In practice, if a motor is not overloaded, cooling is effective and ambient temperature is not over 40 °C, its expected life will be longer. Any rise in ambient temperature conditions above normal will nevertheless cause overheating. Layers of dirt, oil and other material on motor windings, frames or ventilation ducts will act as heat-insulation blankets that reduce heat dissipation and possibly cause overheating. Motors, however, are most susceptible to overheating and burn-out from overload—the most common causes are illustrated in **Figure 13.27**.

Protection is achieved if the motor windings operate within their specified temperature range. Overheating of the windings might not cause immediate failure, but even small temperature increases above the temperature specified as maximum for a particular motor will shorten its life. Note that this is for continuous operation.

The *Wiring Rules, Clause 4.13.3* specifies that any unattended motor over 480 VA rating for the shaded-pole type, 240 VA for other types and every other motor rated over 2.25 kW must be protected by over-temperature devices. Check *Clause 7.2.5* and note that motors operating on emergency services, such as fire-pump drives, need not be protected if the protection could create a hazard.

Over-temperature protection of motors is intrinsic to the motor switching and control methods—which are covered in detail in **Chapter 9**. For the moment, our focus is on the over-temperature protection of motors—the main types are described in **Figure 13.28**.



CHECK YOUR UNDERSTANDING

6. What are the three main types of circuit-breakers?
7. What are the two tripping elements employed by circuit-breakers?
8. What is a shunt trip?
9. What does the term *selectivity* mean?
10. What devices are used for motor over-temperature protection?

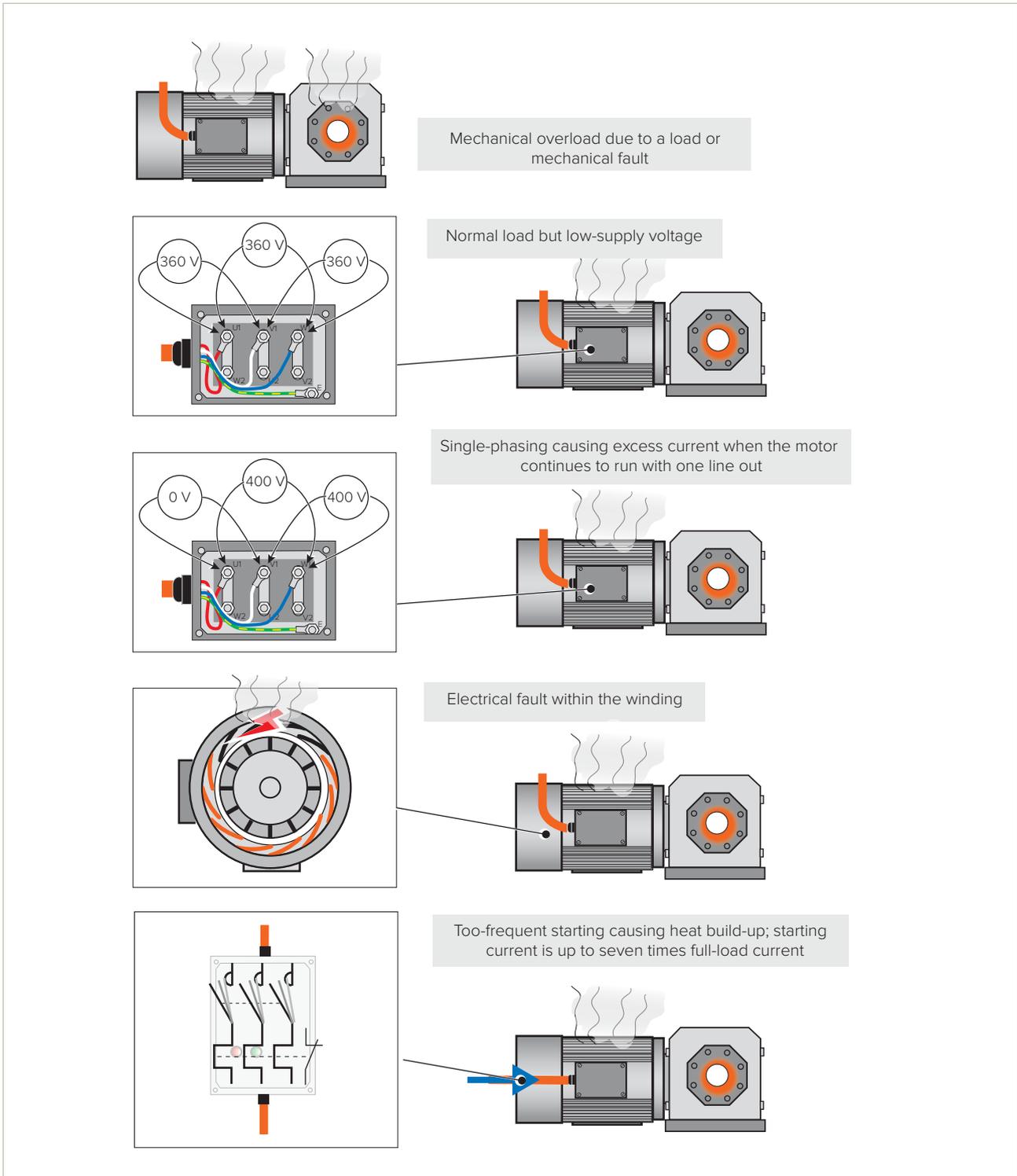
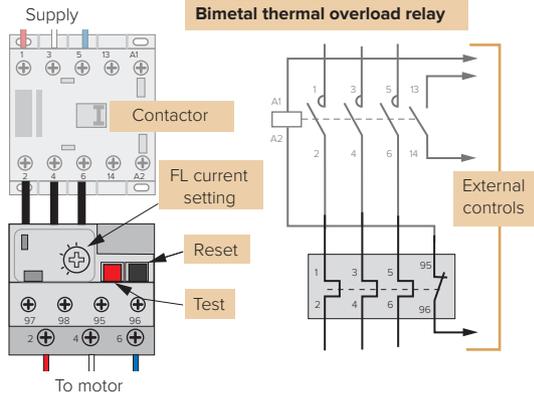
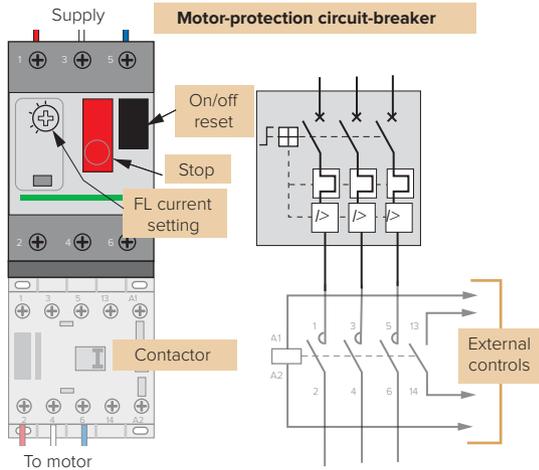


FIGURE 13.27 Common causes of motor overload

The most widely used overcurrent protective device for motors up to, say, 10 kW is the bimetal thermal overload, which acts in exactly the same way as the thermal function of a thermal–magnetic circuit-breaker. Thermal overload relays work with a.c. and d.c. and are usually three pole with temperature compensation to not be affected by ambient temperature variations where they are installed.



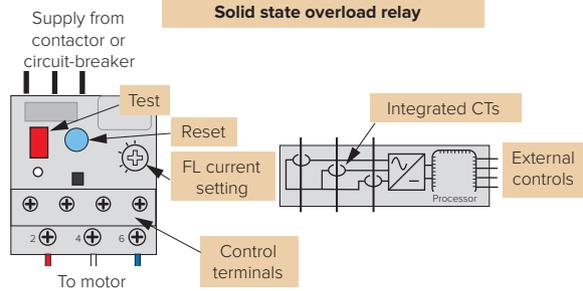
The requirement for protection of circuit wiring against overcurrent, and over-temperature protection for motors, has led to the design of circuit-breakers to do both jobs. These are typically packaged as part of a modular assembly of protective and switching components.



Electronic motor-protection relay

Electronic motor-protection relays offer the ultimate in protection functions and standards. A thermal function follows the motor's heating and cooling cycles, and has a memory that accumulates previous temperature activity and facilitates load rate and performance monitoring. This attribute can also be used to indicate the unused capacity of the motor. Dependent on the model and the cost, other protection facilities may be included, such as earth leakage; PTC and probe temperature control; protection against locking and overtorque, phase inversion, insulation faults and no-load operation; and integration with fieldbus systems.

Modern motors are designed to meet efficiency standards and have less copper and iron for a given output, making them more susceptible to overload and other abnormal conditions. This has brought about the development of the solid state overload relay. These motor-protection devices monitor the motor current through integrated current transformers, the output of which is fed to a microprocessor. The microprocessor identifies excessive current or loss of phase more accurately and reacts to the condition with greater speed and reliability than traditional overload relays.



Positive temperature coefficient (PTC) thermistors are in direct thermal contact with the motor windings and are fitted by the manufacturer during the winding of the motor. Any temperature rise in the windings, due to overload or any other cause, will produce a rapid increase in the resistance of the thermistor; this de-activates the control circuit opening the supply contactor to the motor.

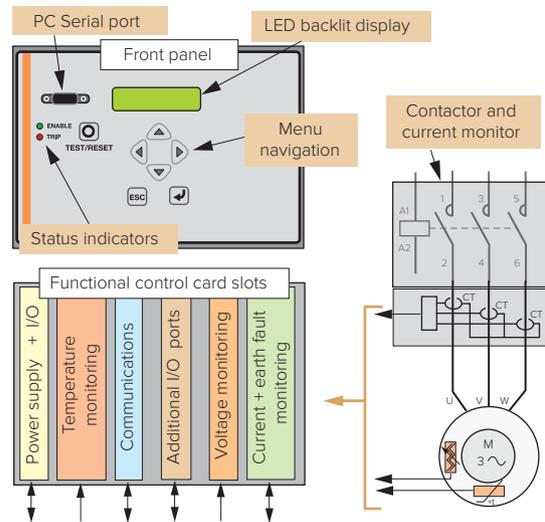
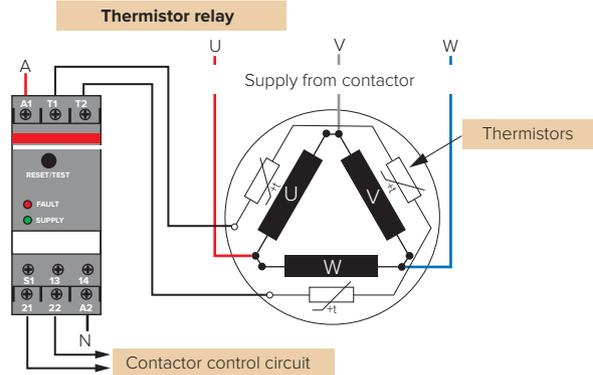


FIGURE 13.28 Motor over-temperature protection devices and features

13.3 Protection against indirect contact with live parts

Although electrical equipment is designed and constructed to meet stringent safety performance standards, there is always the risk of insulation breakdown, which exposes people to the risk of electric shock. A major component of the protection for safety principles that electrical installations are required to comply with is protection against indirect contact with live parts (*Clause 1.5.5*). Indirect contact can come about when insulation breakdown causes exposed (*Clause 1.4.62*) and/or extraneous conductive parts (*Clause 1.4.63*) of the electrical system to become live. Without proper protective methods in place, a person coming in contact with the live exposed conductive part would receive a severe electric shock.

13.3.1 Methods of protection

The *Wiring Rules* require that, if the touch voltage could rise above 50 V a.c. or 120 V d.c., a protective device (circuit-breaker or fuse) must be in place to automatically disconnect the supply to the fault (*Clause 1.5.5.3 (b)*). See **Figure 13.29** for *Wiring Rules* requirements around RCDs.

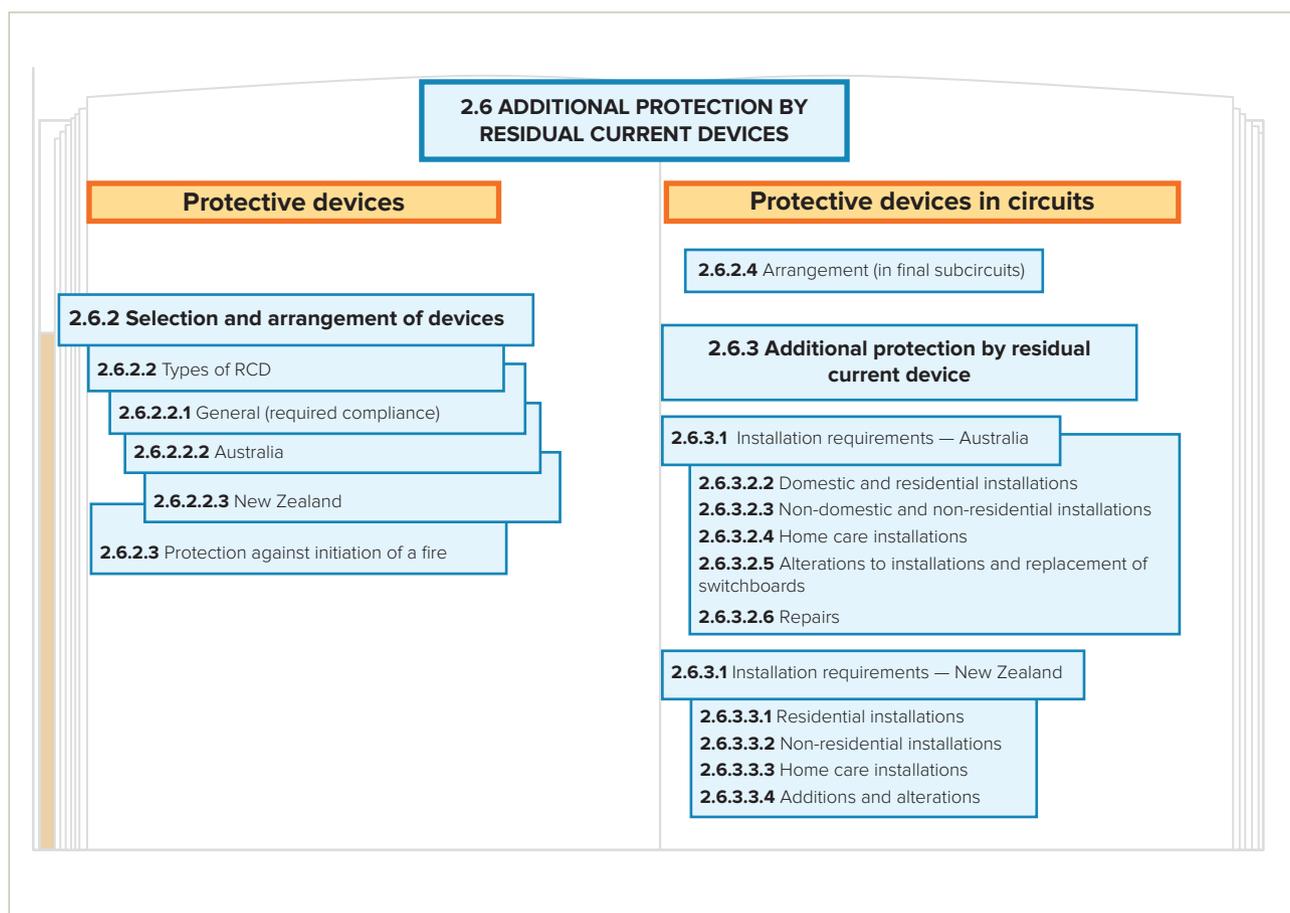


FIGURE 13.29 *Wiring Rules* requirements for additional protection by RCDs

Other acceptable methods of protection—use of Class II equipment or electrical separation—are covered in **Chapter 12**.

In situations where there is a significant risk of shock, additional protection by use of residual current devices (RCDs) is mandatory (*Clauses 1.5.6* and *2.6*). Note that RCDs are not a recognised means of protection against fault current but are intended to *supplement* the circuit-protective devices.

A number of Standards called up by the *Wiring Rules* include specific requirements for the use of RCDs, some of which have already been mentioned. The particular Standards of interest covered in more detail in **Chapter 18** are:

- ▶ *AS/NZS 3001 Electrical installations—Transportable structures and vehicles including their site supplies*
- ▶ *AS/NZS 3002 Electrical installations—Shows and carnivals*
- ▶ *AS/NZS 3003 Electrical installations—Patient areas*
- ▶ *AS/NZS 3004 Electrical installations—Marinas and recreation boats*
 Part 1: Marinas
 Part 2: Recreational boats installations
- ▶ *AS/NZS 3012 Electrical installations—Construction and demolition sites.*

13.3.2 Protection by residual current devices

RCDs were used as supplementary protection in some industrial activities, medical treatment areas and the construction industry for many years before they became a common mandatory requirement. These devices were also known as core-balance units or current-operated earth-leakage circuit-breakers. Originally RCDs were promoted and aimed particularly at the domestic consumer as ‘safety switches’—a misnomer, as they only provide protection against indirect contact between an active conductor and exposed and extraneous conductive parts. Their qualified use is mandatory for particular circuits in all installations.

Regardless of the terms used to describe this type of protection, their purpose is the same: to rapidly cut off the power to a circuit when measured conditions in the circuit indicate that a level of current likely to cause physical harm is leaking to earth. RCDs can also provide protection against current leakage likely to cause damage or start a fire.

HISTORICAL NOTE

In the early development of electrical systems, only limited protection against electric shock was provided because little was known about the causes of death from electrocution or the factors involved. Research into the physiological effects of electricity has taken place alongside the development of electrotechnology (and medical science) since the late eighteenth century. It was not until the 1930s that the mechanisms of electrocution (i.e. the effects on the heart, lungs and other organs, as well as the burning effect) were more fully understood.

Since that time, research has determined specific factors related to electric shock, such as human body impedance, the harmful effects of increasing current levels and the duration of current flow. Much of this research is credited to the Austrian physicist Gottfried Biedermeier, who—acting as his own guinea pig—subjected himself to various voltages. The results from this and other sources are documented by the International Electrotechnical Commission (IEC) in *IEC Report 479: Effects of current passing through the human body*. This information was essential to the development of effective protection techniques against electric shock.

Effects of current on the human body

As discussed in **Chapter 2**, the severity of the effects of electric shock depends on the magnitude of the current, the duration of current flow and the current path through the body. A current of sufficient magnitude and duration passing through the heart will upset the normal heart function, causing it to fibrillate. The time-current effects on the human body, shown in **Figure 13.30**, are based on the IEC research mentioned above and set the accepted standards for the development of RCDs.

DID YOU KNOW?

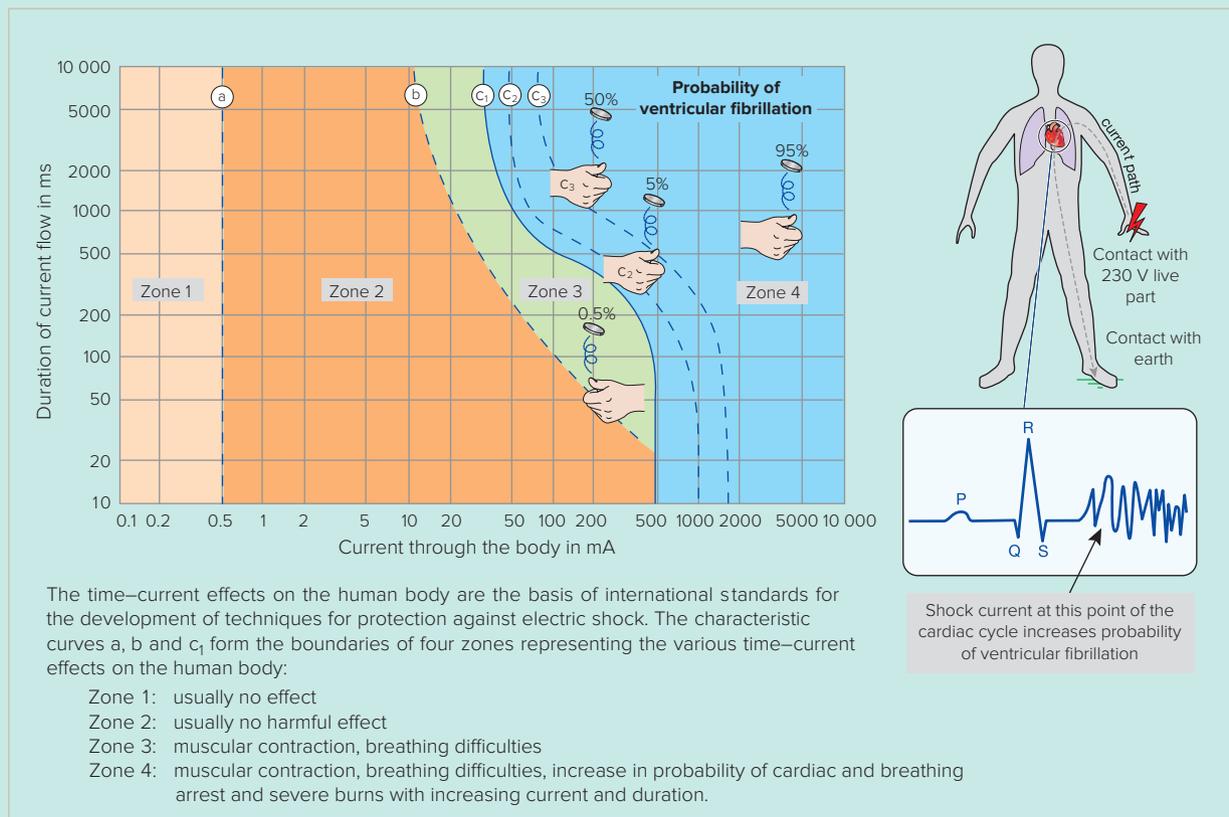


FIGURE 13.30 Time-current effects on the human body

Ventricular fibrillation is a condition where the blood-pumping action of the heart is interrupted, as shown in **Chapter 2, Figures 2.16 and 2.17.**

13.3.3 Operating principles of RCDs

The RCD uses a toroidal transformer, similar to a current transformer, to detect leakage current. The secondary winding is known as the sensing winding or fault-detection winding. It is connected to a trip relay, which, when activated by an earth-leakage current, operates mains contacts to switch off the circuit. The principles are explained in **Figure 13.31**. The polarised-type of magnetically held trip relay shown in the figure only responds to the positive half-cycle of a fault current.

A variation on this type uses a centre-tap toroidal transformer and diodes so that it responds to both positive and negative half-cycles of a fault current. An alternative, the saturation-type relay, responds in the same way, improving the response time by half a cycle or 10 milliseconds for a 50 Hz supply. Some RCDs incorporate electronics that process the small output signal of the toroidal transformer in order to operate a magnetic-release relay or shunt-trip circuit to trip the main contacts. These types derive their operating energy from the mains supply.

The type of mechanism used in an RCD is a compromise between the trip sensitivity required and the cost of production.

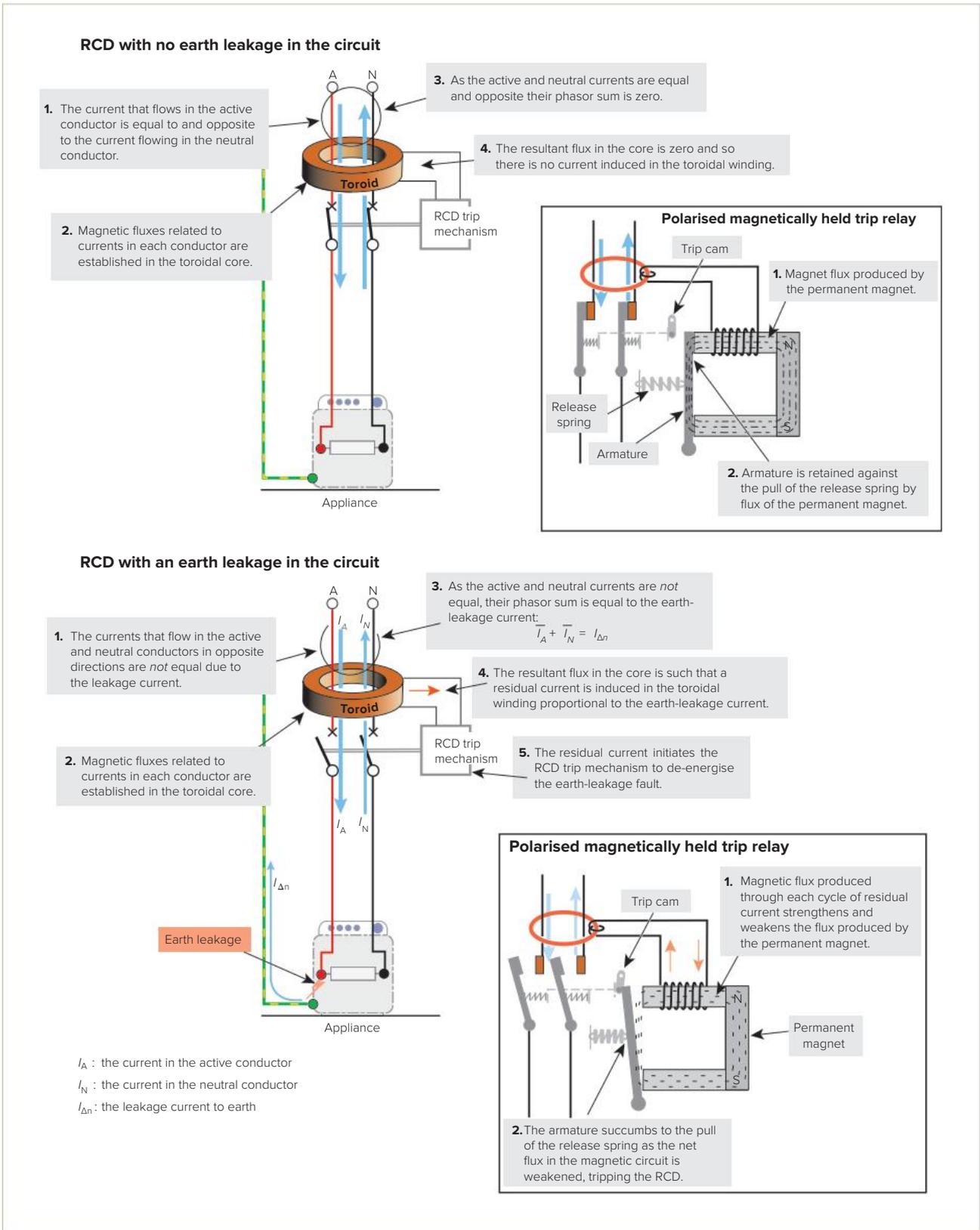


FIGURE 13.31 How RCDs operate

13.3.4 RCD types and applications

RCDs and relays are generally classified by rated residual current, interruption or break time and ability to respond to a.c. and d.c. components of fault current. The rated residual current ($I_{\Delta n}$) of an RCD is the residual (fault) current at which tripping operation of the RCD is ensured—also known as the sensitivity of an RCD. The RCD must operate within a maximum rated time and be able to distinguish between true leakage current and other disturbances that might cause nuisance tripping.

As well as having a tripping sensitivity rating, an RCD has a maximum load current. So, when selecting an RCD for a particular application, both the trip-sensitivity rating and maximum load-current rating need to be specified (e.g. 30 mA/20 A). The prospective fault current at the point where an RCD is to be installed also needs to be considered.

These major features of RCDs and the available types and applications are shown in **Figures 13.32 to 13.35**.

13.3.5 Dealing with nuisance tripping

An RCD must be able to:

- ▶ detect leakage current up to its rated value
- ▶ switch off the supply rapidly when such leakage current has been detected
- ▶ ignore leakage currents 50 per cent below its rated value
- ▶ discriminate between leakage current caused by an earth fault and leakage current caused by other line disturbances (i.e. avoid unwanted tripping).

The major causes of unwanted or nuisance tripping can be reduced to acceptable levels in most cases, namely:

- ▶ standing leakage currents
- ▶ electrical disturbances
- ▶ installation practices and faults.

Standing leakage currents

Although the materials used for insulating electrical equipment and wiring provide excellent insulating properties, they are still subject to some leakage current. As the insulating properties deteriorate with time, the leakage current will increase. The leakage current present in an electrical appliance, circuit or installation is known as the standing leakage current. Sources of standing leakage currents are illustrated in **Figure 13.36**.

Disturbances to the normal line voltage can be caused by lightning strikes, switching transients in the supply system or switching off reactive loads. The standing leakage current at 50 Hz might be acceptably small, but switching transients are usually at higher voltages and frequencies. Whether the residual leakage current includes higher frequency a.c. and/or d.c. components will depend on the presence of loads and switching devices such as fluorescent lighting, solid-state lighting control, soft starters and variable-speed drives. Where residual current protection is called for, Type IV A or B RCDs may be appropriate—keeping in mind that these devices are more costly.

The waveform of a fault current to earth cannot be assumed to be a pure 50 Hz sinusoidal alternating current. Electronic control and switching devices impose d.c. and higher frequency components on the system that can interfere with the effective operation of an RCD. Notes to *Clause 2.6.2.2* stipulate that an RCD of the type designed to cope with such interference shall be selected.

AS/NZ 61008.1 and *AS/NZS 61009.1* designate the following types of RCD for ability to operate for different waveforms of residual current.

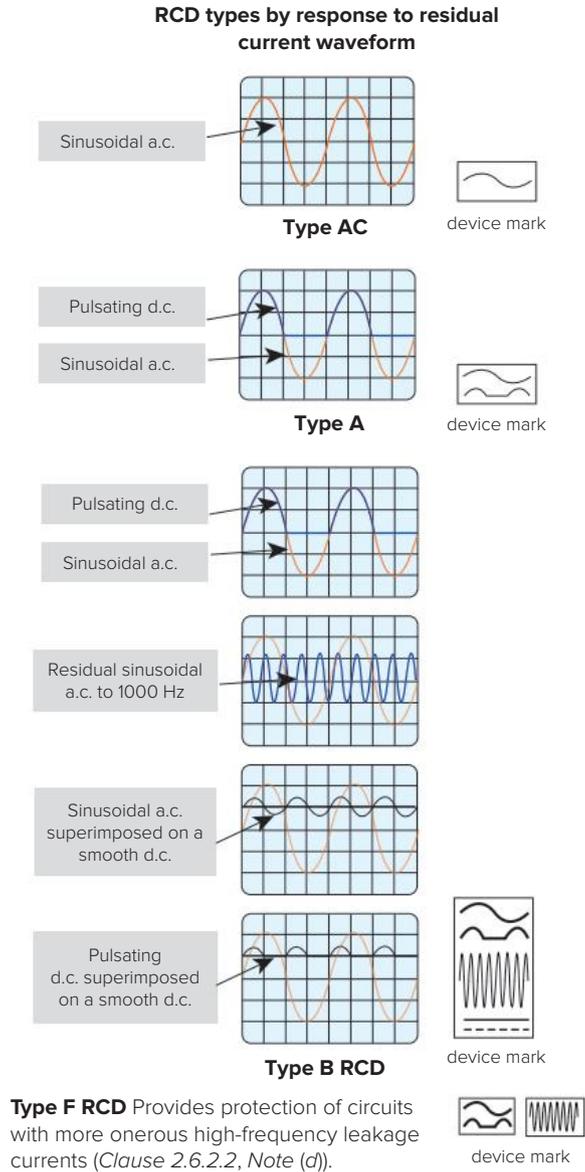


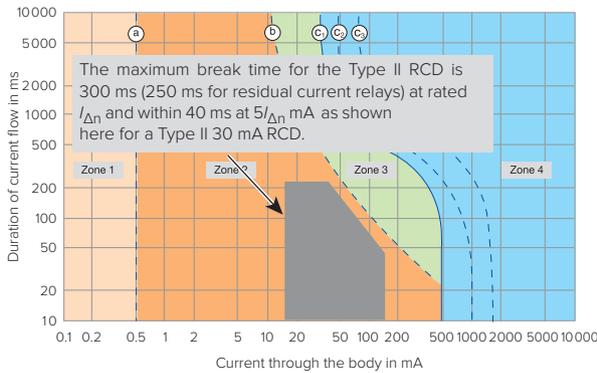
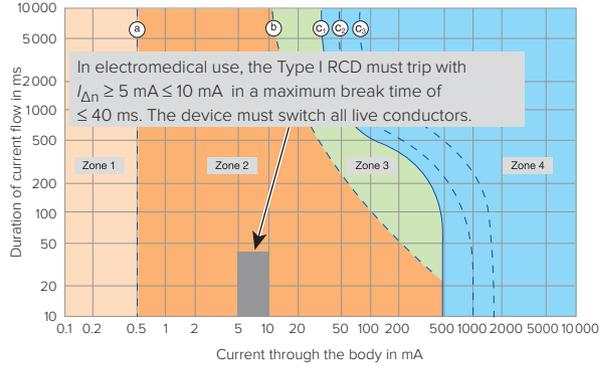
FIGURE 13.32 RCD types by residual current waveform response

Type I RCD

The Type I RCD has a Type A response (sine wave and d.c. pulses) and is specified for use in patient treatment areas by AS/NZS 3003: *Electrical Installations—Patient Treatment Area Electrical installations—Patient treatment areas of hospitals and medical, dental practices and dialysing locations*. This includes home dialysis installations (Clause 2.6.2.3.4).

Medical treatment often requires a patient to be connected to electromedical equipment, and some procedures might involve the insertion of electrodes into the body. Under these conditions, body resistance is lowered and the probability of fibrillation is greatly increased, hence the low $I_{\Delta n}$ and break time.

Note that AS/NZS 61008.1 and 61009.1 specify General Type RCDs that may have an $I_{\Delta n}$ current from 6 mA to 500 mA with maximum break time ≤ 300 ms. A General Type with a $I_{\Delta n} \leq 10$ mA is marked: GENERAL TYPE, NOT FOR PATIENT AREAS.



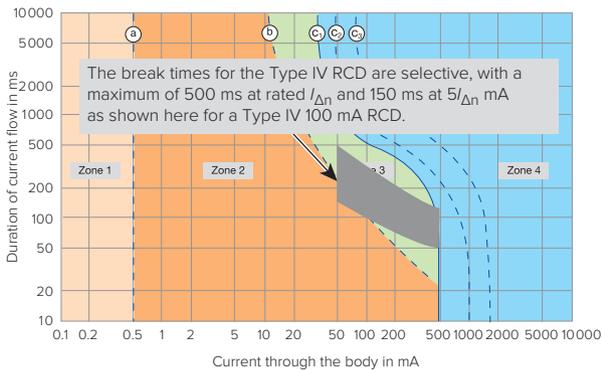
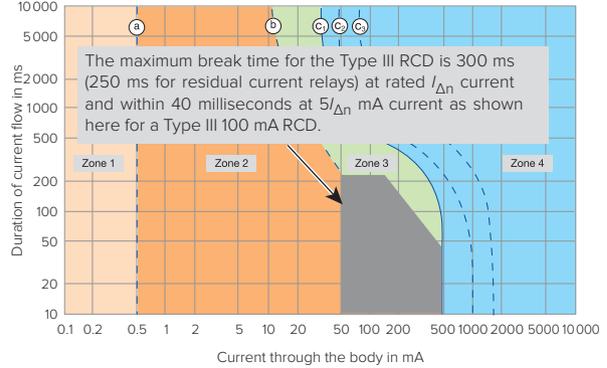
Type II RCD

The Type II RCD is specified by standards as having an $I_{\Delta n}$ current $>10 \leq 30$ mA with the 30 mA rating the most commonly used. The *Wiring Rules* requires final subcircuits supplying all final subcircuits in a domestic installation to be protected by a Type II RCD with maximum $I_{\Delta n}$ of 30 mA (Clause 2.6.3.1). In Australia this requirement extends to other installations for circuits rated up to 32 A (Clause 2.6.3.2.3.3). The requirement may also apply to additions and/or repairs to an existing installation, depending on the extent of the work (Clause 2.6.3.2.6).

Type III RCD

The Type III RCD is specified by standards as having an $I_{\Delta n}$ rating $> 30 \leq 300$ mA. They are available in two $I_{\Delta n}$ ratings, 100 mA and 300 mA.

Although the maximum operating characteristics show the 100 mA device to be below the fibrillation zone, a 300 mA device would be in the zone of probability of fibrillation. Therefore, Type III RCDs are intended for protection against indirect contact with live parts where a high standing leakage current would cause a Type II RCD to trip.



Type IV RCD

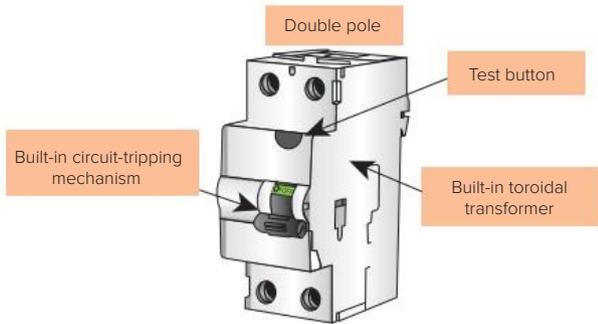
The Type IV RCD is available in the same $I_{\Delta n}$ ratings as the Type III. However, the Type IV has a selective tripping time and is designated a Type S in AS/NZS 61008.1 and 61009.1.

The selective tripping time feature of the Type IV devices makes them suitable as backup protection when connected in the supply to Type II RCDs.

They are also intended for protection against leakage currents likely to cause a fire on circuits where Type II or III devices are not installed.

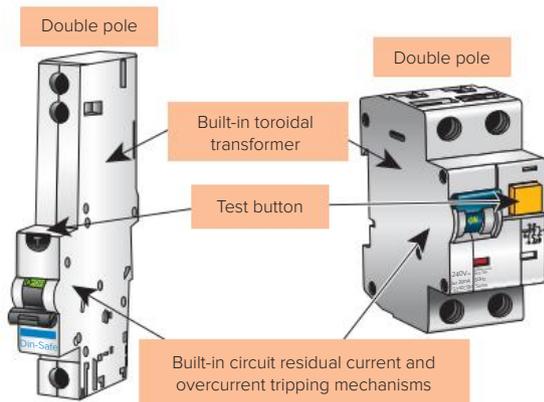
FIGURE 13.33 RCD types by residual current response

AS/NZS 3190 defines a residual current device as containing a toroidal transformer for detecting residual current, a circuit-tripping mechanism and test facilities constructed in one unit. On the other hand, a residual current relay contains a toroidal transformer, test facilities and circuitry necessary to provide an output. The output can be connected to operate an external contactor or shunt-trip circuit-breaker. AS/NZS 61008.1 refers to an RCD as a 'residual current operated circuit-breaker' (RCCB) while AS/NZS 61009.1 refers to RCDs with built-in overcurrent protection as 'residual current operated circuit-breakers with integral overcurrent protection' (RCBO).



RCD according to AS/NZS 3190
RCCB according to AS/NZS 61008.1

These are available in Type I, Type II, Type III and Type IV two-pole and four-pole. The Type II (AC) 30 mA is typical of those used for additional protection as required by Clause 2.6 for domestic and other installations. In New Zealand the 10 mA General Type is required by Clause 2.6.3.3.2.



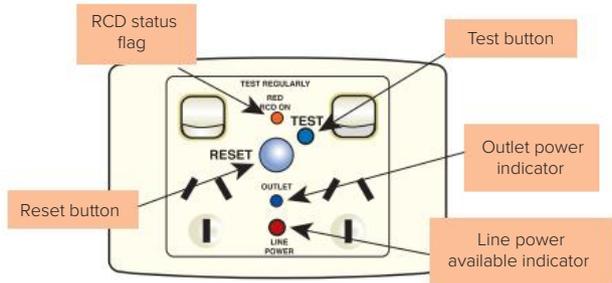
RCD according to AS/NZS 3190
RCBO according to AS/NZS 61009.1

RCD/RCBOs are essentially an RCD and MCB combined in a single unit. They are available in the same residual current ratings as RCD/RCCBs and the same overcurrent ratings as MCBs.

For example, a Type II 30 mA RCBO with an overcurrent rating of 20 A would provide all the required protection for a final subcircuit supplying socket-outlets. Therein lies the advantage of RCBOs over RCD/RCCBs, particularly for new installations.

Typically RCBOs are available with a fault-level capacity of 3 kA, 6 kA and 10 kA.

Where RCD protection is required in residential installations the RCD must be installed at the distribution board from which the circuit originates (see Notes to Clause 2.6.3.1). This precludes the use of integral socket-outlet RCDs as the primary means of RCD protection except for home dialysis installations. The socket-outlets for home dialysis equipment must be supplied from a dedicated circuit without RCD protection at its origin. The socket-outlet has an integral Type I (10 mA/40 ms) RCD located so it can be reset by the patient (see Clause 2.6.3.2.4). Installations in medical treatment areas are covered in more detail in Chapter 5.

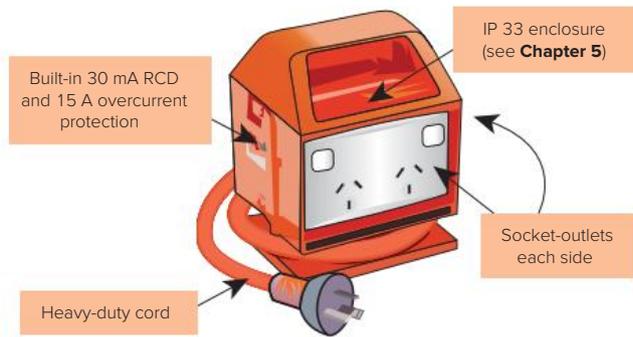


Integral socket-outlet Type I 10 mA RCD
specifically for connection of medical electrical
equipment in accordance with AS/NZS 3003

The socket-outlet RCD may be used in other installations as the primary means of RCD protection. These devices are a convenient way of providing RCD protection to an existing installation as alteration to the switchboard to accommodate RCCB or RCBO is avoided. Note that all sockets connected downstream of a socket-outlet RCD are residual current protected.

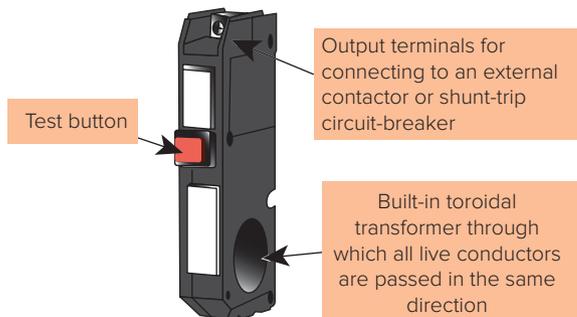
Portable residual current devices known as PRCDs incorporate Type I or II devices, which protect one or more socket-outlets, cord extension sockets or a combination of both. AS/NZS 3190 specifies three types of PRCDs: Class L, a single-phase unit for domestic use; Class H for industrial use; and Class PSOA (portable socket-outlet assembly), primarily for use on construction and demolition sites. The PSOA is a Class H portable unit with integral 30 mA RCD and MCB overcurrent protection of two or more single- or three-phase socket-outlets.

The requirements for all PRCDs, as specified in AS/NZS 3190, include limitations on the lengths of flexible supply cords for a given RCD load-current rating and cord-conductor size.



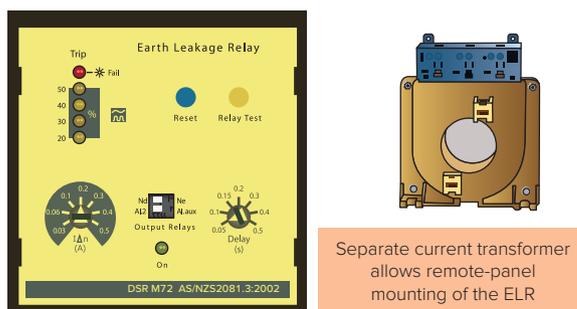
Example of a single-phase PSOA

FIGURE 13.34 RCD examples and applications



RCD relay or unit according to AS/NZS 3190

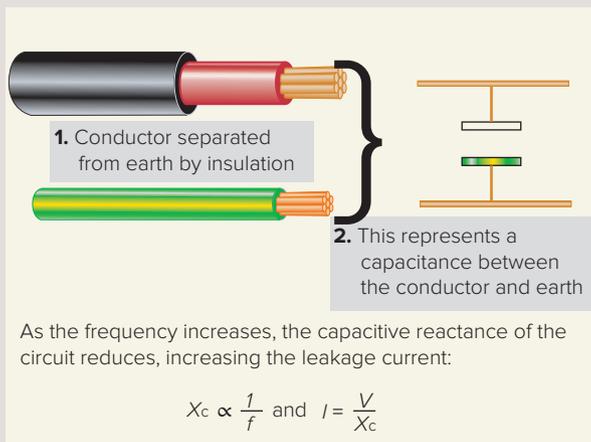
Residual current relays are used in non-domestic installations such as hospitals, heavy industry and mining. They are manufactured in a wide selection of sensitivities, including Types I, II, III and IV. Outputs from residual current relays are intended for the operation of a shunt-trip coil, the undervoltage release coil of a circuit-breaker or the coil of a contactor.



Example of a panel-mounted earth leakage relay (ELR) with selectable time and residual-current settings used in mining applications.

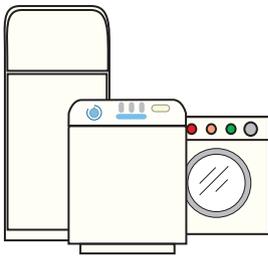
FIGURE 13.35 Examples and applications of residual current relays

NOTE

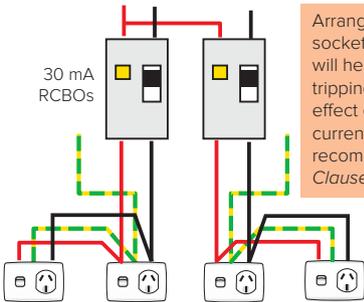


Sources of nuisance tripping

Electrical equipment must comply with the approval and test specifications of the AS 3100 series, which in part sets maximum acceptable levels of leakage current for specific types of equipment.



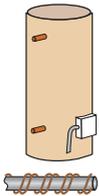
An initial standing leakage current of 5 mA is permitted for Class I appliances containing motors. The cumulative standing leakage current of, say, four such appliances supplied from one circuit could be 20 mA. This is within the tripping range of a 30 mA RCD.



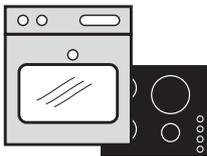
Arranging no more than two socket-outlets on each circuit will help avoid nuisance tripping due to the cumulative effect of standing leakage current. This follows the recommendation of *Notes to Clause 2.6.2.1*.

Socket-outlets for Class I appliances containing motors

Appliances that incorporate calrod-type heating elements can have relatively high leakage currents when new or after long periods of non-use, due to moisture absorbed by the element insulant.



Clause 8.3.6.2 of the *Wiring Rules* permits the insulation between live parts and earth of appliances fitted with heating elements to be as low as 10 000 Ω. Then a standing leakage current could be as high as 23 mA.



Maximum standing leakage current for appliances fitted with heating elements

$$I_L = V \div R$$

$$= 230 \div 10\,000$$

$$= 0.023\text{ A or }23\text{ mA}$$



Moisture in a kettle connection base

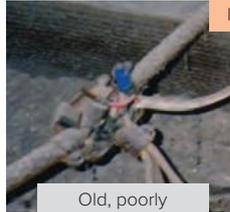


Build-up of crumbs in toaster

Small appliances, even in relatively new installations, are a common source of nuisance tripping.

Sources of high-leakage currents—old installations

Standing leakage currents reach unacceptable levels through the deterioration of insulation or the ingress of moisture and other contaminants between live parts and earthed metal (e.g. dust, insects).



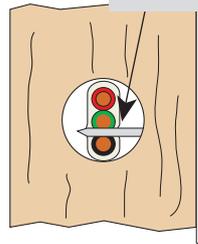
Old, poorly maintained wiring

Before RCD protection is installed, the sources of leakage currents must be located and reduced to acceptable levels.

Old installations, particularly those with Vulcanised India Rubber (VIR) or Tough Rubber Sheathed (TRS) wiring, commonly require rewiring before RCD protection is installed.

Sources of nuisance tripping—damage during building and installation work

Damage to an installation during building repairs, alterations or additions is another common source of high-leakage currents.



Nail driven into wiring, short-circuiting the neutral and earth conductor

This would result in up to half the load current returning via the earthing conductor. Ironically, this may reduce the sensitivity of the RCD protecting the circuit; a difficult and costly fault to locate and repair but obviously it must be done. Compliance with Clause 3.9.4 goes a long way to avoiding such faults.



Unprotected cable installed in a prohibited location



Poor cable management

Poor practices during installation can lead to cable damage and the likelihood of high leakage when the installation is completed. These faults are difficult and costly to find (and repair).

FIGURE 13.36 Sources of standing leakage currents

NOTE:

Wiring Rules, Clause 8.1.2 mandates:

Prior to placing an electrical installation, or any part thereof, in service following construction, alteration, addition or repair thereof, it shall be verified, as far as practicable, that the installation is safe to energise and will operate correctly in accordance with the requirements of this Standard.

Thorough testing of an installation is vital to the process of installing effective residual current protection.

Installation faults

RCDs detect fault current by monitoring the supply and return currents of a circuit. A common fault—particularly in additions to existing installations—is connection between neutrals of different circuits, as illustrated in **Figure 13.37**.

13.3.6 RCD testing

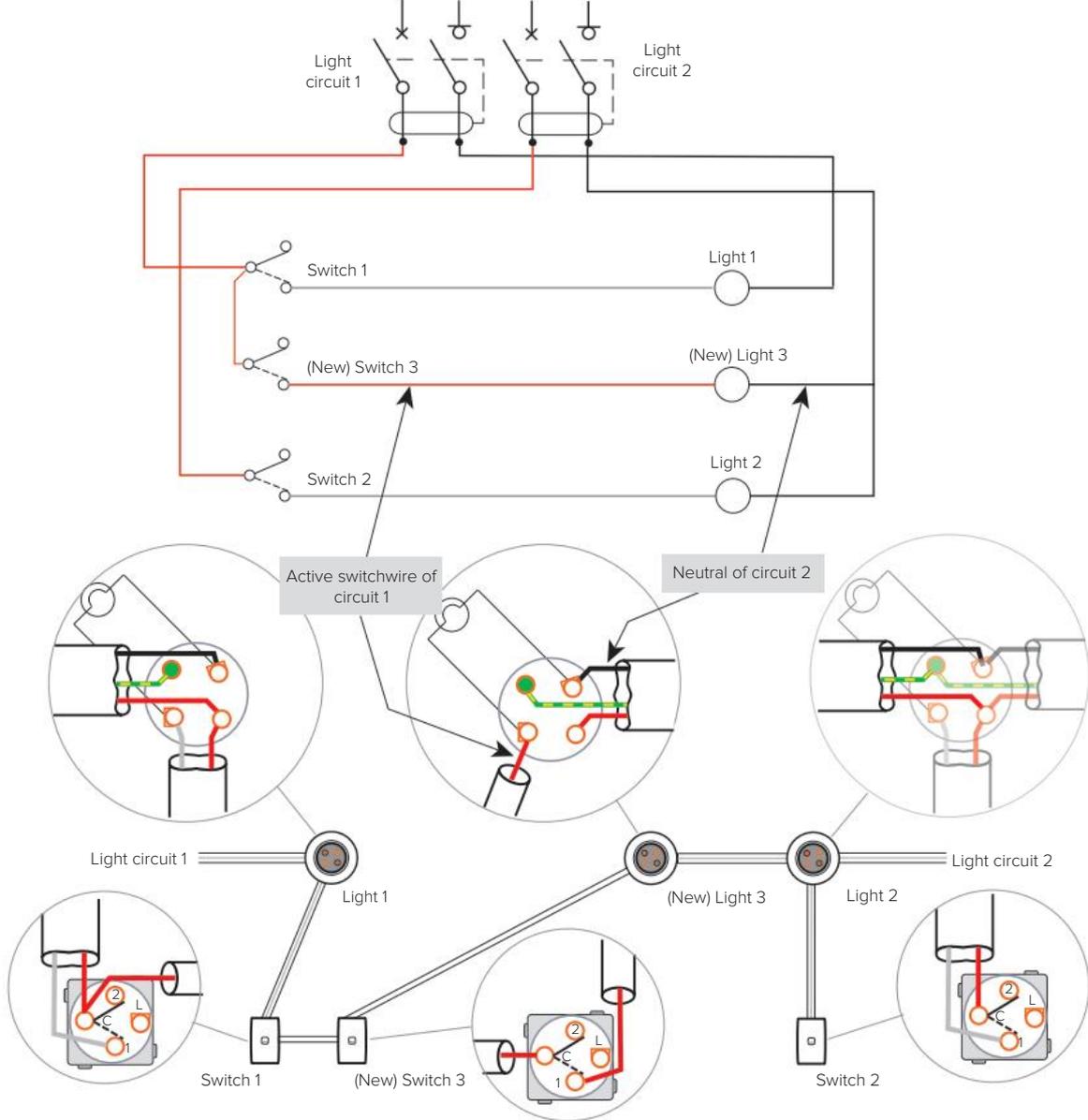
High-standing leakage current is responsible for the majority of nuisance tripping. Therefore, before installing RCD protection into an existing circuit, it is important to locate and rectify any sources of unacceptable leakage current. Insulation-resistance testing—explained in **Chapter 15, Section 15.4**—will reveal the extent of standing leakage current in individual circuits and in the installation as a whole.

A reading of 1 M Ω means that there is a leakage current of 0.24 mA for a potential of 240 V to earth. If the insulation resistance is reduced to 0.1 M Ω then the leakage current will increase to 2.4 mA, because current increases as resistance lowers. If unacceptable levels of standing leakage current are found, repairs will be needed before effective RCD protection can be installed.

The *Wiring Rules* require that, after being installed, each RCD is tested using the integral test button. Depressing this button only tests the electrical and mechanical elements of the tripping mechanism. A test that includes the fault path for a circuit would use voltage-testing devices that draw a current greater than the rated residual current for the device. However, to determine whether or not the RCD is operating within the specified trip time or residual current tolerance, a dedicated RCD tester must be used; see **Figure 13.38**.

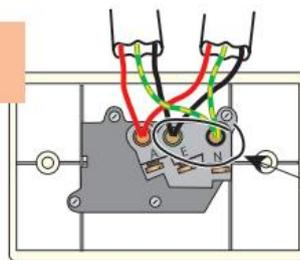
Figure 13.39 following illustrates some examples of RCD installation arrangements.

In this example, a new light point is installed, resulting in the connection between the neutral conductors of two circuits. The convenient location of the new switch and new light point typically lead to such mistakes. If left, this fault will cause RCDs protecting the circuits to trip when the new light is switched on with one or more of the other lights. This is clearly a non-compliance defect and should be picked up during verification testing.



Another installation fault that affects the operation of an RCD is incorrect connection of the neutral and earthing conductors at a socket-outlet or appliance cord.

This polarity defect (Clause 4.4.5) is potentially dangerous but would be picked up during verification testing.

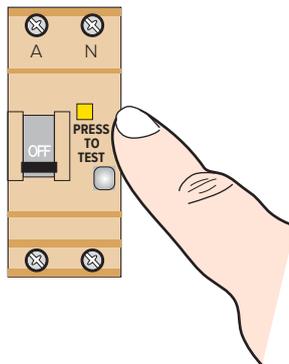


Neutral conductors and protective earthing conductors are crossed over. This type of mistake can come about through lack of attention when making many connections for accessories.

FIGURE 13.37 Common installation faults

Confirming the operation of RCD

Wiring Rules, Clause 8.2.10 requires testing the tripping function of each RCD by using the integral tripping device. In Australia this test is not required if supply is not available.



Tester for checking RCD specified trip times and trip currents

Although not mandated by the *Wiring Rules*, some jurisdictions and job specifications may require RCDs, trip times and current to be confirmed. Multifunction installation testing instruments commonly include a function for testing RCDs, trip times and current.

The Standard *AS/NZS 3017 Electrical installations—Verification guidelines* gives a comprehensive guide to testing procedures. Of interest here is the clause on RCD testing, in particular *Clause 3.7.2.2 Testing by special test equipment*, which gives general advice on RCD testing and includes the tripping time and accuracy for Type I and General Type RCDs.

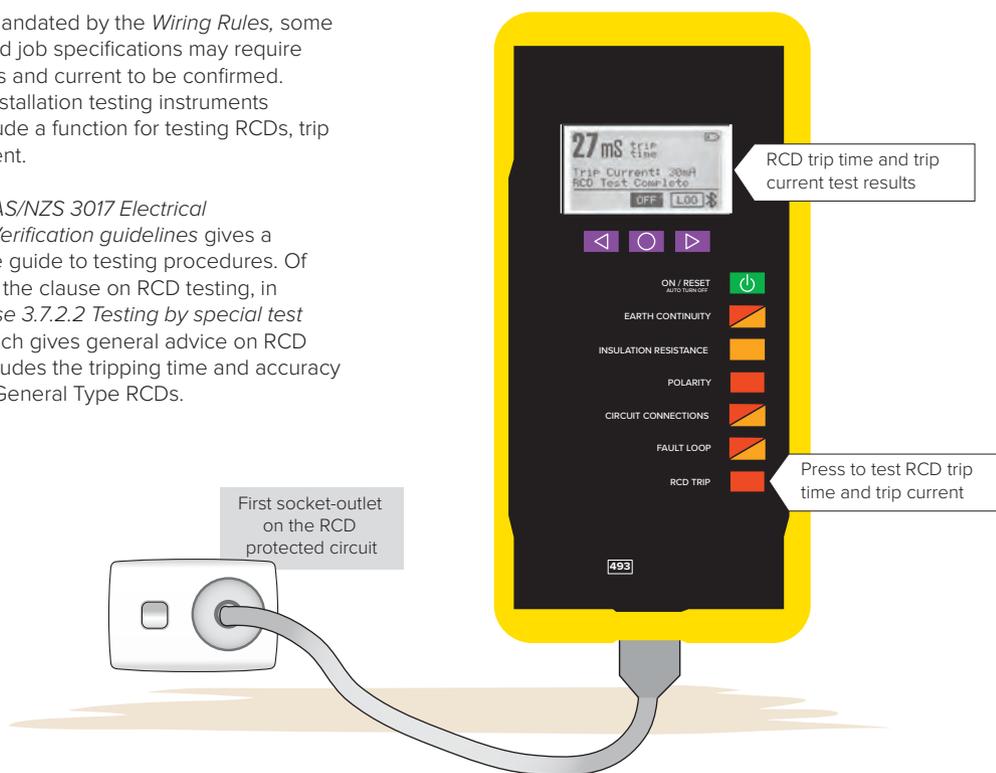
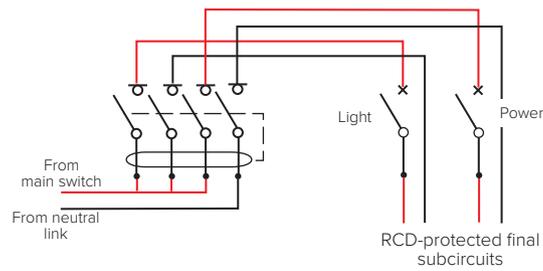
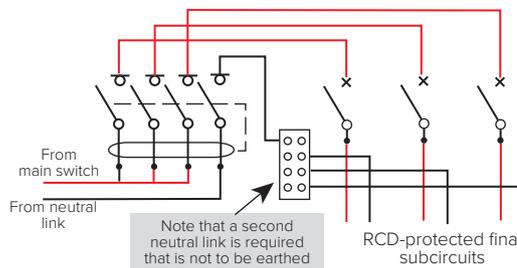


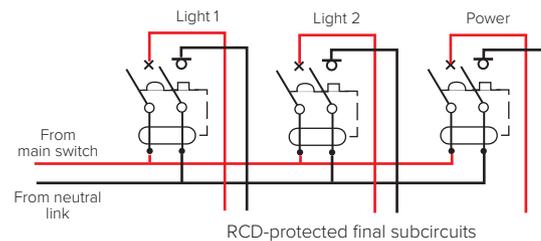
FIGURE 13.38 RCD testers

Protecting two circuits using a four-pole RCCB

This arrangement is useful where lighting is required to be distributed across two or more RCDs, the arrangement being repeated for each group of protected circuits (See *Clause 2.6.2.4*).

Protecting three circuits using a four-pole RCCB

This arrangement of three circuits protected by one RCD is the maximum number permitted in residential installation by *Clause 2.6.2.4(b)(i)*.

Protecting each circuit with an RCBO

The RCBO provides the most economical arrangement, particularly for new installations.

FIGURE 13.39 Examples of RCD installation arrangements

CHECK YOUR UNDERSTANDING

11. What is the minimum potential rise in touch voltage that requires automatic disconnection as a protection method?
12. How does an RCD operate?
13. Will an RCD provide protection against faults between live conductors?
14. What is the purpose of an RCD?
15. Can the operation of an RCD be tested without supply?

13.4 Protection against overvoltage and undervoltage

13.4.1 Overvoltage

In an installation, voltages higher than normal may cause the breakdown of insulation and subsequent damage to either wiring or equipment connected to the wiring, or the nuisance-tripping of RCDs. These high voltages are variously known as voltage surges, overvoltage, voltage transients or voltage spikes; see **Figure 13.40**.

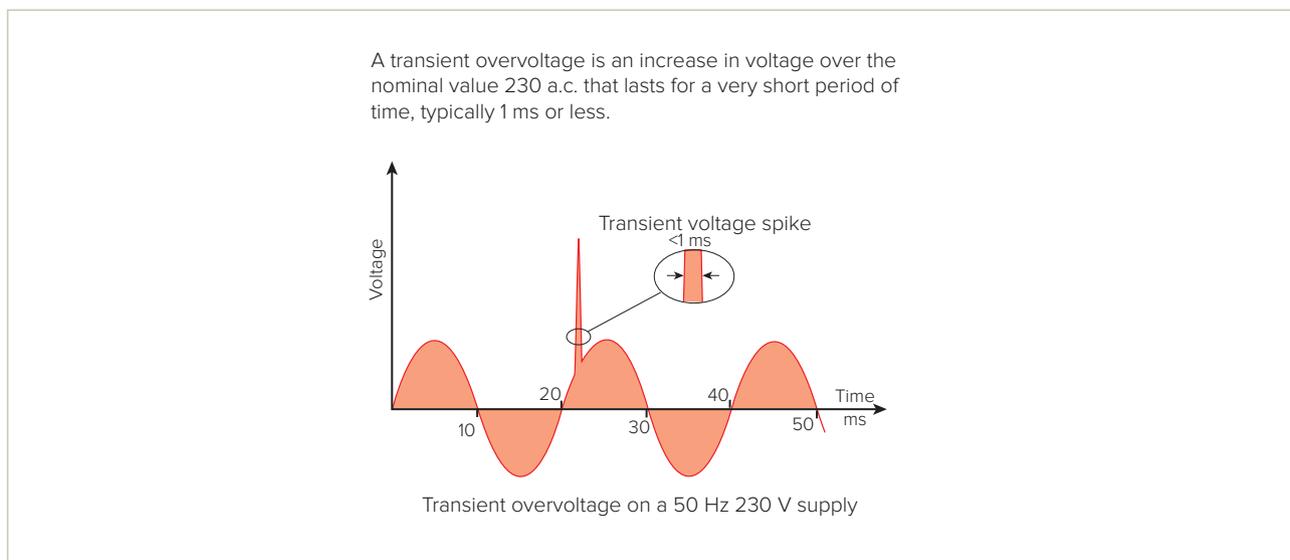


FIGURE 13.40 Overvoltage transients

Causes of overvoltage

Lightning discharge and switching operations are the most common causes of transient overvoltages. A more serious, but uncommon, cause of overvoltage is a breakdown in insulation between low-voltage and high-voltage circuits.

Electricity suppliers use surge-diverting devices installed at critical points along their networks to reduce the damage a lightning strike may cause. Despite this, voltage transients can reach an installation and possibly cause damage to electronic equipment, as well as electrical accessories, wiring and appliances; see **Figure 13.41**.

The major concern of the electrician is providing transient overvoltage protection for an installation where the risk of transient overvoltages is likely. The *Wiring Rules* do not mandate protection from overvoltage transients but provide advice on when it may be necessary and guidance on how it should be done. Note that protection against overvoltage caused by faults or induction between circuits of different voltages is required by *Clause 1.5.11* and *Clause 2.7.2*; see **Figure 13.42**.

Surge protection

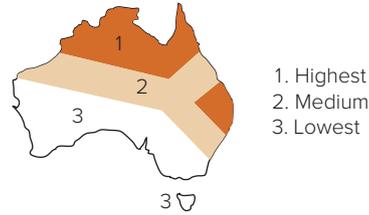
Surge protective devices (SPDs) limit high-voltage transients by diverting unwanted energy surges away from the protected circuits through a protective component connected to earth in parallel and/or in series. There are several types of primary components used in SPDs, the most common being the metal oxide varistor (MOV) as shown in **Figure 13.43**.

Basic protection is achieved where an SPD is used to protect an installation against surges that have a high energy content, such as those that can occur from lightning or during heavy switching transients. Manufacturers advise two levels of basic protection, depending on the likelihood and severity of an overvoltage transient occurring. Fine protection is used to protect individual circuits supplying voltage-sensitive electronic equipment. Used in combination with coarse protection, it provides the most secure protection against voltage surges. **Figure 13.44** illustrates surge protection arrangements.

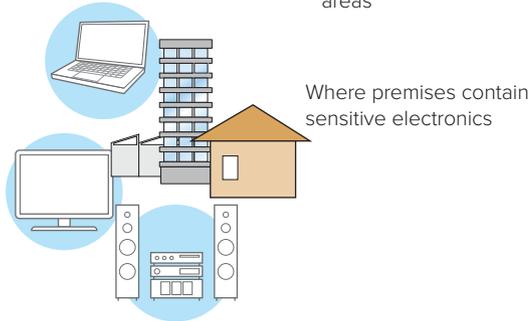
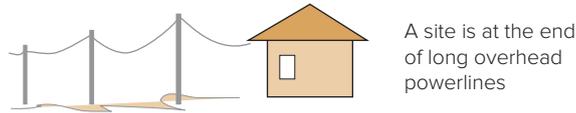
Voltage surges caused by lightning may be divided into two types:

- surges caused by direct strikes
- induced surges due to nearby strikes.

The risk of lightning strikes in areas of Australia is shown below.



Situations most at risk from voltage surges caused by lightning strike



Situations most at risk from voltage surges caused by switching transients

Voltage transients created by switching of inductive loads can be caused by other nearby installations or internally within an installation.

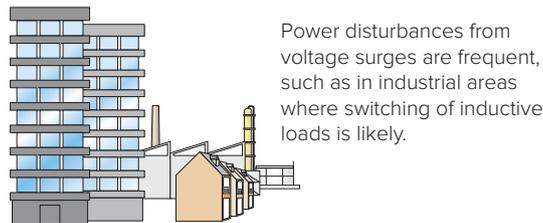


FIGURE 13.41 Where overvoltage transients are likely

2.7 Protection against overvoltage

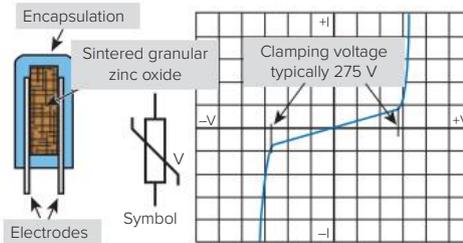
- Mandates protection by insulation or separation between live parts of an installation and circuits supplied at higher voltages
- Advises on the causes of overvoltage and where protection may be necessary
- Describes measures and types of devices for providing overvoltage protection
- Refers to *Appendix F* for guidance on selection and installation of surge protection devices (SPDs)

2.8 Protection against undervoltage

- Specifies conditions where undervoltage protection measures shall be taken
- Describes causes of undervoltage and acceptable methods (device characteristics) for undervoltage protection

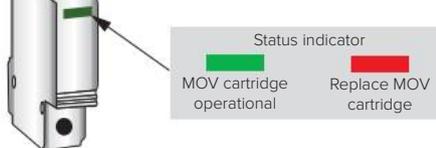
FIGURE 13.42 *Wiring Rules*—protection against overvoltage and undervoltage

Metal-oxide varistor (MOV) is a common element in surge protection devices.



The MOV effectively becomes a short circuit when the voltage across its electrodes is greater than its rated clamping voltage, enabling the conduction of large currents.

This example of an MOV surge protection device has visual indication of its protection status. Typical voltage protection level is ≤ 1.5 kA and impulse current up to 20 kA.



Repeated clamping of minor voltage spikes will cause cumulative deterioration of the surge arrester; that is, the MOV becomes overstressed. These devices commonly include contacts for connection to an audible signal that sounds when the device operates.



An example of a single-phase (two-pole) 'spark gap' arrester. These devices are recommended for protection against direct lightning strikes in areas where they are prevalent. Typical working voltage > 275 V with impulse current ≤ 12.5 kA and response time of 100 ns.

FIGURE 13.43 Overvoltage protection devices

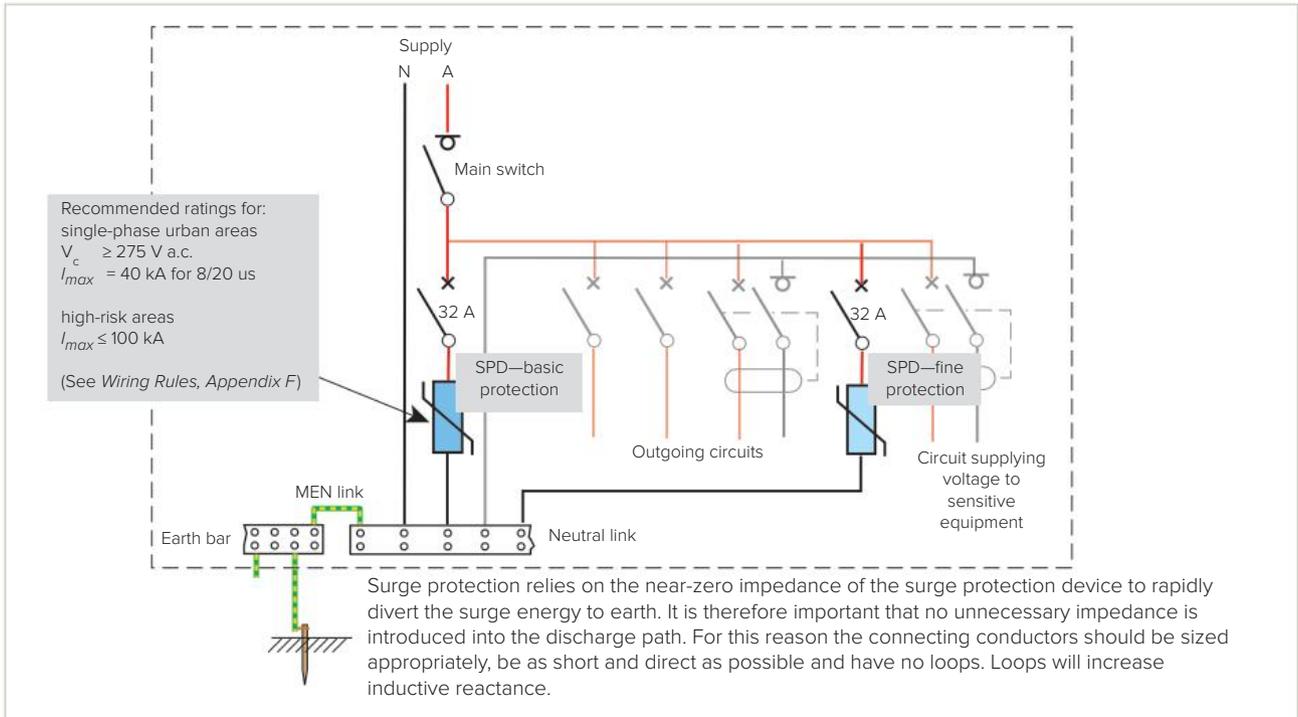


FIGURE 13.44 Voltage surge protection arrangements

13.4.2 Undervoltage

Protection against undervoltage is only an issue where it may cause a danger to persons or property. Undervoltage can be caused by a fault in the supply system or voltage drop due to an overload. **Figure 13.45** illustrates the consequences of excess voltage drop: although the protection and permitted voltage-drop limitations were met, due thought was not given to the voltage drop that would occur when starting the motor.

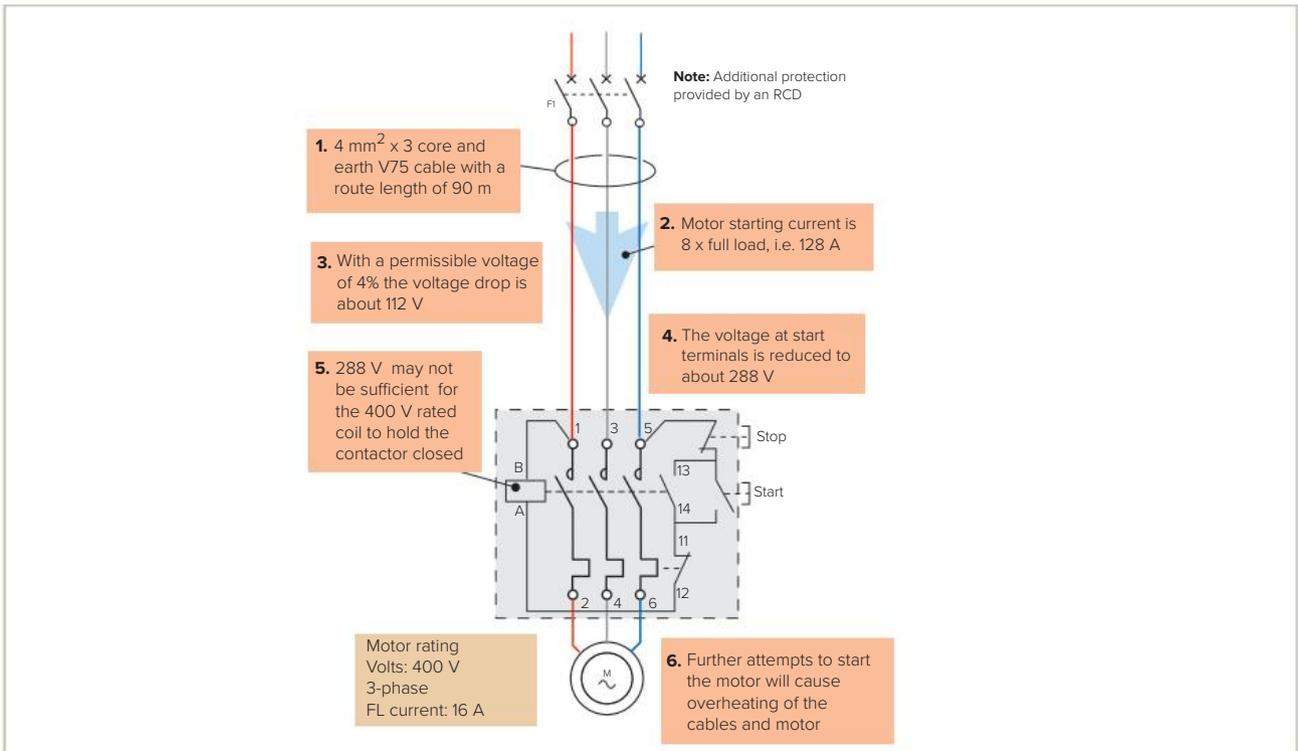


FIGURE 13.45 Example of consequences of undervoltage

Protection devices such as undervoltage relays that operate a contactor circuit-breaker are devices used to protect against undervoltage where it may be dangerous. Devices that automatically re-close once voltage is restored should not be used where there is moving machinery that may pose a further danger.

The only way to protect against a serious undervoltage—in effect a loss of supply—is to have an emergency alternative-supply system available. Emergency alternative-supply systems are commonly installed where loss of supply is likely to create an unacceptable risk, such as hospitals, data centres and continuous-process plants. These are covered in **Chapter 10**.



CHECK YOUR UNDERSTANDING

16. What is considered an overvoltage?
17. What are common causes of overvoltages?
18. What devices are installed to protect against overvoltages?
19. What can cause undervoltages?
20. What devices are installed to protect against undervoltages?

13.5 Protection arrangement and discrimination

13.5.1 Installation arrangement

An installation is required to be arranged into circuits, taking into consideration the relationships, load and operating characteristics of the equipment, consequences of circuit failure, need for safety services and facility for maintenance work (*Clause 2.2.1.1*). At the origin of each circuit is an appropriately rated circuit-breaker or fuse to protect the wiring against overcurrent that may arise from an overload or fault. Typical arrangements are shown in **Figure 13.46**.

The principles for selecting devices for protection against overload current and short-circuit current were discussed earlier in this chapter. In addition to these principles, the *Wiring Rules* requires the coordination of protective devices such that the protective device immediately upstream of a fault or overload operates to clear the fault, while protective devices further upstream remain closed (see **Section 13.4**).

These coordination requirements are intended to:

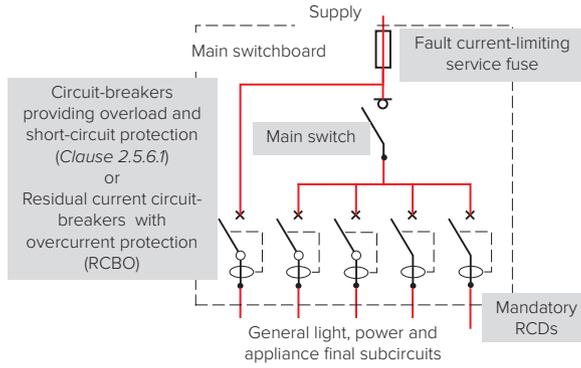
- ▶ ensure the safety of the installation and its occupants under all overcurrent conditions
- ▶ maintain supply to correctly functioning parts of an installation
- ▶ minimise stress on cables, busbars and switches in circuits under overcurrent conditions
- ▶ provide back-up protection when the fault current is beyond the capabilities of the protection device responsible for opening the circuit
- ▶ achieve an acceptable compromise between cost-effectiveness and reliability.

13.5.2 Applying discrimination

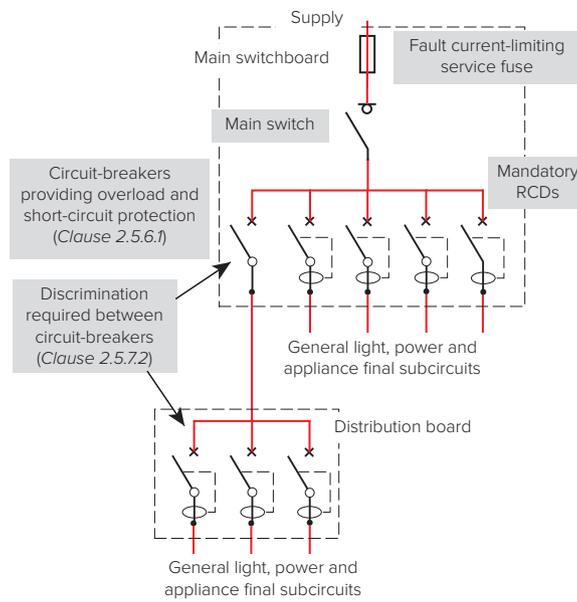
Applying a larger time delay to each successive upstream protective device—so that the time-current curves never cross—would provide total discrimination within the installation. However, the downstream protective devices would have to be fully fault rated in order to interrupt the full prospective fault current if required. This would be a costly exercise and difficult to make compliant with the *Wiring Rules*.

The *Wiring Rules* (*Clause 2.5.7.2.3*) requirements for coordination between circuit-breakers are based on current discrimination where the magnetic-trip settings of the upstream circuit-breaker are set higher than the magnetic-trip settings of the downstream circuit-breaker. Fuse coordination is based on let-through energy (I^2t) between upstream and downstream devices.

Single domestic installation



Installation with additional distribution board



Larger commercial installation

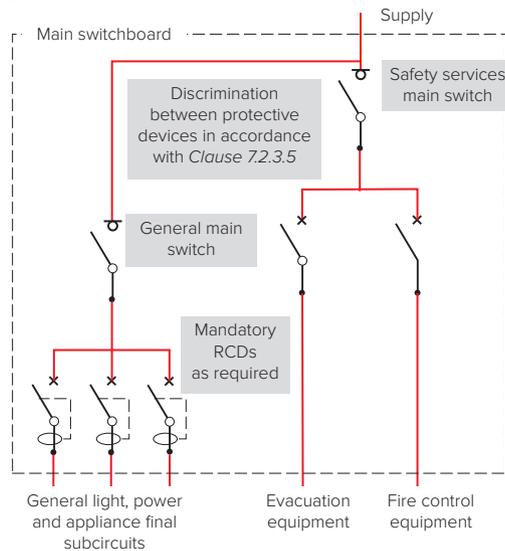


FIGURE 13.46 Typical arrangement of circuits in an installation

Selecting protective devices for discrimination

The protective devices discussed in this chapter have current-limiting properties, operate very quickly to minimise the let-through energy and are typical of the devices used to provide discrimination (and back-up) in an electrical installation. In order to achieve discrimination between overcurrent devices, the upstream device, or the one that is closer to the source of supply, must have a higher nominal current rating than those in series with it downstream. The level of discrimination obtained depends on the characteristics of the different protection devices; see **Figure 13.47**.

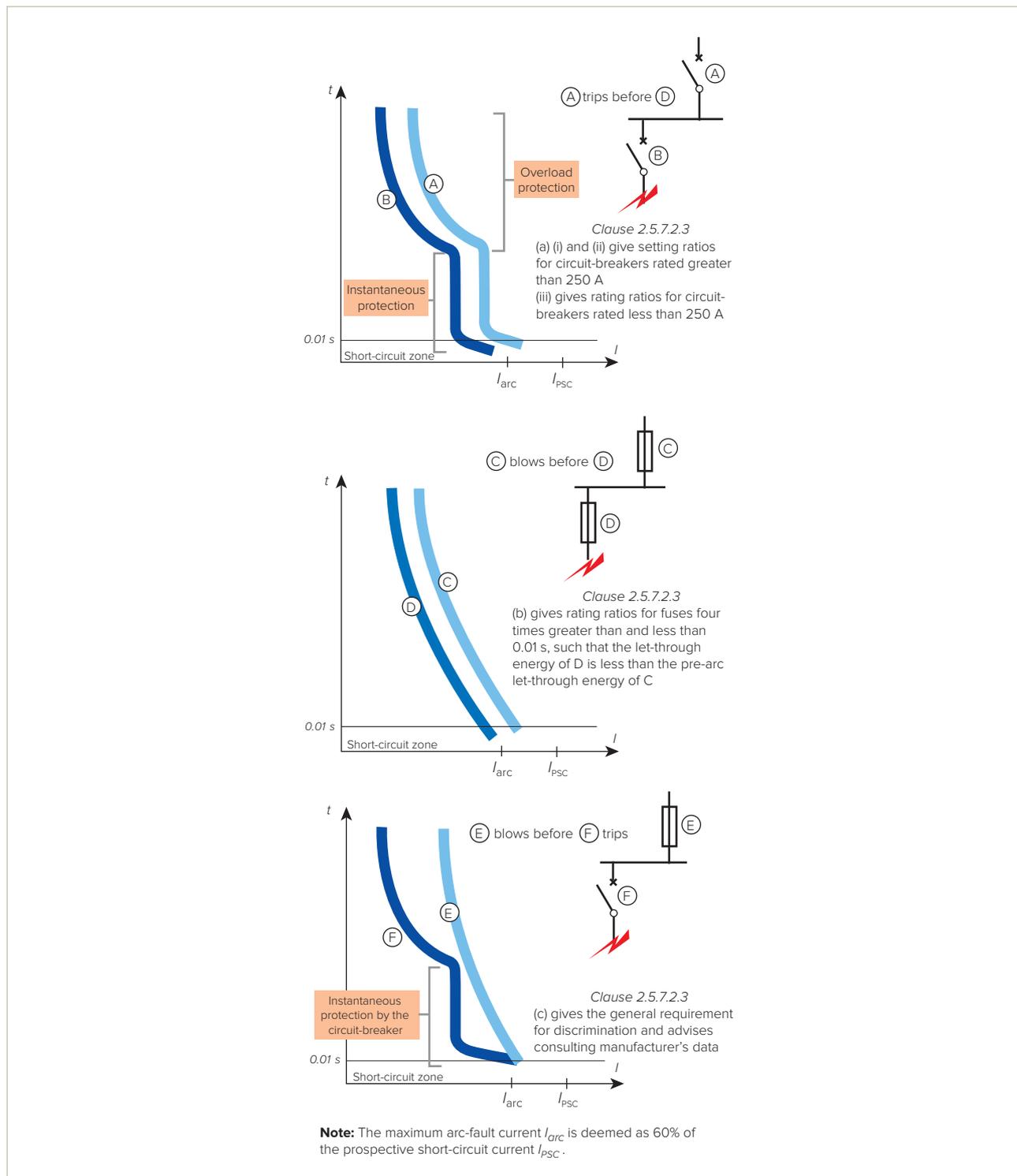


FIGURE 13.47 Coordination between protective devices

For the electrician, the main sources in selecting protective devices are the manufacturers' guides and also software that enables you to optimise discrimination for any installation and to work out the minimum theoretical level of discrimination of a given combination of protection devices.



CHECK YOUR UNDERSTANDING

21. What considerations must be made for circuit arrangements?
22. What does the term *discrimination* mean in an electrical installation?
23. How is discrimination achieved?
24. List the two requirements that satisfy the selection criteria of safety service circuit discrimination.
25. List two sources that can assist in selecting appropriate protective devices for discrimination.

SUMMARY

- ▶ Circuit-breakers or fuses are devices required to protect circuits against overload and short-circuit currents, and to limit touch voltage when an earth fault occurs.
- ▶ Installations require devices for protection against voltage surges and excessive voltage reduction; RCDs provide additional protection by limiting the rise of touch voltage when an earth fault occurs.
- ▶ If specified current limits are exceeded and there is no protection, or the protection is either inadequate or ineffective, the resulting abnormal conditions could produce overheating of conductors, subsequent insulation failure and a possible rise in touch voltage.
- ▶ The heating effect is proportional to the square of the current.
- ▶ Coordination between conductors and protective devices must be maintained to ensure circuits operate as intended, and wiring is protected against overload and short-circuit faults.
- ▶ The PSC is the highest value of current available at the point of installation of the protection. The interrupting capacity of the protective device (circuit-breaker or fuse) must be adequate to enable the interruption of the PSC.
- ▶ A short-circuit to earth in the MEN system is the equivalent of a phase to neutral fault. However, the current would be further reduced owing to the impedance of the earthing system between the fault and the neutral link.
- ▶ Overcurrent protection of a whole installation, submains, final subcircuits and appliances themselves is performed by circuit-breakers or fuses, and in some cases both.
- ▶ Motor protection is achieved if the motor windings operate within their specified temperature range. Overheating of the windings might not cause immediate failure, but even small temperature increases above the temperature specified as the maximum for a particular motor will shorten its life.
- ▶ A major component of the protection for safety principles that electrical installations are required to comply with is protection against indirect contact with live parts.
- ▶ If during a fault the touch voltage could rise above 50 V a.c. or 120 V d.c., a protective device (circuit-breaker or fuse) must be in place to automatically disconnect the supply to the fault.

- ▶ The RCD uses a toroidal transformer, similar to a current transformer, to detect leakage current.
- ▶ In an installation, voltages higher than normal may cause the breakdown of insulation and subsequent damage to either wiring or equipment connected to the wiring, or the nuisance-tripping of RCDs.
- ▶ SPDs limit high-voltage transients by diverting unwanted energy surges away from the protected circuits through a protective component connected to earth in parallel and/or in series.
- ▶ An installation is required to be arranged into circuits taking into consideration the relationships, load and operating characteristics of the equipment, consequences of circuit failure, need for safety services and facility for maintenance work.
- ▶ Requirements for coordination between circuit-breakers are based on current discrimination where the magnetic-trip settings of the upstream circuit-breaker are set higher than the magnetic-trip settings of the downstream circuit-breaker.

REVIEW QUESTIONS

1. Using *AS/NZS 3000*, list the three major types of risk in electrical installations.
2. Using *AS/NZS 3000*, define *touch voltage* and in your own words give an example of this condition.
3. Using *AS/NZS 3000*, define *short-circuit current* and in your own words give an example of this condition.
4. Using *AS/NZS 3000*, define *overload current* and in your own words give an example of this condition.
5. List four types of protective device that will provide protection against overload and short-circuit currents.
6. Where should a device providing overload protection be positioned?
7. Describe the two main protection functions of a circuit-breaker.
8. Describe a switched fuse.
9. Describe an HRC fuse.
10. Why must the utilisation category and rating be considered when replacing a fuse link?
11. Define *extraneous conductive parts* and explain why a steel-framed structure is deemed to be an example of an extraneous live part.
12. What is the purpose of an RCD?
13. A single socket-outlet is replaced with a multiple socket-outlet assembly on a circuit that is not protected by an RCD. Is it mandatory to install an RCD?
14. What is nuisance tripping?
15. Define overvoltage.
16. Is protection against overvoltage transients mandatory?
17. List four causes of overvoltage in an electrical installation.
18. Can protective devices that automatically re-close once voltage is restored be used where moving machinery (e.g. a guillotine) may unexpectedly restart?
19. When should suitable protective measures be taken against undervoltage?
20. An important consideration of any electrical design is appropriate discrimination. Using *AS/NZS 3000* define discrimination and explain why discrimination is important.

CHAPTER 14

Switchboards, control panels and metering

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ identify the Standards that switchboards must comply with
- ▶ explain how a main switchboard differs from a distribution board
- ▶ list the requirements for supply arrangement and metering in your local service and installation rules
- ▶ identify components and sketch the layouts of switchboards that comply with your local service and installation rules
- ▶ determine the arrangement of switchboards for given low-voltage installations with demands up to 400 A
- ▶ describe the role of control panels
- ▶ identify components and sketch the layout for a small control panel
- ▶ describe the features of single and multiphase types 1–4 and 5 electronic meters
- ▶ draw wiring diagrams for different whole-current meters and supply and tariff arrangements, including three-phase alternatives.

By this stage, you will understand that the design, manufacture and installation of electrical equipment are governed and controlled by relevant codes, rules, regulations and specifications. In the case of switchboards, each associated piece of equipment is made in strict accordance with an individual specification and the whole assembly must comply with both the *Wiring Rules* in general and switchboard compliance Standards series *AS/NZS 61439* and *AS/NZS 3439* in particular. In these Standards, switchboards are regarded as low-voltage switch-gear and control-gear assemblies, and in this context an assembly is defined as:

a combination of one or more low-voltage switching devices together with associated control, measuring, signalling, protective, and regulating equipment with all the internal electrical and mechanical interconnections and structural parts.

This is a broad, encompassing definition covering nearly all manufactured and custom-built assemblies, such as those known in the trade as: switchboards, panel boards, control panels, control centres and load centres. The various parts and their interconnections usually require reference to additional codes and specifications, such as *AS/NZS 3100:2017 Approval and test specification general requirements for electrical equipment* and many others.

As will be seen in this chapter, switchboards are often included on meter panels. Electrical energy metering is necessary for electrical retailers to charge the correct amount according to a set charge per unit of energy or the contractual agreement for the conditions under which to deliver that energy.

Government policies to increase the efficiency of the electrical supply industry through competition are having an impact on the pricing structures of electrical energy. Also, technical developments in communications and electrical measurement are having an impact on metering technology.

14.1 Compliance requirements for switchboards

14.1.1 Wiring Rules

The *Wiring Rules* specify that an installation must be divided into circuits and that all circuits must originate from a switchboard. The switchboard with its switchgear must be selected on the principle of providing safety, which includes safety in design and construction, functioning properly in the environment in which it is to operate and not adversely affecting the electrical installation itself, as summarised in **Figure 14.1**.

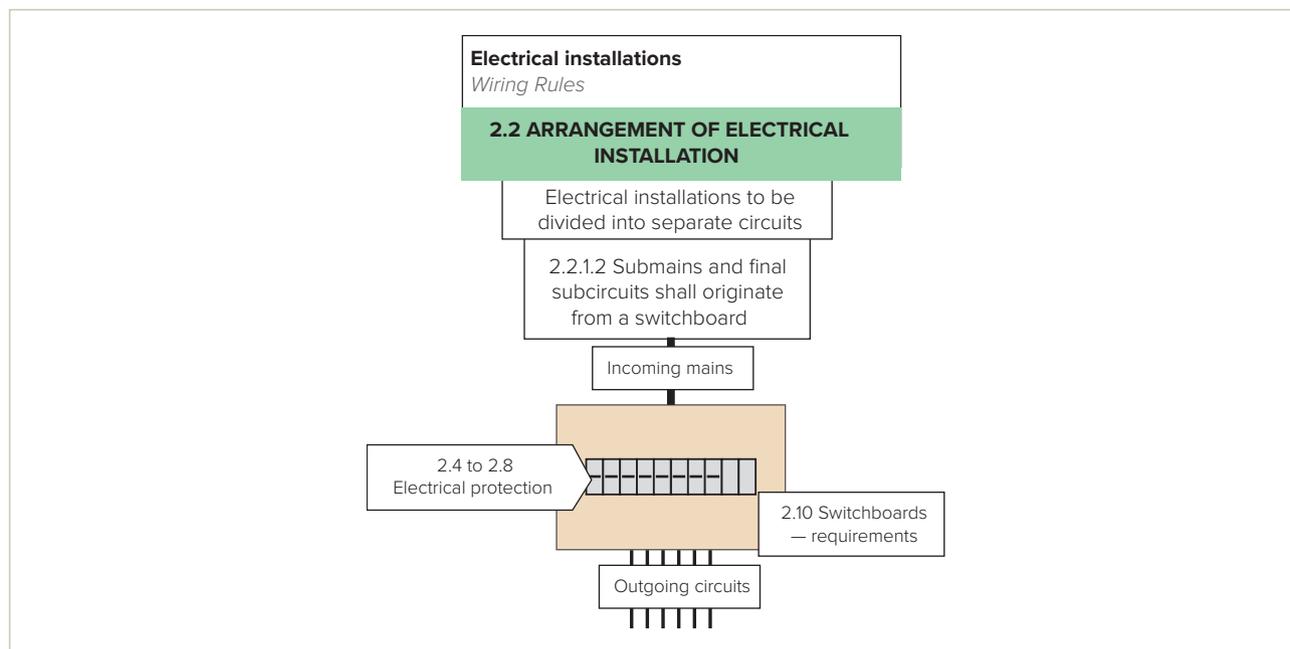


FIGURE 14.1 Switchboards—arrangement of installation

Reference to the *Wiring Rules* reveals that a switchboard is ‘an assembly of circuit protective devices’ for distribution to, and protection of, one or more submains and/or final subcircuits (*Clause 1.4.121*). It may be a main switchboard (*Clause 1.4.122*) from which the supply for the whole of the installation originates, or a switchboard controlling and/or protecting only a portion of the installation fed by one or more submains and/or one or more final subcircuits. In this second type of application, it is called a distribution board (*Clause 1.4.46*). (The terms *switchboard* and *distribution board* are used interchangeably in this text.)

Either a main switchboard or a distribution board may be the origin of a final subcircuit or submains, and both types are distinct from control panels, which, although providing control and protection functions like switchboards, are installed for an individual appliance or group of appliances and may themselves incorporate a switchboard. A control panel is an assembly of devices for controlling one or more appliances, for example an air-conditioning system, but is not itself a switchboard unless it includes circuit-protection devices. (See *Clause 2.3.7 Functional (control) switching*.)

If a control panel is within, or is an integral part of, an appliance, it is no longer regarded as a control panel but is considered to have become part of the appliance. (There are overlapping functions here, and the installing electrician must be aware of the different categories of accessories used for the control and protection of circuits.)

Figures 14.2 and 14.3 provide an overview of the *Wiring Rules* requirements for switchboards.



SAFETY ALERT

Clause 2.10.5 requires the equipment at a switchboard to be arranged or marked to clearly identify its function and/or the circuit of each control. Of particular importance is the correct identification of protection/isolating devices and the corresponding active and neutral for each outgoing circuit.

This will assist any person in the future who needs to isolate a circuit for equipment maintenance and repair. An electrician called on at some future date to find a fault or install additions to the installation could be at a risk from electric shock if, say, a neutral was incorrectly marked.

14.1.2 Switchboard types and Standards

Manufactured switchboards complying with either the *AS/NZS 3439* series or the *AS/NZS 61439* series (*Low-voltage switchgear and control gear assemblies*) satisfy the *Wiring Rules* requirements for the construction of switchboards (Clause 2.10.3.2). Note that, over time, the *AS/NZS 3439* series will be withdrawn.

Broadly speaking, the types of switchboards of most interest to electrical work covered by *AS/NZS 61439* can be categorised as low demand intended for domestic and non-domestic installations, and high demand intended for larger commercial and industrial installations. Switchboards are required to be 'suitable' (Clause 2.10.3.2), meaning they are able to withstand the mechanical, electrical and thermal stresses that are likely to occur in service. These stresses increase with the load demand of the switchboard.

Low-demand switchboards

Switchboards complying with *AS/NZS 61439 Part 3 Distribution boards that are intended to be operated by ordinary persons (DBO)* can be considered low demand. The Standard covers distribution boards with a rated current up to 250 A and outgoing circuits not exceeding 125 A manufactured to accommodate single-pole devices or both single and multiple devices. Typically, these boards are of modular design with both plastic molded and metal components, providing flexibility to suit most installation situations. Examples of the most common types used for domestic and small non-domestic installations are shown in **Figure 14.4**.

In a single installation, it is not uncommon to incorporate the distribution board in the meter enclosure, where it becomes, by definition, the main switchboard, as shown in **Figures 14.5** and **14.6**. These types of switchboards are relatively inexpensive (when compared with the larger commercial boards) and simpler to configure and connect.

An important feature to specify when purchasing a manufactured switchboard is the required number of poles. In this context, a pole is the standard width of a single-pole circuit-breaker (17.7 mm in the case of the miniature circuit-breaker, or MCB). Residual current devices (RCDs) are commonly two poles wide, although a single-pole version is available. Three- and four-pole circuit-breakers are obviously three and four poles wide respectively. The number of poles required, together with the current rating and installation features, needs to be determined before ordering a switchboard for a particular job.

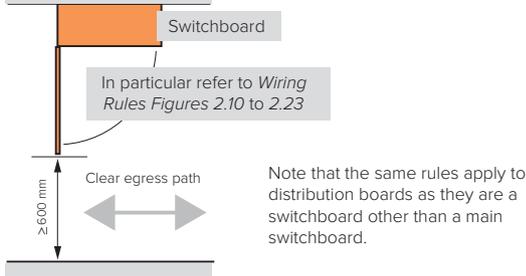
Most manufacturers now offer a single-pole combination circuit breaker and RCD called a residual current breaker with overcurrent (RCBO). These units are proving excellent value from a service point of view by reducing spurious trips due to earth leakage. They are used to protect the final subcircuit, up to 32 A. Three-pole/three-phase units are also becoming more popular in larger domestic installations and can protect circuits up to 63 A (see **Figure 14.7**).

2.10 SWITCHBOARDS

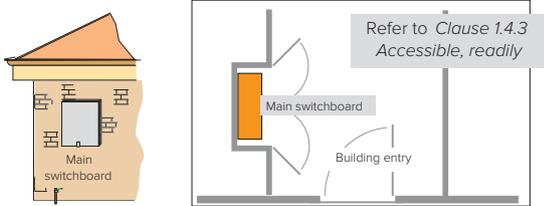
As with other wiring rules, those pertaining to switchboards are about safety; that is, the switchboards are safe to operate, they are installed in a safe and accessible location and are safe for those who must access them. The following overview of these requirements is to prompt a clearer understanding when the rules on switchboards are studied more closely.

2.10.2 Location of switchboard

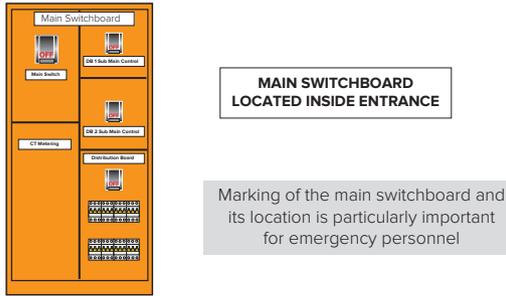
2.10.2.2 Accessibility and emergency exit facilities



2.10.2.3 Location of main switchboard

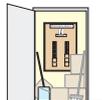


2.10.2.4 Identification of main switchboard



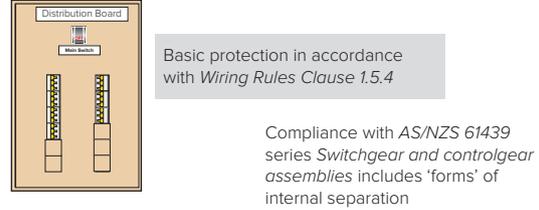
2.10.2.5 Restricted locations

In summary, switchboards are restricted in locations where they:

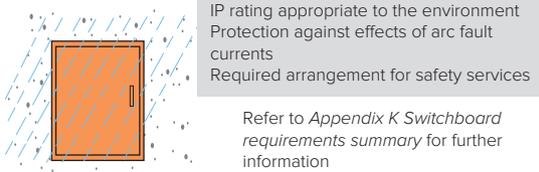
-  are not readily accessible
 -  can be affected by water, moisture or heat
 -  impede emergency exit paths
 -  are in a hazardous area
- Consult this clause before deciding to install a switchboard in a particular location

2.10.3 Construction

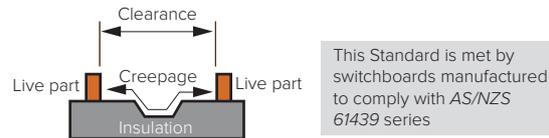
2.10.3.1 Access to live parts



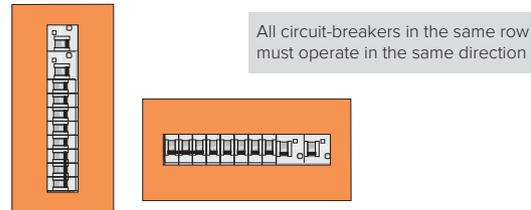
2.10.3.2 Suitability



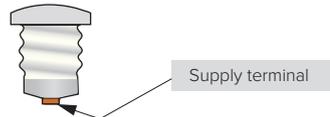
2.10.3.3 Minimum clearances and creepage distances



2.10.3.4 Orientation of circuit-breakers

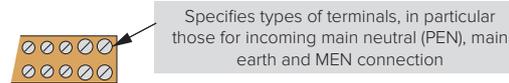


2.10.3.5 Screw-in fuses



2.10.4 Bars or links

2.10.4.2 Tunnel-type terminals



2.10.4.3 Neutral bar or link

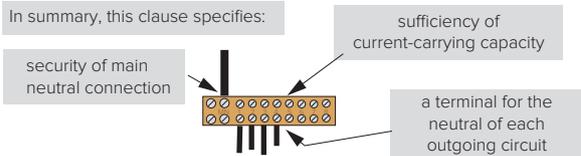
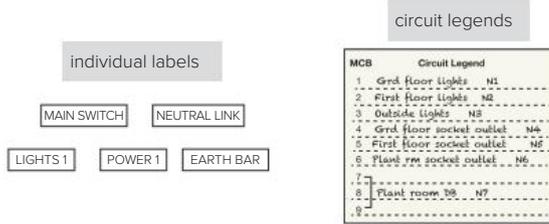


FIGURE 14.2 Overview of *Wiring Rules* requirements for switchboards

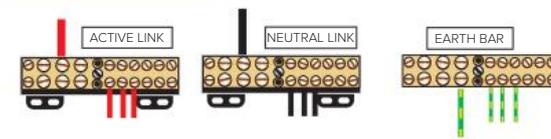
2.10.5 Equipment identification

2.10.5.2 Relationship of electrical equipment

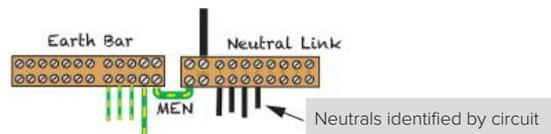
This clause requires switchboard equipment to be clearly marked, for example:



2.10.5.3 Bars and links



2.10.5.4 Terminals of switchboard equipment



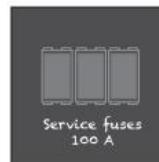
2.10.5.5 Common neutral

Requirement to identify associated active where a common neutral is used, for example:

The oven and hob circuit use a common neutral N5

2.10.5.6 Fuse

Requires associated fuses grouped and ratings marked, for example:



2.10.6 Wiring

Requirements to:

- withstand thermal and magnetic effects
- secure wiring to hinged panels and without strain



2.10.7 Fire-protective measures

Requirement to prevent spread of fire originating in a switchboard

For example, sealing cable entries



FIGURE 14.3 Overview of Wiring Rules requirements for switchboards

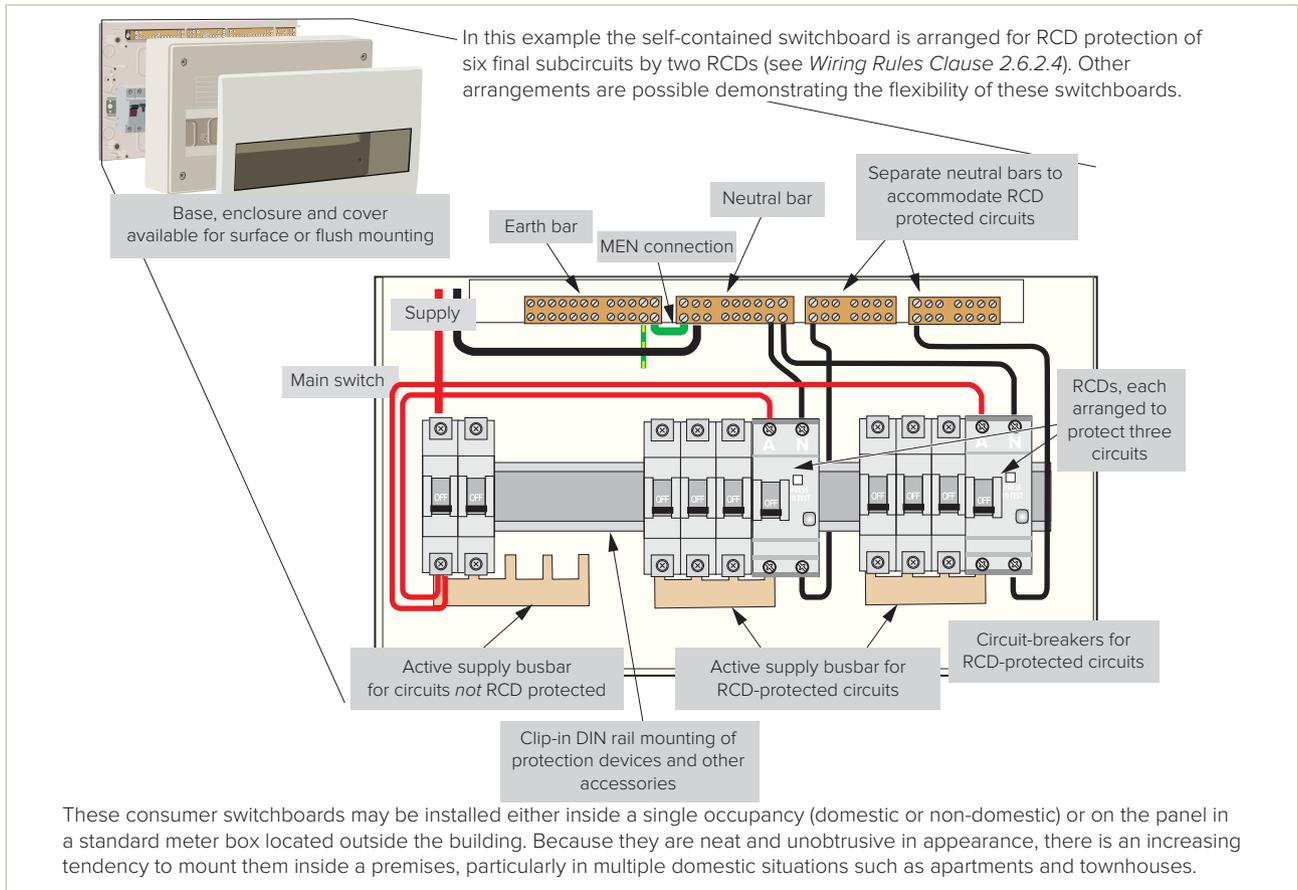


FIGURE 14.4 Features of typical consumer switchboards

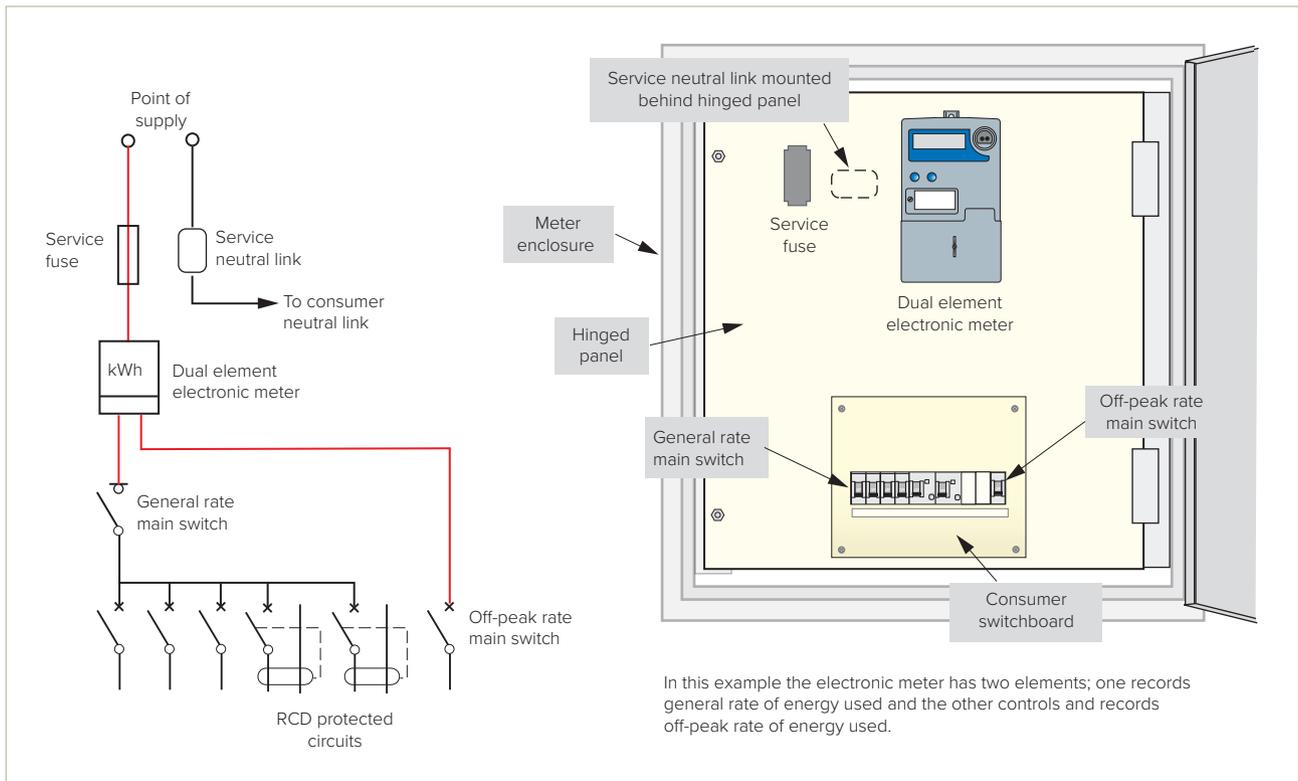


FIGURE 14.5 Example of meter enclosure and main switchboard for a single installation



FIGURE 14.6 Typical three-phase Victorian meter enclosure with main switchboard
Robert Wickstead



FIGURE 14.7 Three-module RCBO 3P+N 6kA C-Curve 30 mA A type with neutral lead

NOTE: Most two-pole RCBOs and some single-pole RCBOs will open circuit the neutral as well as the active when tripped. Most single-pole RCBOs will *not* open-circuit the neutral when tripped.

Examples are shown in **Figures 14.8** and **14.9**.

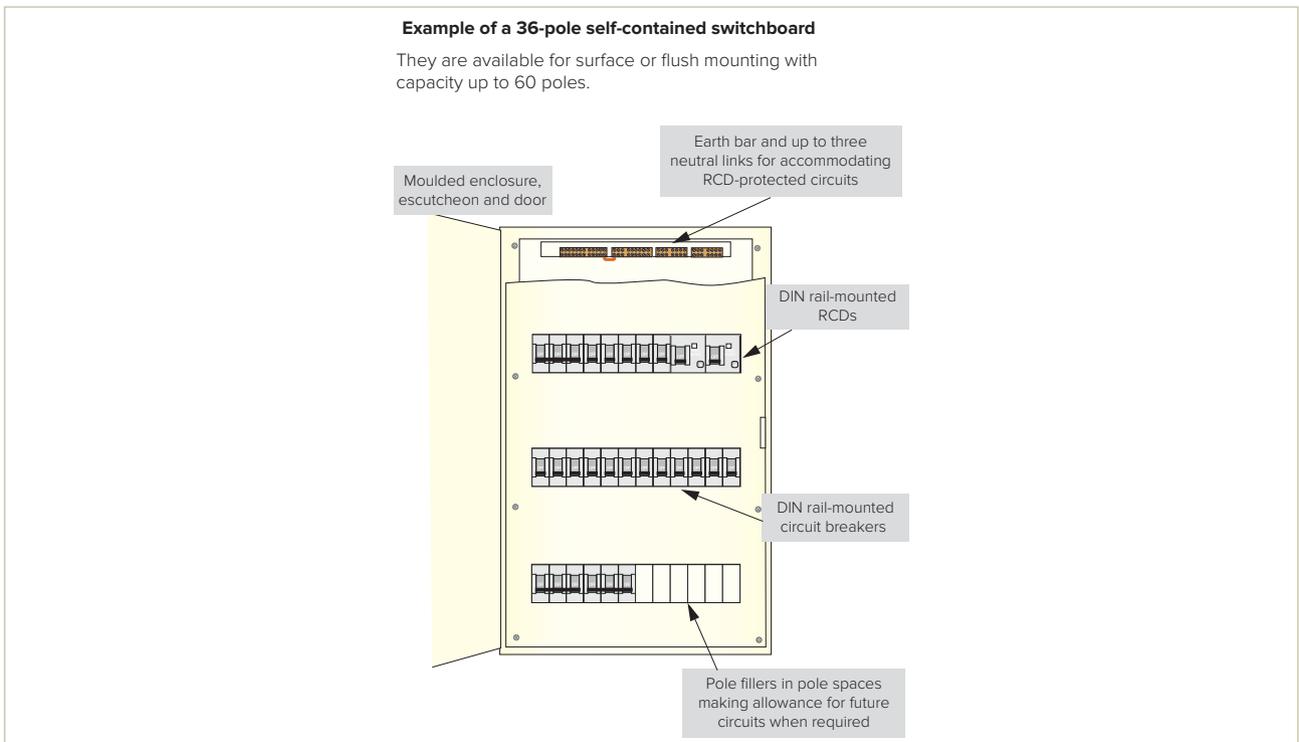


FIGURE 14.8 Example of a low-demand high-pole-capacity moulded switchboard



FIGURE 14.9 Examples of steel conduit used to protect mains cables in a domestic environment

Robert Wickstead

NOTE: When installing switchboards (either main or distribution) in domestic settings, for aesthetic purposes it is common to mount the board flush with the plaster wall (this is known as flush mounted). If the board is made from PVC (plastic), a separate steel plate will need to be installed behind the switchboard if the clearance from the opposite side is less than 50 mm. If the switchboard is backing onto a brick wall, the steel plate does not need to be installed.

This protection applies to cables as well. This often means having to install steel conduit to run the mains and submains in. Flexible steel conduit is ideal for this purpose, although the additional earthing requirement may prove challenging. **Figure 14.8** shows examples of steel conduit in such installations.

Higher demand switchboards

Switchboards complying with *AS/NZS 61439 Part 2 Power switchgear and control assemblies* are essentially intended for all types of loads, in particular those with a high demand current (i.e. > 250 A). It is common that the main switchboard in a large commercial or industrial installation is of this type, generally available as a custom design of modular construction allowing for various arrangements of equipment with some items by agreement with the user. The high cost of these switchboards makes it essential that all required features and characteristics are specified in order for a switchboard manufacturer to provide an accurate quote and proceed with its construction. **Figure 14.10** shows an example of this type of switchboard.

The fault level at the point of supply is very high in installations with a high-demand current. The low impedance of the large conductors needed for consumer mains results in high or very high prospective fault currents at the switchboard, possibly exceeding 100 kA. Fault currents of these magnitudes introduce very high levels of mechanical stress, very high magnetic fields, and difficulties with arc extinguishing and containment.

The switchboard manufacturer verifies compliance with Standards by assessment and testing of all required performance aspects for a given assembly. These include the required form of separation of components and functional units within the assembly, limiting the consequences of an internal fault, and the switchboard's ability to withstand mechanical and electrical stresses in normal use and under fault conditions. A snapshot of the forms of separation is shown in **Figure 14.11**. A switchboard for an installation with a 2500 A demand, complying with *AS/NZS 61439.2* for power switchgear and controlgear assemblies, is shown in **Figures 14.12** and **14.13**.

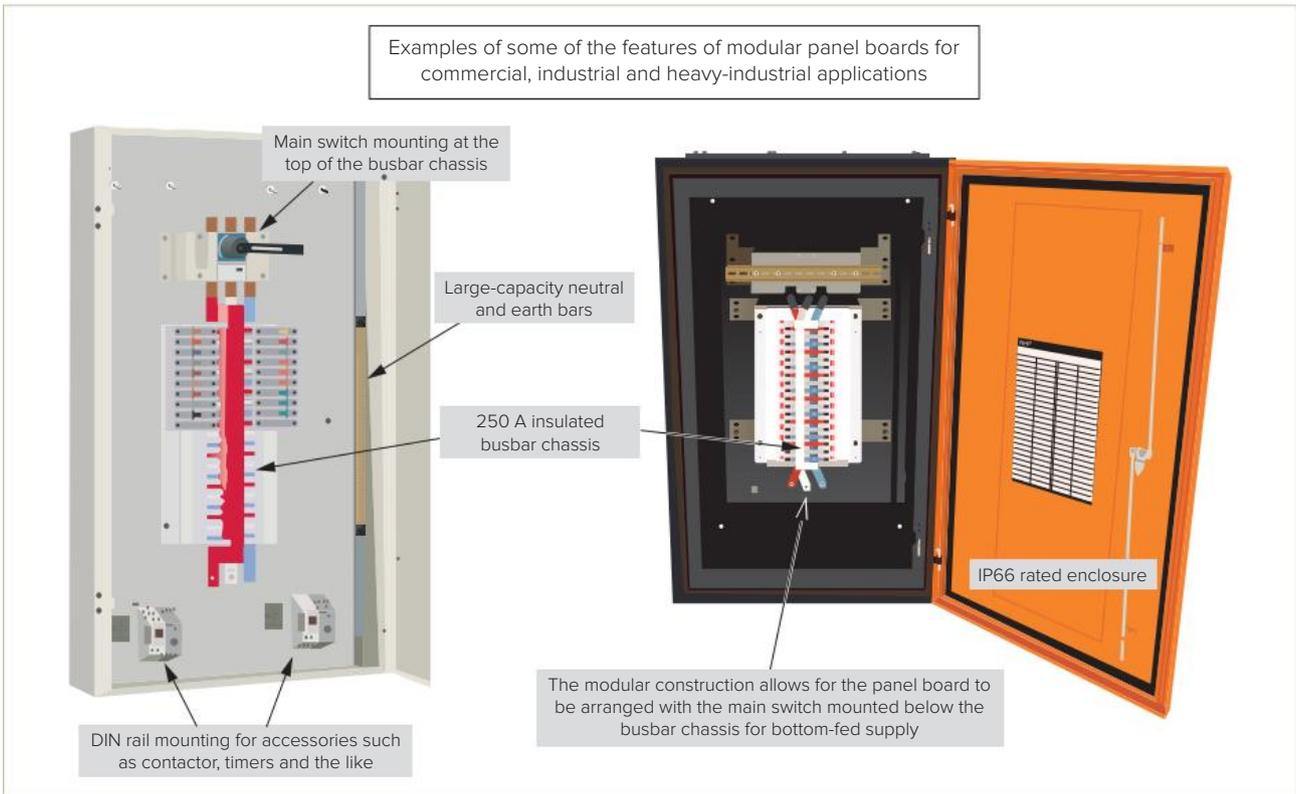


FIGURE 14.10 Examples of modular panel boards used in installations with demand up to 250 A per phase

In switchboards for installation with high-demand current, the likely consequences of a short circuit between components are severe damage, fire and injury to any person in the vicinity. In order to mitigate these risks, these switchboards are designed with internal separation of components. The purpose of having internal separation is to reduce the likelihood of contact between live parts of adjacent components, confine the result of any fault and prevent the passage of solid foreign bodies from one compartment of the switchboard to another. The 'forms of separation' given in the Standard series AS/NZS 61439 provide variations to suit a particular application and needs of the end-user, while being subject to compliance tests and assessments.

In addition to the above, *Wiring Rules Clause 2.5.5* requires heavy current switchboards (≥ 800 A) to have protection against an internal arc fault, as shown in the adjacent concept diagram. Some statistics suggest that arc faults are most commonly caused by human error, mechanical failure of components and poor electrical connections. A more than acceptable number of arc faults occur when work is being done on a switchboard. This is a clear warning to follow all lock-out and safety procedures when working on switchgear assemblies.

Concept of forms of components' separation
(Refer to AS/NZS 61439 for concise information)

Switchboard components subject to internal separation	Functional devices	External conductor terminals	External conductors
	3a; 3b; 4a; 4b	4a; 4b	3a; 3b; 4a; 4b
	2a; 2b 3a; 3b; 4a; 4b	2b; 3b; 4a; 4b;	2b; 3b; 4a; 4b;
	4a; 4b		

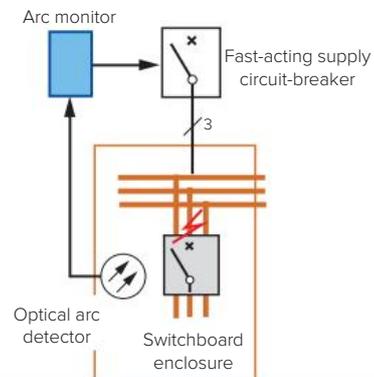


FIGURE 14.11 Forms of internal separation in high-demand switchgear and control assemblies

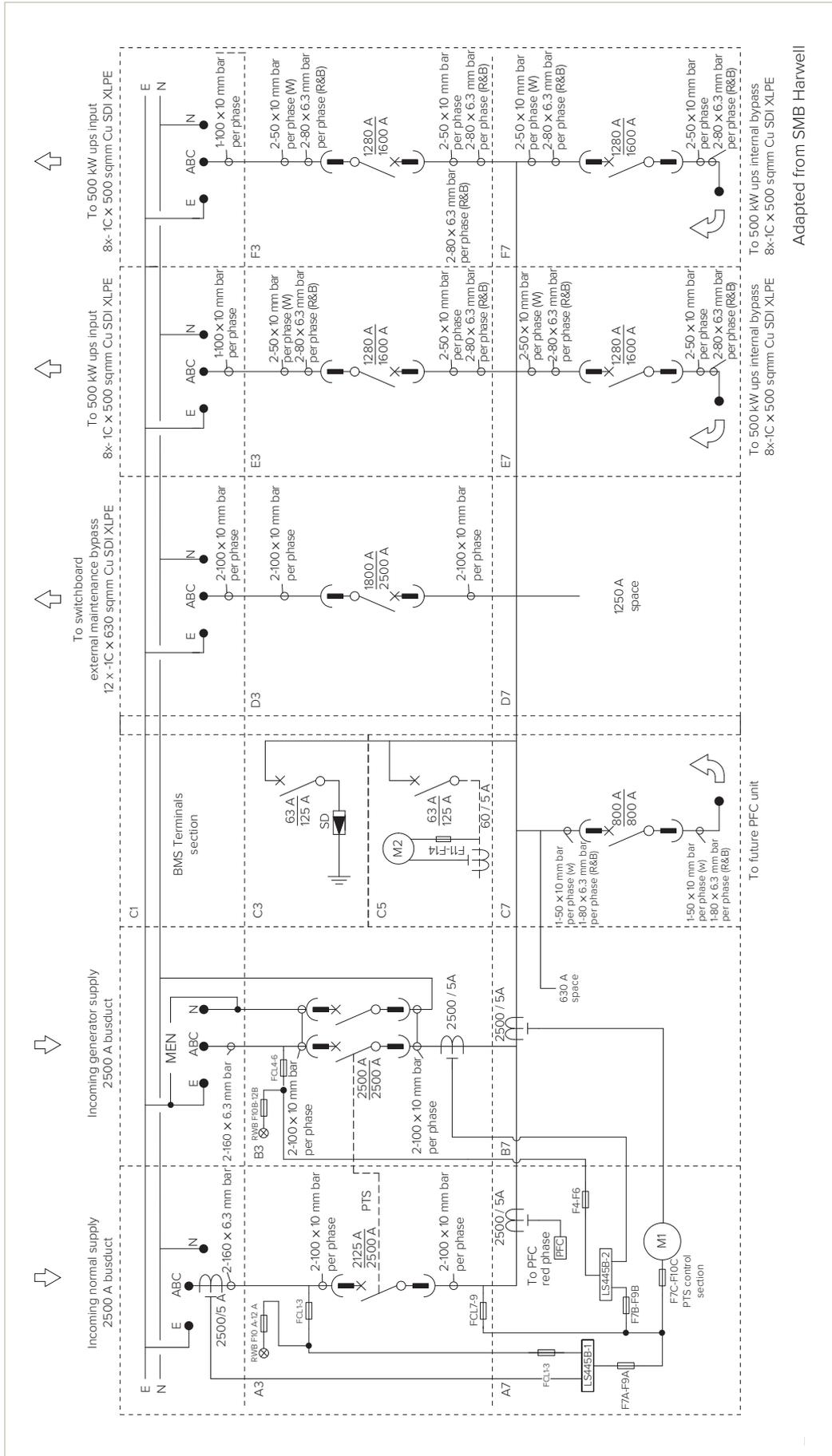


FIGURE 14.12 Switchboard for installation with 2500 A demand—internal circuit arrangement

Fuji SMBE Harwal Pty Ltd

Adapted from SMB Harwell

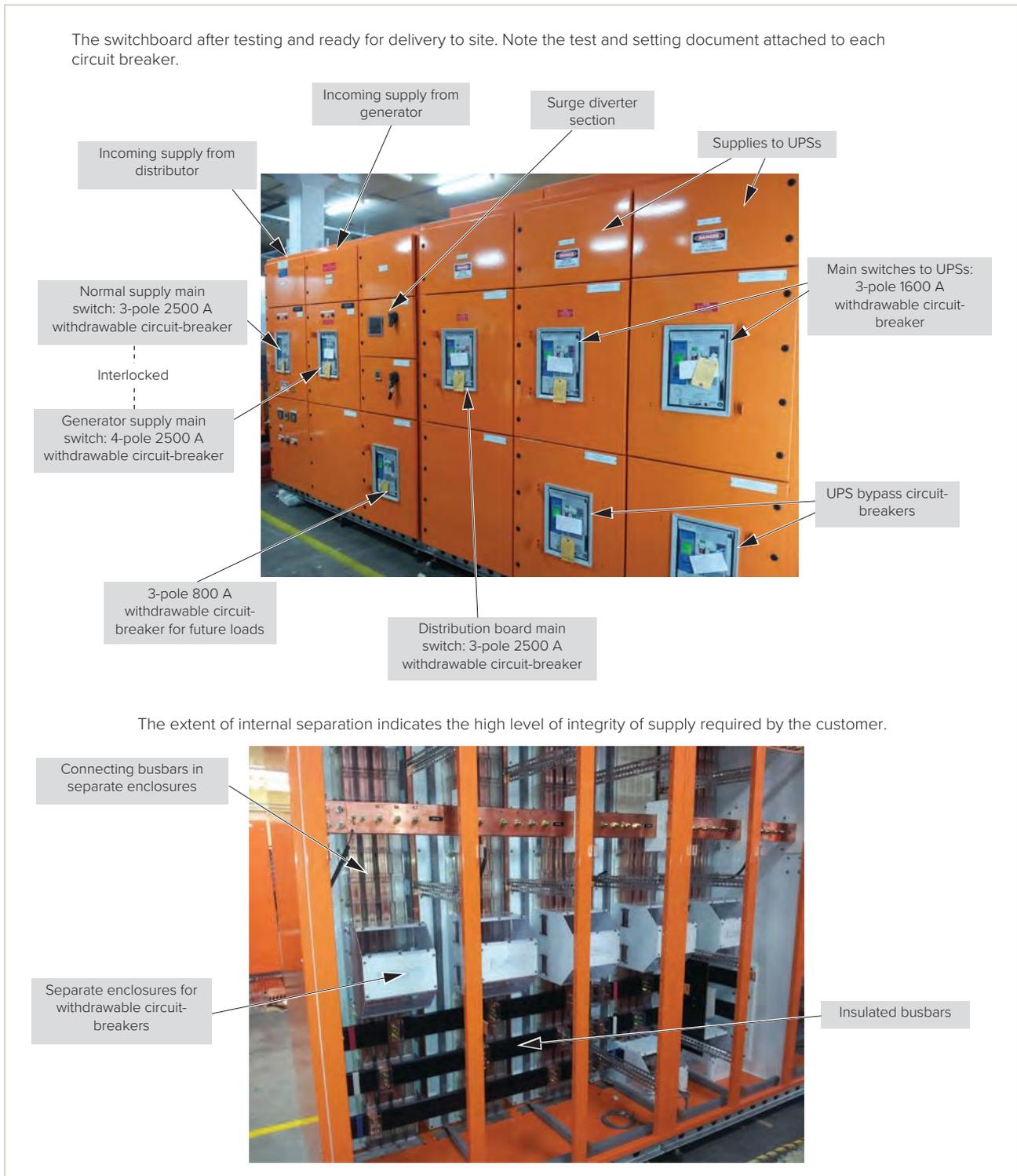


FIGURE 14.13 Switchboard for installation with 2500 A demand—design features

Fuji SMBE Harwal Pty Ltd

In summary, the switchboard types considered in this section can be broadly placed into three groups: those of small-to-medium ratings, those of relatively high ratings and those of extra-high ratings insofar as their demand and prospective short-circuit current capacities are concerned. Attention is drawn to the *Wiring Rules, Clause 1.7.3 Equipment selection* in purchasing a switchboard: as with any item for an electrical installation, the electrician/contractor must be assured that it complies with the relevant requirements. (In recent years some imported items have been found to not meet their claims of compliance.)



CHECK YOUR UNDERSTANDING

1. Using *AS/NZS 3000*, define *switchboard*.
2. How does a main switchboard differ from a distribution board?
3. What is a two-pole RCD and how does it differ from a single-pole RCBO?
4. Using *AS/NZS 3000*, list three requirements that must be considered when deciding on a location for a switchboard.
5. What is the major difference between a low-demand switchboard and a high-demand switchboard?

14.2 Applications of switchboards in the arrangement of electrical installations

As mentioned in the previous section, a switchboard may be a main switchboard or a distribution board fed by a submain from a main switchboard or other distribution board. Distribution boards are used in an installation primarily to avoid having unnecessarily long submain or final subcircuits and the problems of voltage drop that this would bring. Any of the switchboards discussed can be used as a main switchboard or distribution board.

Examples of common practices for switchboard use in the arrangement of installations are given in **Figure 14.14**. Note that, in addition to all other requirements, an installation must comply with local service and installation rules, as summarised in **Figure 14.15**.

Installations or portions of installations with low demand utilise the types of switchboards (as previously shown in **Figures 14.4** and **14.5**) which could be installed either as distribution boards or as the main switchboard of a small installation.

It is not useful to classify switchboards as either domestic or non-domestic. Many large houses and apartments require a switchboard that resembles those found in medium-sized commercial installations. The popularity of apartment living in recent years has resulted in the development of large high-rise apartment buildings. The main switchboards for these installations are similar to those for any high-demand high-rise building, with the need to provide arrangements for separate tenancies, safety services, air-conditioning and other plant equipment.

Each individual tenancy would then use a domestic- or consumer-type switchboard as a final distribution point for their own subcircuits. This will allow individual tenancies to manage their own environment without the need to access floor distribution boards. For instance, if a technician needs to isolate the electrical supply for service, the isolation device for that particular service would be in the tenancy, allowing for ease of operation and observation. This would prevent the need to access the larger distribution board for many tasks.

Installations are not considered to be compliant until properly documented. **Figure 14.16** shows an example of an underground mains supply to a main switchboard detailing the path the mains cable is installed to.

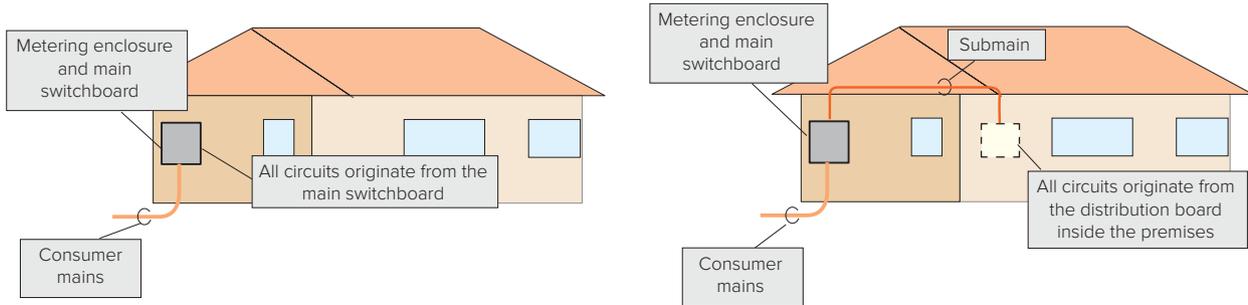


SAFETY ALERT

Modifying a switchboard that has been verified compliant with the *AS/NZS 61439* or *3249* series from its original design can easily render the assembly non-compliant and dangerous. A modification could be as simple as drilling through a separation barrier, so a hands-off approach should be taken when assembling and wiring or connecting these switchboards up.

Wiring Rules Clause 2.2 requires all circuits in an installation to originate from a main switchboard or distribution board. Distribution boards are used in an installation primarily to avoid having unnecessarily long submain or final subcircuits and the problems of voltage drop that this brings.

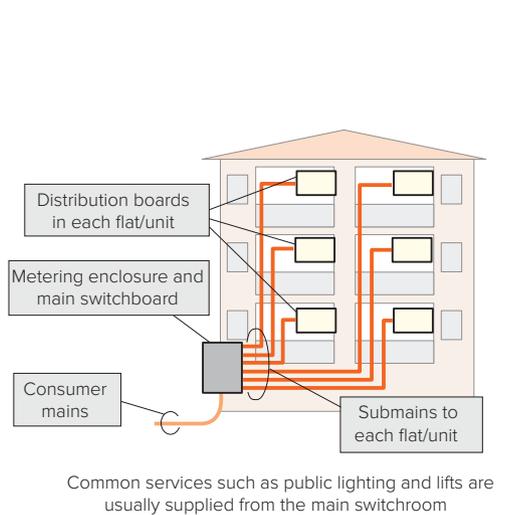
SINGLE-OCCUPANCY INSTALLATIONS



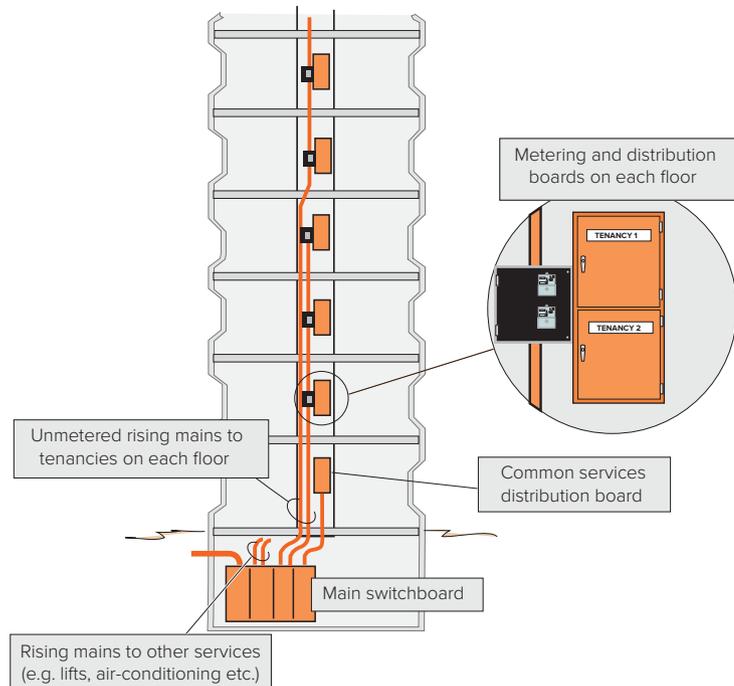
Alternative arrangement for single domestic premises

MULTIPLE-OCCUPANCY INSTALLATIONS

In multiple-occupancy installations the major factor determining the arrangement is the number of occupancies involved; for small installations having few occupancies, one main switchboard containing all of the metering, main switches and subcircuit protection may be installed at a central location. Other arrangements are shown below.



Multiple-occupancy domestic installation



Common services such as public lighting, lifts and air-conditioning are usually supplied from the main switchroom, which should be accessible from a public area.

Multiple-occupancy non-domestic installation

FIGURE 14.14 Examples of how switchboards are used in the arrangement of installations

14.3 Control panels

A control panel is essentially an assembly of switches and controls for the automatic and manual operation of appliances such as motors and ancillary equipment. In many instances, it is common for the functions of a control panel to be combined with protective devices for the circuits supplying the appliances and, in these cases, by definition it is a distribution board requiring compliance with *AS/NZS 61439*. **Figure 14.17** shows a basic diagram of a control panel.

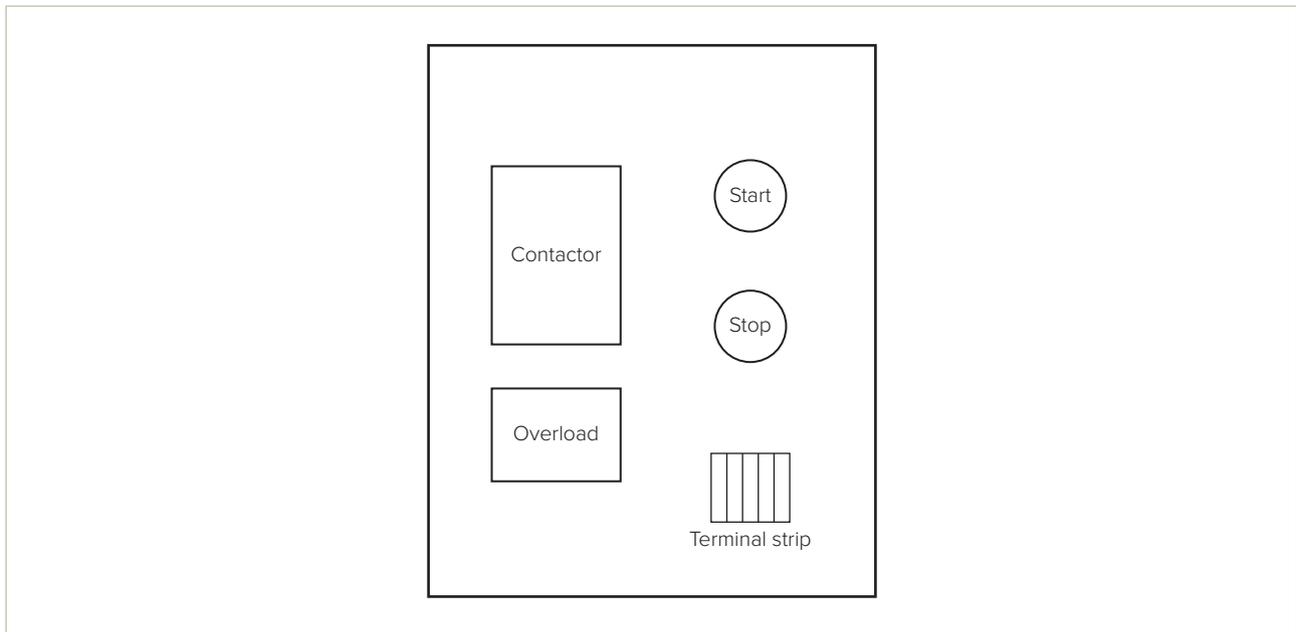


FIGURE 14.17 Basic outline of a control panel

You will notice the basic components needed to safely control a motor (e.g. a drill press): a start button, a stop button, a contactor (rated to handle the start-up current), terminal strips (to connect incoming and outgoing wires and for interconnects) and overloads (to prevent motor damage if an overcurrent situation is encountered). This system would then be installed into a cabinet or box suitable for the environment in which it will be used (i.e. for damp zones or mechanical-damage zones). This is where the use of IP ratings is helpful.

It is common to find a range of switches, push buttons, indicator lamps, circuit breakers, and meters on the outside of these panels; on the inside are relays, contactors, thermal overloads, timers and interconnections for wiring. An example of a simple motor stop/start station control system is shown in **Figure 14.18** and a motor control panel showing terminals and connections is shown in **Figure 14.19**. The design of a distribution board/control panel is the responsibility of a particular plant or control system specialist.

One common location for the combination control panel and distribution board would be in a pool control board. A board (with appropriate IP rating) would be combined with the various pump, filter and lighting circuits. This allows more convenient operation and service. The board is required to be wired in suitably sized submains to comply with *AS/NZS 3000*.

Distribution boards that incorporate a control panel can be encountered in small and large installations. Common applications in large commercial installations are monitoring and control of supply sources, integrated energy control, emergency alarm and evacuation systems and environmental control. In smaller installations, the use of energy-monitoring and integrated control systems is not uncommon. Some examples are given in **Figure 14.20**.

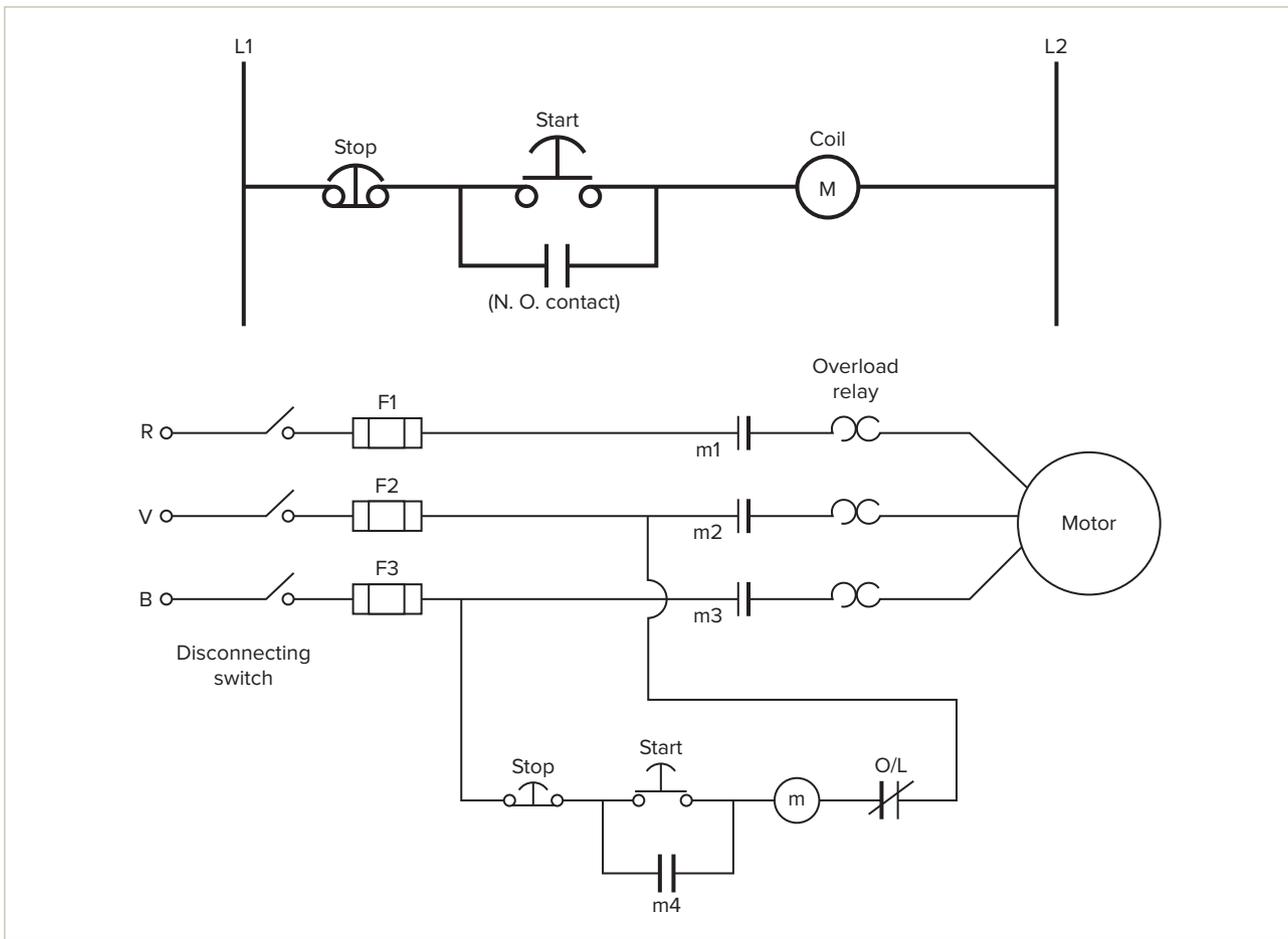


FIGURE 14.18 Simple three-phase motor control panel

Source: Adapted from Electrical Topics, <https://electricaltopics.blogspot.com/2014/11/direct-on-line-starter.html>

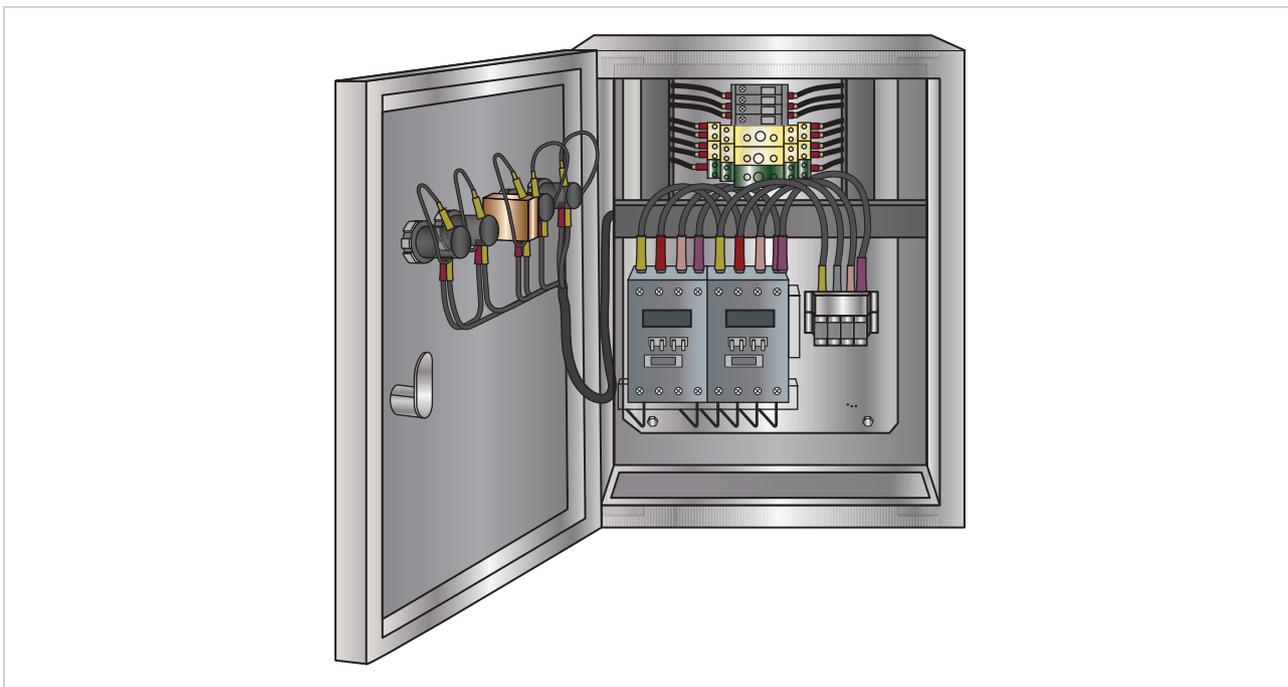


FIGURE 14.19 Motor control panel showing terminals and connections

It is common for a control panel to be incorporated in a switchboard.
 Although often referred to as a control panel, this arrangement is by definition (Clause 1.4.121) a switchboard.

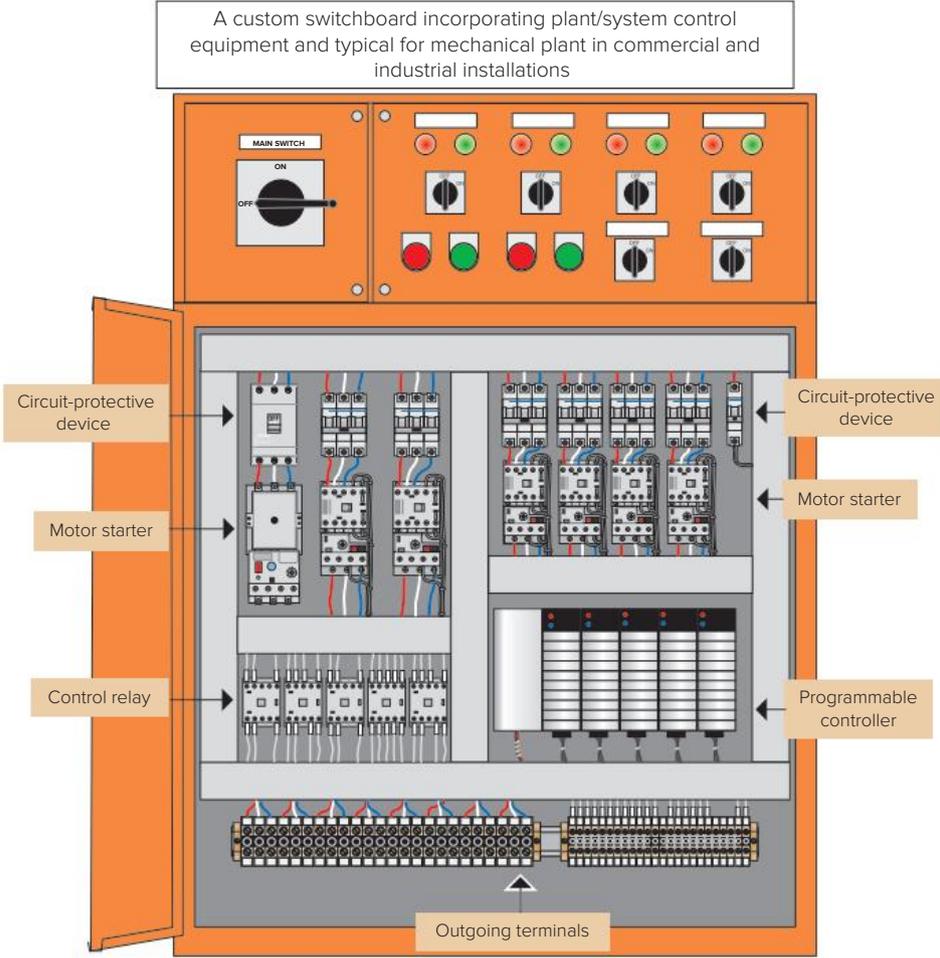
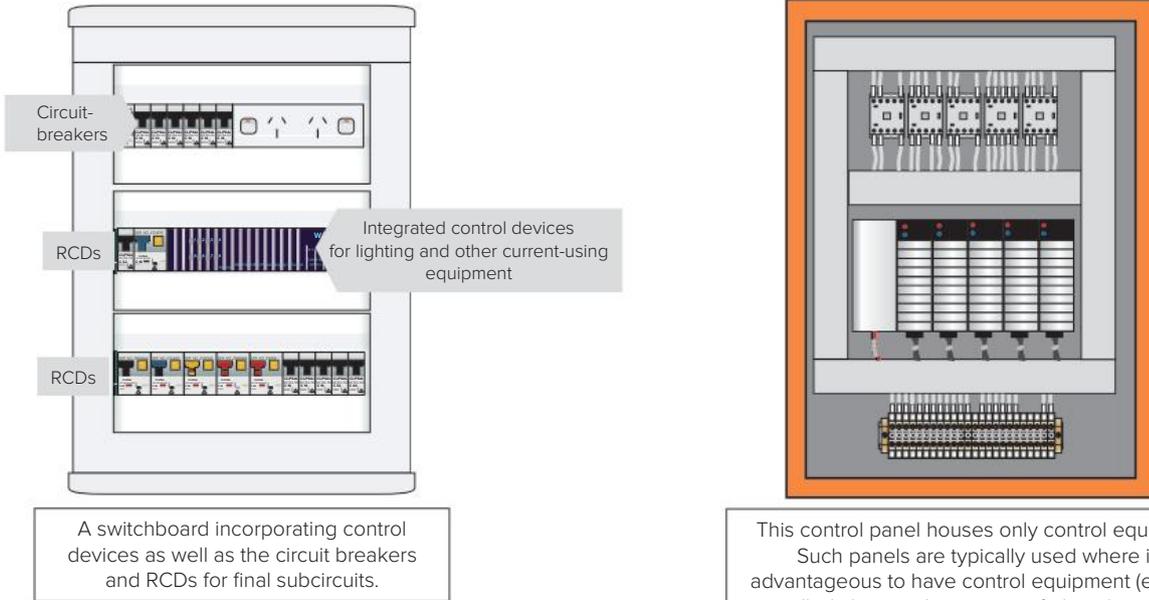


FIGURE 14.20 Examples of distribution boards/control panels



CHECK YOUR UNDERSTANDING

7. Identify why and where a control panel may be used.
8. List some components that could be found on the outer surface of a control panel and some components that could be found within the control panel.
9. Using standard drawing conventions, draw a circuit diagram for a simple motor control system.

14.4 Electrical energy markets and metering

14.4.1 Electrical energy markets

Electrical energy in eastern and southern Australia and in New Zealand is sold to end-users under competitive marketing systems. These systems have evolved in recent decades due to changes in government energy policies since the early 1990s. Electricity retail companies compete to supply energy to customers in their local areas, commonly under a negotiated market contract or, in some circumstances, a regulated price. The negotiated prices will depend on projected annual consumption and such factors as whether time-of-use (off-peak) appliances are used and whether a renewable energy source feed-in applies.

There are some variations across jurisdictions; for example, Western Australia and the Northern Territory are not connected to the eastern-southern electricity network. The increased prevalence of *prosumers* (producer + consumer) feeding electricity to the grid from renewable energy sources such as photo-voltaic (PV) arrays adds another dimension to the electrical energy market. See www.aer.gov.au/consumers/who-is-my-distributor for a current listing of Australian distributors. In Australia, the electricity market is governed under legislation and the National Electricity Rules (NER) through the Australian Energy Market Commission (AEMC) and is managed by the Australian Energy Market Operator (AEMO). New Zealand has similar arrangements. The NER include a range of requirements for metering of energy and provide secure arrangements for energy retailers and their customers to engage fairly in the selling and buying of electrical energy.

The focus here for the electrician is the metering arrangement needed for a given installation. An electrician is not permitted to install energy revenue meters unless accredited under the NER to do so. However, providing an enclosure with suitable space and mountings for metering equipment and pre-wiring between the locations for service protection devices, meters and other accessories are the responsibility of the installing electrician. These requirements are specified in local service and installation rules (see **Figure 14.15**) or in a distributing authority's metering installation documents. It is a requirement that the mounting and connection of electricity meters are carried out by a qualified and accredited meter installer.

14.4.2 Energy metering

Electricity charges generally have two components: one covers the cost of making supply available, which is independent of energy consumption, and the other is based on energy use and typically has several scales. Commonly for domestic customers, there is a basic tariff and a time-of-use tariff (of a lower rate, to encourage greater use of energy outside peak-load periods). An example of an electricity bill is shown in **Figure 14.21**.

The standard unit of measurement of energy in the SI system is the joule (J), or the watt-second (W-s). The joule is a very small unit of energy and so is not a practical commercial unit of electrical energy. The kilowatt-hour (kWh) is often used to measure commercial quantities of electrical energy and the meter used for its measurement is the kilowatt-hour meter.



MR JOHN MACARTNEY
12 TAYNISH AVE
DOUBLE BAY NSW 2140



Electricity

Your electricity bill

19 Feb 24 - 18 May 24

Amounts include GST unless otherwise specified

YOUR ACCOUNT DETAILS	DUE DATE	AMOUNT DUE
Account number 300 000 000 000 Tax invoice 155 001 857 645 Issue date 19 May 24 Total amount due \$177.48	8 Jun 24	\$177.48

YOUR USAGE SUMMARY		Thinking of changing plans? Based on your past usage, our new plan may cost you up to \$169.44 less per year than your current plan. Cost estimated at this bill's issue date. Plans are subject to change at any time.
Average cost per day \$3.95 Average daily usage 13.86 kWh Same time last year 15.14 kWh Your indicative greenhouse gas emissions Total for this bill 1.4 tonnes Same time last year 1.6 tonnes Saved with GreenPower N/A	8.45% decrease in usage since last year   15.14 kWh LAST YEAR  13.86 kWh THIS YEAR	

Faults and emergencies

13 11 22
Call Energy Emergencies 24 hrs

Help and support online

Got a question about your bill?
Call **1800 245 963**

HOW TO PAY

DIRECT DEBIT

Register online to arrange automatic payment of future accounts*

VISA OR MASTERCARD®*

Call **1300 000 000**

MAIL

Send this slip with your cheque made payable to: Electricity Holdings Limited, PO Box 2000 SYDNEY NSW 2000

IN PERSON

Pay at any Post Office**

TELEPHONE & INTERNET BANKING - BPAY®

Contact your bank or financial institution to make this payment from your cheque, savings, debit, credit card* or transaction account.

More info: www.bpay.com.au

FIGURE 14.21 Example of electricity bill showing amount of energy used in kilowatt-hours

EXAMPLE 14.1

3600 seconds is equal to 1 hour.

1000 W is equal to 1 kW.

A 1 kW load left powered for an hour would consume 1000×3600 W-s, which is 3.6 MW-s.

Higher demand customers (who use more than 160 megawatt-hours (MWh) per year) have another component built into the tariff structures, one based on demand. Maximum demand is measured in kVA or kW and encourages users not to have numerous high-demand loads on at once if loads can be organised to sequence their operation, minimising the peak load within the peak period. The demand component of a tariff is required to be measured by an interval meter.

14.4.3 Energy meter types

The NER, under the AEMO procedures, specifies a number of types of metering installations, in essence to assist the roll-out, over time, of smart meters. These metering installation types are designated as follows:

- ▶ Type 1–4 meters have the following characteristics: electronic operation; capability to record energy consumption in NER market intervals and inclusion of communications equipment to permit their reading from a remote location.
- ▶ Type 5 meters are meters that are manually read and have the capability to record in NER 30-minute market intervals.
- ▶ Type 6 metering installations are meters that are manually read, may be electronic or electro-mechanical, and are capable of recording *cumulative* electrical energy consumption only (the electromechanical type is gradually being phased out).

Figures 14.22 and 14.23 show some obsolete electricity meters and the smart meters that are replacing them. Figure 14.4 also shows an electronic smart meter in use in Victoria.

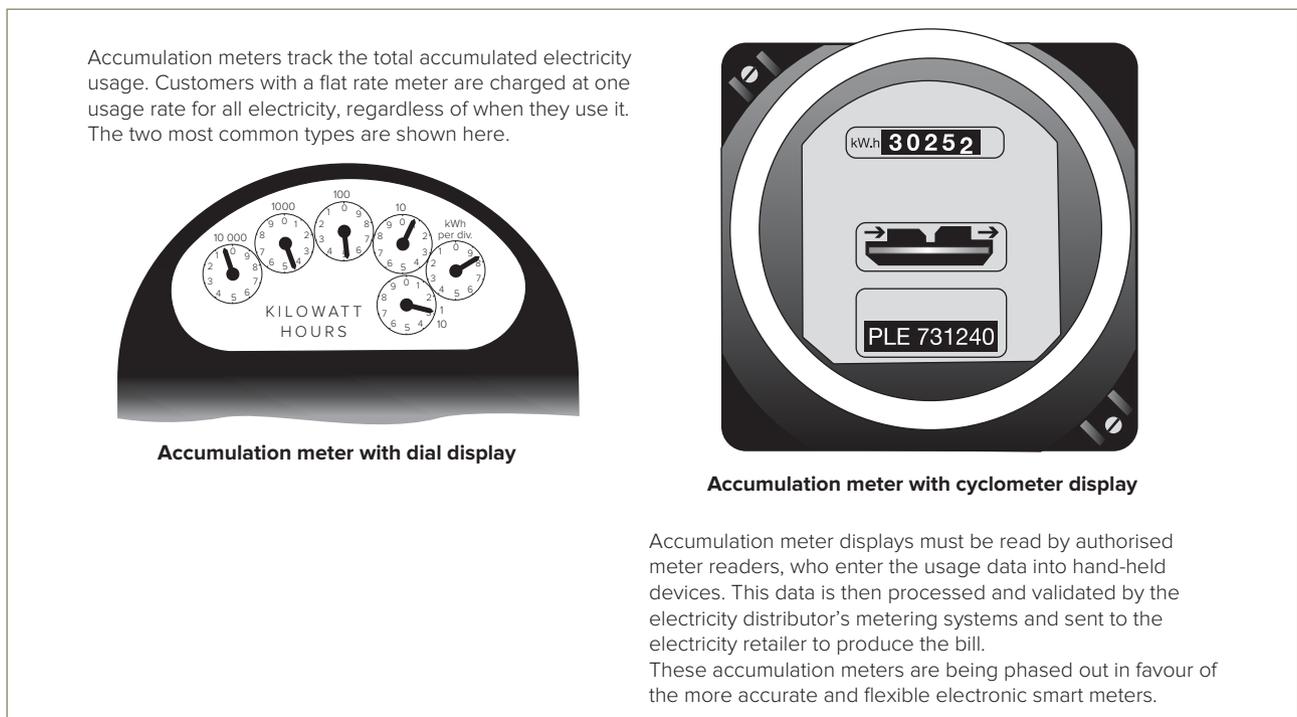


FIGURE 14.22 Examples of the older accumulation meters that are being replaced by smart meters

This single-phase smart meter is a more sophisticated alternative to the electromechanical meter shown in **Figure 14.22**. The meter is compliant for half-hour interval metering and time-of-use (ToU) tariffs with load profile recording for use by retailers in contestable markets.

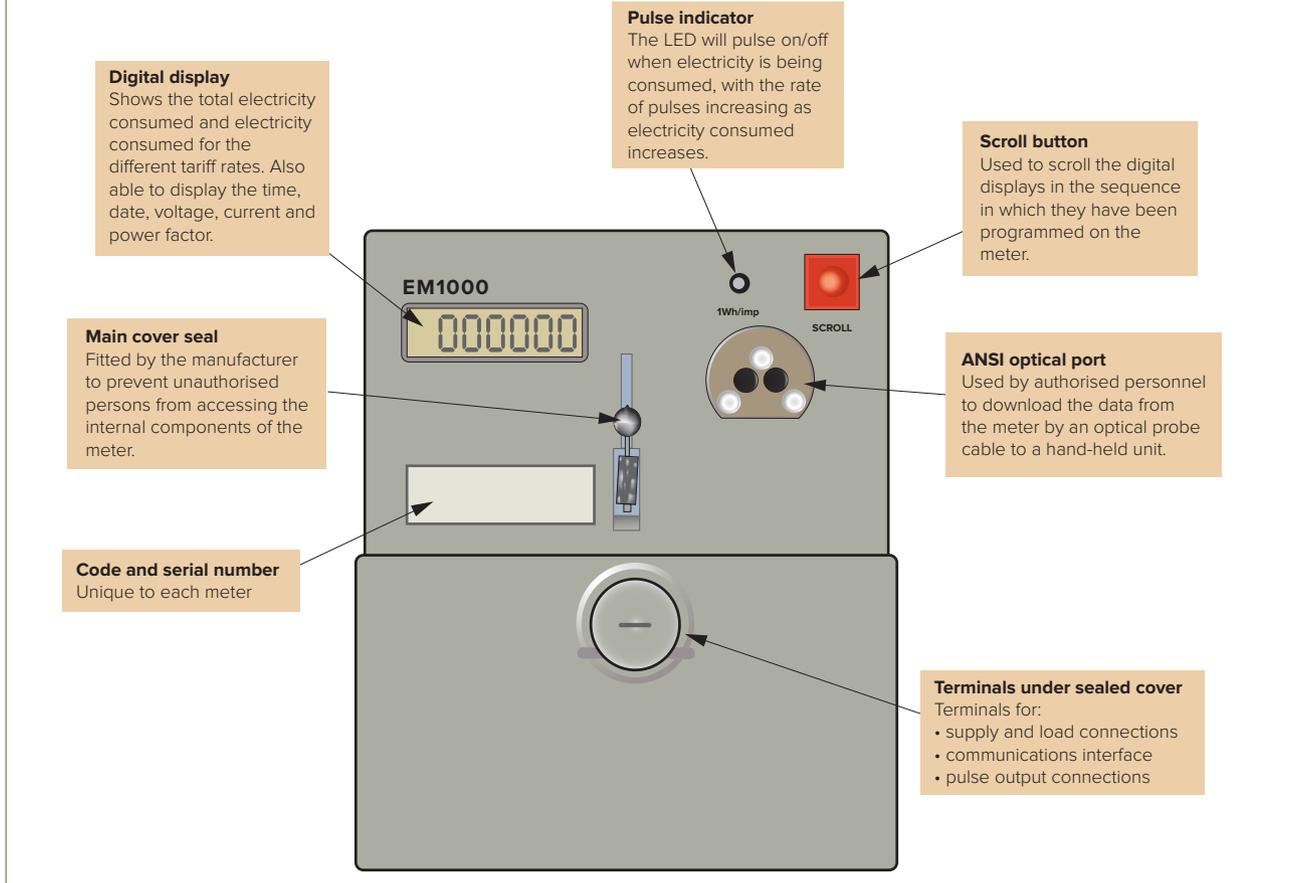


FIGURE 14.23 An example of an electronic smart meter



CHECK YOUR UNDERSTANDING

10. Identify your local distributor of electricity.
11. Using your electricity bill, locate the tariff type, kWh usage and charge per kWh.
12. List the features of Types 1 to 5 electronic meters as determined by the NER.

14.5 Energy metering arrangements

Energy meters in current use are all much the same in terms of principles, operations and connections. They have functions and accuracy that are compliant with energy-meter standards. Design details may vary among manufacturers, but their basic electrical similarity ensures that electrical connections have a fairly standardised format. A meter's location in the electrical supply circuit may differ due to the differing service arrangements and tariffs of providers, so their installation requires reference to the service rules, tariff information and metering diagrams of the local energy provider or retailer. As previously mentioned, metering is commonly installed at the mains switchboard, as shown in **Figure 14.24**.

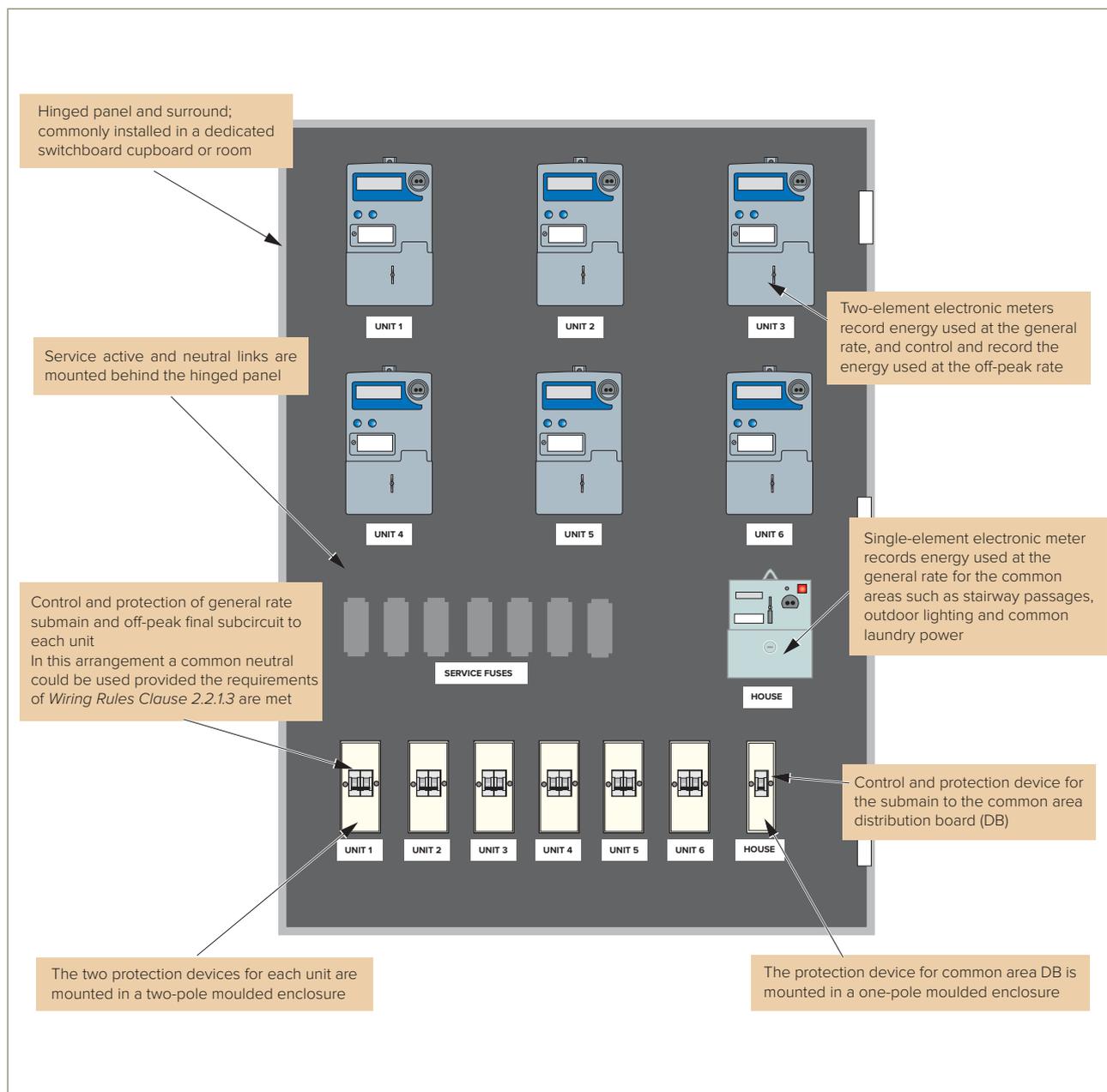


FIGURE 14.24 Main switchboard arrangement for small multi-domestic installations

14.5.1 Whole-current metering

In some jurisdictions, the induction-disc meters that are now being replaced by electronic meters are wired to a plug-in base. The electronic meters depicted in the following figures are of the hard-wired, bottom-connected type. These types of meters are typically used for loads less than 100 A per phase, as the mains cables are connected so that the full-load current goes through the meter measuring system before being distributed via the switchboard.

Each state and territory in Australia will have different connection and installation requirements. The electrician working in the different states will need to be familiar with these peculiarities, especially if they are involved with initial installation of supply.

Figures 14.25 to 14.31 illustrate a number of different metering arrangements that can be produced from the same basic principles, and these figures will be useful for reference. You should, however, set out to understand these principles, rather than attempting to remember all the metering arrangements in detail.

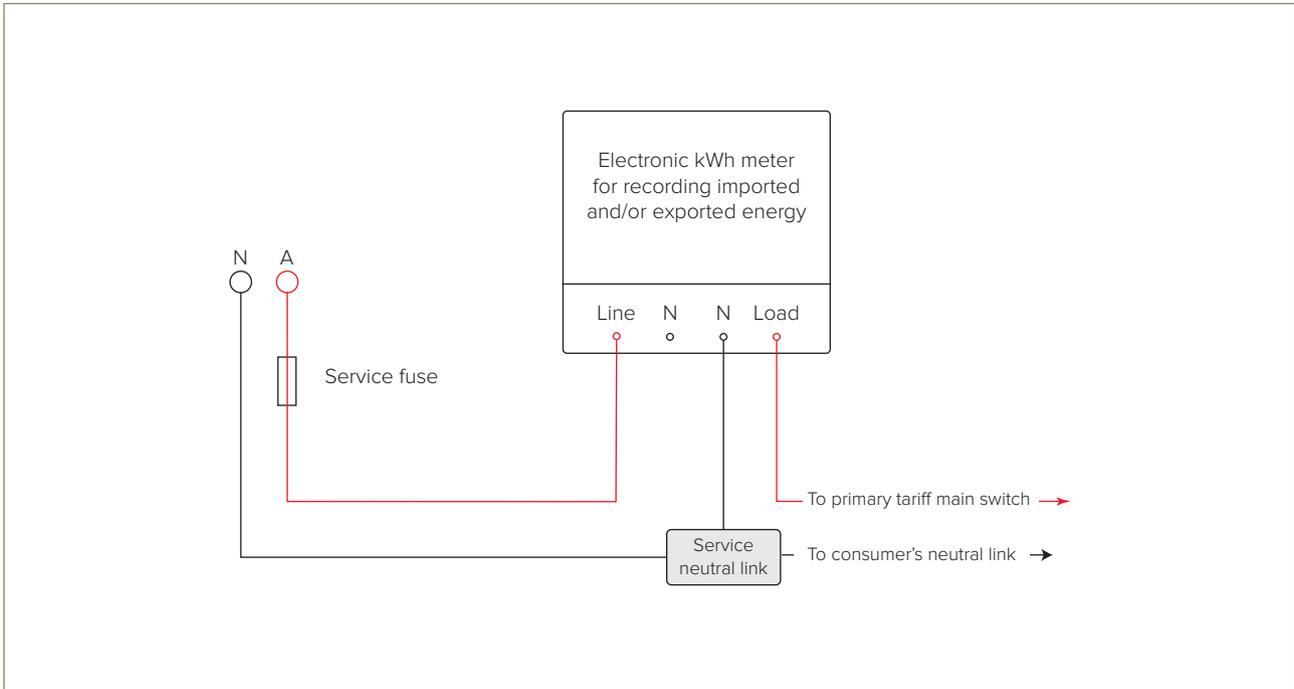


FIGURE 14.25 Single-phase single-element electronic meter

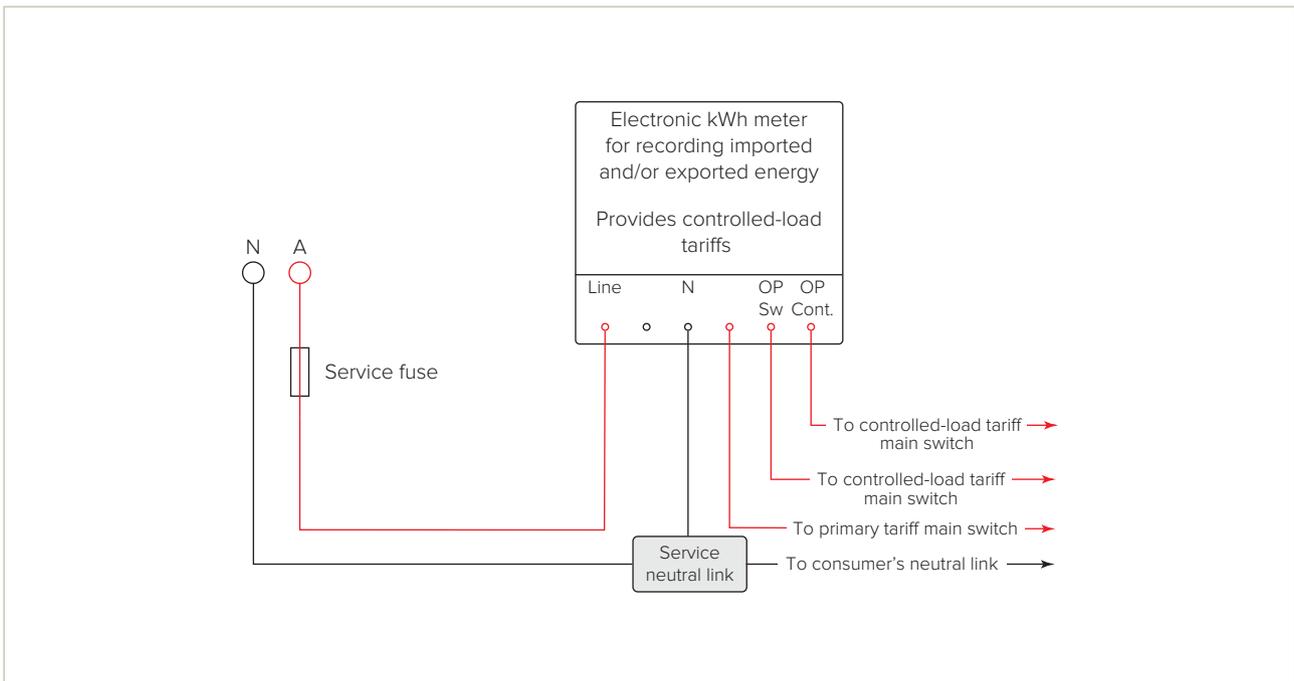


FIGURE 14.26 Single-phase dual-element electronic meter with controlled load facility

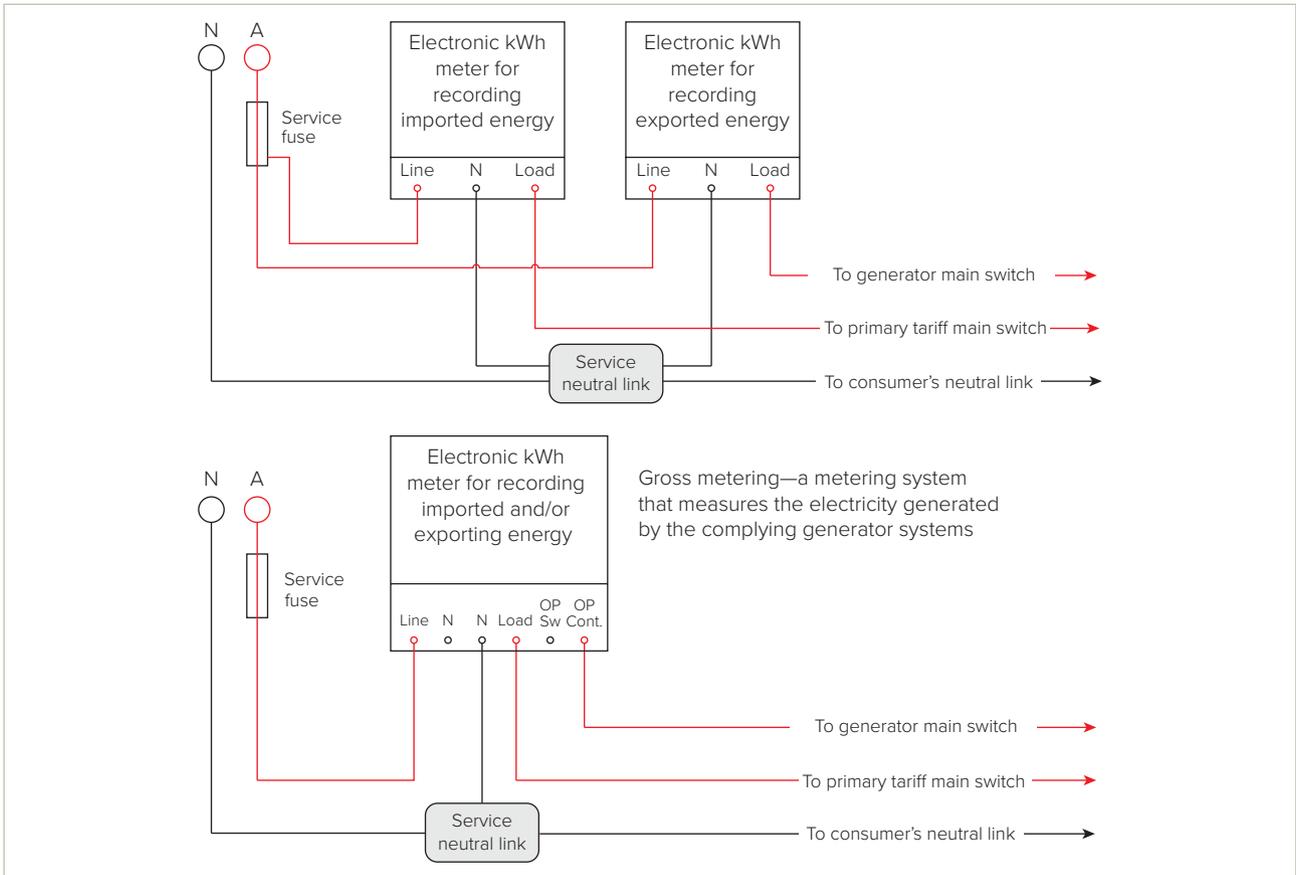


FIGURE 14.27 Gross metering arrangements

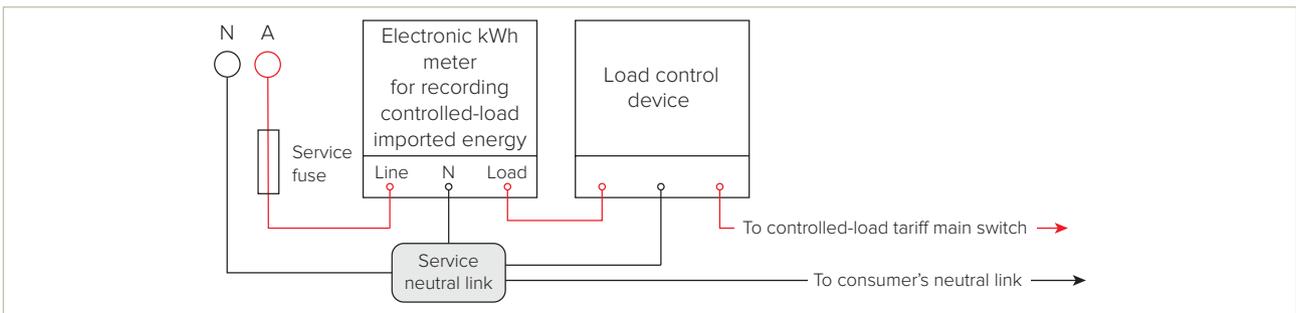


FIGURE 14.28 Single-phase metering with controlled load device

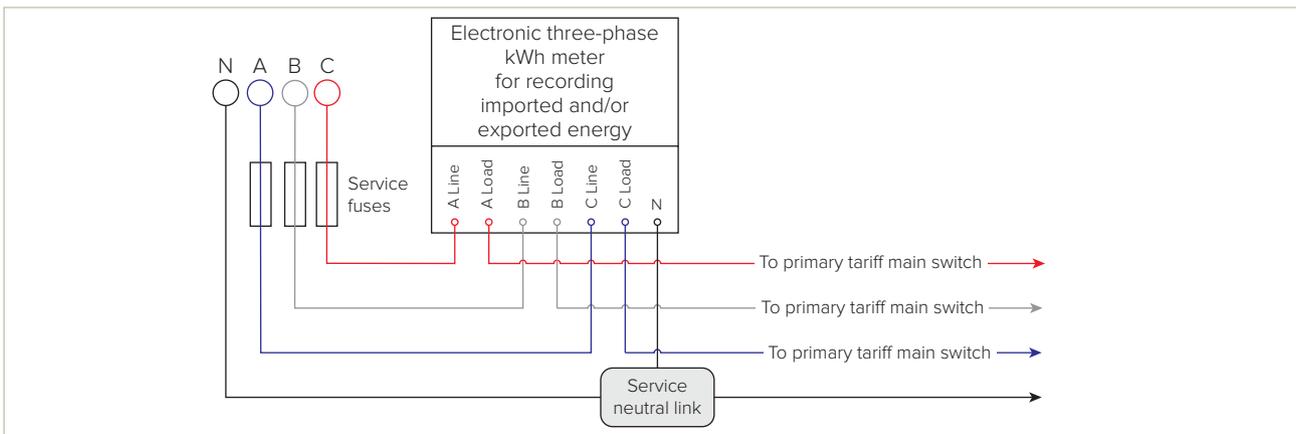


FIGURE 14.29 Three-phase electronic meter for recording imported and exported energy

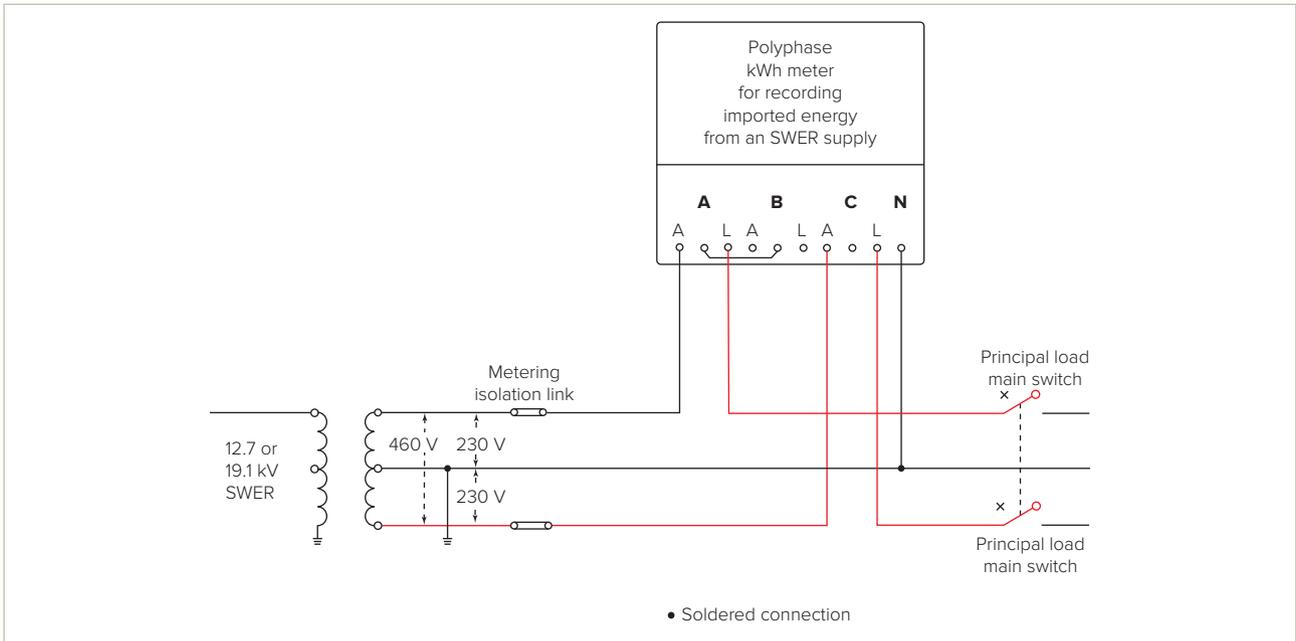


FIGURE 14.30 Metering an SWER installation

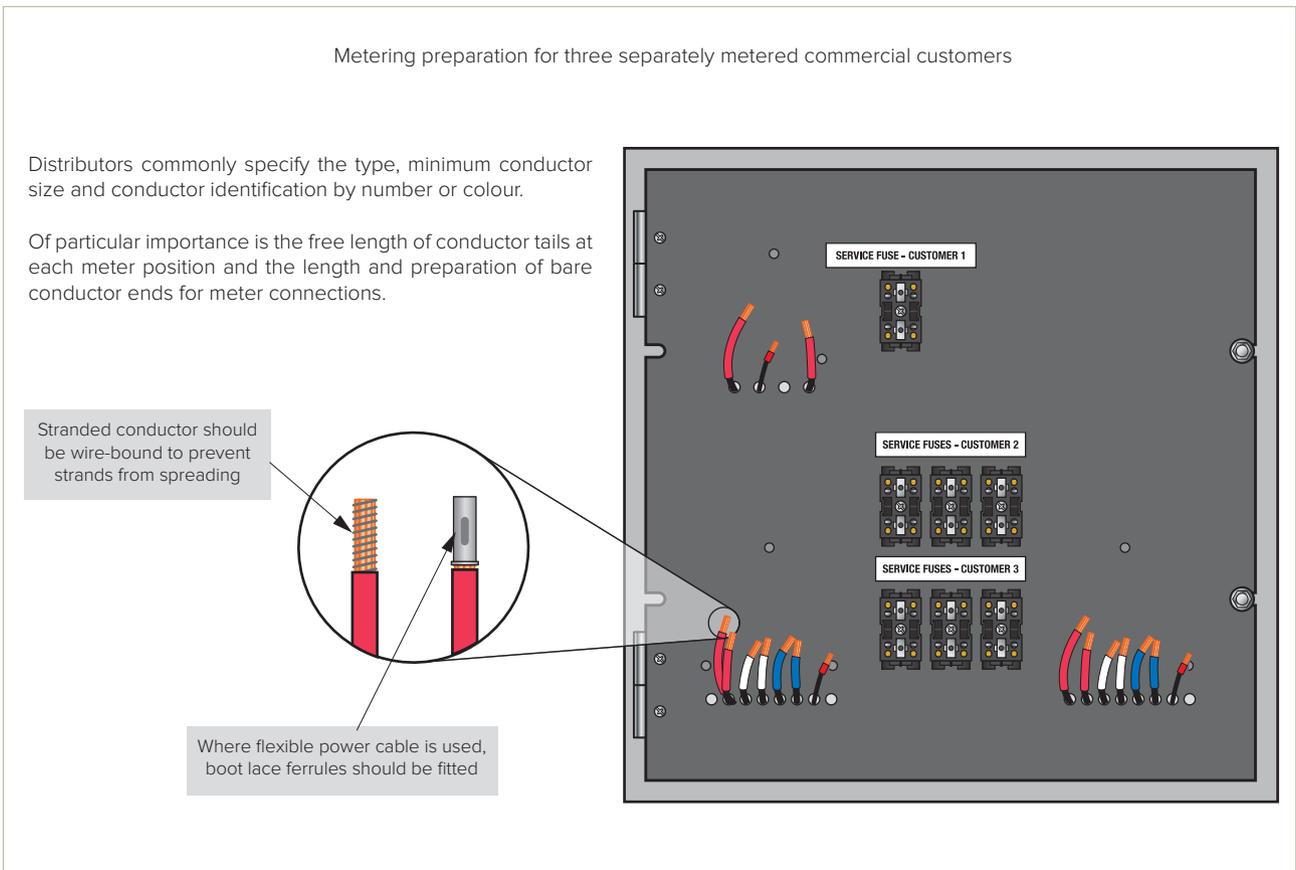


FIGURE 14.31 Preparation for meters to be mounted and connected

This type of metering arrangement is common when an off-peak electric hot-water system is also being used. A common switchboard arrangement, using the three active feeds (primary tariff, off-peak load and off-peak controlled load (booster)), its wiring would resemble the layout shown in **Figure 14.32**.

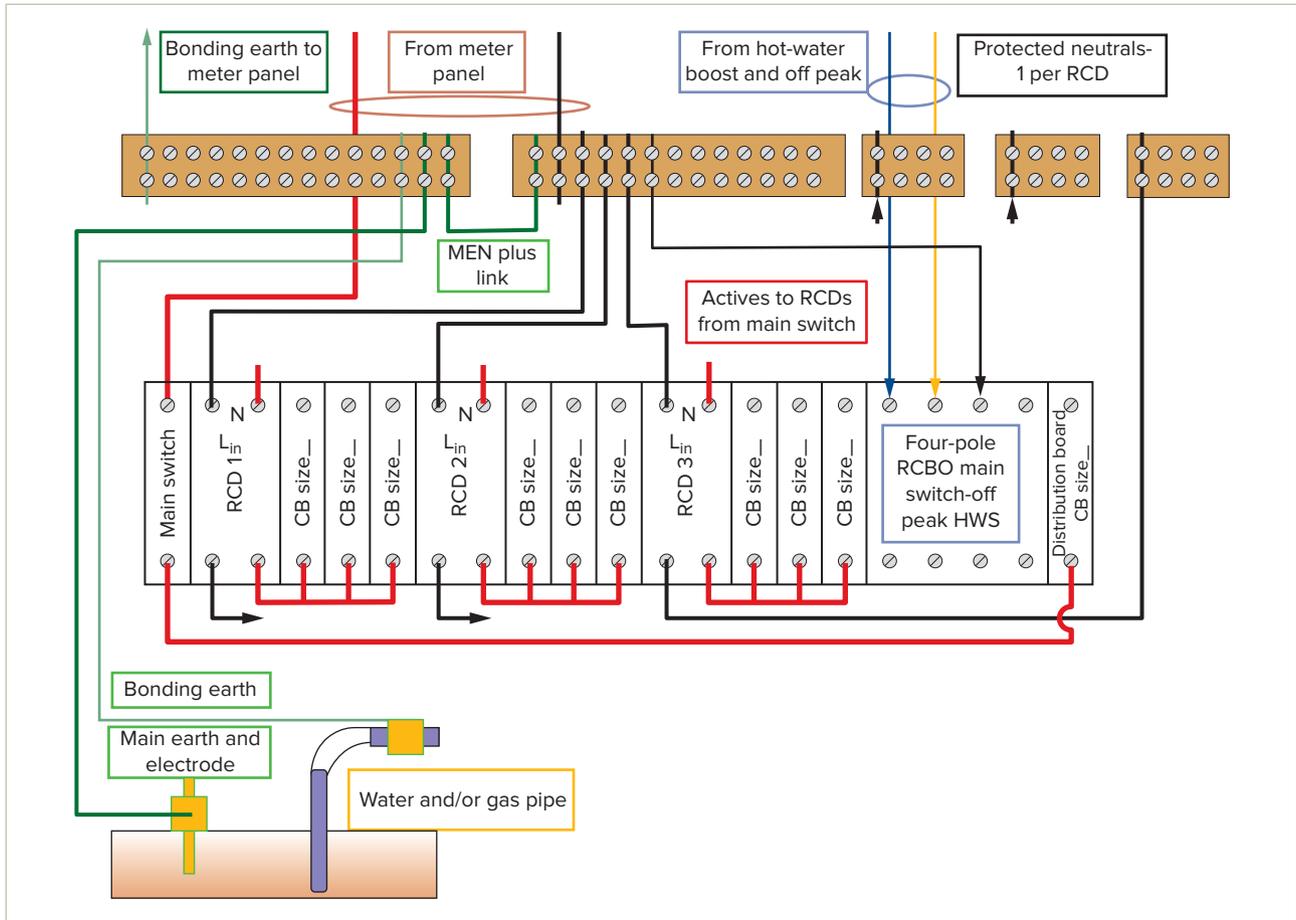


FIGURE 14.32 Common switchboard arrangement using controlled load (off-peak) supply; note the use of a four-pole RCBO for the hot-water service

NOTE: This wiring diagram will vary depending on the wiring codes in place at the time. However, the hot-water service will still require RCD protection. This arrangement will profit from the use of combination CB/RCD (RCBOs) in space savings and wiring complications.

In multi-occupancy buildings, where there are many changes in tenancy and the areas occupied by customers, it is usual to provide meter-paralleling links in order to facilitate the metering changes that are caused by the tenancy changes. Where the multi-occupancy is permanent or where there is little likelihood of the metered areas changing even if a change in tenancy occurs, there is no need for meter-paralleling links. However, the multiple meters to be installed may require active and neutral links (metering links) for metering connections. The position and arrangement of the meters will vary; a typical location for them would be adjacent to the main switchboard in the main switchroom. Alternatively, the meters could be fed by unmetered rising mains to an upper floor level, as depicted previously in **Figure 14.14**. Becoming more common in larger developments, the building management can be accredited through AEMO to sell energy to tenants or owner-occupiers in what is known as an embedded network. It is usually necessary to consult the appropriate distributor/retailer to obtain information about the layout and connections of meters to comply with the retailing requirements.

14.5.2 Use of instrument transformers

Instrument transformers are required in the metering circuits of high-current and/or high-voltage (HV) installations, where they are more commonly referred to as metering transformers. The use of voltage or potential transformers (PTs) is necessary in HV installations to isolate the high voltage from the metering equipment where HV

current-using equipment is used. PTs are not necessary for low-voltage installations, as standard meter types employ potential elements of suitable rating, usually 230 V.

Current transformers (CTs) are necessary in HV metering for isolation purposes, regardless of the value of load current. In low-voltage (LV) installations, CTs are required where the load current exceeds the whole value typical of energy meters and as specified by the distributor, typically 100 A.

Although the operating principles for your electrical theory work have been covered, the basic theory of the operation of transformers as applied to metering work should always be kept in mind, as recalled in **Figures 14.33** and **14.34**.

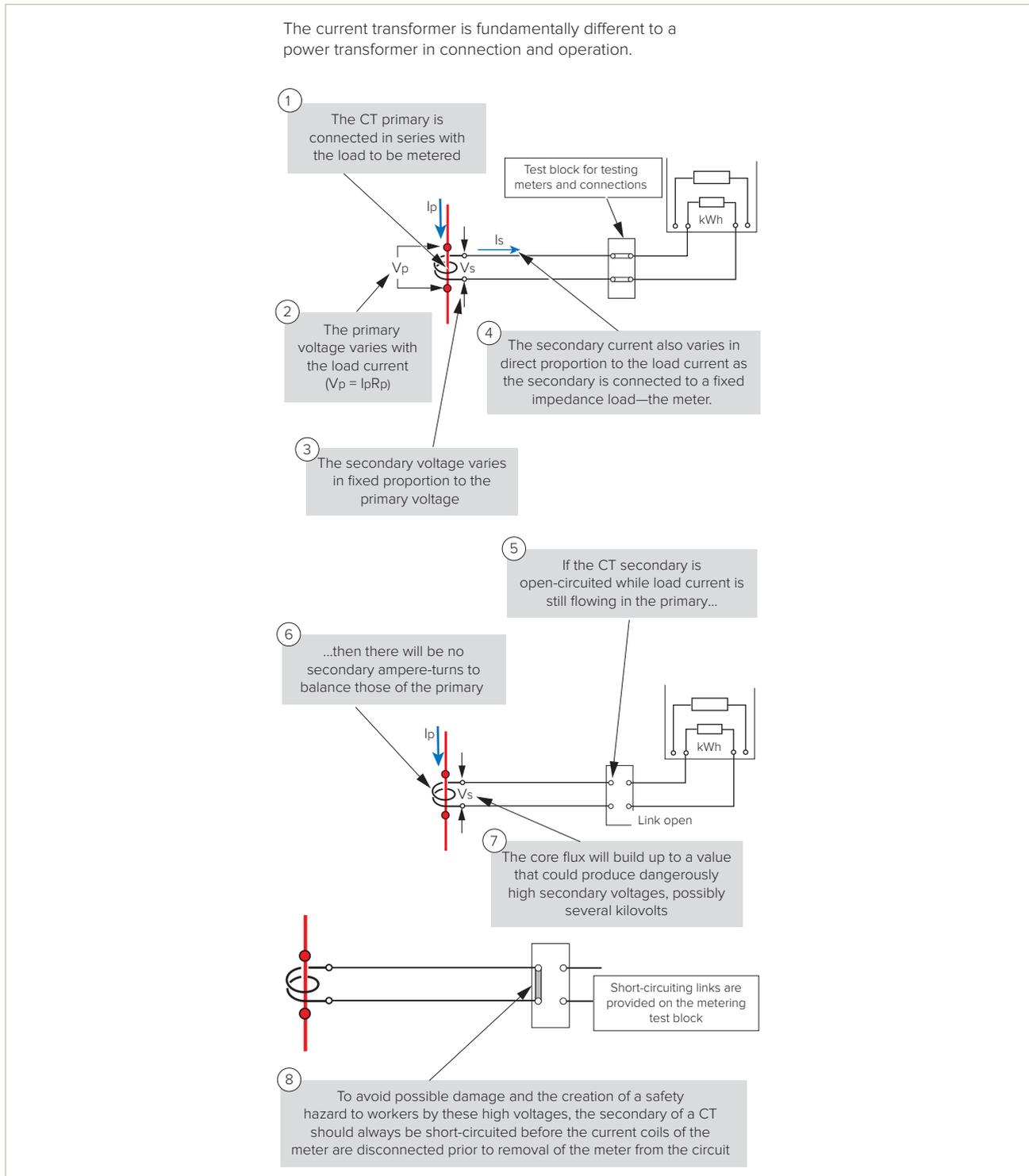


FIGURE 14.33 Basic operating principles of instrument current transformers

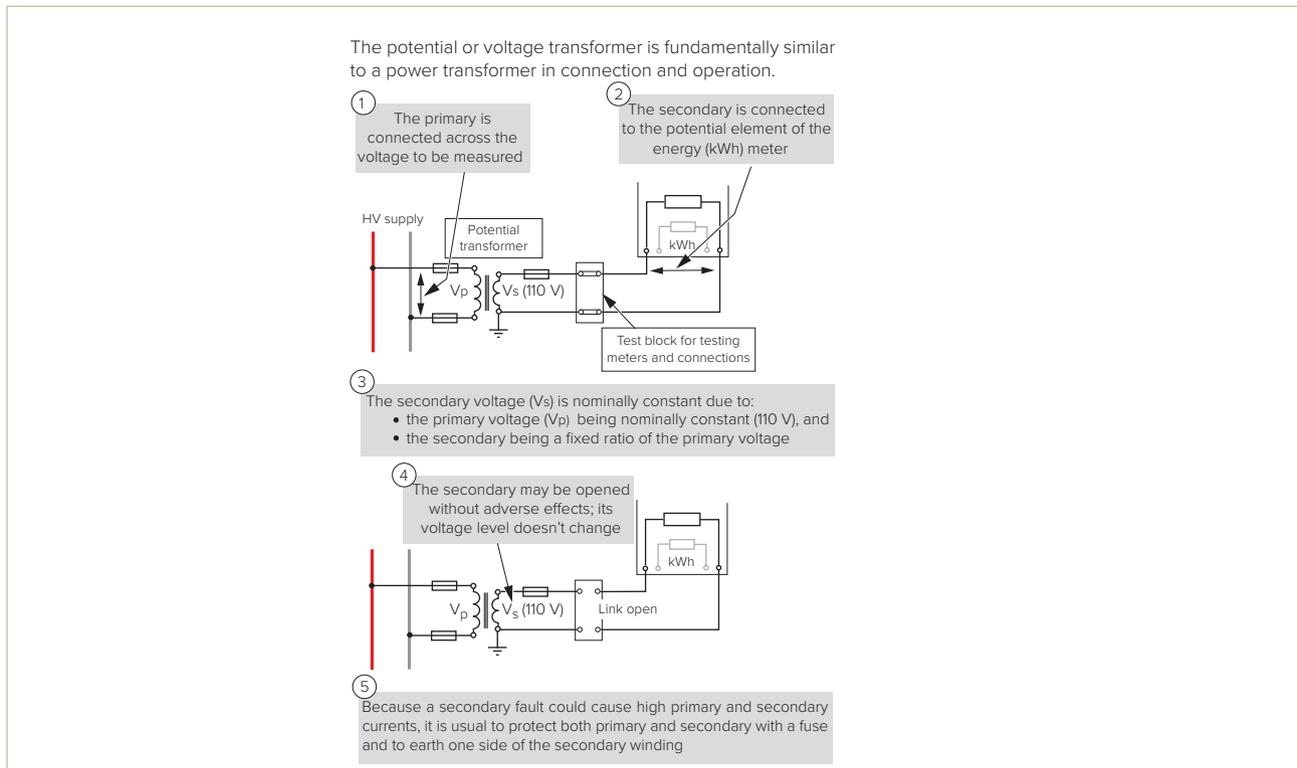


FIGURE 14.34 Basic operating principles of potential or voltage transformers

The most common use of current transformers for metering is in LV higher demand installations and so electricians need to be familiar with providers' requirements, as well as some important hazards and safety issues associated with CTs. In general, service and installation rules specify such things as: the arrangement for mounting CTs and accessories; minimum clearance between meters and conductors carrying high values of current, to prevent the magnetic fields produced by those currents affecting the metering; the type, size, identification and method of installation of meter wiring; and the use of metering test blocks and the like (see **Figures 14.35** to **14.37**).

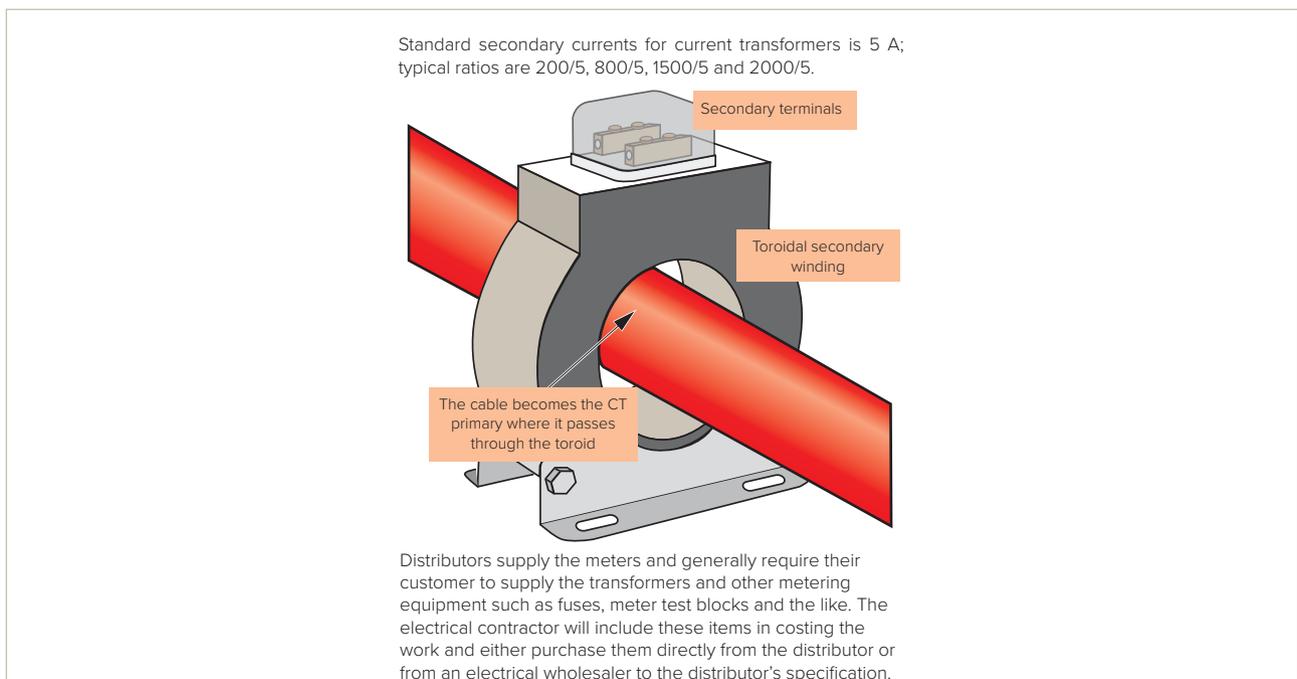


FIGURE 14.35 Typical surface-mounted metering current transformers

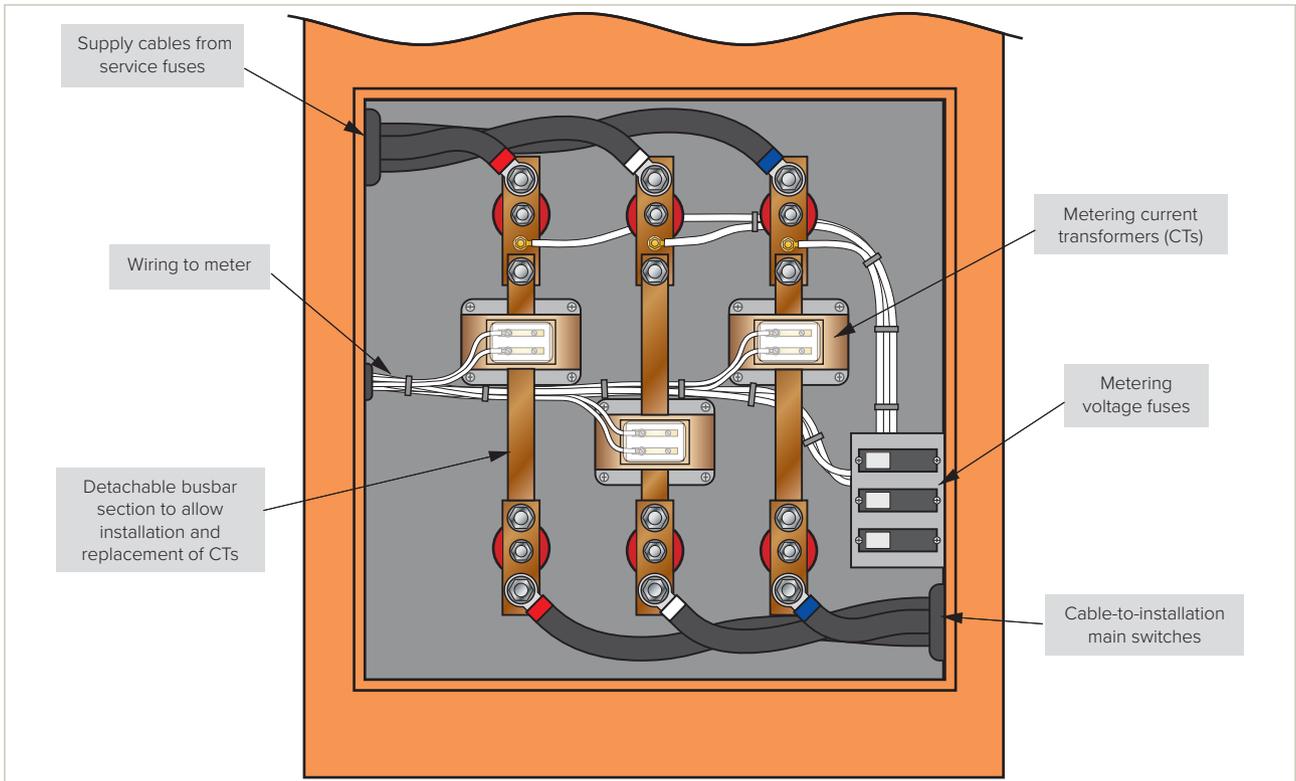


FIGURE 14.36 Arrangement for instrument transformers in a custom-built switchboard

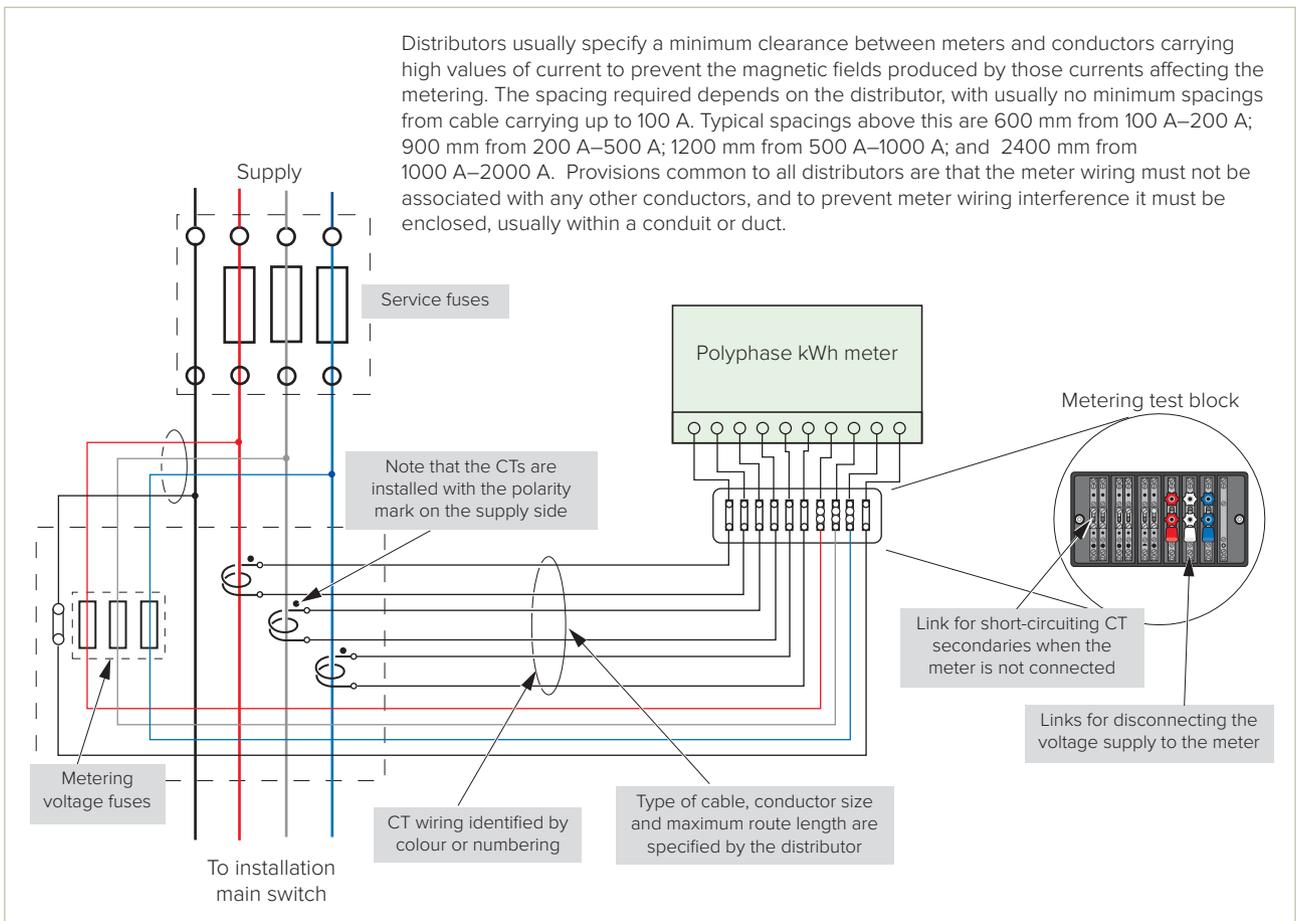


FIGURE 14.37 Metering three-phase load-using current transformers and one polyphase meter

Although the electrical circuitry is the same, the arrangement and actual methods of connection between meters and CTs both depend on the local distributor.

These figures have been included to illustrate the principles involved in metering connections. Distributors, however, provide actual wiring diagrams for metering both for reference and for use within their particular supply areas.



CHECK YOUR UNDERSTANDING

13. What type of metering is required where the assessed load of an installation or portion of an installation to be separately metered exceeds 100 A per phase?
14. Draw a wiring diagram showing the metering arrangement for a single-phase customer with controlled (off-peak) load.
15. Using the local service and installation rules, list the requirements for the installation of metering transformers.

SUMMARY

- ▶ Switchboards and distribution boards must comply with *AS/NZS 3000* for components, locations and circuit arrangements.
- ▶ Switchboards and distribution boards can be loosely categorised as small-to-medium, relatively high and extra-high.
- ▶ Small-to-medium demand switchboards are commonly located in domestic facilities.
- ▶ Control panels are used where local control of appliances and services are needed.
- ▶ Control panels can be combined with distribution boards.
- ▶ The energy market is divided into many local areas.
- ▶ Energy metering is carried out via the electricity retailer's smart meter.
- ▶ There are a variety of metering arrangements available according to the different loads and supplies.
- ▶ Whole current metering is usual for loads less than 100 A per phase.
- ▶ Instrument transformers are used when high currents and/or high voltages are being monitored.

REVIEW QUESTIONS

1. Draw a single-line diagram for a single domestic switchboard. See **Figures 14.5** and **14.26**.
2. List the features by which switchboards are classified in *AS/NZS 3439*.
3. Define the term *form* when related to switchboards.
4. Describe *type testing* when related to switchboards.
5. List the three essential requirements of *AS/NZS 3000* relating to the selection and installation of electrical equipment.
6. Using the local service and installation rules, list the requirements for the installation of metering transformers.
7. Create a wiring diagram for a typical CT metering installation.
8. Using *AS/NZS 3000*, list two Standards that switchboard assemblies must comply with.
9. If a 3kW load is left operating for three hours, how much energy will it consume (in kWh)?

CHAPTER 15

Testing techniques and compliance verification

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ develop a risk management plan for a given electrical testing activity
- ▶ explain the terms *open circuit* and *short circuit* in relation to an electrical fault
- ▶ apply continuity testing using a variety of testing devices
- ▶ list the situations where an energised test is necessary
- ▶ explain the principles by which a clamp meter measures current
- ▶ use a variety of devices to measure electrical quantities
- ▶ apply the *Wiring Rules* requirements for verifying that an installation complies with Standards and is safe to use
- ▶ explain the requirements for safety testing of appliances
- ▶ describe the process for finding electrical faults and their causes
- ▶ describe the types of instruments used to measure power quality and locate faults in power systems.

During the installation of wiring and equipment, tests are carried out from time to time to check the circuitry and the condition of the installation, avoiding or reducing the need for costly repairs or adjustments later. Once the installation is complete and prior to its connection to the supply, final testing and inspecting are a requirement of regulations and assurance of quality of an electrician's work. An existing installation needs similar testing periodically or whenever routine maintenance checks are made.

If a section of wiring or equipment develops a fault while in service, it becomes necessary to commence test procedures immediately to locate and isolate the fault. Tests are required again after repairs or additions to an installation.

15.1 Testing safety

As with many activities involved in electrical work, control measures to limit the risk of death or injury must be followed when testing electrical circuits and equipment. Testing de-energised circuits and equipment is obviously safer than testing with them energised, and some tests, such as an insulation-resistance test, can be performed only with the supply de-energised. Many faults in circuits and equipment can, theoretically at least, be detected through de-energised testing. In the interests of safety, in most cases, working on energised circuits and apparatus can only be justified in testing for isolation where it is the only effective way to diagnose a particular fault. From this, it follows that mandatory testing of new or altered installations should only be conducted with the supply disconnected.



SAFETY ALERT

Testing should be undertaken with the supply de-energised; only when de-energised testing is not viable and the proper safety measures are used is testing of energised circuits acceptable.

15.1.1 Testing hazards

The major hazards associated with testing of electrical circuits and equipment are electric shock and burns, the risk levels of which are high, in some cases resulting in death or permanent or temporary disability. The secondary risk of a fall is also ever present. **Table 15.1** lists risk factors in testing hazards.

TABLE 15.1 Major hazards associated with testing electrical circuits and equipment

Hazard	Risk	Risk control measure
Flashover (short circuit) between phases, or phase and earth, or phase and neutral, while testing energised circuits	Severe burns, electric shock, falls	<ul style="list-style-type: none"> • Use only appropriately certified testing devices and test probes. • Use only testing devices and test probes that have been checked and are not damaged in any way and function correctly. • Before using testing devices and test probes, make sure testing devices are correctly set up. • Use appropriate PPE.
Exposed energised terminals or conductors	Severe burns, electric shock	<ul style="list-style-type: none"> • Isolate and lock off supply. • Use isolation barriers to prevent inadvertent contact with energised parts. • Use PPE.
Periodic energisation of circuits and equipment, such as with controlled loads or automatic control systems	Electric shock, falls	<ul style="list-style-type: none"> • Understand how a circuit and equipment are controlled and operate before conducting any tests. • Do not rely on electrical diagrams for accuracy of 'as installed' circuits and equipment.
Testing of associated energy storage such as batteries and capacitors	Physical injuries and chemical burns, electric shock, falls	<ul style="list-style-type: none"> • Always regard energy-storage devices as energised. • Do not assume ELV circuits and equipment to be safe—apply the same safety measures used for LV.
De-energised cables holding a capacitive charge from an insulation-resistance test	Electric shock, falls	<ul style="list-style-type: none"> • Short-circuit cable ends immediately after conducting an insulation-resistance test.

Selection of testing equipment

Apart from selecting a testing device for the electrical parameter and range to be tested, only those with built-in fundamental safety features should be used. The risks associated with testing can be considerably reduced by selecting equipment with the features shown in **Figure 15.1**.

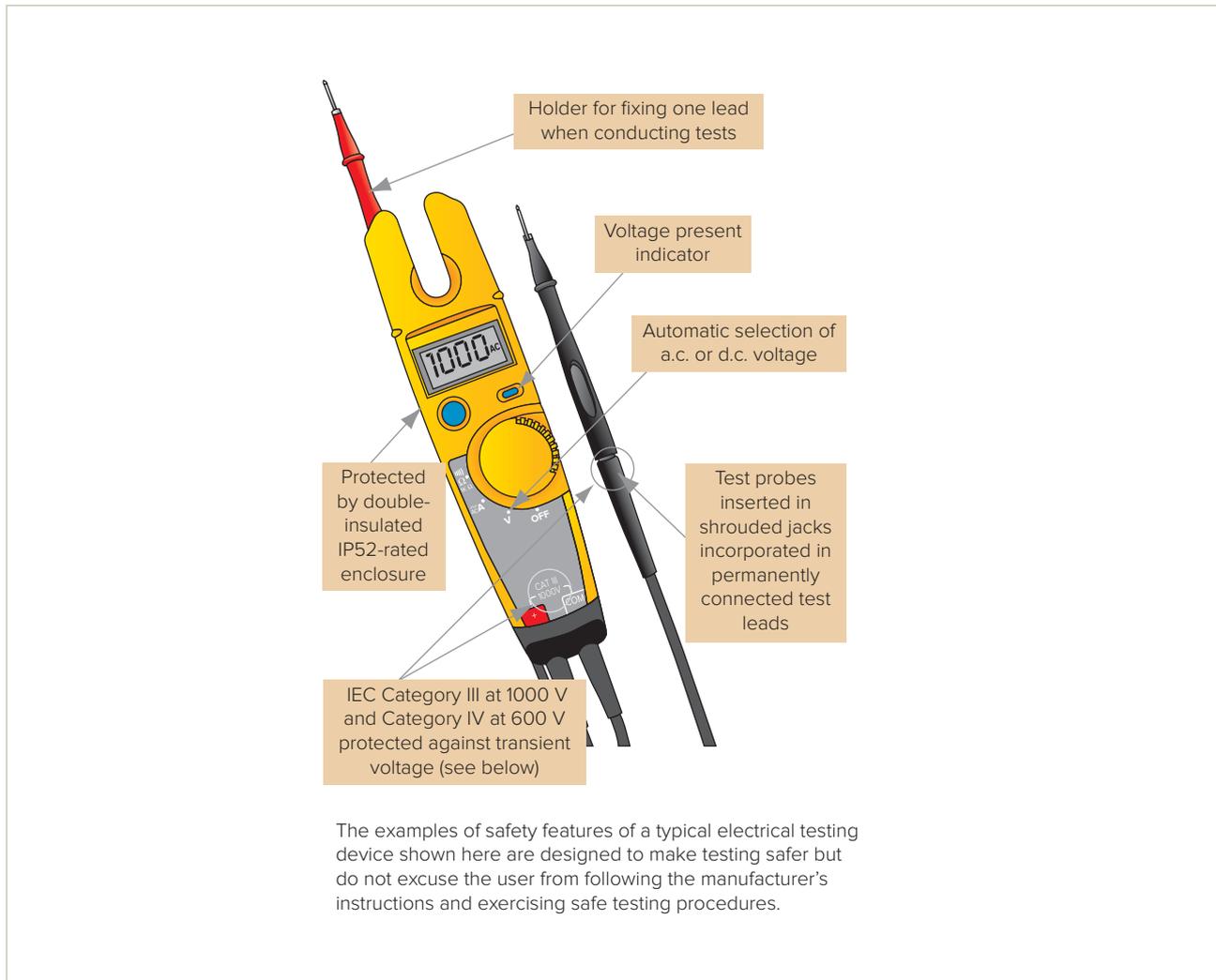


FIGURE 15.1 Built-in safety features of testing devices and accessories

Protection against transient overvoltages

As distribution systems and loads become more complex, the possibility of transient overvoltages on the supply lines increases. Transient overvoltages are sharp increases in voltage, usually microseconds in duration, and are caused by motors, soft starters, variable-speed drives, capacitors and computer power supplies. Lightning strikes on transmission and distribution lines can also cause an extremely hazardous high-voltage transient. An overvoltage transient encountered while conducting tests could result in a flashover (short circuit) between terminals inside the testing device or, worse, a flashover between the external terminals of the device. The arc created by the flashover in a fraction of a second would likely cause grievous harm to the person conducting the test and expose them to the additional danger of contact with live parts.

To address this safety problem, the IEC Standard *61010* was developed for manufacturers to build safety into testing devices. Because the risk from transient overvoltages decreases as the distance from the supply source increases, the IEC Standard categorises the suitability of testing devices by the division of power distribution as shown in **Table 15.2**.

TABLE 15.2 Transient voltage protection by category

Protection category	Protection level
Category IV	Distribution systems, service connection and primary overcurrent protection for larger installations
Category III	Three-phase and single-phase distribution within a premises
Category II	Appliances, lighting points, single-phase socket-outlets and the like
Category I	Transient-protected electronic equipment

Note that, irrespective of their maximum voltage ratings, a Category IV device provides a greater degree of transient protection than those of Category III and lower. Category III devices are suitable for most of the testing undertaken by electricians. **Table 15.2** lists transient voltage protection by category.

Safe testing techniques

No person should be in danger of contact with live parts while a test is being carried out. Testing safely requires adoption of the considered and methodical procedures listed in the safe work method statement (SWMS). When carrying out electrical tests, it is important to follow safe working procedures of tests with the circuit de-energised; only test energised circuits when all other alternatives have been exhausted. This and some important safety testing techniques are illustrated in **Figure 15.2**.

At the completion of each test, the conductors disconnected for testing purposes must be reconnected correctly, and all covers of accessories and appliances replaced. The installation must be left in a safe condition, either safe to operate as proven by the testing or in a safe condition so that the unfinished work does not present a hazard to others in the workplace.

AS/NZS 4836 Safe working on low-voltage electrical installations recommends the following measures:

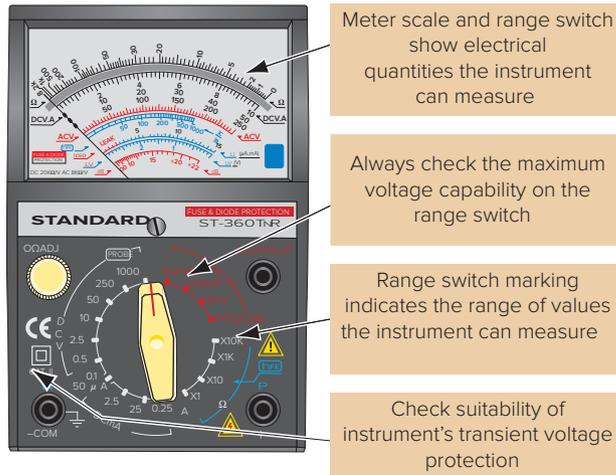
- ▶ Terminate exposed conductors.
- ▶ Physically secure any exposed conductors and surrounding metalwork.
- ▶ Tag and tape off the equipment and/or the work area.
- ▶ Inform relevant parties if the work is not complete.
- ▶ Take the necessary precautions to ensure that exposed conductors cannot become energised.
- ▶ Ensure that switchboards are clearly labelled in relation to their status.



CHECK YOUR UNDERSTANDING

1. Should testing of electrical circuits and equipment be undertaken when the supply is energised?
2. List three hazards associated with testing electrical equipment and installations.
3. What equipment is Category IV test equipment rated for use on?

Always check that the testing instrument selected is suitable for the job. Examples of items to check:

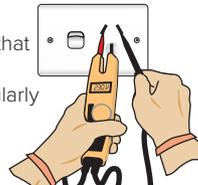


When using this type of instrument, if practicable set the range switch initially to the maximum range, and then switch down as necessary to the range most suitable for the quantity being measured.

Before conducting de-energised testing, isolate, tag and lock off circuits in accordance with safe working procedures.

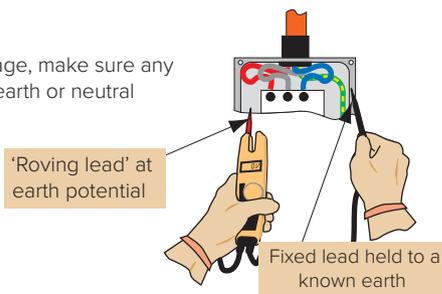


Whatever the testing device employed, test that it is functioning correctly before the test and again after the test. This precaution is particularly important when testing energised circuits or equipment.



Testing instrument on a known voltage

When testing voltage, make sure any 'roving lead' is at earth or neutral potential.



Always check the suitability and condition of test leads and probes and use them correctly.

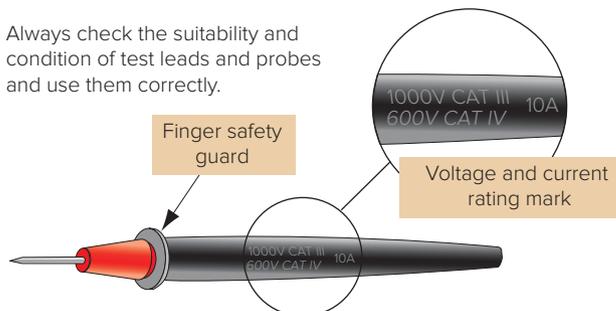


FIGURE 15.2 Safe testing techniques

15.2 Testing principles

Apart from evaluating how well an electrical installation, circuit or equipment is operating, the purpose of electrical testing is to locate faults. This is whether conducting verification tests on new or existing installations or responding to a reported electrical breakdown or fault.

15.2.1 Electrical faults

Underlying the ability to test electrical circuits and find faults is a sound understanding of:

- ▶ Ohm's Law
- ▶ the characteristics of series and parallel circuits
- ▶ the characteristics of electrical control devices and appliances
- ▶ how the wiring for the various types of circuits is arranged.

A fault in an electrical circuit is the result of either an open circuit, a short circuit brought about by damage or deterioration, or a poor or wrong connection. Each of these is illustrated in **Figures 15.3 to 15.5**.

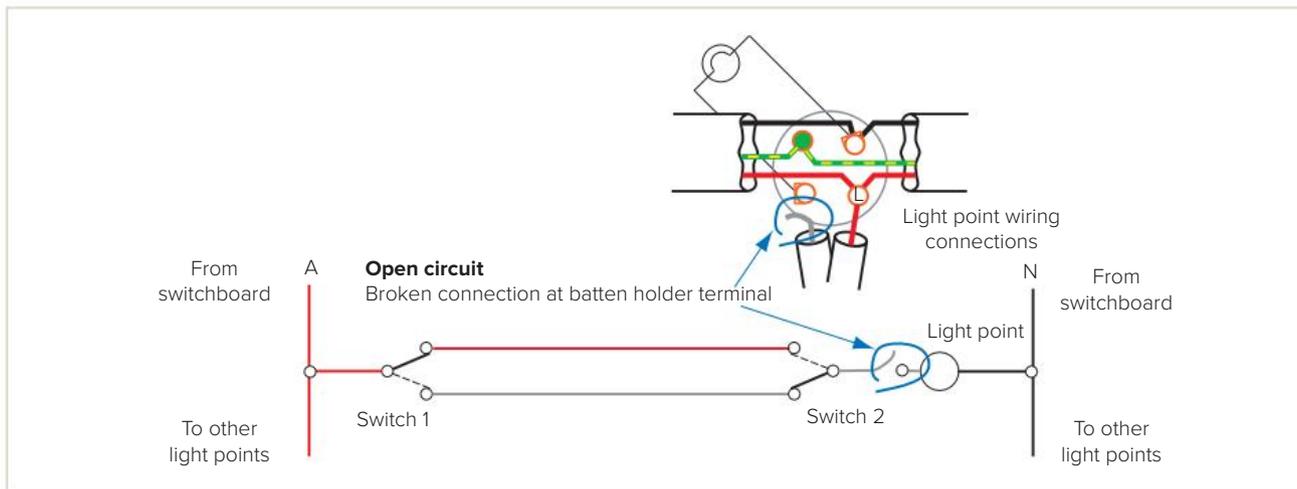


FIGURE 15.3 Example of an open circuit

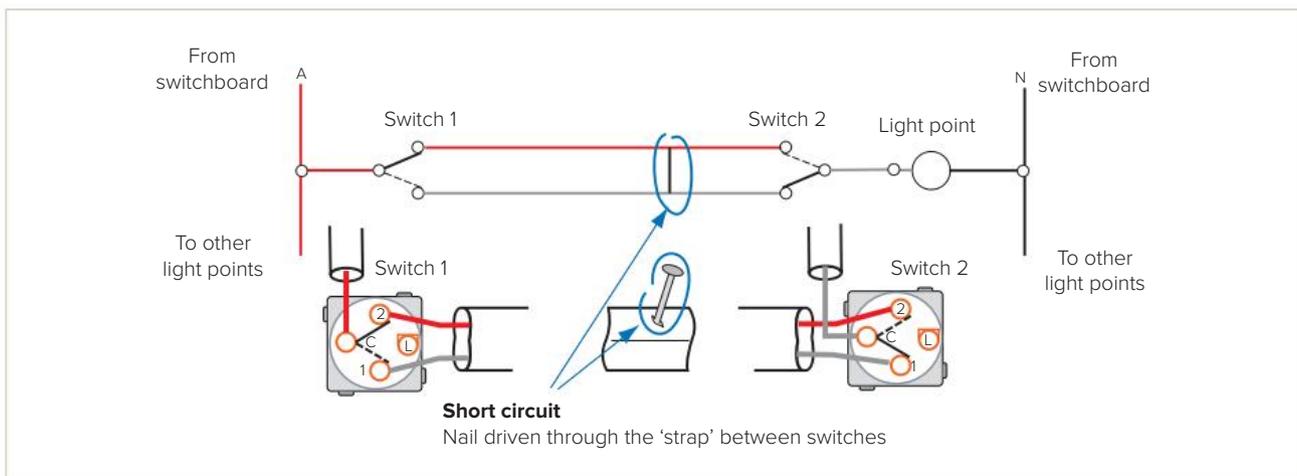


FIGURE 15.4 Example of a short circuit between switch wires

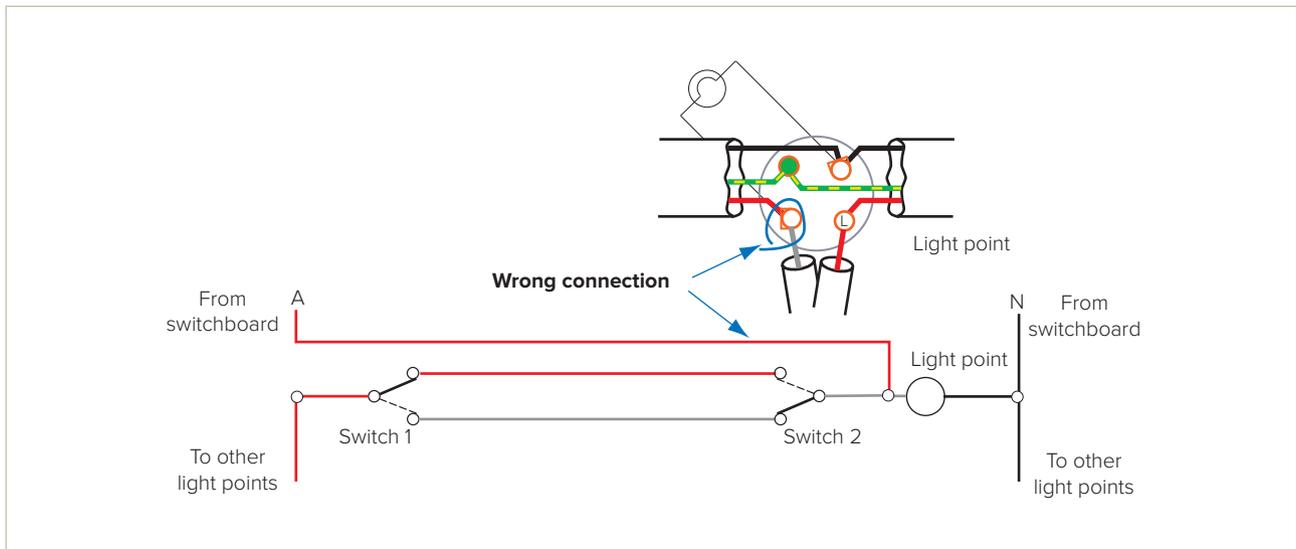


FIGURE 15.5 Example of a wrong connection

Protective and switching devices are designed to open (and close) the current path in a circuit as a deliberate action. The term *open circuit* refers to a fault in which there is an unintended break in the current path of a circuit.

A short circuit refers to an unintentional shortening of the current path in a circuit. An earth fault is a short circuit between an active conductor and earth where the current path is reduced to an almost negligible impedance. On the other hand, a short circuit between conductors in the switch part of a circuit causes problems in the way the circuit is intended to be controlled.

Part of the verification testing of a circuit is to reveal any wrong connections, which will be shown by the testing as an open circuit or short circuit. These faults can also occur in circuit devices and appliances, with the added problem of mechanical failure reflected into the circuit. For example, a bearing failure in a motor will be seen by the supply as an increase in load, increasing the current drawn by the motor; if the motor's overload protection does not operate quickly enough, the motor winding will overheat, destroying the winding insulation and causing a short circuit in the winding.

15.2.2 Testing techniques

As stressed in **Section 15.1**, testing should be undertaken with the supply de-energised; only when de-energised testing is not viable and the proper safety measures are used is testing of energised circuits acceptable. For example, evaluating the performance of an appliance or quality of the supply can only be done with the equipment energised.

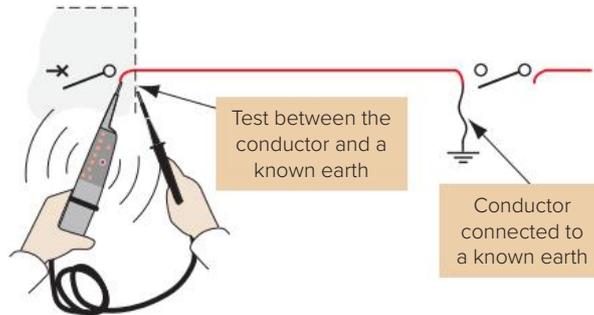
All electrical testing methods employ the same basic principle: connecting an electrical energy source to a circuit to be tested and using electrical indicators or measuring instruments to observe how the circuit behaves. The electrical energy used in testing of de-energised circuits and equipment comes from an energy source built into the testing device. In testing of energised circuits, the energy source is the normal electricity supply itself.

De-energised testing

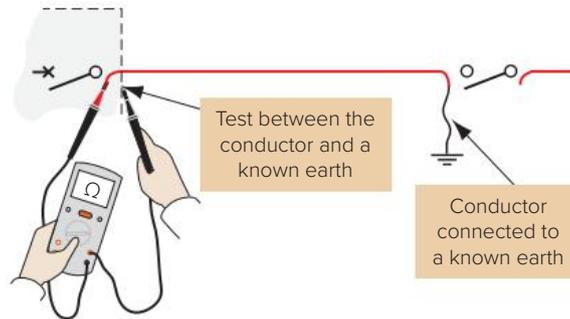
Basically, de-energised testing involves establishing the continuity, or not, of a conductor or between conductors, as illustrated by the methods shown in **Figures 15.6** and **15.7**. This can be as straightforward as identifying a particular cable to make sure it is connected correctly or measuring the resistance of a circuit.

Continuity testing is the most commonly used and versatile testing technique; an example is shown in **Figure 15.8**.

This voltage and continuity tester has a battery as the inbuilt energy source and an audible alarm and indicator that operate when current flows in the circuit under test, showing the circuit is continuous and there is no open circuit.



In this example, the same test as above is done using an ohmmeter which also has a battery as the inbuilt energy source. The meter display will show a very low reading (e.g. $< 1 \Omega$), indicating the circuit is continuous.



An important test carried out during the termination of some cable types and on completion of an installation, or in fault-finding, is to check that the insulation between active conductors and earth has not broken down or will not break down under the stress of the normal operating voltage. This is done with a special ohmmeter known as an insulation tester, which has an in-built energy source that produces test voltages of 500 V d.c. or 1000 V d.c.

In this example, the insulation tester display will show a very high value of resistance in $M\Omega$, equivalent to an open circuit, indicating that the insulation resistance is sound.

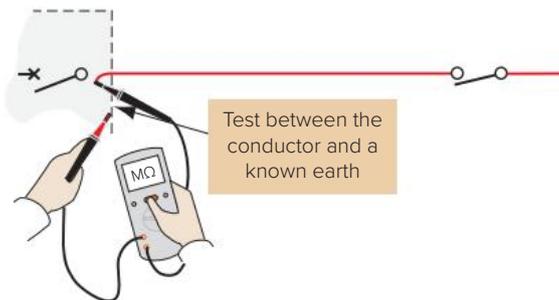


FIGURE 15.6 Basics of de-energised testing

A common test used when fault-finding is to measure the resistance of the circuit within an appliance. In this example, the resistance of the element in a 4.8 kW water heater is tested. Any reading substantially higher or lower than $12\ \Omega$ will indicate that the element may be faulty.

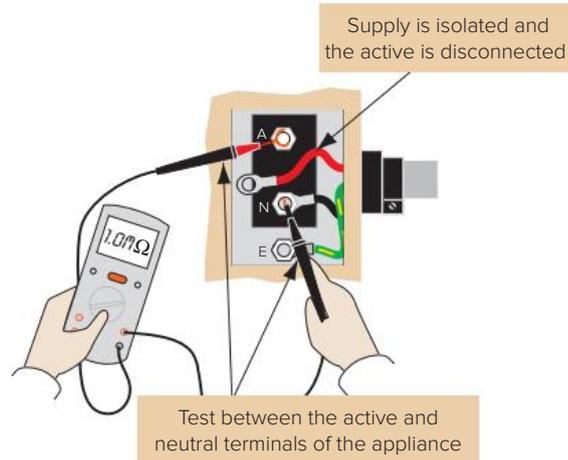


FIGURE 15.7 Measuring the resistance of an appliance

Recalling the wiring arrangement shown in **Figure 8.41**, in order to make the correct connections at Switch 1 it is necessary to check which of the three cables is which. The following steps show the usefulness of continuity testing.

- 1 Strip the sheath and bare the conductors at each cable end, making sure the conductors are not touching.
- 2 Twist the end of two of the conductors together at the end remote from Switch 1. In this example, earth and neutral are chosen.
- 3 At Switch 1 and with the tester set to 'continuity', progressively test between earth and neutral conductor ends of each cable.

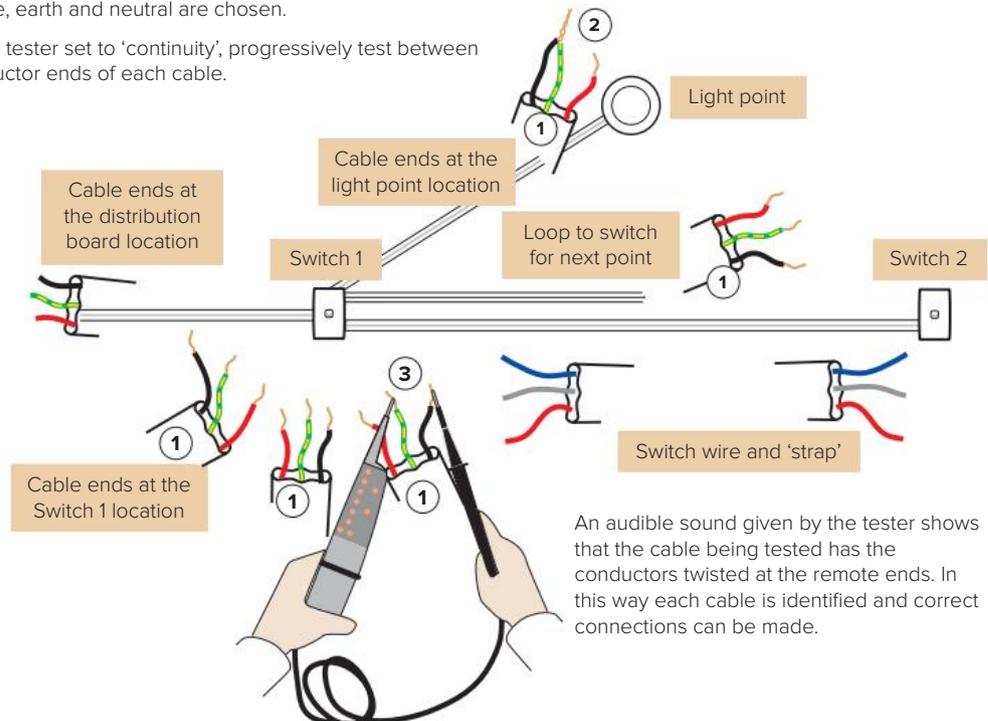


FIGURE 15.8 Using continuity testing to identify cables

Other applications of continuity testing are:

- ▶ checking that the earthing system is electrically continuous and of low resistance
- ▶ identifying the active and neutral conductors in a cable prior to connecting them to an accessory or appliance
- ▶ checking that the wiring of a circuit is connected to the correct terminals at an accessory or appliance
- ▶ checking that there are no short circuits in a new installation or locating a short circuit that might have developed in an existing circuit or equipment
- ▶ checking that there are no interconnections between circuits
- ▶ identifying a circuit by measuring its resistance; and
- ▶ locating high-resistance connections that might have developed in a circuit while in service.

Energised testing

It becomes necessary to conduct tests on energised circuits when carrying out safe isolation procedures such as for the disconnection or reconnection of equipment, evaluating the performance of appliances and protective and control devices, and locating some types of faults. Energised testing is most commonly confined to voltage and current measurement, from which deductions can be made about the operation of a circuit, device or the equipment it supplies. Examples of energised testing are shown in **Figure 15.9**.

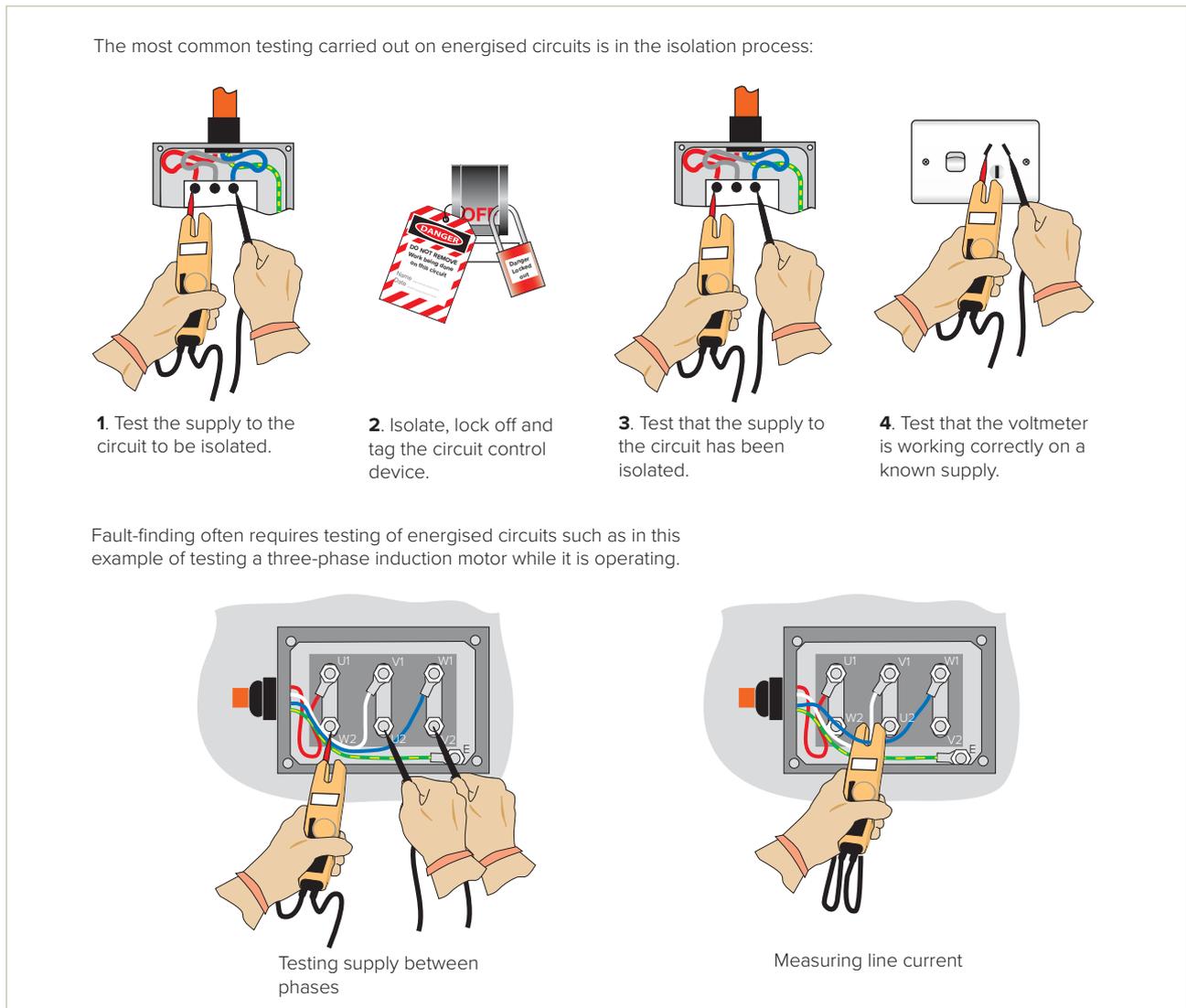


FIGURE 15.9 Basics of energised testing

More sophisticated testing on energised installations is becoming common, bringing concerns for energy efficiency and the safe operation of electronically equipped devices (see **Figure 15.41** later in the chapter).

It is important to apply a sound knowledge of circuit theory and an understanding of wiring arrangements to the testing process, so that the test applied to a circuit and the interpretation of the test results lead to the correct diagnosis of any fault. For example, a defect might occur in a circuit with no apparent effect on the operation of the circuit.



CHECK YOUR UNDERSTANDING

4. What is a short circuit?
5. Define *open circuit*.
6. What resistance would you expect across a 3.6 kW 230 V water heater?

15.3 Testing devices

A brief revision of electrical measuring principles will help remind you of the basic connections of the testing devices used by electricians. See **Figure 15.10**.

15.3.1 Electrical testing devices

The most common electrical testing devices for electricians are those that give a visual/audible indication of the effect being tested and those that measure the actual voltage, current or resistance of a circuit. A number of these functions are incorporated into single devices, such as the electrical testers shown in **Figure 15.11**.

Non-contact devices for detecting voltage, similar to that shown in **Figure 15.12**, sense the electrical field around energised parts of a circuit and give a visual and audible indication to alert that the circuit is energised.

The common voltage tester previously used in the industry was the test lamp set, typically made up of two 230 V pilot lamps connected in series and encased in a plastic enclosure. The better types were equipped with fused probes. However, with the introduction of safety Standards for testing equipment, such as IEC 6010, and the requirements of WHS safety regulations, only approved devices should be used (see *AS/NZS 4836 Safe working on low-voltage electrical circuits, Clause 7.1 and 7.2*).

Ammeters

The most common instrument used for measuring current in the field is the clamp ammeter, which measures current without direct contact with the energised circuit by use of a built-in current transformer or Hall effect sensor. The advantage of the Hall effect instrument is that it can measure both a.c. and d.c. (see **Figure 15.13**).

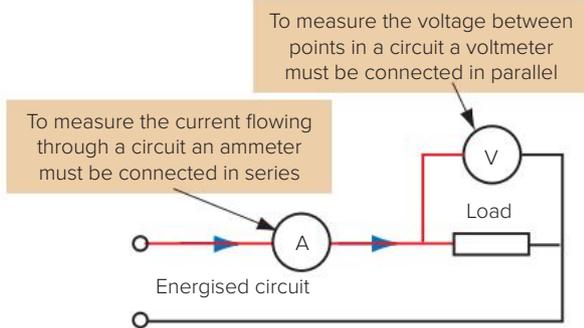
Analogue and digital meters

It is appropriate at this point to make a brief comparison between analogue and digital instruments. The trend in testing instruments used in the field is for devices that display measurements digitally.

Analogue meter movements operate by an electromagnetic mechanism that moves a pointer across a calibrated scale. The reading is subject to parallax error, that is, an apparent change in position of the pointer resulting from a change in position of the person reading the meter. The digital meter mechanism is electronic, with the measured quantity being displayed on an LCD screen, and therefore not subject to this reading error.

Connecting voltmeters and ammeters

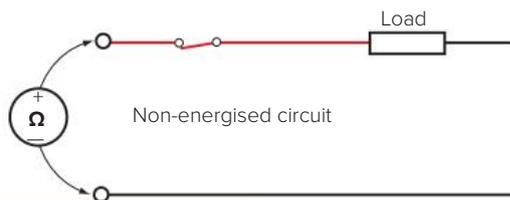
The voltmeter is a testing device that detects the presence of an electromotive force (EMF), but it also indicates the magnitude or value of the EMF in volts, and for this reason is termed a *measuring instrument*. Being connected between the points across which the voltage is to be measured, it is said to be shunt or parallel connected and indicates the voltage between the points.



The ammeter is an instrument for measuring the rate of charge movement or current flow in a circuit. When connected in series with the load, it indicates the value of the load current.

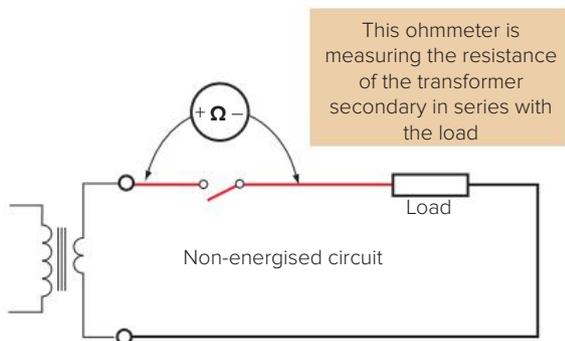
Connecting ohmmeters

Ohmmeters have an in-built power source to provide the current for measuring resistance of a circuit or components and therefore are only used on de-energised circuits.



An ohmmeter is connected across the circuit or component to be measured

Care must be taken in placing the ohmmeter so that it measures the resistance of what is intended, not other parts of the circuit.



In practice ammeters are connected to a current transformer or Hall effect device that does not require direct connection into a circuit which extends the range of currents they can measure. Current transformers and Hall effect devices are measuring the detection components in 'clamp' meters.

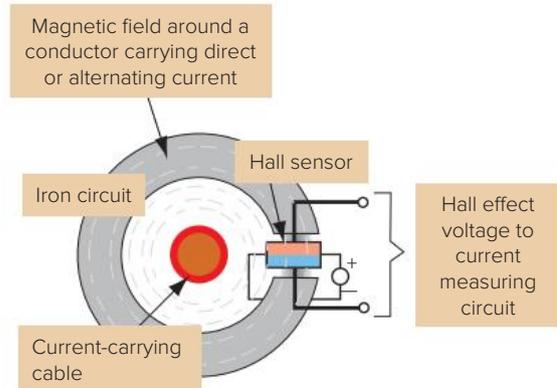
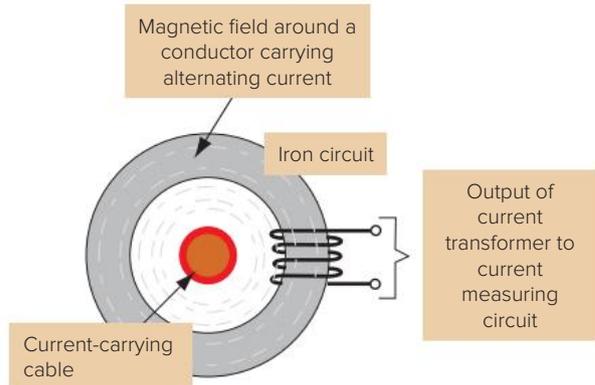


FIGURE 15.10 Electrical measurement basics



FIGURE 15.11 Examples of multifunctional electrical testers

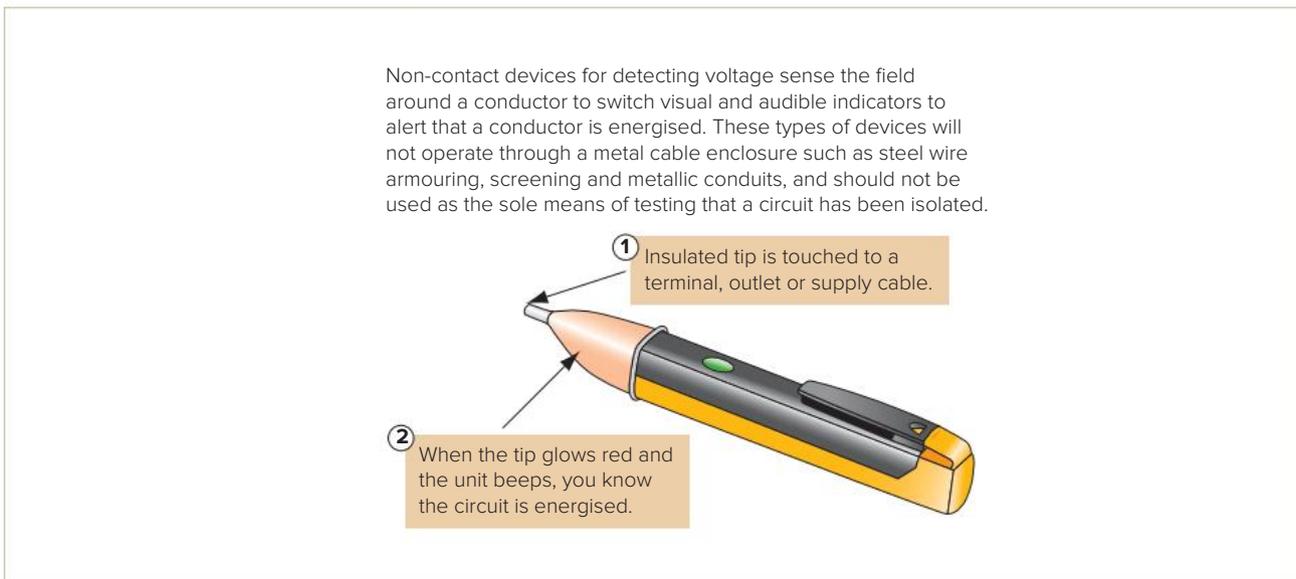


FIGURE 15.12 Non-contact voltage indicator

An inherent property of the analogue meter is that it provides an immediate visual indication through the movement and location of the pointer in relation to the meter's scale much the same as the hands on an analogue watch. This may be preferred by some users; however, the mechanism of the meter movement in analogue instruments is more susceptible to damage than its digital counterpart. Analogue instruments are best used in bench testing work and as permanently installed measuring instruments on switchboards and control panels.

Figures 15.14 to 15.16 illustrate the different features of digital and analogue instruments.

Clamp ammeters are a non-contact instrument. The 'jaws' of the clamp meters open to surround a cable and measure current by coupling magnetically with the cable.



This instrument measures alternating current up to 400 A, a.c. and d.c. voltage up to 600 V and resistance measurement to 400 Ω.

This heavier clamp meter can measure both a.c. and d.c. currents to 2000 A. It also has voltage and resistance measuring functions.

FIGURE 15.13 Examples of clamp ammeters

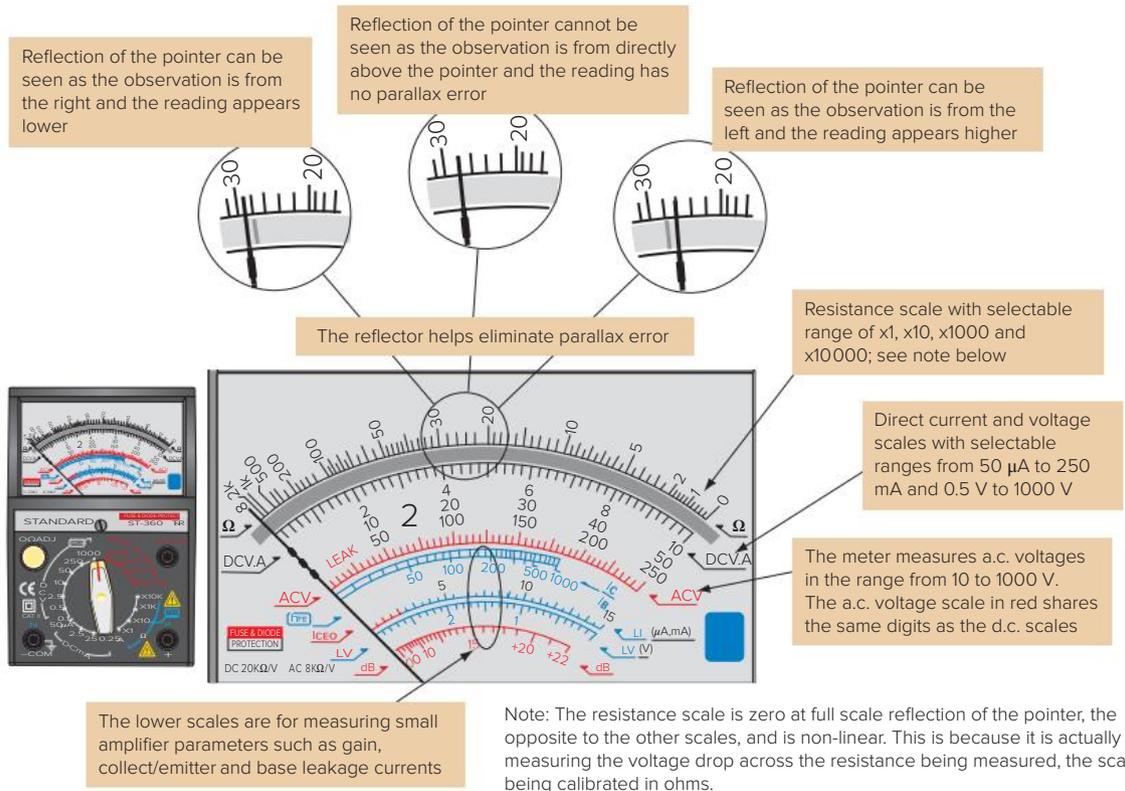


FIGURE 15.14 Example of an analogue meter

Before measuring resistance it is important to zero-adjust the instrument to prevent the resistance of the test leads being added to the reading. This is different from the zero adjustment of the meter movement and is done as follows:

- ① Set the instrument to the ohms range required.
- ② Hold together the tips of the test lead/probes that are to be used in taking resistance measurements. The instrument pointer will move full scale to somewhere near zero.
- ③ Use the $0\ \Omega$ adjustment potentiometer to adjust the point to align exactly with zero.

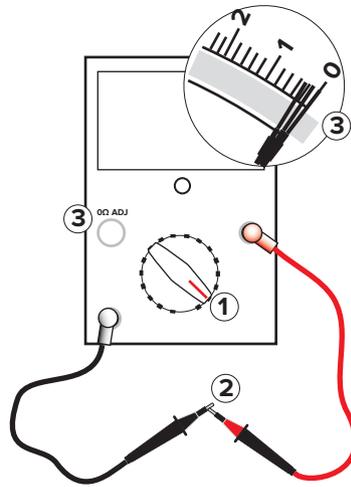


FIGURE 15.15 Zero adjusting the ohm scale on an analogue meter

Digital meters are becoming the instrument of choice for tradespersons because of their accuracy and multiple functions. The instrument shown here is a typical hand-held digital multimeter used in repairing electrical electronic equipment in the field and at the workshop. Functionalities of the latest digital multimeters include:

- non-contact voltage detection
- automatic a.c./d.c. voltage selection
- accurate rms measurements on non-linear loads
- ability to measure 10 A (20 A overload for 30 seconds)
- ability to measure resistance, continuity, frequency and capacitance
- low input impedance to minimise false readings due to ghost voltage.



FIGURE 15.16 Example of a quality digital multimeter

Insulation testers (ohmmeters)

An insulation tester is basically a high-range ohmmeter able to stress test insulation at the voltage for which the insulation is designed. For instance, the *Wiring Rules, Clause 8.3.6.2* (with some exceptions) requires insulation between live parts of a low-voltage installation and earth to be tested at 500 V d.c. Keep in mind that, under normal use, the insulation in the low-voltage installation (i.e. 230/400 V) is subject to peak voltage, which can be as high as 357 V to earth. For convenience, the insulation-testing function is usually combined with other related functions in a single multimeter, as shown in **Figure 15.17**. Although they are multimeters, these instruments are termed *insulation testers* because of the higher test voltages they apply in the insulation-test function, whereas the general multimeter test voltage is rarely more than 9 V.

Features that make modern insulation-resistance testers ideal for verification testing include:

- insulation test range: 0.01 M Ω to 10 G Ω
- insulation test voltages: 50 V, 100 V, 250 V, 500 V, 1000 V
Category IV 600 V overvoltage category rating
- live circuit detection feature that prevents insulation test if voltage > 30 V is detected
- added user protection through auto-discharge of capacitive voltage.

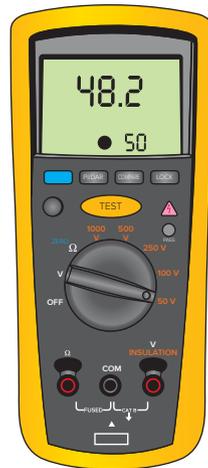


FIGURE 15.17 Insulation-resistance tester with additional functions

Insulation-resistance testing devices are often referred to as meggers, the brand name coined by the manufacturer of the original hand-wind generator type; some are still in use. Whichever device is used, it must be able to hold its terminal voltage within +20 to -10 per cent across a resistance of 1 M Ω on the 500 V range, or 10 M Ω on the 1000 V range. **Figure 15.18** shows how this can be easily checked.

Testing accessories

Manufacturers of testing equipment provide a wide range of general and specialist accessories from test leads, probes and clips, and current clamps to temperature and electronic testing accessories. Most important for safe and accurate testing are the probes; some of their more salient features are shown in **Figure 15.19**. Note that low-impedance voltage-testing devices such as approved test lamps should only be used with certified fused probes.

More elaborate devices for phase rotation testing, power analyses and thermal imaging are becoming more commonly used for fault-finding and implementation of more efficient energy use; these are covered in **Section 15.5**.

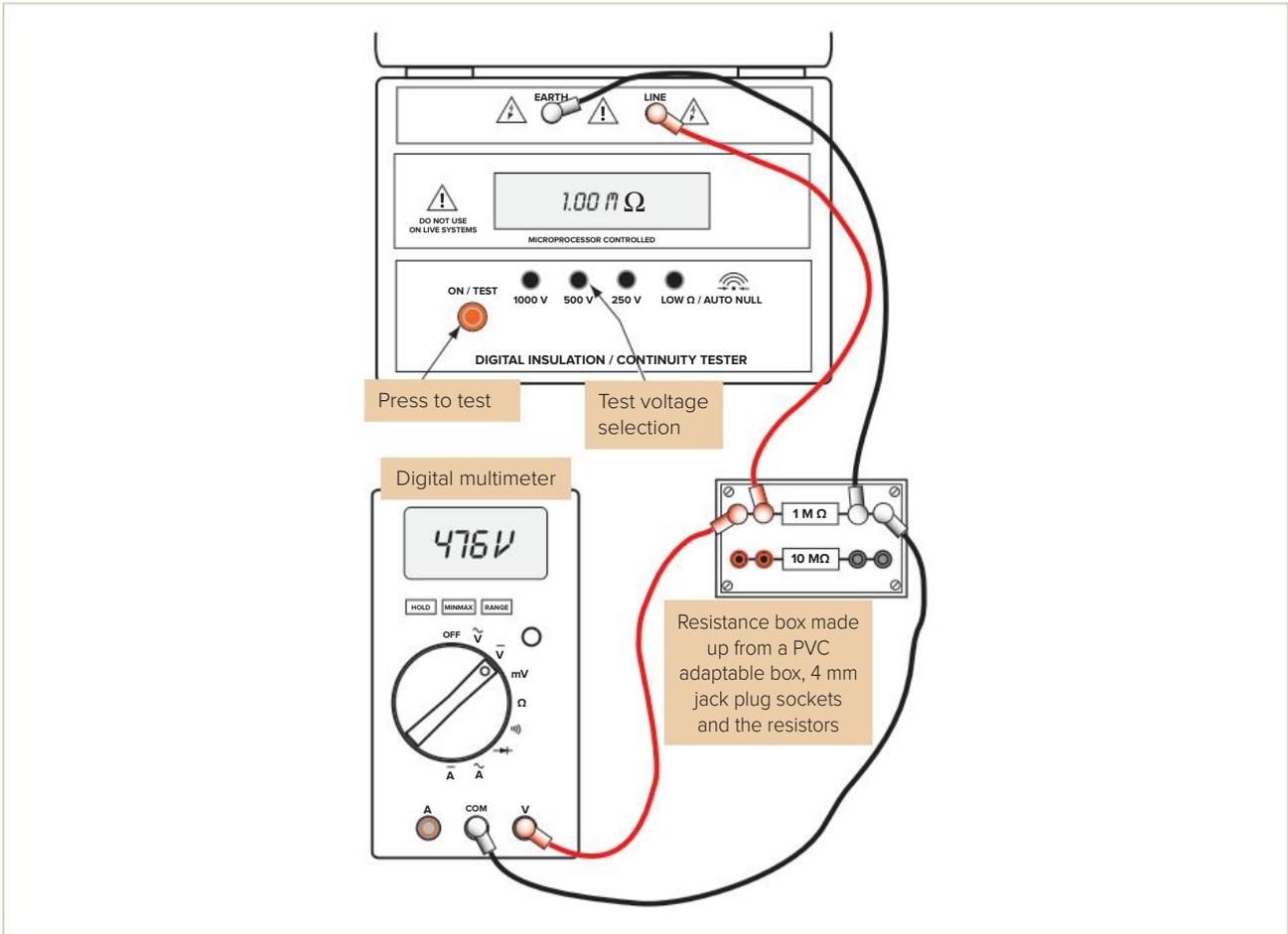


FIGURE 15.18 Checking the test voltage of an insulation tester



FIGURE 15.19 Examples of test leads and probes

For full descriptions of the construction, design and operation of the instruments mentioned in this chapter and others, refer to trade literature produced by the instrument manufacturers and to the textbook *Electrical principles for the electrical trades*.



CHECK YOUR UNDERSTANDING

7. What is the most common instrument for measuring a.c. current?
8. When measuring d.c. current what type of clamp meter must be used?
9. What is the acceptable tolerance for the output voltage of an insulation tester?

15.4 Verification and compliance

Any new installation, or addition or major repair to an existing installation, must be tested and checked to ensure that it is safe and it complies with regulations. This must be done before the new work is connected to the supply. Testing and checking of the installation are the responsibility of the electrical contractor or electrician carrying out the installation work, who must notify the energy distributor in writing that the installation is safe, complies with regulations and is ready for connection to the supply.

It is important that electricians understand the requirements of the relevant regulators where they are working, and ensure they meet the requirements for installation testing, verification and inspection. Electrical conditions such as the continuity of earthing and insulation resistance cannot be seen and, to determine these conditions, suitable tests with instruments must be carried out. Furthermore, a visual inspection of the whole installation must be made to ensure that it complies fully with all legal requirements, specifications, the *Wiring Rules*, service rules and any applicable codes. Although testing and inspection are two separate procedures, in practice they are generally carried out concurrently. **Table 15.3** summarises the purposes of the different verification requirements.

The final testing and visual inspection of an installation form part of an ongoing process of planning, testing and checking that professional electricians use to assure the quality of their work. Many potential defects in electrical installations can be avoided by good planning, then checking and testing while carrying out the installation work. This is the final stage of the installation process, outlined in **Table 15.4**.

For example, a cable installed with insufficient current-carrying capacity is often the result of poor planning, and incorrect connections at a light point or socket-outlet come about from not checking or testing at the time when they were connected. Rectifying defects after the event can be a time-consuming and costly exercise, on top of the poor impression given to the customer.

For large installations the inspection and testing proceed in sectionalised groups, but for small installations the testing for the whole installation is carried out as a single test. A regulatory authority that has not been previously involved in an installation may need information on the criteria for the installation design and arrangements such as those required by *Clause 1.9.4* to conduct an inspection and verify compliance.

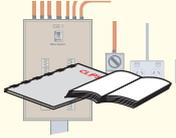
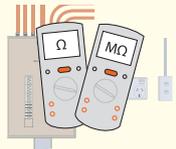
15.4.1 Basic compliance testing

The testing and checking techniques for installations outlined in this chapter cover only some suggested approaches to testing of new and existing installations. For a more comprehensive guide, you should consult *AS/NZS 3017 Electrical installations—Verification guidelines*. To use this Standard effectively, remembering that testing is more than just following a process, requires an understanding of Ohm's Law, the characteristics of circuits and electrical control devices and appliances, and how the wiring for the various types of circuits is arranged.

TABLE 15.3 Purposes of verification inspecting and testing

Verification requirement	Purpose
<p>Overall requirement To verify by inspection and tests that an installation operates as intended</p>	Inspection and testing to verify that new, altered or repaired installations are safe to energise and will operate in accordance with Standards (see <i>Clause 8.1.2</i>)
<p>Visual inspection To verify as far as is practicable by visual inspection that the installation complies with Standards</p>	Inspection to confirm compliance of switchboards and protective devices; consumer mains and submains; wiring systems and how they are installed; electrical control and switching devices; suitability of equipment for its location and duty; earthing; and special aspects of an installation (see <i>Clause 8.2</i>)
<p>Testing of the earthing system To verify by testing that the earthing system is complete and continuous</p>	Testing to confirm that the earthing resistance is sufficiently low for a circuit-protective device such as a circuit-breaker or fuse to operate to cut off the supply in a specified time in the event of a short circuit between active conductors and earth (see <i>Clause 8.3.5</i>)
<p>Insulation resistance To verify by testing that insulation resistance between all live parts and earth is sufficiently high</p>	Testing to confirm that people using the electrical installation cannot come into contact with live parts and so receive an electric shock, and that damage such as that caused by fire due to leakage or short-circuit currents will not occur (see <i>Clause 8.3.6</i>)
<p>Polarity To verify by testing that active, neutral and earthing conductors are connected to the correct terminals</p>	Testing to confirm that the earthing system will not become live and the terminals of appliances, lamp holders and the receptacles of socket-outlets will not remain live when they are switched off (see <i>Clause 8.3.7</i>)
<p>Correct circuit connections To verify by testing that there are no interconnections of conductors between different circuits or short circuits between conductors</p>	Testing to confirm that circuits are connected correctly with no interconnections between circuits, that switches operate in active conductors and that there are no connections between active conductors of different phases, or between active and neutral conductors (see <i>Clause 8.3.8</i>)
<p>Earth fault-loop impedance To verify by testing that the EFLI is sufficiently low</p>	Testing to confirm that the impedance of the earth fault-loop is sufficiently low for the operation of the protective device to automatically disconnect supply (see <i>Clause 8.3.9</i> and <i>Table 8.1</i>)
<p>Operation of RCDs To verify RCDs have been correctly installed and operate</p>	Verification, by either operation of the integral test device or use of special test equipment, that the RCDs are functioning (see <i>Clause 8.3.10</i>)
<p>Other compliance requirements To verify by inspection and testing that an installation complies with all Standards and codes</p>	Inspection and testing to confirm that an installation complies not only with the <i>Wiring Rules</i> but also with any local regulations, codes and additional requirements of a contract specification (see Chapter 5)

TABLE 15.4 Overview of the installation process

	Steps in installation process	Wiring Rules requirements
	<p>1. Design/plan the electrical installation An electrical installation must be designed so it is safe and convenient to operate. The supply characteristics for the installation must be known in order to arrange the installation into appropriate circuits and to inform the distributor of the load to be supplied.</p>	Required by <i>Clause 1.6 Design of electrical installations</i> , which refers to <i>Clauses 2.2.2, 2.3 and 3.6. Appendix C</i> provides guidance on how to arrange circuits.
	<p>2. Select and install the electrical equipment Only electrical equipment that is compliant or approved should be selected and installed. The electrical equipment selected must be installed as required by the <i>Wiring Rules</i> and to manufacturers' instructions.</p>	Required by <i>Clause 1.7 Selection and installation of electrical equipment</i> . As stated by <i>Clause 1.9.1</i> , following the requirements of <i>Part 2</i> will ensure the fundamental principles of <i>Part 1</i> are met. Note that the expectation of safe and sound work practices is outlined in <i>Clause 1.7.2</i> .
	<p>3. Inspect the installation to verify compliance A visual inspection of the electrical installation must be made when the work is completed. If steps 1 and 2 have been diligently followed, the verification inspection should not find any defects. In a well-managed job, checking the work will be ongoing as work is done.</p>	Required by <i>Clause 1.8 Verification (Inspection and testing)</i> , noting that <i>Clause 1.9.1</i> refers to the relevant requirements of <i>Part 2</i> as a means of compliance, that is, <i>Section 8</i> for inspection and testing.
	<p>4. Test the installation to verify compliance Specific electrical tests must be carried out when the work is completed to verify that the installation is safe to energise and use. The correct application of steps 1 and 2 will ensure the test shows that the installation is compliant.</p>	

Earthing systems

The earthing system is tested to confirm whether the four requirements outlined in **Table 15.5** have been met.

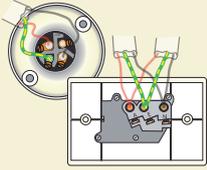
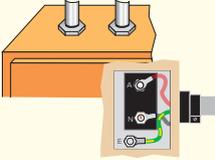
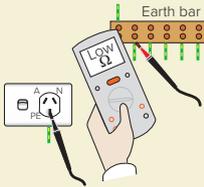
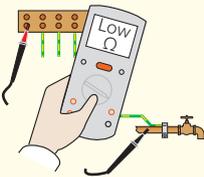
Given that the electrical equipment has been appropriately selected, properly conducted continuity testing should show that the fault-loop impedance (see **Figure 15.20**) is sufficiently low for the protective device to operate as intended under fault conditions. The earth fault-loop path is shown in **Figure 15.20**.

Of interest to electricians carrying out continuity testing of the earthing system is the maximum value of resistance that a protective earthing conductor might contribute to the fault-loop. The *Wiring Rules, Table 8.1* lists the maximum earth fault-loop impedances for protective devices up to 200 A and for 0.4 s and 5.0 s trip times. *Table 8.2* lists the maximum resistance of active and earthing conductors that make up the earth fault-loop within an installation for circuits up to 63 A. **Figures 15.21** and **15.22** show basic methods for testing continuity and **Figure 15.23** shows an earth fault-loop impedance test.

Insulation resistance

Sound insulation is a fundamental protection against the hazards of electricity and a major factor in ensuring an installation is safe. *Clause 8.3.6.3* specifies the insulation resistance of either the whole or part of an installation as being a minimum of 1 M Ω . Note that it is only the resistance between live conductors and to earth that is specified. In preparing to conduct an insulation-resistance test, it is important to pay attention to the points outlined in **Table 15.6**.

TABLE 15.5 Earthing requirements

	Requirements	Wiring Rules reference
	<p>A protective earthing conductor is connected to the earthing terminal of equipment where required; for example, socket-outlets and lighting points.</p>	<p><i>Clauses 5.4.2, 5.4.3 and 8.3.5</i></p>
	<p>Exposed conductive parts of electrical equipment are connected to earth.</p>	<p><i>Clauses 5.4 and 8.3.5</i></p>
	<p>The resistance of the earthing for each circuit is low enough to permit sufficient fault current to operate the protective device; in some cases this will be less than 1 Ω.</p>	<p><i>Clauses 5.7 and 8.3.9 Table 8.2</i></p>
	<p>Extraneous conductive parts (not part of the electrical installation itself) are connected to earth.</p>	<p><i>Clauses 5.6 and 8.3.5</i></p>

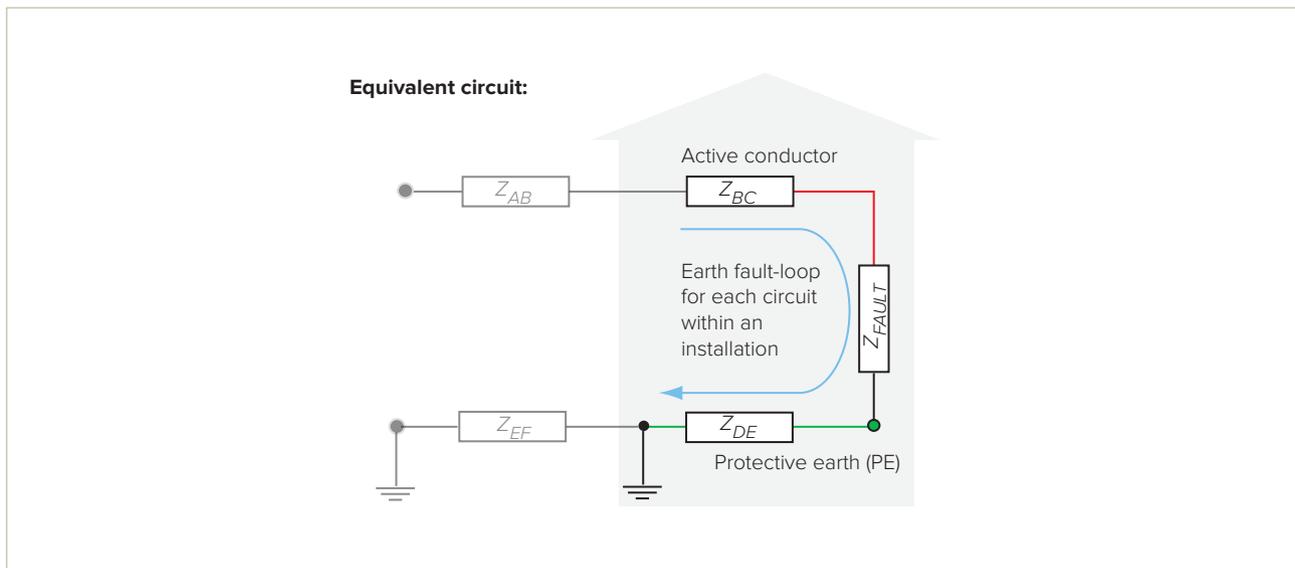


FIGURE 15.20 Earth fault-loop path

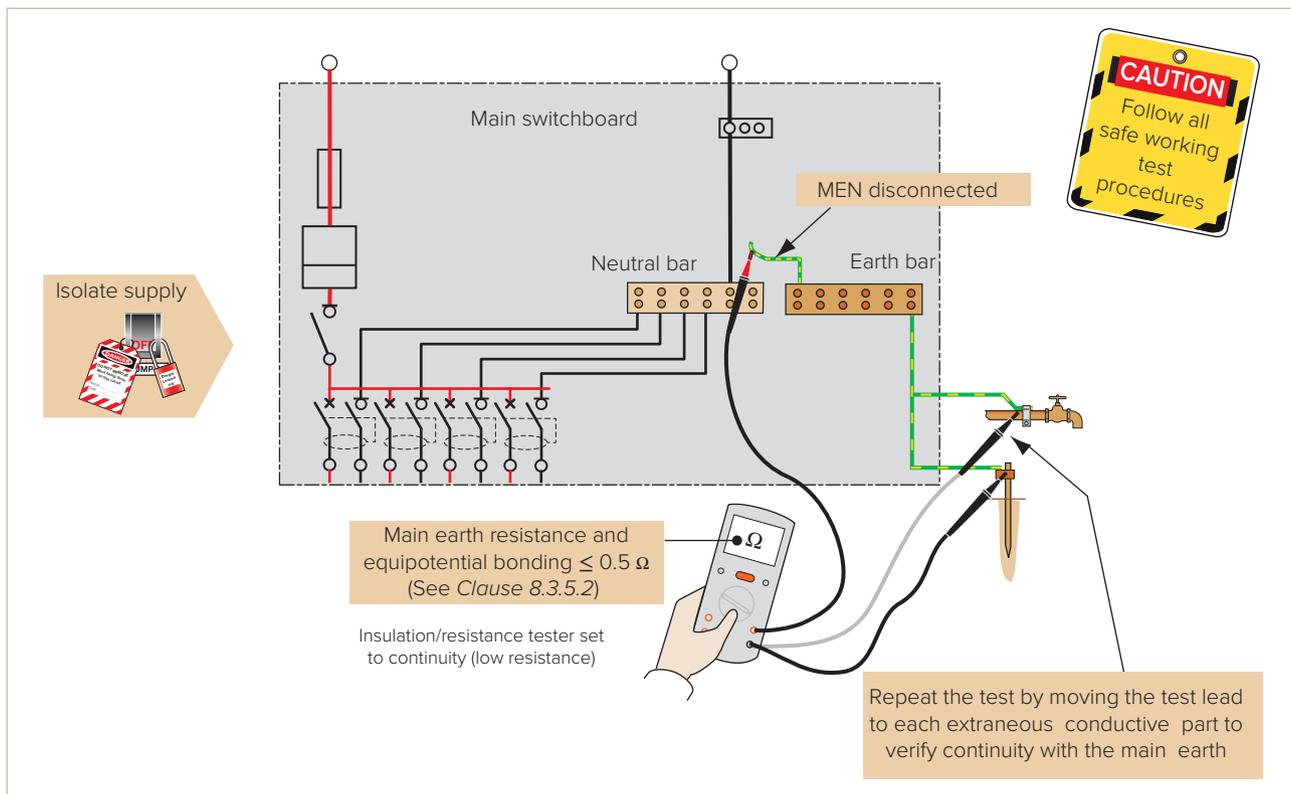


FIGURE 15.21 Example of a continuity test—main earth and equipotential bonding

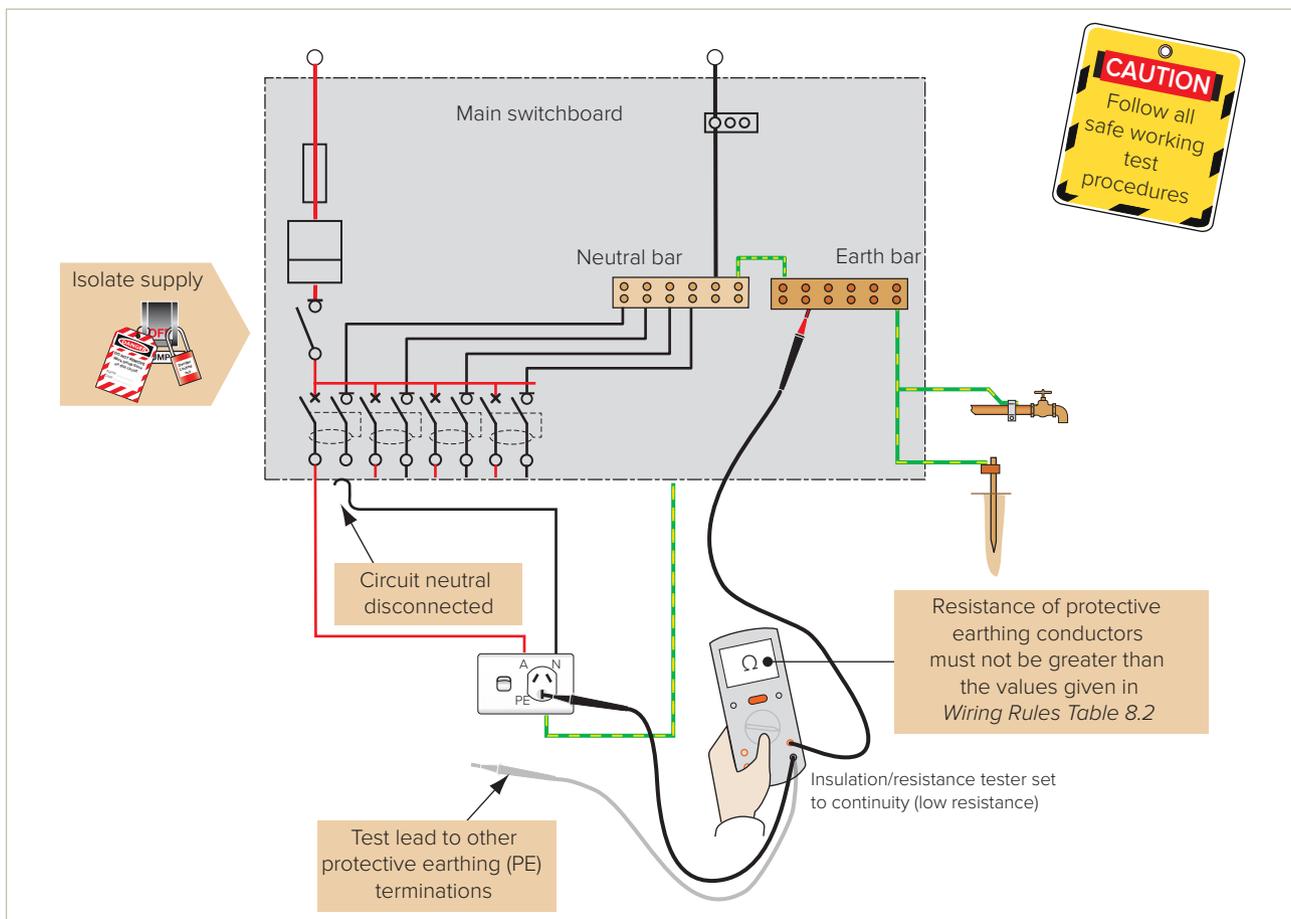


FIGURE 15.22 Example of a continuity test—protective earthing conductors

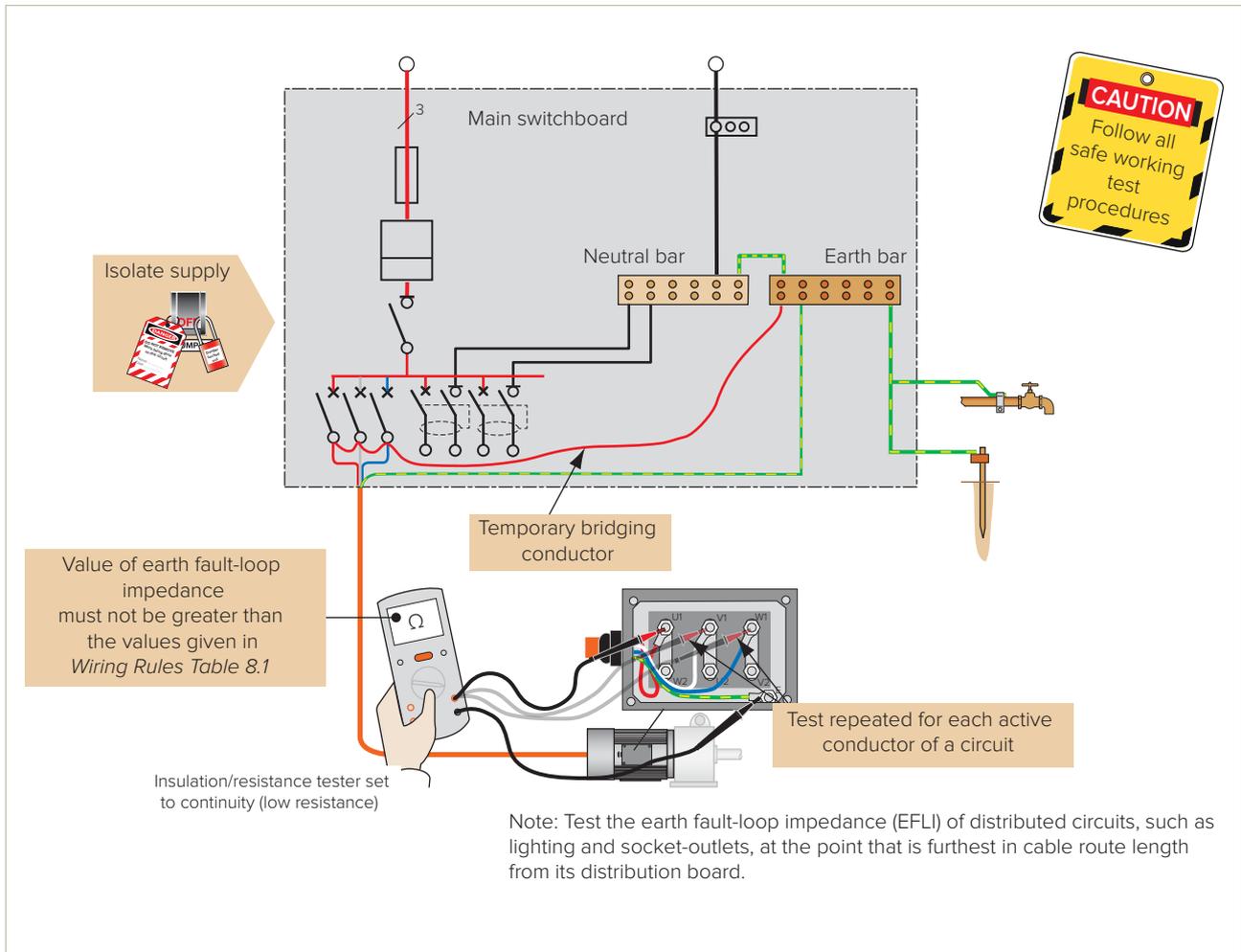


FIGURE 15.23 Example of an earth fault-loop impedance test

For small installations or a section of a large installation, the compliance of the insulation can be verified by a single test of the complete installation, as shown in **Figure 15.24**.

The example shown in **Figure 15.25**, testing the insulation resistance of each individual circuit, is probably more common.

Correct polarity

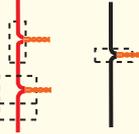
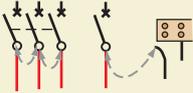
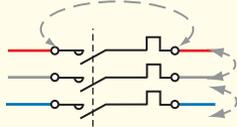
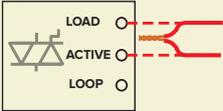
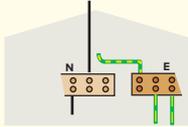
The electrical consequences of incorrect polarity are explained in **Chapter 12**, with particular emphasis on incorrectly connected consumer mains. Although testing of the polarity of consumer mains is usually carried out before the supply is available, a check must be made that they are not connected to the supply before tests are carried out. The test is a straightforward continuity test, as shown in **Figure 15.26**.

In *Clause 4.4.5*, the required polarity for all three-pin flat-pin socket-outlets is stated as being earth, active, neutral in a clockwise direction viewed from the front of the outlet, and other outlets of the same form must be connected alike. It is obviously necessary to carry out polarity tests to ensure compliance with these rules.

A de-energised testing method that checks the polarity of active and neutral, as well as the earth and neutral connections, at socket-outlets is shown in **Figure 15.27**.

Any testing device used on a circuit protected by an RCD must draw less than the specified tripping current of the RCD, to ensure that it does not trip during a polarity test. Otherwise, it will be necessary to bridge out the RCD while the test is being conducted. If the RCD is incorporated within the circuit-protection circuit-breaker, then bridging out of the RCD should include a fuse or circuit-breaker to maintain circuit protection while testing is being conducted.

TABLE 15.6 Preparing for an insulation-resistance test

Important points in preparing to test insulation	
	Isolate the supply and ensure it remains so for the duration of the testing.
	Temporary connections of conductors should be made when the test is done, before all equipment, such as distributor's service protection, links and metering, is installed.
	Connected together, the live conductors for each circuit should be tested.
	Place all control switches in the ON position and disconnect appliances.
	The insulation tests will need to be repeated for each switch position of multi-position switches or, alternatively, bridge all interconnecting conductors.
	Contactors and relays require an energised circuit to operate so, for the test, it is necessary to bridge across their normally open contacts.
	Avoid damaging devices containing electronic or voltage-sensitive components; disconnect them from the circuit and then connect together the circuit conductors that were connected to them.
	Disconnect any MEN connections at an outbuilding (see <i>Clauses 1.4.88</i> and <i>5.5.3.1</i>).

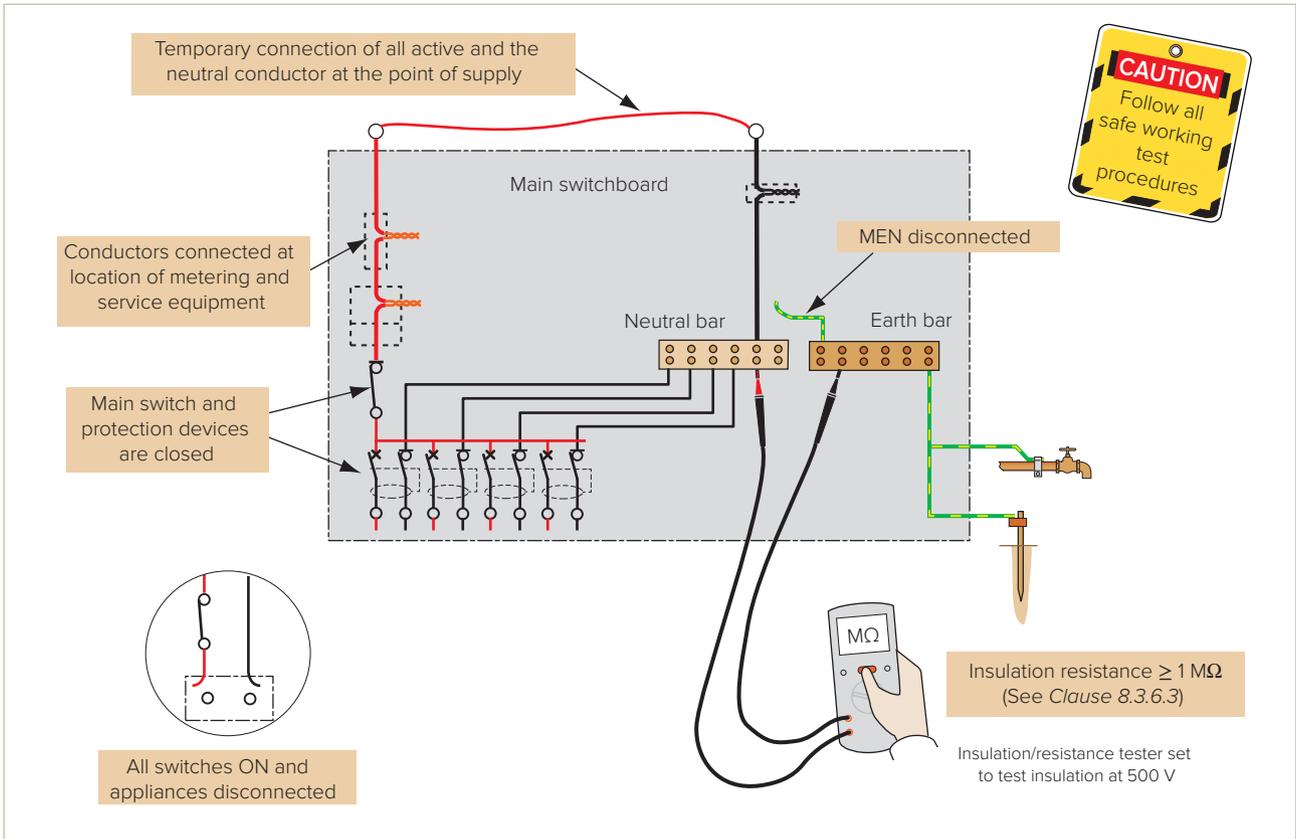


FIGURE 15.24 Testing the insulation of a complete installation

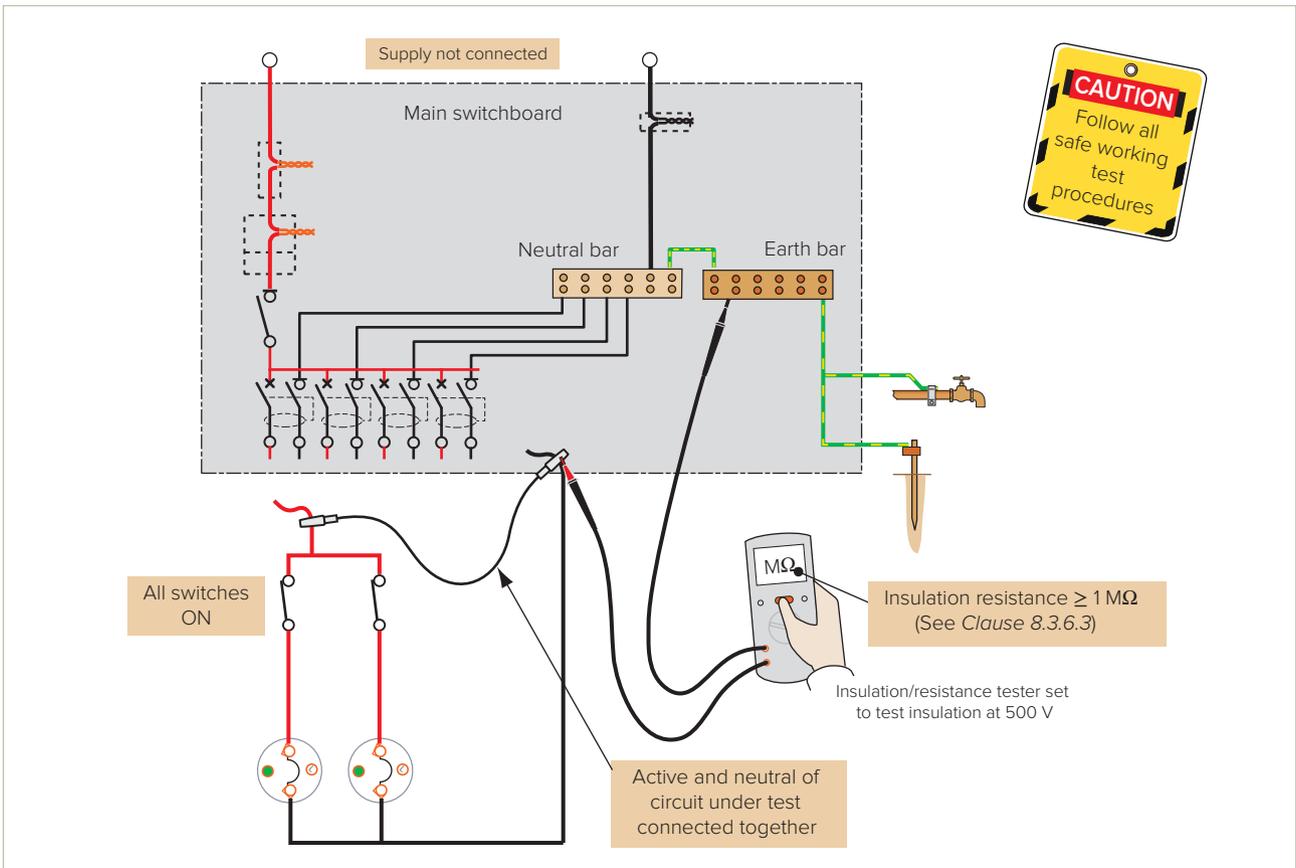


FIGURE 15.25 Testing the insulation of an individual circuit

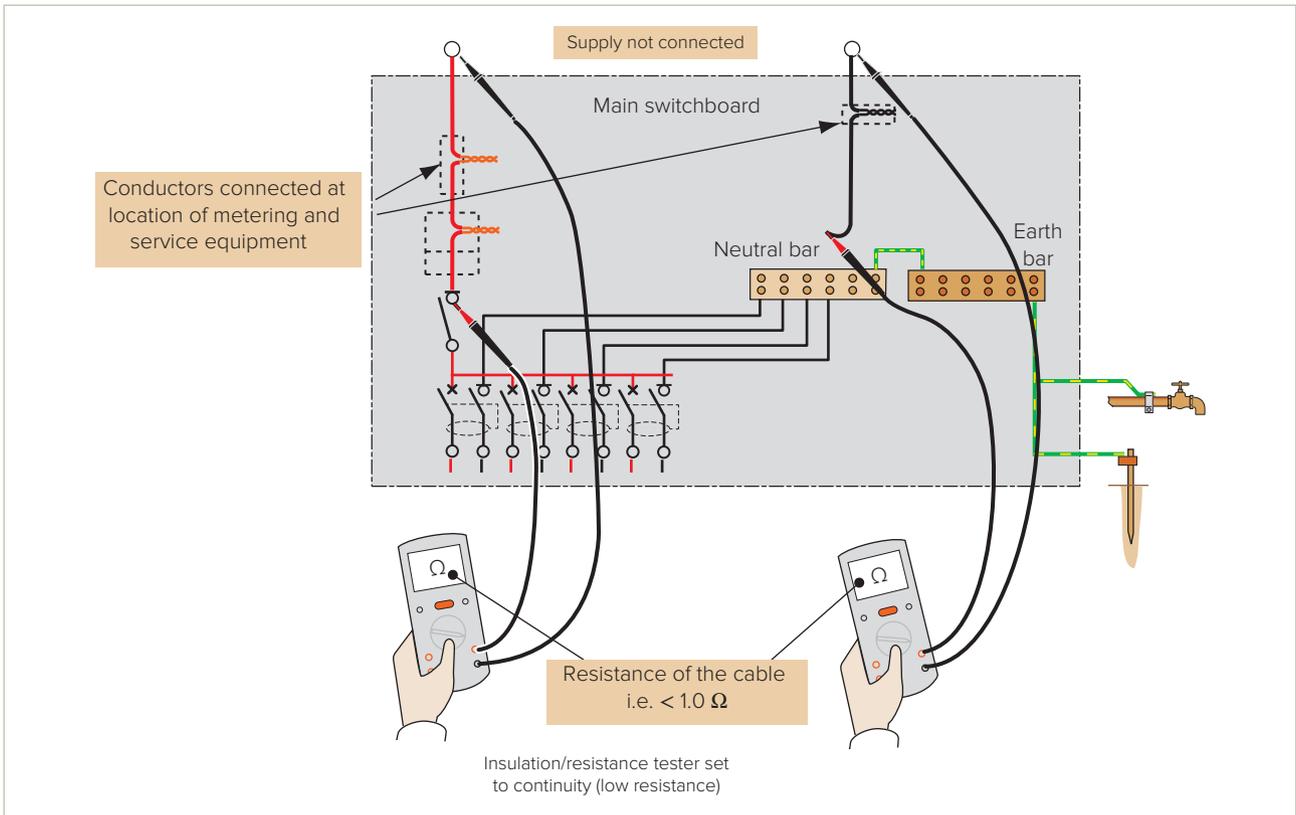


FIGURE 15.26 Continuity test of consumer mains to ensure they are connected correctly

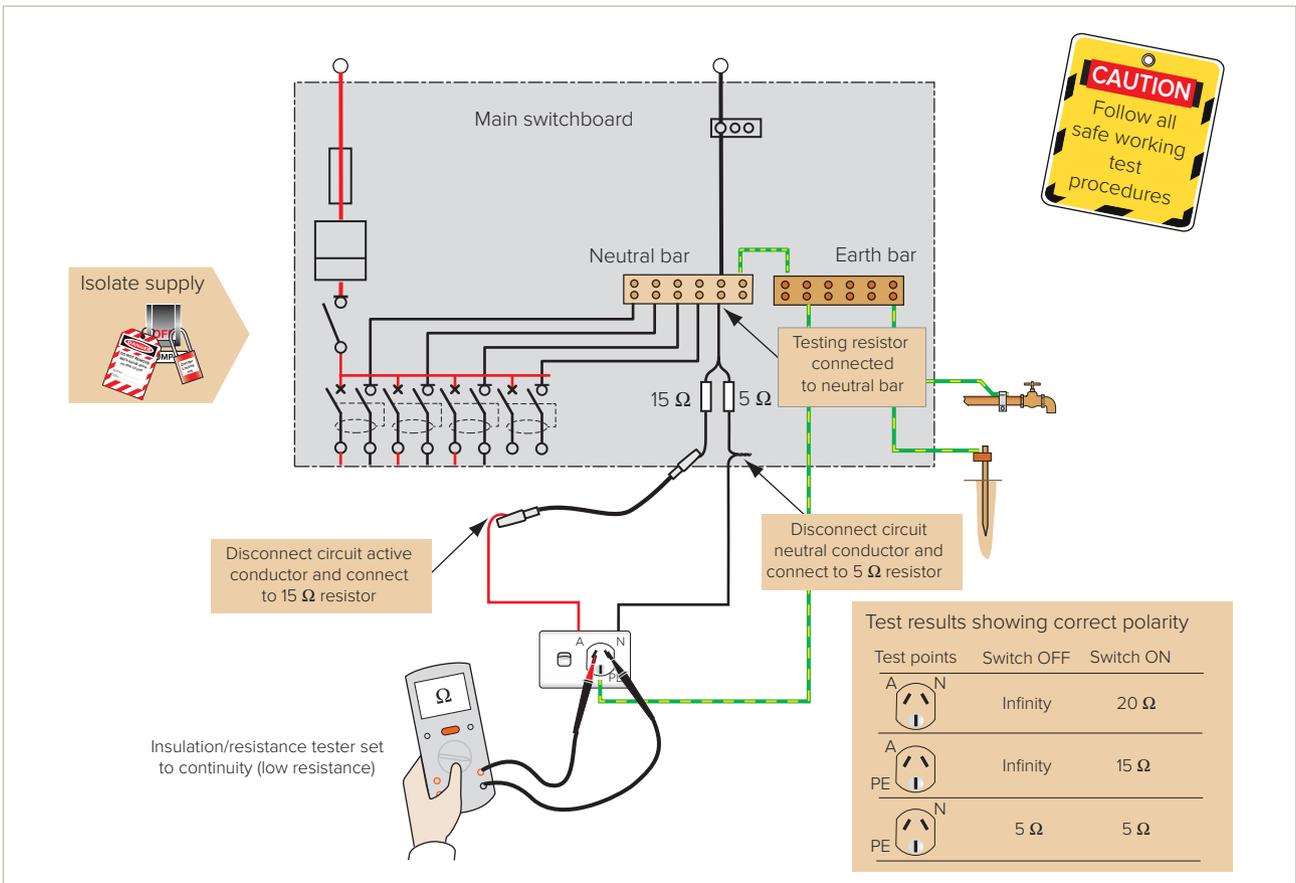


FIGURE 15.27 Example of a de-energised test of polarity of a three-pin socket-outlet

SAFETY ALERT

Discharge any energy that might have been stored in the cables during the test due to their capacitance. This energy can cause electric shock and falls.

SAFETY ALERT

Incorrect polarity can be fatal—the importance of carrying out polarity tests on all parts of an installation cannot be overemphasised.

Clause 2.3.2 of the *Wiring Rules* requires switches to be connected to operate in the active conductors, and Clause 4.5.1.2 restricts the polarity of an Edison screw lamp holder to that of the active at the centre terminal and the neutral for the outer or screw base.

A testing method that checks both the polarity of active and neutral and the earth and neutral connections of lighting circuits is shown in **Figure 15.28**. This test requires the same preparation as the de-energised test for socket-outlets previously discussed. Once again, tracing out the test circuit shows that a correctly connected batten holder and switch will give test results similar to those for the socket-outlet test.

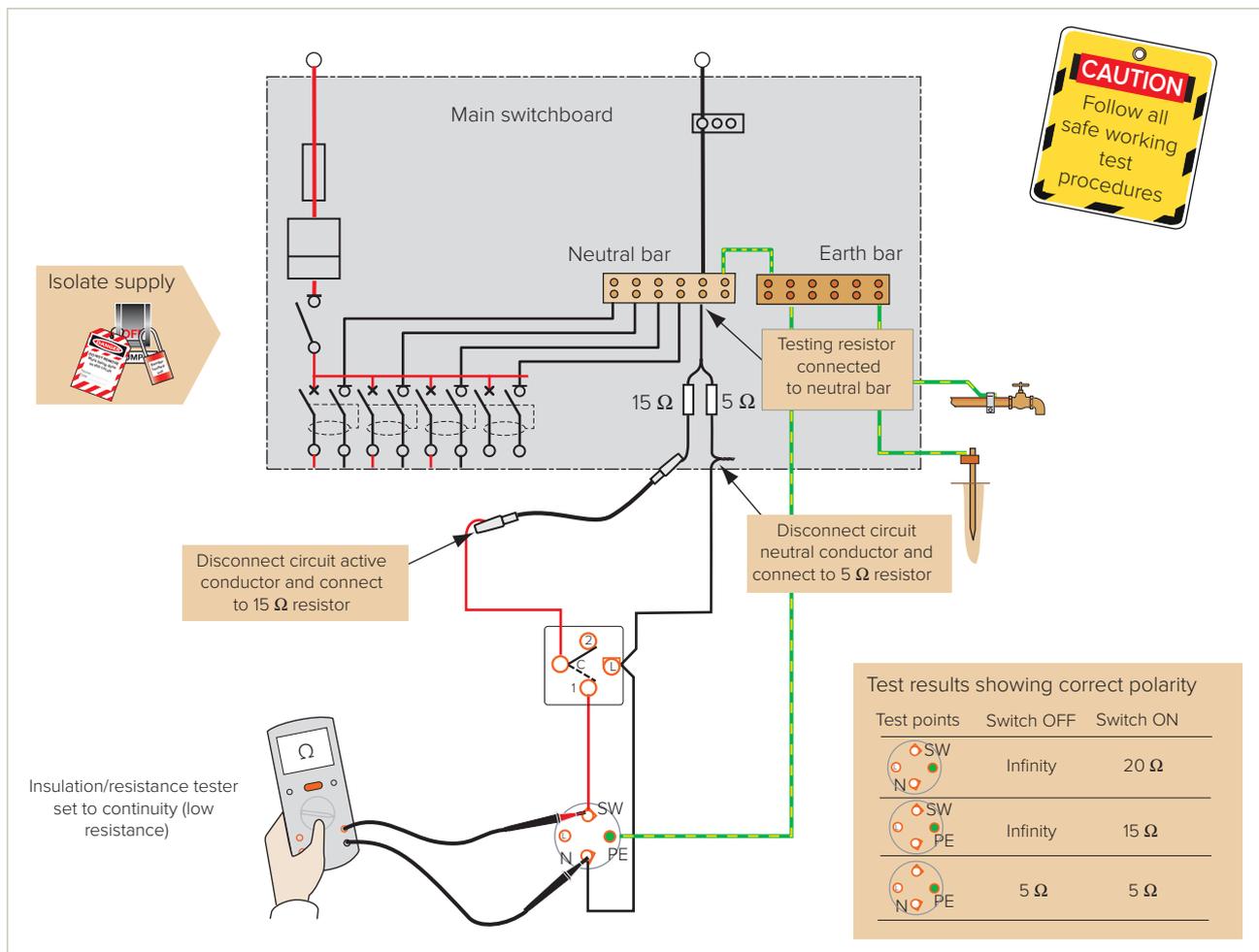


FIGURE 15.28 Example of a de-energised test of polarity of a light point

A method for checking polarity in lighting circuits is illustrated in **Figure 15.29**. In this method of polarity testing, the lamps are left inserted and the test is conducted between the switch terminals and a known earth. Note that one of the lighting points in the figure is incorrectly connected.

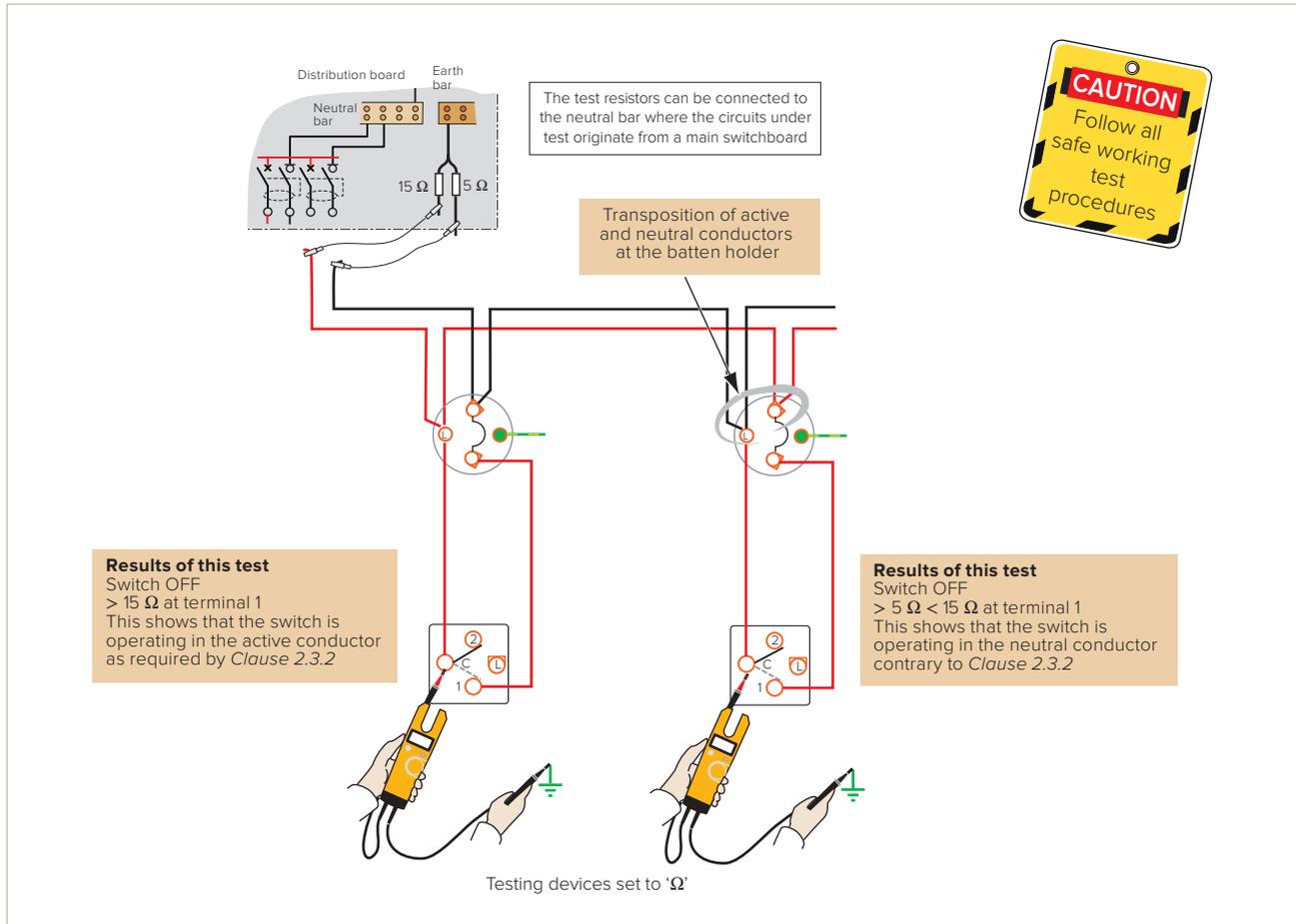


FIGURE 15.29 Example of a de-energised test of polarity at light switches to verify they are operating in the active conductor

15.4.2 Correctness of wiring circuits and connections

Some of the polarity checks described utilise continuity testing to determine that the active feed is continuous, it follows the correct circuit route and it is correctly connected. Continuity testing is also used to identify conductors prior to connection and to check the correctness of circuits and connections. Apart from checking for correct polarity, this includes checking that there are no short circuits, there are no interconnections between circuits, and circuit loads, active conductors and corresponding neutral conductors are correctly identified at their switchboard of origin.

The interconnection of conductors between different circuits has been the cause of many electrical accidents. Anyone working on such an installation is exposed to the risk of electric shock, even though it might appear that the circuit has been isolated correctly. An interconnection between circuits is likely to be an incorrect connection at a junction box or the looping terminal of an accessory; but do not discount the possibility of insulation breakdown, particularly in older installations. An incorrect connection might result in the direct connection of conductors of separate circuits, as shown in **Figures 15.30** and **15.31**. Illustrating both schematic and wiring diagrams, these figures demonstrate how easily such an incorrect connection can be made.

Regarding three-phase (four-pin) socket-outlets, *Clause 4.4.5* requires socket-outlets of the same type to have the same order of connection. The sequence of connections can be verified by continuity testing, usually done at the

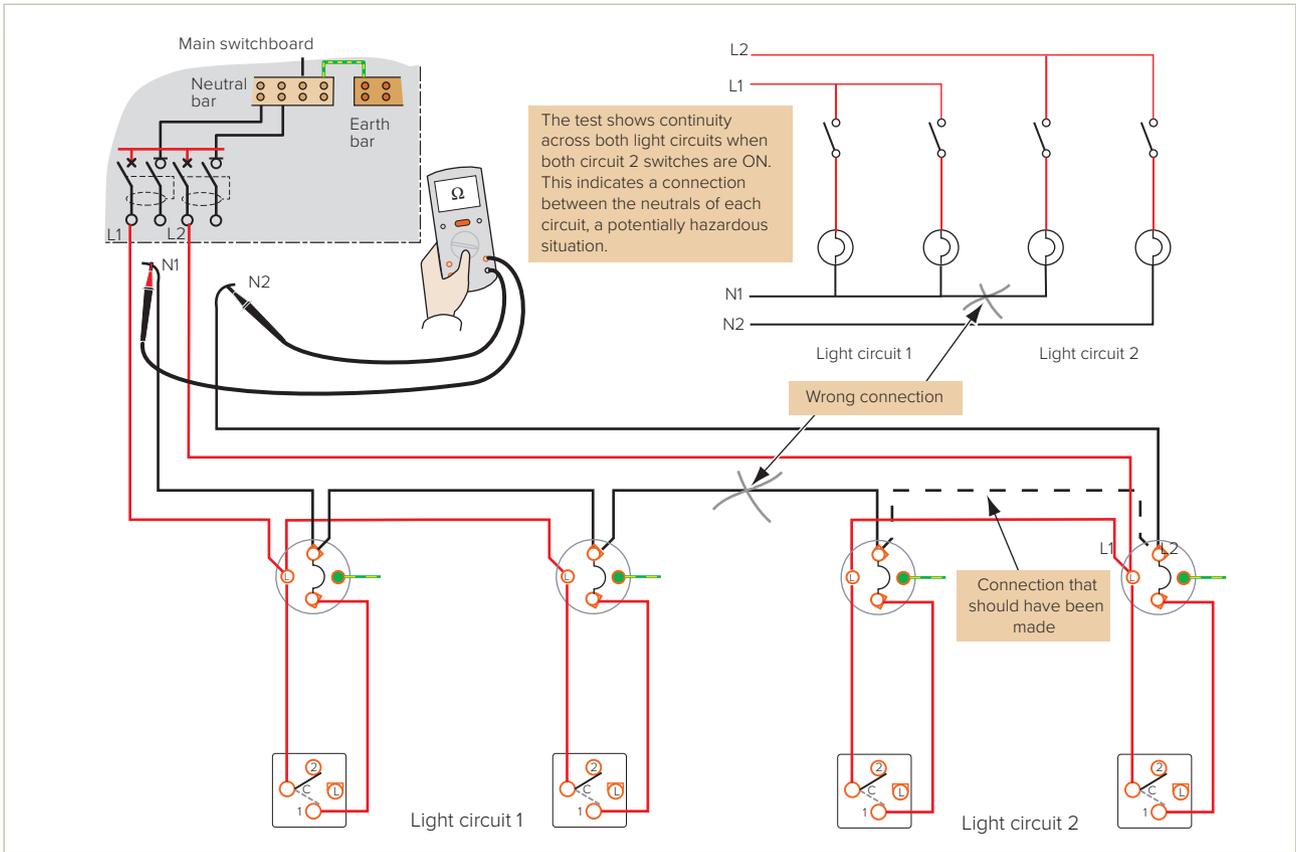


FIGURE 15.30 Example of interconnection of neutral conductors of different circuits

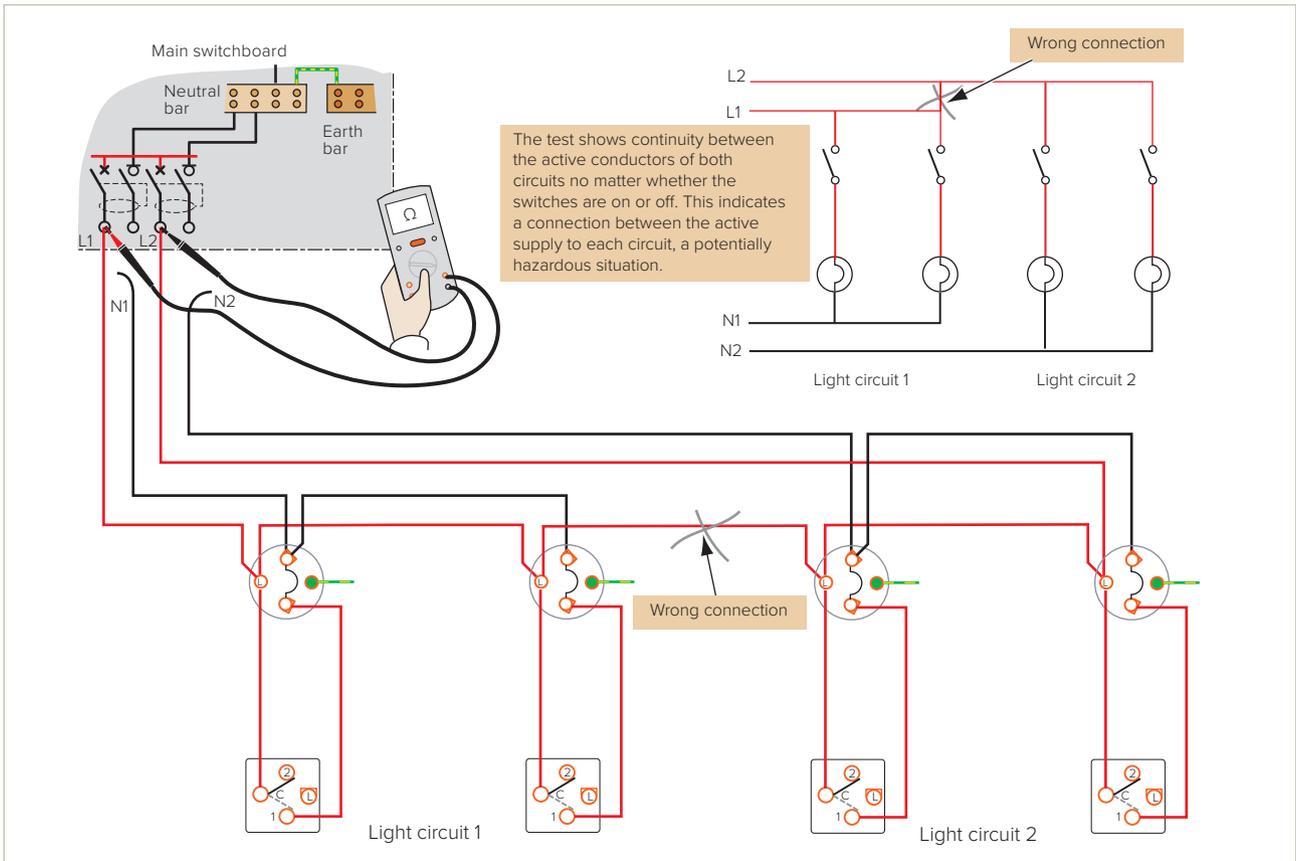


FIGURE 15.31 Example of interconnection of active conductors of different circuits

stage in an installation when socket-outlets are being connected. Alternatively, the sequence of connections can be verified by the use of a phase-rotation device, as shown in **Figure 15.32**.



FIGURE 15.32 Example of a phase-rotation indicator to check the connection sequence of a multiphase outlet

15.4.3 Testing the operation of residual current devices (RCDs)

Residual current devices (RCDs) are generally manufactured with an integral test button. Depressing the button only tests the electrical and mechanical elements of the tripping mechanism. A test that includes the fault path for a circuit is conducted with voltage-testing devices such as approved test lamps that draw a current greater than the rated residual current for the device. For example, a 230/400 V test lamp consisting of 2×15 W lamps connected in series will draw a current in excess of 30 mA, the rated residual current for mandatory RCD protection of socket-outlets and lighting circuits. However, to determine whether or not the RCD is operating within the specified trip time or residual current tolerance, a dedicated RCD tester must be used. The requirements for testing RCDs are covered by *Clause 8.3.10* with some exceptions for Australia. The operation, application and testing of RCDs are covered in detail in **Chapter 12**.

15.4.4 Verification-testing devices and accessories

An installation should not be energised for use until it has been verified to comply with all requirements and is safe to use. It is the responsibility of the electrical contractor to rectify any faults or non-compliance defects found during verification inspection and testing. The final part of the process is to record the inspection and test results that show

the installation complies with the requirements of the Standard. Regulatory authorities require documentation of compliance to be held by the contractor, with copies forwarded to the customer and/or the authority. *Clause 8.4* of the *Wiring Rules* advises that the date on which the installation was first energised must be available on site.

This may sound daunting to an apprentice or even a first-time electrical contractor; however, an instrument supplier has developed a unit, marketed as the InstalTest 3017 (**Figure 15.33**), to help streamline the verification process. The unit is programmed to test compliance with the requirements of the *Wiring Rules* and follows the processes set down in *AS/NZS 3017 Electrical installations—Verification guidelines*.



FIGURE 15.33 Programmable installation tester

Users can input the compliance results of the visual inspection and then choose tests with fixed parameters and limits, or user-defined parameters and limits. Results of tests are clearly displayed on the LCD screen (**Figures 15.33** to **15.35**), with assistance given by a help screen (**Figure 15.36**).

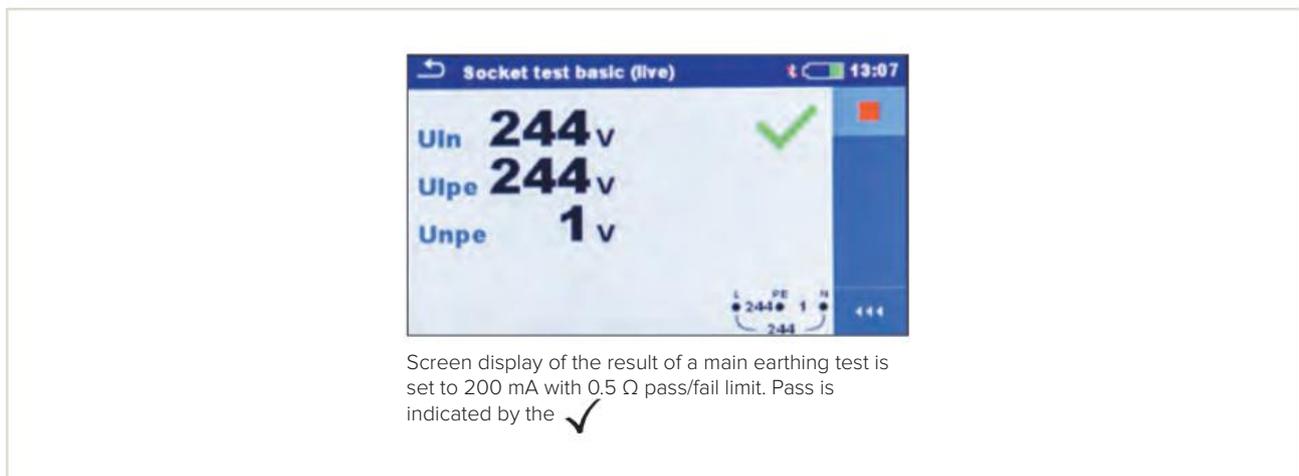


FIGURE 15.34 Earth continuity and resistance test results

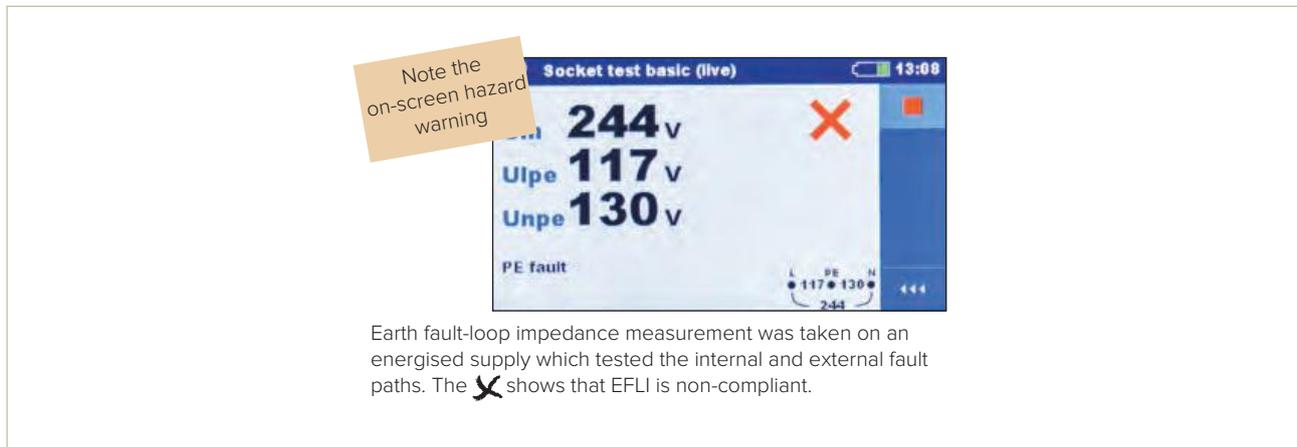


FIGURE 15.35 Earth fault-loop impedance results

Emona Instruments

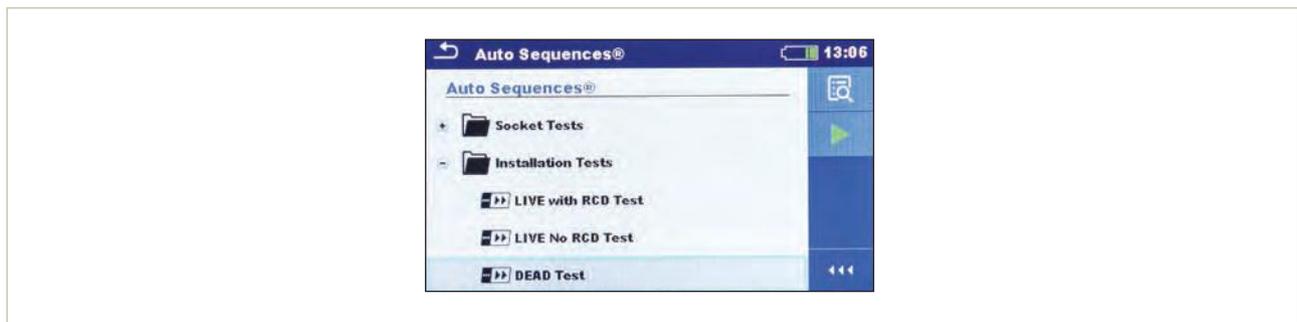


FIGURE 15.36 Help screen

Emona Instruments

Where *AS/NZS 3017* requires specific test parameters and limits, the device is pre-programmed with the compliant test settings. The auto-sequence mode has predefined pass/fail limits and the tests are conducted in the sequence specified by *AS/NZS 3000* and *AS/NZS 3017*. This is particularly useful in installations with large numbers of points such as socket-outlets. The screen also displays a warning message when carrying out supply-available tests, a particular benefit that improves operator safety. Another advantage of a graphics display is that functions can easily be edited or added if Standards or regulations change.

The InstalTest can store up to 4000 results, which can be downloaded via the supplied software to a computer for statutory record-keeping and printing of safety and compliance test reports. The reports are comprehensive and include the user name, licence number, switchboard, sub-boards, article locations and test results.

In addition, the unit can be used as a multimeter, insulation tester, loop-impedance tester and RCD tester for troubleshooting and general electrical work. It is supplied with the essential accessories for conducting tests, such as test leads, alligator clips and a resistor box for polarity and circuit-connection tests on socket-outlets and lighting points, and there are optional accessories such as current clamps and a lux meter adaptor.

The system provides users with a complete installation-compliance management system, allowing contractors to provide a professional report of test results to the installation owner/occupier and to maintain computer-based records for the required statutory period.

15.4.5 Appliance testing

One of the most important safety-assurance aspects in the use of electricity and the requirements for ongoing inspection and testing is the aspect related to portable appliances and extension cords. Work health and safety (WHS) legislation requires that all equipment must be safe to use. Portable equipment and cords, by their very

nature, are likely to be subject to much greater risk of damage than fixed equipment and wiring, and should therefore be inspected and tested more frequently. *AS/NZS 3760 In-service safety inspection and testing of electrical equipment* sets out requirements for periodic checking and testing of portable appliances.

These periodic tests include earthing resistance, which must not exceed $1\ \Omega$ between exposed metal parts for non-double-insulated equipment. Also, insulation resistance must be greater than $1\ \text{M}\Omega$ measured between live conductors and exposed metal parts. Portable RCDs must be tested for operation within the maximum tripping time and tripping current for the particular type of RCD (see **Chapter 14**). Equipment and leads must be inspected for visually obvious damage or deterioration. Intervals between inspection and tests vary from three months to five years, depending on the activities of the environment in which they are used. For example, the heavier use of equipment on a construction site means that it requires more frequent attention than equipment used in an office environment.

Descriptions of testing equipment in this chapter may also be applied to portable testing equipment. However, purpose-built testing devices are available that help to assure the accuracy and improve the efficiency of such testing.

The instrument specifically designed for testing portable appliances, typical of units commonly used, is illustrated in **Figure 15.37**.

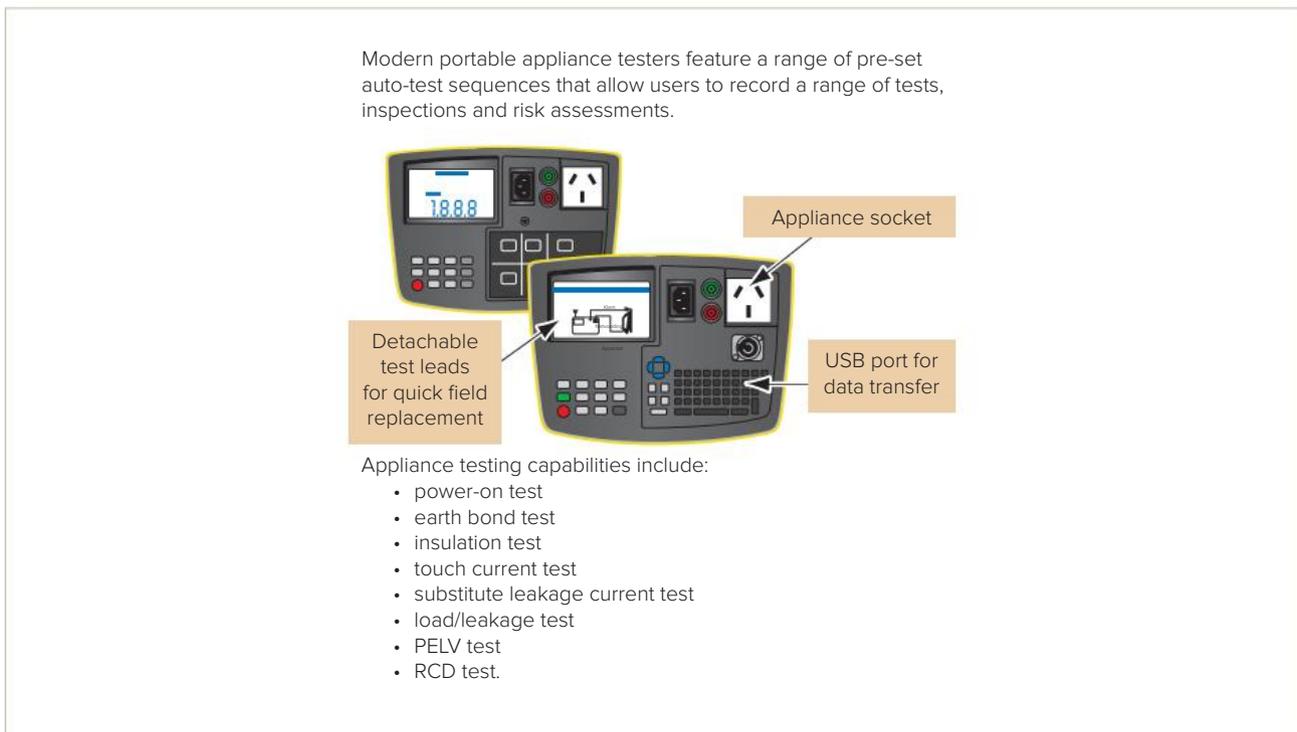


FIGURE 15.37 Portable appliance tester



CHECK YOUR UNDERSTANDING

10. Which chapter of *AS/NZS 3000* deals with verification and testing of new and existing installations?
11. What verification procedure can be undertaken without instruments?
12. What should be applied to any opened isolator or circuit-breaker before testing?
13. How should an ES lamp holder be connected?
14. Which clause of *AS/NZS 3000* contains information concerning socket-outlet pin connections?

15.5 Fault-finding and performance testing

As stated earlier in this chapter, the purpose of electrical testing together with inspection is to verify whether an electrical installation complies with the requirements of the *Wiring Rules* and operates as intended. In other words, the purpose of verification is to find and rectify any defects, that is, faults, in the wiring and equipment that have occurred during the installation. Such defects or faults may be the result of mistaken connections, as shown in **Figures 15.30** and **15.31**, not complying with a particular clause in the *Wiring Rules* or damage by others during construction.

Although the same basic testing methods used in verification of an installation apply to finding and rectifying faults in an existing installation, an investigative approach is needed because many aspects of the installation will not, at first, be known. A guide to initial investigation of a fault is given in **Table 15.7**.

TABLE 15.7 A guide to initial investigation of a fault

Step		Analysis
1	Understand the nature of the reported fault.	Question the person who reported the fault: ‘When did you realise there was a fault?’ ‘What happened when you turned the switch on?’ ‘How do you normally operate the equipment?’ ‘Have you had any structural work done recently?’
2	Carry out a visual inspection.	Look, listen and smell for signs of mechanical or electrical damage, sounds of arcing and the smell of burnt insulation. Observe the location switches and switching positions.
3	Determine how the circuit is wired and arranged.	Do not rely on as-installed drawings. Trace out circuit wiring. Sketch a diagram of the circuit and a switching chart. Recall series and parallel components in common circuit arrangements.
4	Check for any safety hazards.	Use safe work methods for specific hazards. Use safe work methods for fault-finding procedures.
5	Undertake electrical testing, following relevant safe work methods.	Apply first principles to interpreting test results: i.e. $I = \frac{V}{R}$ and $P = I^2R$. Take advantage of split-half testing.

The next steps are to eliminate the possible causes and identify and rectify the actual cause, as outlined in **Table 15.8**. Keep in mind that, apart from damage through natural events or the work of others, the majority of faults occur at connections in switching accessories and current-using devices, and are the result of a breakdown in either continuity (open circuit) or insulation (short circuit), the direct cause being ingress of moisture or dust, wear and tear or just poor selection and/or installation of equipment in the first instance. In the case of motors, it can also be a mechanical fault in the load that the motor drives, such as a pump or fan reflecting back into the circuit as an overload.

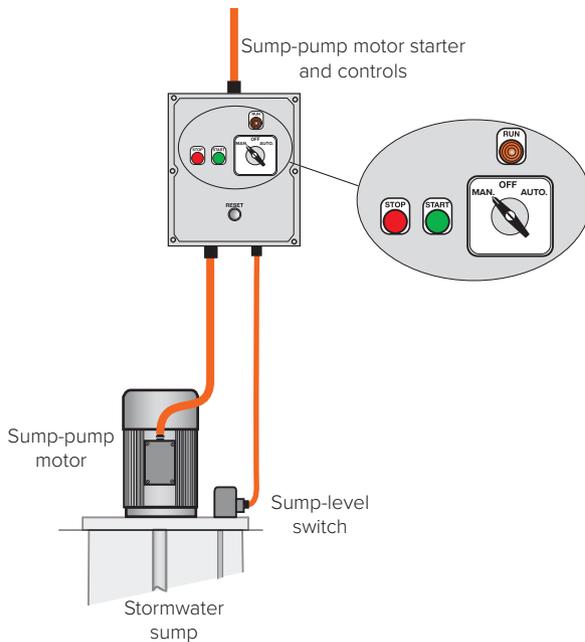
In fault-finding, some energised testing cannot be avoided, such as testing to determine that supply is available at various points in a circuit. Load testing of a motor, as illustrated in **Figure 15.9**, can only be done on an energised circuit. However, as previously discussed, most open-circuit and short-circuit faults can be located by de-energised testing.

Fault-finding exercise 15.1 shows the importance of a visual inspection. **Fault-finding exercise 15.2** shows the importance of following a methodical process for finding a fault in a multi-switched circuit. **Figure 15.38** shows the complete circuit for this exercise.

TABLE 15.8 Fault symptoms and possible causes

Symptom	Possible cause	Investigate further for
Fuse is blown or circuit-breaker is tripped.	Overload Short circuit between actives, active to protective earth or neutral	Too much connected load on the circuit Damage to wiring by others doing non-electrical work Faulty connections at switchboard, accessories or current-using devices Damaged or deteriorated wiring (usually in older installations)
Current-using device does not operate with circuit energised.	Human error Faulty current-using device Control device not operating Open-circuited supply	A switch operated incorrectly Internal open circuit Mechanical fault Faulty control device (field switches, sensors and the like) Faulty control switches Open-circuited control circuit wiring Faulty connections at accessories or current-using devices Open-circuited power wiring
Switch is not operating correctly.	Short or open circuit	Faulty connections at accessories Faulty control wiring
RCD (known to consumers as a safety switch) constantly trips.	Leakage current too high	Faulty current-using devices Too many current-using devices on the circuit

FAULT-FINDING EXERCISE 15.1



A sump pump in the underground carpark of a group of townhouses operates to transfer stormwater from the carpark sump to the stormwater drain when the water in the sump reaches the level set on the level switch. It has a lockable-OFF control switch with a manual setting for testing and maintenance, and an auto setting for level switch control.

It was reported that the pump did not operate during last night's storm, causing minor flooding to the carpark. At the site all that the owner's representative can tell you is that the building is three years old and the pump has worked satisfactorily in the past.

The illustration shows what you see on initial inspection of the pump and controls.

You conduct a manual test which shows that the motor is operating correctly and pumps water.

What could you conclude?

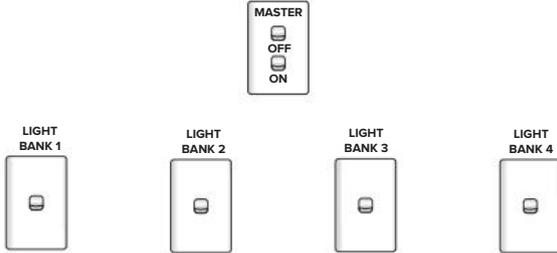
Answer

On initial inspection notice that the control switch had been left in the manual position. This means the motor is not under the control of the level switch and can only be operated by pressing the start button.

FAULT-FINDING EXERCISE 15.2

The reported problem

Each of four banks of lights in an open plan office is controlled by an individual switch. In addition, two master switches are used to switch all banks OFF and all banks ON.



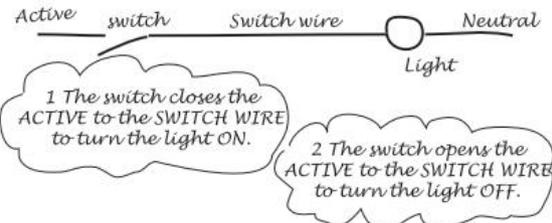
The reported problem is that the only way to switch the lights is by the master OFF switch and the master ON switch. The individual switches have no effect. The only information available from the people who work there is how the lights have normally worked.

1. Identifying the fault

No matter the number of switches when working with multiple-switching arrangements, it helps to sketch a switching chart of how the system is intended to work.

	Switch position		
	Master OFF	Master ON	Light banks
All lights OFF	OFF	OFF or ON	OFF or ON
All lights ON	ON	OFF or ON	OFF or ON
Light Banks controlled by bank switch	ON	OFF	OFF or ON as required

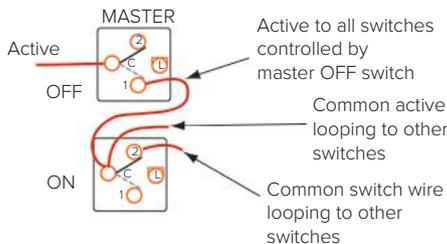
Like all circuit problems where there is no diagram, stop and think about how the circuit is arranged. Starting from first principles, sketch out the switching of a single light.



Applying this to the problem:

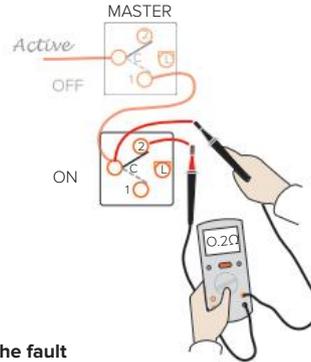
1. the master OFF switch must be making and breaking the active common to all the switches
2. the master ON switch should be switching the active to a switch wire common to all lights.

To confirm this, test at the master switches to identify the active conductor. Then isolate the supply and inspect the connections.



For the master OFF switch to be the only switch controlling the lights, the common switch wire must be connected to the common active somewhere between the master ON switch and the last lighting bank switch (i.e. short circuit between the common active and common switch wire).

This can be confirmed by a simple continuity test repeated for the on and off position of each lighting-bank switch.



2. Locating the fault

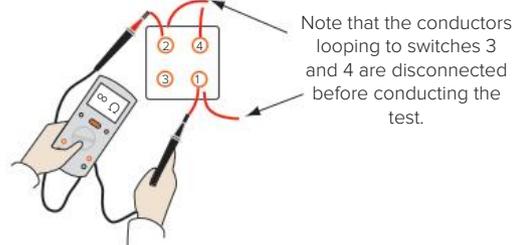
Having established that there is a short circuit between the common active and the common switch wire, the next step is to find where this has occurred. It is most likely that the fault is in one of the switch mechanisms. An inspection and test of the master ON switch shows that it is not faulty.

The most effective way of locating a fault in a circuit that connects to a number of accessories is to divide the circuit into sections and progressively test each section, narrowing down the location where the fault has occurred. This is known as a split-half test.

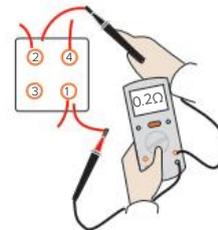
Using this method, start at the switch for light bank 2.

3. Conduct a split-half test at switch 2

The first test is between looped conductors from switch 1. Leaving them connected to the switches tests the conductors and the switch mechanisms.



The infinity result shows there is no short circuit in the conductors between switches 1 and 2 or in the switch mechanisms. This makes it necessary for a second test between the disconnected conductors looping to switches 3 and 4.

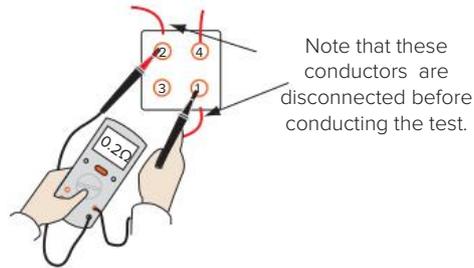


The test result of 0.2 Ω shows there is a short circuit between the conductors or in the mechanism of switch 3 or 4. The same tests are repeated at switch 3 and switch 4 until the fault is located.

FAULT-FINDING EXERCISE 15.2 (CONTINUED)

4. Conduct test at switch 4

The final test at switch 4 shows that the short circuit is in the switch mechanism.



It is now a simple matter of replacing the switch 4 mechanism. The four numbered terminals of the mechanism indicate that it is an intermediate switch.

Finally, reconnect all conductors disconnected during testing and secure all switches before testing that the system is safe and functioning correctly.

The complete circuit diagram is shown in **Figure 15.38**.

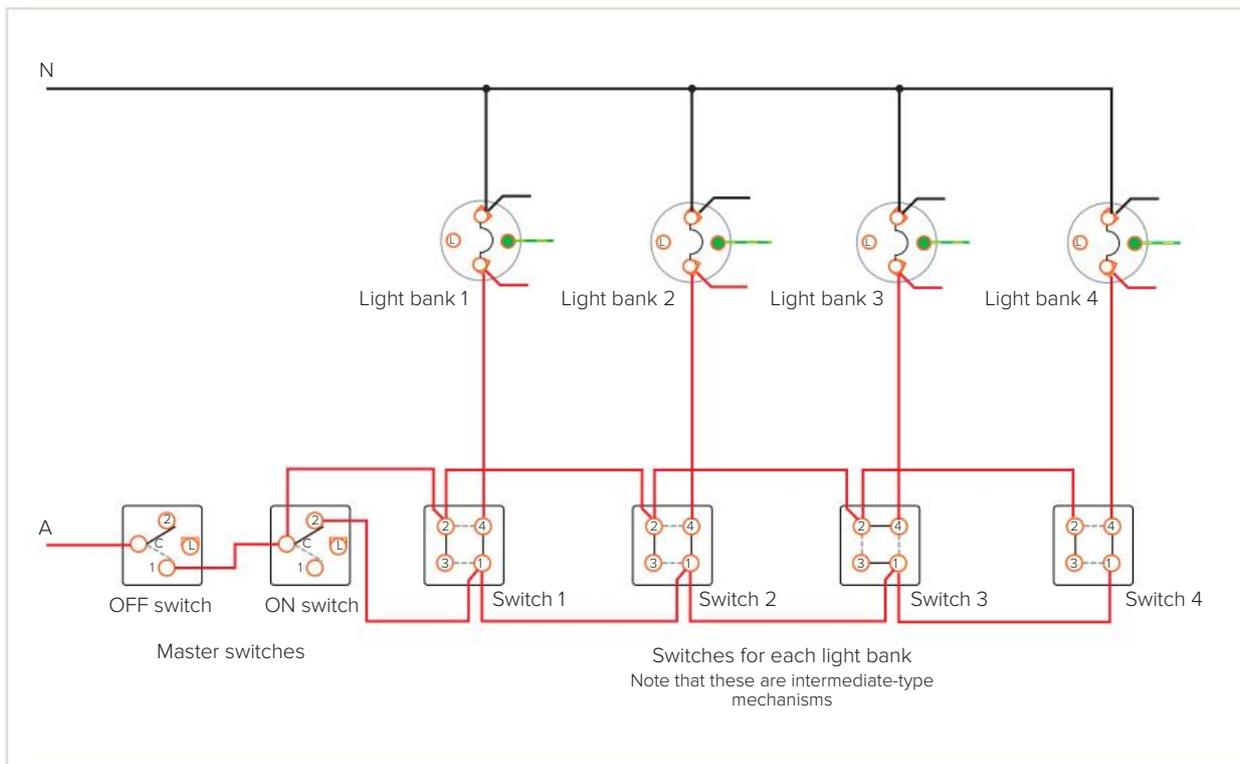


FIGURE 15.38 Complete circuit for **Fault-finding exercise 15.2**

15.5.1 Other testing devices

The testing devices so far covered in this chapter are those that measure resistance, voltage and current. However, there are other portable field devices available for fault-finding and investigating electrical system behaviour in the field. Tracing out cable runs can result in calculated guesswork for those portions that are concealed within a structure or are underground; this is where a cable-tracing device like that shown in **Figure 15.39** can be invaluable.

This line tracer is a universal cable, wire and pipe tracing and locating system. The system comprises a transmitter and a highly sensitive receiver and can be used to:

- trace live or voltage-free cables in walls, ceilings, floors and underground
- locate open and short circuits in cables and concealed junction boxes
- identify circuits with their protective devices and an individual conductor in a bundle of conductors.

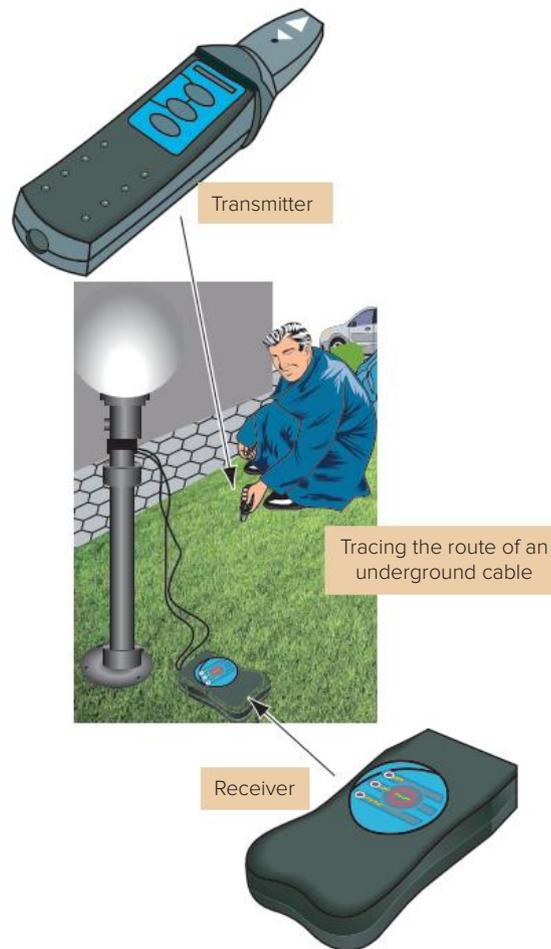


FIGURE 15.39 Cable tracing

Mechanical faults in motors and the loads they drive reflect back into the circuit as increased load and, if left unattended, can result in motor damage and extensive downtime. Thermal imagers are becoming one of the more important diagnostic instruments used to detect temperature changes in electrical and mechanical equipment to indicate a present or pending problem. **Figure 15.40** gives some examples of the scope of application of these devices.



FIGURE 15.40 Applications of thermal imagers

JH Photo/Alamy Stock Photo

Electricians are often called on to evaluate installations for a proposed alteration or addition, for improving energy efficiency or to investigate a functional problem in a system. Whatever the purpose, this is likely to require some sort of electrical testing and measurement. Much of the complexity of electrical systems comes from switching transients and the expanded use of electronic switching devices that create harmonics in the distribution system which may, in turn, diminish the operation of other equipment.

See **Figure 15.41** for some examples of power quality measurement and analysis meters.



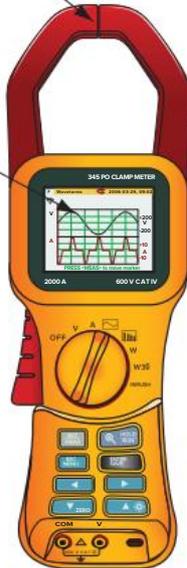
CHECK YOUR UNDERSTANDING

15. What instrument would you use to detect problems in electrical and mechanical equipment such as hot joints or overloads?
16. Name two possible causes of a tripped circuit-breaker.
17. Name two possible causes of a tripped RCD.

Hall effect clamp meter for measuring a.c. and d.c. currents

Real-time parameters displayed

On-screen set-up guide



This single-phase clamp-on meter is a combination power analyser, power quality logger and clamp meter, and is ideal for monitoring and fault-finding power quality on switching loads. The internal memory enables long-term power quality logging for analysis of trends or intermittent problems.

Applications include:

- set up and troubleshoot variable-frequency drives and UPS systems to verify correct operation
- harmonics measurements for uncovering issues that can damage or disrupt critical equipment
- inrush capture to check start-up current where spurious resets or nuisance circuit-breaker tripping occurs
- load studies to verify electrical system capacity before adding loads.

This three-phase power quality meter helps locate, predict, prevent and find problems in power distribution systems. Three-phase parameters are displayed and recorded in real time.



Applications include:

- fault-finding
- predictive maintenance planning
- validating incoming power quality
- long-term analysis to uncover hard-to-find or intermittent issues
- verifying electrical system capacity before adding loads
- quantifying energy consumption before and after improvements to justify energy-saving devices.

FIGURE 15.41 Power quality measurement and analysis meters

SUMMARY

- ▶ It is important to follow safe working procedures when testing electrical installations—testing should be conducted on de-energised circuits. Only if de-energised testing is not viable and the proper safety measures are used is testing of energised circuits acceptable.
- ▶ Some tests can only be performed if the circuit is de-energised.
- ▶ The most common electrical testing devices for electricians are those that give a visual/audible indication of the effect being tested and those that measure the actual voltage, current or resistance of a circuit.
- ▶ In order to correctly carry out testing, it is important to have a sound understanding of which testing device is appropriate for each situation.
- ▶ Effective electrical testing requires the correct equipment and the correct procedure to be followed.
- ▶ *AS/NZS 3000* specifies a number of mandatory tests that must be performed on electrical installations.
- ▶ Once testing has been completed the energy distributor must be notified in writing that the installation is safe, complies with regulations and is ready for connection to the supply. Local supply authorities and others provide documentation to record compliance and test results.
- ▶ Insulation-resistance testing can only be performed on a de-energised installation. It is important to ensure that when power is switched on no short circuits exist.
- ▶ An initial test of an RCD must be followed by regular subsequent tests to verify that it is going to provide supplementary protection for subcircuits.
- ▶ Fault finding and performance testing require a structured and methodical approach in order to locate and rectify any issues.

REVIEW QUESTIONS

1. Under what conditions is the testing of energised circuits acceptable?
2. Name a test that can only be performed with the supply de-energised.
3. What are the major risks associated with electrical testing?
4. List the four categories of voltage measuring equipment.
5. Describe a good safety practice when setting a selectable range on a test instrument.
6. What is the fundamental safety process to be carried out before conducting de-energised testing?
7. Give an example of an electrical problem caused by a mechanical failure.
8. What result from a continuity test shows that a conductor is continuous?
9. Why is it necessary to take care in placing an ohmmeter in a circuit?
10. What common testing devices are used by electricians?
11. Describe how a clamp meter is used.
12. Why is it necessary to adjust an ohmmeter to zero before taking resistance readings?
13. What are the responsibilities of electrical contractors on completion of new installations?
14. Summarise the purpose of a visual inspection for verifying compliance.
15. How are non-compliance defects avoided at the final inspection and testing stage of an installation?
16. The insulation resistance is tested between which two components of an installation?
17. State the polarity arrangement for an Edison screw lamp holder.
18. Give an example of the application of a phase-rotation meter.
19. List the advantages of a programmable installation tester.

CHAPTER 16

Installation planning and design—selecting cables and protective devices

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ explain the factors affecting installation design
- ▶ understand the content of Standards used in selecting cable for an electrical installation
- ▶ arrange an electrical installation into circuits and allocate the number of points on a circuit in accordance with *Wiring Rules* requirements
- ▶ describe the factors affecting the type and size of cables selected for particular circuits
- ▶ explain how different environmental and operational factors affect the current-carrying capacity of a cable
- ▶ use *AS/NZS 3008.1* to select cables based on the minimum current-carrying capacity for a given circuit
- ▶ use *AS/NZS 3008.1* to select cables based on voltage drop using A.m/V values for a given circuit
- ▶ select cables based on earth fault-loop limitations
- ▶ explain the meaning of the short-circuit temperature performance of cables.

As mentioned in **Chapter 5**, there is a design aspect to planning an installation. Before giving a quotation, ordering materials or commencing work, the following information about the job must be known:

- ▶ type and load of the current-using equipment in the installation
- ▶ current required to supply the installation
- ▶ most effective arrangement of circuits for the installation
- ▶ current demand of each circuit
- ▶ circuit protection
- ▶ most suitable wiring systems and cable types
- ▶ route length of cables
- ▶ cable conductor sizes.

This chapter deals with these design aspects and the process of selecting cables and protective devices for particular applications. It draws attention to compliance requirements and reference materials from *AS/NZS 3000 Wiring Rules* and *AS/NZS 3008.1.1:2017: Electrical installations—Selection of cables Part 1.1: Cables for alternating voltages up to and including 0.6/1 kV—Typical Australian installation conditions*.

NOTE: *AS/NZS 3008.1.2* covers New Zealand installation conditions.

Other information that must be determined in a design includes prospective fault current and overcurrent protection needs, which have been covered in **Chapter 13**.

16.1 Factors affecting installation design

The electrical installation process starts with the design. No matter how small an installation is, there are a number of fundamental points to consider. *Clause 1.6.1* of the *Wiring Rules* requires that an electrical installation must be safe for people to use, must function correctly and must be compatible with the electricity supply.

To start with, the installing electrician needs to have a clear understanding of the factors that affect how the installation is to be designed. **Figure 16.1** outlines factors to consider related to the available supply and **Figure 16.2** outlines factors related to the installation itself.

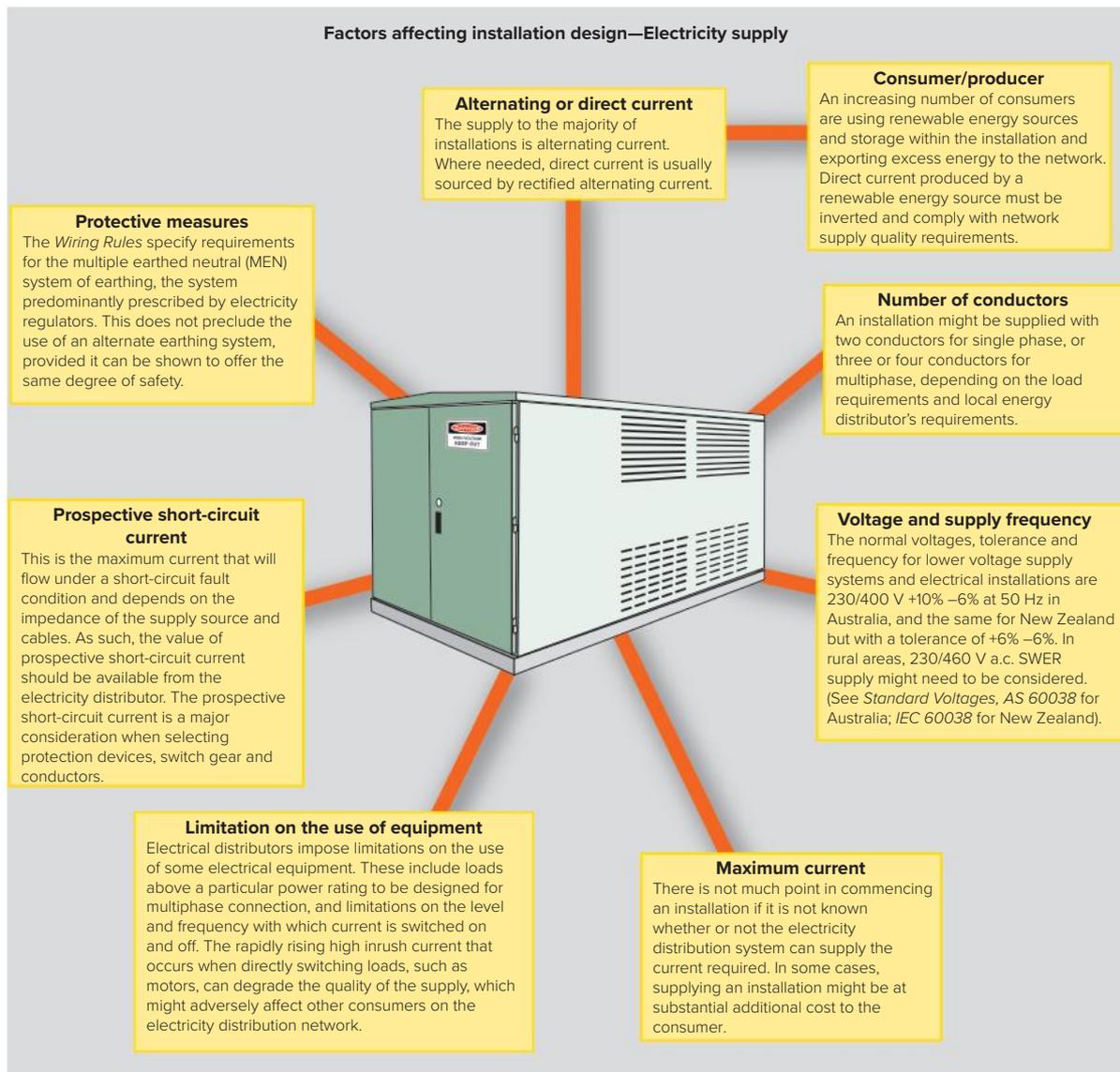


FIGURE 16.1 Factors affecting installation design—electricity supply

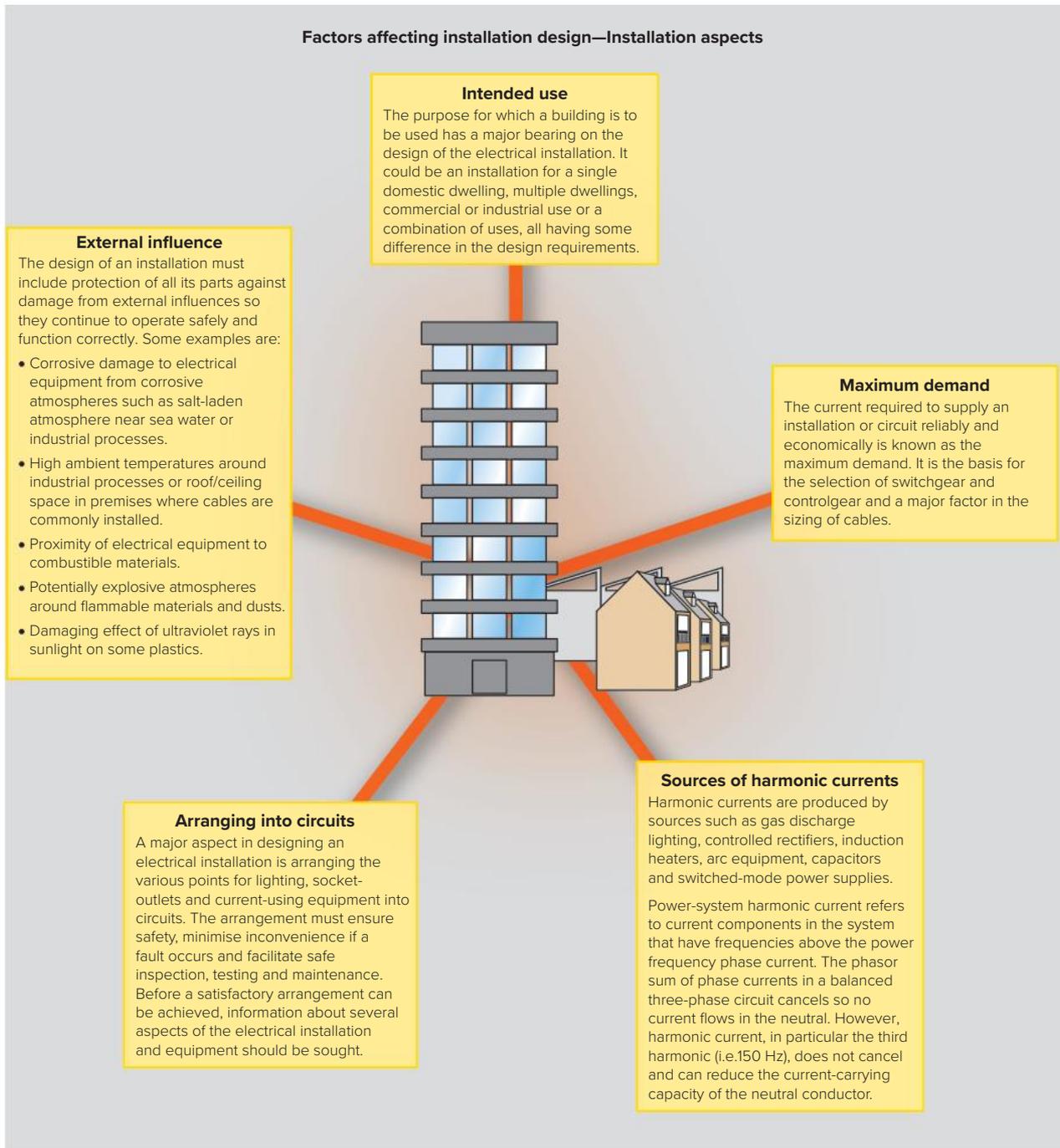


FIGURE 16.2 Factors affecting installation design—installation aspects

Figure 16.3 shows the relationships between the main clauses of the *Wiring Rules* and the selection Standards, to clarify what might appear at first to be a complicated set of requirements for arranging and selecting equipment for electrical installations.

At this point, it is appropriate to review the clauses and appendices of the Standard series *AS/NZS 3008.1: Electrical installations—Selection of cables. Part 1* of the series is based on the temperature conditions of Australia, while *Part 2* applies to New Zealand (see **Figure 16.4**).

Clause 3.4.1 of the *Wiring Rules* specifies that ‘Every conductor shall have a current-carrying capacity in accordance with *AS/NZS 3008.1.1*, not less than the current to be carried by’.

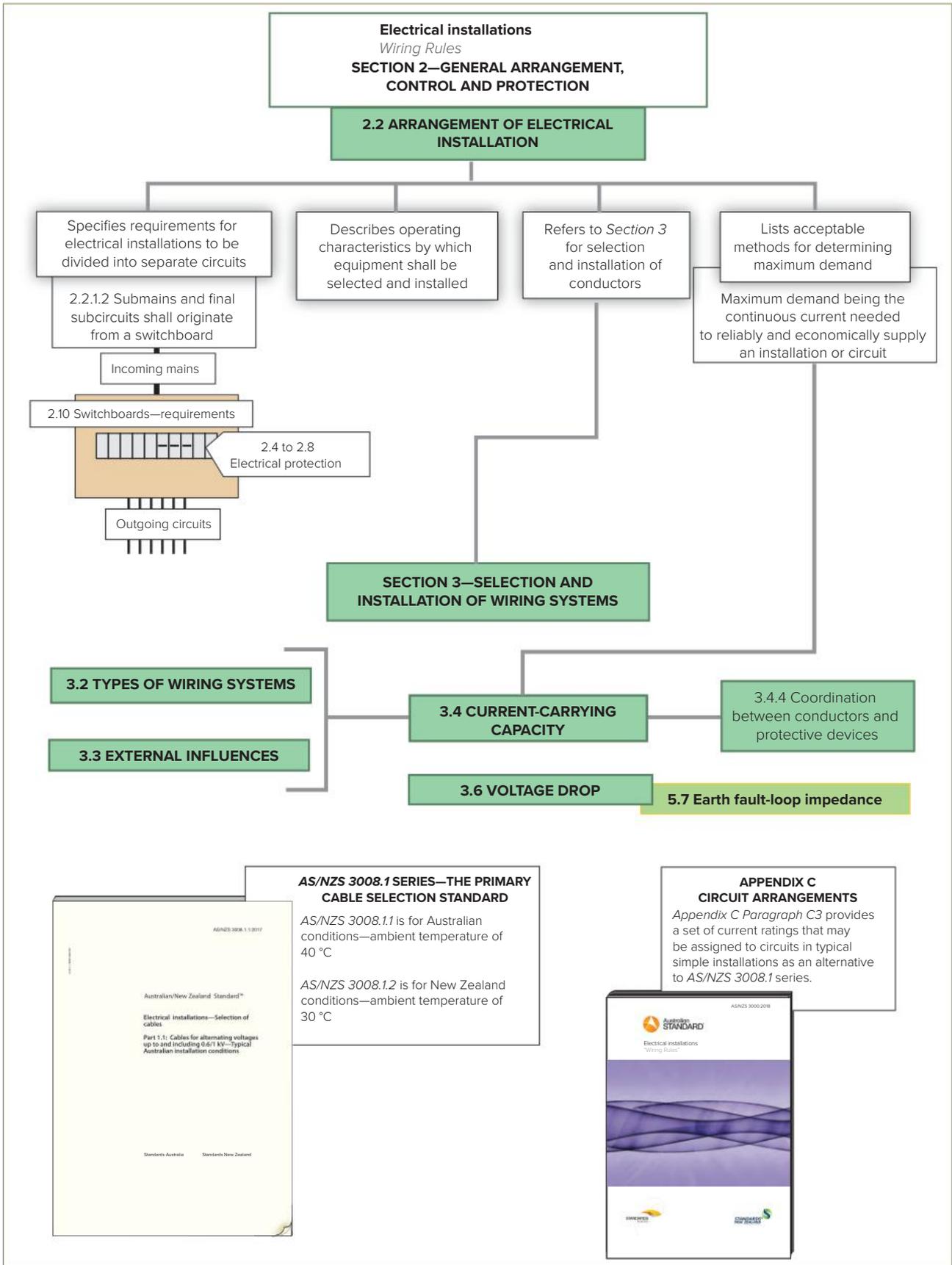


FIGURE 16.3 Relationships of *Wiring Rules* clauses and selection Standards

Graphic created using information from the *Wiring Rules* © Standards Australia Limited. Copied by McGraw-Hill with the permission of Standards Australia and Standards New Zealand under Licence CLE0722MGH

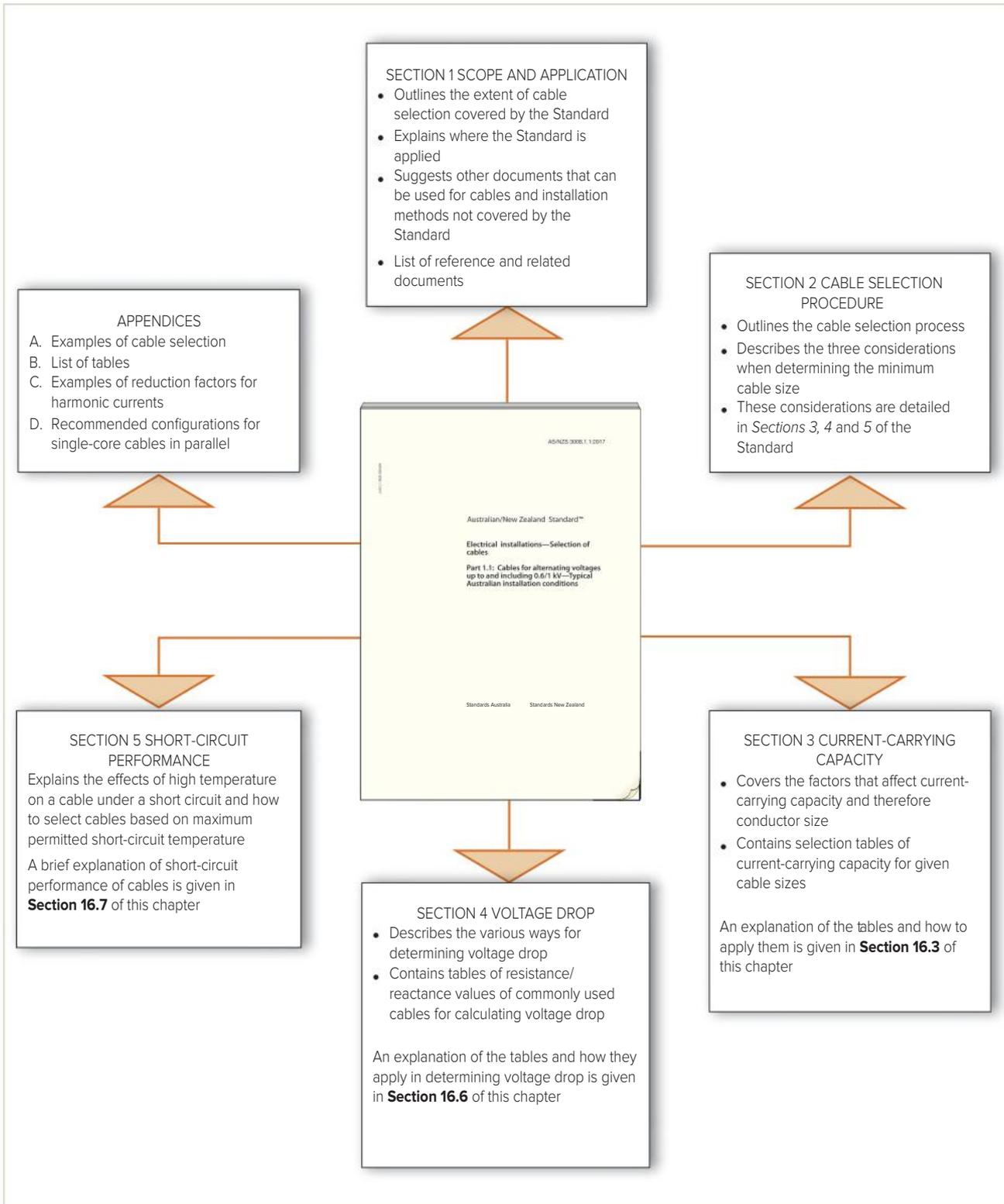


FIGURE 16.4 Overview of AS/NZS 3008.1



CAUTION

An electrical installation must be designed so that it is both safe and convenient to operate and maintain. To comply, the wiring system must satisfy the *Wiring Rules* and the energy distributor's requirements, as well as the conditions set down in any job specification or design brief. Specifically:

- ▶ Various current-using equipment shall be divided into a logical arrangement of circuits (*Clause 2.2*).
- ▶ The wiring system shall be able to withstand the environment in which it is installed and its intended use without deterioration or damage (*Clause 3.1.2 (e) and (f)*).
- ▶ Cables shall be able to carry the current demanded by the load without overheating (*Clauses 3.1 and 3.4*).
- ▶ Cables shall be able to carry the current demanded by the load without exceeding the maximum permissible voltage drop (*Clauses 3.1.2 (b) and 3.6*).
- ▶ Cables shall be protected from damage by overcurrent (*Clause 2.5*).

AS/NZS 3008.1.1 thus becomes the reference for cable selection, covering the cable types and installation methods in common use and for working voltages up to and including 0.6/1 kV a.c. This Standard may seem a bit daunting at first glance, with its five sections, 62 tables and two appendices, but when seen in its logical arrangement it becomes fairly straightforward to use.

Although *Appendix C Paragraph C3* of the *Wiring Rules* provides current ratings for simple installations, the authors of this text emphasise that all competent electricians must be skilled in using *AS/NZS 3008.1.1*.

Clause 1.3 of *AS/NZS 3008.1.1* mentions alternative specifications that may be used for determining the current-carrying capacity of certain cable types, and installation methods not covered by the Standard.



CHECK YOUR UNDERSTANDING

1. What must be known about an electrical installation before any work can commence?
2. Explain how the available electricity supply may affect the installation design.
3. What *Wiring Rules* requirements for the wiring system must be met in the design of an electrical installation?
4. List the factors affecting installation design.
5. Outline cable-selection procedures given in *AS/NZS 3008.1 Section 2*.

16.2 Arranging an electrical installation into circuits

A major aspect of designing an electrical installation is arranging the installation into circuits as required by the *Wiring Rules, Section 1 Clause 1.6.5* with the deemed-to-comply arrangement given in *Section 2 Clause 2.2 Arrangement of electrical installations and other related clauses* (as shown previously in **Figure 16.3**).

The arrangement of an electrical installation must ensure safety, minimise inconvenience if a fault occurs, and facilitate safe inspection, testing and maintenance. Before a satisfactory arrangement can be designed, information about several aspects of the electrical installations and equipment should be discovered. Some considerations are raised in **Figure 16.5**.

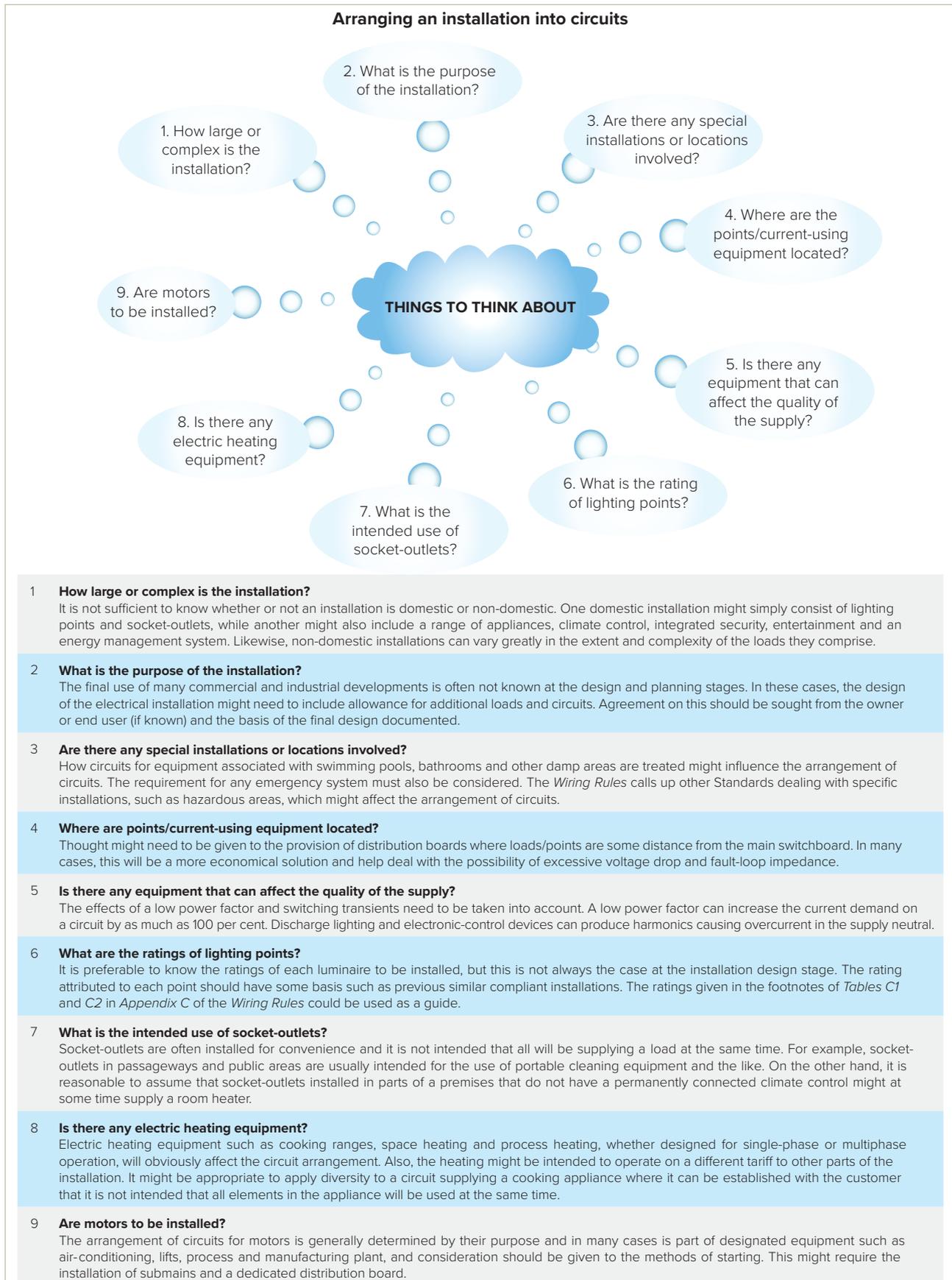


FIGURE 16.5 Arrangement of circuits—things to think about

Typically, separate circuits are allocated for:

- ▶ lighting
- ▶ socket-outlets
- ▶ heating appliances
- ▶ cooking appliances
- ▶ air-conditioning appliances
- ▶ motors that drive plant and machinery
- ▶ control and monitoring equipment
- ▶ the various safety services.

The number and type of circuits required are to be determined by the loads on the circuits and the expected variations in loads. This may include the use of more than one distribution board, meaning that submains will be part of the installation arrangement. Typical situations where additional distribution boards are used are shown in **Figure 16.6**.

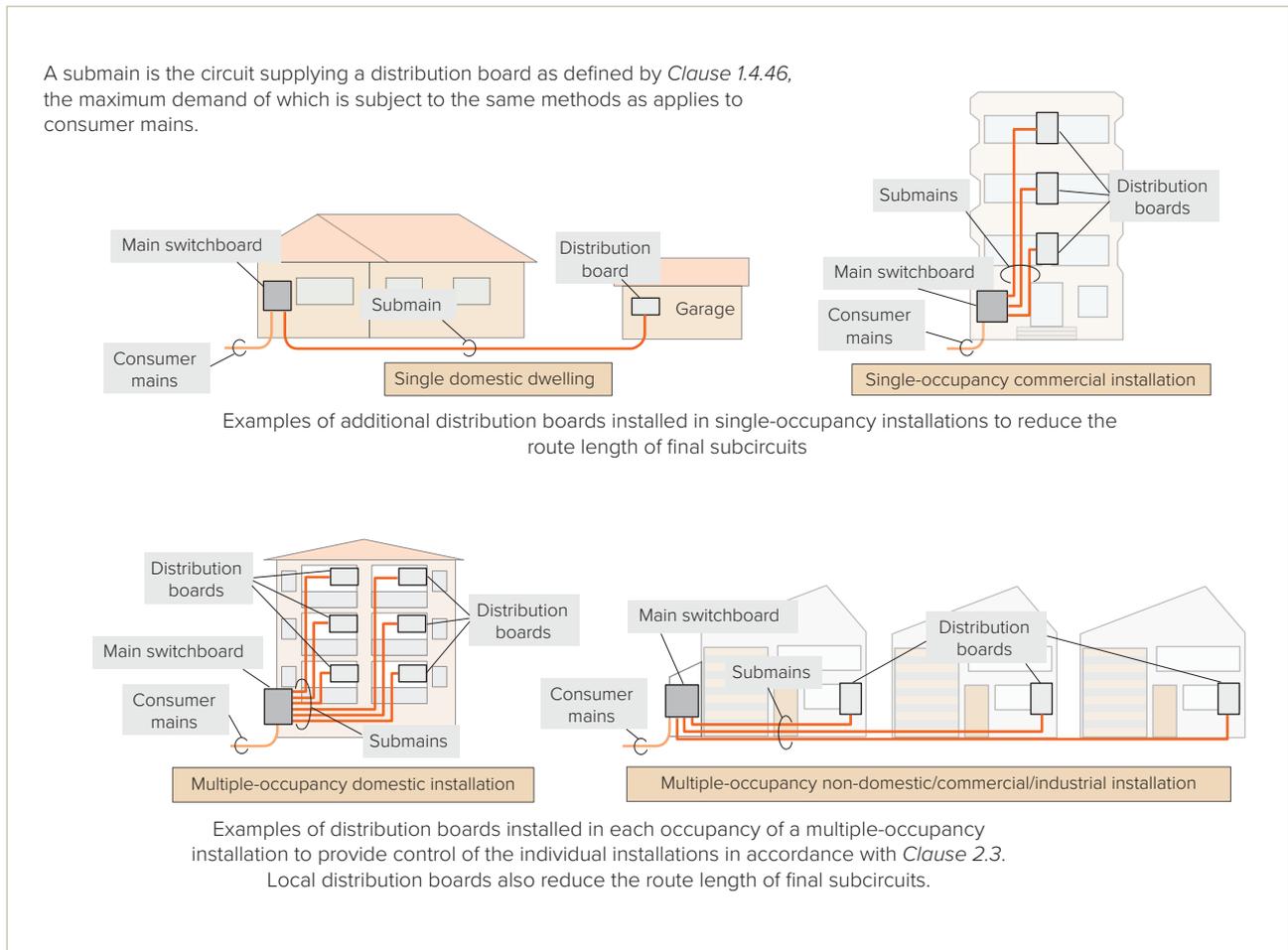


FIGURE 16.6 Using more than one switchboard—typical situations

16.2.1 Number of points on a circuit

Even though the *Wiring Rules* only gives guidance in allocating the number of points that may be connected to one circuit, the factors outlined in **Figure 16.7** should be considered before deciding the number of points to connect on each circuit.

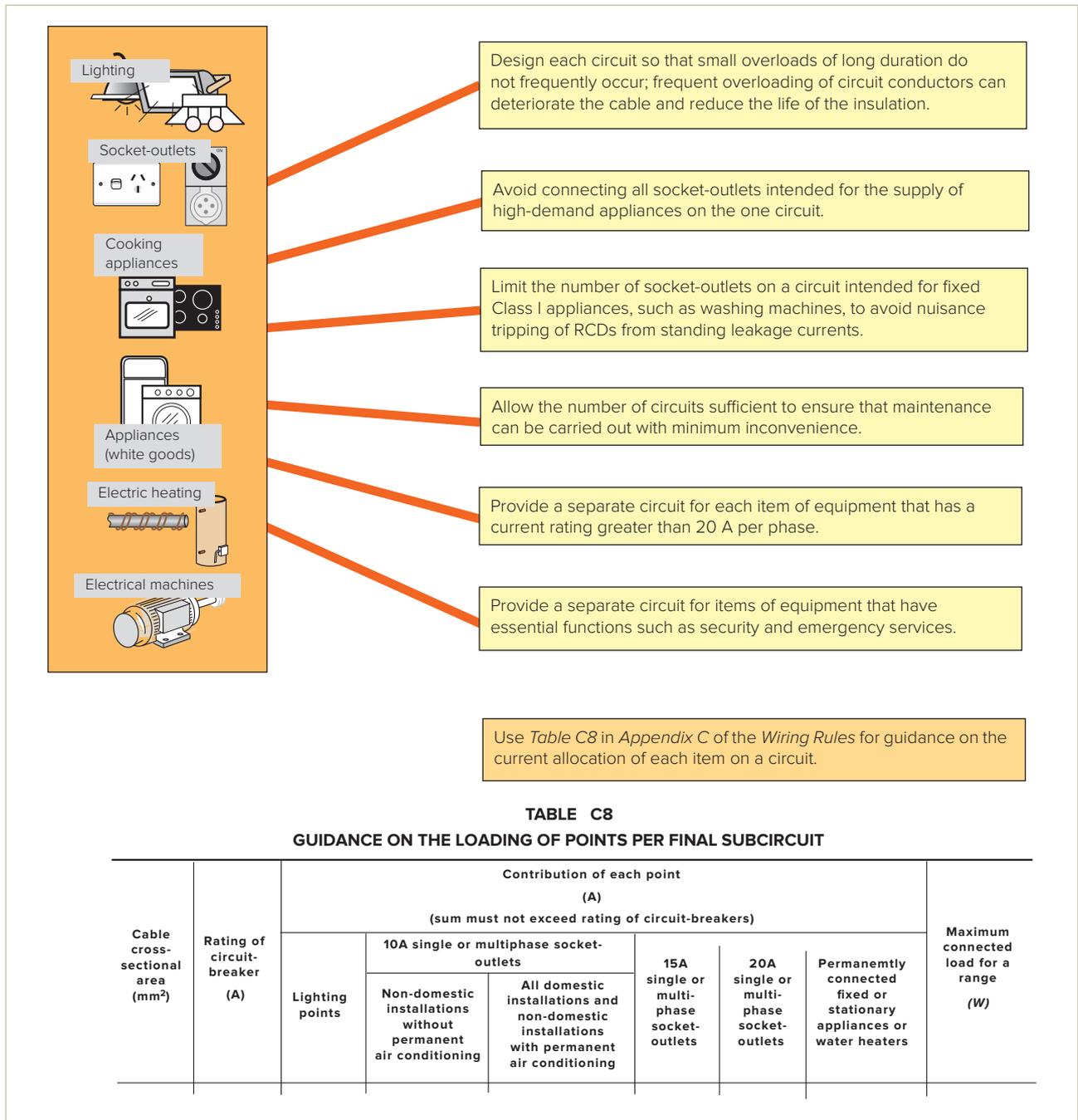


TABLE C8
GUIDANCE ON THE LOADING OF POINTS PER FINAL SUBCIRCUIT

Cable cross-sectional area (mm ²)	Rating of circuit-breaker (A)	Contribution of each point (A) (sum must not exceed rating of circuit-breakers)						Maximum connected load for a range (W)
		Lighting points	10A single or multiphase socket-outlets		15A single or multiphase socket-outlets	20A single or multiphase socket-outlets	Permanently connected fixed or stationary appliances or water heaters	
			Non-domestic installations without permanent air conditioning	All domestic installations and non-domestic installations with permanent air conditioning				

FIGURE 16.7 Working out how many points should be connected to one circuit

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The features of cables themselves that limit current-carrying capacity are shown in the next section in **Figure 16.9**.

One major consideration for having a number of circuits is to prevent frequent overload on the circuit. Repeated high current on a circuit, whether or not the protective device operates, will put high stress on the cables, connections, protective devices and the actual equipment itself. There can also be the added problem of excessive voltage drop in the cable. This is explored further in **subsection 16.3.3** of this chapter. Nuisance tripping due to overloads can also cause problems in other circuits due to voltage surges and some equipment being shut down that should not have problems.

When designing a system, it is quite important to follow the requirements outlined in *AS/NZS 3000* and *AS/NZS 3008.1* by ensuring the correct size cable and protective device is utilised for the different loads. Regardless of the number

of circuits and the number of points connected on one circuit, the requirements for protection and safety must all be met. In other words, the rating of the circuit protection device must not be greater than the current-carrying capacity of the cable, and the current-carrying capacity of the cable must be sufficient to supply the load under the expected normal operating conditions.



CHECK YOUR UNDERSTANDING

6. List the factors that should be considered when arranging an electrical installation into circuits.
7. When arranging an installation, why should you consider the intended use of socket-outlets?
8. What effect could the installation of electric motors have on how an installation is arranged?
9. What effect does frequent overloading have on circuit wiring?
10. Name an advantage in arranging an installation with a distribution board remote from the main switchboard.

16.3 Factors affecting cable selection

Once the arrangement of circuits is decided, the cables for each circuit are selected. Before this can be done, a number of interrelated factors must be well thought out. Apart from the economic aspects, the installation designer must take into account the current requirements of the installation and circuits (maximum demand), external influences, installation methods and limitation requirements of voltage drop, earth fault-loop impedance and, in some circumstances, cable short-circuit performance. Each of these is discussed in this section.



DID YOU KNOW?

Manufacturing standards allow an RCD with a rated tripping current of 30 mA to have a tolerance of ± 7.5 mA, while standards for Class 1 appliances permit a standing leakage current not exceeding 5 mA. Remember: too many such appliances connected to one circuit will likely cause nuisance tripping.

For example, a 30 mA RCD has an actual tripping current of 24 mA. There are seven power supplies for charging batteries on the circuit, each with a leakage of 3.5 mA. $7 \times 3.5 = 24.5$ mA. The RCD would be tripping at random times yet would pass all tests. An electrician will need to know these nuisances when designing an installation.

16.3.1 Maximum demand

The continuous current required to supply an installation or circuit effectively (i.e. reliably and economically) is known as the maximum demand (see **Figure 16.8**). This is the basis for the selection of switch gear and control gear, and is a major factor in the sizing of cables.

The experience of energy distributors over many years, together with statistical and field research, has shown that the level of continuous current needed to supply an installation is somewhat less than the total current of all the individual loads (i.e. current-using equipment) in an installation. This is because either not all loads are switched on at the same time and/or when they are, some are switched on only for short periods. The same is true for the final subcircuits supplying a varying load, such as those supplying cooking and welding equipment.

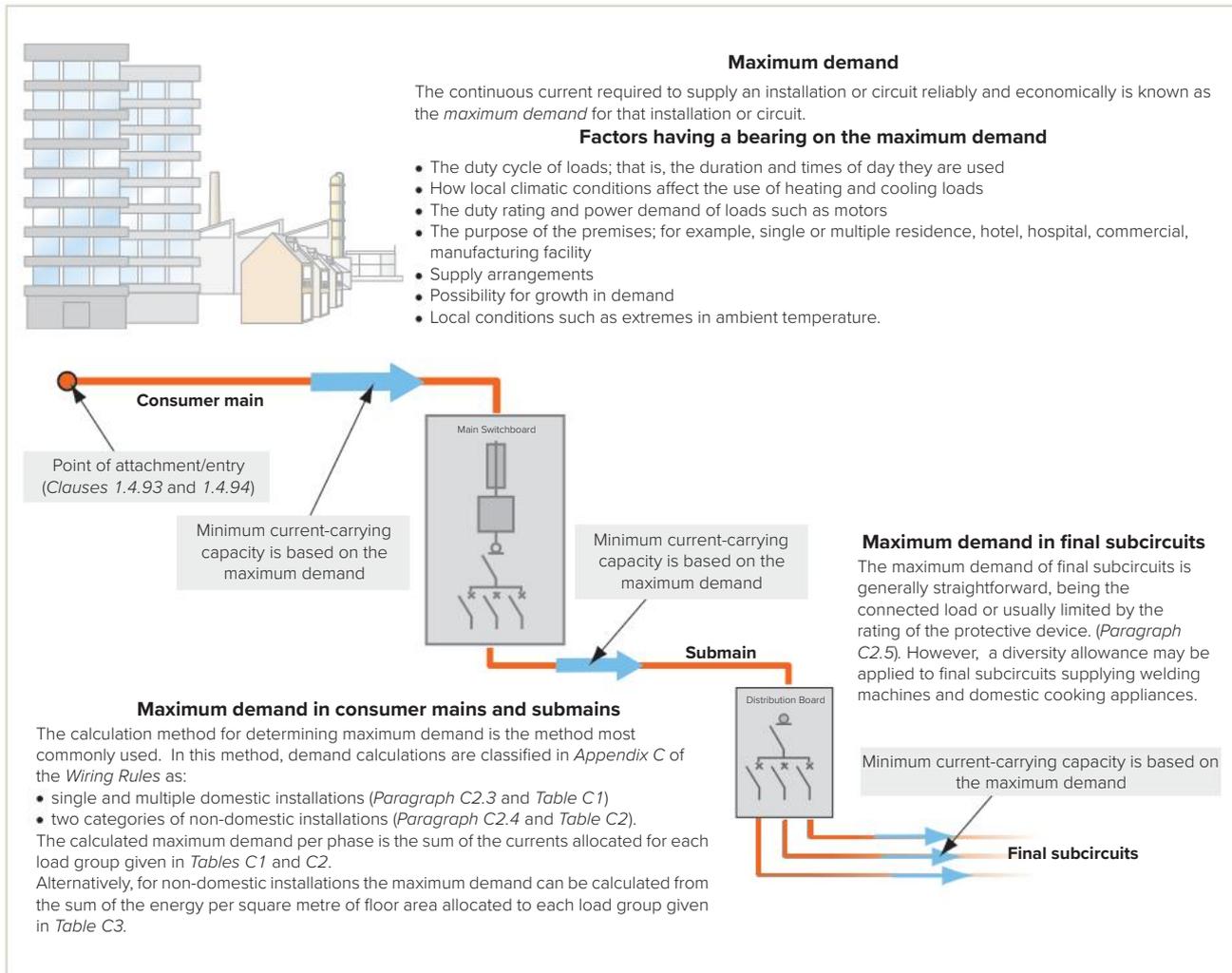


FIGURE 16.8 About maximum demand

16.3.2 Current-carrying capacity of cable

The maximum continuous current that a cable can carry without exceeding its maximum permissible temperature is known as the current-carrying capacity of the cable.

NOTE: Heat is produced in a conductor when it carries current due to the conductor's resistance. The amount of heat produced is expressed as:

$$H = I^2 R t$$

where H = amount of heat produced in joules

I = cable current in amperes

R = resistance of cable in ohms

t = time for which current flows in seconds.

The resistance of a conductor decreases with an increase in its cross-sectional area (CSA) and therefore less heat will be produced for the same current.

The heat produced in the conductor is an energy loss, known as the I^2R loss.

NOTE: A de-rating factor is used where the condition under which it applies can only result in an increased cable size, as when cables are closely grouped. See *AS/NZS 3008.1 Tables 21 to 26(2)*.

A rating factor is commonly used where the condition under which it applies can result in either an increase or a decrease in cable size, as with ambient temperature. See *AS/NZS 3008.1 Tables 27(1) to 28*.

Applying a de-rating/rating factor to a cable:

$$I_c = \frac{I_{MD}}{k}$$

where

I_c is the minimum current-carrying capacity required of the cable

I_{MD} is the maximum demand for the circuit; and

k is the de-rating/rating factor.

Applying more than one de-rating/rating factor to a cable gives us:

$$I_c = \frac{I_{MD}}{k_1 \times k_2 \times \text{etc}}$$

The features of cables themselves that limit current-carrying capacity are shown in **Figure 16.9**.

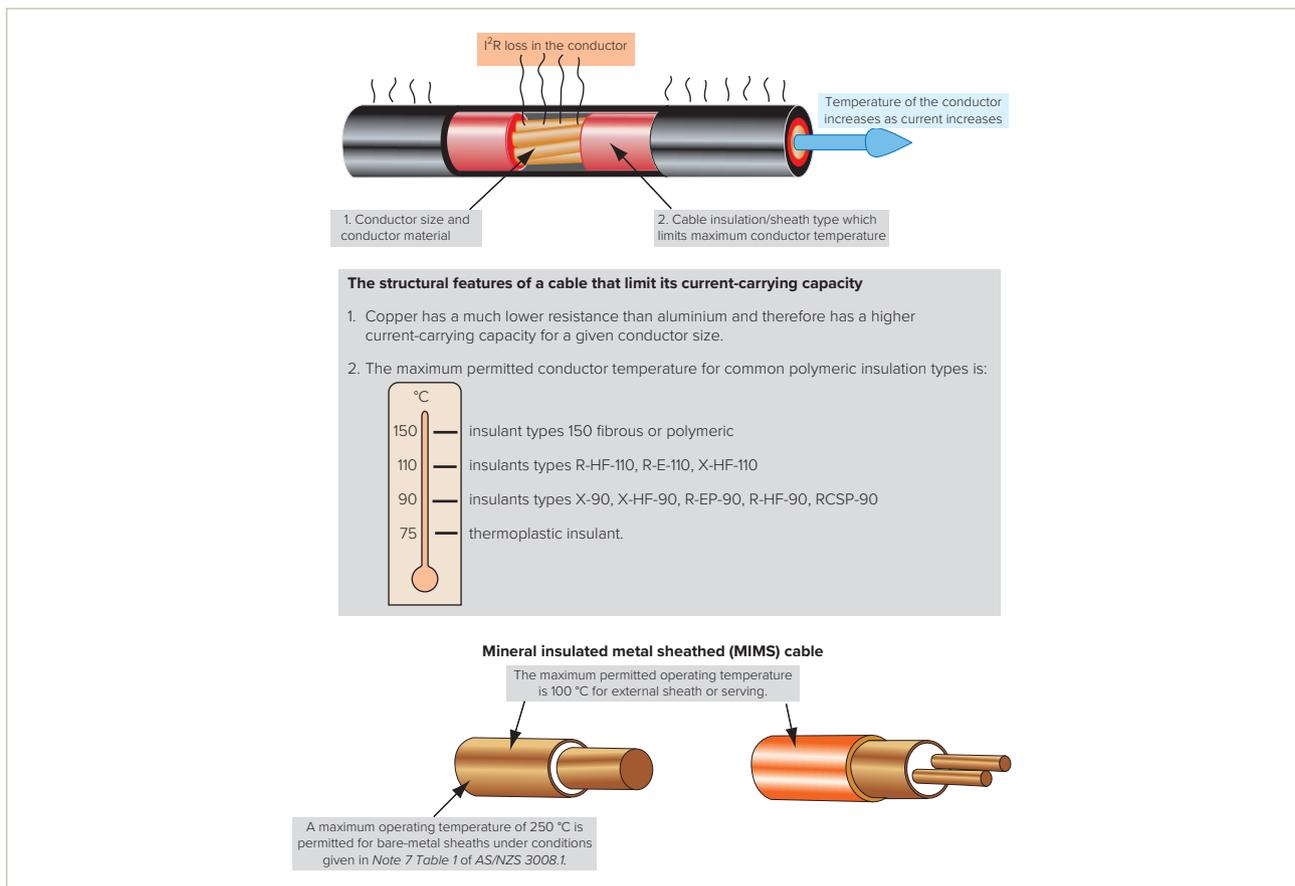


FIGURE 16.9 Features of a cable that limit its current-carrying capacity

External influences that affect cable current-carrying capacity

Apart from the features of the cables themselves, for a given maximum demand and cable type, the factors that affect the minimum conductor size needed to carry the current (current-carrying capacity) are:

- ▶ ambient temperature
- ▶ cables installed unenclosed, enclosed and/or in thermal insulation

- ▶ cable installed in direct sunlight
- ▶ grouping of cables
- ▶ cables installed in-ground
- ▶ harmonic current (due to the type of load)
- ▶ varying load.

These factors are explained in **Figures 16.10 to 16.15**.

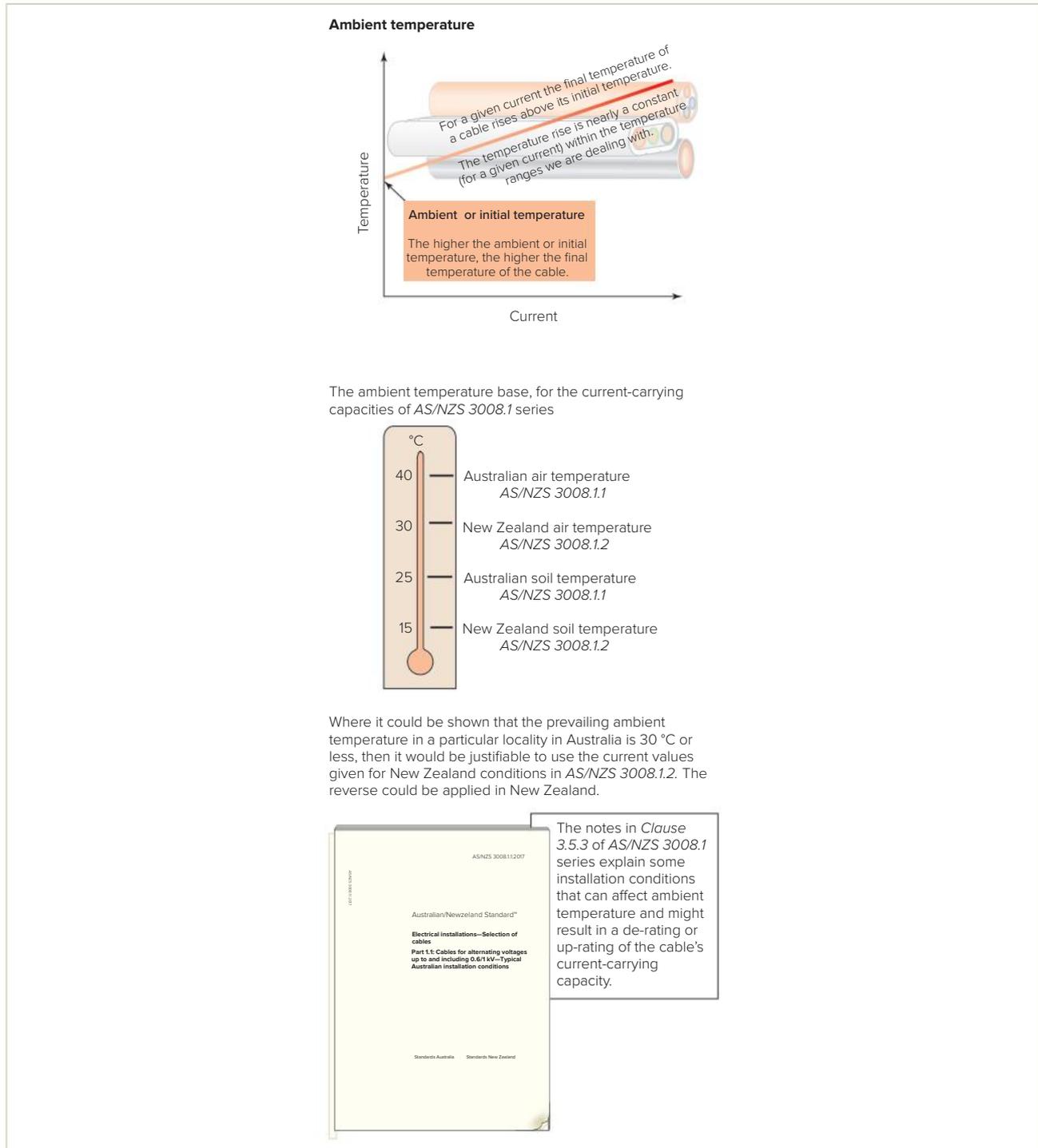
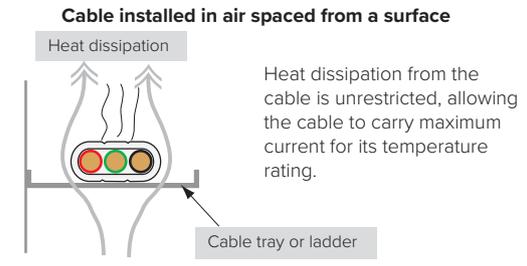


FIGURE 16.10 Effects of ambient temperature

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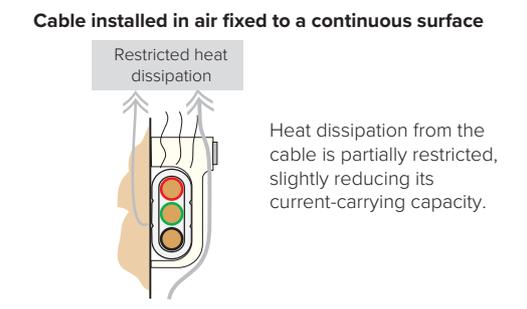
The effect of installation conditions and examples of the resulting current-carrying capacity are shown in tables in AS/NZS 3008.1

The examples are extracted from Table 10 (AS/NZS 3008.1.1) showing the current-carrying capacity of 2.5 mm² two-core sheathed cable with thermoplastic insulation (75 °C).

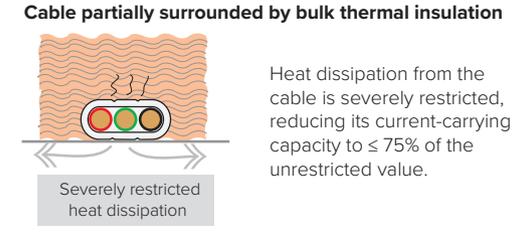


Conductor size mm ²	Cu		Al
	Solid/ Stranded	Flexible	
1	15	16	—
1.5	19	20	—
2.5	27	26	—

Maximum current-carrying capacity for ambient temperature of 40 °C



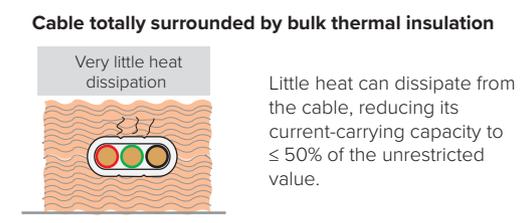
Conductor size mm ²	Cu		Al
	Solid/ Stranded	Flexible	
1	14	15	—
1.5	18	18	—
2.5	26	25	—



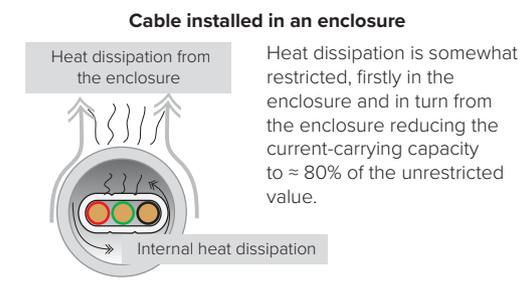
Conductor size mm ²	Cu		Al
	Solid/ Stranded	Flexible	
1	11	—	—
1.5	14	—	—
2.5	20	—	—

Conductor size mm ²	Cu		Al
	Solid/ Stranded	Flexible	
1	7	—	—
1.5	9	—	—
2.5	13	—	—

Note the dramatic reduction in current-carrying capacity compared with a cable spaced in air



Note: Bulk thermal insulation such as fibreglass batts is used to improve the energy efficiency of buildings.



Conductor size mm ²	Cu		Al
	Solid/ Stranded	Flexible	
1	13	13	—
1.5	16	17	—
2.5	23	23	—

FIGURE 16.11 Effects of installation conditions

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Effects of direct sunlight

Even though ambient temperature might be within specified limits, a cable's ability to transfer heat to the surroundings could be decreased due to its absorbing heat energy from an external radiant heat source. A prime example of this is where cables are subject to direct sunlight. Often the cable sheath colour for these situations is black, which absorbs heat quite readily.

Extracted from *Table 10 (AS/NZS 3008.1.1)* showing the current-carrying capacity of 2.5 mm² two-core sheathed cable with thermoplastic insulation (75 °C)

Spaced			Exposed to sun		
Cu			Cu		
Solid/ Stranded	Flexible	Al	Solid/ Stranded	Flexible	Al
15	16	—	11	12	—
19	20	—	14	14	—
27	26	—	20	19	—

Compare the reduction in current-carrying capacity between 'spaced' and 'exposed to sun'

FIGURE 16.12 Effects on cables installed in direct sunlight

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Cables installed in the ground

The maximum current-carrying capacity of cables installed in the ground, whether directly or in an underground enclosure, is slightly less than for the same cables installed spaced in air. The de-rating/rating factors for cable installed in the ground applicable to variations in ambient temperature and grouping of cables are shown in **Figures 16.10** and **16.13**. However, the two other factors that must be applied are the depth at which cables are laid and the thermal resistivity of the soil, as explained in **Figure 16.14**.

Effects of harmonics on balanced three-phase systems

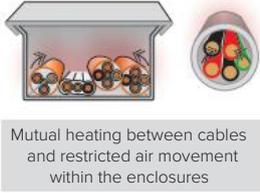
Power system harmonics are voltage or current components in the systems that have frequencies above the fundamental supply frequency. The most harmful is the 3rd harmonic, that is, 150 Hz (3×50 Hz), as it can cause overheating of line and neutral conductors, as shown in **Figure 16.15**. Higher order harmonics (e.g. the 9th and 12th) may also cause overheating if they amount to more than 10 per cent of the content of the phase current.

Varying load

The heating effect of a current is due to an average current value. Advantage can be taken of this when determining the maximum demand of a circuit, which in turn usually determines the current-carrying capacity of the circuit cables. For example, if a duty cycle can be established, an equivalent steady current can be determined under a specific design (*Wiring Rules, Clause 1.9.4*). Similarly, *Appendix C, Paragraph C2.5* provides criteria for the duty cycles of welding machines.

As explained in *Clause 3.5.6 of AS/NZS 3008.1*, the current-carrying capacities and de-rating factors given are based on continuous loading conditions on all conductors. Up-rating factors may be applied where intermittent or cyclic load variations occur or where not all conductors can be loaded simultaneously.

The effect of cables of more than one circuit installed in groups



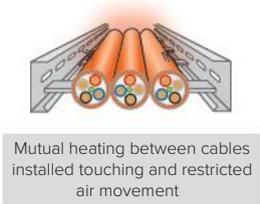
The ability of a cable to dissipate heat to the surrounding environment is reduced when it is installed in contact with cables of other circuits. Grouping cables inhibits the free circulation of air around each cable and promotes the mutual heating of the cables in the group. De-rating of cables effectively increases conductor size required.

This example is extracted from Table 22 (AS/NZS 3008.1.1) showing the de-rating factor for bunched circuits of single and multicore cables.

Item No.	Arrangement of cables (see Notes 1 & 2)	Derating factors				
		Number of circuits				
		1	2	3	4	5
1	Bunched in air	1.00	0.87	0.75	0.72	0.70
2	Bunched on a surface or enclosed	1.00	0.80	0.70	0.65	0.60

In the example of the circuits installed in conduit, the conductors are increased one size, e.g. from 2.5 mm² to 4.00 mm²

In the example of the circuits installed in trunking, the conductors are increased two sizes, e.g. from 2.5 mm² to 6.00 mm²



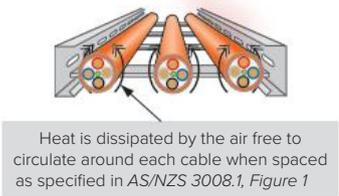
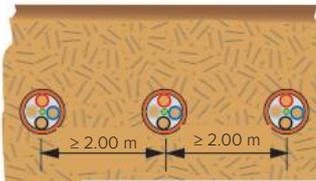
Cables of more than one circuit suitably spaced

In these examples of cables installed in ground and in air, de-rating of cables due to grouping is avoided by installing cables with sufficient clearances to prevent mutual heating.

This example is extracted from Table 24 (AS/NZS 3008.1.1) showing the de-rating factor for circuits of multicore cables installed on supports in air.

Item No.	Installation	Number of tiers or rows of cable supports	Derating factors			
			Number of cables			
			1	2	3	4
13	Touching (see Note 6)	1	1.00	0.87	0.82	0.80
14		2	1.00	0.86	0.80	0.78
15		3	1.00	0.85	0.79	0.76
16	Ladder supports, racks and cleats	1	1.00	1.00	1.00	1.00

In this example of the circuits, conductors are increased in size, e.g. from 2.5 mm² to 4.00 mm²



**TABLES 25(1) TO 26(2)
DERATING FACTORS FOR GROUPING OF CIRCUITS BURIED DIRECT; IN UNDERGROUND ENCLOSURES**

SECTION 3 CURRENT-CARRYING CAPACITY

3.5 EXTERNAL INFLUENCES ON CABLES

3.5.2 Effects of grouping of cables

3.5.2.2 Installation conditions that avoid derating

Figure 1 MINIMUM CABLE SPACING IN AIR TO AVOID DERATING

3.5.2.5 Cables buried direct in ground

3.5.2.6 Cables installed in underground enclosures

AS/NZS 3008.1.1:2017

Australian/New Zealand Standard™

Electrical Installations—Selection of cables

Part 1.1: Cables for alternating voltages up to and including 0.6/1 kV—Typical Australian installation conditions

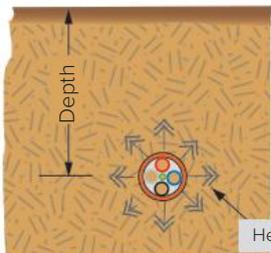
Standards Australia Standards New Zealand

FIGURE 16.13 Effects of grouping of cables

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Cables installed in ground

The current-carrying capacity of cables installed in the ground, whether directly or in an underground enclosure, is slightly less than the same cable installed spaced in air.

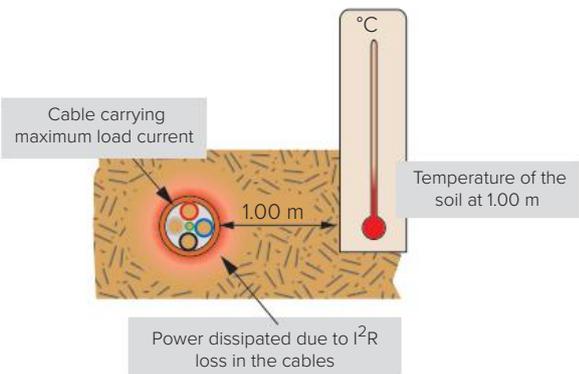


Heat is dissipated from the cable to the soil, allowing the cable to carry maximum current for its temperature rating based on depth of laying and thermal resistivity of the soil.

Heat dissipation

Thermal resistivity of soil

Soil thermal resistivity is the resistance to heat flow between the cable and the ambient environment of the soil. It is measured as the temperature in degrees centigrade for a metre of soil per watt dissipated by cables carrying the maximum load current (i.e. °C.m/W).



The rating factors are based on a soil thermal resistivity of 1.2 °C.m/W. Higher values mean less heat is dissipated and therefore a de-rating factor will apply, leading to the selection of a larger conductor size.

AS/NZS 3008.1, Clause 3.5.5 gives guidance on thermal resistivity and common backfill mixtures for maintaining at the base of 1.2 °C.m/W.

This example is an extract from *Table 10 (AS/NZS 3008.1.1)* showing the current-carrying capacity of 2.5 mm² two-core sheathed cable with thermoplastic insulation (75 °C).

Conductor size mm ²	Buried direct		Underground wiring enclosure		
	Cu	Al	Cu		Al
			Solid/ Stranded	Flexible	
1	17	—	17	18	—
1.5	21	—	21	22	—
2.5	30	—	30	29	—

Maximum current-carrying capacity for ambient soil temperature of 25 °C

TABLE 29
RATING FACTORS FOR THERMAL REISTIVITY OF SOIL

TABLES 28(1) & 28(2)
RATING FACTORS FOR DEPTH OF LAYING

SECTION 3 CURRENT-CARRYING CAPACITY

- 3.4 INSTALLATION CONDITIONS
 - 3.4.4 Cables buried direct in ground
 - 3.4.5 Cables installed in underground enclosures
- 3.5 EXTERNAL INFLUENCES
 - 3.5.4 Effects of depth of laying
 - 3.5.5 Effects of thermal resistivity of soil

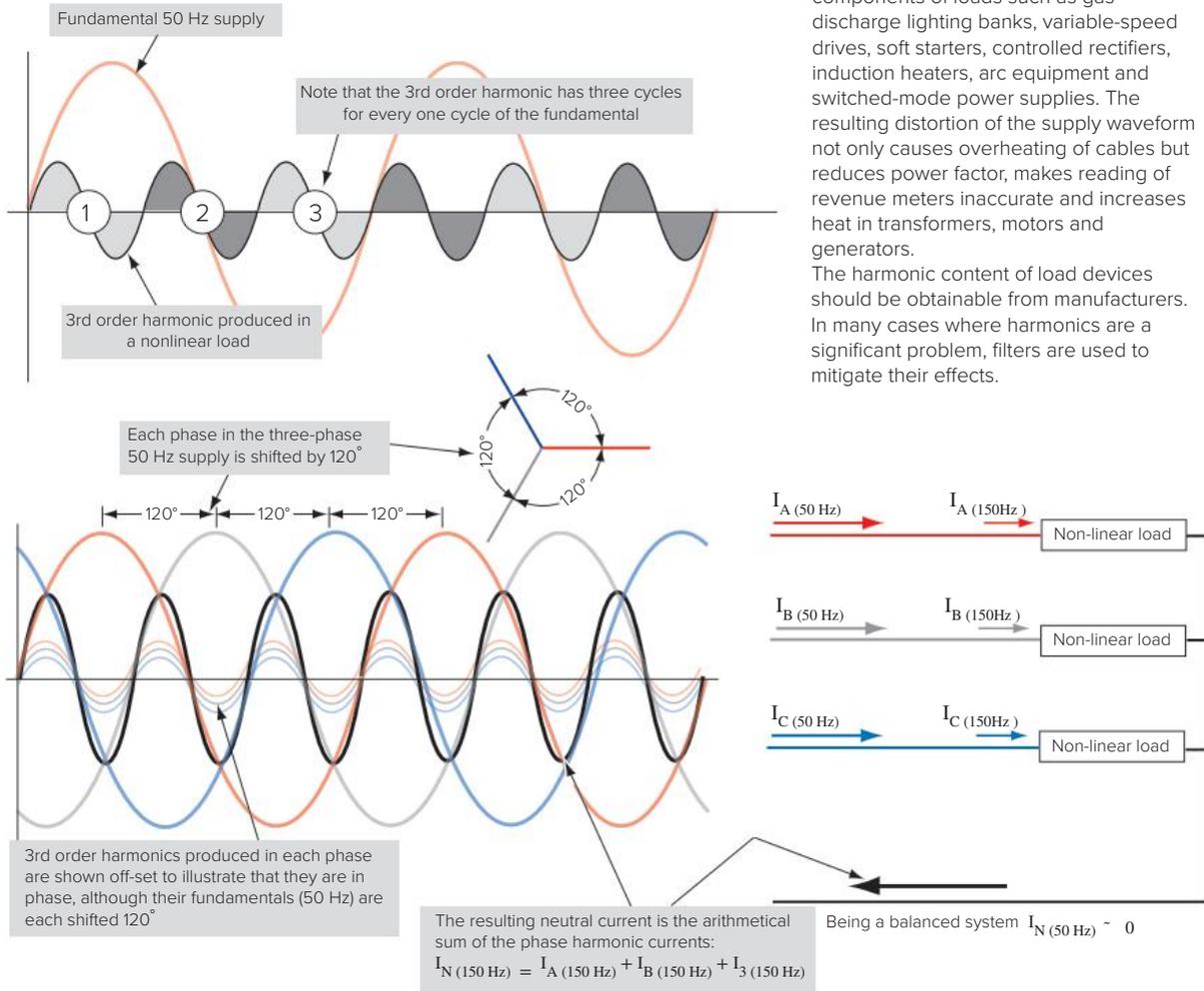


FIGURE 16.14 Effects of cables installed in the ground

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Effects of harmonics on balanced three-phase systems

Power system harmonics are voltage or current components in the system that have frequencies above the fundamental supply frequency, the most harmful being the 3rd harmonic, i.e. 150 Hz (3 × 50 Hz), as it can cause overheating lines and neutral conductors as shown below. Higher order harmonics (e.g. 9th and 12th) may also cause overheating if more than 10% of content of the phase current.



Harmonics are produced in non-linear components of loads such as gas discharge lighting banks, variable-speed drives, soft starters, controlled rectifiers, induction heaters, arc equipment and switched-mode power supplies. The resulting distortion of the supply waveform not only causes overheating of cables but reduces power factor, makes reading of revenue meters inaccurate and increases heat in transformers, motors and generators. The harmonic content of load devices should be obtainable from manufacturers. In many cases where harmonics are a significant problem, filters are used to mitigate their effects.



Clause 3.5.9 and Table 2 specify reduction factors that apply to 4-core and 5-core cables where the third-harmonic content of phase current is greater than 15%. Examples of how these reduction factors are applied are provided in Appendix D of the Standard.

FIGURE 16.15 How harmonic current can cause overheating of line and neutral conductors

Other up-rating factors include low ambient temperature conditions and the use of a cable to supply a continuous load below the cable's rated current-carrying capacity. The use of an alternative de-rating factor to those published in *Tables 22 to 26(2)* of *AS/NZS 3008.1* may be justifiable where there is a mixture of loaded and unloaded cables and the connected loads have a known diversity, or where there is a known cycle or shape for a daily load pattern.

The current-carrying capacity of all common types of cables and their de-rating and rating factors are given in the tables of *Section 3* of *AS/NZS 3008.1*, as shown in **Figure 16.16**.

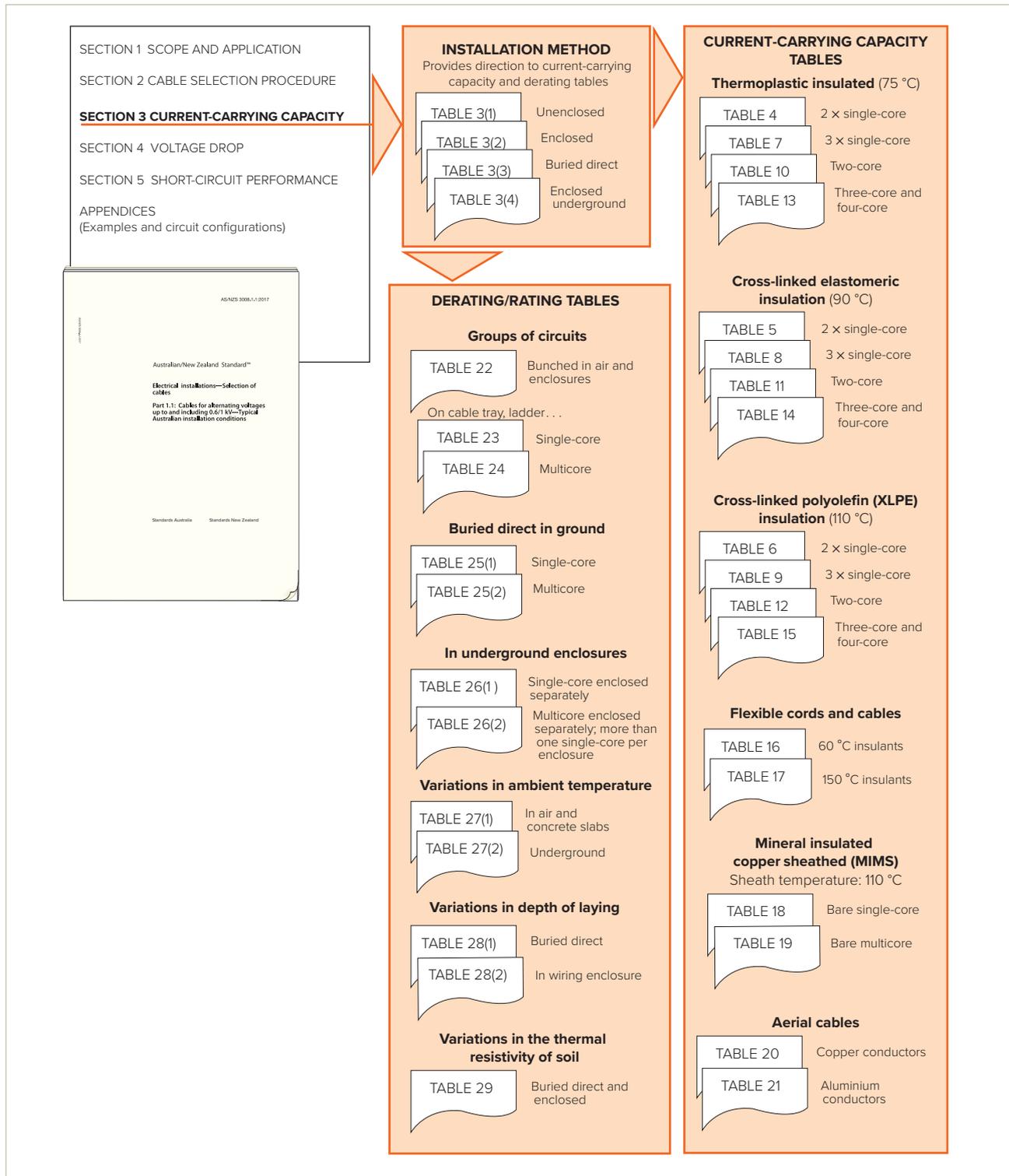


FIGURE 16.16 Current-carrying capacity

16.3.3 Voltage drop and earth fault-loop impedance

Both voltage drop and earth fault-loop impedance (EFLI) limit the maximum route length of a circuit for a given conductor size load current and protective device. *Clauses 1.6.4 and 3.6 of the Wiring Rules* limit voltage drop to 5 per cent for an installation (e.g. 230 volts nominal \times 5% = 11 V total drop allowed or a minimum voltage at the load of 218.5 V). In extra-low-voltage (ELV) circuits, it is 10 per cent. This is the voltage drop across the series arrangement of circuits in the installation from the point of supply to the furthest current-using device or point in each final subcircuit, as shown in **Figure 16.17**.

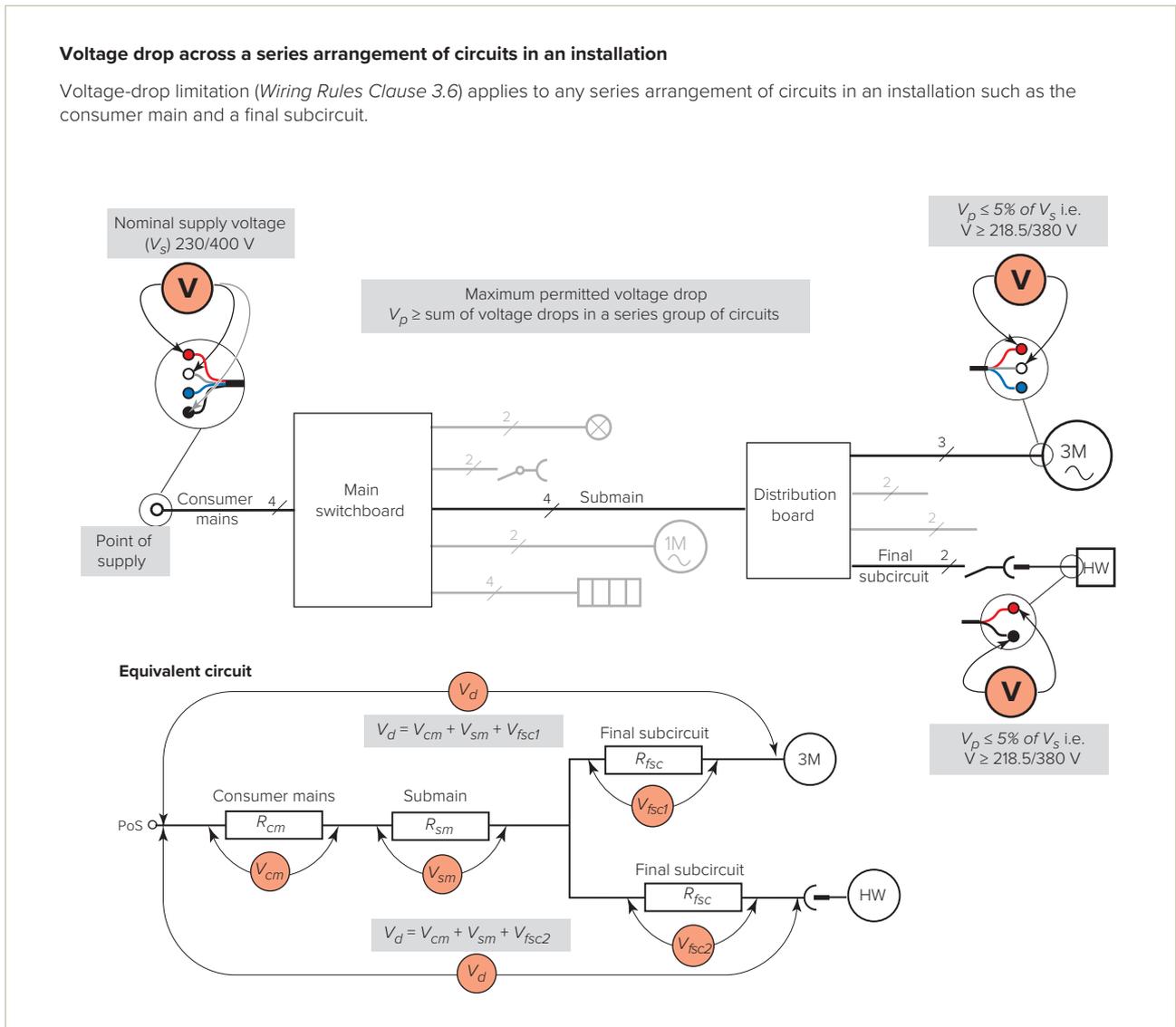


FIGURE 16.17 Voltage drop across a series arrangement of circuits in an installation

Recall that the voltage drop is proportional to both current and resistance, that is:

$$V = IR$$

and resistance is proportional to the resistivity of the conductor material (i.e. copper or aluminium) and the conductor length, and inversely proportional to its cross-sectional area (CSA), that is:

$$R = \frac{\rho L}{A}$$

Applied to the voltage drops in an installation:

V is the voltage drop across the conductor

I is the current carried by the conductor

R is the resistance of the conductor

ρ is the resistivity of the conductor material (Cu 1.72×10^8 ; Al 2.83×10^8)

L is the length of the conductor

A is the CSA of the conductor.

Consequently, the factors to consider when selecting cables to meet voltage-drop limits are:

- ▶ the load current
- ▶ the conductor size and
- ▶ the route length of the circuit.

A cable (in a series group) selected for an installation may satisfy the current-carrying requirements but the resistance of the cable might be too high due to the length of the cable runs needed to meet voltage-drop limitations. In this case, the cable size or CSA of one or more cables (in the series group) will need to be increased. The path associated with the MEN link should also be considered when determining EFLI.

The EFLI is the impedance of the conductors in the series path taken by the current in the event of a fault between an active conductor and an earth. As discussed in **Chapter 15**, the earth fault-loop is made up of the distribution transformer and supply conductors external to the installation, plus the active and protective earthing conductors within the installation. The EFLI, in most cases resistance, must be sufficiently low to:

- ▶ allow enough current to flow to operate the protective device and disconnect the supply in the prescribed time
- ▶ therefore limit the rise in touch voltage as required by the *Wiring Rules, Clauses 1.5.5.3 and 2.4.2*. Note: Additional explanations of touch voltage are given in *Appendix B, Paragraph B4* of the *Wiring Rules*.

The focus here in selecting cables is the internal EFLI, as reviewed in **Figure 16.18**.

In a similar way to voltage drop, EFLI is dependent on the cable resistance, in this case the size or CSA of the active conductor, the protective earthing conductor and the route length of the circuit. Given the previous discussion of voltage drop, it should be clear that the maximum route length of a circuit must satisfy the limitations of both EFLI and voltage drop.

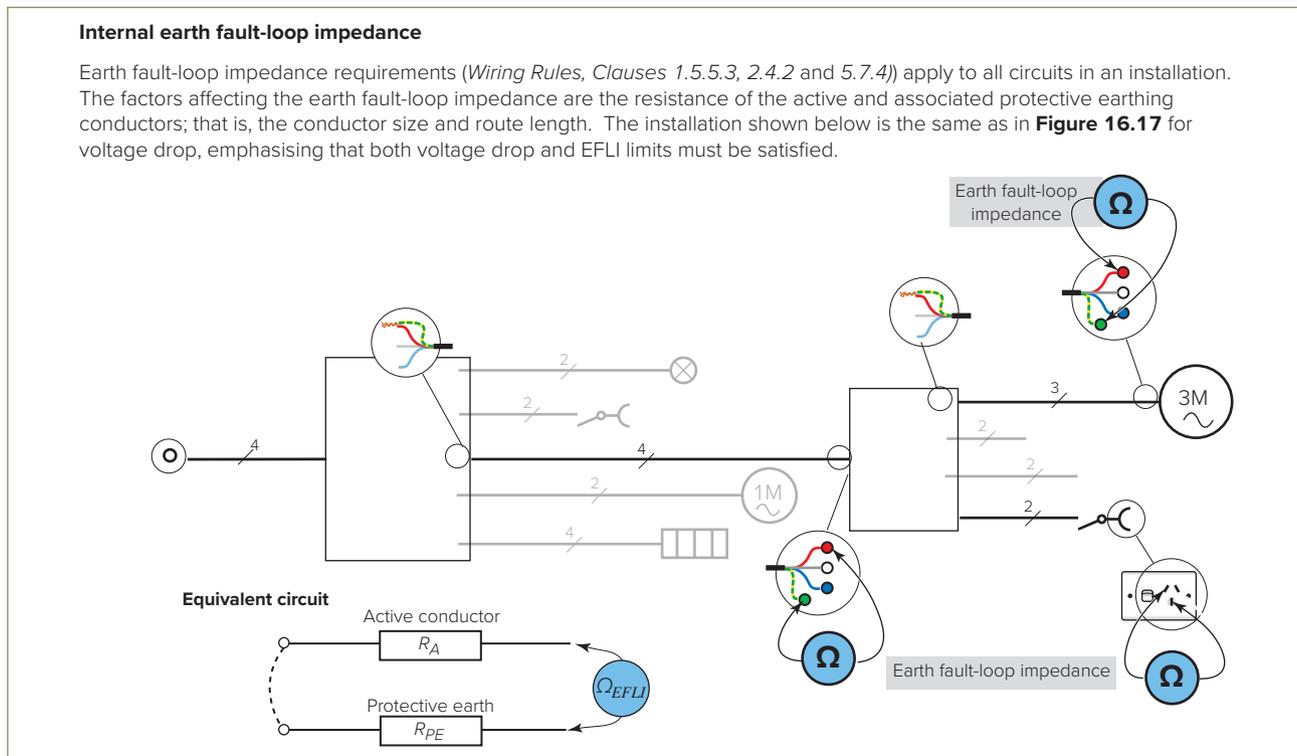


FIGURE 16.18 Internal earth fault-loop impedance (EFLI) in an installation

A concern is that the route length of the cables selected on the basis of voltage drop should not result in a fault-loop impedance that is too high. In most instances, cables for single phase that comply with the limits of voltage drop will also be within the limits of fault-loop impedance. This does not mean the integrity of the fault-loop impedance for each circuit should not be verified: such checking is an essential part of ensuring the protective measures required in an electrical installation will operate as intended.

The methods and tables for determining voltage drop are summarised in **Figure 16.19**.

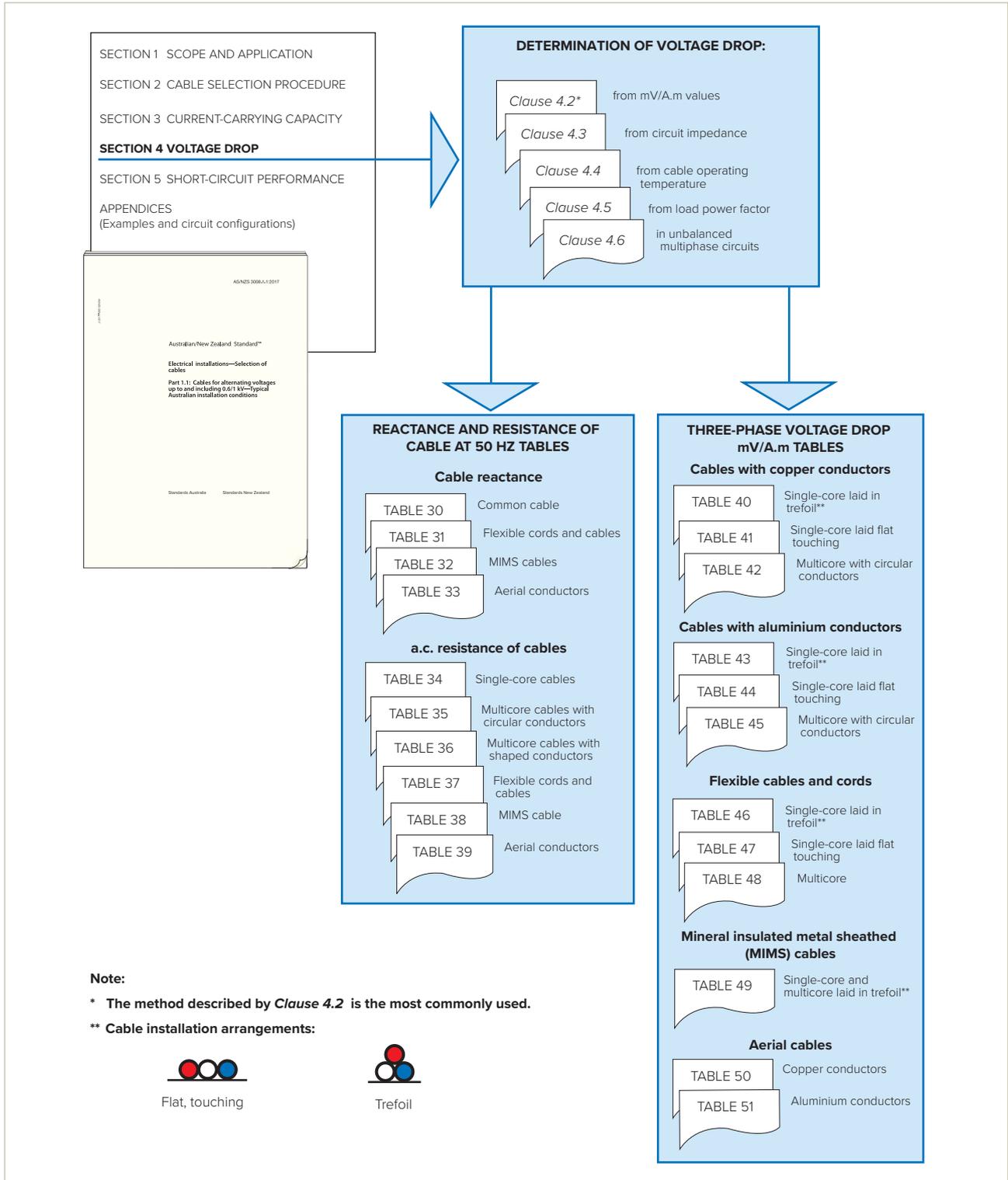


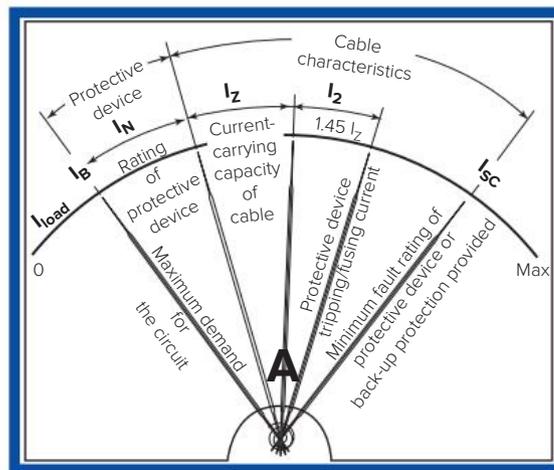
FIGURE 16.19 Voltage drop

NOTE: The *Wiring Rules*, Appendix B Paragraph B5 and Table B1 provide information on the maximum length of circuits—this only relates to EFLI.

16.3.4 Relationship between cables and protective devices

Assigning current-carrying capacities to cables ensures they are cost-effective and ensures the continued safe functioning of the electrical installation. The previous discussion and examples have shown that the current-carrying capacity or rating of a cable varies depending on the conditions that prevail where it is installed. The particular ratings are assigned so that the maximum permissible cable temperature is not exceeded in normal use. If cables are operated above their current-carrying capacity, insulation will deteriorate, increasing the likelihood of insulation breakdown and risk of injury to persons or damage to property. This is why *Clause 2.5.3.1* of the *Wiring Rules* requires protecting circuit conductors against overload (see **Figure 16.20**). The simultaneous operation of a number of appliances on a circuit of socket-outlets or a motor with a mechanical fault are typical issues that cause overloading of cables (i.e. they have to carry current higher than their current-carrying capacity).

The *Wiring Rules* stipulates that in the event of an overload, a protective device (circuit-breaker or fuse) must disconnect the supply before the temperature rise caused by the excess current damages the cable insulation, circuit connections or adjacent cables. To do this without the inconvenience of nuisance tripping, *Clause 2.5.3.1* of the *Wiring Rules* requires the following relationships to be met:



$$I_B \sim I_N \sim I_Z$$

and

$$I_2 \sim 1.45 I_Z$$

where I_B = the maximum demand of the circuit
(current needed to supply the load)

I_N = the nominal current rating of the protective device

I_Z = current-carrying capacity of the cable

I_2 = the current ensuring the operations of the protective device to disconnect the supply.

$I_{load} = I_B$, the current needed to supply the load

FIGURE 16.20 Coordination of cables and protective devices

The current required to trip a circuit-breaker in a conventional time is taken as 1.45 times its nominal current rating. For a fuse (complying with the *AS 2005* series) the fusing current is 1.6 times its nominal current rating. Therefore, where a fuse is used, it is de-rated to 90 per cent ($1.45 \div 1.6$) of its rated value. For example, a fuse with a nominal current rating of 20 A becomes 18 A (20×0.9) for the purpose of providing overload protection.

The main point is that, when selecting cables for their current-carrying capacity, consideration should also be given to the protective device being used. The maximum demand of final subcircuits can be regarded as the nominal current rating of the circuit-protective device. This should be sufficient current to supply the load but must not be greater than the current-carrying capacity of the cables.

In addition to the overload protection discussed here, protection against indirect contact and short-circuit currents must be provided. Protection and protective devices are discussed in **Chapter 13**.



CHECK YOUR UNDERSTANDING

11. Why is it important to limit the number of socket-outlets on a circuit for the connection of Class 1 appliances?
12. What is the maximum recommended number of light points on a 1.5 mm^2 circuit protected by a 16 A circuit-breaker?
13. Sketch a diagram showing the basic arrangement of consumer mains, submains and final subcircuits.
14. What features limit the current-carrying capacity of a cable?
15. What is the effect on the current-carrying capacity of a cable if it can be shown that the ambient temperature the cable is to be installed in is lower than the base ambient temperature?

16.4 Determining maximum demand

The continuous current required to supply an installation or circuit reliably and economically is known as the maximum demand. It is the basis for the selection of switchgear and controlgear, and a major factor in the sizing of cables. As mentioned in **Section 16.3**, the level of continuous current needed to supply an installation is somewhat less than the total current of all the individual loads (i.e. current-using equipment) in an installation. This is because either not all loads are switched on at the same time, and/or when they are, some are switched on only for short periods. The same is true for some final subcircuits, such as those supplying lighting and socket-outlets.

A number of methods are used around the world for determining a load current representing the assumed maximum demand of an installation, and wide research has been carried out to arrive at satisfactory methods for its estimation. If the estimated demand figure is too high, money is wasted on cables and equipment of higher ratings than necessary, whereas if it is too low, the wiring will be subject to high voltage drop, overload resulting in overheating and perhaps shock and fire hazards.

Clause 2.2.2 of the *Wiring Rules* sets out methods for determining maximum demand in consumer mains, submains and final subcircuits. Australia and New Zealand follow the general principles set down by the international standards body, the International Electrotechnology Commission (IEC). *Clause 2.2.2* of the *Wiring Rules* accepts any of the methods for estimating maximum demand, as outlined in **Table 16.1**.

TABLE 16.1 Methods of estimating maximum demand in consumer mains and submains

Method	Application	Wiring Rules reference
Calculation	This is the method most commonly used in the design phase. Because the various loads in an installation are used for diverse purposes and at diverse times, a diversity allowance is applied to each load type in different installations to determine the maximum-demand figure. It is probably more accurately referred to as after-diversity maximum demand.	Clause 2.2.2(a) Appendix C Paragraphs C2.3, 2.4 and 2.4.3. Tables C1, C2 and C3
Assessment	This is used where a large load (e.g. a motor) or special equipment (e.g. an X-ray machine) is involved. Assessment is based on experience, records of similar types of loads or electrical specifications, as well as manufacturers' recommendations. The assessment method is invariably used in consultation with the local energy distributor, which may insist this method is used for particular installations or load types.	Clause 2.2.2(b)
Measurement	This method is typically used when additions are to be made to an existing installation and the present maximum demand is not known. A maximum-demand indicator or recorder is connected to indicate a figure representing the highest-sustained demand over any 15-minute period. The energy distributor may use this method to check the accuracy of a calculated or assessed value and, where the measured value is shown to be greater, it is deemed to be the maximum demand for the installation.	Clause 2.2.2(c)
Limitation	The maximum demand is limited by overcurrent and tripping current of a fixed- or load-setting circuit-breaker. This method has gained popularity with the use of circuit-breakers as a main switch, which limits maximum demand to the value of the circuit-breaker. It must be remembered, however, that the installation must still function as intended.	Clause 2.2.2(d)

The maximum demand of final subcircuits is generally straightforward, being the connected load and usually limited by the rating of the protective device. However, *Paragraph C2.5* of the *Wiring Rules* provides information on the diversity allowances applicable to final subcircuits that supply welding machines (*C2.5.2*) and domestic cooking appliances (*C2.5.3* and *Table C5*).

16.4.1 Calculating maximum demand in consumer mains and submains

The underlying purpose of all methods used to determine maximum demand is to arrive at a figure for the selection of mains, submains, switchgear, metering and protective equipment. The demand figure must be adequate yet economical in its use of material and equipment, allow efficient supply to the consumer and include an allowance or reserve capacity for any anticipated additional load.

The method most commonly used for determining maximum demand classifies calculations as:

- ▶ single and multiple domestic installations (*Paragraph 2.3* and *Table C1*)
- ▶ non-domestic installations (*Paragraph C2.4* and *Table C2*).

Where an installation consists of both domestic and non-domestic (multiple installations), the applicable load allocation given in *Tables C1* and *C2* is used.

As previously mentioned, the maximum demand of final subcircuits is generally considered to be the connected load and is usually limited by the rating of the protective device.

The methods used for demand calculations of all types of installations based on the current allocated to load groups are much the same. However, the need to set out demand calculations in a logical and systematic manner is very important. Effective layout of demand calculations will reduce the possibility of error and allow for easy checking of mathematics, load grouping and phase balancing. The suggested approach is illustrated in **Figure 16.21** and the examples that follow.

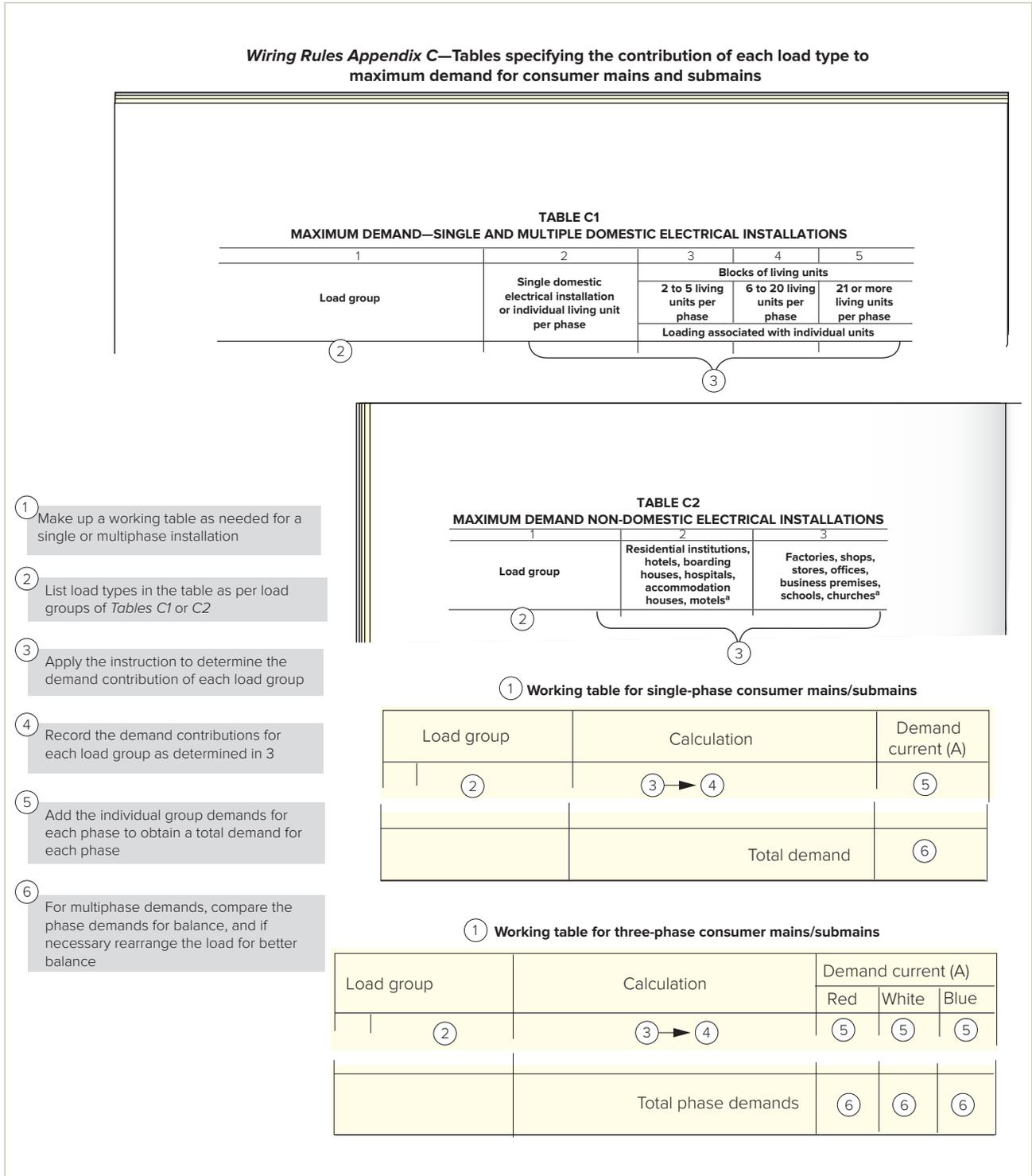


FIGURE 16.21 Systematic method for calculating maximum demand

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DID YOU KNOW?

Electricity distributors' specifications for the number of phases supplied to installations that only have single-phase loads are usually based on the total maximum demand for the installation. As an example, a distributor may provide an installation with single phase where maximum demand is ≤ 70 A, two phase where maximum demand is > 70 A ≤ 140 A and three phase where maximum demand is > 140 A based on a single-phase calculation.

Installations that include three-phase appliances, such as motors, are supplied with three phases, as are installations consisting of multiple occupancies, a block of flats for instance.

NOTE: Calculating to one decimal point is sufficiently accurate for the demand contribution of the individual load groups. It is reasonable to round up the total maximum-demand figure to the next whole number, as cable current-carrying capacities are given as whole-number values.

However, you may be required to provide calculations to more than 1 decimal point for in-class assessment purposes. Check with your instructor for the accuracy needed.

16.4.2 Single and multiple domestic demand

The footnotes to *Table C1* and the worked examples in *Appendix C* of the *Wiring Rules* provide a guide to the calculation of maximum demand for single-phase and three-phase domestic and multiple domestic installations. These should be studied together with the following examples.

NOTE: Check with your instructor as to the best method for laying out and calculating the maximum demand for the examples in this chapter. The different licensing authorities may have different approaches in their licensing exams. However, the methods shown in the chapter are accurate and can be modified for your particular area.

EXAMPLE 16.1

Determine the maximum demand for a single-phase 230 V installation that comprises:

- ▶ 23 lighting points
- ▶ 2 × 15 A plug socket-outlets
- ▶ 6 single and 10 double socket-outlets
- ▶ 10 kW range
- ▶ 4.8 kW controlled-load water heater
- ▶ 4 × 300 W floodlights in swimming pool area.

Use *Table C1*, column 2 of the *Wiring Rules* and list or tabulate the load groups to solve the problem, as shown in **Table 16.2**. **Table 16.3** shows an alternative method of solving the problem. Note that, even with lower maximum-demand current values, the energy distributor usually stipulates a minimum rating for consumer mains in domestic installations.

TABLE 16.2 Example 16.1—maximum-demand calculation for a simple single domestic installation

	Load group	Calculation	Demand current
A(i)	23 lighting points	$3 \text{ A} + 2 \text{ A} = 5 \text{ A}$	5.0
A(ii)	4 × 300 W floodlights	$\frac{4 \times 300 \text{ W}}{230 \text{ V}} \times 0.75 = 3.913 \text{ A}$	3.9
B(i)	6 single + 10 double socket-outlets	$10 \text{ A} + 5 \text{ A} = 15 \text{ A}$	15.0
B(ii)	2 × 15 A plug socket-outlets	Allow 10 A	10.0
C	10 kW range	$\frac{10\,000 \text{ W}}{230 \text{ V}} \times 0.5 = 21.739 \text{ A}$	21.7
F(i)	4.8 kW controlled-load water heater	$\frac{4800 \text{ W}}{230 \text{ V}} = 20.869 \text{ A}$	20.9
		Total demand	76.5 i.e. 77.0 A

TABLE 16.3 Example 16.1—alternative method for maximum-demand calculation for a simple single domestic installation

Load group	Description	Allowance	Calculation	Demand current
A(i)	23 lighting points	3 A for 1–20 points 2 A for 21–23 points	$3 \text{ A} + 2 \text{ A} = 5 \text{ A}$	5.0
A(ii)	4 × 300 W floodlights	75% load if > 1200 W	$\frac{4 \times 300 \text{ W}}{230 \text{ V}} \times 0.75$ $= 3.9 \text{ A}$	3.9
B(i)	6 × single socket-outlets 10 × double socket-outlets = 26 × single socket-outlets	10 A for 1–20 points 5 A for 21–26 points	$10 \text{ A} + 5 \text{ A} = 15 \text{ A}$	15.0
B(ii)	2 × 15 A socket-outlets	10 A total	10 A	10.0
C	10 kW range	50% connected load (greater than 10 A)	$\frac{10\,000 \text{ W}}{230 \text{ V}} \times 0.5$ $= 21.739 \text{ A}$	21.7
F(i)	4.8 kW controlled-load water heater	Full-load current	$\frac{4800 \text{ W}}{230} = 20.869 \text{ A}$	20.9
			Total maximum demand	76.5

NOTE: The 10 kW range is assessed for the purposes of maximum demand according to *Table C1*, in this instance of 21.7 A. You may notice a discrepancy between *Table C1* and *Table C5*, where a 10 kW range is now 25 A. *Table C5* is used to determine the final subcircuit current for the purposes of the protective device used. The final cable for the range is based on *Table C5*, whereas *Table C1* is used for determining the mains cable size. Further discussion on the final subcircuit cable size follows.

The main supply cable size will be determined from this calculation, after taking into account other de-rating factors (explained below).

EXAMPLE 16.2

A single domestic installation comprises:

- ▶ 42 light points
- ▶ 4 × 300 W floodlights
- ▶ 48 socket-outlets
- ▶ 6.65 kW oven, 2.4 kW hotplates
- ▶ three-phase ducted air-conditioning rated at 10.6 A per phase
- ▶ 1.2 kW pool pump rated at 3.6 A
- ▶ 4.8 kW spa heater.

NOTE: This installation will require a three-phase supply because of the ducted air-conditioning.

To determine the maximum demand, arrange the load for balance over the three phases as in **Table 16.4**, then employ *Table C1, Column 2* (individual living unit) as shown in **Table 16.5**.

TABLE 16.4 Example 16.2—arrangement of load across three phases

Red	White	Blue
21 light points	21 light points	
		4 × 300 W floodlights
16 socket-outlets	16 socket-outlets	16 socket-outlets
	6.65 kW oven	2.4 kW hotplate
10.6 A air-conditioning	10.6 A air-conditioning	10.6 A air-conditioning
4.8 kW spa heater		3.6 A pool pump

TABLE 16.5 Example 16.2—maximum-demand calculations for a single domestic installation supplied with three phases

	Load group	Calculation	Demand current (A)		
			R	W	B
<i>Table C1, Column 2</i>					
A(i)	light points	21 points per phase $3 A + 2 A = 5 A$	5.0	5.0	0
A(ii)	floodlights	$\frac{3 \times 400 W}{230 V} \times 0.75 = 3.913 A$	0	0	3.9
B(i)	socket-outlets	16 points per phase	10.0	10.0	10.0
C	oven	$\frac{6500 W}{230 V} \times 0.5 = 14.13 A$	0	14.1	0
C	hotplates	$\frac{2400 W}{230 V} \times 0.5 = 5.217 A$	0	0	5.2
D	air-conditioning	$10.6 A \times 0.75 = 7.95 A$	8.0	8.0	8.0
G	spa heater	$\frac{4800 W}{230 V} \times 0.75 = 15.652 A$	15.7	0	0
L	pool pump	full load (3.6 A)	0	0	3.6
		Total demand per phase	38.7	37.1	30.7

Phase demands

The phase demands should now be examined to see whether or not balance can be improved. In the case of **Example 16.2**, a small improvement could be made by moving the spa heater (15.7 A) from the red phase to the blue phase, and moving the hotplate (5.2 A) and pool pump (3.6 A) from the blue phase to the red phase, resulting in demands of 31.7 A, 37.3 A and 37.5 A for the red, white and blue phases respectively.

Alternatively, lights can be moved from the red phase to the blue phase, resulting in a demand of 33.7 A, 37.1 A and 35.7 A, which is a more balanced spread over the load. No one solution is perfect, although additional costs may be incurred by having one phase more heavily loaded than the other two, resulting in a larger mains cable needed. A good guide would be to aim for no more than 10 per cent difference between the highest loaded phase and the lowest loaded phase.

Always check for balance because, although only a small improvement is achieved in this example, a significant improvement can often be made.

Maximum demand for the multiple-phase installation in **Example 16.2** is taken as the heaviest loaded phase: the red phase at 38.7 A.



DID YOU KNOW?

Electricity distributors place requirements on installations supplied with multiple phases for balancing the maximum demand across phases. Typically, phases must be balanced within a percentage of demand current or a maximum-current value. Check this out in the local service rules for your area.

EXAMPLE 16.3

A block of units includes:

- ▶ 2 three-bedroom units
- ▶ 8 two-bedroom units
- ▶ 6 one-bedroom units.

Each unit is connected to a single-phase supply and fed by submains from the main switchboard. The individual unit loads are:

- ▶ three-bedroom unit
 - ▶ 16 lights
 - ▶ 18 socket-outlets in unit; 1 socket-outlet in common laundry
 - ▶ 8 kW range
 - ▶ 4.8 kW continuous water heater (80 W/L)
- ▶ two-bedroom unit
 - ▶ 14 lights
 - ▶ 14 socket-outlets in unit; 1 socket-outlet in common laundry
 - ▶ 8 kW range
 - ▶ 4.8 kW continuous water heater (80 W/L)
- ▶ one-bedroom unit
 - ▶ 13 lights
 - ▶ 12 socket-outlets in unit; 1 socket-outlet in common laundry
 - ▶ 7 kW range
 - ▶ 3.6 kW continuous water heater (80 W/L)
- ▶ community services
 - ▶ 9 socket-outlets
 - ▶ 10 lights: 6 × 75 W, 4 × 150 W outside lights.

Determine the maximum demand for the installation.

In multiple domestic installations, the contribution of each load group is dependent on the number of units per phase, as given in the *Wiring Rules, Table C1, Columns 3, 4 and 5*. The first requirement is to balance the units over the phases, as shown in **Table 16.6**. See how the first totals of phase demands work out before balancing community services.

TABLE 16.6 Example 16.3—balancing the unit load

	Red	White	Blue
	1 × 3 BR	1 × 3 BR	2 × 2 BR
	2 × 2 BR	2 × 2 BR	2 × 2 BR
	2 × 1 BR	2 × 1 BR	2 × 1 BR
Units per phase	5	5	6

Then employ *Table C1*, as shown in **Table 16.7**.

TABLE 16.7 Example 16.3—multiple domestic maximum-demand calculation

Load group		Reference table and column	Calculation	Demand current (A)		
				Red	White	Blue
5 units per phase						
A(i)	light points	C1, Col 3	allow 6 A (total)	6.0	6.0	
B(i)	socket-outlets	C1, Col 3	$10\text{ A} + (5\text{ A} \times 5) = 35\text{ A}$	35.0	35.0	
C	range	C1, Col 3	allow 15 A (total)	15.0	15.0	
F	water heater	C1, Col 3	$6\text{ A} \times 5 = 30\text{ A}$	30.0	30.0	
6 units per phase						
A(i)	light points	C1, Col 4	$5 + (0.25\text{ A} \times 6) = 6.5\text{ A}$	6.5		6.5
B(i)	socket-outlets	C1, Col 4	$15\text{ A} + (3.75\text{ A} \times 6) = 37.5\text{ A}$	37.5		37.5
C	range	C1, Col 4	$2.8\text{ A} \times 6 = 16.8\text{ A}$	16.8		16.8
F	water heater	C1, Col 4	$6\text{ A} \times 6 = 36\text{ A}$	36		36.0
Total demand current for units				86.0	86.0	96.8
The best load balance for the installation is for the community loads to be divided between the lowest unit-loaded phases, i.e. the red and white phases.						
Community services						
H	lights	C1, Col 3, 4, 5	$(6 \times 75\text{ W}) + (4 \times 150\text{ W}) = 1050\text{ W}$ $\frac{1050\text{ W}}{230\text{ V}} = 4.565\text{ A}$		4.6	
I	5 socket-outlets	C1, Col 3, 4, 5	$2\text{ A} \times 5 = 10\text{ A}$	10.0		
I	4 socket-outlets	C1, Col 3, 4, 5	$2\text{ A} \times 4 = 8\text{ A}$		8.0	
Total phase demands				96.0	99.4	96.8

Maximum demand is that of the heaviest loaded phase, in this case the white phase at 100 A, rounded up to the next whole number.

The maximum demand of the submains to each individual living unit is calculated in the same way as the maximum demand for a single domestic dwelling: by the application of *Table C1, Columns 1 and 2*, as shown in **Table 16.8**.

TABLE 16.8 Example 16.3—maximum-demand calculations for submains for each unit

Three-bedroom unit			
	Load group	Calculation	Demand current
A(i)	16 lighting points	allow 3 A	3.0
B(i)	19 socket-outlets	allow 10 A	10.0
C	8 kW range	$\frac{8000 \text{ W}}{230 \text{ V}} \times 0.5 = 17.391 \text{ A}$	17.4 A
F(i)	4.8 kW continuous water heater	$\frac{4800 \text{ W}}{230 \text{ V}} = 20.87 \text{ A}$	20.9
		Total demand	51.3 i.e. 52 A
Two-bedroom unit			
	Load group	Calculation	Demand current
A(i)	14 lighting points	allow 3 A	3.0
B(i)	15 socket-outlets	allow 10 A	10.0
C	8 kW range	$\frac{8000 \text{ W}}{230 \text{ V}} \times 0.5 = 17.391 \text{ A}$	17.4
F(i)	4.8 kW continuous water heater	$\frac{4800 \text{ W}}{230 \text{ V}} = 20.987 \text{ A}$	20.9
		Total demand	51.3 i.e. 52 A
One-bedroom unit			
	Load group	Calculation	Demand current
A(i)	13 lighting points	allow 3 A	3.0
B(i)	13 socket-outlets	allow 10 A	10.0
C	7 kW range	$\frac{7000 \text{ W}}{230 \text{ V}} \times 0.5 = 15.217 \text{ A}$	15.2
F(i)	3.6 kW continuous water heater	$\frac{3600 \text{ W}}{230 \text{ V}} = 15.65 \text{ A}$	15.7
		Total demand	43.9 i.e. 44 A

16.4.3 Non-domestic demand

The maximum-demand assessments considered so far follow a common pattern, and a broadly similar approach may be used for a non-domestic installation, such as a commercial building, factory or residential institution. *Paragraph C2.4.1* and *Table C2*, together with *Paragraph C2.5.2.2* (where welding machines are installed) of the *Wiring Rules* should be used to determine the various diversity factors to be applied to the load groups.

EXAMPLE 16.4

A commercial/industrial complex consists of eight separate occupancies. The distribution board for each occupancy is supplied from a main switchboard for the complex, as shown in **Figure 16.22**. Determine the maximum demand for the submains to a unit, allowing 10 per cent for additional future load (see **Table 16.9**).

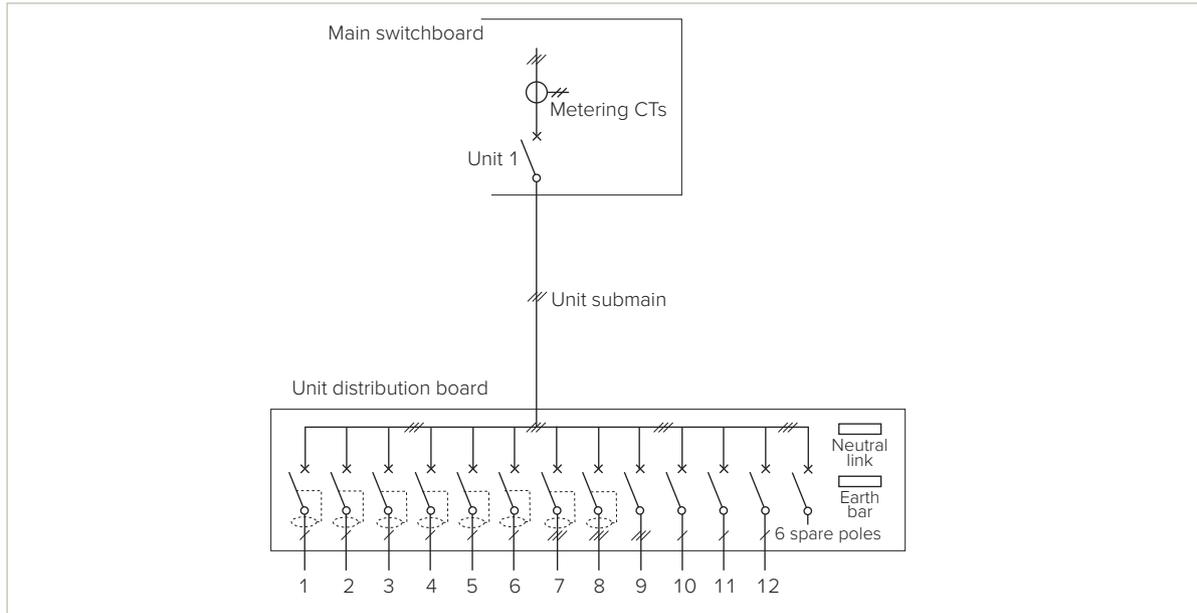


FIGURE 16.22 Installation for Example 16.4

NOTE: The unit distribution board is a standardised multi-pole panel board with phases sequenced red, white and blue across every three poles.

TABLE 16.9 Example 16.4—load for each unit

Circuit	Load group	Rating	Quantity
1	400 W high-bay MV luminaires	2.1 A	6
2	400 W high-bay MV luminaires	2.1 A	6
3	twin 36 W fluorescent troffer	0.38 A	10
4	400 W floodlights	1.9 A	2
5	single-phase socket-outlets	10 A	10
6	single-phase socket-outlets	15 A	1
7	three-phase socket-outlets	10 A	4
8	three-phase socket-outlets	20 A	1
9	three-phase socket-outlets	32 A	1
10	water heater	2.4 kW	1
11	oven	1.2 kW	1
12	split air-conditioner	15 A	1

To simplify the calculations, the loads in each load group can be re-arranged, starting from the largest to the smallest as shown in **Table 16.10**.

TABLE 16.10 Example 16.4—load for each unit from largest to smallest

Circuit	Load group	Rating	Quantity
1	400 W high-bay MV luminaires	2.1 A	6
2	400 W high-bay MV luminaires	2.1 A	6
3	twin 36 W fluorescent troffer	0.38 A	10
4	400 W floodlights	1.9 A	2
5	three-phase socket-outlets	32 A	1
6	three-phase socket-outlets	20 A	1
7	single-phase socket-outlets	15 A	1
8	three-phase socket-outlets	10 A	4
9	single-phase socket-outlets	10 A	10
10	split air-conditioner	15 A	1
11	water heater	2.4 kW	1
12	oven	1.2 kW	1

From *Table C2*, we will use *Column 3* to assign maximum demands to each load in the groups. By clever moving of loads, a fairly balanced load distribution can be achieved, which may save on cable and conduit costs—see **Table 16.11**.

TABLE 16.11 Example 16.4—calculation of maximum demand for submain to each unit

	Load group	Refer Table, Col.	Calculation	Demand current (A)		
				Red	White	Blue
A	6 × 400 W high-bay MV luminaires	C2 Col 3	6 × 2.1 A = 12.6 A			12.6
A	6 × 400 W high-bay MV luminaires	C2 Col 3	6 × 2.1 A = 12.6 A			12.6
A	10 × twin 36 W fluorescent troffer	C2 Col 3	10 × 0.38 A = 3.8 A			3.8
A	2 × 400 W floodlights	C2 Col 3	2 × 1.9 A = 3.8 A	3.8		
B (iii)	1 × 32 A three-phase socket-outlets	C2 Col 3	Full rating	32.0	32.0	32.0

(Continues)

TABLE 16.11 (Continued)

		Load group	Refer Table, Col.	Calculation	Demand current (A)		
					Red	White	Blue
B (iii)		1 × 20 A three-phase socket-outlets	C2, Col 3	$20 \text{ A} \times 75\% = 15 \text{ A}$	15.0	15.0	15.0
B (iii)		1 × 15 A single-phase socket-outlets	C2, Col 3	$15 \text{ A} \times 50\%$	7.5		
B (iii)		4 × 10 A three-phase socket-outlets	C2, Col 3	$\frac{1000 \text{ W} + (100 \text{ W} \times 3)}{230 \text{ V}} = 5.652 \text{ A}$	5.7	5.7	5.7
B(ii)	10 × 10 A single-phase socket-outlets	C2, Col 2, 3		$\frac{10 \times 100 \text{ W}}{230 \text{ V}} = 4.348 \text{ A}$		4.4	
C (i)		1 × split air-conditioner	C2, Col 3	Full connected load	15.0		
C (i)	1 × 2.4 kW water heater	C2, Col 3		$\frac{2400 \text{ W}}{230 \text{ V}} = 10.435 \text{ A}$		10.44	
C (i)	1 × 1.2 kW oven	C2, Col 3		$\frac{1200 \text{ W}}{230 \text{ V}} = 5.217 \text{ A}$			5.2
				Subtotal	74.0	79.1	74.3
				Allow 10% of heaviest loaded phase	8.0	8.0	8.0
				Total phase demands	82.0	87.1	82.3

As is the case for consumers, the main maximum demand for a multiple-phase submain is taken as the heaviest loaded phase—the white phase at 87.1 A in this example.

There are a few traps to watch out for in doing these calculations:

- ▶ A 10 A socket-outlet is a 10 A socket-outlet, single-phase or three-phase. You only need to account for the first one at 1000 W. All remaining socket-outlets on that phase are allocated 100 W each.
- ▶ If there are multiple socket-outlets above 10 A, the largest one is calculated at 100 per cent and all others are calculated at 50 per cent.
- ▶ For load group C (i), each load is calculated at full connected load *unless* it is on the same phase as another C (i) load. Then it is calculated at 75 per cent.
- ▶ When multiphase and single-phase loads are equal, the multiphase loads should be calculated first. This will allow better balancing of loads.

Where an energy distributor has a separate tariff, it may prefer that lighting is connected on one phase for economy in metering, unless lighting forms a major part of the load.



CHECK YOUR UNDERSTANDING

16. Describe the possible consequences of underestimating the maximum demand for an installation or circuit.
17. List four accepted methods for estimating the maximum demand in consumer mains and submains.
18. Why is it important to set out maximum-demand calculations in a logical and systematic manner?
19. Give two reasons why an installation would be supplied with three phase.
20. Determine the maximum demand for the heaviest loaded phase of a rehabilitation hospital supplied by three phase with the following load:
 - ▶ 62 × 20 W compact fluorescent downlights rated at 0.16 A each
 - ▶ 54 × twin 28 W fluorescent troffer luminaires rated at 0.30 A each
 - ▶ 7 × 400 W floodlights
 - ▶ 188 × 10 A socket-outlets
 - ▶ 5 × 15 A socket-outlets
 - ▶ 1 × 20 A socket-outlet
 - ▶ 1 × 13.6 kW range (arranged for connection across two phases)
 - ▶ 1 × 4.0 kW food warmer
 - ▶ 2 × 5.5 kW lift motors rated at 10.2 A per phase
 - ▶ 1 × 4.0 kW hydrotherapy pool pump rated at 8.5 A per phase
 - ▶ 2 × 10.4 kW ducted air-conditioning units, each rated at 20 A per phase.

16.5 Selection of minimum cable size based on current-carrying capacity

The current-carrying capacity of a cable must not be less than the current to be carried by the cable it supplies (i.e. the maximum demand of the circuit). The maximum demand—together with the previously discussed factors affecting current-carrying capacity—determines the minimum conductor size for a particular application. This is provided that voltage drop, EFLI limitations and short-circuit performance are all satisfied.

16.5.1 Selection guide

The following examples provide a guide to the selection of conductor sizes and should be studied in conjunction with *AS/NZS 3008.1*. These examples refer to, and are extensions of, the examples for calculating maximum demand given in **Section 16.4** of this chapter.

EXAMPLE 16.5

In the case of the single domestic dwelling in **Example 16.1**, the maximum demand was calculated at 77 A. The consumer mains are to be single-core V75 thermoplastic-sheathed (TPS) stranded-copper cables installed in heavy-duty PVC conduit in air, in accordance with the *Wiring Rules, Clause 3.9.7.1.2(i)* for consumer mains without short-circuit protection.

NOTE: The *Wiring Rules* place no minimum requirement for consumer mains. Energy distributors, however, commonly stipulate a minimum cable size, for example 16 mm².

A starting point for referring to the correct current-carrying capacity tables in *AS/NZS 3008.1* is the *Table 3* series, in this case *Table 3(2)* for cables installed in a wiring enclosure (see **Figure 16.23**).

Table 3(2)
Schedule of installation methods for cables deemed to have the same current-carrying capacity and cross-references to applicable de-rating tables—enclosed

1	2	3	4	5	6
Item no.	Cable details (see Note 1)	Reference drawing (see Note 2)	Current-carrying capacity table reference	Method of installation for cables deemed to have the same current-carrying capacity (See Note 3)	Derating tables for more than one circuit
1	Two single-core cables		Tables 4 and 5 Columns 15 to 17 Table 6 Columns 11 and 12	Cables in wiring enclosures installed in — (a) air; (b) plaster, cementrender, masonry or concrete in a wall or floor;	
2	The three tables referenced cover one of the three insulation types and maximum conductor temperature.				

FIGURE 16.23 *AS/NZS 3008.1, Table 3(2)*

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Item 1 of the table shows that the current-carrying reference tables for two single-core cables installed in a wiring enclosure in air are *Tables 4* or *5, Columns 15–17*, or *Table 6, Columns 11 and 12*. Turning to these tables, you can see that *Table 4* covers cables with thermoplastic 75 °C insulants and applies to non-armoured, sheathed and unsheathed cables, as indicated by Note 1 to the table (see **Figure 16.24**).

Table 4 Australian conditions			Table 4 New Zealand conditions		
mm ²	CU		mm ²	CU	
	Solid/ Stranded	Fley:		Solid/ Stranded	Fley:
1	13		1	15	
1.5	18		1.5	21	
2.5	24		2.5	27	
4	32		4	36	
6	41		6	47	
10	54		10	62	
16	70		16	80	
25	94		25	107	
35	112				

FIGURE 16.24 *AS/NZS 3008.1, Table 4*

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NOTE: The more popular V90 refers to thermoplastic sheathing rated to 90 °C yet must be treated as V75 cable. This cable is not to be confused with the X90 cable, which has a much higher thermal characteristic.

Column 15 of *Table 4* for Australian conditions shows that a 25 mm² cable with a current-carrying capacity of 94 A is the lowest size able to carry 77 A. For New Zealand conditions, *Table 4* shows that the lowest-size cable is 16 mm² with a current-carrying capacity of 80 A.

EXAMPLE 16.6

The multiphase consumer mains supplying the single domestic dwelling of **Example 16.2** is to be V75 insulated single-core copper cable installed in polyvinyl chloride (PVC) conduit, underground. The maximum demand for each phase was determined as 31.7 A, 37.3 A and 37.5 A, respectively. The minimum current-carrying capacity for all cables is equal to that of the highest phase, that is, the blue phase at 38 A.

For cables enclosed in underground pipes or ducts, *Item 2 of Table 3(4) of AS/NZS 3008.1* refers the reader to *Table 7* (which covers thermoplastic-insulated cables with a maximum conductor temperature of 75 °C) and *Columns 24–26* for the suitable conductor size. The table shows that a 6.00 mm² cable with a current-carrying capacity of 45 A has sufficient current-carrying capacity. For New Zealand conditions, a smaller size cable—4.00 mm² with a current-carrying capacity of 40 A—will comply. The energy distributor, however, would likely insist on a larger cable for consumer mains—typically 16.00 mm²—to allow for future additions and to accommodate short-circuit performance where the consumer mains is unprotected.

EXAMPLE 16.7

In the multiple domestic installation of **Example 16.3** each flat is to be connected to a single-phase supply and fed by unenclosed twin TPS (75 °C) copper submains installed in air from the main switchboard. The consumer mains is to comprise four-core X-90 (90 °C) (insulated and sheathed) stranded-copper cable enclosed in PVC conduit in air.

The phase with the highest maximum demand in the consumer mains was previously calculated at 100 A (99.4 A actual). Reference to *AS/NZS 3008.1, Table 3(2) Item 8*, points to *Tables 13 and 14, Columns 11–13*. *Table 13* is for TPS cables and *Table 14* is for X90 cables, so this is the one to use for this calculation. Using *Column 11* and considering Australian conditions, a 35 mm² cable with a current-carrying capacity of 114 A will meet the minimum requirements (a 25 mm² cable is not suitable due to the cable being in conduit). For New Zealand, a 25 mm² cable rated at 100 A would be sufficient. In either case, mains controls and equipment would be rated at 100 A.

The maximum demand of the single-phase submains cables is 52 A for the two- and three-bedroom units, and 44 A for the one-bedroom unit. According to *AS/NZS 3008.1, Table 3(1) Item 12*, we need to use *Tables 10 and 11, Columns 5–7*. *Table 10* is for V75 cable and *Column 5* shows the nearest-sized cable suitable is 10 mm² rated at 60 A to supply each two-bedroom and three-bedroom unit. The submains to each one-bedroom unit would be adequately supplied by 6 mm² cable rated at 44 A.

Note that the available or preferred sizes for circuit-breakers for these mains are 63 A and 50 A. Therefore, both cables will need to be upgraded to the next size, being 16 mm² and 10 mm² respectively (see **subsection 16.3.4**).

EXAMPLE 16.8

The submains to each unit of the commercial/industrial complex of **Example 16.4** are to be an X-90 multicore-copper cable installed in an underground wiring enclosure at a depth of 0.5 m and all touching for part of their length.

The highest phase maximum demand was calculated at 97 A. Consulting *AS/NZS 3008.1, Table 3(4), item 4, Column 4* directs the reader to current-carrying capacity, and *Table 14, Columns 25–27* for cable installed as a single circuit. *Column 6* references *Table 26(2)* for de-rating factors applied to groups of circuits installed in separate enclosures.

Turning to *Table 26(2)*, a de-rating factor of 0.70 is specified for eight circuits (the eight submains of this example) installed touching. Under these installation conditions, the minimum current-carrying capacity is determined by:

$$I_C = \frac{I_{MD}}{k}$$

where I_C is the minimum current-carrying capacity for the cable
 I_{MD} is the maximum demand for the circuit
 k is the de-rating/rating factor

Then:

$$I_c = \frac{97 \text{ A}}{0.7} = 139 \text{ A}$$

Returning to *Table 14, Column 25*, the smallest size of conductor that will carry this current is 50 mm² in Australia and 35 mm² in New Zealand.

If the load is better balanced (as per the example), while the maximum demand is not much different (88 A vs 97 A), when the de-rating factor is applied, the maximum current then would be:

$$I_c = \frac{88 \text{ A}}{0.7} = 126 \text{ A}$$

Returning to *Table 14, Column 25*, the smallest size of conductor that will carry this current is now 35 mm². This size difference, spread over the entire site, could translate to many hundreds, if not thousands, of dollars in costs.

This example highlights the importance of installation design and the avoidance of group de-rating by following the minimum clearances and configurations shown in *AS/NZS 3008.1*. The minimum conductor size must satisfy both current-carrying capacity and voltage-drop requirements. In the previous examples, the voltage-drop limitations remain to be addressed. Voltage drop is more likely to be a significant factor in selecting the correct cable size for circuits with non-distributive loads where the maximum demand for the circuit is close to the current-carrying capacity of the cables.



CHECK YOUR UNDERSTANDING

21. What is the current-carrying capacity for a 6 mm² two-core thermoplastic sheathed cable with stranded conductors installed spaced in air?
22. How would the current-carrying capacity of the cable in **Question 21** be affected if for 3 m of its route length it is installed partially surrounded by thermal insulation?
23. How can direct sunlight affect a cable?
24. With the aid of a diagram, show how a group of three multicore cables would be installed horizontally on 'ladder support' to avoid the need to de-rate their current-carrying capacity.
25. Determine the current-carrying capacity of a cable for a circuit with a maximum demand of 20 A where the cable is installed unenclosed on a cable tray bunched with two other circuits.

16.6 Selection of minimum cable size based on voltage-drop and earth fault-loop impedance (EFLI) limitations

16.6.1 Voltage drop

Voltage drop, the third consideration listed in **Section 16.3** for selecting a cable, is of great practical importance. The conductor size of a cable selected for a particular application must be such that excessive voltage drop does not occur when the conductor is carrying its maximum current—or the current that is assumed it will be required to carry as determined in accordance with *Section 3* of the *Wiring Rules*.

Where route lengths of circuits are short and where de-rating factors apply, the current-carrying capacity usually determines cable size, and voltage drop might not influence cable selection. On the other hand, where circuits have relatively high maximum demand and long route lengths, the voltage drop is more likely to be the deciding factor for cable size in association with any rating factors and current-carrying capacities. Excessive voltage drop will not only reduce the voltage available to the load equipment but can cause cable overheating by limiting the magnitude of short-circuit currents and by increasing the time delay before protection can operate (see **Chapter 9**).

Remember: the maximum permitted voltage drop applies to all series groups of circuits in an installation, as previously discussed (see **Figure 16.17**).

16.6.2 Selecting cables based on voltage-drop limitations

Section 4 of *AS/NZS 3008.1* describes several ways to select cable with regard to voltage drop and to verify that cable selected by other criteria (e.g. current-carrying capacity) does not exceed voltage-drop limits for the circuit. These include determination of voltage drop from:

- ▶ millivolt per ampere-metre values (*Clause 4.2* of *AS/NZS 3008.1*)
- ▶ circuit impedance (*Clause 4.3* of *AS/NZS 3008.1*)
- ▶ cable-operating temperature (*Clause 4.4* of *AS/NZS 3008.1*)
- ▶ load-power factor (*Clause 4.5* of *AS/NZS 3008.1*).

The first two are basic methods, applied where the route length and load current of circuits are known. The methods using cable temperature and power factor are applicable where the cable size is known and give a more accurate result. A simplified method for determining maximum percentage voltage or cable size where load current and circuit route length are known is provided in the *Wiring Rules, Appendix C, Paragraph C4* (see **Section 16.6.4**).

The most common methods for selecting cables based on voltage-drop limitations are the millivolt per ampere-metre method and the simplified method given in the *Wiring Rules*, and these are the methods dealt with here. In the millivolt per ampere-metre method, the smallest conductor that meets the voltage-drop limitations for a given circuit is a cable with a unit value (millivolts per ampere-metre) equal to or less than that determined by the following equation:

$$V_c = V_d \frac{1000}{L \times I}$$

and V_c = sum of voltage drops on circuit run

where V_c = cable voltage drop, for each ampere, across each metre of cable length; the voltage drop over a metre of cable is very low so the value of V_c is given as millivolts per ampere-metre (mV/A.m)

V_d = actual voltage drop in volts

V_p = permissible voltage drop on the circuit (e.g. 5% of supply voltage, i.e. 11.5 V for 230 V supply and 20 V for 400 V supply) route length of circuit in metres, which is the distance from the load

L = terminals to the point of supply (fuse or circuit-breaker) or between any two points under consideration

I = the current carried by the cables in amperes, normally the maximum demand current

The unit of voltage drop 'millivolt per ampere-metre' is the voltage drop for each metre of cable length and ampere of current. Because the voltage drop across each metre of cable is low, it is expressed in millivolts.

The unit values of voltage drop (mV/A.m) are given in *Tables 40 to 51* of *AS/NZS 3008.1* and are for balanced three-phase circuits for various cable configurations, materials and conductor temperatures.

NOTE: Unit values of voltage drop for single-phase circuits obtained from the equation above must be multiplied by 0.866 to convert them to three-phase values in order to determine the minimum conductor size from the voltage-drop tables. Conversely, multiply the unit values given in the tables by 1.155 to convert them to single-phase values.

Three worked examples are included in *Appendix A* of *AS/NZS 3008.1* and **Examples 16.9 to 16.14** are provided to further your understanding of this important topic. The tables referred to in the examples are those in *AS/NZS 3008.1*.

EXAMPLE 16.9

A 230 V 15 A load is to be supplied by a two-core V90 thermoplastic-insulated TPS copper cable, run as surface wiring (unenclosed) with a route length of 40 m. What is a suitable conductor size for the cable if the voltage drop in the single-phase consumer mains is 1 per cent?

$$\begin{aligned}
 V_c &= ? & V_c &= \frac{1000 V_d}{L \times I} \\
 V_d &= (5 - 1)\% \text{ of } 230 \text{ V} \\
 &= 9.2 \text{ V} & &= \frac{1000 \times 9.2 \text{ V}}{40 \text{ m} \times 15 \text{ A}} \\
 L &= 40 \text{ m} & V_c &= 15.33 \text{ mV/A.m} \\
 I &= 15 \text{ A}
 \end{aligned}$$

This is the maximum permissible V_c but it must be converted to a three-phase value for reference to the tables of *AS/NZS 3008.1.1*. Therefore:

$$\begin{aligned}
 \text{three-phase value} &= 15.33 \times 0.866 \\
 &= 13.28 \text{ mV/A.m}
 \end{aligned}$$

Reference must now be made to the relevant table—in this case *Table 42, Column 6*—which shows that a 2.5 mm² cable has a unit value of voltage drop of 15.6 mV/A.m, while a 4.0 mm² cable has a value of 9.71 mV/A.m, making a 4.0 mm² cable the smallest suitable.

NOTE: The cable selected must have a voltage drop equal to or less than the calculated maximum drop permitted. Always check the current rating of cable selected on voltage-drop considerations, because it is sometimes possible for a cable to fulfil voltage-drop considerations but not comply with current-carrying requirements.

EXAMPLE 16.10

A single-phase final subcircuit is limited to a voltage drop of 6 V due the voltage drop in the consumer mains and submains. The circuit is wired in twin V90 thermoplastic-insulated TPS copper cable, unenclosed, to supply a 30 A 230 V factory load at a distance of 8 m from the protective circuit-breaker at the distribution board. What size cable should be selected?

$$V_c = ? \quad V_c = \frac{1000 V_d}{L \times I}$$

$$V_d = 6 \text{ V}$$

$$L = 8 \text{ m} \quad = \frac{1000 \times 6 \text{ V}}{8 \text{ m} \times 30 \text{ A}}$$

$$I = 30 \text{ A} \quad = 25 \text{ mV/A.m}$$

Converting to a three-phase value:

$$V_c = 25 \times 0.866$$

$$= 21.65 \text{ mV/A.m}$$

Using *Table 42* with a conductor temperature of 75 °C, it can be seen that a 1.5 mm² cable fulfils the voltage-drop considerations, but its current-carrying capacity is only 21 A (*Table 10, Column 5*). To comply with *Clause 3.4 of AS/NZS 3000*, a 2.5 mm² cable rated at 30 A is required.

EXAMPLE 16.11

A three-phase 400 V motor with a rated full-load current of 50 A is to be supplied by a three-core 1/1 kV MIMS cable with a route length of 60 m from the main switchboard to the motor position in a boiler room. Determine the minimum size of cable required for the circuit if the voltage drop in the consumer mains is 8 V:

$$V_c = ? \quad V_c = \frac{1000 V_d}{L \times I}$$

$$= 20 - 8$$

$$V_d = 12 \text{ V} \quad = \frac{1000 \times 12 \text{ V}}{60 \text{ m} \times 50 \text{ A}}$$

$$L = 60 \text{ m} \quad = 4.00 \text{ mV/A.m}$$

$$I = 50 \text{ A}$$

Reference to *Table 49, Column 10* for MIMS cable, conductor temperature 100 °C, shows that a 10 mm² cable is suitable, with a V_c value of 3.92 mV/A.m. Checking the current-carrying capacity of the cable, *Table 19, Column 5* shows that the cable is able to carry 67 A when clipped to a wall.

The equation:

$$V_c = \frac{1000 V_d}{L \times I}$$

may of course be transposed to provide:

- The maximum route length permitted for a particular cable and current:

$$L = \frac{1000 V_d}{V_c \times I}$$

- The maximum current permitted on a cable if route length and cable type are known:

$$I = \frac{1000 V_d}{L \times V_c}$$

EXAMPLE 16.12

What is the maximum permissible route length for a three-phase 400 V three-wire circuit, protected by a 30 A C-type circuit-breaker, using 6 mm² thermoplastic-insulated and sheathed V90 copper cables in PVC conduit? Because of voltage drop in the consumer mains, the voltage drop in the circuit is limited to 3.5%. Note the cable is in conduit. According to *AS/NZS 3008.1, Clause 3.2.2* and *Table 1, Note 2*, the temperature of 90 °C can be used for calculations.

To determine the maximum permissible route length without exceeding the maximum voltage drop permitted, first transpose the voltage-drop equation. Then:

$$\begin{aligned}
 L &= ? & L &= \frac{1000 V_d}{V_c \times I} \\
 V_c &= 6.81 \text{ mV/A.m (Table 40)} & & \\
 &= 400 \times 0.035 & & = \frac{1000 \times 14 \text{ V}}{6.81 \text{ m} \times 30 \text{ A}} \\
 V_d &= 14 \text{ V} & & = 68.5 \text{ m} \\
 I &= 30 \text{ A} & &
 \end{aligned}$$

EXAMPLE 16.13

An unenclosed 4 mm² V75 two-core TPS copper cable is supplying a 10 A load on a 230 V circuit with a route length of 50 m. What additional current could this cable carry without exceeding the permissible voltage drop for the circuit (V_d) of 9.2 V?

Table 42 shows that, for a 4 mm² cable, the three-phase $V_c = 9.71$ and converting to single phase is $9.71 \times 1.155 = 11.22$ mV/A.m for the circuit in question. To determine the maximum current that may be carried by the cable while not exceeding permissible voltage drop, first transpose the equation for the current. Then:

$$\begin{aligned}
 I &= \frac{1000 V_d}{L \times V_c} \\
 &= \frac{1000 \times 9.2}{50 \times 11.22} \\
 &= 16.4 \text{ A}
 \end{aligned}$$

Accordingly, the load may be increased to 16.4 A—an increase of 6.4 A. Note, however, that 16.4 A is the maximum current permissible because of the long cable run, but it is well below the cable's current-carrying capacity of 34 A, as shown in *Table 10, Column 5*, when clipped to a structure.

EXAMPLE 16.14

An existing 95 m run of three-core 4 mm² V75 thermoplastic-insulated sheathed cables supplies a three-phase 400 V, 19 A motor in a factory where protection is by a 20 A, D-type circuit-breaker. It is proposed to add a small 400 V, 2 A motor to the circuit, bringing the cable loading up to 21 A. Is this permissible if the voltage drop in the circuit must not exceed 18 V?

First, check the voltage-drop limitation for the required current-carrying capacity:

$$\begin{aligned}
 I &= ? & I &= \frac{1000 V_d}{L \times V_c} \\
 V_c &= 9.71 \text{ mV/A.m (Table 42)} \\
 V_d &= 18 \text{ V} & &= \frac{1000 \times 18 \text{ V}}{95 \text{ m} \times 9.71} \\
 L &= 95 \text{ m} & &= 19.51 \text{ A}
 \end{aligned}$$

The maximum current is 19.51 A for the maximum permissible voltage drop, so the additional 2 A is not allowed: only 0.51 A additional load can be added. Due to the voltage-drop considerations, the current-carrying capacity of the cable has been reduced from 29.0 A (Table 13, Column 5, clipped to a building structure) to 19.51 A.

This and similar problems might also be approached by assuming that the proposed load is carried by the cable and calculating the voltage drop (V_d) using the equation:

$$\begin{aligned}
 V_d &= \frac{V_c / L}{1000} \\
 V_d &= \frac{9.71 \times 21 \text{ A} \times 95 \text{ m}}{1000} \\
 &= 19.37 \text{ V}
 \end{aligned}$$

The value calculated exceeds the stipulated voltage drop of 18 V by 1.37 V, so the additional load may not be connected.

Summation of voltage drops

As previously explained, voltage drop commencing at the point of supply comprises a series of successive voltage drops that must be added to obtain the total voltage drop as specified by Clause 3.6 of AS/NZS 3000. The current used for determining voltage drop may be the total connected load or the maximum demand of the circuit.

Clause 3.6.2 indicates that the value of current used for calculating voltage drop need not exceed the total of the connected load or the maximum demand for a circuit. For final subcircuits, this can be taken as the current rating of the circuit-protective device. Diversity is given to circuits supplying distributive loads, such as socket-outlets and lighting, where half the current rating of the protective device is used.

For a mixed three-phase and single-phase load, it is usual to calculate the voltage drop in each line conductor separately, then add them:

$$\begin{aligned}
 \text{Total } V_d &= \frac{V_d \text{ due to three-phase load}}{\sqrt{3}} \\
 &+ V_c \text{ due to single-phase load}
 \end{aligned}$$

With a two-phase three-wire supply (two phases and neutral) taken from a standard 120° three-phase earthed-neutral system, the assigned table values for V_c in mV/A.m may be multiplied by 0.75 for use in the voltage-drop calculation.

If the supply is single-phase three-wire, such as the single-wire earth-return (SWER) system in rural areas—with two actives at 180° and the neutral from an earthed-centre tap—the assigned table values of V_c in mV/A.m. may be multiplied by 0.5.

16.6.3 Excessive voltage drop

Now that you have developed your skills in calculating voltage drop in the various circuits of an installation, you should turn your attention to methods that can be adopted to avoid excessive voltage drop in practice. **Example 16.15** is a demonstration.

EXAMPLE 16.15

Figure 16.25 illustrates the particulars of an installation in which the total voltage drop from the commencement of the consumer mains to a 3.6 kW air-conditioner exceeds the permissible value. Circuit-breaker protection is used for all circuits.

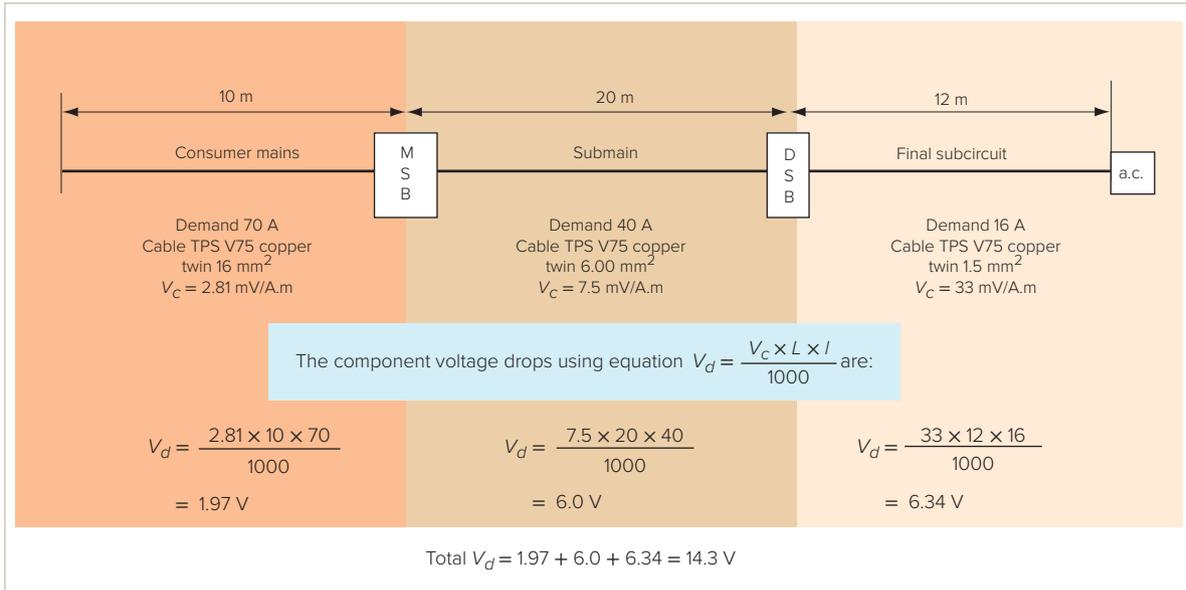


FIGURE 16.25 Installation for Example 16.15

The overall voltage drop of 14.3 V is 2.8 V above that permitted, but the main and submain voltage drops are acceptable. Referring to *Table 42* of *AS/NZS 3008.1.1*, 2.5 mm² cable has a three-phase voltage drop of 15.6 mV/A.m. Therefore:

$$\begin{aligned} \text{single-phase voltage drop} &= 15.6 \times 1.155 \\ &= 18 \text{ mV/A.m} \end{aligned}$$

The most practical solution here is to wire the final subcircuit in 2.5 mm² cable with a V_c of 18 mV/A.m, thus reducing the subcircuit voltage drop to:

$$\frac{18 \times 12 \text{ m} \times 16 \text{ A}}{1000} = 3.46 \text{ V}$$

and the overall voltage drop to 11.43 V, which is acceptable.

Voltage drop in an a.c. circuit is the product of current and impedance:

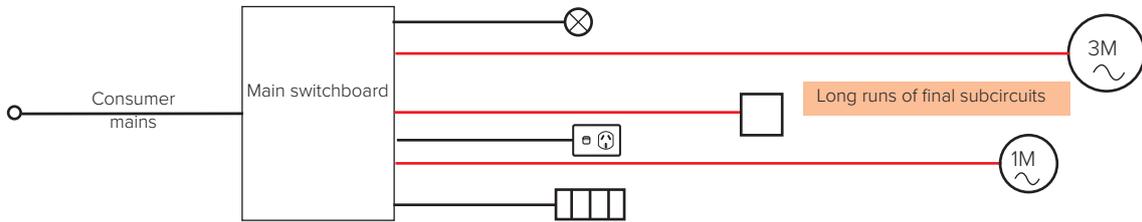
$$V = IZ$$

If voltage drop is excessive, the impedance or current must be reduced to lower it. Usually the load current cannot be altered, so the impedance must be reduced.

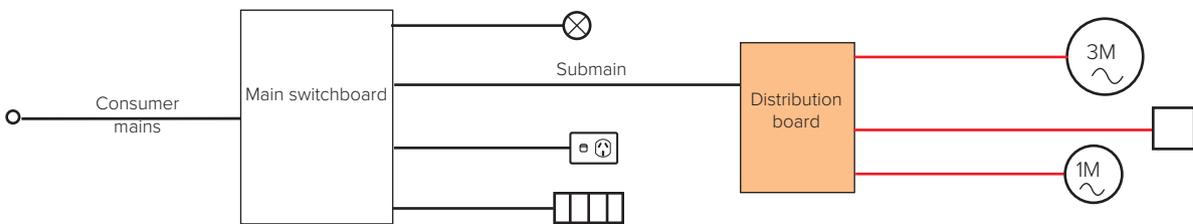
In general wiring, the main component of the impedance is conductor resistance. Remember: resistance is proportional to the length of the conductor, changes if the conductor material changes, and varies inversely with the cross-sectional (CSA) area of the conductor (i.e. length, quality and size). An option at the installation planning/design stage for the reduction of impedance and hence voltage drop is shown in **Figure 16.26**.

In the planning/design stage, long runs of conductors having small cross-sectional areas, with their resultant high-voltage drops, can be avoided by using distribution boards situated as close as practical to the centre of the electrical load. With the approval of the energy distributor, it is sometimes possible to reduce the length of the consumer mains by a suitable point of attachment and main switchboard position.

Arrangement without a distribution board



Arrangement with a distribution board



Note: The comparative costs of alternative arrangements are a major factor in the final installation design.

The route length of final subcircuits is reduced by the use of a distribution board closer to these loads

FIGURE 16.26 Avoiding excessive voltage drop

As it is usually impractical to reduce the length of an existing circuit, the only alternative is to increase the conductor size (CSA), as done in **Example 16.15**. This is the only option that can be adopted in the majority of cases.

16.6.4 Other methods of determining voltage drop

The previous examples used the method described in *Clause 4.2* of *AS/NZS 3008.1*, which provides an approximate but conservative solution for sizing cables with regards to voltage drop.

Clauses 4.3–4.6 of *AS/NZS 3008.1* provide other methods for determining a more accurate value of actual voltage drop (V_d). **Table 16.12** summarises all the methods for determining voltage, where each method is best used and the relevant *AS/NZS3008.1* reference tables.

A simplified method for determining voltage drop is provided in the *Wiring Rules, Appendix C Paragraph C4*. It allows the cable size, circuit length and/or percentage voltage drop to be determined using ampere-metres per cent of voltage drop (A.m per % V_d) values rather than V_c values directly. It also provides for percentage voltage drops in single-phase and three-phase circuits in series groups to be added directly. The *Wiring Rules, Table C4* provides values A.m per % V_d for single- and three-phase circuits for V75 cables, sizes 1 mm² to 95 mm².

Examples of the application of this method are given in *Paragraph C4* of the *Wiring Rules*.

Ampere-metres per cent of voltage-drop value for other cable temperatures can be tabulated from the expression:

$$\frac{10 \times V_o}{V_c}$$

where V_o = supply voltage

V_c = unit value of voltage drop (mV/A.m) for a given conductor size and temperature for a given circuit power factor given in the voltage drop table of *AS/NZS 3008.1*.

TABLE 16.12 Summary of methods for determining voltage drop

Method		Requirements	AS/NZS 3008.1 reference tables	Application
1. Actual voltage drop	$V_d = \frac{L \times I \times V_c}{1000}$	$VP \geq$ sum of V_d s in series arrangement	Tables 40–50 give three-phase V_c values for various cable types, conductors, unit materials and size, and cable temperature.	Most commonly used method: typically used where route length and load current of balanced circuits are known.
2. Unit value	$V_c = \frac{1000 V_d}{L \times I}$	Select conductor size with unit value \geq calculated V_c		
3. Cable temperature—equations from AS/NZS 3008.1 series	$\left(\frac{I_o}{I_R}\right)^2 = \frac{\theta_o - \theta_A}{\theta_R - \theta_A}$ then use methods 1 and 2	As for 1 or 2 calculated temperature raised to nearest temperature given in tables for calculating V_c/V_d		
4. Load power factor—equations from AS/NZS 3008.1 series	Single phase: $V_{d1\phi} = IL[2(R_c \cos \theta + X_c \sin \theta)]$ Three phase: $V_{d3\phi} = IL[3(R_c \cos \theta + X_c \sin \theta)]$	As for 1	Tables 30–33 give X_c for various cables and cords. Tables 34–39 give R_c for various cable types, conductors and cable temperature limits.	A more accurate method that takes into account load power factor, for example circuits supplying large inductive loads such as motors.
5. Unbalanced multiphase circuits	$V_d = I_A \times L_A \times Z_{CA} + I_N \times L_N \times Z_{CN}$ may include cable temperature as variation as in method 3	As for 1	Tables 40–50 give three-phase V_c values. Note: $Z_c = \frac{V_c}{3 \times I}$ for a single conductor.	Used where current in each phase can be shown to be different magnitudes for consistent periods.

 V_d = actual voltage drop V_p = maximum permissible voltage drop V_c = unit value of voltage drop in millivolts per ampere metre (mV/A.m) I_o = operating current (A) I_R = rated current given in Tables 3 to 21 θ_o = operating temperature of cable when carrying I_o (°C) θ_R = rated maximum operating temperature from Table 1 θ_A = ambient air or soil temperature in °C I = current flowing in cable L = route length of circuit R_c = cable resistance in ohms per metre X_c = cable reactance in ohms per metre Z_c = cable impedance in ohms per metre Z_{CA} or

$$Z_{CN} = \sqrt{(R_c^2 + X_c^2)}$$

 I_N = current in neutral conductor L_A = route length of active conductor L_N = route length of neutral conductor

16.6.5 Earth fault-loop impedance

The effect of voltage-drop limitations on a circuit is to limit its route length for a given cable size and maximum demand. For example, a 3 per cent voltage drop applied to a final subcircuit with 2.5 mm² active conductors and protected by a 20 A circuit-breaker is limited to a maximum route length of 19 m:

$$\begin{aligned} 3\% i &= 230 \text{ V} \times 0.03 \\ &= 6.9 \text{ V} \end{aligned}$$

Note: The three-phase V_c value for multicore 2.5 mm² cable at 75 °C is 15.6 mV/A.m (Table 42 AS/NZS 3008.1). Then:

$$\begin{aligned} \text{single-phase } V_d &= 15.6 \times 1.155 \\ &= 18.02 \text{ mV/A.m} \end{aligned}$$

Then:

$$\begin{aligned} L &= \frac{1000 V_d}{V_c \times I} \\ &= \frac{1000 \times 6.9 \text{ V}}{18.02 \times 20 \text{ A}} \\ &= 19.15 \text{ m} \end{aligned}$$

As described in **Section 16.3**, fault-loop impedance is the impedance of the conductors in the series path taken by the current in the event of a fault between an active conductor and an earth fault. The impedance of the fault-loop—usually resistance—must be sufficiently low to allow enough current to flow to operate the protective device and disconnect the supply in a prescribed time.

The factors affecting the portion of the fault-loop in an installation are the resistance of the active and associated protective earthing conductors—the conductor sizes and route length. Similar to voltage drop, the effect is to limit the route length of a circuit.

The first concern here is ensuring the route length of the cables—selected on the basis of voltage drop—does not result in a fault-loop impedance that is too high. Cables for single phase that comply with the limits of voltage drop will, in most instances, be within the limits of fault-loop impedance, as shown by the example in **Table 16.13**.

TABLE 16.13 Example of comparison of maximum circuit lengths based on voltage-drop and EFLI limitations

Protective device rating A	Active conductor mm ²	Earth conductor mm ²	Maximum circuit length for 3% single-phase voltage drop V	Type C circuit-breakers maximum circuit length for EFLI limitations m
16	2.5	2.5	23	85
20	2.5	2.5	19	68
32	4.0	2.5	19	52
40	6.0	2.5	23	48
63	16.0	6.0	39	76

This does not mean that the integrity of the fault-loop impedance for each circuit should not be verified, because such checking is an essential part of ensuring that the protective measures required in an electrical installation will operate as intended.

The maximum route length of a circuit in ensuring the fault-loop impedance is sufficiently low is determined by the following equation:

$$L_{max} = \frac{0.8 \times U_o \times S_{ph} \times S_{pe}}{I_a \times \rho(S_{ph} + S_{pe})}$$

where L_{max} = maximum route length in metres

U_o = nominal phase voltage (e.g. 230 V)

S_{ph} = cross-sectional area of the circuit's active conductor(s) in square millimetres (mm^2)

S_{pe} = cross-sectional area of the circuit's protective earthing conductor in square millimetres (mm^2)

I_a = current required for the protective device to operate and disconnect the supply
(i.e. trip-current setting of circuit-breaker or fusing current for a fuse) (A)

ρ = resistivity at normal working temperature in ohm-square millimetres per metre

(i.e. 22.5×10^{-3} for copper conductors and 36×10^{-3} for aluminium conductors).

NOTE: Paragraph B5.2.1(b) of the *Wiring Rules* suggests that in most instances the voltage at the protective device will be 80 per cent or more when a fault occurs. However, this value will decrease as the distance from the supply increases, such as circuits supplied through a series of distribution boards—the effect being to reduce the maximum length of circuits. Best results are obtained when the impedance of the external portion of the fault-loop or the prospective short-circuit current is known. This information can be obtained from the energy distributor or by testing the fault-loop at the points where the protective devices are to be installed.

Given the previous discussion on voltage drop, it is clear that the maximum route length of a circuit must satisfy the limitations of both the fault-loop impedance and the voltage drop. That is:

$$\begin{aligned} L_{max} &= \frac{0.8 \times U_o \times S_{ph} \times S_{pe}}{I_a \times \rho(S_{ph} + S_{pe})} \\ &= \frac{1000 V_d}{V_c \times I} \end{aligned}$$

EXAMPLE 16.16

The maximum route length determined in **Example 16.12** was 68.5 m for the three-phase circuit. Does this satisfy the fault-loop impedance limit?

$$L_{max} = ?$$

$$U_o = 230 \text{ V}$$

$$S_{ph} = 6 \text{ mm}^2$$

$$S_{pe} = 2.5 \text{ mm}^2 \text{ (from Table 5.1 of the Wiring Rules)}$$

$$I_a = 225 \text{ A (mean tripping current for a Type C circuit-breaker is 7.5 times rated current)}$$

$$r = 22.5 \times 10^{-3}$$

$$\begin{aligned} L_{max} &= \frac{0.8 \times U_o \times S_{ph} \times S_{pe}}{I_a \times \rho(S_{ph} + S_{pe})} \\ &= \frac{0.8 \times 230 \text{ V} \times 6.0 \text{ mm}^2 \times 2.5 \text{ mm}^2}{225 \text{ A} \times 0.0225 \times (6.0 \text{ mm}^2 + 2.5 \text{ mm}^2)} \\ &= 64.14 \text{ m} \end{aligned}$$

The route length determined for voltage drop at 68.5 m is clearly too long to meet the limits of fault-loop impedance. The solution is to increase the size of the protective earthing conductor to 4.0 mm², which increases the maximum fault-loop impedance length to 87.22 m and thus satisfies both limitations, as shown below:

$$\begin{aligned} L_{max} &= \frac{0.8 \times 230 \text{ V} \times 6.0 \text{ mm}^2 \times 4.0 \text{ mm}^2}{225 \text{ A} \times 0.0225 \times (6.0 \text{ mm}^2 + 4.0 \text{ mm}^2)} \\ &= 87.22 \text{ m} \end{aligned}$$

EXAMPLE 16.17

Will the impedance of the existing circuit in **Example 16.14** be low enough to trip the circuit-breaker if a fault to earth occurs?

$$\begin{aligned} L_{max} &= ? \\ U_o &= 230 \text{ V} \\ S_{ph} &= 4 \text{ m m}^2 \\ S_{pe} &= 2.5 \text{ mm}^2 \text{ (from Table 5.1 of the Wiring Rules)} \\ I_a &= 375 \text{ A (mean tripping current for a Type D circuit-breaker is 12.5 times rated current)} \\ r &= 22.5 \times 10^{-3} \\ L_{max} &= \frac{0.8 \text{ V} \times S_{ph} \times S_{pe}}{I_a \times p(S_{ph} + S_{pe})} \\ &= \frac{0.8 \times 230 \text{ V} \times 4.0 \text{ mm}^2 \times 2.5 \text{ mm}^2}{375 \text{ A} \times 0.0225 \times (4.0 \text{ mm}^2 + 2.5 \text{ mm}^2)} \\ &= 33.55 \text{ m} \end{aligned}$$

Clearly the route length of the circuit is too excessive to meet the fault-loop impedance limits. The impedance to ensure operation of the protective device can be calculated from Ohm's Law: $Z = 0.8 \text{ V} \div I_a = 0.8 (230 \div 250) = 0.73 \Omega$. The fault-loop impedance of the circuit at 95 m is approximately 1.39 Ω , as determined from the a.c. resistance values for 4.0 mm² and 2.5 mm² conductors given in *Table 3.5 of AS/NZS 3008.1*:

$$\begin{aligned} 4 \text{ mm}^2 @ 75 \text{ }^\circ\text{C}: & 5.61 \Omega/\text{Km} \times 0.095 \text{ Km} = 0.533 \Omega \\ 2.5 \text{ mm}^2 @ 75 \text{ }^\circ\text{C}: & 9.01 \Omega/\text{Km} \times 0.095 \text{ Km} = 0.856 \Omega \\ 0.533 \Omega + 0.856 \Omega &= 1.389 \Omega \end{aligned}$$

Being an existing circuit and without rewiring, the likely solution would be to install an RCD. Because RCDs have such a low trip current (in this case a 100 mA device would suffice), the impedance of the fault path is not as critical [$Z = 0.8 \text{ V} \div I = 0.8 (230 \div 0.1) = 1840 \Omega$] as it is for a circuit-breaker (0.73 Ω) in providing protection against indirect contact, in accordance with *Clauses 1.5.6 and 2.6 of the Wiring Rules*.



CHECK YOUR UNDERSTANDING

26. Explain the unit of voltage drop expressed as millivolt per ampere-metre.
27. A new distribution board is needed for a new processing area in a large plant. Given a route length of 58 m, a voltage drop not to exceed 2 per cent, a maximum demand of 235 A per phase, the cable is X90 and run as trefoil. What is the minimum size cable needed with a 250 A Type C circuit breaker?
28. If the earth size is 25 mm², does **Question 27** satisfy the fault-loop impedance requirements for the cable run?
29. When is voltage drop likely to be the deciding factor in the minimum cable size for a circuit?
30. A single-phase final subcircuit is limited to a voltage drop of 5 V due to the voltage drop in the consumer mains and submains. The circuit is wired in twin V75 thermoplastic-insulated TPS copper cable, unenclosed, to supply a 30 A 400 V factory load at a distance of 18 m from the protective circuit breaker at the distribution board. What size cable should be selected?

16.7 Short-circuit temperature performance of cables

Section 5 of AS/NZS 3008.1 provides guidance on the selection of cables likely to be subject to damage from a short circuit. Under a short circuit of negligible impedance, that is, a bolted fault, a cable will heat rapidly due to the high current that flows. Cable temperature might rise to a point where the insulation, sheath or conductor are permanently damaged. This problem is usually limited to cables subject to high prospective-fault currents, such as a consumer mains connected directly from a distribution transformer to the main switchboard of a large installation. In this text, selecting cables by short-circuit temperature limitations is given as a basic understanding of the concept and factors involved (**Figure 16.27**) so that you can recognise such situations and seek advice from cable manufacturers or other experts in the field.

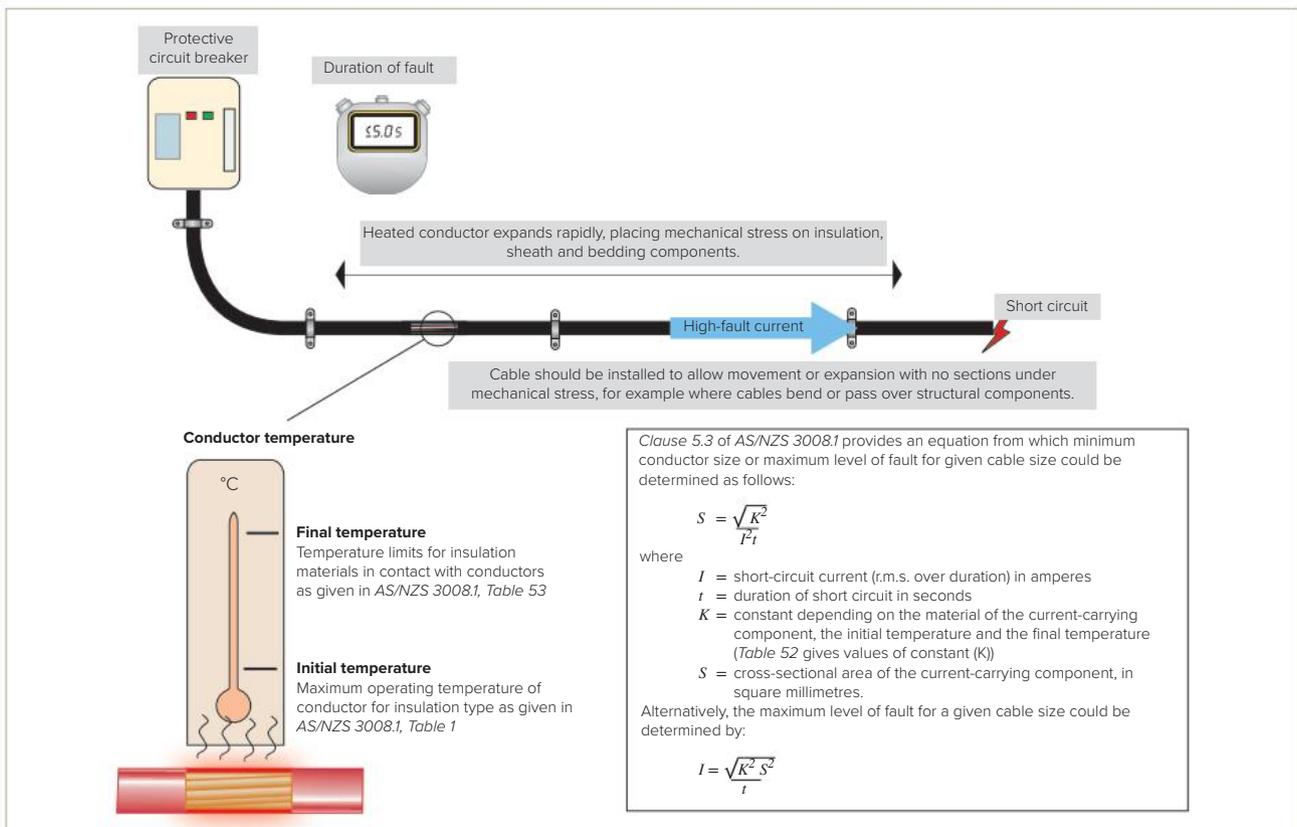


FIGURE 16.27 Concept of short-circuit temperature limitations of cables



CHECK YOUR UNDERSTANDING

31. Explain the possible consequences on a cable that has a bolted-fault short circuit.

SUMMARY

- ▶ There are many factors involved in designing an electrical installation, including number and size of conductors, maximum current, limitations and protective measures.
- ▶ An electrical installation must be arranged into a number of circuits.
- ▶ Individual circuits assist in fault-finding and limit nuisance tripping.
- ▶ There are a number of factors that dictate cable selection, including maximum demand of the property, current-carrying properties of the cables, types of loads, cable routes and protective devices used.
- ▶ Maximum demand is a calculation based on a number of tables in the *Wiring Rules*, dictating how a circuit is to be used.
- ▶ The particular site dictates individual current allocations for the same device.
- ▶ Cable selection is a complex process, involving voltage-drop considerations due to length, heat dissipation, maximum current, frequency and voltage transients, cable routes and installation methods, protective device ratings and protective earth sizes.
- ▶ Cables ‘perform’ differently according to their maximum temperature and type of insulation used.

REVIEW QUESTIONS

1. Where could you use the information in *Appendix C, Tables C5 and C6* of the *Wiring Rules*?
2. Describe two typical situations where the arrangement of the installation includes additional distribution boards.
3. Describe what is meant by the term *maximum demand*.
4. Name the type of cable that may have a maximum operating temperature of 250 °C and the conditions under which this is permitted.
5. What installation conditions and external factors affect the current-carrying capacity of cables in underground wiring systems?
6. Explain the term *thermal resistivity of soil*.
7. Briefly explain the effects of 3rd-order harmonics in three-phase four-wire systems.
8. What information do *Tables 3(1)–3(4)* of *AS/NZS 3008.1* provide?
9. Identify the group of *AS/NZS 3008.1* tables that give current-carrying capacity for cables with cross-linked elastomeric (90 °C) insulation.
10. Which *AS/NZS 3008.1* table specifies de-rating factors for multicore cables for groups of circuits installed on a cable tray?
11. What advantage can be taken in selecting cables for loads that have intermittent or cyclic operation?

12. Name three factors to consider when selecting cables to meet voltage-drop limitations.
13. What limitations do voltage drop and earth fault-loop impedance place on a circuit?
14. Why must the impedance of the earth fault-loop of a circuit be low?
15. Name the conductors of a circuit that form the path of an internal earth fault-loop.
16. Describe the relationship required for each circuit between the conductors and the circuit-protective device.
17. A three-phase submain supplies the distribution board in the processing area of a manufacturing complex. Determine the maximum demand for the submain given the following loads and allowing 15 per cent for future increase:
 - 4 × twin 36 W fluorescent troffer luminaires each rated at 0.38 A
 - 16 × 400 W mercury vapour high-bay luminaires each rated at 2.28 A
 - 8 × 10 A single-phase socket-outlets
 - 4 × 15 A three-phase socket-outlets
 - 2 × 20 A three-phase socket-outlets
 - 1 × 63 A three-phase socket-outlet
 - 1 × 12 kW three-phase induction heater (for processes, not space heating)
 - 1 × 15 kW motor rated at 27.1 A per phase
 - 3 × 7.5 kW motors rated at 13.54 A per phase
 - 2 × 3.5 kW motors rated at 6.48 A per phase
18. Select a suitable cable for the consumer mains of Question 17 given that the point of supply is at an underground pillar 15 m from the main switchboard and V75 cable is to be used.
19. What parameter limits the route length of a single-phase circuit with 3 per cent voltage drop and comprising 6.0 mm² active and 2.5 mm² earth conductors, protected by a 40 A C-type circuit-breaker?
20. What is the maximum route length of a circuit with 6.0 mm² active and 4.0 mm² protective earth conductor and protected by a 50 A D-type circuit-breaker?

CHAPTER 17

Wiring and cabling systems

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ describe the purpose of the main construction components of common building types
- ▶ explain each of the factors to consider when select a wiring system and where the various wiring systems are typically used
- ▶ apply the *Wiring Rules* to the installation of wiring systems
- ▶ describe the features of commonly used conduits and where they may be used
- ▶ apply the *Wiring Rules* and sound trade practices to working with conduits
- ▶ apply the *Wiring Rules* and sound trade practices to working with trunking enclosures
- ▶ apply common work practices for drawing/pulling cables into enclosures
- ▶ illustrate the main requirements for the various categories of underground, aerial and catenary wiring systems
- ▶ apply *Wiring Rules* requirements for different wiring systems.

As indicated by *Clauses 1.4.52 and 1.4.50* of the *Wiring Rules*, an electrical installation consists of all the wiring and associated equipment used to convey and control electrical currents between the source of supply and the energy-consuming devices (lighting and appliances) on the consumer's premises.

The necessary distribution of power within a consumer/customer's premises, together with the connection of data, voice, fire protection and security equipment, is achieved by wiring/cabling systems. Broadly speaking, a wiring system can be regarded as consisting of the cables or conductors and the method used for their support, protection against damage and protection against the risk of electric shock. *Wiring system* can refer to a type of cable, a type of cable installed in a certain way, or various combinations of cables or conductors, cable support systems and cable enclosures.

All equipment selected for an electrical installation, including wiring systems, must comply with the requirements of *Clause 1.7*; that is, the equipment itself must be safe in design and construction, an integral part of which is its proper assembly and installation. Equipment must also be able to function properly in the environment in which it is installed and not cause any damaging effect on the electrical installation or the premises in which it is installed. Wiring/cabling systems for telecommunications services must comply with *Australian Standard AS/CA S009 Installation requirements for customer cabling (Wiring Rules)*. (In New Zealand, compliance documents PTC103 and PTC106 prevail.)

At this stage, you should aim to gain knowledge of the characteristics and applications of wiring systems in general use, so that you are able to select the most appropriate wiring system for a specific situation. Selection of cable conductor sizes is covered in **Chapter 16**.

17.1 Wiring and cable routes through buildings and structures

Before looking more closely at wiring systems, it is necessary to gain an understanding of the environments of the buildings and structures where wiring and cables are installed. To work effectively with builders, engineers, architects and other tradespeople, the electrician must be conversant with building plans and drawings, and also with building terms, construction methods and construction sequences. There are many standards covering building materials, construction methods and building services. However, in Australia and New Zealand the National Construction Code (NCC) and the New Zealand Building Code (NZBC) are the overall standards that buildings must comply with. Aspects of national building codes affecting electrical installations are outlined in *Appendix E* of the *Wiring Rules*.

17.1.1 Building components and construction methods

An electrician's working knowledge of construction and building methods should extend to types of buildings according to intended use, types of construction defined by structural method, and components that affect the installation of wiring/cabling and equipment. The apprentice needs to take a particular interest in the typical routes for installing cable runs in a building, as this involves working with and around building components without damaging them. An existing building may pose an additional challenge, as the routes of cable that would normally be installed as a structure is being built are not always accessible in a completed building.

The sequence of construction is another important factor, as the electrician must be on site with the necessary materials to complete certain work as the building progresses. For example, the wiring for switches and socket-outlets needs to be installed in, say, a framed wall before the wall is lined with plasterboard.

The important components for the most common building types, building sequence and cable routes are shown in **Figures 17.1** to **17.7** and **Table 17.1**.

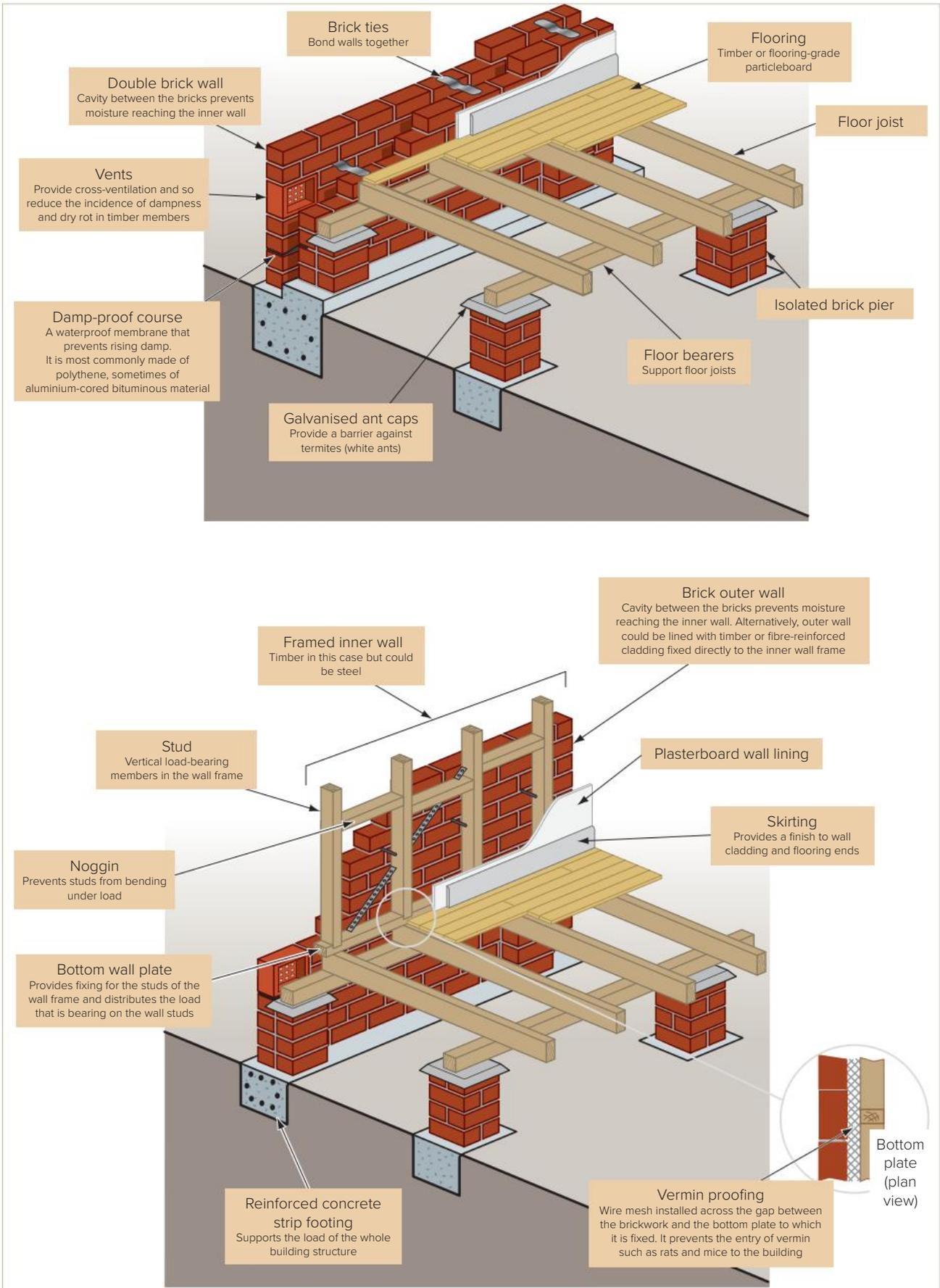


FIGURE 17.1 Low-level buildings—subfloor construction

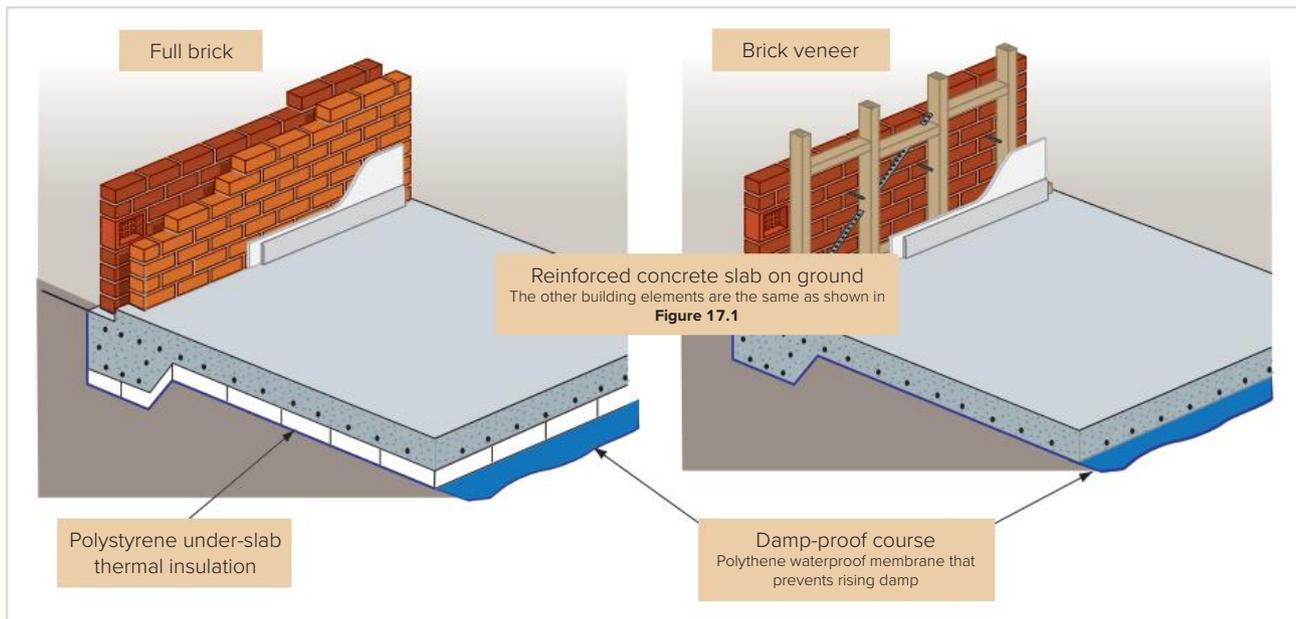


FIGURE 17.2 Low-level building—slab-on-ground construction

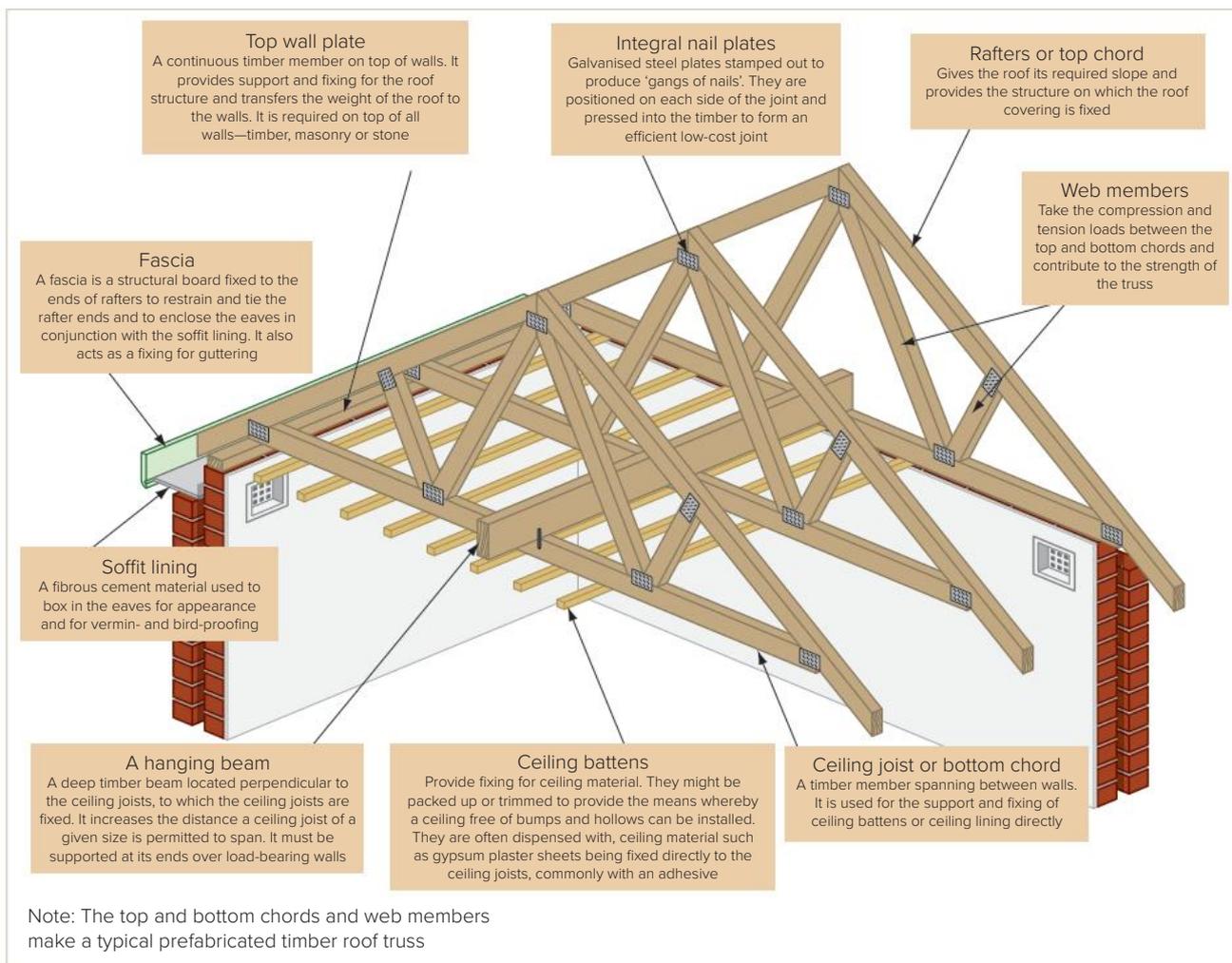


FIGURE 17.3 Low-level building—ceilings and roofs

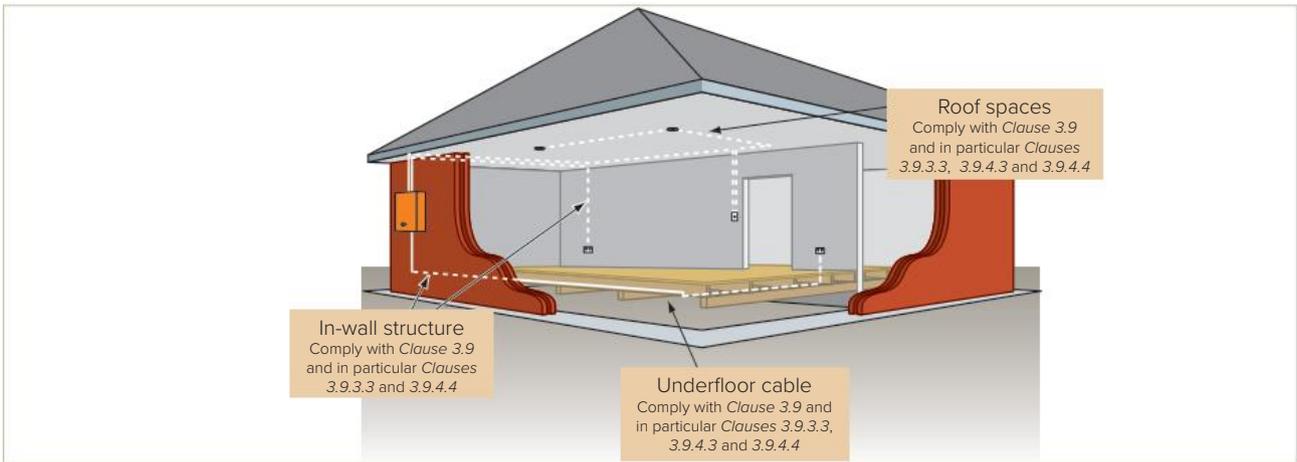


FIGURE 17.4 Typical cable routes through a low-level building

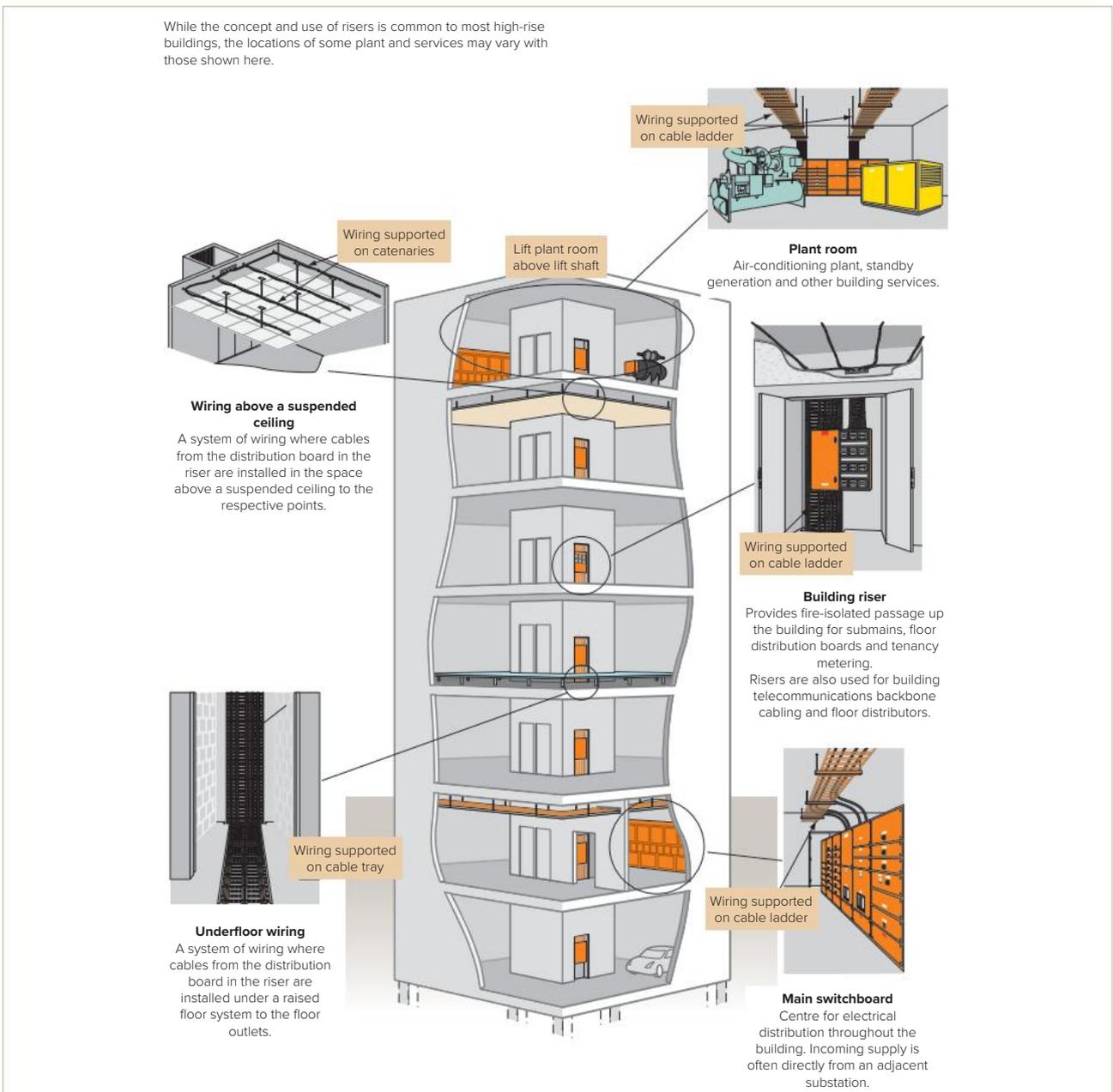
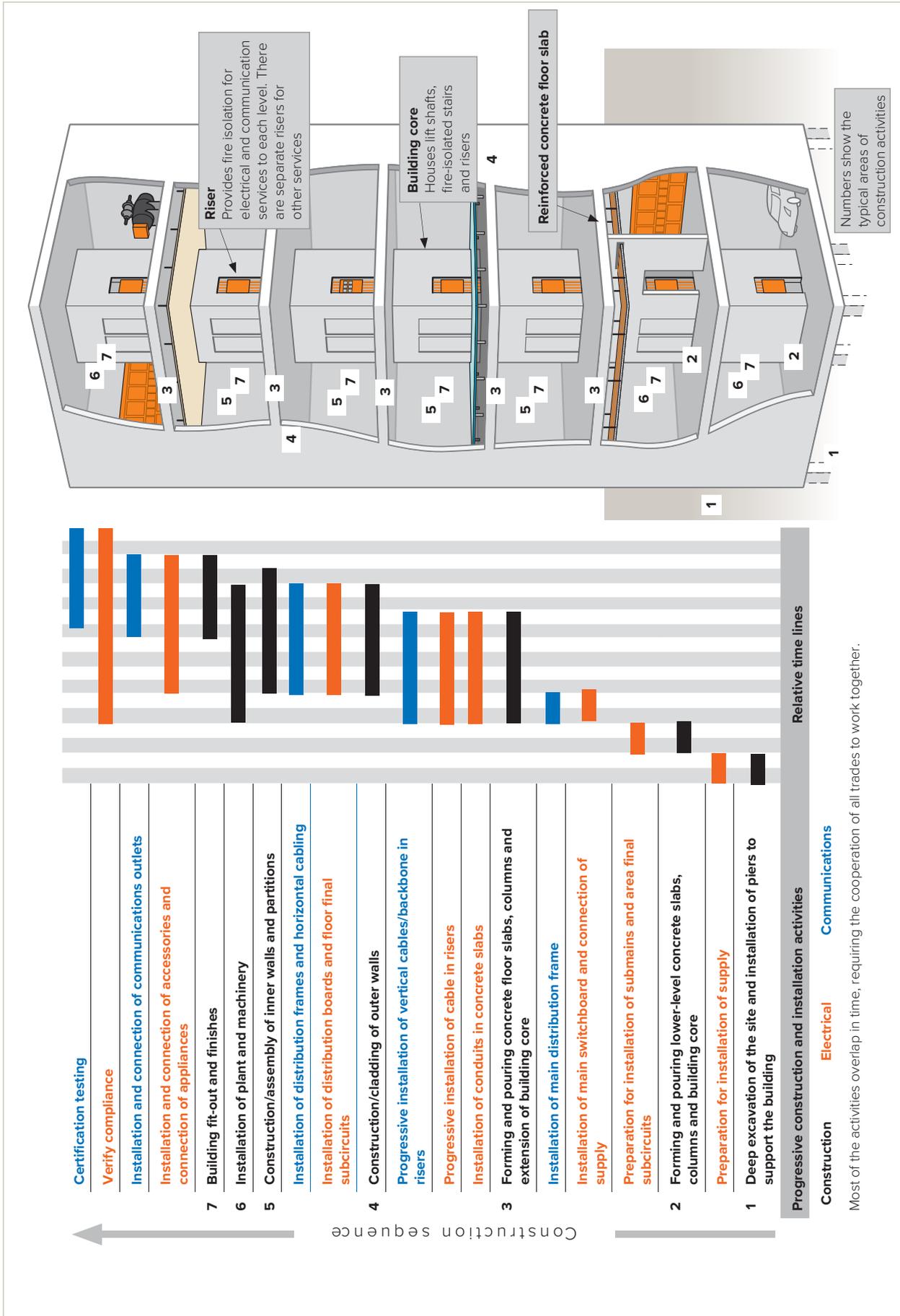


FIGURE 17.5 Multilevel building—cable routes and services



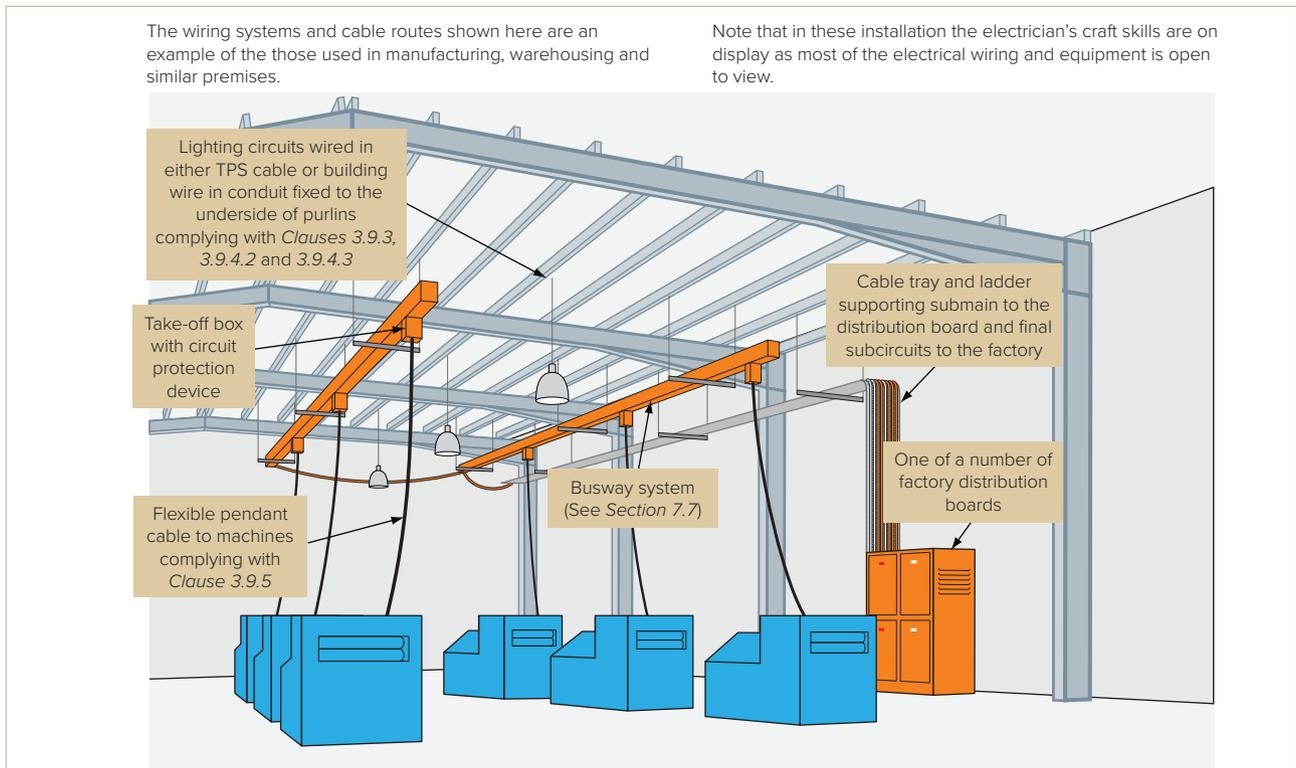


FIGURE 17.7 Commercial/industrial building—components and cable routes

TABLE 17.1 Summary of building types, construction methods and typical wiring routes

Purpose of use	Construction type	Foundation	Internal structure	Roof	Thermal insulation	External finish	Typical wiring routes
Single domestic dwelling	Timber or metal frame; or brick/block	Concrete slab on ground; or concrete footing for supporting walls	Concrete slab or timber floor. Timber or metal frame and plasterboard walls; or rendered brick/block walls	Tile or metal	Walls and roof spaces and underfloor of subfloor construction	Brick or timber cladding; or fibrous cement cladding	Underground conduits below foundations; conduits in concrete slabs; or through wall frames and ceiling spaces
Single- and multiple-use high-rise and specific-purpose building	Concrete slab on concrete or steel columns	Concrete piers deep in ground	Concrete slab floors (several levels below ground); timber or metal frame and plasterboard walls; or rendered brick/block suspended ceilings	Concrete slab or metal	Thermal rating integrated in building design	Glass, decorative cladding of concrete, plastic or tile	Underground conduits below foundations; conduits in concrete slabs; cable risers (built into structure); through spaces above suspended ceilings and below raised floors; or open wiring in carpark levels and in switch rooms and plant rooms
Industrial buildings and unenclosed plant structures	Concrete slab and clad metal frame or open steel frame	Concrete piers deep in ground	Concrete slab or metal on supporting steel frame	Metal	Dependent on industrial processes for which building is to be used	Metal or brick/block; or open in the case of unenclosed plant structures	Unconcealed wiring on cable tray and ladder or in conduit or trunking supported by structural members



CHECK YOUR UNDERSTANDING

1. Name the national codes which building structures must comply and state where the *Wiring Rules* refer to such codes.
2. Why does an electrician need to know about construction and building methods?
3. What is the important safety feature of a riser in a multilevel building?

17.2 Wiring and cabling systems

A wiring or cabling system refers to a particular type of wire or cable, its methods of support and fixing and, where required, the type of cable enclosure used. In most installations, the wiring and cabling systems are made up of a number of common components in various combinations. For example, in a commercial building, a lighting circuit may commence from the switchboard in circular TPS cable supported on a cable tray and change to a catenary support above a suspended ceiling in the area where the lights are to be installed. As well as the common wiring systems, integral wiring systems are available that include the conductors, enclosures and connection devices such as busway systems.

Table 17.2 provides a snapshot of the most common wiring and cabling system components and where they are typically used.

TABLE 17.2 Components of common wiring systems

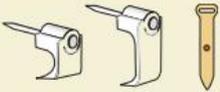
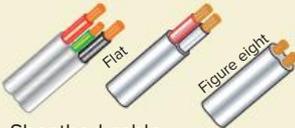
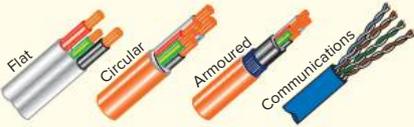
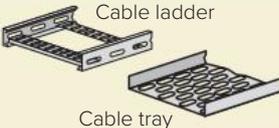
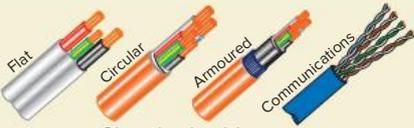
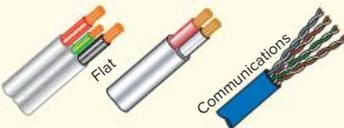
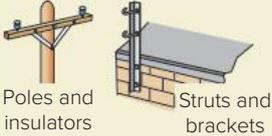
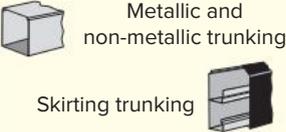
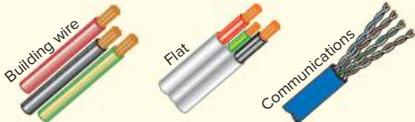
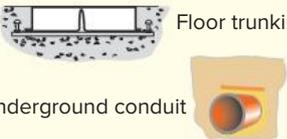
Fixing and support	Common use in wiring systems	Cable types
	Cable clips are used to fix double-insulated cables to timber and like surfaces; they are best used in accessible locations not in general view, such as ceilings and under floor spaces (see <i>Clauses 3.3.2.8</i> and <i>3.9.3</i>)	 <p>Sheathed cable</p>
 <p>Cable tie</p>	Cable ties are used to attach and secure these cables to support structures such as catenary wire, cable ladder and cable tray; also used to tie cable groups together, although care needs to be taken when bundling groups of cables due to the de-rating factor of the cables from mutual heating (see <i>AS/NZS 3008, Table 22</i>)	 <p>Sheathed cables</p>
 <p>Cable ladder Cable tray</p>	Cable ladder and cable tray are the main support system for sheathed cables run in basements, risers, plant rooms and switch rooms in commercial, high-rise and industrial buildings (see <i>Clauses 3.3.2.8</i> and <i>3.9.3</i>)	 <p>Sheathed cables</p>
 <p>Catenary support</p>	A catenary wire has become a common method of supporting cable above suspended ceilings; if used outdoors, the supported cables must be suitable for exposure to sunlight (see <i>Clauses 3.9.3.2</i> and <i>3.13</i>)	 <p>Sheathed cables</p>

TABLE 17.2 (Continued)

Fixing and support	Common use in wiring systems	Cable types
 <p>Poles and insulators Struts and brackets</p>	<p>The extent of aerial wiring in consumers' premises in urban areas is mostly confined to the service lines from the overhead supply to a point of attachment; it is more common in rural areas to cover longer distances between the distributor's supply, premises and outbuildings (see <i>Clause 3.12</i>)</p>	 <p>Aerial cables</p>
<p>Enclosures</p>		
 <p>Conduit</p>	<p>Conduit is probably the most common cable enclosure; whereas unsheathed cable must be enclosed, sheathed cable is installed in conduit where additional protection against mechanical damage is needed or it is deemed a more convenient or efficient method of fixing and support (see <i>Clause 3.10</i>)</p>	 <p>Building wire Flat Circular Armoured</p> <p>Must be enclosed Sheathed cables</p>
 <p>Metallic and non-metallic trunking Skirting trunking</p>	<p>Trunking is a convenient system for neatly supporting a number of cables, provided the cables therein are not de-rated below the required current-carrying capacity (see <i>AS/NZS 3008 Table 22</i>); PVC minitrunking is a neat way of supporting a surface run of TPS or communications cable, particularly if it is open to view; and skirting trunking has become almost standard in commercial installations</p>	 <p>Building wire Flat Communications</p> <p>Must be enclosed Sheathed cables</p>
 <p>Non-metallic slotted trunking</p>	<p>Slotted trunking is used exclusively in control panels and switchboards; it provides a means of separation where required (see <i>Clauses 3.9.8.2, 3.9.8.3 and 3.9.8.4</i>) and ease of tracing conductors and altering circuits while maintaining a tidy appearance</p>	 <p>Building wire</p> <p>Unsheathed cables</p>
 <p>Floor trunking Underground conduit</p>	<p>Underfloor trunking systems are used in large open commercial spaces to supply power and services to work areas; they compete with other systems such as raised floor and service poles and the like. HD (heavy-duty) conduit is commonly used in underground wiring systems (see <i>Clause 3.11</i>)</p>	 <p>Flat Circular Armoured Communications</p> <p>Sheathed cables</p>

17.2.1 Selecting a wiring/cabling system

No universal wiring/cabling system can be claimed as the best for all applications, but there is usually one system that can be selected as the best or most suitable for a particular application after due consideration of all technical and economic aspects. The decision to employ a particular wiring system will depend on many factors and the way they affect the installation. **Table 17.3** describes the main factors to be considered when selecting a wiring/cabling system.

TABLE 17.3 The main factors in selecting a wiring/cabling system

Factors	Considerations
Type and purpose of a building structure	Whether the building is timber, steel, aluminium or concrete, and what its function is, will have considerable influence on the wiring system chosen. As an example, the type of wiring used in a prefabricated steel structure such as a temporary field maintenance workshop would differ from that supplying similar equipment permanently installed in a high-rise building.
Appearance of completed installation	As an example, the wiring system suitable for a factory would certainly be adequate and suitable, both electrically and mechanically, for the wiring of a church, but its appearance would almost certainly offend in this environment. Wiring systems are available that are specifically designed to be unobtrusive in the environment where they are installed; some examples are track systems for display lighting and skirting trunking in offices.
Ambient temperature of environment in which system operates	This is important because different cables and enclosure materials have different operating-temperature limits (see Chapter 16). Therefore, a system used for office wiring would be unsuitable for the temperatures encountered in a boiler house or sauna.
Mechanical hazards likely to affect wiring system	For example, the conditions present in an industrial plant differ from those in the roof space of a domestic dwelling, where wiring is less likely to be disturbed.
Hazards associated with environment	These include situations where explosive gases or vapours are present, where the wiring system is exposed to seawater spray, ocean atmosphere or high temperatures, and corrosive materials in industrial plants, to list a few. Environmental hazards often make a specific wiring type necessary.
Cost	This is a major consideration, together with the above factors where these factors apply. Most often the main concern is the initial cost of the system. However, in installations for industrial production facilities, hospitals, prestigious buildings and the like, the reliability of the wiring system is another major consideration. Here the operating and maintenance costs with respect to the wiring system will be of concern, including depreciation and the estimated life of the system.

There are many other situations where an unusual or special environment exists and so it will be the deciding factor in the choice of wiring system. From the above, it is obvious that the selection of a suitable wiring system requires a practical knowledge of the many systems available and their suitability for different situations.

Unenclosed wiring and cabling

Sheathed cables form the basis of the most widely used wiring system in all types of structures. The TPS flat-type cable is the most used wiring for lighting, power and single-phase appliance circuits. Circular TPS cable is commonly used for submains and three-phase appliance circuits, although there are circumstances where it may be selected as the most suitable cable for, say, single-phase power circuits. Note that TPS cables, when used with all-insulated accessories, form a double-insulated wiring system (see *Clause 1.4.73(c)*).

The main reason for the widespread use of the TPS wiring system is that it is easily installed as both surface and concealed wiring and, where required, supporting and fixing are quite straightforward. Mainly due to these advantages, its installation cost is usually less than that of other systems.

TPS cable does, however, have some disadvantages. For example, it is prone to mechanical damage during installation if not handled carefully, and it must be protected against mechanical damage in some situations. Alternatively, where severe conditions in the environment or mechanical damage are risks to the wiring, sheathed steel wire armoured (SWA) cable or cross-linked polyethylene cable are commonly chosen. In areas where higher temperatures are an issue, fire-rated sheathed cables are used. Although not as common, in extreme temperature conditions mineral-insulated metal-sheathed (MIMS) cables may be an appropriate choice.

Apart from direct surface fixing, the most common support systems for unenclosed cables are cable tray and cable ladder, which are used mostly for installation in commercial and industrial installations. Common types are shown in Figure 17.8, with Figures 17.9 to 17.14 in Section 17.3 giving examples of where cable tray and cable ladder are used.

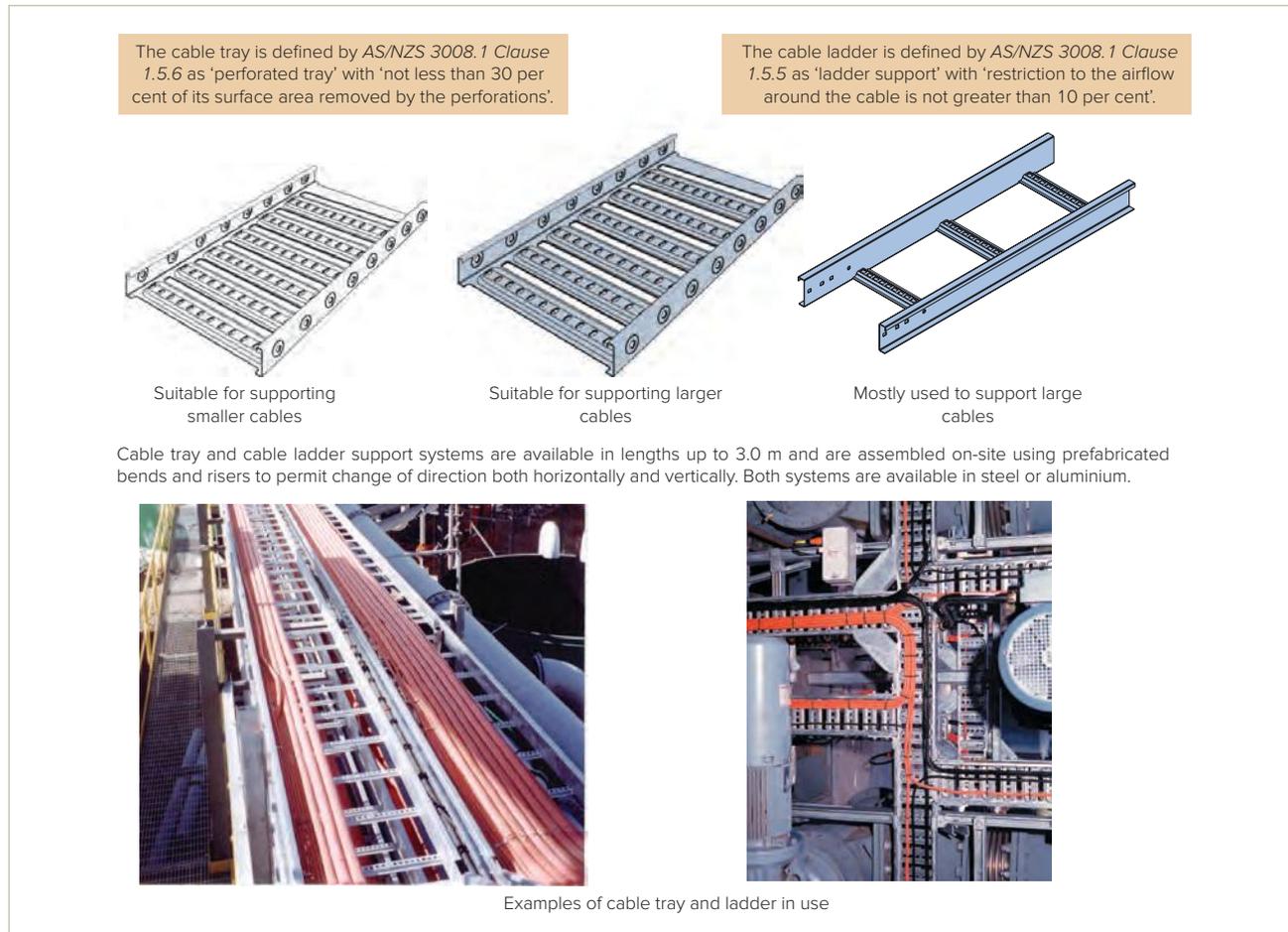


FIGURE 17.8 Cable tray and cable ladder

Enclosed wiring and cabling

It is mandatory for unsheathed insulated cables to be installed in an approved enclosure, such as conduit or trunking. Sheathed cables are also required to be enclosed in underground systems (see *Wiring Rules, Table 3.5*). It may be the case that a TPS cable is enclosed in conduit for a portion of its run where additional mechanical protection is necessary.



CHECK YOUR UNDERSTANDING

4. State the three elements of a wiring/cabling system.
5. When selecting a wiring system, why is it important to take into account the ambient temperature of the environment where the wiring is to be installed?
6. Give an example of where mechanical hazards may affect the type of system selected.
7. What types of power cable may be supported by a catenary?
8. How must insulated, unsheathed cable be installed?

17.3 Installing wiring systems

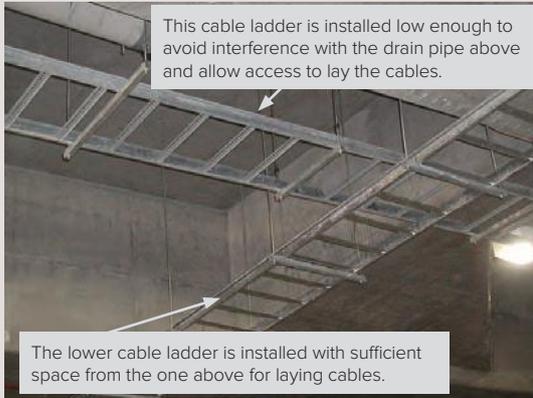
The selection and installation of wiring is subject to the requirements of *Part 1, Clause 1.7* of the *Wiring Rules*, with *Part 2, Section 3* giving detailed requirements that are deemed to comply. This means that wiring installed to the rules in *Section 3* will meet the requirements of *Part 1* for the selection and installation of wiring. Selecting cable conductor size is covered in more detail in **Chapter 16**. For now, our focus is on wiring systems, a summary of which is given in *Table 3.1* of the *Wiring Rules* and *Clause 3.9 Installation requirements*, and techniques for meeting these requirements.

The general approach to the installation of a wiring system, whether for a new domestic installation, a renovation or a larger installation, is to follow some straightforward management rules, as the following guide suggests.

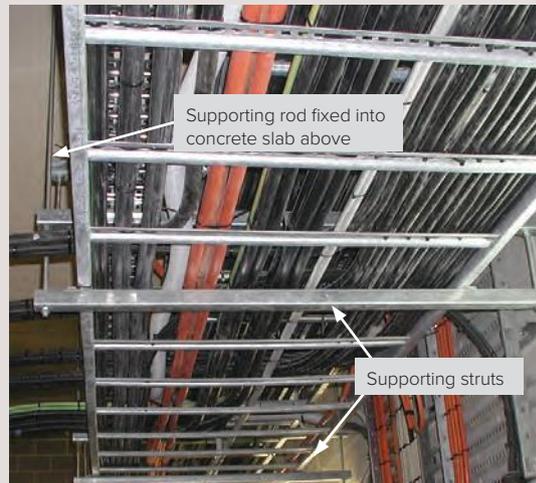
Guide to managing the installation of wiring systems

1. Plan routes of wiring systems, considering the following factors (see also **Figure 17.9**):
 - ▶ requirements of job specifications, including any cable schedule
 - ▶ ease and safety of installing the wiring systems and the economical use of materials
 - ▶ conflict of the wiring with other services such as communications, plumbing, air-conditioning ductwork and the like (*Clause 3.9.8*)
 - ▶ crossovers of cables, and in particular wiring enclosures such as conduits and trunking; these should be avoided, as they degrade the appearance of the completed work
 - ▶ how the cables for each circuit are to be laid; bunching cables together reduces the current they can carry without overheating. There is more about selecting cables based on their current-carrying capacity in **Chapter 16**.
2. Install wiring systems in accordance with *Clause 3.9 Installation requirements* and accepted sound and safe practice:
 - ▶ avoid mechanical strain on cables during and after installation and on connections once cables are terminated (*Clause 3.3.2.8*)
 - ▶ for cables required to be fixed (*Clause 3.9.3*) the usual fixing accessories for unenclosed cable are plastic cable clips, pin clips of soft brass and nylon cable ties; cables are to be supported and fixed in locations where they are unlikely to be disturbed, above suspended ceilings and where they run vertically (*Clauses 3.9.3.2, 3.9.3.3 and 3.9.5*)
 - ▶ protect against the hazards of exposed live conductors of wiring systems at risk of mechanical damage because of where they are in building structures; locations of wiring systems requiring protection and acceptable protection methods are given in *Clause 3.9.4*
 - ▶ where cables change direction, observe minimum bending radiuses in accordance with the manufacturers' recommendations or *Clause 3.9.6* and protect them against damage from sharp edges
 - ▶ ensure penetrations for wiring/cables in building elements do not weaken the structure and are within the limits imposed by National Building Codes (*Clause 3.9.3.1*)

The importance of planning wiring system runs cannot be over-emphasised. Good planning will avoid clashes with other services such as air-conditioning and plumbing and ensure sufficient space is available for all cables in the run.



Cable ladder in the sub-level of a commercial building in preparation for the installation of submains to floor distribution boards and plant rooms.



Cable ladder in two layers in a switch room to support outgoing submains and final subcircuits. The planning of these cable runs involves:

- determining the number and size of cables to be installed, allowing for any reduction in current-carrying capacity from the way the cables are laid
- deciding on the number and size of cable ladders needed
- selecting struts, rods and fixings that will safely support the weight of the cables and ladders, and
- planning the position of cables for each circuit on the cable ladders to avoid crossovers and bunching.

FIGURE 17.9 Examples of the need for planning cable runs ■

- ▶ make sure cables are installed so as not to interfere with other electrical and non-electrical systems, as required by several interrelated Clauses and Standards under *Clause 3.9.8* and shown in **Figure 17.10**.
- ▶ seal the openings where a wiring system passes through fire-rated barriers in the building elements, in accordance with *Clause 3.9.9.3*; common fire-rated building elements are the walls and ceilings enclosing emergency exit stairs, the walls, floor and ceiling of a main switchboard room, and the walls of service risers in multilevel buildings
- ▶ in the spirit of sound job management and safety, keep a record of the wiring system installation as each part is completed.

Examples of installation practices are shown in **Figures 17.11 to 17.20**.

3. When all cables are fixed and secure, and the wiring into equipment is complete, the final connections are made at junction boxes, switchboards and equipment, and the installation is prepared ready for service. Once again, record the completion of each circuit including the as-installed marking-up on job drawings of any changes to the original installation design.
4. Before the system is put into service, final testing is carried out.

WIRING RULES PART 2

3.9.8 PREVENTION OF MUTUAL DETRIMENTAL HARMFUL EFFECTS BETWEEN SERVICES

3.9.8.1(a)
Between different installations

3.9.8.2
Different electrical installations

Installations are different when they are separately connected to the supply.

3.9.8.1(b)
Between different parts of the same installation

3.9.8.1(c)
Between low-voltage and extra-low voltage circuits

3.9.8.1(d)
Between different circuits of different safety services

3.9.8.1(e)
Between safety service and the rest of an installation

3.9.8.1(f)
Between electrical and non-electrical installations

3.9.8.4 (a)
Proximity to non-electrical services

3.9.8.4 (b)
Gas and water services

3.9.8.1(g)
Between the electrical installation and telecommunication and data cable installations

3.9.8.4 (c)
Telecommunication services

7.5 EXTRA-LOW VOLTAGE ELECTRICAL INSTALLATIONS

7.5.11
Wiring systems

7.2 SAFETY SERVICES

7.2.2; 7.2.5 to 7.2.10
Wiring systems for each component of a Safety Services installation

Gas service AS/NZS 5601
Water services AS/NZS 3500

5.6 EQUIPOTENTIAL BONDING

5.6.2.2
Conductive waterpipes

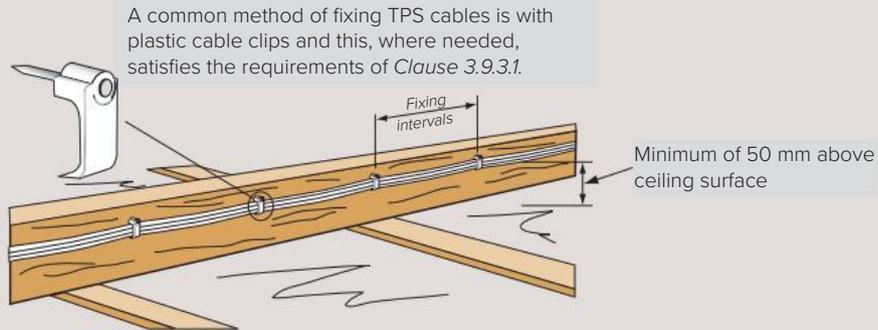
5.6.2.3
Other conductive piping systems

4.10 ELECTRIC HEATING CABLES . . .

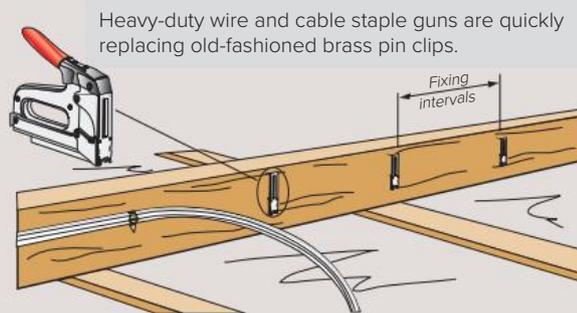
4.10.2
Heating cables

AS/ACIF S009 Installations requirements for customer cabling (Wiring Rules) [Australia]
TCF Premises Wiring Code of Practice (NZ)

FIGURE 17.10 Preventing interference with other electrical and non-electrical systems



An example of cables fixed in an accessible ceiling space in a location where they are likely to be disturbed (*Clause 3.9.3.3*). No fixing interval is specified in the *Wiring Rules*, but where cables are likely to be disturbed or where appearance is a factor, an appropriate fixing interval might be 0.3 m.



It is usually best practice to use pin clips on long runs, where you can install the clips for the whole run prior to fixing the cable. This reduces the risk of damage to the cables, which is more likely when they are installed and fixed at the same time.

FIGURE 17.11 Methods of fixing flat TPS cable

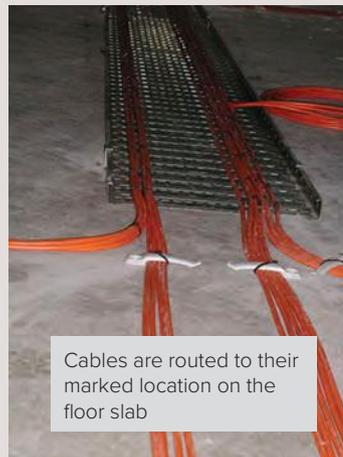
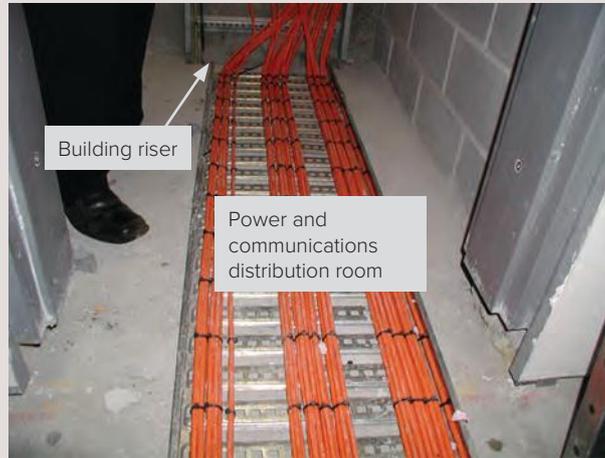


An example of sound job planning and trade skills in the way these cables have been neatly arranged and fixed to cable tray using plastic cable ties.

In this case the cables are able to be closely bunched without greatly affecting their current-carrying capacity because of the low load each cable is supplying.

FIGURE 17.12 Example of support and fixing of cables

The photos below show cables for final subcircuits in a prestigious office building installed on the surface of a floor slab in preparation for the installation of a raised floor.



Wiring under a raised floor is generally easier and quicker to install than alternative methods.

Also, working at ground level eliminates hazards of other methods such as installing power cables above a suspended ceiling or in conduits installed in the concrete slab.

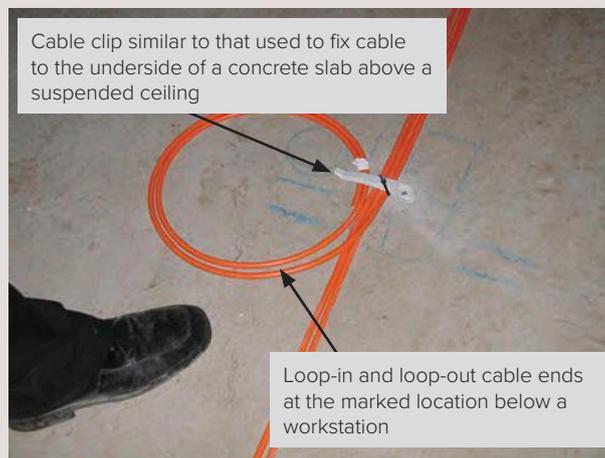


FIGURE 17.13 Cables installed in preparation for a raised floor ■

The four single-core cables and earth wire in this riser are a submain to a plant room in an upper level of a six-level building. They are installed vertically, fixed at intervals to a cable ladder to avoid possible damage from their own weight (see *Clause 3.9.5*).



The cables are fixed and supported to the cable tray by plastic cable ties (*Clause 3.9.3.1*).

Cable tray fixed to riser wall

FIGURE 17.14 Fixing of cables installed vertically

Large cables to and from a switchboard for a standby generator supply change direction from horizontal to vertical.

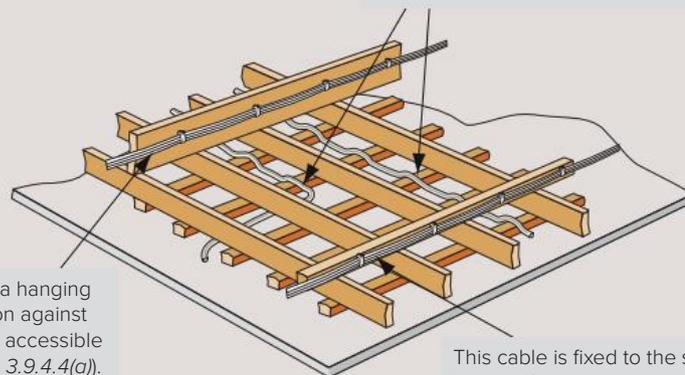
The cable supports are curved to ensure the bending radius does not damage the cables (see *Clause 3.9.6*).



The cables are fixed and supported to the cable ladder by plastic cable ties (*Clause 3.9.3.1*).

FIGURE 17.15 Example of how change in direction is made with large cables

These cables, although within 50 mm of the surface of a ceiling, need no additional protection against mechanical damage (see *Exception to Clause 9.3.4.2*).



Cable fixed to the side of a hanging beam to provide protection against mechanical damage in an accessible ceiling space (see *Clause 3.9.4.4(a)*).

This cable is fixed to the side of a batten to provide protection against mechanical damage in an accessible ceiling space (see *Clause 3.9.4.4(a)*).

FIGURE 17.16 Protecting cables against mechanical damage in ceilings

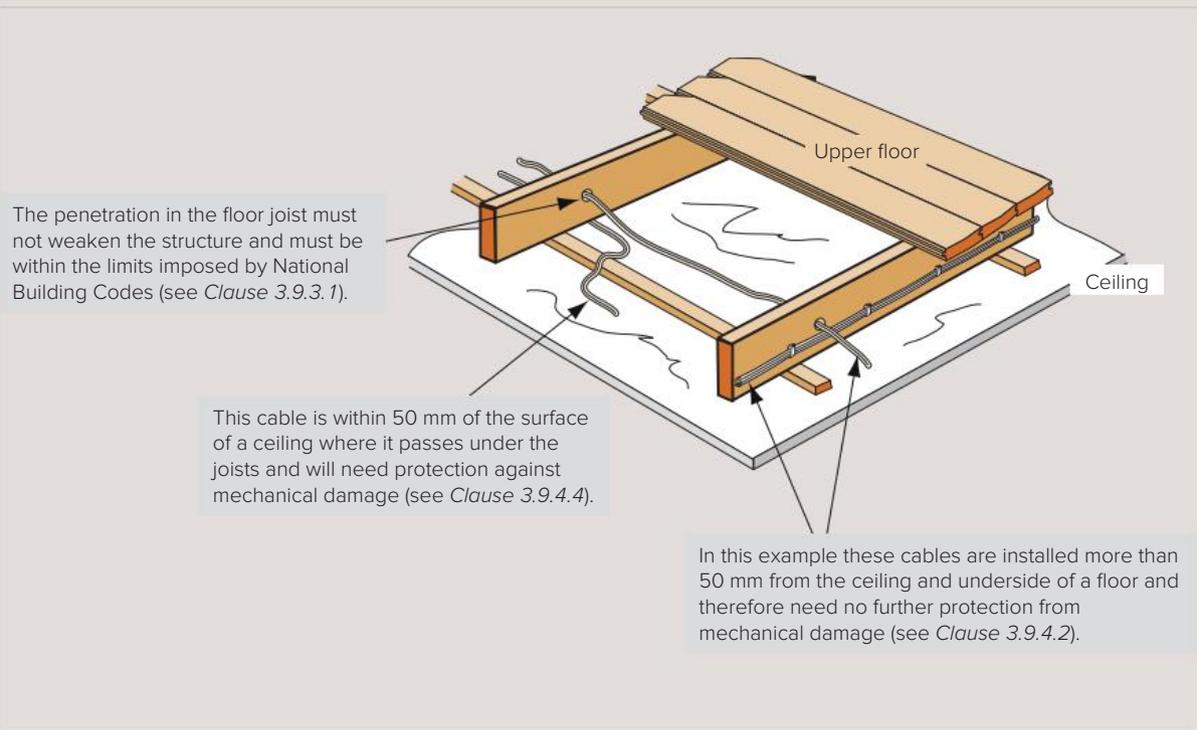


FIGURE 17.17 Protecting cables against mechanical damage in upper-floor space on a two-storey framed structure

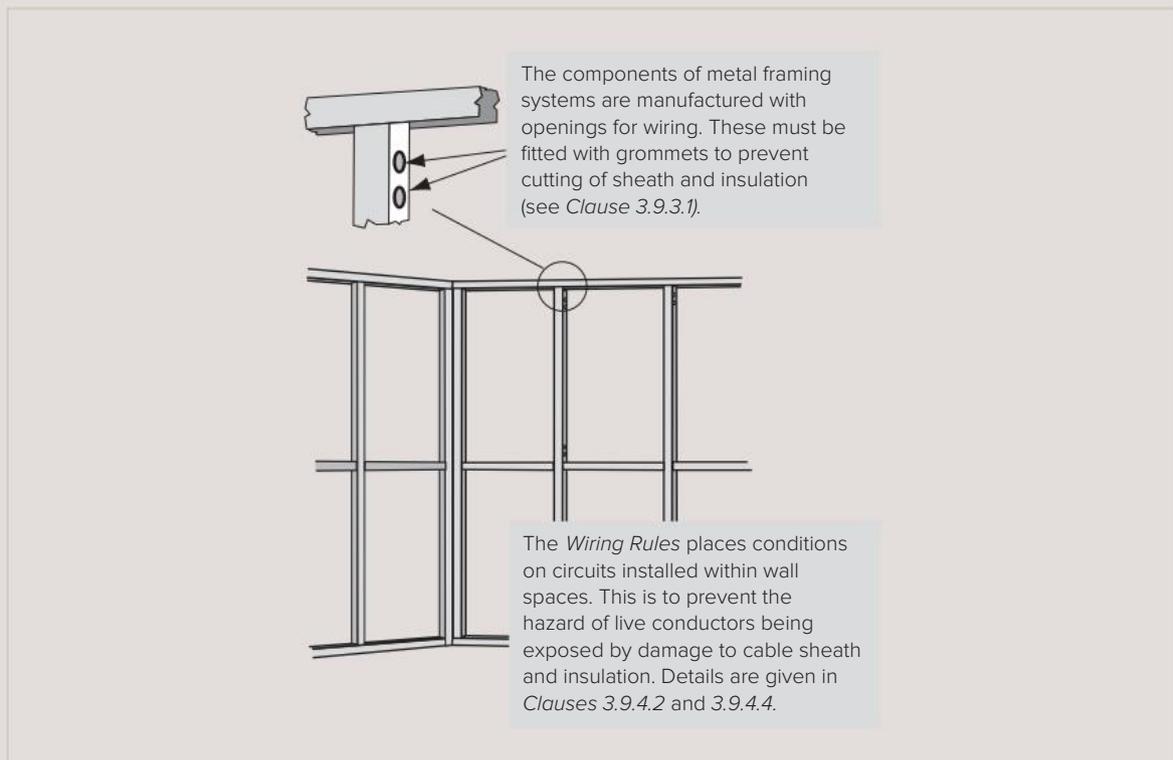


FIGURE 17.18 Installing cables in wall spaces

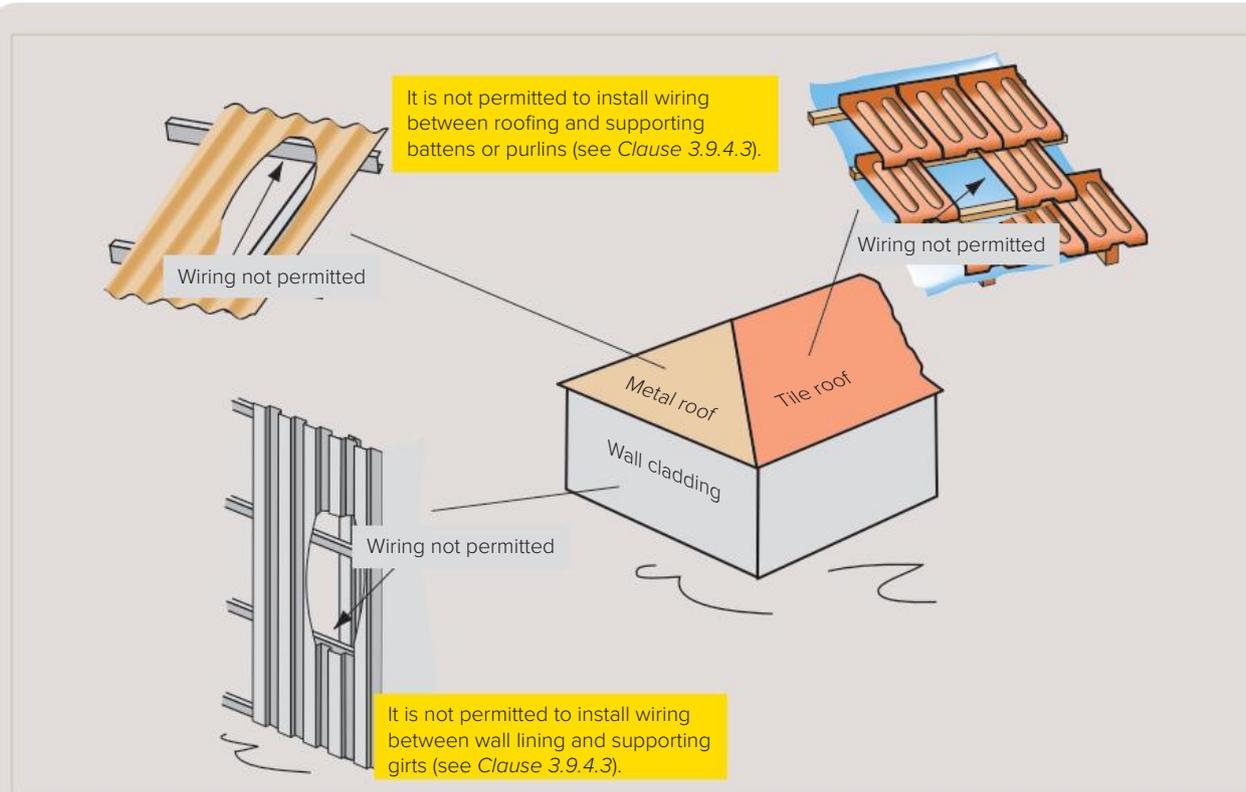
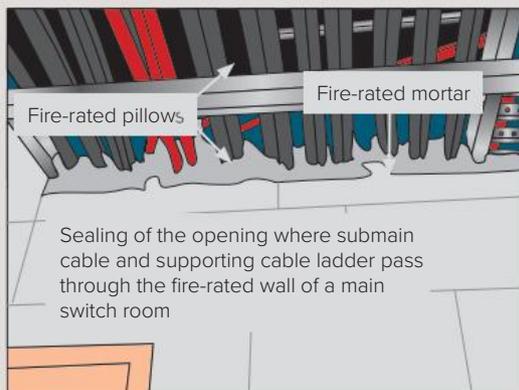


FIGURE 17.19 Examples of where it is not permitted to install a wiring system (Clause 3.9.4.3)

Important mandatory installation practices for minimising the spread of fire stipulated by Clause 3.9.9.3 are:

- to seal penetrations where a wiring system passes through a fire-rated building component; and
- internally sealing wiring systems such as conduits and trunking.

Read this clause for further details of openings and wiring systems that are required to be fire-rated and arrangements for the application of sealing systems. Two examples are shown below.



The fire-rated pillows shown here are made of a cloth (green) envelope, enclosing a high-temperature fire-resistant granulated material. In the event of fire, the pillows remain in place and form a fire barrier by charring and creating a solid mass of insulating material.



The firestop foam marketed by Hilti is able to be worked after it is installed, allowing subsequent installation of additional single cables. It has a fire-rating of up to three hours. Other firestopping products from this company are firestop bricks, similar to fire-rated pillows, firestop plugs for circular openings and firestop cable coating for protecting cables from damage by fire and reducing the spread of fire along wiring systems.

FIGURE 17.20 Protection against spread of fire



DID YOU KNOW?

The current-carrying capacity of a cable is reduced where it is likely to be in contact with thermal insulation (see *Clause 3.4*). This may result in the need to increase the cable conductor size.

The same applies where the ambient temperature rises above the reference level, as is common in ceiling spaces (see *Clause 3.3.2.1*).

Both of these issues are discussed in more depth in **Chapter 16**.

There are some further points worth noting on the installation of single-core cables intended to carry a high current or where several cables are to be connected in parallel. *Clause 3.9.10* stipulates measures for reducing the harmful effects of induced circulating currents and eddy currents where single-core cables carry high alternating current (a.c.), as illustrated in **Figures 17.21** and **17.22**.

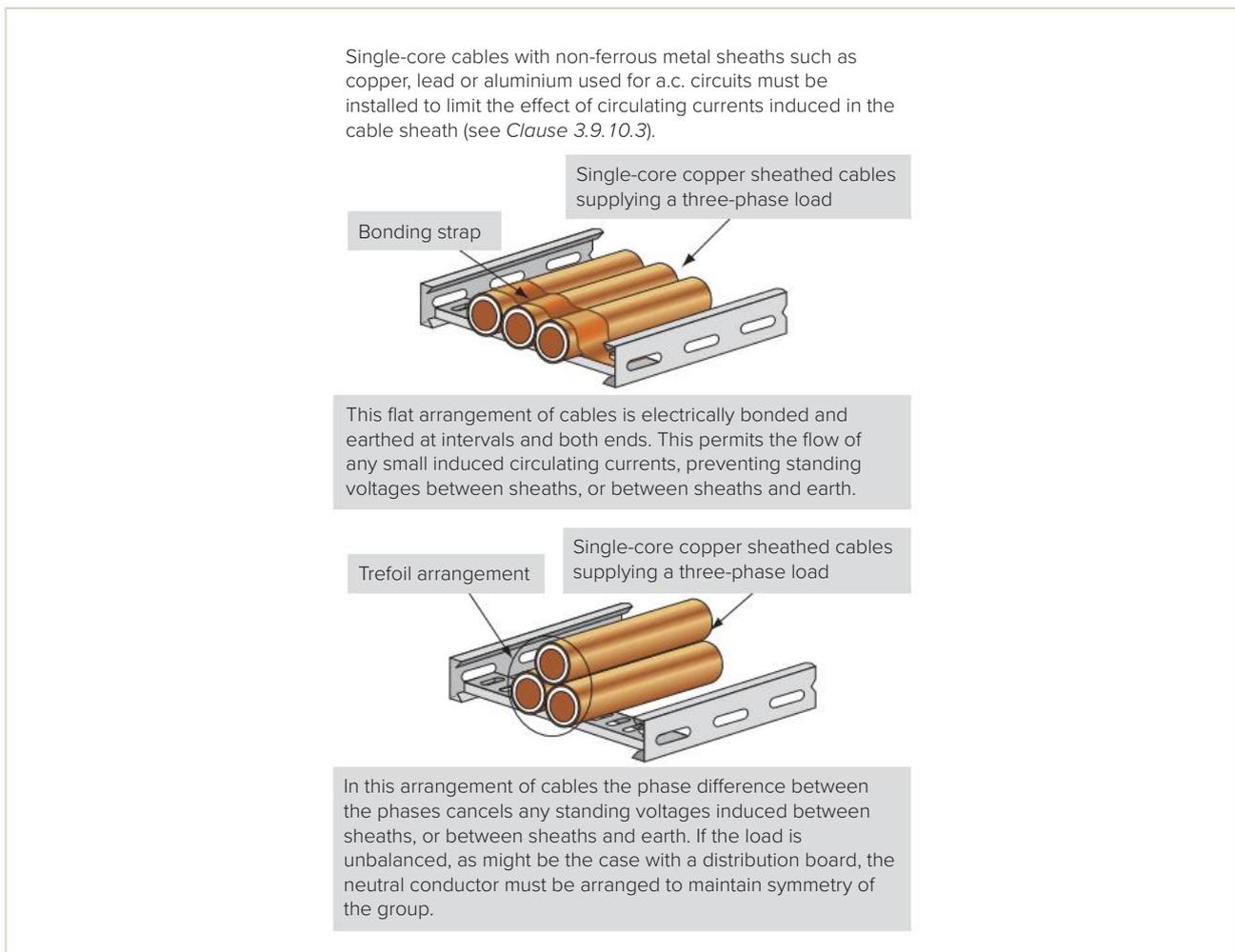


FIGURE 17.21 Dealing with circulating currents

It is not an uncommon practice for each live conductor of a circuit such as a submain to have the conductors of two or more cables connected in parallel. More relatively smaller cables, rather than fewer larger cables, are generally easier and safer to handle and install, given a weight difference alone of up to 60 per cent. Paralleling cables is also an economical way of increasing the capacity of an existing circuit, by installing an additional cable per phase and connecting it in parallel with the existing cable. Parallel connection of cables must be done in accordance with *Clause 3.4.3* and the recommended arrangement for paralleling cables is given in the *AS/NZS 3008.1* series of Standards. Some examples are shown in **Figure 17.23**.

The fluctuating magnetic field around a cable carrying an alternating current will induce eddy currents in a ferrous metal gland plate where the cable enters an enclosure such as a switchboard. The heating effect of the eddy currents becomes a problem when the cable carries current in excess of 300 A.

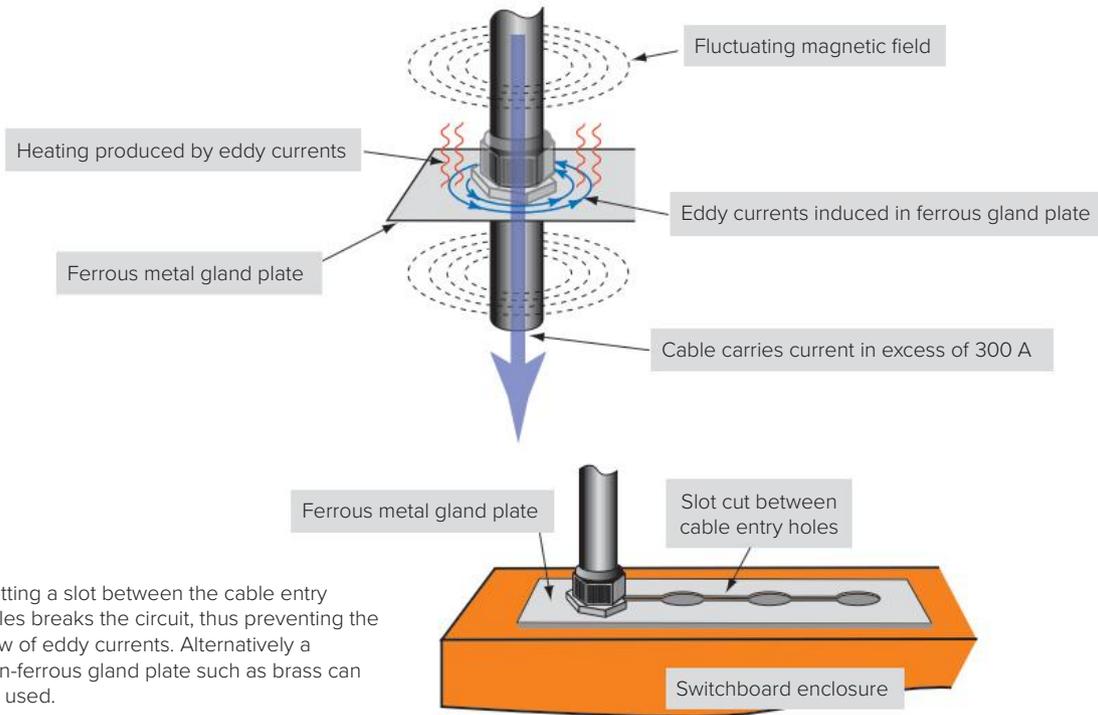


FIGURE 17.22 Dealing with eddy currents

The purpose of the recommended arrangements of the cables is to eliminate any net mutual inductance from the fluctuating magnetic field produced as current flows in the conductors.

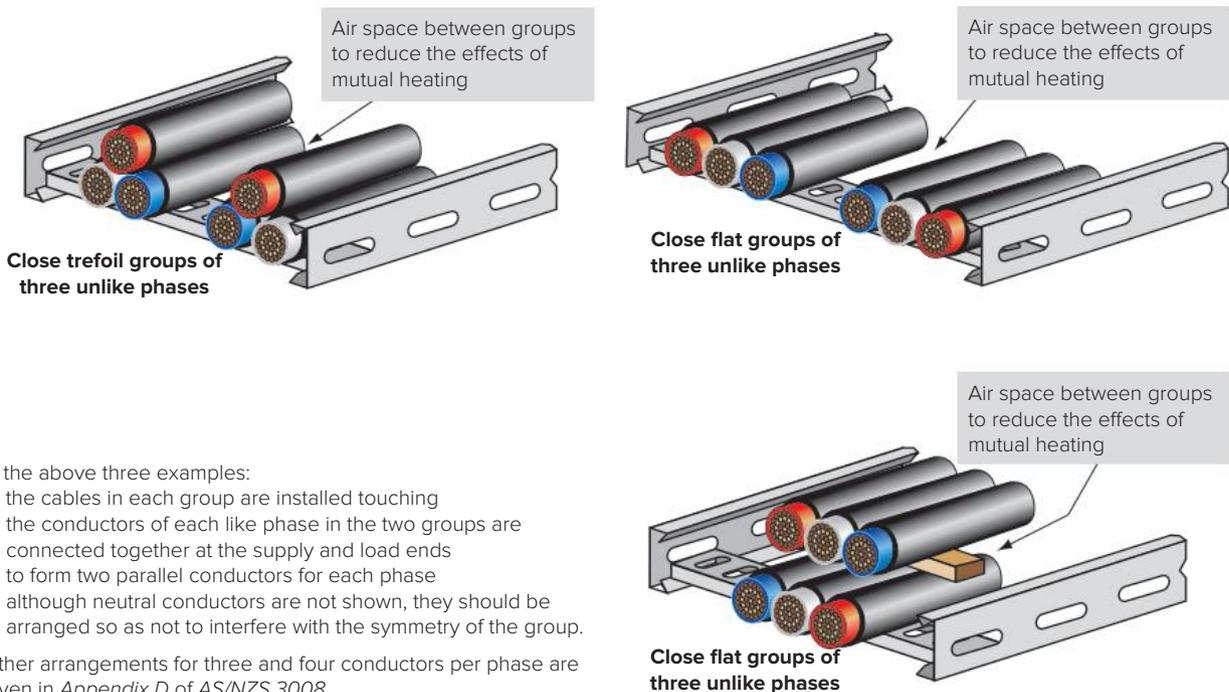


FIGURE 17.23 Installing cables to be connected in parallel



CHECK YOUR UNDERSTANDING

9. What are the requirements for fixing and support of cables installed vertically?
10. How is a cable affected where it is likely to be in contact with thermal insulation?
11. Where in a structure is it not permitted to install wiring?
12. Explain the *Wiring Rules* requirements for the prevention of harmful effects between different parts of the same installation.
13. Describe how eddy currents are induced in a steel enclosure where single-core cables enter the enclosure. What is the potentially harmful effect?

17.4 Enclosed wiring and cables

The commonly used enclosures for cables are conduit and trunking, the most common of these being conduit. Apart from aerial wiring, insulated unsheathed cables must be installed in a wiring enclosure (*Clause 3.10.1.1*) (i.e. a switchboard), which in many cases will include a conduit system. Unarmoured sheathed cables (typically thermoplastic-sheathed or TPS) must be enclosed when installed in concrete (*Clause 3.9.7.2(b)*). Also, cables of this type must be protected where they are likely to suffer mechanical damage. The invariable choice in both these cases is to enclose them in conduit.

Cable trunking is useful for providing support and mechanical protection for installing many cables along the same route. It can also be used to support accessories such as power and communications outlets on trunking designed as skirting. Many strip-lighting designs incorporate a form of trunking. Cable trunking is equipped with a cover, must be retained in position and if readily accessible (*Clause 1.4.3*) can only be removed with the use of tools (*Clause 3.10.2.1*).

17.4.1 Conduit

Commonly used conduits

Conduit manufactured to the Australian/New Zealand Standard series *Conduits and fittings for electrical installations AS/NZS 2053* and *Conduit systems for electrical installations AS/NZS 61386* are accepted as meeting the *Wiring Rules* requirements for conduit (*Clause 3.10.2.1*). Other types that provide at least the equivalent level of protection as those specified by *AS/NZS 2053* may be used; see **Table 17.4**.

TABLE 17.4 Summary of properties of commonly used conduit types

Conduit type	Properties
Material	Most commonly made from electrically insulating materials or metal, although fibre-reinforced concrete materials, used mainly for underground wiring, are also available
Temperature	Minimum and maximum temperatures that conduit may be subject to in normal service
Flame propagation	Whether conduit material will cause a fire to spread; related to this is the acid-gas emission property, that is, whether conduit is halogen-free
Electrical characteristics	Whether conduit material is conductive or insulating
External influences	Protection afforded against corrosive or polluting substances and effects of solar radiation; protection against entry of water or foreign objects
Mechanical strength	Ability of conduit to sustain mechanical stress without damage
Assembly method	Whether conduit is joined by threading or another method
Bending ability	Whether a tool or treatment is needed to bend the conduit

Rigid PVC conduit

Conduits are classified by the properties of the material from which they are made and by their structure. Rigid PVC conduits are the most commonly used and are specifically available for electrical, communications and security wiring/cabling systems, as illustrated in **Figure 17.24**.

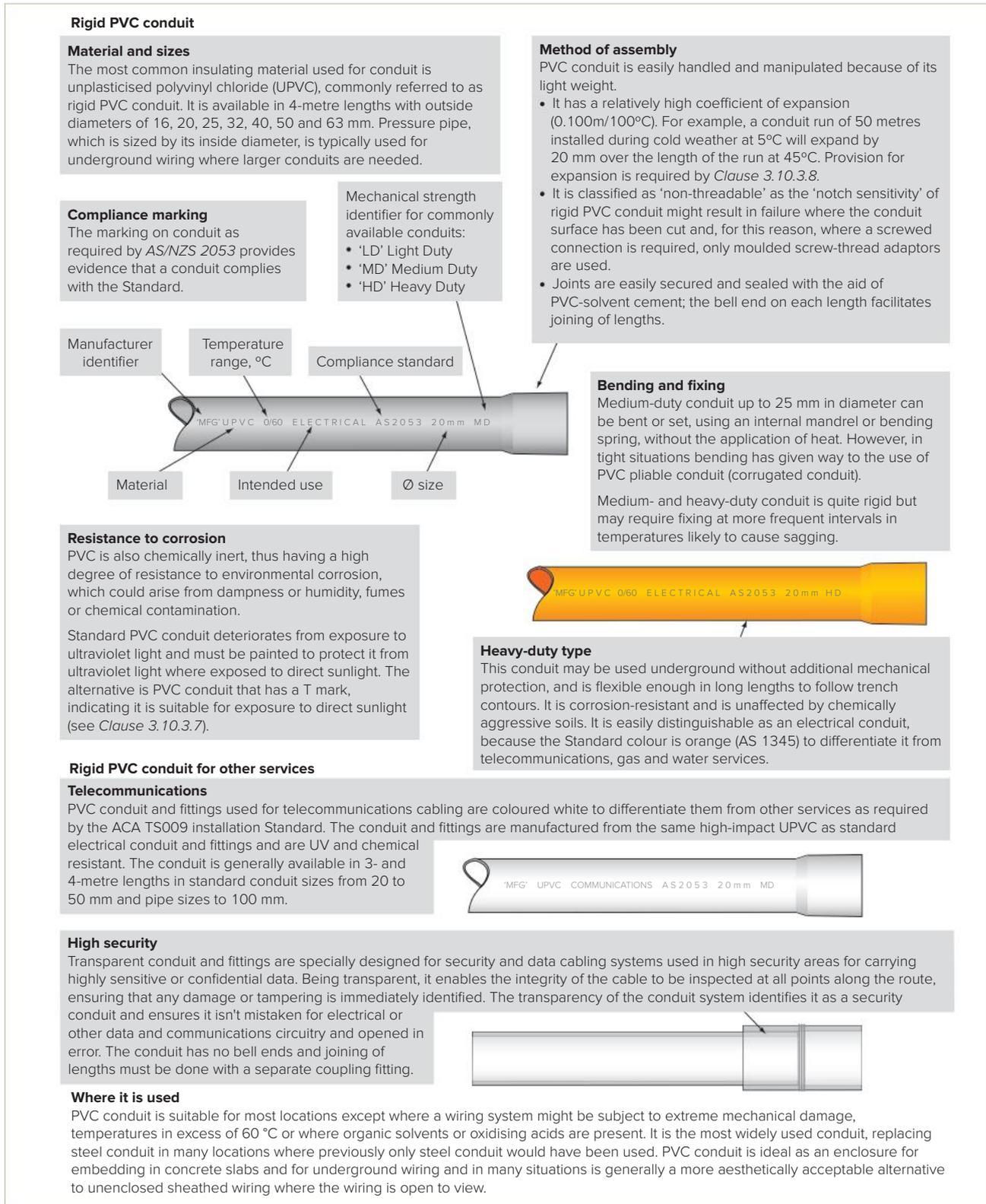


FIGURE 17.24 Features of rigid plain conduit and fittings of insulating material—PVC conduit

PVC at temperatures higher than its rated value emits toxic and corrosive fumes, which in a fire will further endanger people and cause danger to a building and equipment. A conduit made from a halogen-free, temperature-stable PVC known as HFT deals with this shortcoming. It should be noted that both rigid and corrugated HFT conduits have poor resistance to petrol, petrol vapours, kerosene and a number of other chemicals. Before using HFT conduit, the manufacturer's catalogues should be consulted to determine the conduit's suitability for the environment in which it will be used (see **Figure 17.25**). HFT conduit is usually black in colour but can also be light grey, white or orange. Some manufacturers may label this type of conduit differently (e.g. FRAS—fire-resistant anti-static: see www.evcco.com.au/catalogue/conduit).

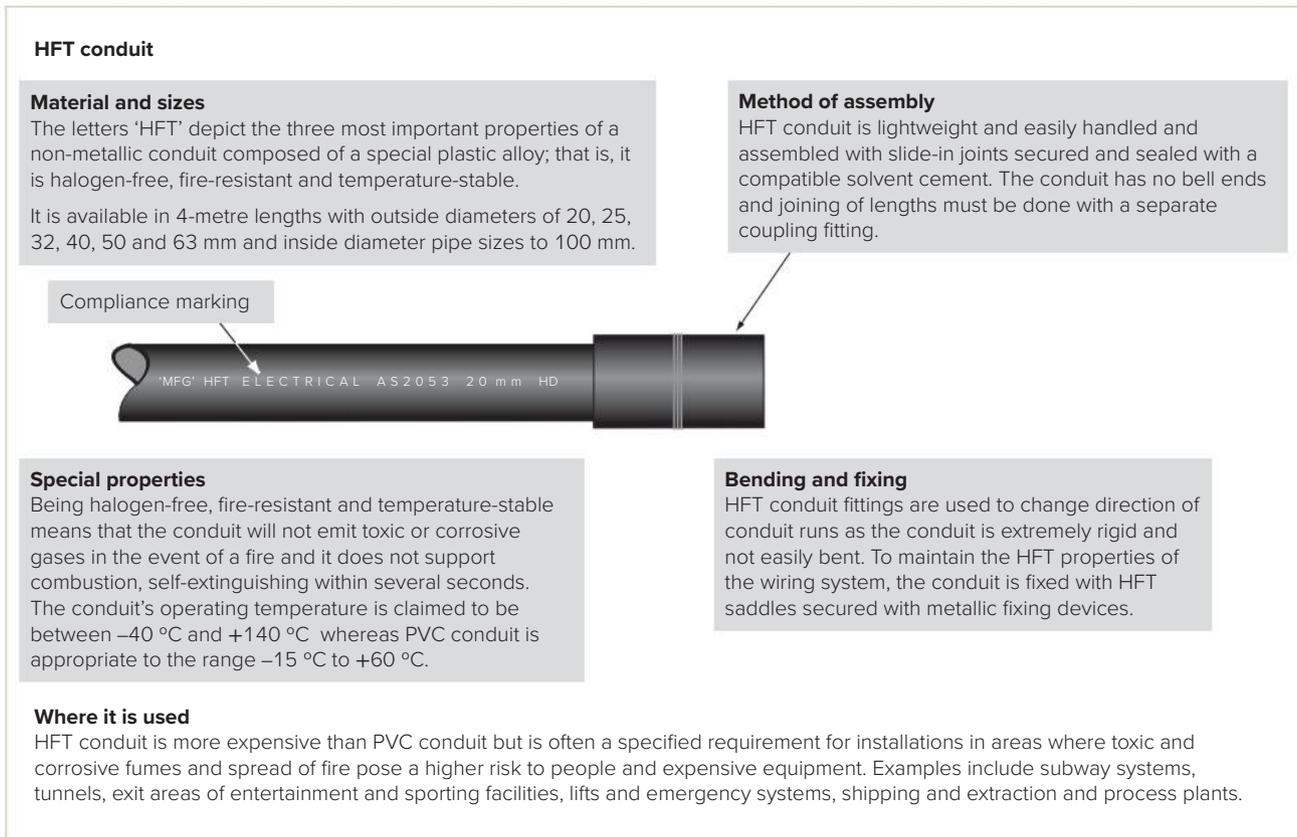


FIGURE 17.25 Features of rigid plain conduit and fittings of insulating material—HFT conduit

Flexible PVC conduit

Corrugated conduit, often marketed as flexible, is actually classified as pliable conduit according to the *AS/NZS 2053* Standard. It can be bent by hand to follow complicated curves and retains its shape after bending, and should only be used in certain situations. Excessive use of corrugated conduit should be avoided where rigid conduit will suffice, as it can look unattractive when open to view. Installing wires through corrugated conduit can also be challenging, therefore lengths should be kept short.

Flexible conduit is not used as a complete wiring system but is used in situations where flexibility is essential; for example, to take up movement due to vibration (*Clause 3.3.2.7*) of a permanently wired machine or appliance, or where an appliance such as an oven or motor needs to be moved to provide access for adjustment or servicing without disconnecting the appliance from the supply.

The Standard *AS/NZS 2053* includes performance Standards for two types of flexible conduit, the most common being flexible PVC, much like hose. Different from regular conduits, it is measured by inside diameter and available in sizes from 16 to 50 mm. A composite flexible conduit made of interlocking spirals of galvanised pressed metal encased in a PVC sheathing is used mainly in industrial and severe environments. With trade names such as Seal

Flex and Anaconda, the conduit is resistant to the effects of oil and chemicals, and prevents ingress of liquids. These flexible conduits are available in conduit sizes from 16 to 63 mm, with claimed temperature ranges as low as $-60\text{ }^{\circ}\text{C}$ and up to $+150\text{ }^{\circ}\text{C}$.

See examples of corrugated conduit in **Figure 17.26**.

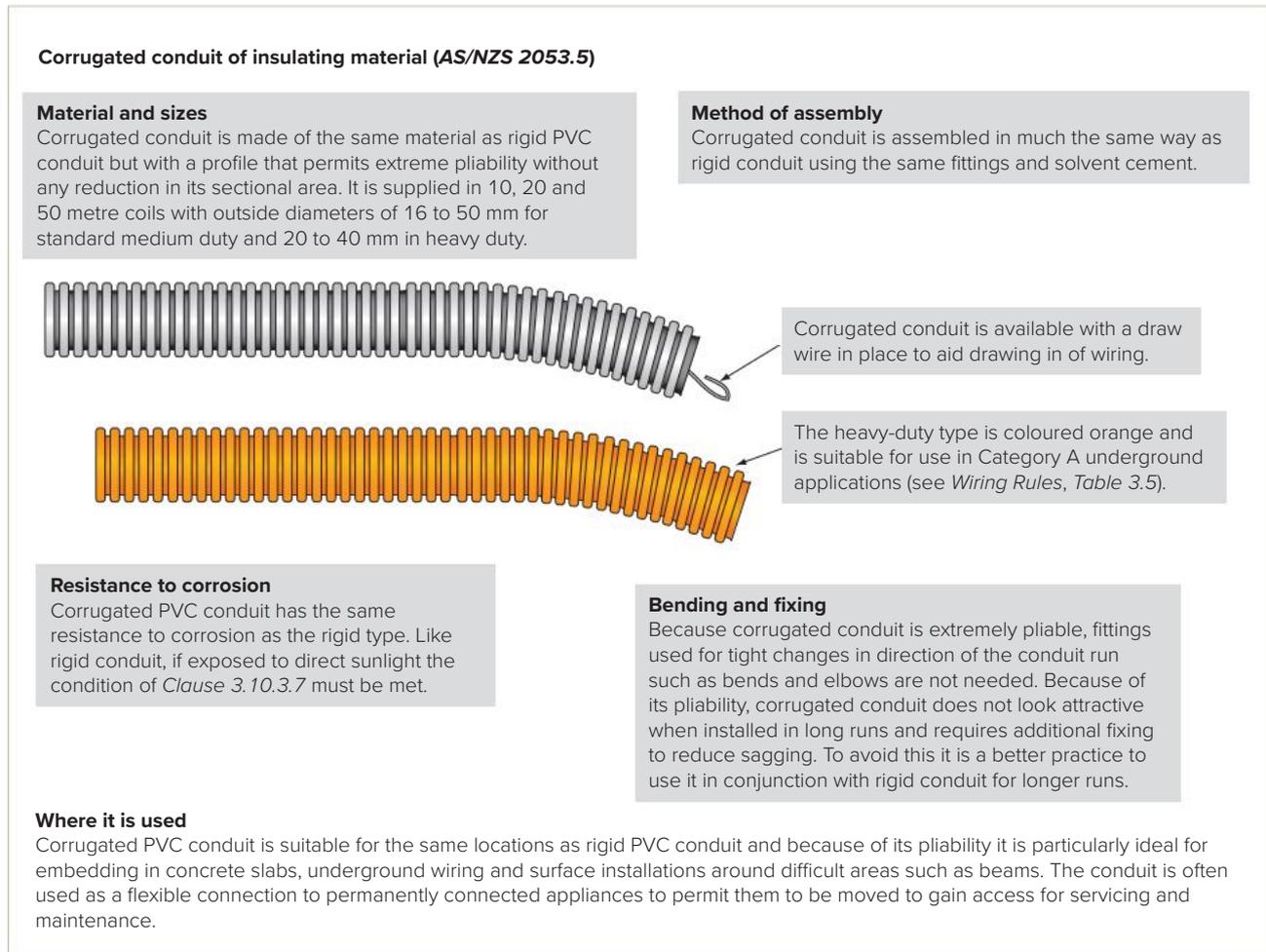


FIGURE 17.26 Corrugated conduit of insulating material

Steel conduit

Steel conduit has approximately 10 times the tensile strength of PVC conduit, which allows it to be used where the wiring system is exposed to severe mechanical injury; for example, in manufacturing plants, mining sites and heavy traffic areas. It may be used as a complete wiring system or for parts of a wiring system where cables require additional protection against possible mechanical damage or other detrimental environment conditions. It is extremely rigid and retains its mechanical strength through extremes of temperature. Its melting point is in excess of $1300\text{ }^{\circ}\text{C}$, which is higher than the temperature at which cable insulation failure occurs.

Steel is not flammable and its coefficient of expansion is relatively low compared with that of PVC, where expansion presents a practical problem; therefore, expansion joints are rarely required in steel conduit runs. Steel conduit also provides an earthed screen for the conductors it encloses; this feature is often overlooked, but is becoming more important where electrical interference between power, communications and other electronic circuits is increasingly apparent. Steel conduit can be prefabricated and is sometimes considered economical on large jobs where many bends of the same form or many lengths of known dimensions are required.

The main features of steel conduit are shown in **Figure 17.27**.

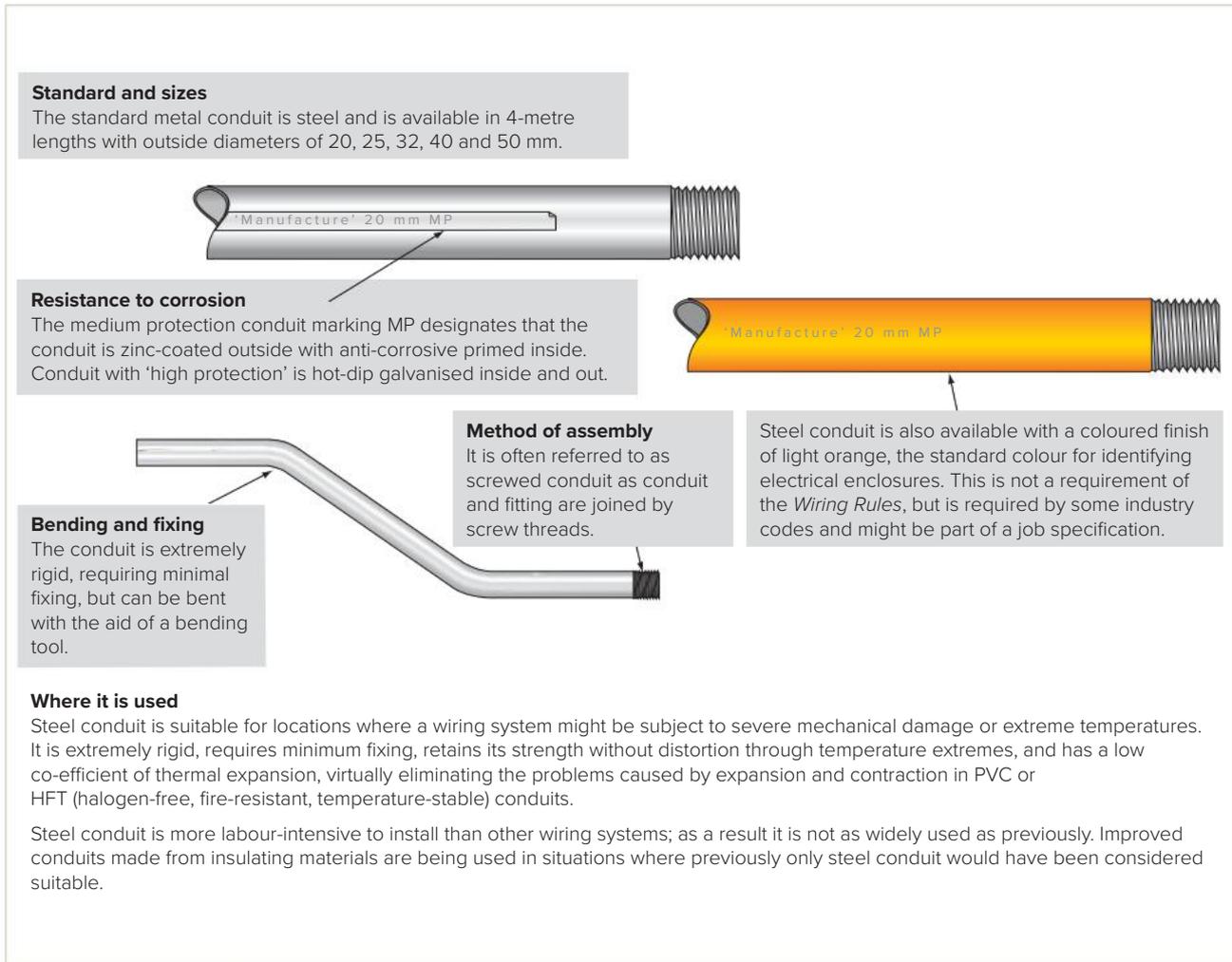


FIGURE 17.27 Features of rigid metal conduits and fittings—steel conduit AS/NZS 2053.7

Other materials used as conduit

Steel piping is not specifically manufactured as an electrical conduit; however, galvanised pipe may be used as a wiring enclosure, provided that it meets the requirements for the installations of cables (*Clause 3.9*) and enclosures for cables (*Clause 3.10*). It must be installed in such a manner that it complies with the *Wiring Rules*, *Clause 3.10.3* relevant to the selection and installation of cable enclosures. *Clause 3.11.3.1(c)* specifies galvanised steel pipe, not conduit, as suitable for underground wiring.

AS/NZS 2053.2 also specifies larger PVC conduit sizes of 65, 100, 125 and 150 mm inside diameter in grades from light duty to heavy duty based on their wall thickness and essentially manufactured to pipe specifications.

Other materials used as electrical conduits do not comprise a complete system, usually being confined to specific applications. For example, *AS/NZS 2053.3* specifies Standards for *Plain conduit of fibre-reinforced concrete material* used mainly in underground wiring systems.

Working with conduit

Keep in mind that the predominant wiring system in most installations is unenclosed sheathed cables of one type or another, and that conduit wiring is mainly used only where it is considered most economical. Once decided on, installing a conduit wiring system follows much the same procedures as for any wiring/cabling system installation of selecting, planning, installing, connecting circuit wiring and testing.

SELECTING CONDUIT

The decision to use a particular conduit type must first be made to meet the *Wiring Rules* requirements for the selection of wiring systems, in particular *Clauses 3.3* and *3.10.2*. Some of the more important considerations are:

- ▶ external heat sources that may raise the ambient temperature of the environment in which the system operates; for example, a temperature above 65 °C would rule out the use of regular PVC conduit. The same applies with cables within the conduit that are carrying their rated current, as the lowest permissible maximum operating temperature for general cables is 75 °C, which is above that of most PVC conduit (see *Wiring Rules, Table 3.2*).
- ▶ mechanical hazards likely to affect the wiring system; for example, in areas where forklifts operate, it may be preferable to use steel conduit instead of PVC.
- ▶ hazards associated with the environment such as corrosive liquids and gases, exposure to seawater spray, ocean atmosphere or the presence of explosive gas or vapours, to list a few. In some of these environments, additional cable sheathing may be needed in conjunction with the correct conduit.

Additionally, the job specification must be checked for any particular wiring system that it may stipulate, remembering that, irrespective of what is specified, the installation must comply with the *Wiring Rules*.

Finally, cost is always a major consideration; when more than one conduit type is suitable, the choice will obviously be the least expensive.

PLANNING CONDUIT RUNS

Once the conduit type has been decided on, the run is planned to determine not only the number of lengths of conduit required, but also the size of conduits, and type and number of fittings. Conduits are sized for each particular job according to the number and size of cables to be enclosed and the useable space in the conduit. The recommendation in *Appendix C* of the *Wiring Rules* of a useable space factor in conduit is the maximum needed for the ease of drawing cables into conduit without damaging them; see **Figure 17.28**.

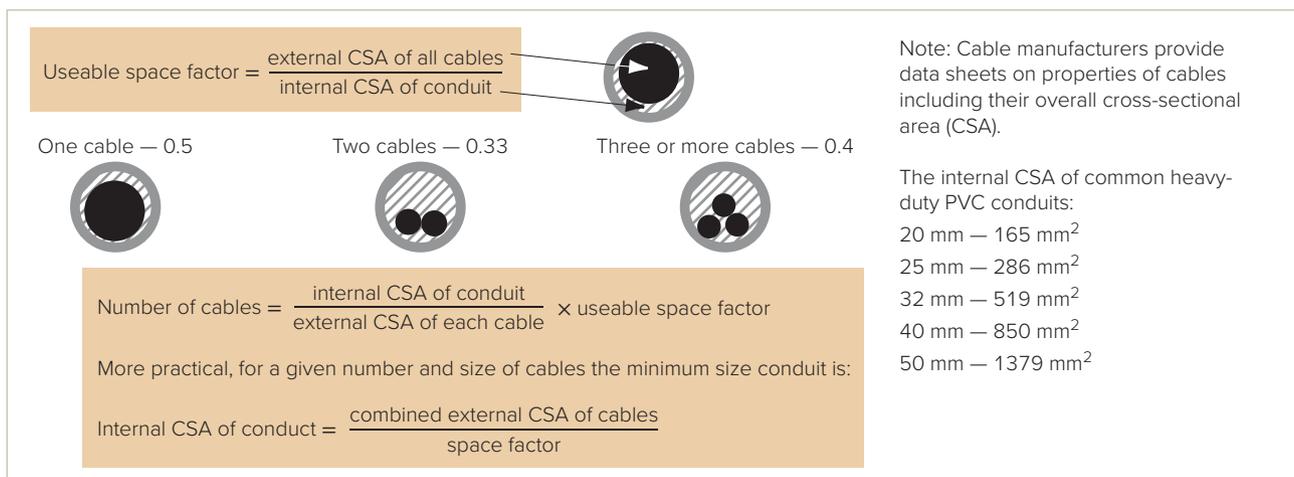


FIGURE 17.28 Useable space factor in conduit

Looking up the tables in *Appendix C, Circuit Arrangements* of the *Wiring Rules* provides sizes of UPVC conduit by type and the number of cables by size and type they can accommodate, based on the useable space factor. In using these tables, it is important to first read *Paragraph C6.2 Application notes*.

If a conduit is to be surface run with other conduit, thought needs to be given to the best arrangement to avoid conduits having to cross over and to give a neat symmetrical appearance. The fittings used with conduit are for changing direction, splitting the conduit run, connecting to accessories or facilitating drawing-in of wires. Examples are shown in **Figure 17.29**.

Care should be taken when planning a conduit route to ensure it is possible to assemble the conduit. Assembly of screwed conduit requires enough space to rotate a fitting or a piece of conduit. Competence in bending conduit is an

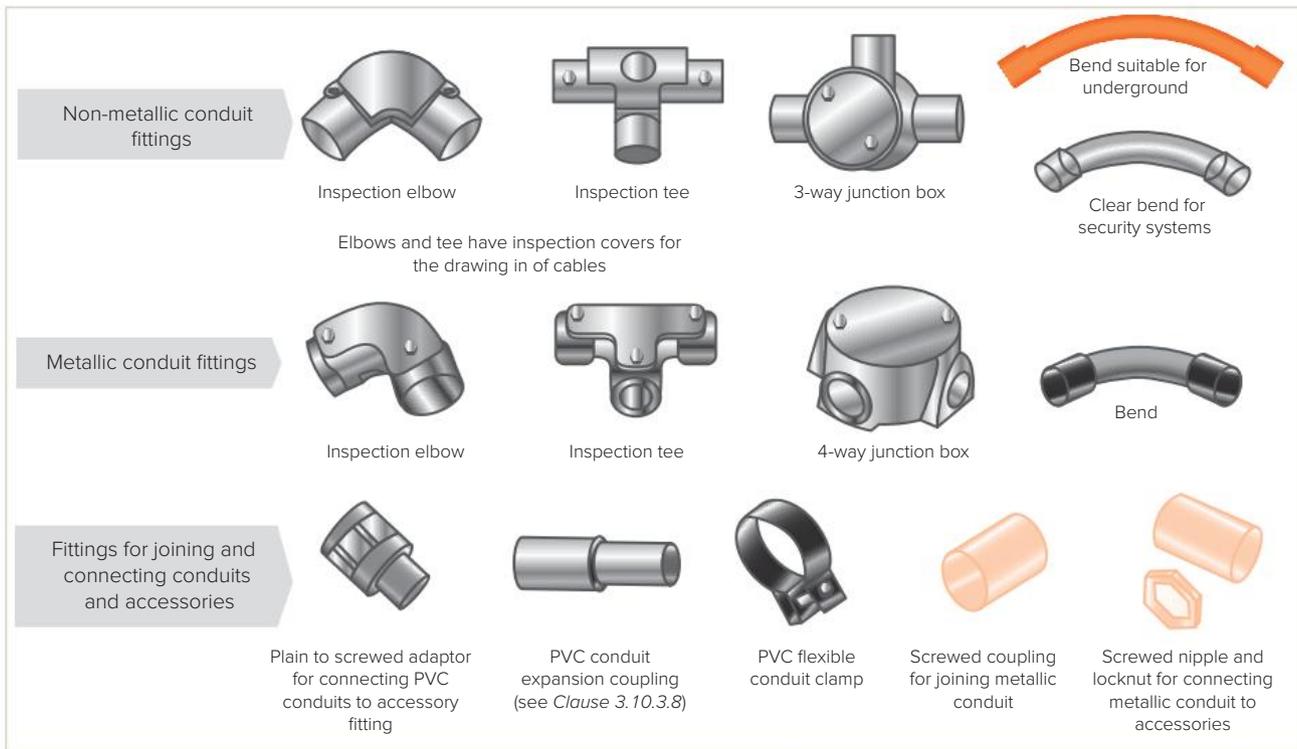


FIGURE 17.29 Examples of conduit fittings

important skill, as it is often more efficient; for example, a 90° set in a 20 mm conduit eliminates a fitting (i.e. a bend or elbow) and the need to cut the conduit to attach the fitting. In the case of steel conduit, attaching a fitting also requires cutting thread. However, care must be taken when bending rigid conduit not to reduce the internal diameter. As a guide, a correctly executed bend with a radius not less than six times the conduit diameter will not significantly distort the conduit. Common types of sets are illustrated in **Figure 17.30**.

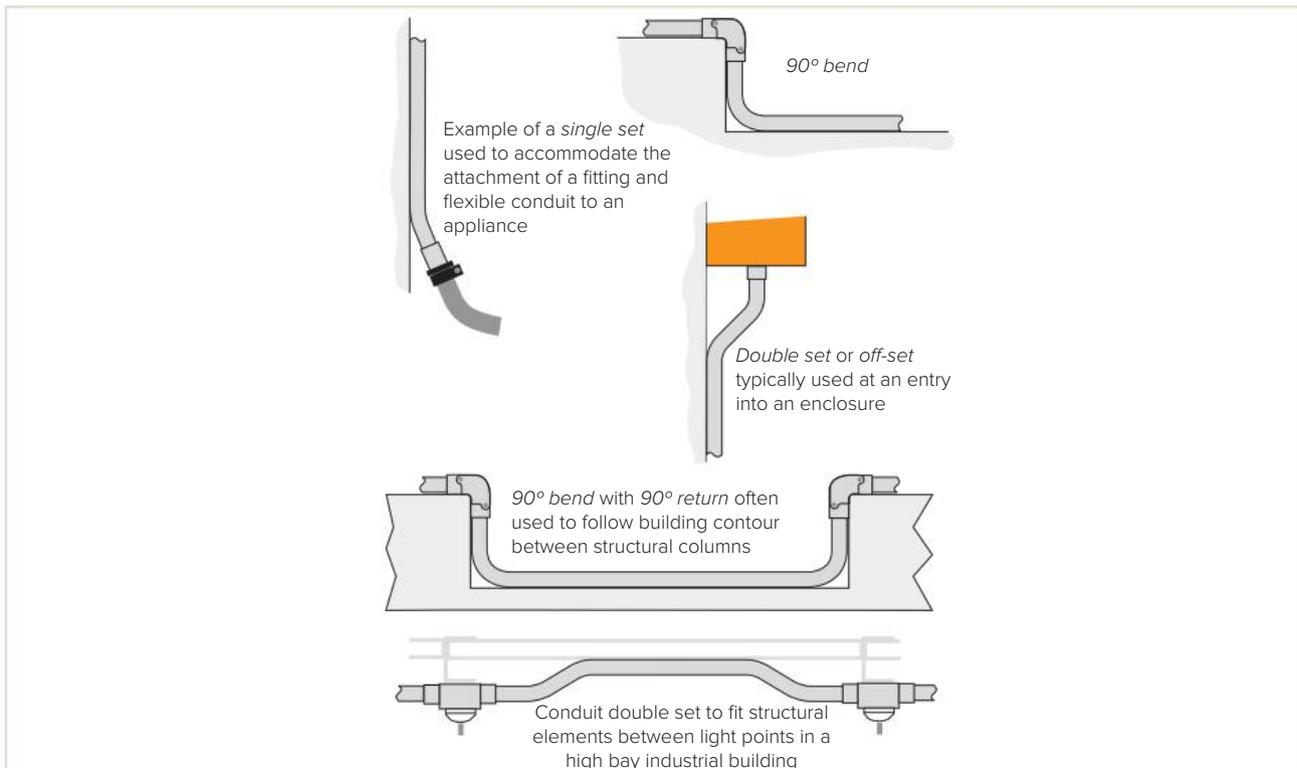


FIGURE 17.30 Common conduit sets

An important part of planning is setting out conduit for embedding in a concrete slab. This is commonly referred to as deck work as it is done on the formwork deck while it is prepared for the concrete pour. Conduits are embedded in the slab with junction boxes and conduits turned down or up at the locations of points, switches and distribution boards that are to be wired above or below the slab. **Figure 17.31** illustrates the setting-out process.

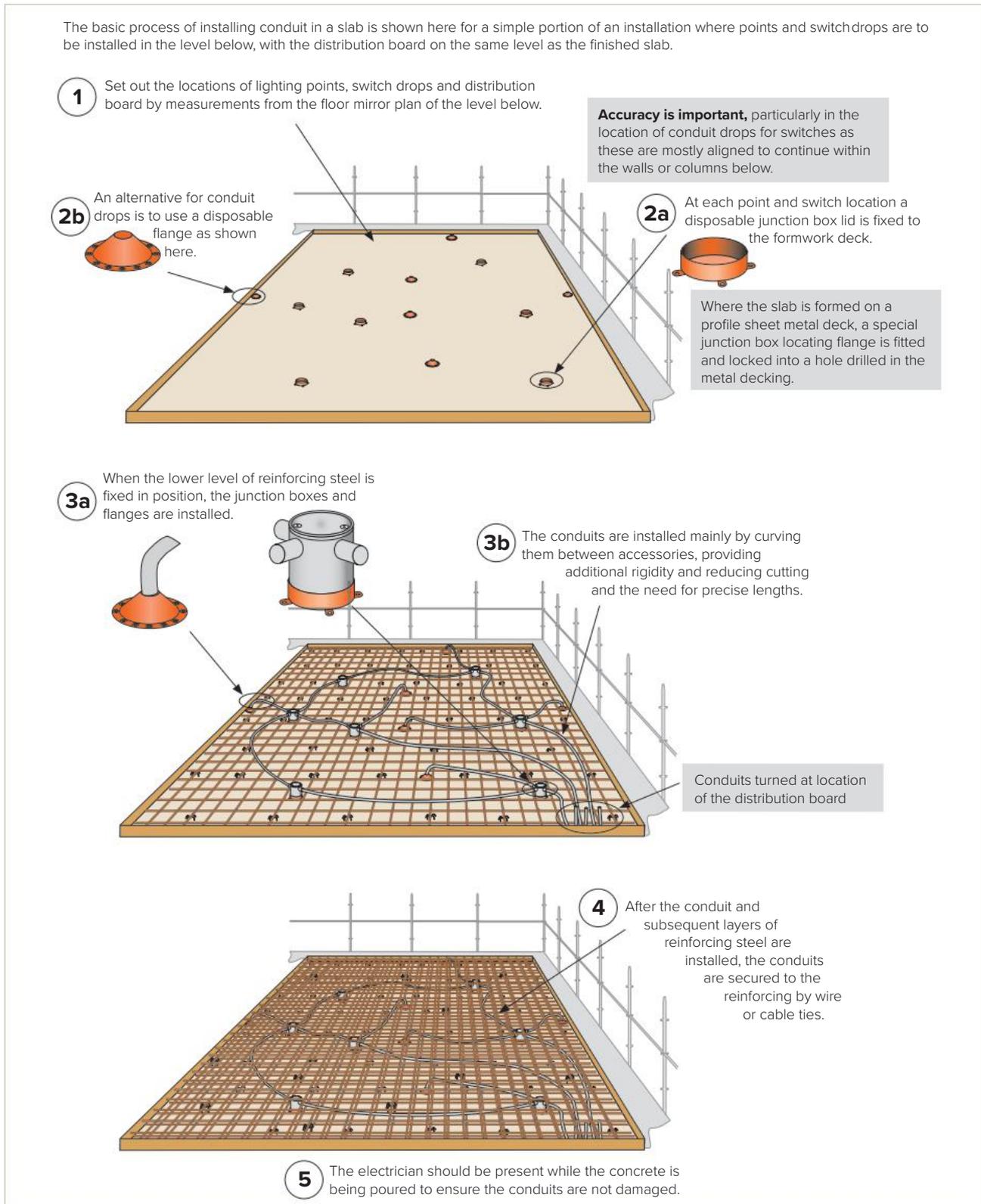


FIGURE 17.31 Setting out conduit for embedding in a concrete slab

NOTE: It is highly recommended to ensure conduits buried in concrete pours are kept well below the finished surface. The use of nylon (or similar) cable ties on the conduit to the reinforcing steel can help with this by keeping conduits from floating when the concrete is poured.

INSTALLING CONDUIT—PVC CONDUIT TECHNIQUES

The actual finished installation of PVC conduit runs follows a pattern similar to that of steel conduit, but the distance between supports is closer, at 1 m maximum intervals, and this spacing should be reduced if temperatures or conditions are likely to cause sagging. Saddles or supports should be free enough to allow for movement of the conduit due to temperature change.

All sizes are easily cut by a fine-toothed hacksaw; the conduit being hand-held and the knee sometimes used as a steady rest for the conduit. However, conduit cutters such as the one shown in **Figure 17.32** are normally used for cutting PVC and HFT conduit except in the larger sizes.



FIGURE 17.32 Cutting rigid PVC conduit

For all bending processes, an internal mandrel in the form of a metal spring is used, and conduit up to 25 mm in diameter may be bent cold if the ambient temperature is not below 15.5 °C. At lower temperatures or for larger conduits, heat must be applied. Note that rigid HFT conduit cannot be set. However, HFT conduit is also manufactured as a corrugated conduit, with glands and connector adaptors available for joining the two types. The liquid cement for joints is actually a PVC solvent and so the process is one of solvent welding.

Processes of setting and joining PVC conduit are shown in **Figure 17.33**.

Bending rigid PVC conduit

Circular conduit not exceeding 25 mm in diameter can be bent 'cold' if the ambient temperature is not too low. If needed, sufficient heat can sometimes be generated by rubbing the conduit briskly with a rough material such as hessian. In cooler conditions, smaller sized conduits can often be softened sufficiently for bending by exposing them to sunlight for a short period.

For bonding larger conduits, heat is usually applied by a stream of hot air from an electric heat gun. Alternatively, a liquid-petroleum (LP) gas torch adjusted to yield a soft flame may be used, with care not to overheat the conduit or scorch it.

The following is a basic guide in bending the common sizes of rigid PVC conduit. Although rigid PVC conduit is much easier to manipulate than screwed steel conduit, the same geometry and sets apply (see **Figure 17.35**).



1. Insert an appropriate sized bending spring into the conduit position in the centre of where the conduit is to be bent. The bending spring maintains the profile of the conduit and prevents it from distorting under bending stress.



2. Smaller sized conduits can be bent across the knee.



3. It is necessary to initially overbend the conduit, as it tends to creep back slightly to its original shape; so this will allow the conduit to ease to the desired position.

Joining rigid PVC conduit

The following is a simple, quick method for effectively joining rigid PVC conduit and fittings using PVC jointing cement.

1. Remove all burrs from the cut end of the conduit and clean any dirt or grease with a cloth dipped in methylated spirits.



2. Coat the surface of the end of the conduit to be joined to the accessory.



3. Coat the inside surfaces of the accessory entry to be joined to the conduit.



4. Within one minute push the conduit into the accessory. Give a quarter turn to spread cement evenly, making sure the accessory is correctly aligned with any sets in the conduit. Wipe off excess cement immediately.

5. Do not handle the joint for 5 minutes. 'Drying' time for the solvent can be up to 24 hours, so take care not to rough handle the assembled conduit during this time.

FIGURE 17.33 Setting and joining PVC conduit

INSTALLING CONDUIT—STEEL (THREADABLE) CONDUIT TECHNIQUES

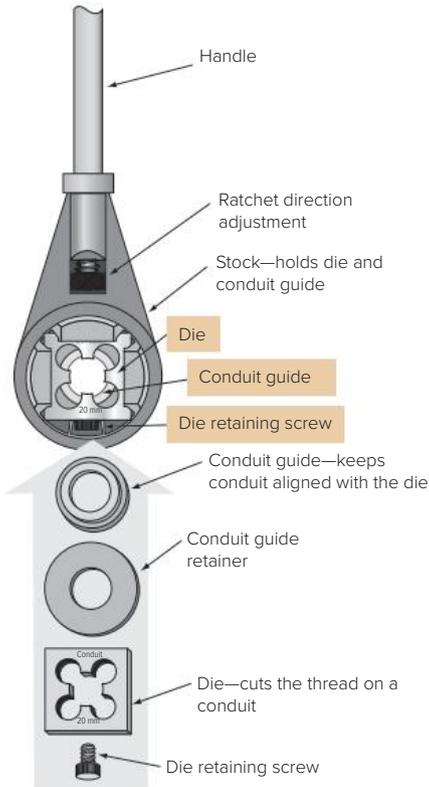
Conduit is cut by holding it firmly in a pipe vice and using a hacksaw with a fine-toothed blade. A wheel-type pipe cutter is not suitable for cutting conduit because it decreases the internal bore, leaves sharp edges and tends to distort the internal section, making it difficult to cut a thread.

The threading of conduit is effected by holding it firmly in a pipe vice and using either a single block-type stock and die, or a stock that contains four individual dies that are adjustable to different conduit diameters. Whereas with the block-type stock and die a separate die is necessary for each conduit size, with the adjustable type the same dies may be adjusted over a range of sizes because the thread pitch is the same for conduit sizes 16 to 50 mm.

Lubrication must be provided for the dies; this may be in the form of a proprietary preparation such as sulfuretted lard or tallow, or ordinary household dripping. After threading, all internal burrs must be removed to prevent damage to cable insulation; a round file, reamer or similar tool is used for this purpose. Threads should be clean, be a firm fit in an accessory and be half the length of a standard coupling. Ideally, when threads are screwed into an accessory there should be no exposed thread, except where locknuts are used with a running thread, as shown in **Figure 17.34**.

Tools used to cut conduit threads

The threads are cut on conduit by a stock and die assembly. The block-type stock and die shown below requires a separate die for each conduit size and is commonly used for conduits up to 25 mm. For larger conduits an adjustable stock and die is used where the same 4-piece die set may be adjusted over a range of sizes because the thread pitch is the same for conduit sizes 16 to 50 mm. A thread-cutting machine is often used where a large number of threads are to be cut.



Cutting and threading steel conduit

1. Conduit is cut by holding it firmly in a pipe vice, and using a hacksaw with a fine-toothed blade.

Note that a wheel-type pipe cutter is not suitable for cutting conduit because it decreases the internal bore, leaves sharp edges and tends to distort the internal section, making it difficult to cut a thread.



2. Lubrication is applied to the end of the conduit to assist the die in cutting a 'clean' thread; this may be in the form of a proprietary preparation.



3. The stock and die assembly is slid onto the end of the conduit via the conduit guide. The thread is cut using the action shown in the illustration below. As a guide, threads should be half the length of a standard coupling and, ideally, when threads are screwed into an accessory, there should be no exposed thread.



4. After threading, all internal burrs must be removed to prevent damage to cable insulation; a round file, reamer or similar tool is used for this purpose.



FIGURE 17.34 Cutting and threading steel conduit



DID YOU KNOW?

Bends in conduit must comply with the requirements of *Clauses 3.10.3.4* and *3.9.6*.

Unlike PVC conduit, which can sometimes be set by hand or across the knee, steel conduit requires the use of a bending tool. In practice, it is difficult to set steel conduit accurately with a manual bending tool in sizes above 25 mm and use of a power-operated tool is virtually essential. If conduit is to be set using a manual bender, manufacturers can usually supply tables or guidance in some other form to enable reasonably accurate sets to be executed. An example of an effective method for the fairly accurate setting of a 20 mm conduit is shown in **Figures 17.35** and **17.36**.

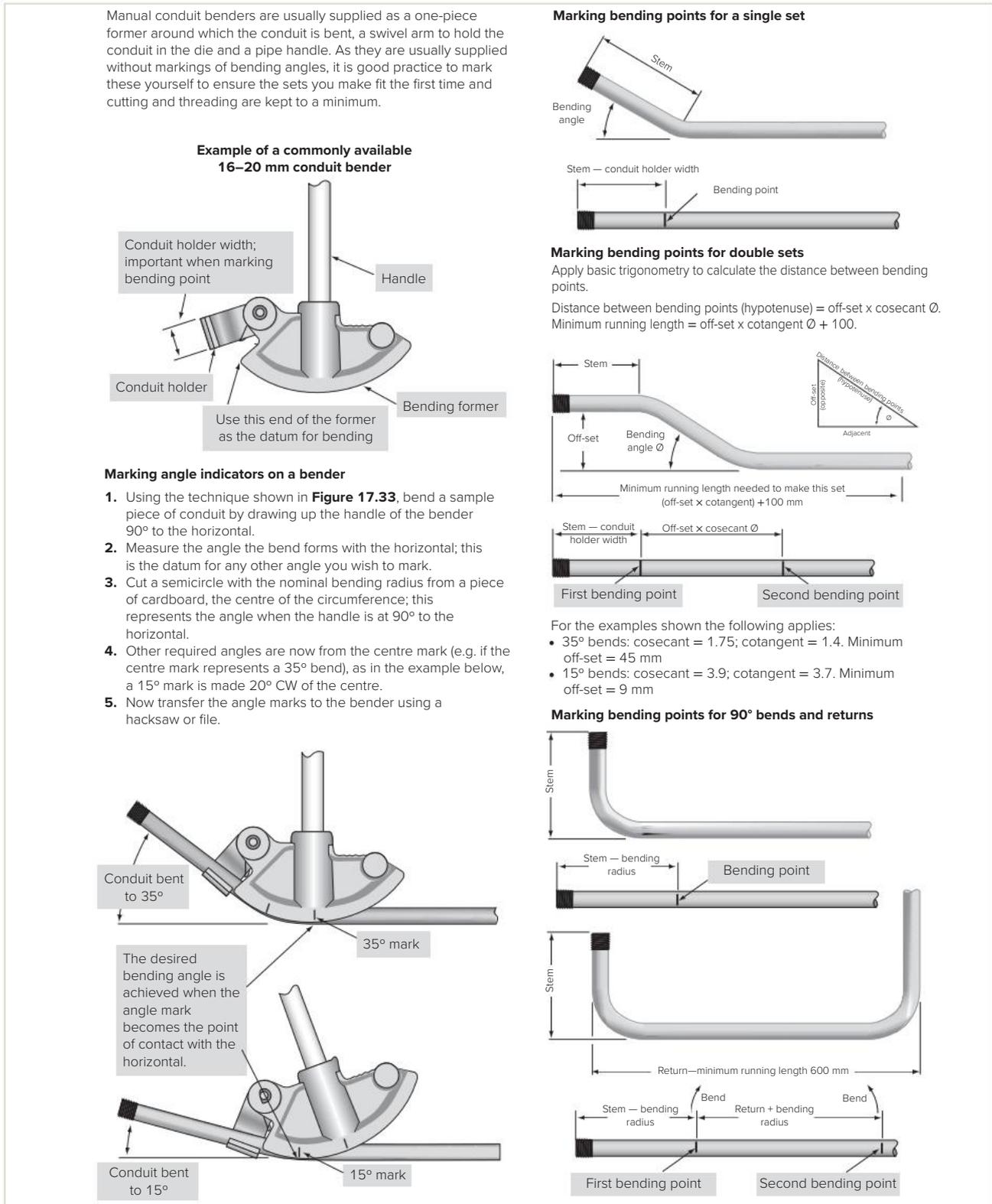


FIGURE 17.35 Preparing to bend steel conduit

Making a double set in steel conduit

Example:

A double set of 100 mm is required in 20 mm conduit with a stem length of 120 mm. As the off-set is above 45 mm the bending angle chosen is 35°. Bender conduit holder width is 40 mm.

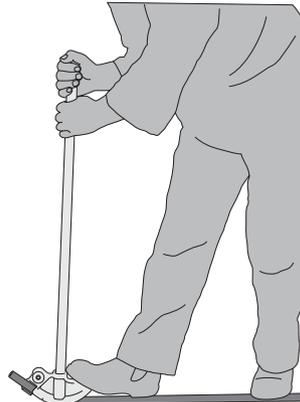
1. Calculate the position of the two bending points.

$$\begin{aligned} \text{First bending point} &= \text{stem} - \text{conduit holder width} \\ &= 120 - 40 \\ &= 80 \text{ mm} \\ \text{Second bending point} &= \text{off-set} \times \text{cosecant } 35^\circ \\ &= 100 \times 1.75 \\ &= 175 \text{ mm} \end{aligned}$$

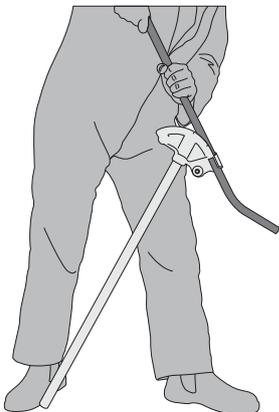
2. Mark the bending points on the conduit.



3. With the conduit on the floor, fit the bender to the conduit so that the first bending point lines up with the bender datum.



4. Draw the handle of the bender upwards, forcing the conduit around the die. The first bend is complete when the bender handle is at 90° to the floor. The bend in the conduit will be 35°.



5. Lift the conduit, with the bender attached, from the floor and turn the assembly over so that the bender handle is facing downwards.

6. Rotate the conduit in the die 180°.

7. Tilt the bender forwards and secure the handle from slipping with the left foot.



8. In this position, force the conduit down and around the bender die. Bend the conduit sufficiently to enable completion of the second bend on the floor.



9. Finish the second bend on the floor as in steps 3 and 4. The double set is completed when the stem is parallel to the floor.



FIGURE 17.36 Example of techniques for bending steel conduit

As previously discussed, the assembly of screwed conduit requires enough space to rotate a fitting or a piece of conduit. Where this is not possible, two pieces of conduit can be joined effectively without turning, by use of either a barrel union or running thread, as shown in **Figures 17.37** and **17.38**.

There are two important requirements for installing metallic enclosures. Firstly, cable insulation and sheathing must be protected against damage from sharp metal edges where cables enter or exit an enclosure. Secondly, the enclosure must be earthed at its origin and earth continuity must be maintained over the complete enclosure run. **Figures 17.39** and **17.40** illustrate how this is commonly done in practice with steel conduit. The same requirements apply to other metallic enclosures such as trunking.

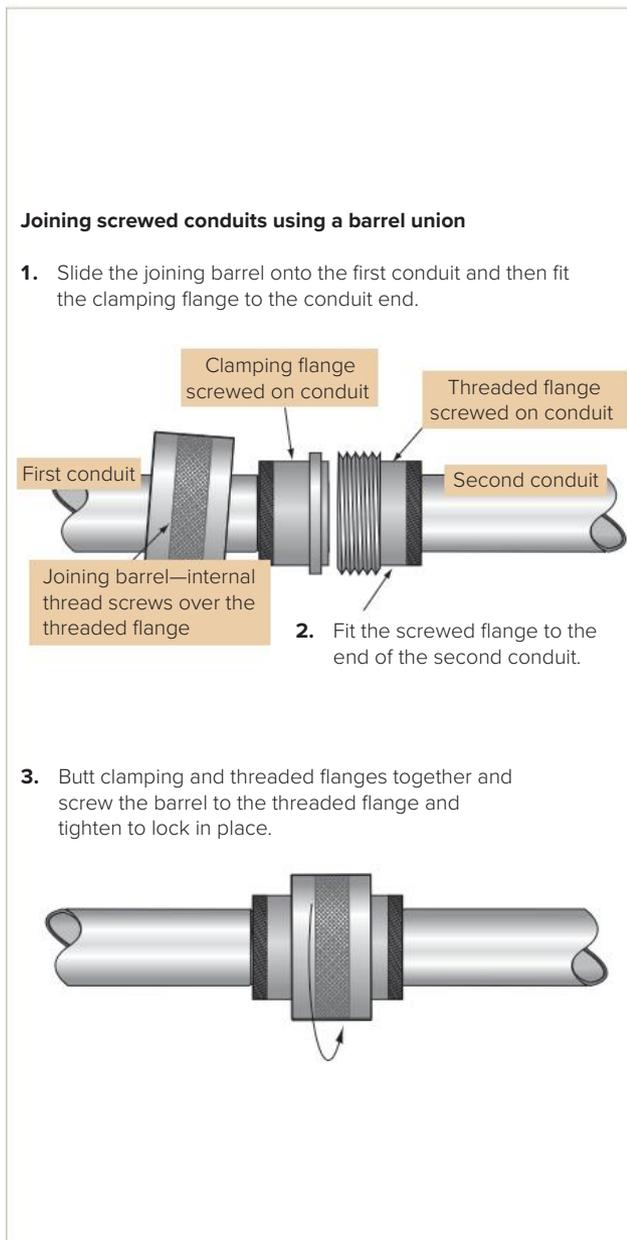


FIGURE 17.37 Joining steel conduit using a barrel union

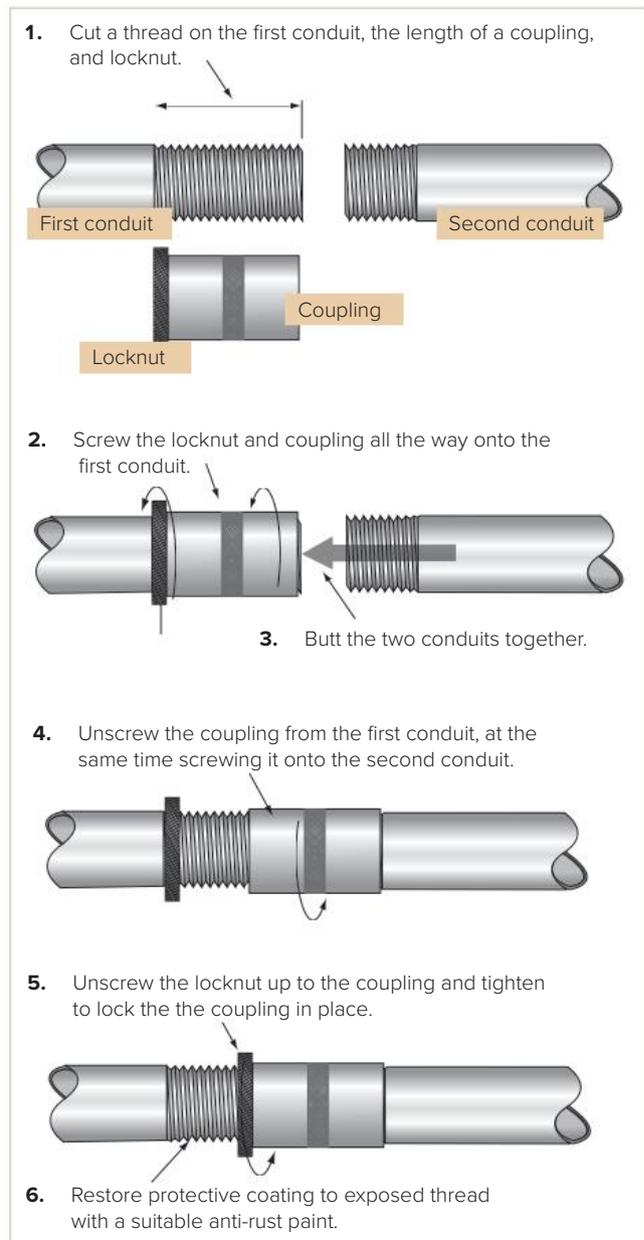
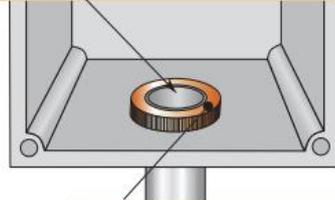


FIGURE 17.38 Joining steel conduit using a running thread

Terminating a steel conduit at an accessory

Clause 3.10.3.5 requires the protection of cable insulation and sheathing where they pass through metalwork such as the ends of metallic conduit. The common practice in terminating steel conduit is to:

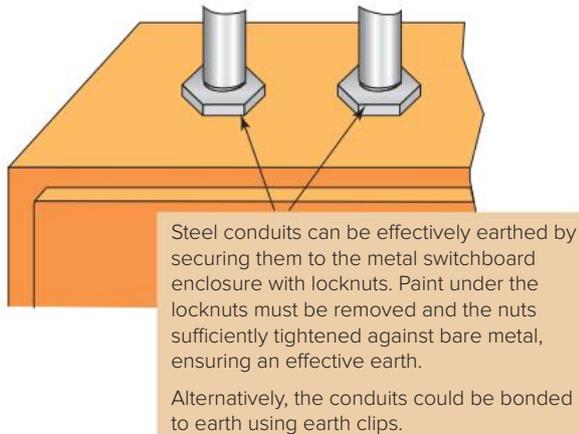
1. Clean the inside of the conduit end of burrs and sharp edges with a file or reamer (as shown in **Figure 17.34**).



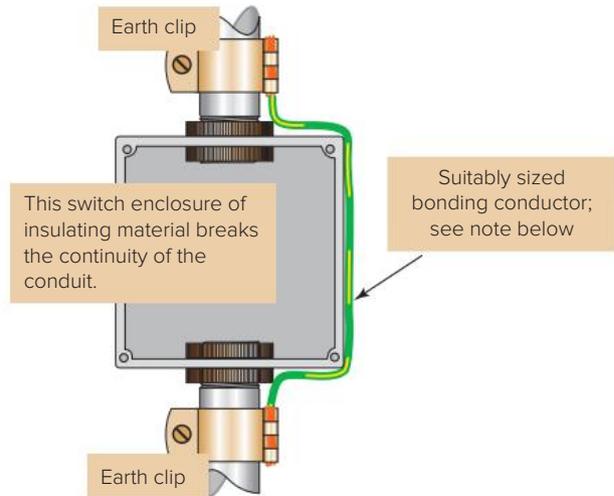
2. Fix the conduit end flush with the face of the lock ring/nut to provide a smooth flat surface.

FIGURE 17.39 Bushing steel conduit ends

A run of metallic conduit must be both electrically and mechanically continuous, the conduit being earthed at the commencement of the run (usually a switchboard) as required by *Clauses 3.10.3.3* and *5.5.3.2*.



If there is a break in the mechanical continuity of a steel conduit run, such as at an all-insulated accessory, the electrical continuity must be maintained as shown below.



Note: In the event of an earth fault, the conduit run might have to carry a large value of earth-fault current back to the switchboard and thence to earth and the supply neutral via the MEN link. To do this effectively, the resistance of the conduit run must be low enough to permit sufficient fault current to operate the circuit protection. This is a requirement of *Clauses 5.5.4.2* and *5.7*; how this is done and the importance of low-resistance earthing systems are explained in **Chapter 12**.

FIGURE 17.40 Steel conduit earthing and continuity

 **DANGER**

Do not pull cables into enclosures in which energised conductors are installed or that have energised live parts such as switchboards or switch gear. *Never work live!* is a good saying to go by.

17.4.2 Cable trunking systems

After conduit, cable trunking systems are the most commonly used enclosures, accommodating both power and communications cabling. Trunking is an enclosure in which the cables are laid before covers are fitted to completely enclose the cables. 'Duct' was previously a defined term but is no longer used in the *Wiring Rules*. The term 'cable duct' is used by some manufacturers and in the trade generally has the same meaning as 'trunking' as defined by *Clause 1.4.127*.

Some trunking systems are designed for surface work, while others are for embedding in a concrete pour or to be installed as concealed wiring, provided that access provisions are incorporated in the design, as required by *Clause 3.10.3.9(c)*. Trunking and duct systems are mostly used in combination with other wiring systems and, although their initial cost is relatively high, trunking systems are used for their flexibility to accommodate refurbishments and integration with building structures and fit-outs.

The common type of trunking is a surface wiring enclosure system that is available in galvanised or colour-coated steel and in an insulating material such as PVC. Metal and PVC surface trunking has similar stock sizes, with the PVC types being more commonly used. Some of the finer points of surface trunking systems are given in **Figure 17.41**.

NOTE: Take care when planning a trunking installation. Make sure you select accessories that have the correct orientation. As shown in **Figure 17.41**, an elbow used for a change in *horizontal* direction is different from an elbow used for a change in *vertical* direction.

A smaller version of PVC trunking, generally referred to by trade names such as mini trunking or mini duct, is designed as a tidy solution for surface fixing of sheathed power cable (TPS) and communications cables, and for managing interconnection cables between devices such as computers and printers. Examples and applications are shown in **Figure 17.42**.

Trunks divided into compartments are designed to meet the requirements of *Clause 3.9.8* for the segregation of wiring; services such as low-voltage power and lighting, security-system wiring and telephone, signal and communications systems use separate compartments within the common trunk. One such compartmented trunking is designed to replace skirting boards and integrate into the general architectural scheme. Skirting trunking, examples of which are shown in **Figure 17.43**, is commonly used in non-domestic installations.

Two similar forms of cable enclosure used in many installations are trunk and duct systems installed as a trench in the floor, known as underfloor trunking or duct. The trunk is fitted with a lid that can be readily removed to give access to the trunk wiring. The duct system includes junction boxes for access to install cables. The main application for these systems is under checkout counters in supermarkets, for computer and security wiring in banking institutions, in large column-free office areas and in any heavy-traffic areas. Examples are shown in **Figure 17.44**.

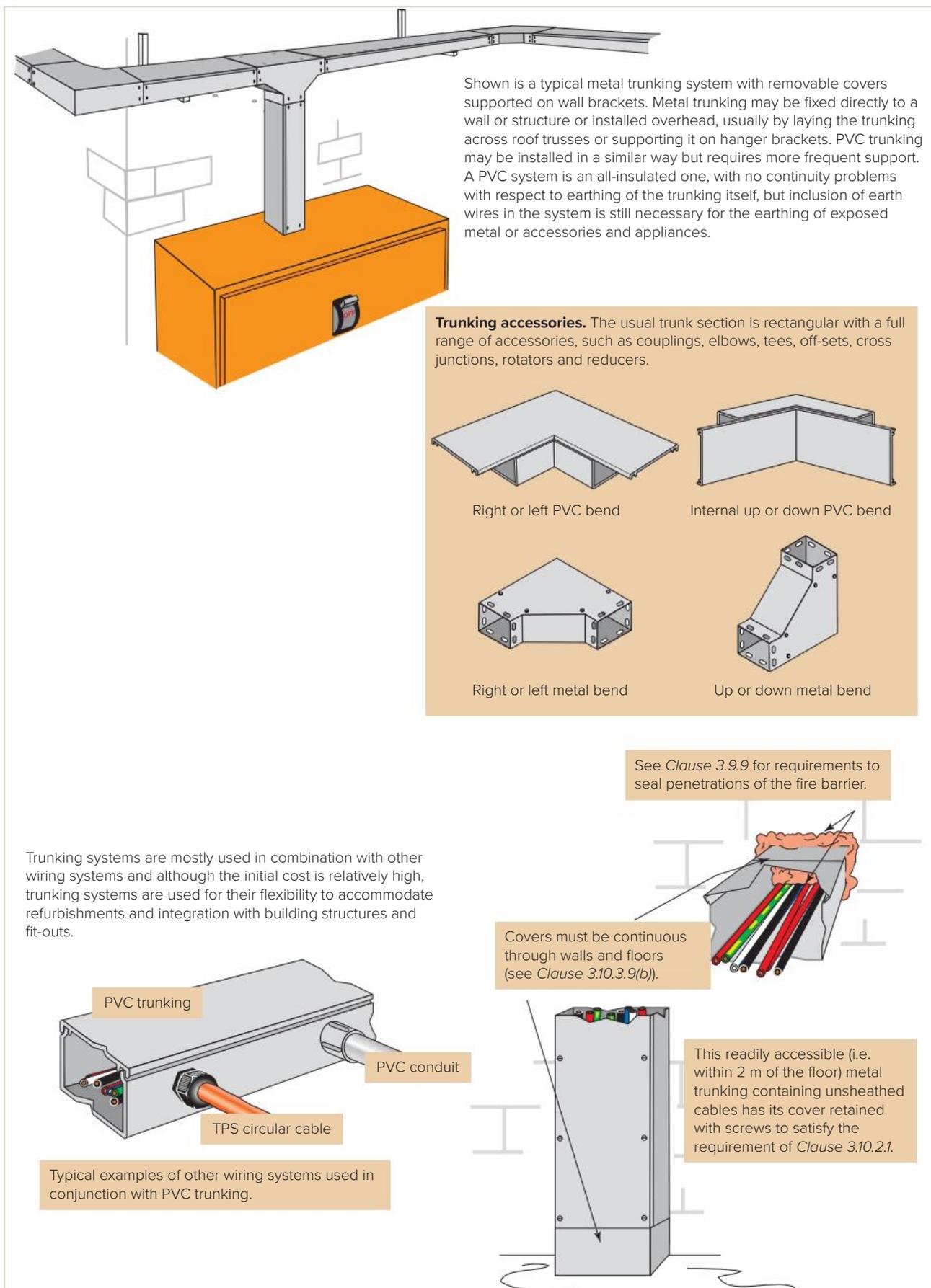


FIGURE 17.41 Surface trunking systems

Mini trunking is a neater alternative to conduit where surface wiring cannot be avoided as is generally the case where lease restrictions prevent structural or below-the-surface modifications to the electrical system. It is an ideal cable management system for use in domestic and commercial applications and can be easily altered to allow for upgrade or re-arrangement. As with the larger trunking, a variety of elbows, tees and other accessories are available.

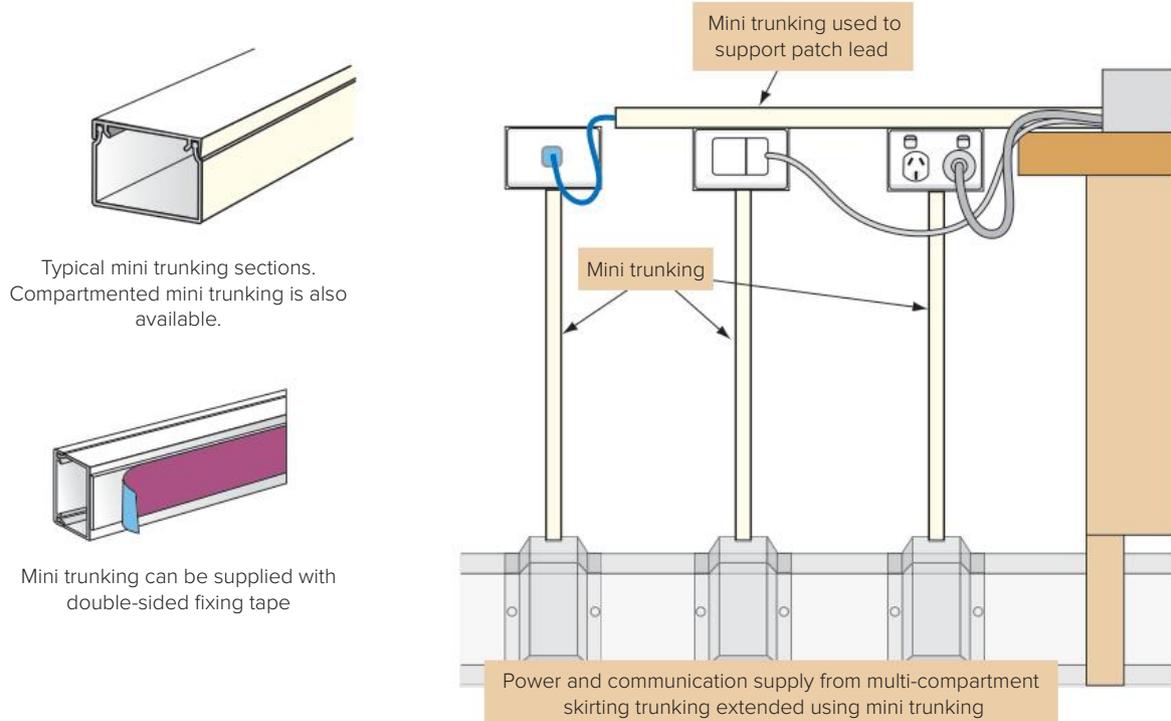


FIGURE 17.42 PVC mini trunking

An example of a typical two-compartment skirting trunk. Skirting trunking is also available with three compartments where separation of various data, voice and other communications services is required.

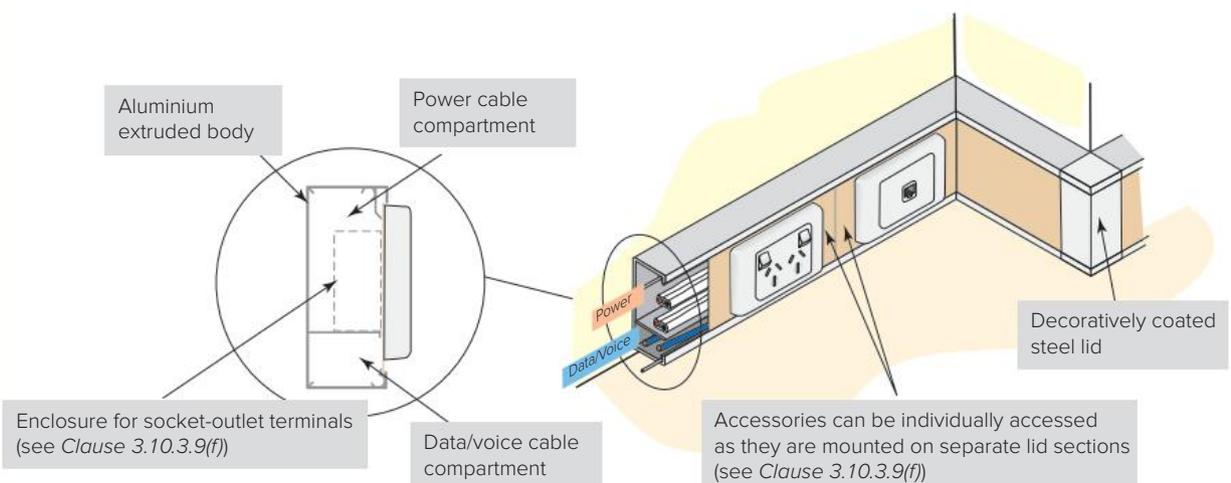


FIGURE 17.43 Skirting trunking

This trunking is designed with removeable covers making installing the initial wiring easy. Any further wiring to be installed or altered after the floor finish is completed can be drawn in.

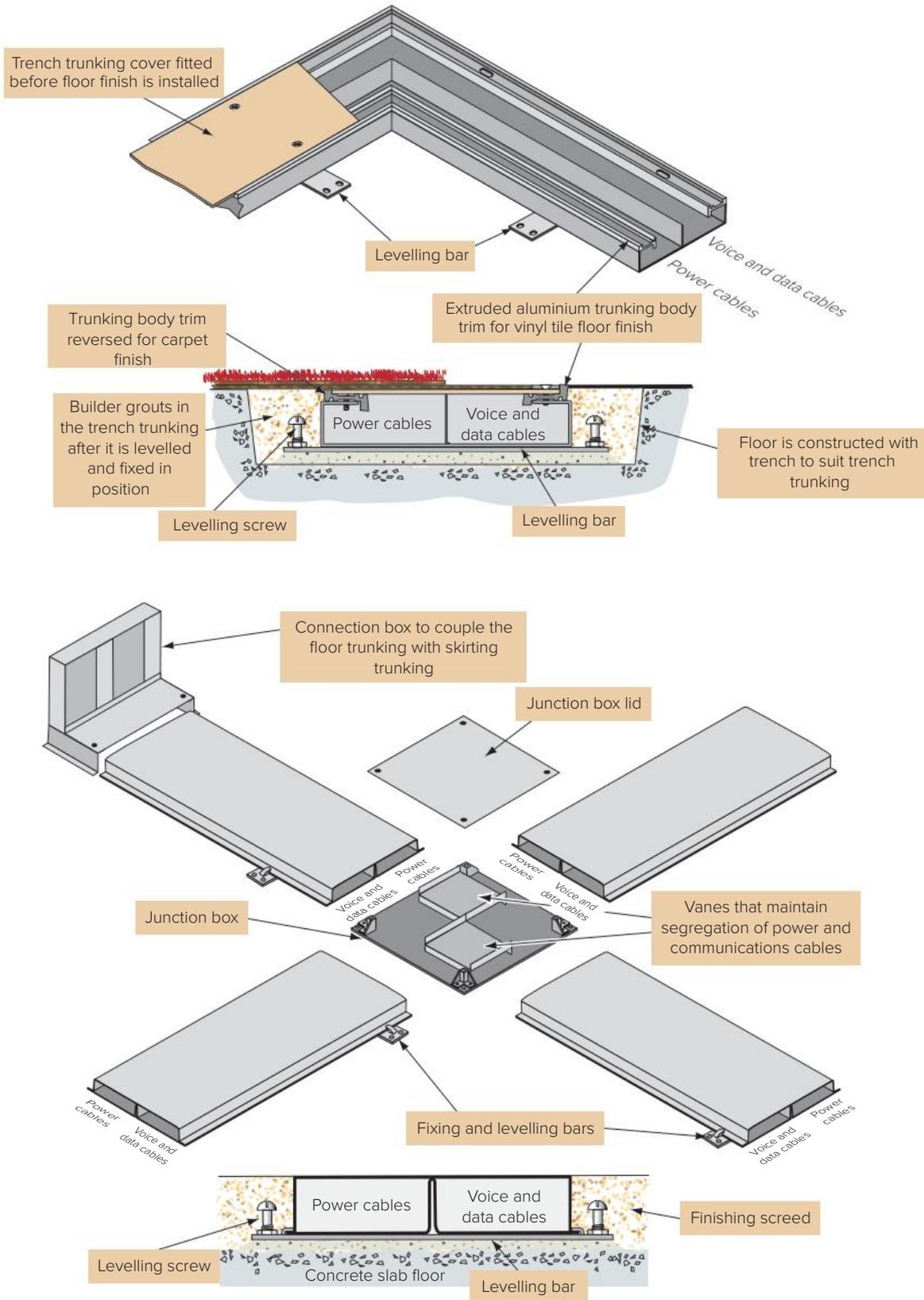


FIGURE 17.44 Underfloor trunking systems

Other trunk- and duct-type systems shown in **Figures 17.45** and **17.46** illustrate the versatility of trunking and duct enclosures.

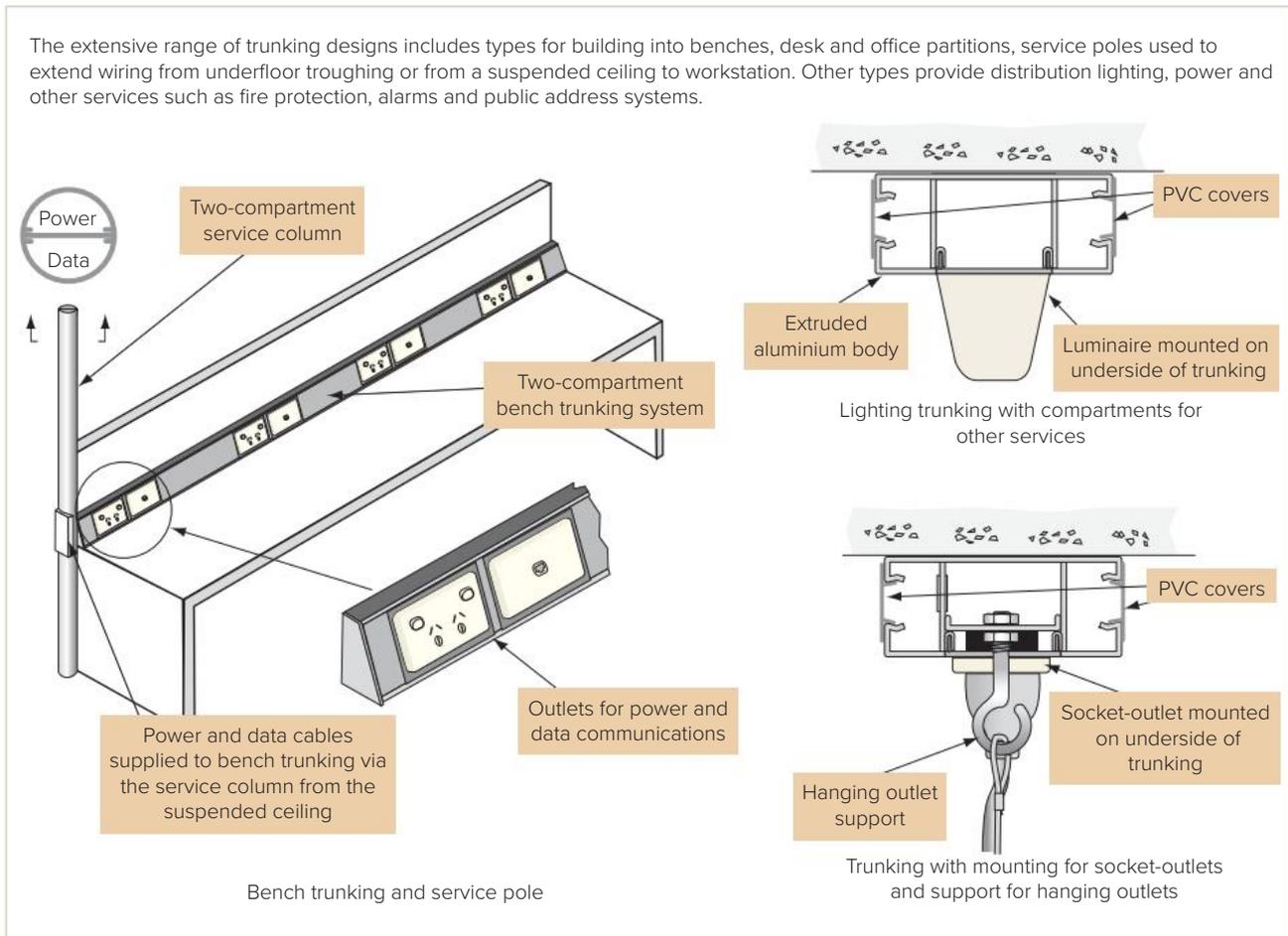


FIGURE 17.45 Office trunking system

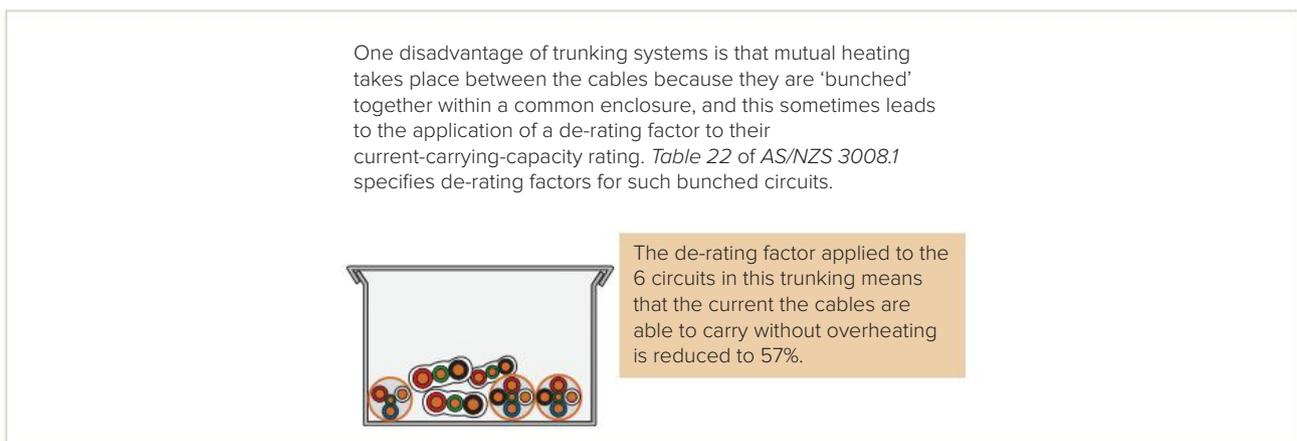


FIGURE 17.46 De-rating of cables in trunking

17.4.3 Pulling cables

There are a number of aids for pulling cables, whether it be pulling unenclosed cables on cable ladder/tray or drawing cables into conduits or trunking. In particular, aids for pulling large cable that reduce manual handling and make pulling cable more efficient and safer are available through plant hire companies. Examples are shown in **Figure 17.47**.

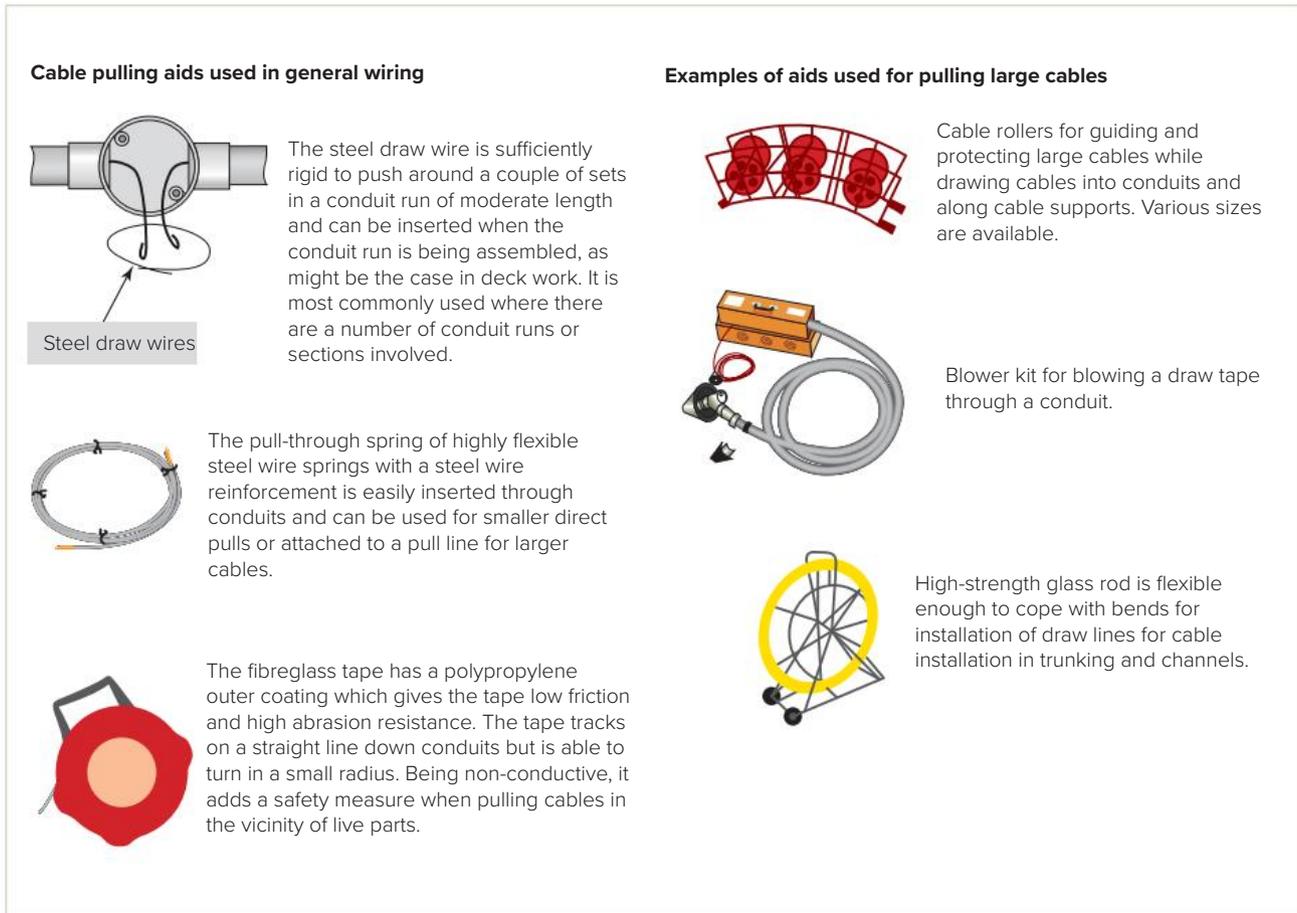


FIGURE 17.47 Cable pulling aids

Drawing cable into conduits and trunking is usually done with steel draw wire, steel draw springs or fibreglass tapes (see **Figure 17.48**). Steel draw wire is sufficiently rigid to push around a couple of sets in a conduit run of moderate length and can be inserted when the conduit run is being assembled, as might be the case in deck work (**Figure 17.31**). It is most commonly used where there are a number of conduit runs or sections involved.

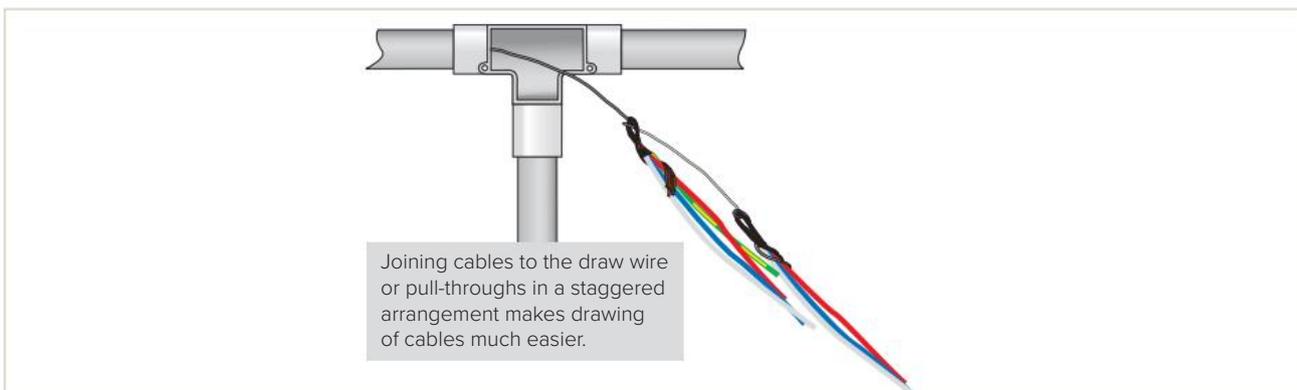


FIGURE 17.48 Drawing cable into conduit

Pulling/drawing cables is made much easier and will ensure they are not damaged if you take care to apply the practices shown in the Caution box.



CAUTION

- ▶ Set cable drums on jacks or drum rollers.
- ▶ For unenclosed cables, set up cable rollers at each change of direction.
- ▶ Attach cables to the pulling/drawing aid securely and without bunching; where cables are to be drawn into conduit or trunking, avoid using insulation tape, as it can be caught on bends and jam, making pulling unnecessarily difficult (see **Figure 17.48**).
- ▶ Ensure the person feeding the cable directs the persons pulling at all times; this may require the use of electronic communications.
- ▶ Feed cables to avoid kinking and crossovers of cables.
- ▶ Draw cables into steel conduit after erecting the conduit, because any attempt to install cables while the conduit is being erected would be impractical; the joins of conduit and of conduit to fittings have to be made by twisting either the conduit or the fittings to thread them together, and this would result in twisted and damaged cables.
- ▶ It is possible to install cables in PVC or HFT conduit while it is being erected because the fittings and conduits are pushed together without twisting; however, this method should be avoided, if possible, because it involves much more handling of the cables and so the likelihood of damage is far greater than when the draw-in system of the erected conduit is used.
- ▶ Use cable-pulling lubricant sparingly; lubricant is sometimes necessary for drawing cables, particularly into non-metallic conduits. (*Note:* when planning a run of conduit or trunking that is to follow a somewhat tortuous route, it is often more expedient to select a size larger than needed to satisfy the recommended space factors given in **Figure 17.28**.)
- ▶ Data cables (and especially fibre optic cables) are delicate and will not tolerate much tension when pulling through conduit, so care must be taken when carrying out this task. It is also important to ensure the conduits are not overfilled. A good guide for communications cables is 50 per cent.



CHECK YOUR UNDERSTANDING

14. Which PVC conduits would be used for general power wiring, underground power wiring, telecommunications, high security and HFT?
15. What is the recommended minimum size of HD PVC conduit needed to accommodate $4 \times 4 \text{ mm}^2$ and $4 \times 2.5 \text{ mm}^2$ insulated unsheathed cables? Assume the respective CSA of each cable size is 18.1 mm^2 and 11.3 mm^2 .
16. Explain how metallic and PVC conduits are joined.
17. Explain the difference between a cable trunk and a skirting trunk.
18. How does mutual heating affect cables installed in a trunk?

17.5 Underground systems

In the densely populated areas of a large city, most of an energy distributor's low-voltage and high-voltage reticulation is underground. Low-voltage reticulation and service mains are also commonly installed underground in many housing estates. In consumers' installations, underground wiring is often employed for the wiring to outbuildings and outside lighting. In commercial and industrial installations, extensive underground wiring systems are also commonly used.

The energy distributor's reticulation is its own domain and responsibility but, if underground service mains are required, they are usually installed by the electrical contractor in accordance with the distributor's specified requirements, an example of which is shown in **Figure 17.49**.

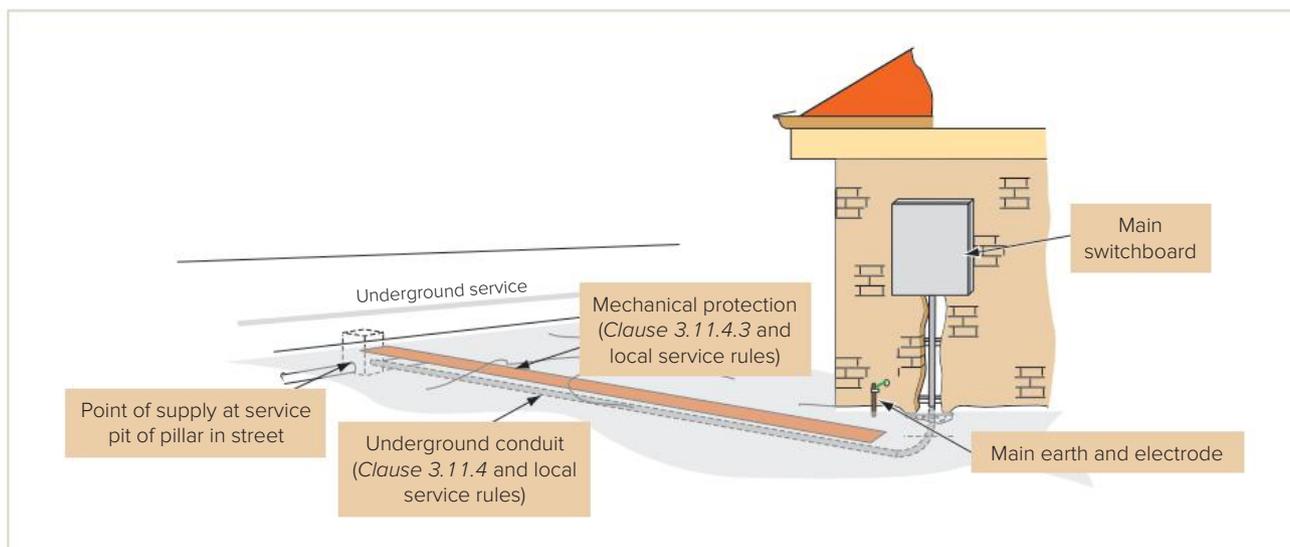


FIGURE 17.49 Example of underground consumer mains

The electrician is usually concerned with wiring on a consumer's premises, to which *Clause 3.11* relates. This rule sets out the various forms of acceptable enclosures, the depth of laying and protection required, and other provisions relevant to underground wiring.

Decisions on the type of cable to be used, the form of the enclosure and the cable route are made on the job, and are largely influenced by cost and the type of terrain under which the cables will be laid. For example, a sheathed, armoured and served cable may well be considered for a 50 m underground submain in a factory yard, whereas insulated and sheathed cable in medium-duty conduit would be suitable for a 10 m underground feed from a house to a garden light.

An important aspect of underground wiring is to avoid encroaching on other services such as gas, water and telecommunications, and to have separation from the earth electrode. The minimum distance of separation from these is listed in *Table 3.7* of the *Wiring Rules*. A pictorial summary of underground wiring systems is shown in **Figures 17.50** and **17.51**.

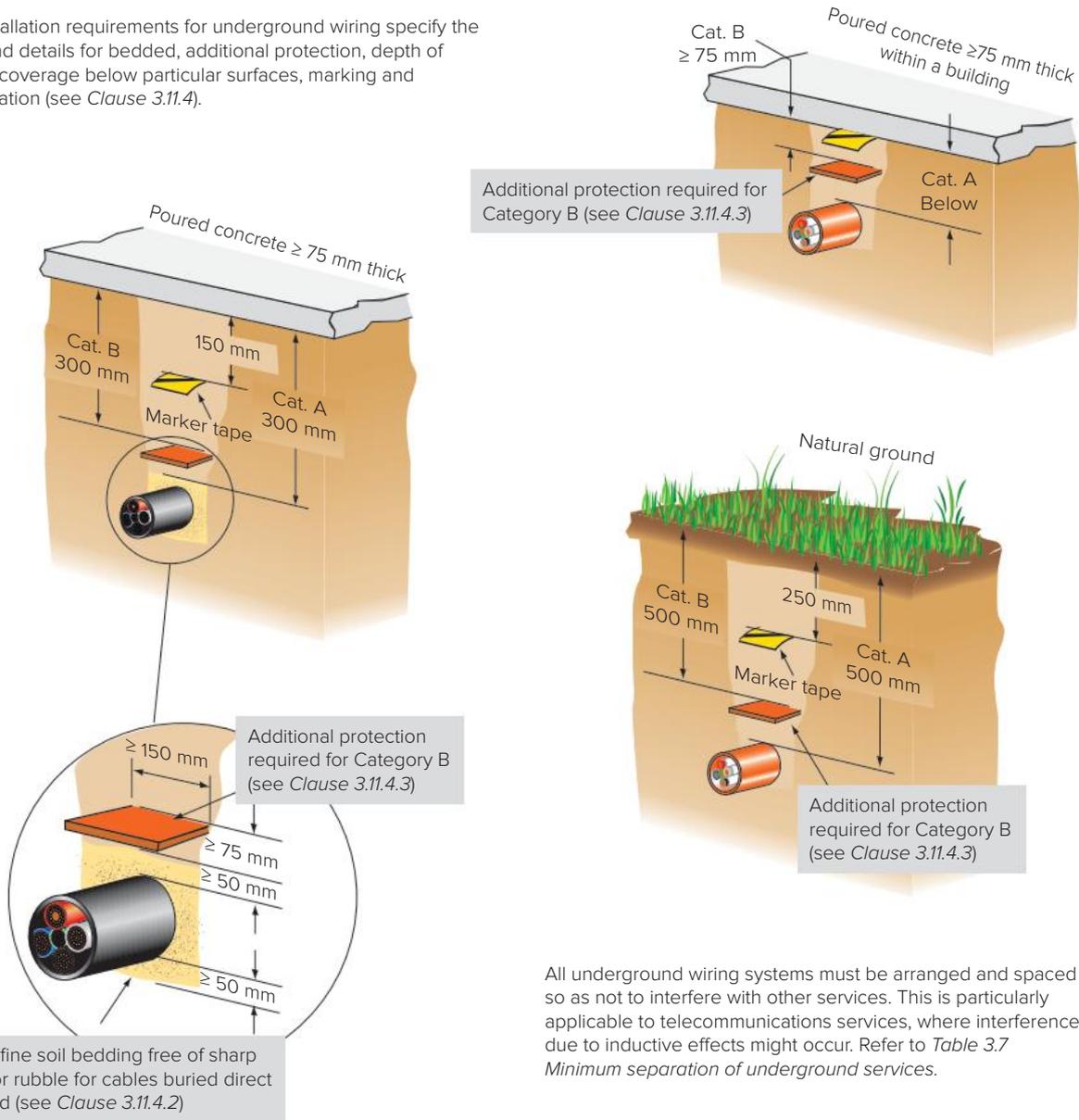
Earthing conductors, whether bare or insulated, that are buried directly in the ground or enclosed underground must meet the requirements of *Clause 3.11* with regard to depth and mechanical protection (see *Clause 5.5.5.5*). If a bare separate earthing conductor is buried directly in the ground or in an underground enclosure, it must have copper conductors and be not less than 25 mm² in accordance with *Clause 5.5.5.5(b)*.



DID YOU KNOW?

Underground wiring systems are classified by cable type and method of mechanical protection used in Categories A and B, and a further Category C for wiring systems laid in solid rock. *Table 3.5* of the *Wiring Rules* lists seven cable types that may be used and the acceptable forms of mechanical protection as Category A, B or C. The depth underground in which the wiring system is laid is governed by the wiring system category and type and the location of the covering surface above the wiring, as listed in *Table 3.6*. The *Wiring Rules* also provide several illustrations regarding depth layer and installation.

The installation requirements for underground wiring specify the need and details for bedded, additional protection, depth of ground coverage below particular surfaces, marking and identification (see Clause 3.11.4).



All underground wiring systems must be arranged and spaced so as not to interfere with other services. This is particularly applicable to telecommunications services, where interference due to inductive effects might occur. Refer to Table 3.7 *Minimum separation of underground services*.

FIGURE 17.50 Examples of Categories A and B underground wiring (see *Wiring Rules*, Figures 3.10 to 3.15)

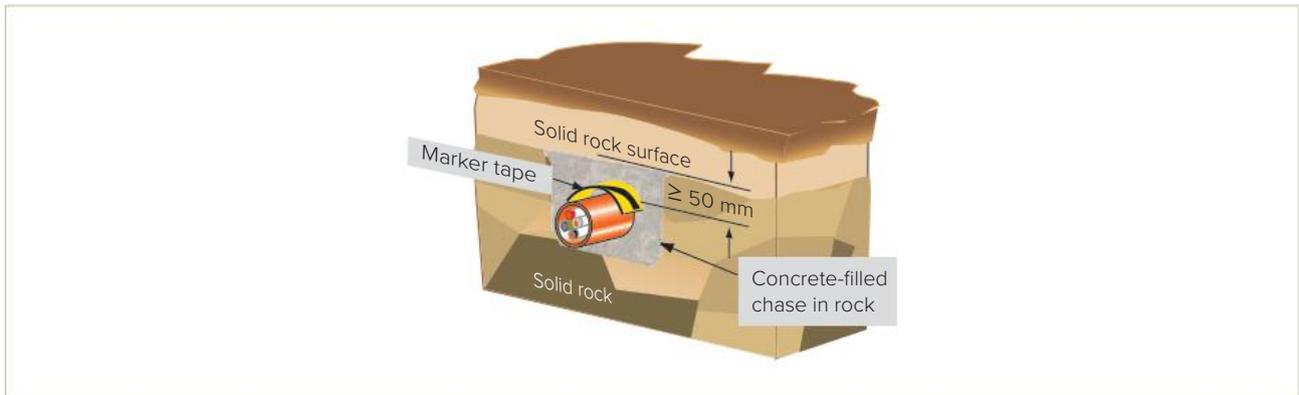


FIGURE 17.51 Category C underground wiring



CAUTION

The finished ground level and intended locations of other services are not generally obvious at the start of a job. Before installing underground wiring, establish the actual finish level of the ground and locations of other services with the person responsible for the project. This will avoid the possibility of expensive defect repairs for not complying with the minimum depth layer or being too close to other services.



CHECK YOUR UNDERSTANDING

19. Name the category of underground wiring system for insulated and sheathed cable buried directly in the ground with no enclosure.
20. What type of cable is allowed to be installed as a Category C?

17.6 Aerial and catenary systems

Bare or insulated conductors directly exposed to the weather and supported above the ground are classed as aerial conductors (*Clause 1.4.7*). The requirements for aerial wiring systems are covered by *Clause 3.12*. The major part of an energy distributor's distribution system is through bare aerial conductors. The *Wiring Rules* do not apply to these but relate to all aerial wiring on the consumer's premises, including aerial consumers mains if they exist. **Figure 17.52** shows a typical street pole supporting low-voltage distributors with connections to service lines, which are usually parallel-webbed, twisted or bundled, aerial insulated cables.

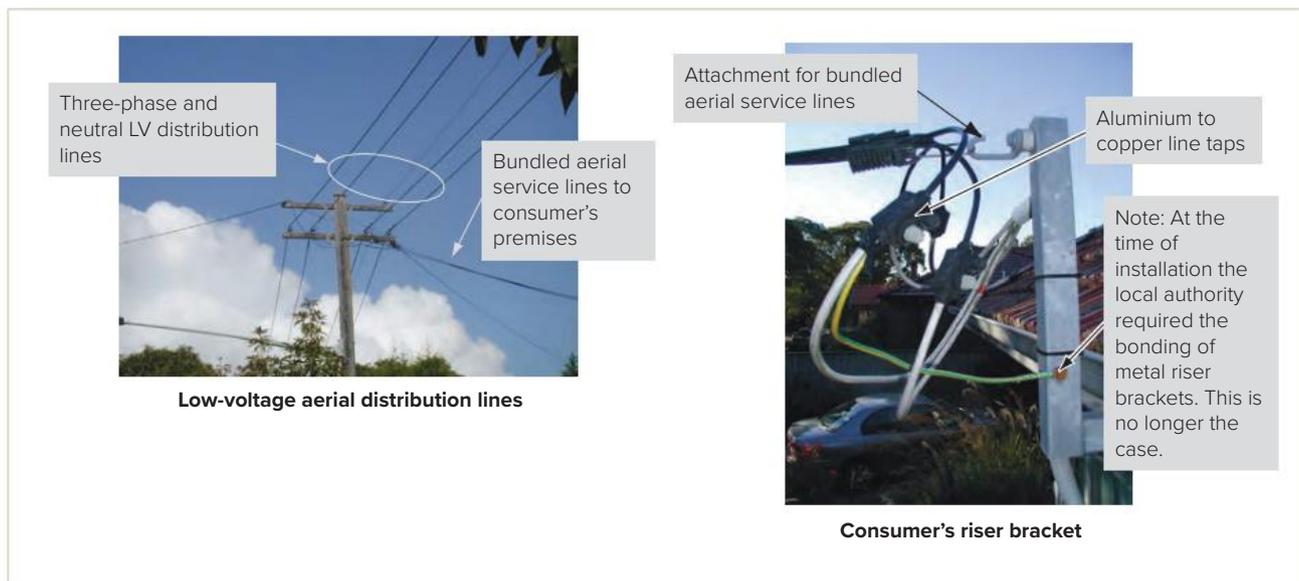


FIGURE 17.52 Energy supplier's low-voltage aerial distribution and service lines

Aerial wiring systems are becoming less common in consumer installations in urban areas but are more likely to be used in rural properties. Although for the majority of electricians aerial wiring is generally confined to preparation for the connection of single-span aerial service lines or consumers mains, the same requirements apply. In addition to *Clause 3.12* of the *Wiring Rules* the local distributor's service rules will include specific details such as the type and style of brackets and hardware, and acceptable points of attachment (see *Clause 1.4.93*).

Clause 3.12 and Appendix D of the *Wiring Rules* provide reference tables giving aerial line data for determining the size of supports in relation to the number, type and size of conductors to be supported, and the span between supports. Figure 17.53 shows the relationship between the *Wiring Rules* clauses and guidance in Appendix D and the process of selecting an aerial line support.

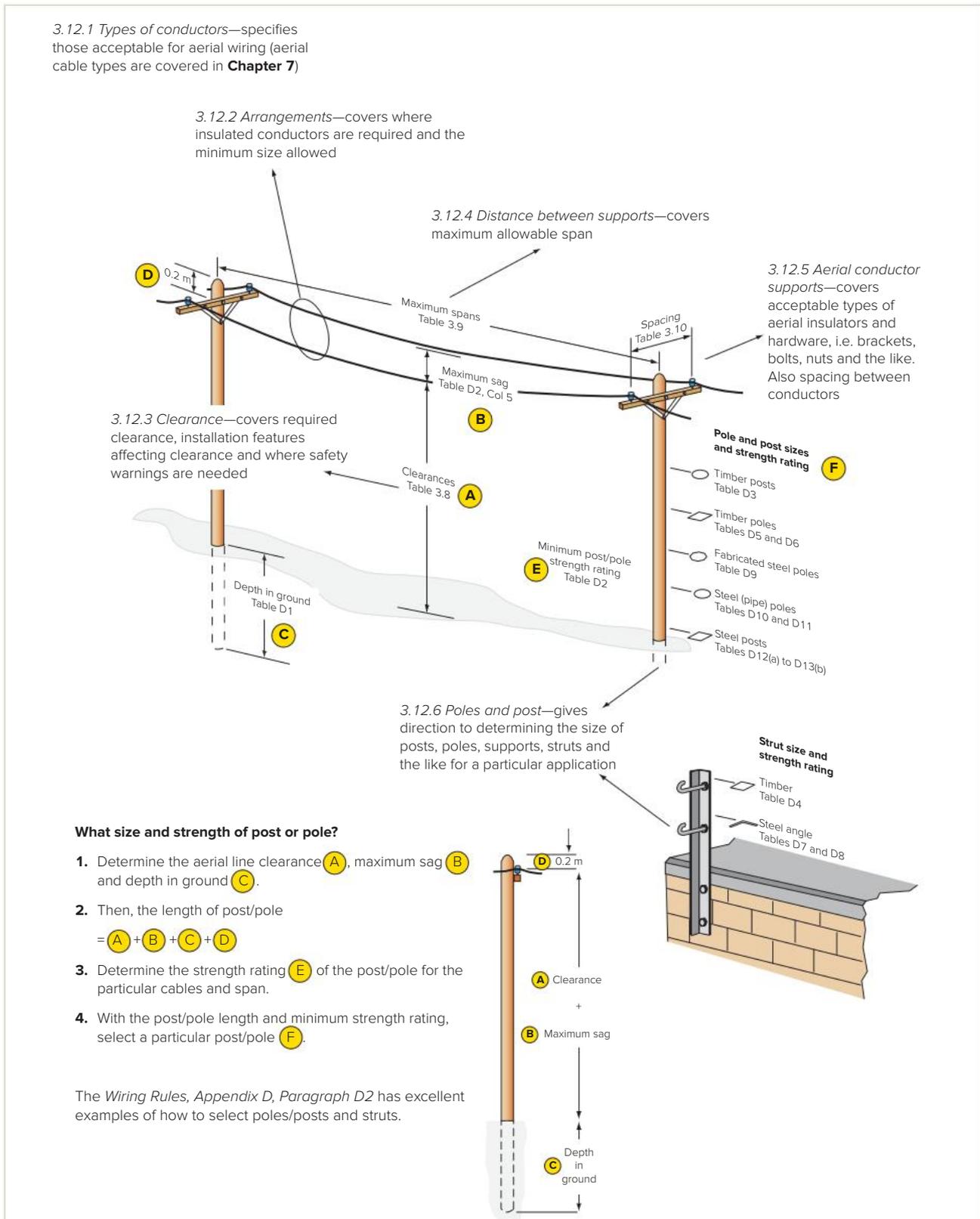


FIGURE 17.53 Arrangements for an aerial wiring system

Provided that a cable has stranded conductors (for flexibility) and is double insulated, the catenary system of support may be used. Although this system can be used outdoors, indoor applications have become more common, particularly to support lighting and communications cables above suspended ceilings and flexible trailing cables for overhead cranes and hoists.

If the cable is to be installed outdoors, it must be of a type suitable for exposure to direct sunlight (see *Clause 3.13.1*). The clearance for catenary wiring in outdoor applications is the same as for neutral screened aerial cables given in the *Wiring Rules, Table 3.8* with an added allowance for cable sag.

The catenary support must be of material resistant to corrosion or deterioration, commonly galvanised mild steel or stainless steel, effectively secured at each end, and of adequate strength to support the load in a uniform manner. Cables are available with an inbuilt catenary support cable, in which case the manufacturer's instructions should be followed for their installation.

Best practice dictates the electrician install their own catenary support structures. Building frames, walls, columns and so on can be used (if suitable) to mount support structures. Also, do not utilise any fixings installed by other trades (e.g. suspended ceiling rod hangers) and maintain a minimum of 100 mm clearance above any suspended ceiling tiles. This ensures any insulation or other fittings are not installed into the ceiling tiles.

Principles and examples of catenary support are given in **Figure 17.54**.

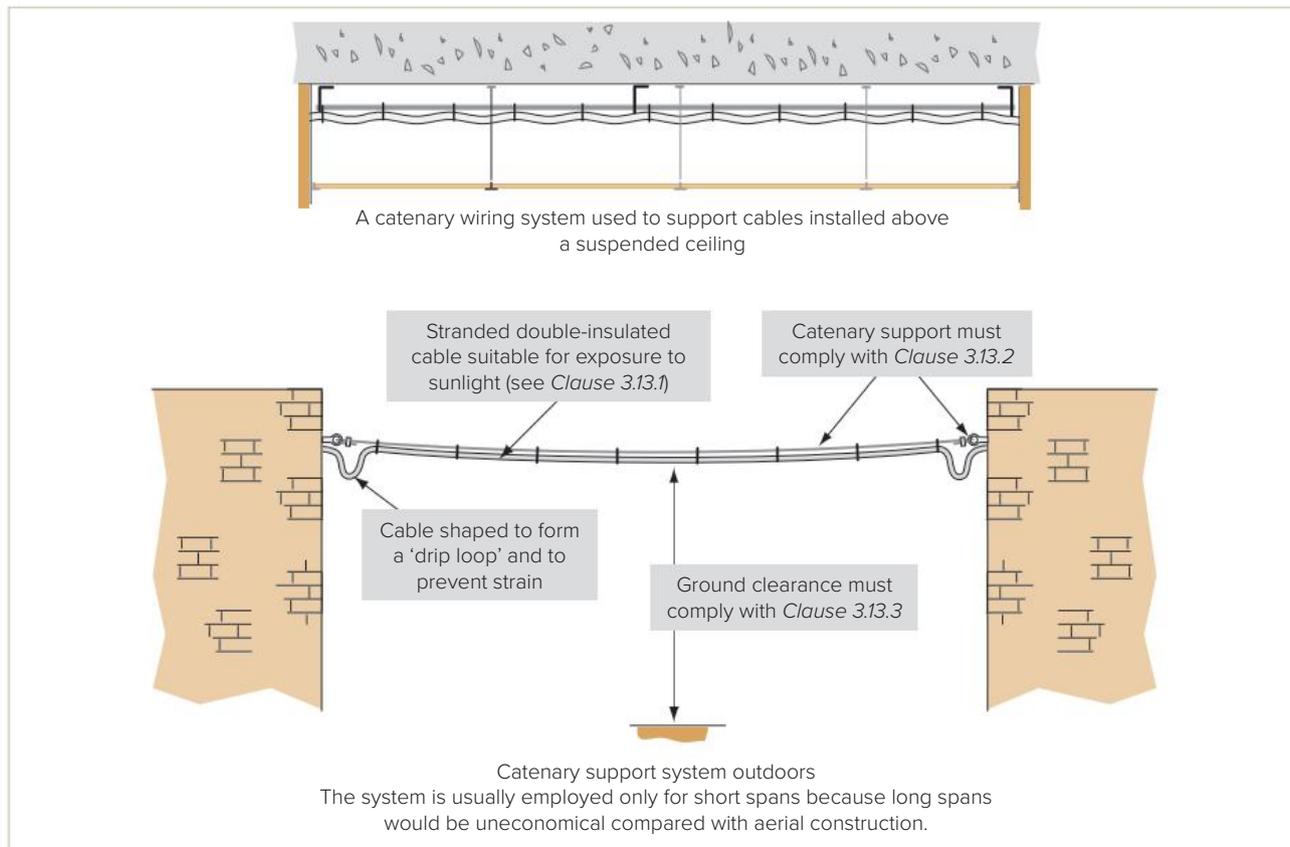


FIGURE 17.54 Principles and examples of catenary support



CHECK YOUR UNDERSTANDING

21. Determine the size of a grade 250 pipe to support $1 \times 25 \text{ mm}^2$ insulated aluminium aerial cable over a distance of 18 m in an area used by vehicles. Assume the soil is good.
22. If the soil in the Question 21 is found to be poor quality, what needs to happen to improve the soil quality?
23. What clearances are required for catenary support cables in indoor locations?

17.7 Composite wiring systems and applications

Busways, low-voltage track systems and soft wiring systems can all be regarded as composite wiring systems, as they combine all the elements of a wiring system, that is, conductors, enclosures/supports and termination components, into a single design for a specific application. Integrated in an installation with conventional wiring, composite systems are used for circuits for which they are specifically designed.

17.7.1 Busway systems

Busbar trunking, more commonly known as the *busway* system, consists of solid copper or aluminium conductors supported by insulated barriers at intervals within a formed trunk or similar enclosure, from which supply to current-using devices is affected by plug-in units; the concept is shown in **Figures 17.55** and **17.56**.

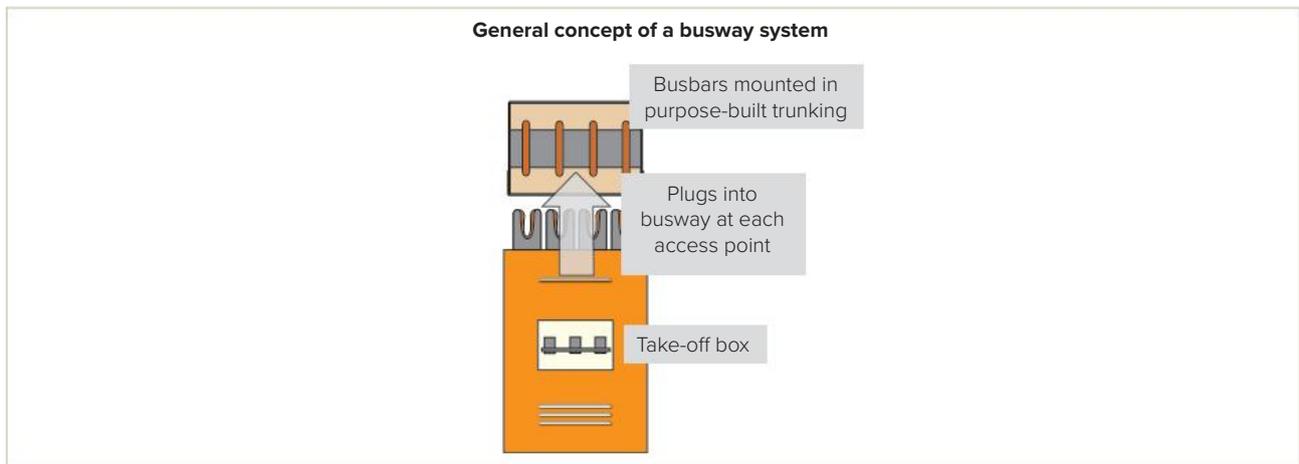


FIGURE 17.55 Busway concept

The type of busway shown below is typically available in ratings from 100 A to 1000 A three-phase, neutral and earth rated. It is available in lengths of 1.5 m and 5.0 m, together with change of direction accessories, power connection ends and terminations in modular assembly. It is used to install arrangements of distribution boards and wiring systems.

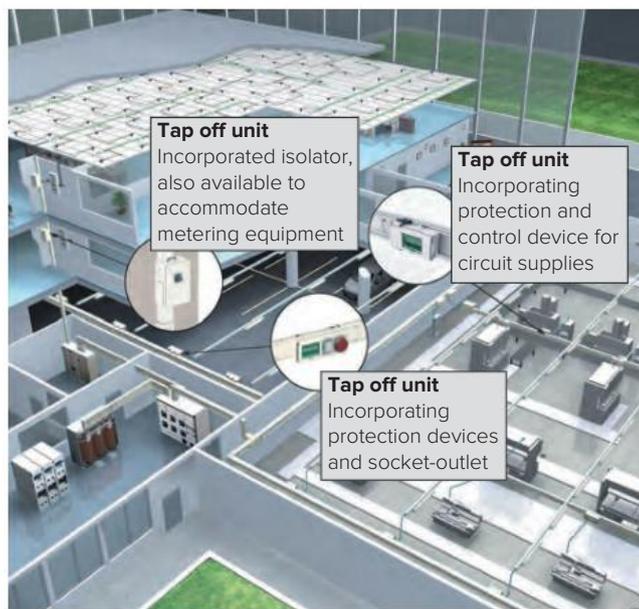


FIGURE 17.56 Industrial applications of a busway system

A common application is reticulation and distribution to equipment and machines in industrial facilities (**Figure 17.56**), which can have a distinct advantage over conventional wiring. The system has the advantage of effectively reducing the number of distribution boards and submains, thereby simplifying the wiring layout, as demonstrated in **Figure 17.57**.

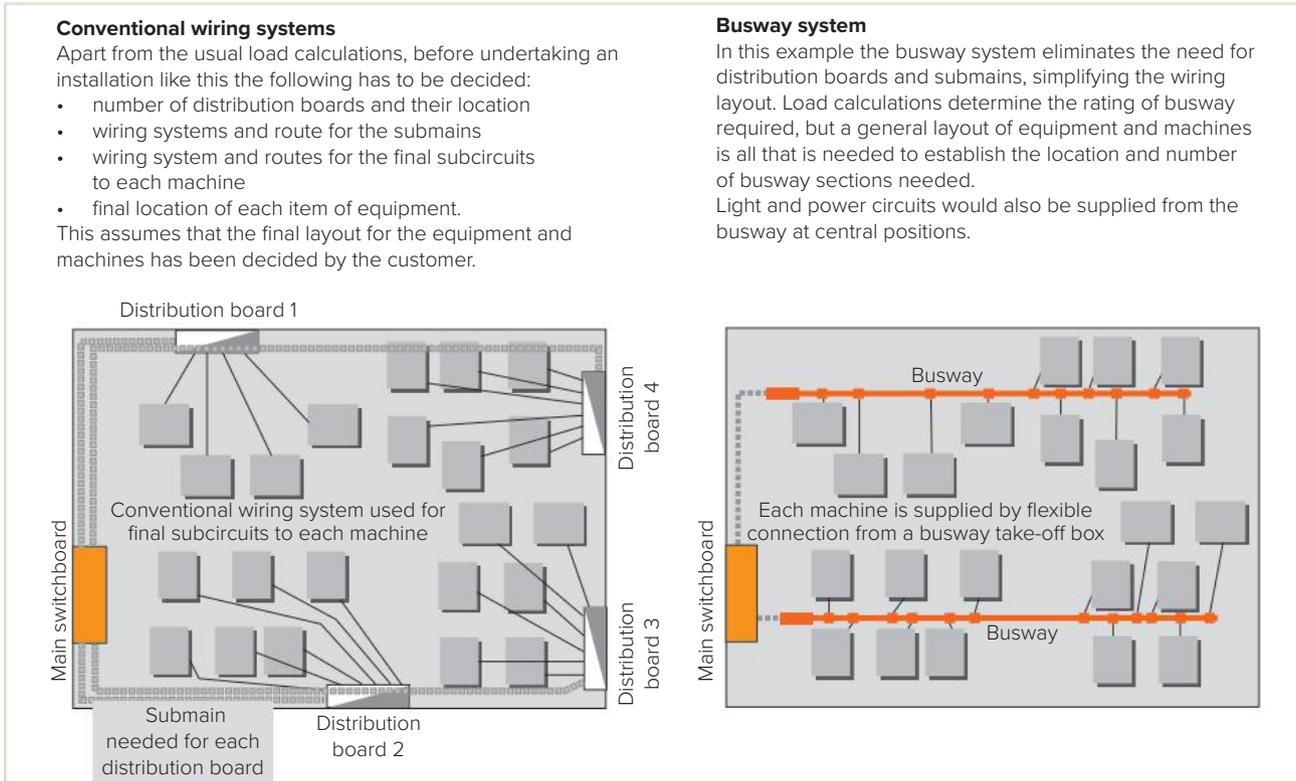


FIGURE 17.57 Comparison of conventional wiring and busway system in a manufacturing facility

The other main application for busway systems is as high-current feeders with ratings from 600 A to 7000 A a.c. and in excess of 12 000 A d.c. They are often used for rising mains in high-rise commercial buildings, where take-off boxes provide supply to metering and distribution boards for tenants at each level.

The system will allow individual isolation switches to be installed at each floor. This provides local isolation control for any floor distributors requiring isolation, without disturbing other floors or needing to access the main switchboard (usually in the basement, requiring additional levels of access and isolation).

Some applications are shown in **Figure 17.58**.



FIGURE 17.58 Example of busway systems used as an alternative to conventional switchboard and wiring systems

Busways must comply with the International Electrotechnical Commission Standard *IEC 61439.6*. The Standard sets performance requirements such as: voltage and current ratings; maximum temperature rise; short-circuit and fault-current withstand capacity; insulation resistance; conductor resistance; reactance and impedance; flux density and international protection (IP) ratings. The main features specified by the Standard to consider when selecting a busway are:

- ▶ IP rating signifying indoor or outdoor types (see **Chapter 17** and *Wiring Rules, Appendix G*)
- ▶ rated voltage
- ▶ continuous current ratings
- ▶ short-circuit, fault-current withstand capacity.

17.7.2 Low-voltage track systems

Low-voltage track systems are similar to busway systems in that they consist of manufactured channels or modules with take-off plugs that can be installed at convenient positions along the run. They are most commonly used in sale display lighting and atmosphere lighting in restaurants, hotels, clubs and the like.

A typical track system comprises an extruded anodised aluminium section enclosing a plastic extrusion carrying the active and neutral conductors. A copper earth conductor, which is an integral part of the aluminium extrusion, is provided. Luminaires fitted with pre-wired take-off plug adaptors provide the connection facility. The track is commonly available in set lengths, typically 1, 2 and 3 m, with a variety of fittings such as joiners for extending a run of track, and elbows and tees for changing direction. Some features of the low-voltage track system are:

- ▶ As the name implies, they are confined to single phase but may incorporate two circuits.
- ▶ The system must be installed so that contamination, say by corrosive fumes or dust, is minimised.
- ▶ The system must be installed so that it is exposed to view throughout its entire length and supported at intervals of 1.5 m or less or to manufacturers' specifications, as required by *Clause 3.9.7.5*.
- ▶ Only accessories that are expressly designed for use in the specific system should be used.
- ▶ Track systems often vary in design and, as with all electrical equipment, must be installed in accordance with the manufacturer's instructions.

Some commercial applications can utilise three-phase low-voltage track systems, allowing more complex lighting systems to be used (e.g. stage lighting).

17.7.3 Soft wiring systems

Today it is common for enterprises to carry out their business by leasing a commercial space in a high-rise, low-rise or purpose-built building. Under this arrangement, the enterprise leasing the space must then have it fitted out with offices, work areas and other facilities needed; a re-leased space will invariably require alterations to meet the needs of the new tenant.

Soft wiring systems were developed to provide a flexible, reusable method of connecting socket-outlets and lighting in these facilities to the existing installation wiring, and integrating it with communications cabling systems.

The principles and examples are shown in **Figure 17.59**. Soft wiring is used in combination with desk and floor trunking systems and service poles, and is regarded as installation wiring and therefore may only be installed by a licensed electrician.

Undercarpet systems

An undercarpet wiring system is one that is installed directly on top of structural floors, beneath modular carpet tiles. It is usually an integrated system of power, telephone and data communications wiring, and is specifically designed for installation in industrial and commercial offices. All cables are manufactured in flat configurations and the power wiring uses flat copper-strip conductors rather than the circular conductors used in other wiring systems and in telephone and data undercarpet wiring. The communications wiring system is also available as an optical fibre building-wire system designed for undercarpet use. Only the power wiring system is described here.

Soft wiring is essentially a prefabricated system of wiring made up of purpose-built plug and socket couplers that are factory assembled onto starter and interconnecting leads. The basis of the system are compact three-pole (active, neutral and earth) plug interconnecting cables and coupling devices. Plug-in plug-out splitters act much like junction boxes; the plugs and interconnecting accessories are defined by *Clause 1.4.58* as 'installation couplers'.

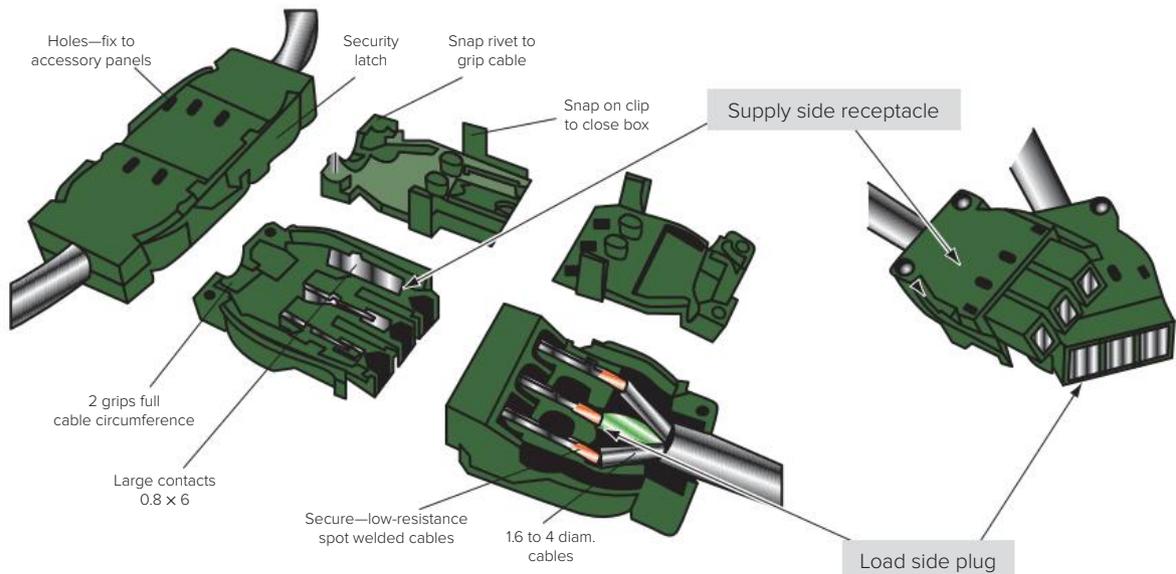


FIGURE 17.59 Principles and examples of soft wiring

In Australia, undercarpet wiring is subject to the requirements of *Clause 3.9.7.6* of the *Wiring Rules* and may be used only for final subcircuits in non-domestic installations. Each circuit must be protected by an overcurrent circuit-breaker.

This chapter has covered the basics of the most common wiring systems in current use. However, to keep up to date with new compliant wiring products as they come onto the market, the electrician should be open to training opportunities presented by product and Standards seminars.



CHECK YOUR UNDERSTANDING

24. What are some advantages of busway systems over conventional wiring systems?

SUMMARY

- ▶ Electricians installing wiring systems need to be familiar with the different construction methods, various building materials, different wiring routes and protection methods that are available.
- ▶ There are many different types of wiring systems and the type of protection required will dictate the installation practices used.
- ▶ Cabling installation will vary considerably and will involve a combination of cable tray and ladders, surface fixing to wood, concrete or metal, above or in floor, above or in ceiling and in or through walls systems.

- ▶ Enclosing cabling systems add an additional level of protection for cables. Commonly used enclosures are PVC conduit or trunking, HFT conduit, corrugated and flexible conduit and metallic conduit or trunking.
- ▶ The joining and terminating of protection systems is determined by the type of system used.
- ▶ Underground cabling systems require different levels of protection, depending on the type of cables used.
- ▶ Aerial and catenary systems require complex calculations to ensure appropriate heights above ground level are maintained.
- ▶ Composite wiring systems include busway systems, low-voltage track systems and soft wiring systems.

REVIEW QUESTIONS

1. What is the purpose of a wiring system?
2. List the typical sequence for the construction of a multilevel building, including the electrical installation.
3. Name three types of wiring systems that might be used in a manufacturing facility.
4. Describe the typical wiring/cable routes in a domestic dwelling.
5. How does the type and purpose of a building structure affect the wiring system selected?
6. Describe two situations where cables enclosed in conduit would be used.
7. Name two applications of cable ladder and cable tray.
8. What constitutes double insulation in a wiring system?
9. List the main steps in managing the installation of wiring systems.
10. Why is it important to plan the route of wiring system runs in an installation?
11. Describe a suitable method for fixing flat TPS cable where it is likely to be disturbed.
12. How are wiring systems to be protected against damage when they are installed near building surfaces?
13. In an electrical installation, list the precautions that must be taken to limit the spread of fire.
14. What advantage is there in having each live conductor of a submain made of two or more cables connected in parallel?
15. Name three situations where conduit is the likely choice for enclosing cables.
16. What compliance information is marked on a length of PVC conduit?
17. List the four main points to consider when selecting a conduit.
18. Describe two important requirements for the installation of metallic wiring enclosures.
19. Why do trunk systems have separate compartments for power, communications and other services?
20. Summarise the main features of soft wiring systems and where soft wiring is used.

CHAPTER 18

Damp situations and other specific electrical installations

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ explain how the ingress protection ratings for equipment are assigned
- ▶ identify a damp situation
- ▶ explain how damp situations are classified into zones
- ▶ explain the risks associated with damp situations and the means of preventing electric shock
- ▶ identify a hazardous area
- ▶ list the factors that must be considered when planning an installation in a hazardous area
- ▶ explain how hazardous areas are classified into zones
- ▶ describe the principal method of explosion protection
- ▶ list the methods of explosion protection and the types incorporating the methods
- ▶ understand and apply the requirements of medical installations
- ▶ determine requirements of Australian Standards as they apply to particular installations.

An electrical system must be installed so that its safe operation is ensured. As emphasised in previous chapters, this is achieved by the use of materials and techniques suitable for the conditions in which the electrical system is to operate. The intended use of an area may create the need for the electrical installation to meet special requirements, such as areas where water or moisture is normally present or likely to be present, described in *Section 6* of the *Wiring Rules* as *damp situations*. *Section 7* refers to a number of electrical installations as *Special electrical installations*, a category that covers safety services, electricity-generation systems, isolated supply, extra-low voltage installations and hazardous areas, often calling up other Standards. Some of these have been discussed in previous chapters. *Clause 7.8* calls up a number of Australian and Australian/New Zealand compliance Standards for particular electrical installations such as construction sites, medical treatment areas, recreation areas and equipment, and lifts and hoists.

Electrical work in many of these installations is not an everyday occurrence and opportunities for you to gain installation experience in all of these areas may be limited. The knowledge and experience you have gained thus far in using the *Wiring Rules* and their application in general installations will hold you in good stead in using and applying other Standards for special installations. Nonetheless, a basic knowledge of the risks these installations present and the methods and equipment used to meet the installation requirements is essential.

18.1 Electrical enclosures—ingress protection

The enclosures for electrical equipment must be appropriate for the environmental conditions in which the equipment is to operate. For example, a switch located outside and exposed to the weather must be enclosed to prevent the entry of rainwater, which could cause corrosion of the switch mechanism or a short circuit. The degree of protection assigned to electrical enclosures to prevent contact with live parts and to limit or prevent the entry (ingress) of objects, dust or water is known as the ingress protection or IP rating. The performance requirements for enclosure protection are specified in *AS 60529 (IEC 60529)* and appear as *Appendix G* in *AS/NZS 3000*.

The way IP ratings are assigned is explained in **Figure 18.1**.



CHECK YOUR UNDERSTANDING

1. What would be the IP rating of a completely submerged piece of equipment?
2. Where in the *AS/NZS 3000* can you find the table of IP rating?

18.2 Damp situations

The definition of a damp situation (*Clause 1.4.44*) requires that moisture be present either permanently or intermittently to such an extent that the safety or effectiveness of the installation is impaired. A person partially or totally immersed in water, as in a bath or pool, is particularly susceptible to the effects of electric shock. It has been shown that very low potentials which would usually be considered safe (e.g. 10–15 V), if present as an electric field in the water, are capable of causing muscular spasms that can lead to drowning or ventricular fibrillation, in which the blood flow to vital organs is disrupted, causing brain damage and death. The level of susceptibility to electric shock is not much reduced in areas immediately adjacent to or above any vessel containing water, as there is still a high risk of contact with the water, if only from splashing. The sole purpose of specific rules for installations in damp areas is to protect against electric shock.

Figure 18.2 shows the basic principles for classifying zones of risk in damp situations, while **Figure 18.3** gives the mandatory requirements for damp situations.

18.2.1 Equipotential bonding

The *Wiring Rules, Clause 5.6.2.5* requires the equipotential bonding of reinforcing steel in concrete bathroom floors. This is to avoid any potential differences that can occur between conductive material in contact with the electrical installation earthing system and the concrete floor or wall. *Clause 6.3.3.2 Supplementary equipotential bonding* is a reminder that equipotential bonding connects extraneous conductive parts to the earthing system of the installation to eliminate any potential difference that can occur between the extraneous and exposed conductive parts.

Figure 18.4 gives an example of the risk of a voltage gradient in a swimming pool.

18.2.2 Installation and equipment

The factors that make electrical equipment suitable for installing in damp situations include the degree of protection of the enclosures (IP rating); equipment type, design and construction; type and voltage of supply; type of electrical protection; and location of the equipment. A list of the *Wiring Rules* clauses and where they apply is given for each of the defined damp situations in **Tables 18.1** to **18.6**.

International (ingress) protection (IP) rating

Rating of ingress protection complying with AS/NZS 60529 assigned by manufacturers to their equipment enclosure.

First number	Degree of protection access to live parts and against solid foreign objects	Second number	Degree of protection against water
X	No specific protection.	X	No specific protection.
0	No protection of persons against contact with live or moving parts inside the enclosure. No protection of equipment against ingress of solid foreign bodies.	0	No protection.
1	Protection against accidental contact with live or moving parts inside the enclosure by a large surface of the human body, such as a hand. Protection against ingress of large solid foreign bodies.	1	Protection against drops of condensed water. Drops of condensed water falling on the enclosure have no harmful effect.
2	Protection against contact with live or moving parts inside the enclosure by fingers. Protection against ingress of medium-sized solid foreign bodies.	2	Protection against drops of falling liquid which, when the enclosure is tilted at any angle up to 15 degrees from the vertical, shall have no harmful effect. (Sometimes referred to as drip-proof.)
3	Protection against contact with live or moving parts inside the enclosure by tools, wires or objects thicker than 2.5 mm. Protection against ingress of small, solid foreign bodies.	3	Protection against rain. Driving rain at an angle up to 60 degrees from the vertical shall have no harmful effect.
4	Protection against contact with live or moving parts inside the enclosure by tools, wires or objects thicker than 1 mm. Protection against ingress of very small solid foreign bodies.	4	Protection against splashing. Liquid splashed from any direction shall have no harmful effect.
5	Complete protection against contact with live or moving parts inside the enclosure. Protection against entry of harmful deposits of dust sufficient to interfere with satisfactory operation of the equipment. (Dust protected).	5	Protection against water jets at low pressure. Water projected by a nozzle from any direction under stated conditions shall have no harmful effect.
6	Complete protection against contact with live or moving parts inside the enclosure and against the ingress of dust. (Dust-tight).	6	Protection against water jets at high pressure. Water from high-pressure jets of water, such as experienced in exposure to heavy seas, shall not enter the enclosure under prescribed conditions.
		7	Protection against temporary immersion in water. It shall not be possible for water to enter the enclosure under stated conditions of depth and time.
		8	Protection against indefinite immersion in water. Under specified conditions, it shall not be possible for water to enter the enclosure.

Example

An IP 56-rated socket-outlet

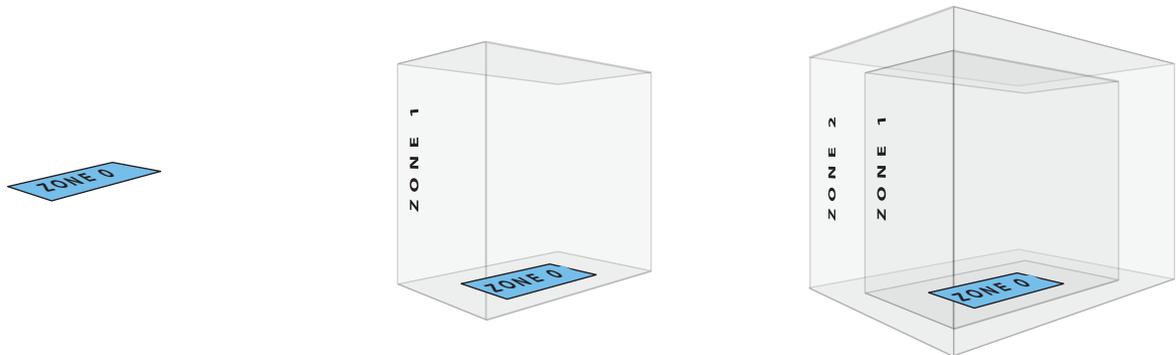


IP 56

FIGURE 18.1 How IP ratings are assigned

Damp situations—zones of risk of electric shock

Zones of risk are used to apply restriction on the types of electrical equipment and how they are installed in each specific damp situation. Zones for baths, showers, fixed water containers, swimming pools and the like, fountains and water features are defined by the dimensions of the water containers or source of water and the three-dimensional open spaces around them. The delineation of these spaces and how they are varied by barriers, like a shower curtain or pool fencing, can be confusing when first encountered. However, understanding the reasons for the classification of each zone from principles for reducing risk of electric shock should help in making the *Wiring Rules* requirements a little easier to understand and apply.



Zone 0:

Highest risk of electric shock; area within vessel containing water such as a bath, tub, pool, pond, fountain and the like.

Zone 1:

High risk of electric shock; areas adjacent to Zone 0 where wetting is likely or within a source of water such as a showerhead.

Zone 2:

Still at risk of electric shock; areas adjacent to Zone 1 where wetting of the body can occur.

Zone 3:

Still a risk of electric shock; areas adjacent to Zone 2 in a bath or shower room.

FIGURE 18.2 Basic principles for classifying zones of risk in damp situations

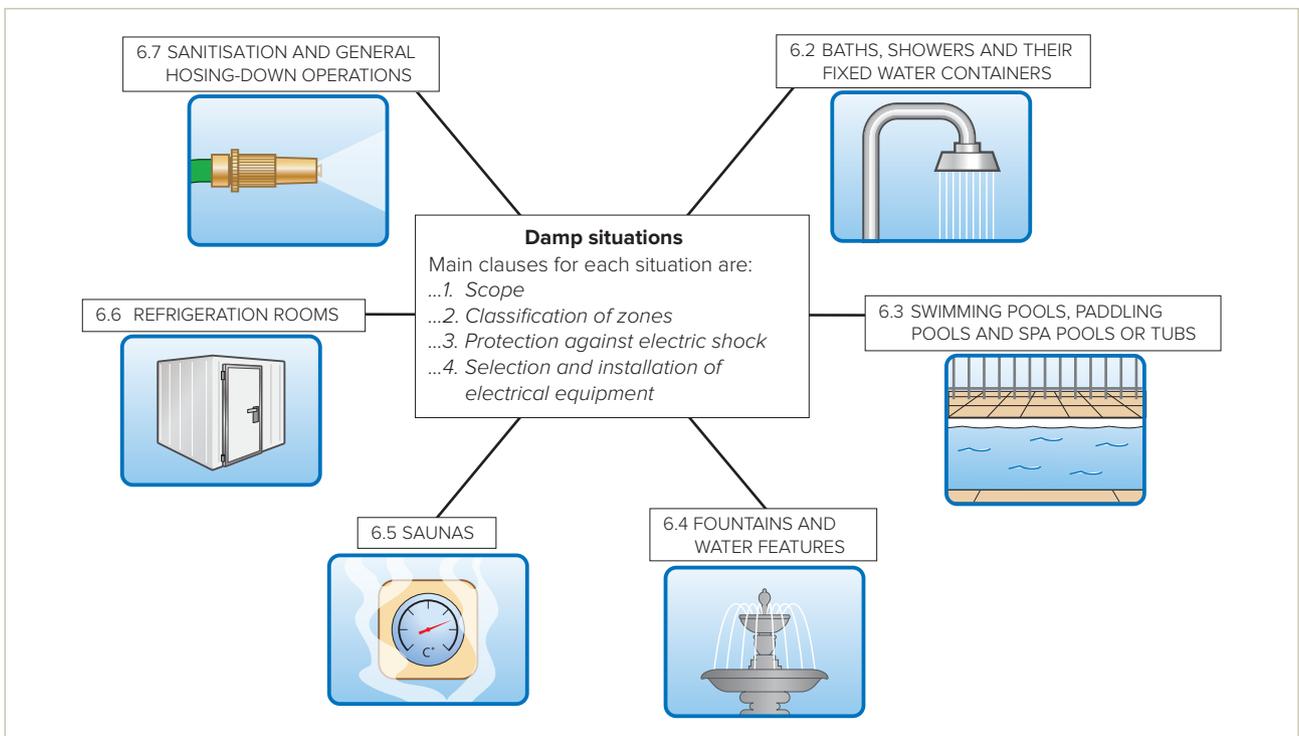
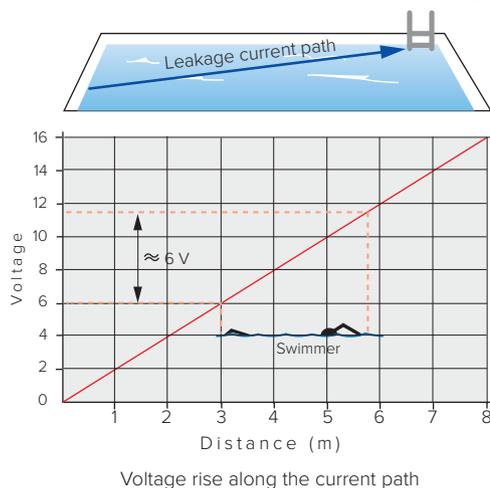


FIGURE 18.3 Requirements for damp situations

What is a voltage gradient and how does it present a risk in a pool?

Clause 6.3.3.3 suggests three alternative means of protection from 'voltage gradients' in a pool. A voltage gradient is the voltage between various points along a current path, much like a voltage divider. In a swimming pool the water can act as a conductive path for a leakage current, producing a voltage gradient in the water. Recall from **Chapter 2** that the severity of an electric shock is dependent on the impedance of the skin at the contact site and the area of contact.

Take the example of a leakage current across, say, an 8-metre pool with a voltage gradient of 16 V or 2 V per metre. A 2-metre-tall person swimming along the current path is subject to almost 6 V potential between hands and feet. This may not seem high but the skin of a person immersed in a chlorinated or salted pool becomes saturated, dramatically reducing its impedance and, being in the water, increases the contact area. At best this can lead to muscle cramping but at worst this could in turn result in drowning.



The susceptibility to the effects of electric shock under these conditions is further increased for those with an impaired physical condition.

FIGURE 18.4 Example of the risk of a voltage gradient in a pool

TABLE 18.1 Summary of *Wiring Rules* requirements for baths, showers and other fixed water containers

Equipment and installation	Zone 0	Zone 1	Zone 2	Zone 3	Wiring Rules clauses
IP rating	IPX7	IPX4; IPX5 in communal areas		IPX5 in communal areas	6.2.4.1
Socket-outlets	Not permitted		Shaver unit or RCD protected and in a cupboard	RCD protected or separated circuit or SELV or PELV	6.2.4.2
Switches and other accessories	Not permitted	Restricted location and required degree of protection		Restricted location	6.2.4.3
Luminaires	IPX7, specific for purpose, at specified voltage from SELV or PELV outside zone	Required degree of protection	Required degree of protection; some exceptions	Required degree of protection	6.2.4.4
Other electrical equipment	IPX7, specific for purpose, at specified voltage from SELV or PELV outside zone	Required degree of protection. Floor heating in accordance with <i>Clause 4.10</i> permitted			6.2.4.5
Switchboards	Not permitted				6.2.4.6

TABLE 18.2 Summary of *Wiring Rules* requirements for swimming pools, paddling pools and spa pools or tubs

Equipment and installation	Zone 0	Zone 1	Zone 2	Wiring Rules clauses
IP rating	IPX8	IPX5	IPX4	6.3.4.1
Wiring system	Prevent entry of moisture or water siphoning enclosures/cables			6.3.4.2
Socket-outlets	Not permitted	Restricted locations		6.3.4.3
		Required degree of protection and RCD protected or separated circuit or SELV or PELV		
Switches and other accessories	Not permitted	Required degree of protection		6.3.4.4
Luminaires, appliances and other electrical equipment	IPX8, specific for purpose, at specified voltage from SELV or PELV outside zone. Not earthed	IPX5 Supplied as an SELV or PELV system or Class II or RCD protected Class I	IPX4 Separated supply or supplied as an SELV or PELV system or Class II or RCD protected Class I	6.3.4.5
Switchboards	Not permitted			6.3.4.6

TABLE 18.3 Summary of *Wiring Rules* requirements for fountains and water features

Equipment and installation	Zone 0	Zone 1	Wiring Rules clauses
IP rating	IPX8	IPX5	6.4.4.1
Wiring system	Sheathed copper cable or flexible cords suitable for immersion in water Installed in wiring enclosure if subject to damage Prevent entry of moisture or water siphoning enclosures/cables		6.4.4.2
Socket-outlets	Not permitted		6.4.4.3
Switches and other accessories	Not permitted	IPX5	6.4.4.4
Luminaires, appliances and other electrical equipment	IPX8, specific for purpose, at specified voltage from SELV or PELV outside zone Not earthed	IPX5, supplied as an SELV or PELV system or Class II or RCD protected Class I	6.4.4.5
Switchboards	Not permitted		6.4.4.6

NOTE: The processing area of many industries must be cleaned at regular periods as a requirement of health and safety regulations. The cleaning might include hosing down, as is done in the slaughter and processing areas of abattoirs, in dairies, in some areas of papermaking and in coal plants and the like.

TABLE 18.4 Summary of *Wiring Rules* requirements for saunas

Equipment and installation	Zone 1	Zone 2	Zone 3	Wiring Rules clauses
IP rating	IPX4B or IP24			6.5.4.1
Requirements for classified zones	Equipment belonging to sauna heater only	No requirement	Suitable for minimum temperatures: Equipment 125 °C Wiring 170 °C	6.5.4.2
Wiring system	Heat resistant, metallic sheathed or metal conduit not accessible		Heat resistant, metallic sheathed or metal conduit not accessible	6.5.4.3
Socket-outlets, switches and other accessories	Not permitted except switches and accessories that are part of the heater			6.5.4.4
Other equipment	Sauna heaters installed to manufacturers' instructions			6.5.4.5
Switchboards	Not permitted			6.5.4.6

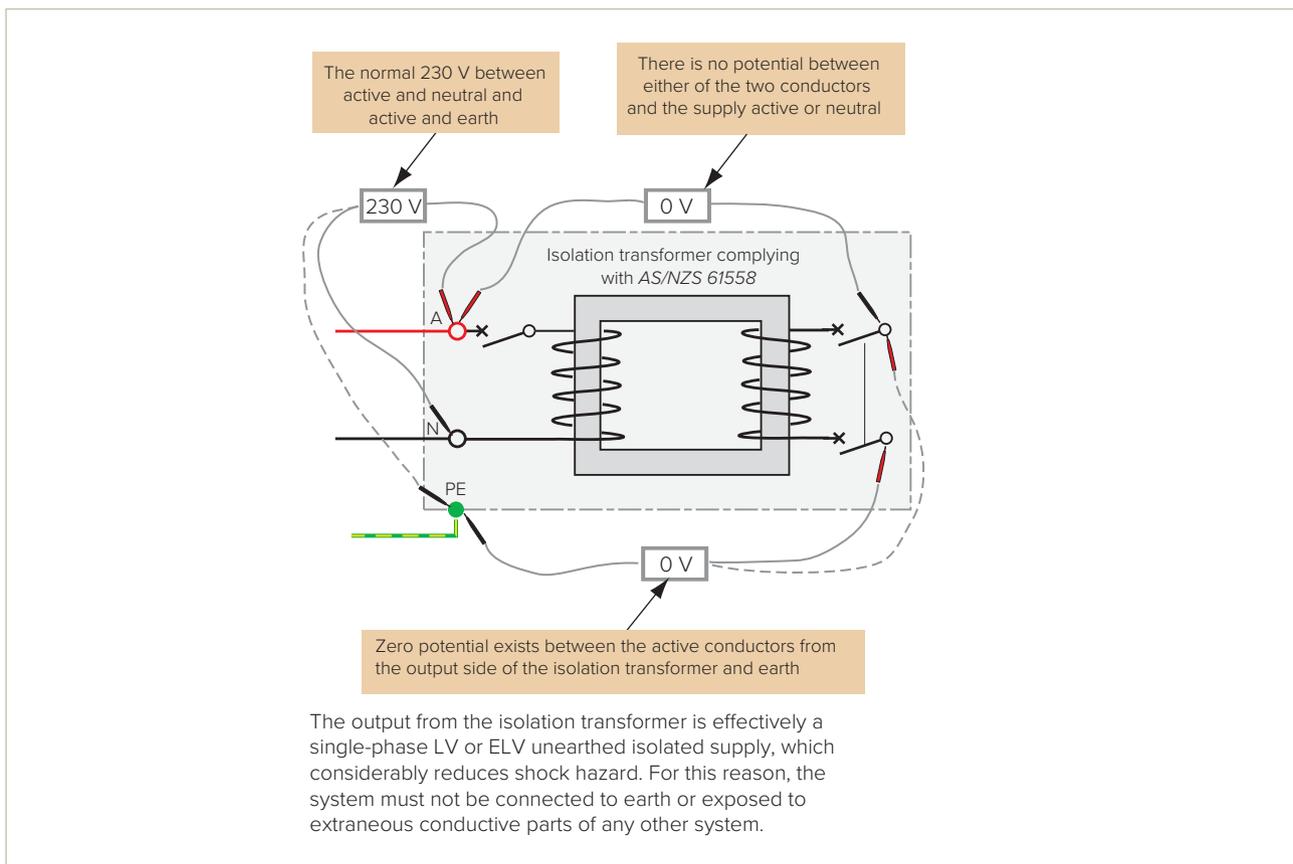
TABLE 18.5 Summary of *Wiring Rules* requirements for refrigerated rooms

Equipment and installation	Classified zone	Wiring Rules clauses
IP rating	IPX4B or IP24	6.6.4.1
Wiring system	Not affected by temperature Does not accumulate or channel moisture into electrical equipment	
Types	Unenclosed sheathed cables, unsheathed insulated or sheathed cables in wiring enclosures with drainage facilities or served MIMS cable	6.6.4.2
Sealing	See Figure 18.1	
Socket-outlets, switches and other accessories	Required degree of protection and sealed to prevent retention of moisture	6.6.4.3
Luminaires	Designed and constructed to prevent entry of moisture to live parts; prevent retention of moisture in or on the fitting	
Lamp holders	All insulated or type where external metal portion cannot become live. Flexible pendant not suspended below 2.5 m from floor	6.6.4.4
Fixed appliances and motors	Designed and constructed for location and conditions including suitable degree of protection	6.6.4.5
Door seal heating	Additional protection by 30 mA RCD	6.6.4.6
Switchboards	Not permitted	6.6.4.7

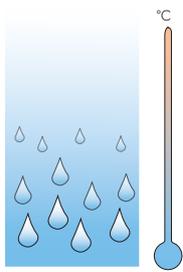
TABLE 18.6 Summary of *Wiring Rules* requirements for sanitisation and general hosing-down operations

Equipment and installation	Classified zone	Wiring Rules clauses
General	Equipment suitable for: <ul style="list-style-type: none"> the temperature and pressure of the fluids used in the process exposure to the relevant chemicals used in that process in accordance with <i>Clause 3.3</i> 	6.7.4.1
IP rating	Minimum IPX5 where subject to low-pressure hosing; IPX6 where subject to high-pressure hosing	6.7.4.2
Electrical equipment	Not affected by hosing, materials, temperature or pressure Protected against accumulated moisture Does not accumulate or channel moisture into electrical equipment	6.7.4.3
Switchboards	With IPX6 degree of protection are permitted	6.7.4.4

Regarding supply to electrical equipment for fountains and water features, *Clause 6.4.3.2.1* provides alternative protective measures against electric shock. Included is protection by 30 mA RCDs (see also *Clause 2.6.3*). Another compliant arrangement is to supply low-voltage or extra-low voltage equipment through an isolation transformer, as shown in **Figure 18.5**.

**FIGURE 18.5** Isolation transformer

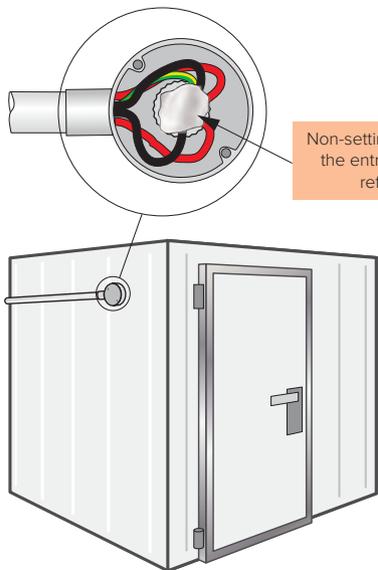
In both saunas and refrigerated rooms, the sources of moisture are from condensation of water vapour in the air at locations where there is a difference in air temperatures, such as where a wiring system enters a damp zone. This requires special consideration for enclosures for electrical equipment and wiring, as shown in **Figure 18.6**.



The source of damp in refrigerated rooms is condensation of water vapour from the air. This is due to the reduced ability of air to hold a specific amount of water vapour as the temperature of the air falls. Condensation is commonly seen on a car where water vapour in the overnight air condenses on contact with the colder metal and glass of the car.

The recommended approach to electrical installation in any damp situation is to keep equipment out of damp zones; however, in the case of refrigerated rooms this is not possible. Shown here are some common methods used to satisfy the installation requirements of *Clause 6.6*.

Circuit entry into a refrigerated room

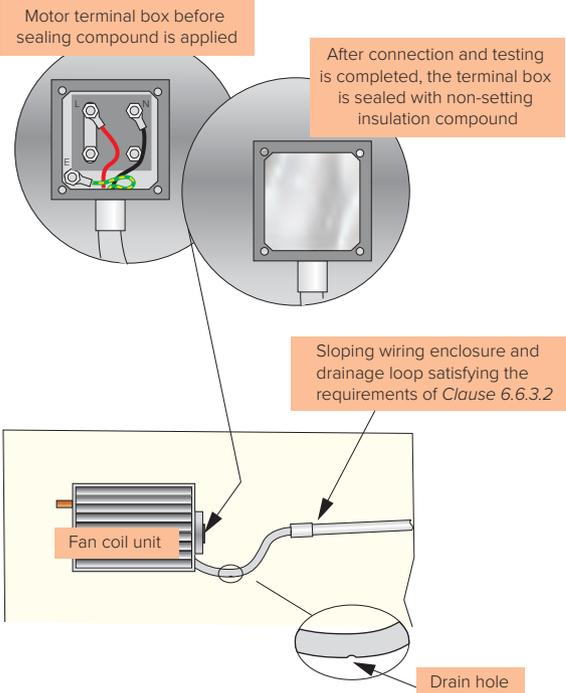


Non-setting compound sealing the entry of circuits into the refrigerated room

Clause 6.6.3.2.3 requires wiring in the enclosure to be sealed at points where it passes from the non-refrigerated to the refrigerated space.

Sealing is also required at the point of entry of cables into motors, luminaires, switches or other electrical equipment.

Sealing motor terminals



Motor terminal box before sealing compound is applied

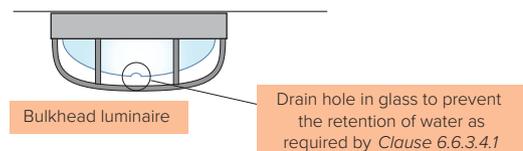
After connection and testing is completed, the terminal box is sealed with non-setting insulation compound

Sloping wiring enclosure and drainage loop satisfying the requirements of *Clause 6.6.3.2*

Fan coil unit

Drain hole

Drain in a luminaire



Bulkhead luminaire

Drain hole in glass to prevent the retention of water as required by *Clause 6.6.3.4.1*

FIGURE 18.6 Example of installation techniques for refrigerated rooms



CHECK YOUR UNDERSTANDING

3. What would be the required IP rating for electrical equipment within a building?
4. What are the zones with regard to the installation of showers and baths?
5. What is the term given to the connection of all non-electrical conductive parts to the earthing system?

18.3 Installations for hazardous areas

Many of the limitations and requirements placed on electrical equipment and installations are to minimise heat loss and to prevent arcing of switch gear, fault currents and the like from starting a fire. In locations where highly combustible and potentially explosive materials are handled, the electrical installation could easily become a source of ignition, causing an explosion and fire, if additional precautions are not taken.

The great variety of flammable materials used by modern society, and the techniques used to prevent these materials from igniting, make electrical installations and the maintenance of these materials one of the most difficult areas in electrical work. Highest quality work and precise compliance with the appropriate Standards are required of tradespersons, technicians and engineers working in this area.

Locations where highly flammable and combustible materials are handled may at first seem obvious, such as petroleum refineries, chemical plants and coal mines. However, many other activities can produce combustible materials, such as the dust from grain, which becomes highly explosive when suspended in air. Locations where these materials exist are known as hazardous areas and special techniques are applied to the design of electrical equipment and to electrical installations in these areas. These techniques are specified in a number of Australian/New Zealand Standards which are called up by *Clause 7.7* of the *Wiring Rules*.

Electrical work for hazardous areas requires clear understanding of the hazards, how the electrical system can become a source of ignition and the methods or techniques that are used to prevent this from occurring. The competencies to do this work are specified in *AS/NZ S4761.1 Competencies for working with electrical equipment in hazardous areas Part 1: Competency Standards*.



DID YOU KNOW?

What is a hazardous area?

A hazardous area is an area where an explosive atmosphere is present or may be expected to be present in the form of gas, vapour, dust, fibres or filings. In sufficient quantities mixed with air, these are explosive and can be ignited by heat from electrical equipment. See the *Wiring Rules, Clauses 1.4.15* and *1.4.61*.

18.3.1 Hazardous area installations and explosive-protection techniques

Before commencing any electrical installation, planning must be carried out to determine the circuit arrangements and loads (maximum demand), the most suitable wiring system, cable type and size, the type and rating of protective devices, switching requirements, and the motor and control equipment to be installed. When planning an installation in a hazardous area, the following additional factors must be considered:

- ▶ definition and classification of all hazardous areas
- ▶ strategies for reducing the need for electrical equipment to be installed in the hazardous areas
- ▶ methods and types of explosive protection that can be used
- ▶ selection of equipment to meet the requirements for the type of explosive protection to be used
- ▶ selection of wiring systems to meet the requirements for the type of explosive protection to be used
- ▶ general installation and maintenance techniques to be adopted.

Hazardous areas are classified into zones based on the frequency of occurrence and duration of an explosive gas atmosphere being present. They are based on the requirements of *AS/NZS 60079.10.1* for explosive gas atmospheres

and *AS/NZS 60079.10.2* for combustible dust. The responsibility for this rests with the parties in control of the installation, who should appoint an expert in the field to undertake the classification process.

The zones for hazardous areas are defined in **Figure 18.7**.

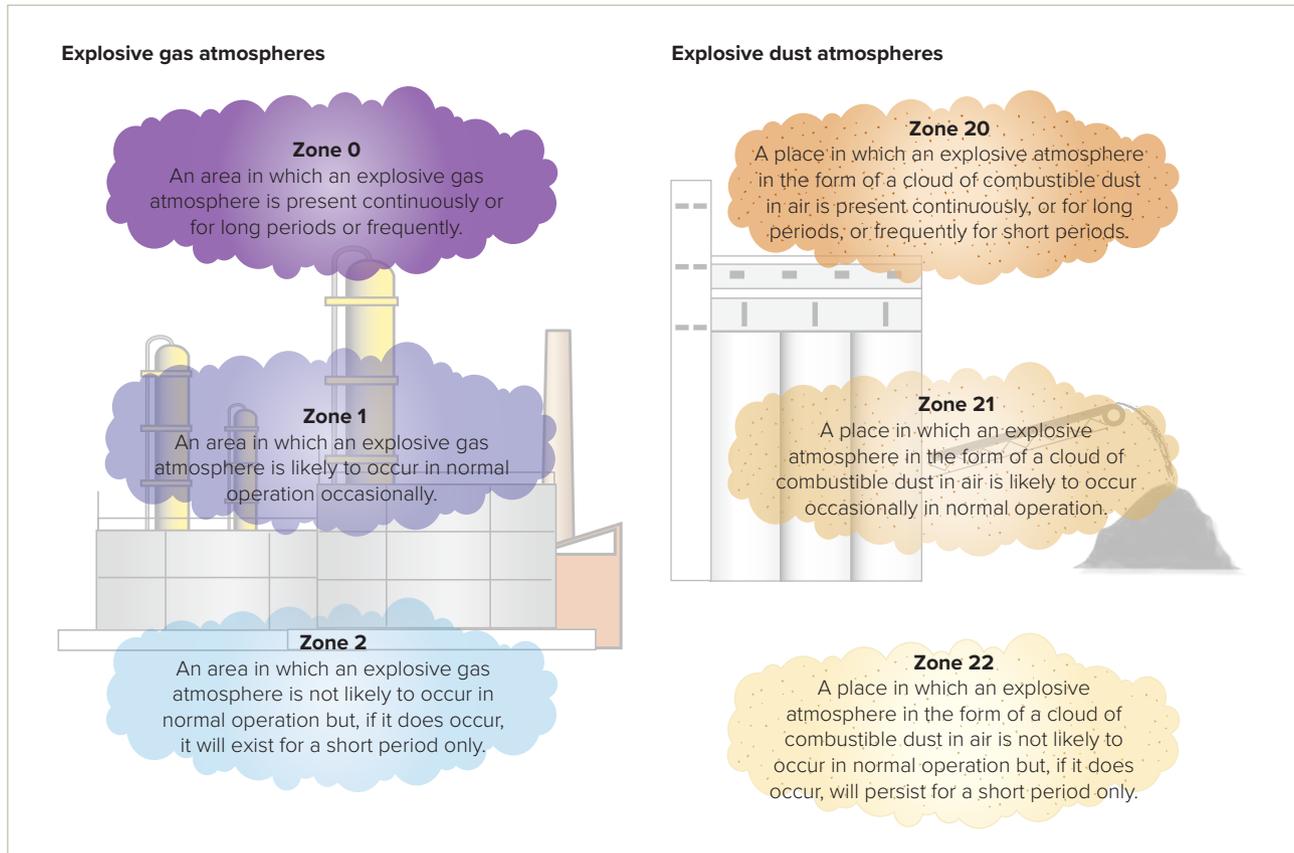


FIGURE 18.7 The zones for hazardous areas

Explosion-protected equipment is initially expensive and expensive to maintain, so designers of hazardous area installations endeavour to keep electrical equipment out of the hazardous area. Where this is not practical, an approved explosive-protection technique must be employed.

Methods of explosive protection and relevant techniques

The several methods and equipment types of explosive protection used, either individually or in combination, in hazardous areas are summarised in **Figure 18.8**.

Other important equipment parameters applicable to the relevant types of equipment are equipment grouping and temperature limitations. Electrical equipment for explosive atmospheres is divided into the following groups:

- ▶ Group I: Equipment for use in mines susceptible to firedamp
- ▶ Group II: Equipment for use in places with an explosive gas atmosphere and subdivided by the type of explosive gas:
 - ▶ IIA (propane)
 - ▶ IIB (ethylene)
 - ▶ IIC (hydrogen).
- ▶ Group III: Equipment for use in places with an explosive dust atmosphere and subdivided by the type of explosive dust:
 - ▶ IIIA combustible flyings
 - ▶ IIIB non-conductive dust
 - ▶ IIIC conductive dust.

The methods of explosion protection define general principles for separating an ignition source from the explosive atmosphere, limiting ignition energy or limiting the explosive atmosphere. These principles are applied in the design and certification of the various types of explosive-protected equipment as shown below:

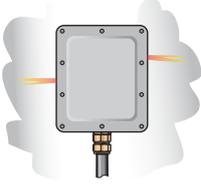
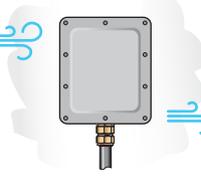
Methods of explosion protection	Equipment types
 <p>Exclusion method: The hazardous material is prevented from entering the electrical equipment so that arcing and heat cannot produce ignition suitable for gas and dust hazards.</p>	<p>Dust ignition protection type 'tD' or 't' An enclosure providing dust ingress protection and a means to limit surface temperatures.</p> <p>Pressurisation 'p' Enclosures for electrical equipment and machinery in which air or non-flammable gas is maintained at a pressure to exclude the entry of an explosive atmosphere external to the enclosure.</p> <p>Protection type 'n' Non-sparking devices/components including those that are encapsulated; hermetically sealed; enclosed-break; sealed or energy-limited.</p> <p>Encapsulation 'm' Parts that are capable of igniting an explosive atmosphere by either sparking or heating are enclosed in a compound such that the explosive atmosphere cannot be ignited.</p> <p>Oil-immersion 'o' The electrical equipment or parts are immersed in a protective liquid such that an explosive gas atmosphere which may be above the liquid or outside the enclosure cannot be ignited.</p> <p>Powder filling 'q' Parts capable of igniting an explosive gas atmosphere are fixed in position and completely surrounded by filling material to prevent the ignition of an external explosive atmosphere.</p>
 <p>Explosion containment method: If an explosion does occur within the electrical equipment, it will not ignite the hazardous material outside the electrical equipment.</p>	<p>Flameproof enclosure 'd' An explosion within the enclosure will not damage the enclosure, but at the same time will prevent the transmission of flame or heat to the explosive atmosphere external to the enclosure.</p>
 <p>Energy limitation method: The energy level in the electrical installation is kept below the minimum energy required to ignite the hazardous material; suitable for gas and dust hazards.</p>	<p>Intrinsic safety 'i' Electrical apparatus and circuits in which the energy from sparks and thermal effects is insufficient to ignite a given explosive atmosphere under normal and fault conditions.</p> <p>Protection type 'n' Non-sparking enclosed break devices.</p>
 <p>Avoidance of ignition source method: Equipment use and design are selected to prevent the occurrence of an ignition source; suitable for gas and dust hazards.</p>	<p>Increased safety 'e' A higher standard of design parameters, such as of insulation, creepage, connections, sealing against foreign materials and temperature, is applied to equipment that does not normally produce arcing or sparks.</p> <p>Protection type 'n' Non-sparking devices.</p>
 <p>Dilution method: The level of an explosive gas in the air is eliminated or reduced below the level needed for an explosion.</p>	<p>Ventilation Not an equipment type as such but a means of protection by the movement of air and its replacement with fresh air by:</p> <ul style="list-style-type: none"> • the effects of wind and temperature gradients, or • artificial means such as fans or extractors. <p>Ventilation is a consideration when classifying a hazardous material.</p>

FIGURE 18.8 Explosion-protection methods and equipment types

Temperature limitations are classed as follows:

- ▶ Group I: The surface temperature of equipment is not permitted to exceed:
 - ▶ 150 °C where coal dust can form a layer
 - ▶ 450 °C if coal dust is prevented from forming a layer.
- ▶ Group II: A temperature class designated 'T' is assigned to equipment as shown in **Figure 18.9**.
- ▶ Group III: Maximum surface temperature shall not exceed:
 - ▶ maximum surface temperature assigned to equipment
 - ▶ layer or cloud ignition temperature of the specific combustible dust for which it is intended.

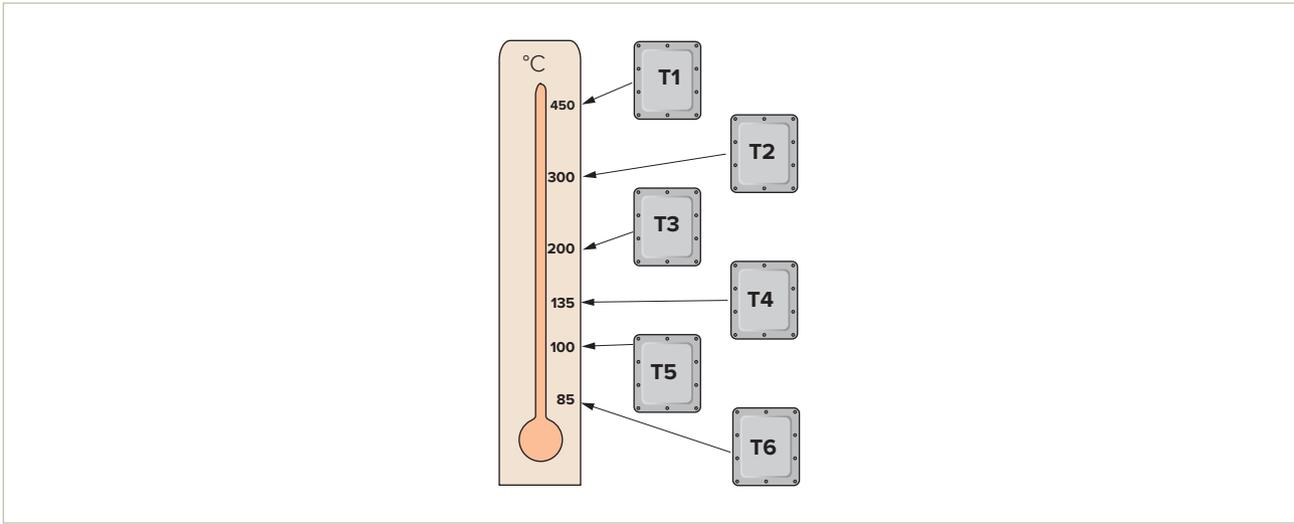


FIGURE 18.9 Temperature class

Another aspect related to explosion equipment appropriate to a particular situation is the equipment protection level (EPL). This is based on assessing the risk of whether ignition of an explosive atmosphere requires the use of equipment of a higher or lower equipment protection level and, if considered, is determined in the classification process.

The design, equipment selection and installation requirements are specified in *AS/NZS 60079.14* with inspection and maintenance requirements given in *AS/NZS 60079.17*. The installation of explosion-protected equipment and wiring systems, while straightforward in following the general skills of a competent electrician, must be carried out precisely to the specifics of each explosion-protection technique. Only equipment that carries a certification of compliance with the relevant Standard in the *AS/NZ 60079* series can be installed. Finally, records of the hazardous area zones, the installation design, equipment-protection levels, certification for each item of equipment, initial verification and testing, and maintenance plan must be kept in a verification dossier.



CHECK YOUR UNDERSTANDING

6. What are the three zones for explosive gas atmospheres?
7. What are the three zones for explosive dust atmospheres?
8. What are three methods of explosion protection?

18.4 Installations for transportable structures and sites

The term *transportable structures and sites* brings to mind recreational caravans and camping grounds; however, the scope of this Standard is much broader, including the following:

- ▶ vehicles offering accommodation, including caravans, campervans, motorhomes, campertrailers and livestock or car transporters with accommodation included
- ▶ vehicles such as food and drink vending vans and trailers, walk-through educational display caravans and trailers, mobile classrooms and television outdoor-broadcast vans
- ▶ transportable structures such as relocatable homes, transportable huts, tents for accommodation, and rigid and non-rigid annexes to vehicles
- ▶ temporary site offices, cloakrooms, meeting offices, dormitories, canteens, toilets or other facilities provided on construction and demolition sites
- ▶ display units not intended for occupation, for example, mobile electronic scoreboards, advertising signs and mobile traffic-information signs
- ▶ in New Zealand, mobile medical connectable installations complying with the requirements of this Standard.

Although these installations must conform to the *Wiring Rules*, their very nature makes them more vulnerable to the risks from electricity, hence the variations given in *AS/NZS 3001* that also apply. **Figure 18.10** gives an overview of the Standard.

18.4.1 Installation features

The following briefly discusses some of the features of these installations that differ from general installations.

An important feature addressed by the Standard is the supply to service pillars in camping grounds and caravan parks that provide socket-outlets for connection of caravans and the like. These sites cover large areas, so careful planning is needed in placing the switchboards from which the supply to the pillars is obtained. This will reduce the route lengths of circuits and avoid the need to increase conductor size to cope with voltage-drop limitations. In Australia, where the MEN earthing system is used, a service pillar can be treated as an outbuilding, in accordance with the *Wiring Rules Clauses 2.3.2* and *5.5.3.1*. This is not permitted in New Zealand, where the issue of a low-impedance earth is resolved by the requirement for a minimum size of 16 mm² copper earthing conductor. A guide to calculating maximum demand in camping and caravan sites is given in *Appendix A of AS/NZS 3001*.

The Standard specifies socket-outlets for each site and requirements covering the type, rating, overload and RCD protection. Typically, service pillars contain a number of socket-outlets to service a number of sites.

Transportable structures may occupy locations where mains supply is not available. For these situations, the Standard specifies safety requirements for the arrangement of supply from a portable generator and inverter. Roadside electronic display trailers are typical of transportable structures that source supply via an inverter.

The electrical installation in transportable structures must comply with the *Wiring Rules* and the additional requirements of *AS/NZS 3001, Section 3*. These cover the detachable supply-connection device, control and protection of circuits, wiring systems, accessories, earthing and equipotential bonding. Verification of compliance is required as specified by the *Wiring Rules* including the additional requirements for these installations. In New Zealand, periodic re-verification is required.

Regarding tents and annexes, the Standard provides a variety of acceptable arrangements for supply and protection to lamps and a single appliance via an outlet box. The Standard also specifies the type, size and maximum length of leads for connection of caravans and the like to the site supply and how the leads should be installed.

An overview of AS/NZS 3001 Electrical installations—Transportable structures and vehicles including their site supplies

SECTION 1 Scope and general	1.1 Scope	1.2 Application	1.3 Referenced documents	1.4 Definitions	1.5 Alterations, additions and repairs
	Describes the types of transportable structures covered by this Standard. There are more than you may think	Specifies that <i>Wiring Rules</i> apply except as varied and added to in this Standard	Reference made in this Standard	Additional to those in the <i>Wiring Rules</i>	The <i>Wiring Rules</i> (Clause 1.9.3) apply

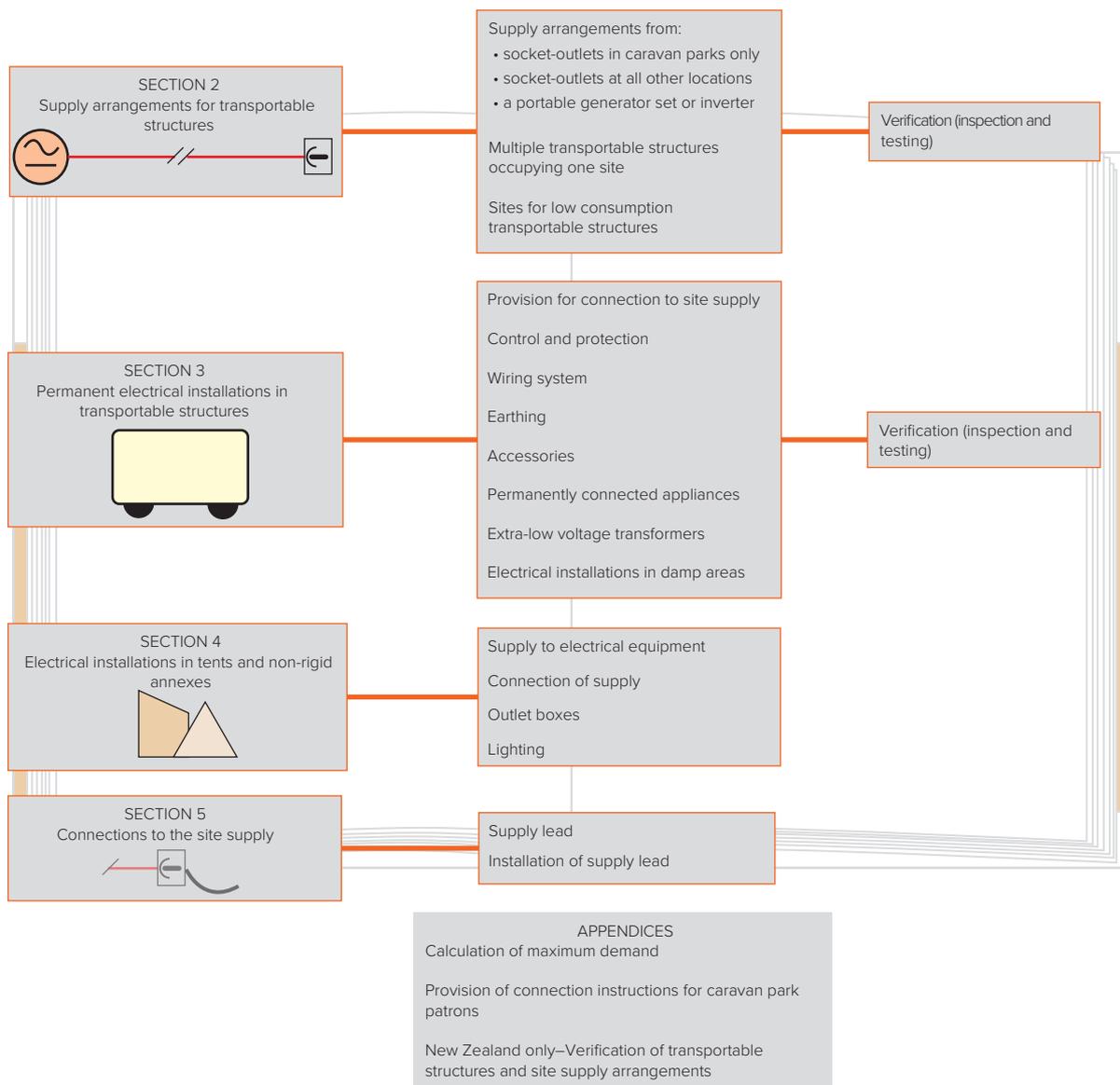
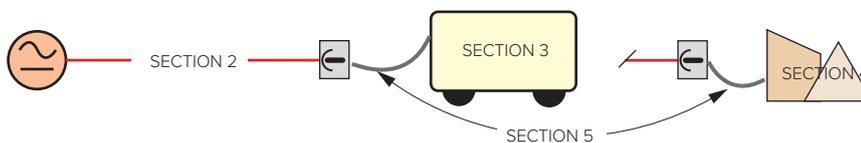


FIGURE 18.10 Overview of AS/NZS 3001 Electrical installations—Transportable structures and vehicles including their site supplies



CHECK YOUR UNDERSTANDING

9. Provide five examples of transportable structures and sites.
10. When considering installations for transportable structures and sites, how is a service pillar treated in Australia where the MEN systems is used?

18.5 Shows and carnivals

The local showground first comes to mind as typical of the sites where shows and carnivals are held. However, the Standard *AS/NZS 3002 Electrical installations—Shows and carnivals* has a broader application, covering events such as exhibitions, shows, carnivals, Scouting jamborees and army camps with a maximum duration of four weeks and an expected attendance of over 30 people.

The Standard sets out requirements for low-voltage supply to power-consuming devices used for accommodation, entertainment or display purposes within:

- ▶ concessions (a single booth, display ride and the like)
- ▶ tents
- ▶ living quarters
- ▶ other structures.

The temporary nature of these types of events can lead to a lax attitude to electrical safety, with a tangle of cables and leads that are not adequately protected from damage or the weather and overloaded circuits—increasing the risks of shock and fire. The purpose of the Standard is to provide standards of safety expected of any compliant electrical installation with regard to these sites. The electrical installation must comply firstly with *AS/NZS 3000* and, secondly, with the additional requirements of *AS/NZS 3002*, an overview of which is given in **Figure 18.11**.

Note that under *Section 4* of this Standard, which covers the temporary distribution system, the maximum length and conductor size are limited to a voltage drop of no more than 5 per cent. Although single cord sets are recommended, the maximum length applies to the total circuit length if cord extension sets are used.

An item of equipment used in shows and carnivals that you may not be familiar with is a cascable reticulation unit (CRU). These units, more formally known as assemblies for construction sites (ASC) (complying with *AS 3439.4*), are switchboard assemblies equipped with RCD-protected socket-outlets that have an inlet connection for supply and an outlet connection for connecting another ACS in a daisy-chain fashion.



CHECK YOUR UNDERSTANDING

11. According to *AS 3002*, what is the maximum duration of events such as exhibitions, shows, carnivals, Scouting jamborees and army camps?
12. What level of expected attendance relates to the application of *AS/NZS 3002*?

An overview of AS/NZS 3003 Electrical installations—Shows and carnivals

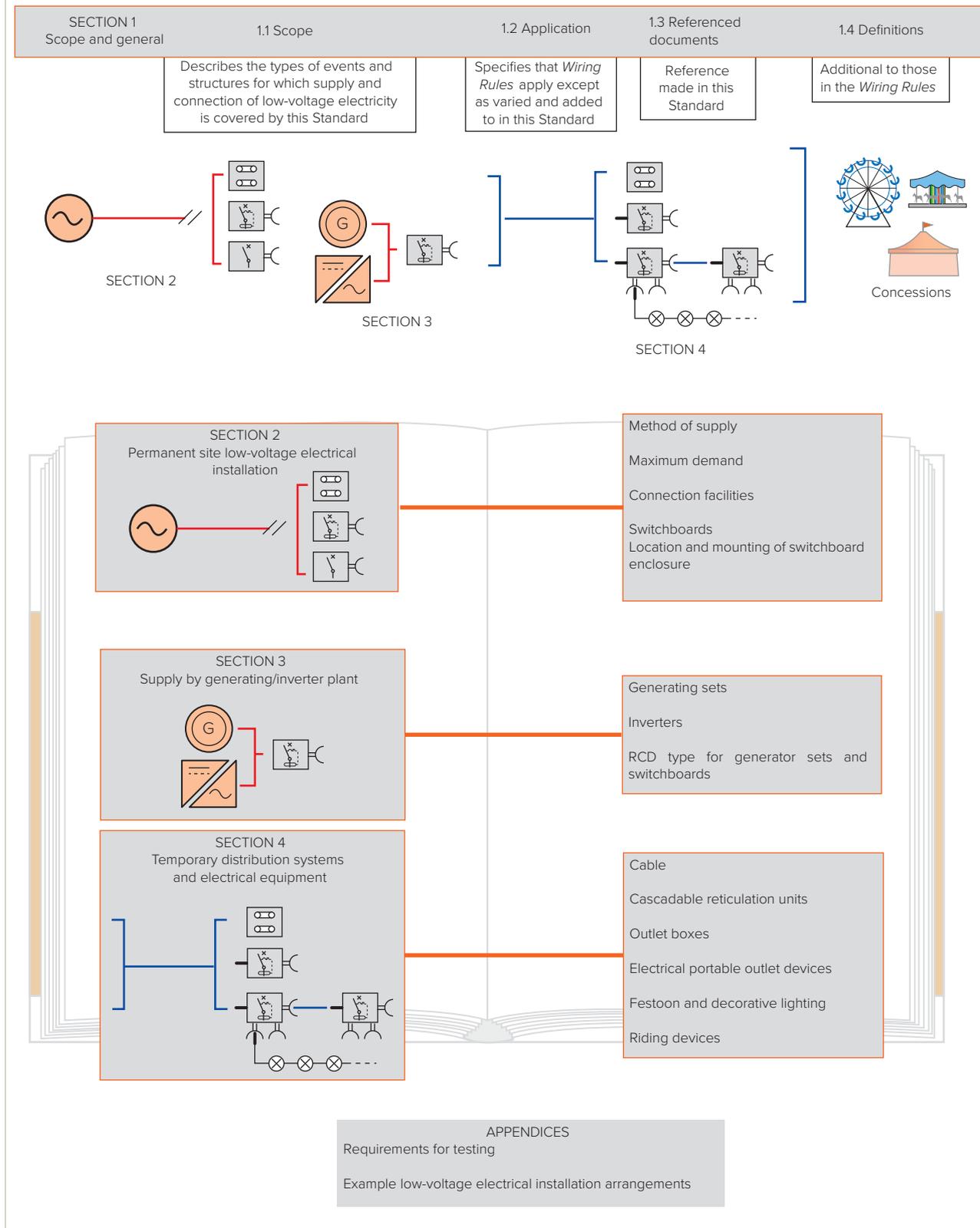


FIGURE 18.11 Overview of AS/NZS 3002 Electrical installations—Shows and carnivals

18.6 Medical treatment areas

Many medical procedures involve the use of electrically operated equipment for the purpose of diagnosis, therapy or monitoring of patients. This equipment is generally known as medical electrical equipment. In locations where medical treatments are administered using medical electrical equipment, special precautions need to be taken with electrical installations in order to provide patients with additional protection against electric shock.

Some medical procedures require a direct connection of low resistance between the patient and medical electrical equipment, with probes attached to various parts of the body. Under these conditions, with body contact resistance reduced, a fault in the equipment could result in a fatal electric shock, even at a relatively low voltage. It is also probable that an impaired physical condition would make the patient more likely than a healthy person to be severely affected by electric shock.



DID YOU KNOW?

The specific areas in which such an electrical installation requires special attention are those where:

- ▶ a patient is connected to medical electrical equipment such that the impedance of the skin is reduced but there is no direct contact with the heart; this is known as a body-type procedure
- ▶ procedures involve contact with the heart by an electrically conductive medium; this is known as a cardiac-type procedure.

The electrical installations in the areas where body-type and/or cardiac-type procedures are carried out must comply with the *Wiring Rules* (the *Electricity (Safety) Regulations* in New Zealand) and the variations given in *AS/NZS 3003 Electrical installations—Patient areas*, an overview of which is given in **Figure 18.12**. The boundaries of a patient area as defined by the Standard are shown in **Figure 18.13**.

18.6.1 Installation features

The features of an electrical installation in patient areas that attract special attention are:

- ▶ leakage protection of circuits supplying equipment and outlets in the treatment area
- ▶ indication of supply status and monitoring of fault and hazard currents
- ▶ location of protection and monitoring equipment
- ▶ number of outlets (for connection of medical electrical equipment) per circuit
- ▶ earthing and equipotential bonding arrangements in cardiac treatment areas.

A leakage protection device (LPD) is required on circuits supplying fixed medical electrical equipment or socket-outlets intended for cord-connected medical equipment. Leakage protection is provided by any of the following:

- ▶ isolation transformer and line isolation monitor (LIM)
- ▶ uninterruptible power supply (UPS) in combination with a LIM
- ▶ UPS in combination with a type I RCD
- ▶ UPS in combination with an isolation transformer, LIM and overload monitor
- ▶ type I RCD.

Isolation transformers (as shown in **Figure 18.5**) must be provided with a LIM that continually checks the hazard current. The hazard current is the one which flows from an isolated supply to earth and it must not exceed a pre-set value. When the hazard current exceeds the pre-set value, the LIM activates an alarm. Each LPD must be equipped with an indication showing supply is available; for UPS this includes when they are operating in emergency mode.

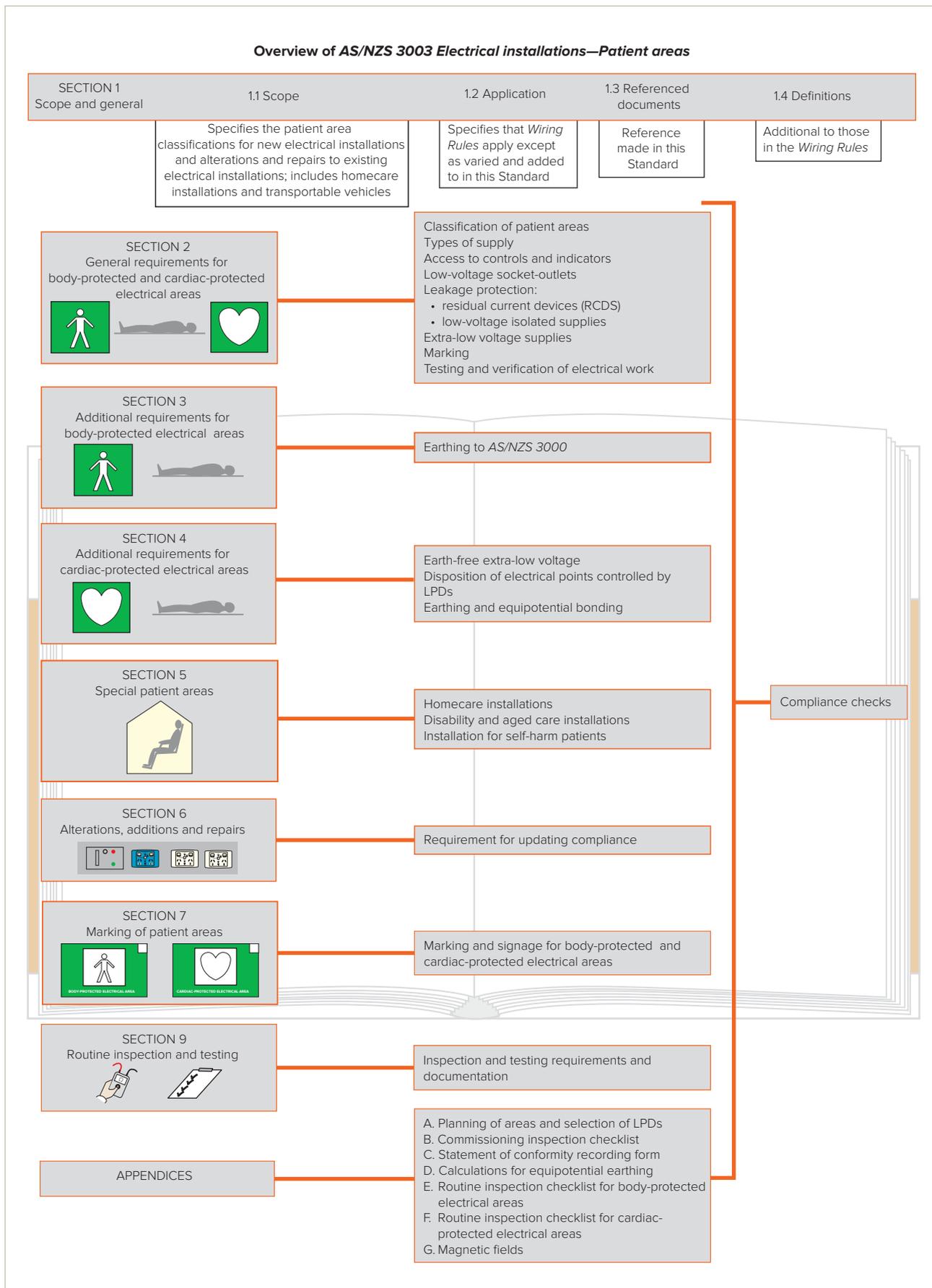


FIGURE 18.12 Overview of AS/NZS 3003 Electrical installations—Patient areas

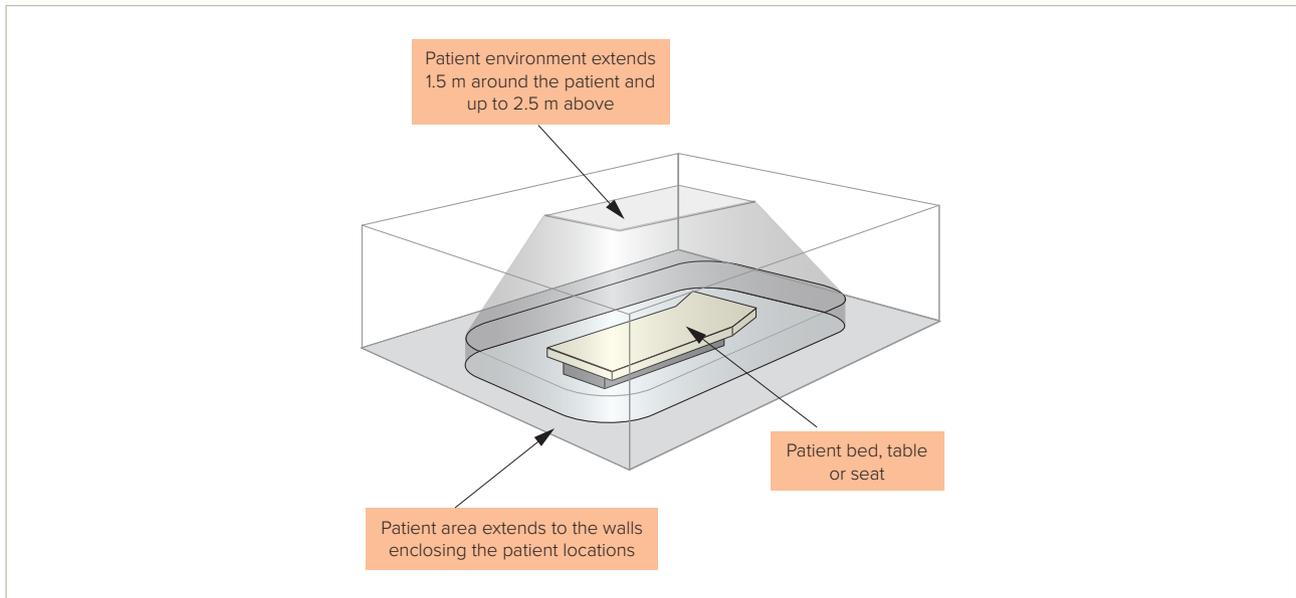


FIGURE 18.13 Boundaries of a patient area

Protection and monitoring equipment must be accessible without the use of a key, and the indication and monitoring devices must be located within the treatment area. This equipment can be installed as a separate device or is available as a complete unit incorporating socket-outlets, an RCD and/or isolation transformer indication, and line isolation and overload monitor (LIOM).

The Standard stipulates the disposition of socket-outlets for each patient location and the maximum number of socket-outlets per circuit, and also limits the number of points supplied from an isolation transformer.

Earthing arrangements

Earthing as required by the *Wiring Rules* is specified for body-protected areas. However, in cardiac-protected areas there must be an equipotential system bonding all conductive and extraneous conductive parts such that the potential difference between earth points and the equipotential conductor is not greater than 50 mV. A conceptual arrangement is shown in **Figure 18.14**.

An electrician undertaking installation or maintenance work in patient areas must consult *AS/NZS 3003* for details of specific requirements; the *Appendices* provide guidance in planning such an installation, as well as templates for compliance reporting. As with all electrical installations, testing and verification are to be performed after completion of the work. In addition, the very nature of these installations requires an extensive commission process, as indicated in *AS/NZS 3003 Appendix B*, carried out by a qualified person and acceptable to the responsible organisation or entity authorising the work for the facility.



CHECK YOUR UNDERSTANDING

13. Why do special precautions exist for electrical installations in medical treatment areas?
14. Define a body-protected area.
15. List the main features of an electrical installation for a patient area.
16. What is the maximum potential difference between all conductive and extraneous conductive parts in a cardiac-protected area?
17. Who typically undertakes the compliance check of a patient area?

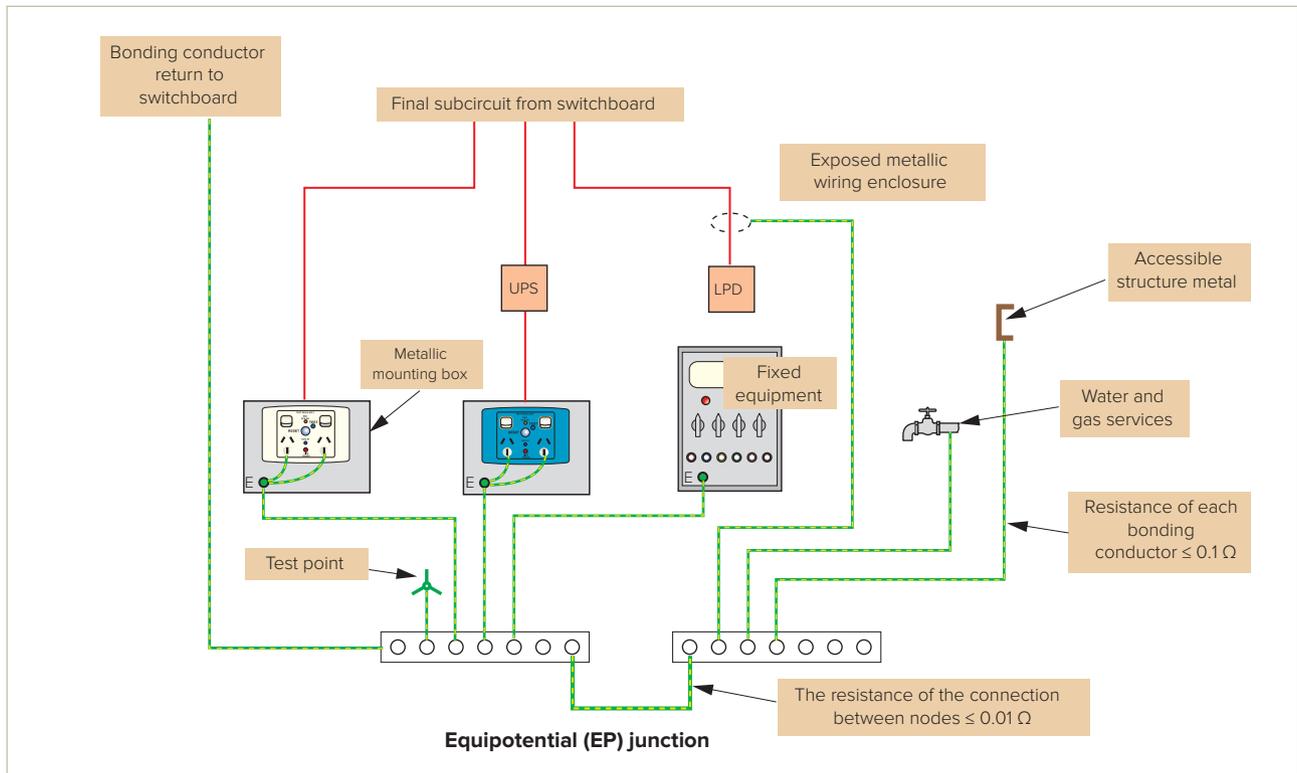


FIGURE 18.14 Concept for equipotential bonding system for cardiac-protected areas

18.7 Marina electrical installation

In some respects, electrical installations in a marina have similarities to a caravan park, in that the supply to the individual caravan sites and boat berths is provided via a service pillar. However, *AS/NZS 3004.1, Clause 1.6.2* points out the additional risks of electrical installations for the supply of power to recreational boats: marina installations are characterised by the risk of corrosion, the effects of movement of structures, mechanical damage and the risk of electric shock being increased by a reduction in body resistance and contact of the body with earth potential.

Like most special electrical installations, the *Wiring Rules* are the base Standard for compliance, but the electrician needs to be mindful of the additional requirements of *AS/NZS 3004.1* when dealing with these installations. An overview of *AS/NZS 3004.1* is provided in **Figure 18.15**.

18.7.1 Installation features

A necessity of these installations is an acceptable wiring system that can withstand the rigours of the function it performs. For this reason, metallic conduits and enclosures are not suitable, nor are aluminium conductors. Any thermoplastic or elastomer cables in a non-metallic conduit or served with PVC or polyethylene-armoured or copper-clad MIMS are appropriate.

Appendix D provides guidance and an example for determining the maximum demand for mains and submains for marina supplies. Note that a service pillar is essentially a distribution board, and therefore the supply circuit is a submain. Depending on the size and layout of the marina, a number of distribution boards may be needed to supply the individual service pillars. Unlike caravan parks, these service pillars cannot be regarded as outbuildings.

The requirements for service pillars include the maximum number of outlets, types of outlets, and overcurrent protection and additional protection by isolation transformer or RCD.

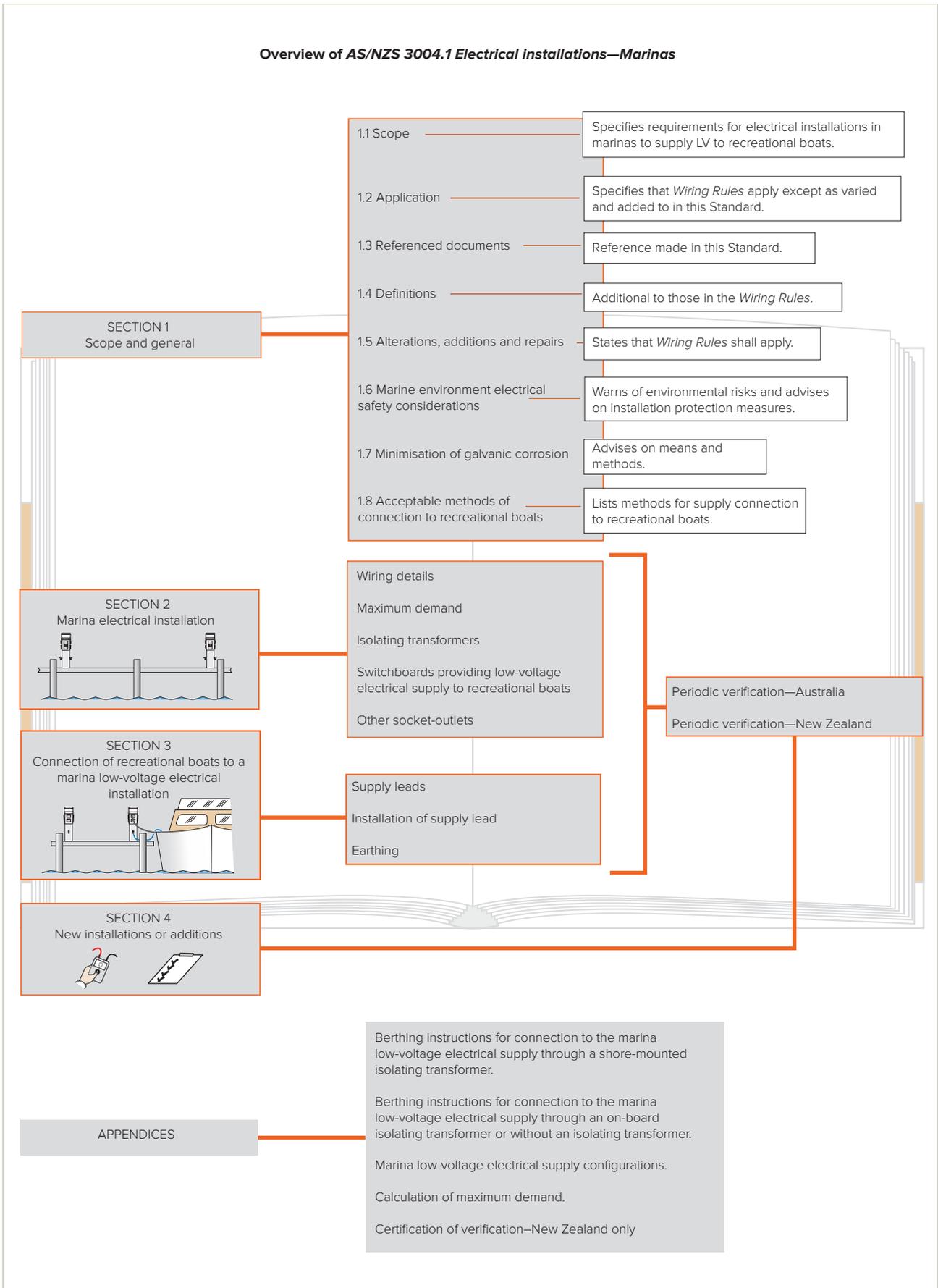


FIGURE 18.15 Overview of AS/NZS 3004.1 Electrical installations—Marinas

The Standard reminds the reader that verification of compliance for new installations, additions or alterations must be in accordance with the *Wiring Rules* but with the additional requirement for periodic testing of RCDs. In New Zealand, periodic re-verification is required.

AS/NZS 3004.2 specifies requirements for the design, construction and installation of electrical systems in recreational boats that have a length of up to 50 m and are designed for use on inland waters or at sea. Electrical installation in recreational craft can be quite comprehensive and is a specialised area of work. It is mentioned here to create interest as another avenue of electrical work.



CHECK YOUR UNDERSTANDING

18. What is the Australian Standard that applies to marina installations?
19. Which Australian Standard is applicable for the electrical installations on boats up to 50 m?

18.8 Construction and demolition sites

In building and construction work, electrically powered tools and equipment are used fairly extensively. Although the electrical installation for the supply of power for this work is of a temporary nature, it must meet the highest standards for safe and effective operation. The difficult and potentially dangerous conditions on construction sites, and the wide use of flexible leads and extension cords, add to the need for additional requirements for these installations.

The *Wiring Rules*, *Clause 7.8.2.1* calls up *AS/NZS 3012 Electrical installations—Construction and demolition sites*, which is mandatory in itself or as a ‘code’ in most jurisdictions. The Standard gives a broad definition of construction sites to include excavations, civil work, new building work, building extensions, demolition and temporary buildings on these sites, such as site offices. As with all electrical work, the electrical tradesperson should make sure they are familiar with the application of Standards and local requirements. An overview of the Standard is shown in **Figure 18.16**.

18.8.1 Installation features

Electricity used in construction activities may be supplied through wiring installed specifically for the purpose of these activities, or through the wiring installed in and forming a permanent part of the structure or building. Wiring installed for the purpose of construction work and not intended to form part of the permanent wiring is known as fixed construction wiring. *AS/NZS 3012* stipulates the types of cables that may be used for construction wiring and the installation requirements for this wiring.

When selecting cables for the mains and submains of fixed construction wiring, the maximum demand can be determined by one of the methods specified by *Clause 1.6.3* of the *Wiring Rules*. However, *AS/NZS 3012* assigns a rating to socket-outlets that is to be applied when the maximum demand is determined by calculation.

Every final subcircuit of construction wiring supplying, for example, lighting points, fixed appliances or socket-outlets must be protected by an overcurrent circuit-breaker. In addition, most final subcircuits of fixed construction wiring must be protected by a 30 mA RCD. For example, every final subcircuit supplying socket-outlets is required to be protected by a separate RCD and, where supply for equipment can only be obtained from a socket-outlet connected to the permanent wiring, the equipment must be protected by a portable RCD. Final subcircuits supplying appliances at ELV, or through an isolation transformer, do not require RCD protection.

One important requirement for socket-outlets connected to construction wiring is that they must be controlled by a double-pole switch operating in both the active and neutral conductors, as required by *Clause 2.4.7* of *AS/NZS 3012* and the accompanying figures.

Overview of AS/NZS 3012 Electrical installations—Construction and demolition sites

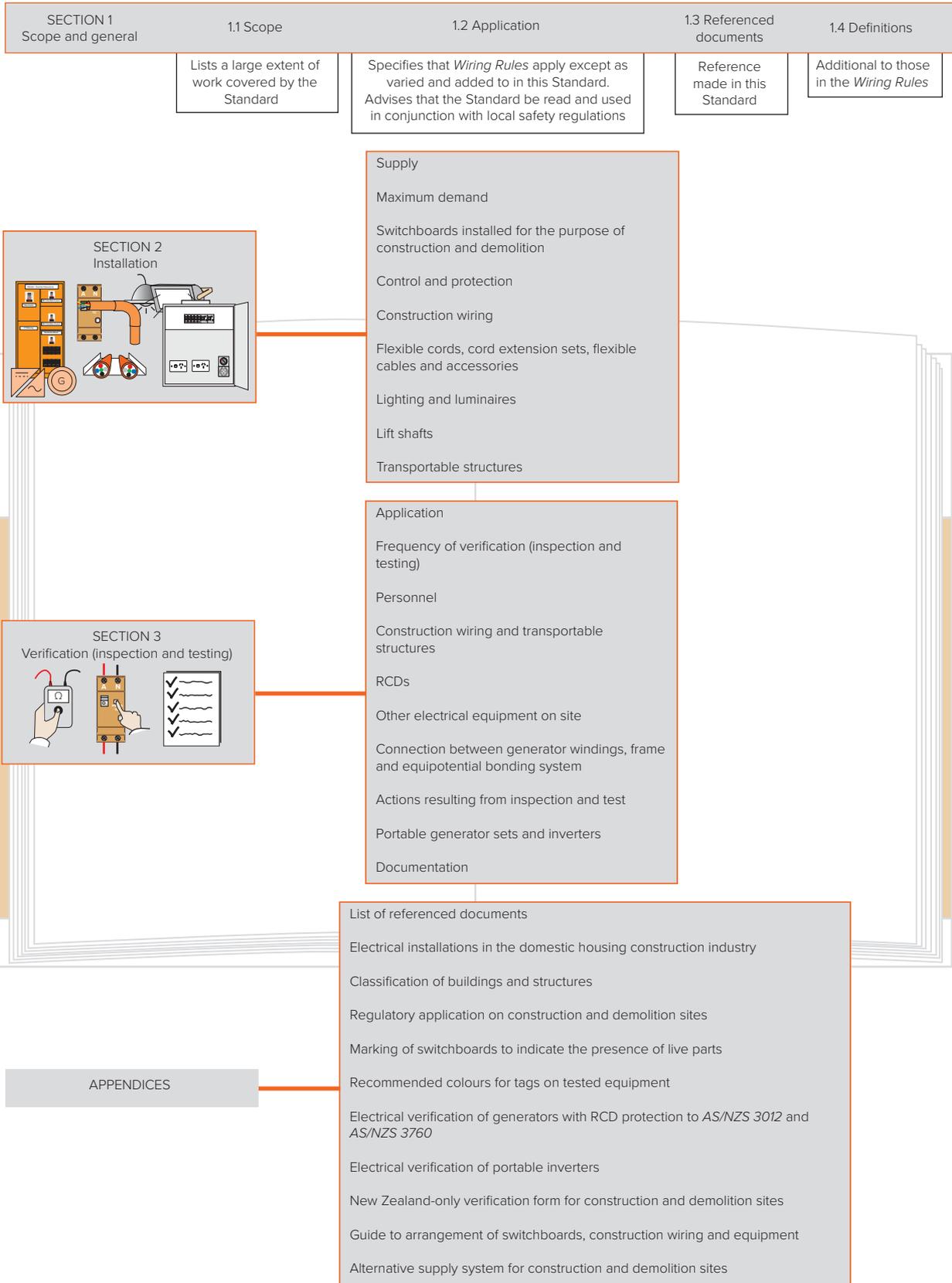


FIGURE 18.16 Overview of AS/NZS 3012 Electrical installations—Construction and demolition sites

All switchboards for the construction site must be in accordance with the *Wiring Rules*. It is common for distribution boards to incorporate 10 A socket-outlets for the connection of power tools and other portable appliances. Each distribution board must incorporate at least one 15 A socket-outlet. A note to *Clause 2.3.2.1* points out that:

Some Regulatory Jurisdictions require provision to be made on construction and demolition switchboards supplying more than one final subcircuit, for the fitting of a lockable or sealable cover over circuit-breakers and RCDs associated with these circuits or other devices that would control the resetting of circuit-breakers and RCDs, but does not prevent access to isolation switches.

This means that a site electrician is required to reset tripped circuit-breakers for the purpose of investigating whether the cause was a potentially dangerous fault or overload.

Careful consideration should be given to the placement of these distribution boards and socket-outlets generally, because *AS/NZS 3012* places limitations on the length of flexible cords that may be used on a site. Also, flexible cords and cables that are not installed as fixed construction wiring are not permitted to be run between levels in a multilevel structure. A switchboard known as an Assembly for Construction Sites (ACS) complying with *AS/NZS 3439.4* allows for a daisy-chain type installation for supply to distribution boards under the strict requirements set down by *Appendix K* of *AS/NZS 3012*.

The luminaires on a construction site must be supplied by more than one final subcircuit and installed in a distributed pattern in order to provide adequate and even lighting in the event of a circuit failing. The use of festoon lighting and portable luminaires is permitted, provided that they comply with the construction and installation requirements of the Standard.

A requirement of *AS/NZS 3012* is the periodic testing of fixed construction wiring, flexible cords, extension cords, portable outlets and portable tools and equipment within specified periods. The testing, normally carried out by an electrician, must be in accordance with that Standard and also with *In-service safety inspection and testing of electrical equipment (AS/NZS 3760)*. All testing and corrective action must be recorded in a logbook kept on the site. Portable equipment must have a tag attached that shows the date and identifies the person who carried out the test.

For more details of the requirements for electrical installations on construction sites, you should consult *AS/NZS 3012*. In order to carry out the periodic testing of site wiring and equipment, you must be totally familiar with the procedures set down in *AS/NZS 3760*.



CHECK YOUR UNDERSTANDING

20. According to *AS/NZS 3012*, how should socket-outlets connected to construction wiring be controlled?
21. In addition to a standard 10 A socket-outlet, what other type of socket-outlet must construction switchboards incorporate?

18.9 High-voltage electrical installations

Design, commissioning, installation and maintenance of high-voltage (HV) installations are multidisciplinary activities involving several specialised disciplines, including HV engineering, protection, control, HV testing, metering, installation, testing, commissioning and maintenance. This work was previously the domain of electricity distributors but, with the ever-increasing move to completion, a number of electrical contractors have sought to specialise in HV installations.

HV installation commonly starts with a substation for providing a low-voltage supply and/or high voltage to current-using devices, HV motors being the most common. *Clause 7.6 of the Wiring Rules* briefly summarises issues relevant to HV installations and cites *AS 2067 Substations and high-voltage installations exceeding 1 kV a.c.* as the compliance Standard in Australia, and in New Zealand the *Electricity (Safety) Regulations*.

The opportunity for an apprentice to gain experience in this work is limited and the risks associated with high voltage require additional safety training. Those who do find opportunities for this work may wish to undertake relevant competencies as part of the elective stream of their qualification.



CHECK YOUR UNDERSTANDING

22. Are licensed electrical tradespeople permitted to work on high-voltage installations without additional training?
23. Which areas are exempted in *AS/NZS 3000* from being high-voltage installations?

SUMMARY

- ▶ IP ratings indicate the degree of protection assigned to electrical enclosures to prevent contact with live parts and to limit or prevent the entry of objects, dust or water.
- ▶ A damp situation requires that moisture be present either permanently or intermittently to such an extent that the safety or effectiveness of the installation is impaired.
- ▶ Damp situations are classified into zones of risk of electric shock. *AS/NZS 3000* clearly details the installation requirements for each zone including the IP rating; equipment type, design and construction; type and voltage of supply; type of electrical protection; and location of the equipment.
- ▶ Hazardous areas are classified into different zones based on the frequency of occurrence and duration of an explosive gas atmosphere being present. Standards determine methods of explosion protection and equipment that should be used in such areas.
- ▶ Transportable structures including caravan parks are governed by an additional Standard, *AS/NZS 3001*, that details specific requirements be those outlined in *AS/NZS 3000*.
- ▶ Shows and carnivals present a range of different risks and require adherence to *AS/NZS 3002* to ensure public and operator safety.
- ▶ Installation of medical electrical equipment must conform to *AS/NZS 3003*, which provides additional cardiac protection to patients.
- ▶ Given their harsh and wet environments, marinas have an additional Standard, *AS/NZS 3004*, to ensure the safety of operators and the public.
- ▶ Construction and demolition sites have additional hazards and dangers and also have their own specific requirements (specified in *AS/NZS 3012*) in addition to those outlined in *AS/NZS 3000*.
- ▶ The role of the electrician in high-voltage installations is limited until they receive specific and detailed training in the safe operation of high-voltage equipment.

REVIEW QUESTIONS

1. Which section of *AS/NZS 3000* refers to special electrical installations covering safety services, electricity generation systems, isolated supply, extra-low voltage installations and hazardous areas?
2. List six damp situations for which *Section 6* of *AS/NZS 3000* contains specific requirements.
3. Identify the four main requirements for installations in damp situations.
4. Define the term *zones of risk*.
5. Identify and define the highest risk zone as specified within *AS/NZS 3000*.
6. Is it permissible to install a socket-outlet for the purpose of shaving in a Zone 2 area within a bathroom?
7. Using *AS/NZS 3000*, define *hazardous area*.
8. What are some of the additional factors that must be considered when planning a hazardous area installation?
9. List one way designers of hazardous area installations attempt to reduce the risk of explosion.
10. Give an example of a transportable structure as defined by *AS/NZS 3001*.
11. Using *AS/NZS 3001*, determine the maximum length of a 2.5 mm² connecting lead.
12. Why do special precautions exist for electrical installations in medical treatment areas?
13. Who typically undertakes the compliance check of a patient area?
14. Identify the additional risks in an electrical installation for a marina.
15. Is it permissible to install a PVC-served MIMS cable for a marina installation?
16. What types of activities listed in *AS/NZS 3012* are used to define a construction site?
17. Using *AS/NZS 3000*, list three issues related to high-voltage installations.

CHAPTER 19

Preparing and maintaining cabling

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ understand the telecommunications industry and the regulations governing cabling work in both domestic and commercial premises
- ▶ name the regulatory body responsible for governing telecommunications and describe the role played by registrars in auditing and maintaining cabling providers
- ▶ recognise the requirements for becoming a registered cabling provider
- ▶ understand what is needed when preparing to install and maintain cabling
- ▶ understand and recognise different cables used in the telecommunications industry
- ▶ explain common terminations
- ▶ identify three common cabling systems used in the telecommunications industry
- ▶ identify basic earthing systems
- ▶ explain associated earthing connections.

In order to install and connect telecommunications and data cable, telephone systems, computer and networking equipment, audio/video systems, television systems or optical fibre, it is necessary to have a minimum level of technical training and to be registered with (or recognised by) a professional organisation as a cabling provider. This is for the protection of not only the installer but also clients.

19.1 Australian Communications and Media Authority and open cabling registration

To legally install and connect telecommunications cabling to client access points, a cabler is required to be registered with one of the authorised cabling registrars and to show a minimum level of competence and experience in cabling before they can proceed unsupervised. This system of registration and training is overseen by the Australian Communications and Media Authority (ACMA), which allocates different areas of responsibility to different organisations.

19.1.1 A brief history of the ACMA

The ACMA was created from a series of mergers between different government agencies in the 1990s and early 2000s, notably the Australian Communications Authority (ACA) and the Spectrum Management Authority. The business of the ACMA is to regulate the telecommunications market, from the operation of a simple telephone line to allocating radio frequencies for broadcast to ensuring equipment that is used in the telecommunications system is safe. The ACMA's website provides a comprehensive account of its functions: www.acma.gov.au.

The area of the ACMA's activities that most affects the cabling installer (also referred to as a cabler) is its role in imposing rules and regulations. It carries this out through:

- ▶ The *Telecommunications Cabling Provider Rules (2014)* (CPRs) set out a national system of 'competency requirements with which a cabling provider must comply before being eligible for registration or renewal of registration under the registration system' (CPRs, p. 16, CC BY 4.0) to specify a minimum level of technical training in order to legally install cables.
- ▶ The Communications Alliance (CA) is an organisation created to 'provide a unified voice for the Australian communications industry and to lead it into the next generation of converging networks, technologies and services' (www.commsalliance.com.au/about-us/overview). This technical group is tasked with writing up the *Wiring Rules* that are applicable to the telecommunications industry's cablers. (Previously, the CA was the Australian Communications Industry Forum, or ACIF.)

The activities of these various groups help the Australian telecommunications system to work, providing Australians (and, as a flow-on, the South Pacific area) with a fairly solid, reliable network.

19.1.2 Standards

The telecommunications standards (also referred to as the *Wiring Rules*) are written specifically for the telecommunications industry and state the mandatory minimum requirements for working with telecommunications cabling. Every industry has standards that it must follow which ensures everyone working in the industry applies the same rules and regulations to maintain compliance. The most recent Standard used in the telecommunications industry is *AS/CA S009:2020*, available as a free download from: www.commsalliance.com.au/__data/assets/pdf_file/0010/71488/S009_2020.pdf.

All cabling installed in Australia has to comply with the Telecommunications Labelling Notice. This notice lets cabling providers know that the cabling product is compliant and has been tested for use within Australia and on the public switched telephone network. Other countries will have similar directives. The ACMA has adopted a symbol (the regulatory compliance mark, or RCM) to identify cabling products as being compliant with the labelling notice (see **Figure 19.1**).



FIGURE 19.1 Regulatory compliance mark symbol

If a cabling product does not have this symbol it is important to check with the supplier or manufacturer before installing the product. If a cabler installs a product that does not carry an RCM and there is a fault with the equipment, they will be held liable for repairs and may also face litigation for failing to comply with the *Telecommunications Act*. Cablers could also be subject to a fine from the ACMA.

More information can be found in *AS/CA S008:2020*, available as a free download from: www.commsalliance.com.au/__data/assets/pdf_file/0009/71487/S008_2020.pdf.

Unsupervised cabling work

The ACMA takes steps to ensure compliance with the *Telecommunications Act* and the *Wiring Rules*. Cablers caught performing cabling work without a registration will be fined under the *Telecommunications Act*. An unregistered cabler who is not properly supervised or whose work does not comply with the *Wiring Rules* is committing a criminal offence and could face an on-the-spot fine of \$2040 or more. The fine can exceed \$90 000 or more if court action is taken.

Cablers can avoid these penalties by being directly supervised by a properly registered cabling provider (e.g. a supervisor with open cabling registration). It is strongly recommended that cabling installers pursue qualification and registration.

19.1.3 Standards applicable to the telecommunications industry

What is a standard?

Standards Australia defines standards as ‘voluntary documents that set out specifications, procedures and guidelines that aim to ensure products, services and systems are safe, consistent and reliable’ (www.standards.org.au/standards-development/what-is-standard). According to Standards Australia, the three kinds of standards are international, regional and national.



DID YOU KNOW?

International standards are developed by the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC) and the International Telecommunication Union (ITU). Countries can adopt these standards directly for their national use, and Standards Australia embraces the development and adoption of international standards. For more detailed information see: www.standards.org.au/getmedia/d9da035d-2fbc-4417-98c1-aa9e85ef625d/SG-003-Standards-and-Other-Publications.pdf.aspx.

- ▶ **International Organization for Standardization.** The ISO is an international standard-setting body composed of representatives from various national standards organisations. It promotes worldwide proprietary, industrial and commercial standards.
- ▶ **International Electrotechnical Commission.** The IEC prepares and publishes international standards for all electrical, electronic and related technologies—collectively termed *electrotechnology*. It also manages three global systems for assessing whether equipment, systems or components conform to the standards.
- ▶ **International Telecommunication Union.** The ITU is an agency of the United Nations whose purpose is to coordinate telecommunication operations and services throughout the world. Originally founded in 1865 as the International Telegraph Union, the ITU is the oldest existing international organisation.

Specific regions have their own standards. For example, joint Australian/New Zealand Standards can be considered regional standards and European Norms (from the German *Europäische Norm*) standards are developed by the European Union.

National standards can be developed by a national standards body such as Standards Australia or other accredited bodies. The standards that fall under the brand of Australian Standard® are either developed within Australia or are international standards that have been adopted.

Telecommunications standards

The ACMA may, under *Section 376* of the *Telecommunications Act 1997*, produce technical standards for specified telecommunications customer equipment or customer cabling. These standards for the cabling provider will mostly be informative. Standard *AS/CA S009:2020* may reference these ACMA standards.

The ACMA creates standards to deal with work health and safety (WHS) issues and address changes within the telecommunications industry. As the industry is changing, essentially from a primarily copper-based network to a mixed optical-fibre network, the national broadband network standards and guides will be used to help cabling providers ensure compliance with the *Wiring Rules*.

Technical standards made under *Section 376* of the *Telecommunications Act* will adopt industry standards created for use within the telecommunications industry and will be amended and updated by the ACMA as the industry changes.



DID YOU KNOW?

Standards and guidelines: CPRs

The *Telecommunications Cabling Provider Rules (2014)* (CPRs) cover all sectors that involve customer cabling work—including telephone, data, fire and security alarm systems cabling—that connects or is intended to connect with the telecommunications network. This work must be performed by a registered cabling provider or carried out under the direct supervision of a registered cabling provider.

Previously, the most common Standard used was *AS/NZS 3080* but this has been superseded by a new set of international Standards released in 2019, the *11801 Suite of Standards*. This six-volume collection is comprised of the following:

- ▶ *AS/NZS 11801.1:2019 Information technology—Generic cabling for customer premises, General requirements.* This Standard is based on *ISO/IEC 11801-1:2017*.
- ▶ *AS 11801.2:2019 Information technology—Generic cabling for customer premises, Office premises.* This Standard is based on *ISO/IEC 11801-2:2017*.
- ▶ *AS 11801.3:2019 Information technology—Generic cabling for customer premises, Industrial premises.* This Standard is based on *ISO/IEC 11801-3:2017*.
- ▶ *AS 11801.4:2019 Information technology—Generic cabling for customer premises, Single-tenant homes.* This Standard is based on *ISO/IEC 11801-4:2017*.
- ▶ *AS 11801.5:2019 Information technology—Generic cabling for customer premises, Data centres.* This Standard is based on *ISO/IEC 11801-5:2017*.
- ▶ *AS 11801.6:2019 Information technology—Generic cabling for customer premises, Distributed building services.* This Standard is based on *ISO/IEC 11801-6:2017*.

Volume 1 has been adopted by both Australia and New Zealand, while Volumes 2–6 have been adopted by Australia only.

19.1.4 Cabling registrars

The ACMA is responsible for governing the telecommunications industry but it does not have direct access to cabling providers. Instead, it uses individual companies, called registrars, to manage cabling providers. The ACMA advises cabling providers to choose a registrar that relates to their field of work. The ACMA's roles include ACMA auditor, ACMA inspector and registrars.

ACMA auditor

An auditor is authorised by the ACMA to inspect cabling providers' records for the purpose of monitoring compliance with the CPRs. An auditor typically obtains telecommunications cabling advice (TCA) forms from a registrar and works through a paper trail. The auditor then contacts the registrar with a decision on whether a cabling provider has achieved compliance or not.

ACMA inspector

An inspector could be sent to carry out an inspection by the ACMA following a complaint or they may conduct a random inspection at a construction or building site. An inspector has the power to come onto a job site without notice. Typically an inspector will be following up on a telecommunications cabling advice 2 (TCA2) complaint form from a customer or cabling provider and will work under the guidance of the *Telecommunications Act*.

NOTE: TCA2 forms are used to inform customers of non-compliant cable installations. These forms can be found on the ACMA website: www.acma.gov.au/publications/2019-06/form/form-tca2-telecommunications-cabling-advice.

Registrars

Five registrars are accredited by the ACMA to manage the cabling registration system. Registrars compete for cabler registrations and offer a range of services, including:

- ▶ providing a national cabler registration service
- ▶ verifying a cabler's eligibility for registration
- ▶ managing a complaints and referral system
- ▶ sending information to cablers.

Registrars are divided into different industries that match the cabling providers' fields, as shown in **Table 19.1**. A cabler need only register with one of the five registrars.

TABLE 19.1 Registrars accredited by the ACMA

Registrar	Trade
Australian Security Industry Association Ltd (ASIAL)	Security
BICSI Registered Cablers Australia Pty Ltd (BRCA)	Cabling—general
Fire Protection Association Australia (FPA Australia)	Fire
TITAB Australia Cabler Registry Services (TITAB)	Cabling—general
Australian Cabler Registration Service (ACRS)	Cabling—general

More information on registrars can be found at www.acma.gov.au/contact-cabling-registrar.

Telecommunications cabling advice form 1

It is a mandatory requirement for cabling providers to fill in telecommunications cabling advice 1 (TCA1) on completion of cabling work (see **Figure 19.2**). The form can be incorporated into a job sheet or invoice; alternatively,

cabling providers can download it from the ACMA website: www.acma.gov.au/publications/2019-06/form/form-tca1-compliance-telecommunications-customer-cabling-advice. The ACMA website also provides written guidelines on completing TCA1 forms.

 Telecommunications Cabling Advice (TCA) Communications Cabler	
<small>ABN 15 062 111 222</small>	
<small>Copies: 1. Customer - White 2. Cabler - Yellow 3. Employer (if applicable) Cablers must retain a copy of the form for 12 months</small>	
Registered/Licensed Cabling Provider (Cabler's Name)	
SURNAME: Hand _____	GIVEN NAMES: Graham _____
BUSINESS PHONE: (02) 5550 1716	MOBILE (OPTIONAL): 0491 570 156
ADDRESS: 100 City St., Jamisontown NSW 1111	
Registration or Licence Number: T13299	Name of Registrar: TITAB
Employer	
Name of Company: Clever Communications	Job Number: 30014 _____
Address: Unit 2, Fake St., Jamisontown NSW _____	
POSTCODE: 1111	PHONE: (02) 5550 1716 FAX: (02) 5550 1716
Description of work - (INCLUDING ANY SUPERVISION)	
<u>Install telecommunications outlets as per plans</u> <u>Install fibre optic cable from hospital CC01 to car park 01</u> <u>Install communications racks and patch panels</u> <u>Install and test outlets to AS/CA S009:2020</u> <u>Install cabling in car park through conduits installed by others</u>	
Customer Details	
Customer Name: Important St. Clinic _____	
Address: 123 Important St., Sydney NSW _____	
POSTCODE: 2000	PHONE: (02) 7010 4746 FAX: (02) 7010 4746
Customer Signature (IF POSSIBLE)	Date: 13/03/2022
Certification	
I hereby certify that the cabling work described in this advice complies with the Wiring Rules (AS/CA S009:2020 or its replacement).	
Signature: 	Print: Graham Hand Date: 13/03/2022

FIGURE 19.2 Sample of a telecommunications cabling advice (TCA1) form

Australian Communications and Media Authority © Commonwealth of Australia

The form shown in **Figure 19.2** accurately reflects the requirements of the TCA1 while being suitable for the business standard. Doing TCA1s in the commercial world in this manner is quite common. The form contains details of the cabling work undertaken and a signed declaration from the cabling provider that the work is compliant with *AS/CA S009:2020*.

TCA1 forms must be kept for 12 months. They are used by both registrars and the ACMA to audit and check that cabling work is compliant. Failure to produce or complete TCA1 forms is an offence under the CPRs and could result in a cancellation of registration or a fine.

NOTE: The ACMA will contact registrars and ask for a list of registered cabling providers to audit each year. Typically, audits are performed using TCA forms.

19.1.5 Cabling providers

To become a registered cabling provider, it is necessary to undertake the requisite training course for the type of cabling registration that you are seeking: open, restricted or lift registration. Those with previous telecommunications cabling experience or cabling experience in other industries (e.g. electrical) may be able to undertake a reassessment of their cabling skills under recognition of prior learning provisions. A reassessment may eliminate or substantially reduce the training required to qualify for registration.

Individuals who have previously held a licence or registration or have a qualification from overseas, will need to make contact with a registered training organisation, which will assess their qualifications in the technical, vocational and trade areas. They may be required to complete further studies or, in some cases, undergo reassessment.

In all cases, those seeking registration will need to be able to demonstrate to the registrars their ability to competently work in the industry. Requirements include:

- ▶ a completed WHS/OHS qualification (the White Card)
- ▶ a minimum of 360 hours of relevant on-the-job cabling experience
- ▶ having passed a mandatory cabling regulations test (this is a test of 50 questions for the open registration, and it is necessary to answer 80% of the questions correctly in order to pass)
- ▶ minimum skills training involving basic electricity, tool usage and cabling installation.

The basic level of registration is the restricted registration; this registration is designed for those technicians that require only limited access to telecommunications systems. As a restricted cabler you can complete cabling within homes, small businesses and multi-storey buildings where cabling is behind a device such as an alarm panel or modem. Restricted cablers **MUST NOT** do any cabling work if the cabling connects via a jumperable distributor, frame or patch panel or if the reticulated electrical power in the building exceeds 230 V single phase or 415 V three phase or if the cabling needs to share cable sheaths with other services.

The broadest type of registration is the open cabling registration (OCR), which allows a suitably qualified person to perform a basic-level installation in a client's premises downstream of (after) the carrier's termination point (this will be covered later in the chapter). This is to install low-level telecommunications cables and connections that are necessary to allow a client to connect to the carrier's telecommunications network.

Cablers wishing to work on higher-level communications will need to add to their OCR specialised endorsements. These endorsements are designed to allow an OCR to do specialist work in the telecommunications area for a customer, again downstream of the carrier's connection point. To gain these endorsements, additional training in the individual areas will need to be undertaken, where cablers will learn basic installation techniques associated with the endorsements and will need to demonstrate new-found skills at a minimum level. **Chapter 21** covers the endorsements for structured cable and coaxial cable.

The endorsements recognised for the OCR are:

- ▶ optical fibre (F)
- ▶ coaxial (C)
- ▶ structured cable (S)
- ▶ underground (U)
- ▶ aerial (A)
- ▶ testing of fibre optical systems (TF)
- ▶ testing of metallic cable systems (TM).

The ACMA has a comprehensive list of requirements on its website (www.acma.gov.au).

19.1.6 A guide to using *AS/CA S009:2020—the Wiring Rules*

Main section layout

1. *Interpretive guidelines*—Contains normative and informative elements. Normative elements (mandatory requirements) are indicated by the words ‘shall’ or ‘shall not’. All other elements are informative.
2. *Scope and general*—Sets out the aims of the Standard and what it does and does not cover (e.g. carriers or a.c. mains supply).
3. *References*—Lists other standards and associated publications referred to in developing the *Wiring Rules*.
4. *Definitions and abbreviations*—A listing of definitions of the terms mentioned in the Act as applying to cablers and relevant abbreviations. Includes the definitions of arm’s reach, voltages, boundaries and other terms.
5. *Requirements*—Outlines the basic practices commercial cablers need to follow, such as those concerning red-sheathed cable, terminations, alterations and others.
6. *Hazardous conditions associated with high-voltage power*—Specifically the need to understand EPR hazard zones associated with HV, LFI and terminations.
7. *Hazardous areas and damp locations*—Discusses explosive and damp or wet areas and how to mount equipment. Draws on the *Wiring Rules, AS/NZS 3000*.
8. *Cable supports and enclosures*—Catenaries, ducts, trays and conduits and the use of telecommunications cables in different areas sharing services. Includes *Table 1, Conduit Colours*.
9. *Separation of services*—Discusses the need and requirements of separation of cables from electrical and other services. Includes *Table 2, Minimum Separation Distances*.
10. *Surge suppression*—The *How* and *Where* of surge suppression and earthing requirements.
11. *Optical fibre and coaxial cable systems*—Basic requirements when installing and terminating fibre and coaxial cables.
12. *Distributors*—General requirements for all types of distributors.
13. *Main distribution frame*—Describes the network boundary between the customer and the carrier’s incoming lines and the associated installation requirements for distributors.
14. *Network termination device*—Explains this device and where it is used.
15. *Telecommunications outlets*—Basic description and locations of different types of outlets used in the industry.
16. *Indoor cabling*—General requirements for installing cable designed for indoor use, in lifts and under floors. Discusses fire stopping and electrical separations.
17. *Outdoor cabling*—General requirements for outdoor cabling and connections.
18. *Underground cabling*—General requirements for installing cable and conduit underground. Includes pits (drainage and access to and from), driveways and roadways (depth of cover and types of protection), pillars and cabinets (location and protection), conduit and tape (installation and protection, colours, separations, etc.) and trenches (shared and separate, and crossing of other services). Contains *Table 3 Conduits* and *Table 4 Underground Separation from Power*.
19. *Aerial cabling*—General installation instructions for outdoor aerial cabling, including ground clearances, crossings, poles and attachments, shared poles with low voltage and/or high-voltage and exclusion zones. Contains *Table 5 Minimum Separations to Power*.
20. *Telecommunications earthing and power distribution*—Definitions and guidelines on earthing and grounding, including types of earthing systems (CES, TRC, ELV d.c., d.c. earth return), labelling and protection of conductors and connections, bonding and earthing conductors and connections, types of electrodes and interconnections and surge suppression devices and uses. Contains *Table 6 Resistance vs Length of Earth Conductors* and *Table 7 Minimum Earthing Conductor Sizes*.

Appendix layout

- A. *Restricted zones in damp locations (NORMATIVE)*—A summary of wet areas from the *Wiring Rules* showing exclusion and restriction zones. *Figures A1 to A6*.
- B. *Common cable colour codes (INFORMATIVE)*—Colour codes and pair numbering for multi-pair cables used in the telecommunications industry. Includes colours for optical fibre cables. *Tables B1 to B7*.

- C. *Telecommunications outlets (INFORMATIVE)*—Connection diagrams for most of the common outlets used. *Tables C1 to C3 and Figures C1 to C3.*
- D. *Recommended access clearances for MDFs and NTDs (INFORMATIVE)*—Mounting heights and other access considerations for carrier’s terminations. *Figures D1 to D4.*
- E. *Direct current in the communications bonding conductor (INFORMATIVE)*—Current flows in the earthing system.
- F. *Power feeding in telecommunications networks (INFORMATIVE)*—Requirements and safety considerations for power-feeding devices (POE, etc.).
- G. *ES3 separation of telecommunications and electrical circuits (INFORMATIVE)*—Safety and marking requirements for SELV and LV power (emergency evacuation, remote power, etc.). *Table G1.*
- H. *Hazards and interference from high-voltage power systems (INFORMATIVE)*—In-depth discussion of the problems, hazards and potential solutions when encountering sources of high-voltage interference: low-frequency induction and earth potential rise when working around high-voltage sites. *Tables H1 to H3 and Figures H1 and H2.*
 - I. *The IP Code (INFORMATIVE)*—How the IP code is laid out. *Table I1 and Figure I1.*
- J. *The network boundary (INFORMATIVE)*—Legislations and drawings showing the different locations and types of carrier boundaries (satellite, fibre optic, etc.). *Figures J1 to J20 and Table J1.*
- K. *Cabling provider rules (INFORMATIVE)*—Concise discussion of what the CPRs are and where they apply.
- L. *Guidance for domestic installations (INFORMATIVE)*—Minimum suggestions for domestic installations (e.g. Category 5).
- M. *Aerial cabling requirements (INFORMATIVE)*—Outlines the hazards, conditions and solutions for cabling and equipment installed in an outdoor environment. Includes the use of shared power poles (e.g. low voltage and/or high voltage) and the separations required in different situations. *Figures M1 to M8.*
- N. *Cabling between buildings (INFORMATIVE)*—Requirements and recommendations for aerial cabling between buildings. *Figures N1 to N5 and Table N1.*
- O. *NBN fibre to the curb (kerb) connectivity (INFORMATIVE)*—Basic discussion of connecting carrier’s fibre to the premises. *Figures O1 and O2.*
- P. *AS/NZS 60950.1 and AS/NZS 62368.1 equivalence (NORMATIVE)*—Basic discussion of telecommunications voltage levels and the new ES1, ES2 and ES3 levels used. *Table P1.*



CHECK YOUR UNDERSTANDING

1. What is the name of the form that a registered cabling provider is required to provide at the completion of work in order to comply with the *Wiring Rules (AS/CA S009:2020)* and ACMA requirements?
2. Who is responsible for the completion of the telecommunications cabling advice form (TCA1) at the conclusion of all cabling installation and relocation work?
3. What is the organisation that authorises inspectors to inspect cabling work?
4. How long does a cabler need to keep TCA1 forms?
5. What is the new installation standard that is recommended for the telecommunications industry?

19.2 Cables

The telecommunications network relies on a wide variety of technologies to function properly, and many of these technologies rely on the proper cable being used in the install. For instance, if installing a system that requires high-speed data cables, a cabler would supply and install cables and associated outlets that would best meet the clients’

requirements and specifications. They would probably not consider coaxial or basic telephone cable, but would use the best copper data cable (and possibly fibre optical cable) for the installation. This would also include using the proper outlets, cable support mechanisms and termination panels.

One way to check if the equipment being installed is approved is to check for the compliance mark, shown in **Figure 19.1**. All approved cable and components will have this mark to indicate they have been tested to meet Australian Standards for a range of safety considerations, most importantly that of voltage withstand parameters (i.e. will the proposed voltages to be placed on the item not cause failure and pose a risk of electric shock to clients or installers).

CAUTION

AS/CA S009:2020, Section 5.3 Compliance Labelling states:

A Cabling Provider shall not install any Customer Cabling or Customer Equipment that is subject to a standard under the *Telecommunications Act 1997* unless it is labelled in accordance with the Telecommunications Labelling Instrument.

An installer must NOT install any equipment that is not approved. Always check the compliance documentation if in doubt.

19.2.1 Telecommunications cables

There are a variety of different cables used in telecommunications and a basic understanding of each type is necessary. **Figure 19.3** shows a basic cable construction. A basic cable (often referred to as a wire) is a conductor wrapped in an insulator. In most cases, the conductor will be copper with an insulation of a compound of polypropylene, HDPE, or fluorocarbon (i.e. perfluoroalkoxy (PFA) and fluorinated ethylene-propylene (FEP)), which is commonly referred to as *Teflon™*.

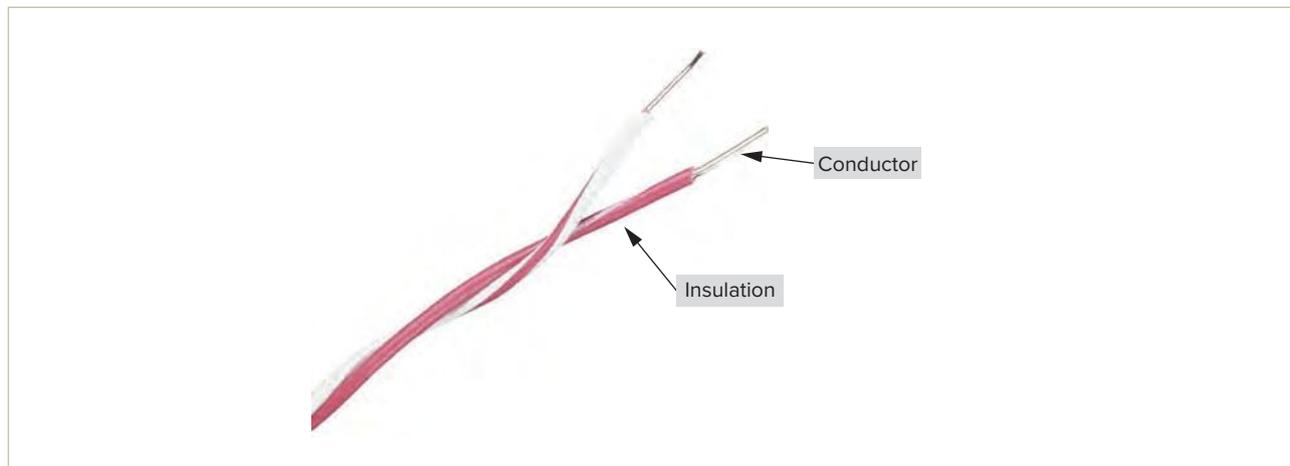


FIGURE 19.3 Basic cable construction

Graham Hand

Most telecommunications cables will be constructed using a pair of wires twisted together, and then different numbers of pairs will be placed into a bundle with a sheath holding the pairs together. This assembly is referred to by the number of pairs of wires in the sheath: 2-pair cable, 3-pair cable, 4-pair cable and so on (see **Figures 19.4** and **19.5**). This chapter will focus on a range of cables from 2-pair up to 100-pair. The most common type of cable is a 4-pair cable.

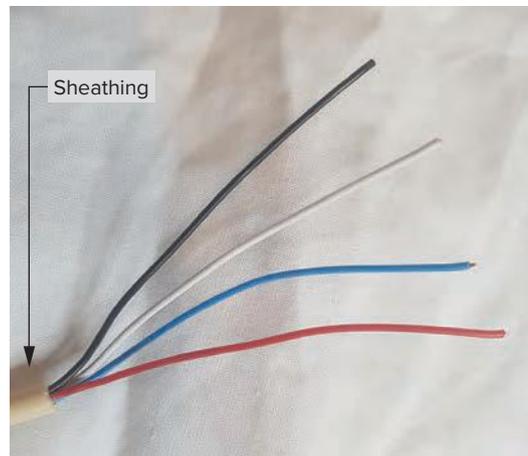


FIGURE 19.4 2-pair telephone cable

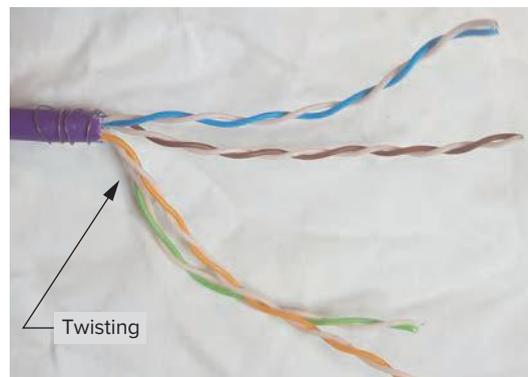


FIGURE 19.5 4-pair data cable

The amount of twist is usually (but not always) an indication of the amount of data that can be reliably transmitted down the cable with limited faults. Telephone cable will usually have around six to 12 twists per metre, whereas data cable can have 200!

The most used type of copper cable installed commercially is a 4-pair cable, commonly referred to as data cable. This can be a bit misleading, as data cables come in a wide range of types for use in different areas. Currently, the most popular cable would arguably be the type called Cat 6, or Category 6. This categorisation refers to the cable's construction and dictates how the installation should be done. This is covered in greater detail in **Chapter 20**.

An individual wire from a pair of cables, whether for telephone or data, is sometimes referred to as the A or B wire. This is a legacy system to help identify the purpose of each wire. The A leg, commonly called the mate (usually white), is connected to the positive terminal of a communications device, historically a telephone. The B leg will be terminated to the negative of the device.

To add to the complexity of cables, in the copper network the same type of cable can be either balanced or unbalanced. Unbalanced cable is where one leg of a cable is grounded (i.e. connected to earth) and the other leg carries the signal. This is explored later in the chapter. Most single-pair telephone systems, including the National Broadband Network (NBN), use this system for their signals, whether for voice or 300 megabits-per-second data.

On the other hand, a balanced cable is where both legs are *not* grounded and each carries the signal, for example a data cable (Category 5 or Category 6), where the signal from a device is split over two or four pairs of cables, each wire carrying part of the signal. A data cable can carry a telephone signal *or* a data signal, depending on what service it is connected to.

In a telephone system using 2-pair wire, the white is the A leg and the blue is the B leg for the first pair, and the red is the A leg and the black is the B leg for the second pair.

19.2.2 Cable types

Cables are identified not only by their number of pairs but also by the type of sheath used. *AS/CA S009:2020* discusses the major types and cabling should become familiar with the differences. Cables are generally identified as either indoor or outdoor cable and have properties that are shared or unique.

Indoor cables

Indoor cable sheathing is usually more flexible and easier to handle and terminate. Indoor cables do not have to be protected from weather or other harsh outdoor environments but they must be able to withstand other conditions that may be found in indoor settings. When selecting indoor cables, considerations cabling must take into account include:

- ▶ Does the cable need to be fire rated?
- ▶ Does the cable need to be riser rated?
- ▶ Does the cable need to be armoured?
- ▶ Will the cable be exposed to harsh chemicals such as those found in a manufacturing or chemical plant?
- ▶ Do the cables need to be installed in conduit or other trunking systems?
- ▶ Do the cables need to be shielded?

There are cables to address all of these concerns and a cable installer must be able to ensure the correct cable is used in the right setting.

Outdoor cables

Outdoor cables can be loosely divided into *underground* and *aerial* cables. Underground cables in a commercial environment are usually installed in their own underground conduit (coloured white or with a white stripe and labelled *communications*). By necessity underground cables are filled with a water-repellant gel, which is usually silicon-based (see **Figure 19.6**). In some situations non-gel-filled cables are permitted to be installed underground but the cabling will need to exercise additional care when doing so. An example of this would be for specialised control wiring to an outdoor location. However, there is usually a gel-filled cable that can be substituted. Underground cables need to be protected from sunlight due to the potential for harsh UV rays to cause them damage, so have an additional layer of UV protection when above ground (e.g. approved conduit).



FIGURE 19.6 Underground telephone cable (note the gel at the left)

Robert Wickstead

There are specialised cables suitable for underwater use; however, they tend to be the carrier type of cables used for undersea laying, and are composed of many fibre-optic strands, significant armouring and a lot of gel.

Aerial cables are used above ground. The carrier is a major user of these types of cables and they can be seen on many power poles throughout Australia. The sheath can be made of a more durable (e.g. harder) material than that used for underground cables and will be UV resistant. Some of these cables will also have a gel infill (called gel-filled cable). **Figure 19.7** illustrates this type of cable.



FIGURE 19.7 Aerial cable copper-twisted pairs (note the shield on the right)

Robert Wickstead

Aerial cables can have a structure called a bearer wire added to them. The bearer wire is designed to support the cable along the entire length and provide a mechanical attachment method to allow the cable to be run between two supports outside. The bearer wire should not be used as an earth wire but can be earthed in certain circumstances. An example of a bearer wire for a coaxial cable (such as that used by Foxtel or the NBN) is shown in **Figure 19.8**.



FIGURE 19.8 Aerial coaxial cable with attached insulated bearer wire (bottom portion of the cable)

Robert Wickstead

Aerial and underground cables should not be run as internal cables and should have a system where they terminate close to the site at which they penetrate the building structure. To continue the cable run, internal cable should then be used for the rest of the circuit. If an internal cable is used inside a building it needs to be suspended between two points; it is not considered an aerial cable but does use a catenary system for support. Best practice is not mixing up the cables but instead using the proper cable for the correct run.

19.2.3 Conduit

All conduit must comply with the *Wiring Rules*. Most conduit used in the telecommunications industry is for indoor use and thus should be coloured white. This conduit is available from most electrical wholesalers. If grey conduit is used, it must not contain the word *electrical* on it. Black conduit can be used but ideally it features a white stripe also. Conduit is manufactured under the electrical conduit sizing dimensions (i.e. 20 mm, 32 mm, etc.)

For safety reasons *AS/CA S009:2020, Section 8.3* outlines prohibited conduit colours for use in telecommunications cables, as shown in **Table 19.2**.

TABLE 19.2 Prohibited conduit colours for customer cabling as outlined in *AS/CA S009:2020, Section 8.3, Table 1*

Colour	Service normally associated with the colour
Orange	a.c. mains power
Yellow or Yellow-ochre	Fuel, process, toxic or medical gases
Silver-grey	Steam
Brown	Flammable and combustible liquids
Violet	Acids and alkalis
Light blue	Compressed air

Source: *AS/CA S009:2020, Section 8.3, Table 1*, Communications Alliance Ltd 2020



CAUTION

Orange electrical conduit is used extensively for low-voltage electrical cables (above 50 V a.c. or 120 V d.c.) for 230 V a.c. power and light, and mains and submains supply.

Using orange conduit may lead to injury from electric shock if the conduit is accidentally accessed.

Orange conduit should never be used for telecommunications cables unless the cables are in their own telecommunications conduit and are sub-ducted in a larger, orange conduit (e.g. 100 mm) allocated for this feature. See *Section 18.3.5* of *AS/CA S009:2020*.

When conduit is used outdoors it must be protected from the sun's UV rays, and if used underground it must be able to withstand the rigours of trenching and laying. White conduit purchased from wholesalers should also be rated for UV blocking when it is being used outdoors. Telecommunications conduit is now made so that it is suitable for most locations. The advantage of this type of conduit is that it can use normal electrical fittings (e.g. saddles, joiners, bends), which can also be used for electrical work. *AS/CA S009:2020, Section 18* details the requirements for using conduit in telecommunications work.

There is a limit to how many cables a conduit can carry and this is roughly 40 per cent cable and 60 per cent space. This allows for cable movement without putting undue strain on the cables and permits an additional cable to be installed at a later date (with care).

NBN and carrier (e.g. Telstra) conduits are made differently and are not compatible with typical conduit. They differ in size and do not align with electrical sizing; for example, the internal diameter of a 20 mm Telstra conduit

is slightly larger than the outside diameter of a typical 20 mm conduit. Carriers' fittings and saddles also differ, which means they must be used when installing the carriers' conduit. Often, this conduit is stored next to the telecommunications conduit, and many an installer has been surprised onsite by this.

19.2.4 Colour codes

Telecommunications cables are colour coded to assist installers to differentiate between cables in a bundle. *AS/CA S009:2020, Appendices B and C* outline the colours applicable to the different cables (see **Tables 19.3 to 19.10** and **Figure 19.9**). All approved cable used in Australia and New Zealand must abide by the colour-coding system.

TABLE 19.3 2-pair and 3-pair telephone cable colour code as outlined in *AS/CA S009:2020, Appendix B, Table B1*

Pair number	Colours
1	White Blue
2	Red Black
3	Orange Green

Source: *AS/CA S009:2020, Appendix B, Table B1*, Communications Alliance Ltd 2020

TABLE 19.4 4-pair cable colour code as outlined in *AS/CA S009:2020, Appendix B, Table B2*

Pair number	Colour code variations		
1	White Blue	White-Blue Blue	White-Blue* Blue-White*
2	White Orange	White-Orange Orange	White-Orange* Orange-White*
3	White Green	White-Green Green	White-Green* Green-White*
4	White Brown	White-Brown Brown	White-Brown* Brown-White*
5	White Grey	White-Grey Grey	White-Grey* Grey-White*

*The first-named colour is the predominant colour

Source: *AS/CA S009:2020, Appendix B, Table B2*, Communications Alliance Ltd 2020

TABLE 19.5 Colour code for up to 100-pair cables (20-pair units) as outlined in *AS/CA S009:2020, Appendix B, Table B3*

Pair number	A leg (L+)	B leg (L-)
1	White	Blue
2	White	Orange
3	White	Green
4	White	Brown
5	White	Grey
6	White	Blue-White
7	White	Blue-Orange
8	White	Blue-Green
9	White	Blue-Brown
10	White	Blue-Grey
11	White	Orange-White
12	White	Orange-Green
13	White	Orange-Brown
14	White	Orange-Grey
15	White	Green-White
16	White	Green-Brown
17	White	Green-Grey
18	White	Brown-White
19	White	Brown-Grey
20	White	Grey-White

Pair range	Mate colour
1–20	White
21–40	Yellow
41–60	Black
61–80	Violet
81–100	Red

Note: These cables are normally constructed using layer stranding, with the pair count sequence commencing from the centre and progressing through successive outer layers.

Source: *AS/CA S009:2020, Appendix B, Table B3*, Communications Alliance Ltd 2020

TABLE 19.6 Colour code for up to 100-pair cables (25-pair units) as outlined in *AS/CA S009:2020*, Appendix B, Table B4

Pair number	Mate	Colour
1	White	Blue
2	White	Orange
3	White	Green
4	White	Brown
5	White	Grey
6	Red	Blue
7	Red	Orange
8	Red	Green
9	Red	Brown
10	Red	Grey
11	Black	Blue
12	Black	Orange
13	Black	Green
14	Black	Brown
15	Black	Grey
16	Yellow	Blue
17	Yellow	Orange
18	Yellow	Green
19	Yellow	Brown
20	Yellow	Grey
21	Violet	Blue
22	Violet	Orange
23	Violet	Green
24	Violet	Brown
25	Violet	Grey

Pair range	Whipping colour
1–25	Blue
26–50	Orange
51–75	Green
76–100	Brown

Note 1: 50- to 100-pair cables are constructed with 25-pair sub-units and coloured whipping.

Note 2: The mate conductor may include a thin band of the corresponding colour, while the coloured conductor may have a thin band of the corresponding mate colour.

Note 3: At installation, each of the whippings should be tied around each bundle at the end of the cable sheath to maintain the bundle identification.

Source: *AS/CA S009:2020*, Appendix B, Table B4, Communications Alliance Ltd 2020

TABLE 19.7 Colour code for up to 100-pair cables (10-pair units) as outlined in *AS/CA S009:2020*, Appendix B, Table B5

Pair number	A leg (L+)	B leg (L-)	Pair range	Whipping colour
1	White	Blue	1–10	Blue
2	White	Orange	11–20	Orange
3	White	Green	21–30	Green
4	White	Brown	31–40	Brown
5	White	Grey	41–50	Grey
6	Red	Blue	51–60	Blue-White
7	Red	Orange	61–70	Orange-White
8	Red	Green	71–80	Green-White
9	Red	Brown	81–90	Brown-White
10	Red	Grey	91–100	Grey-White

Note 1: The cable pairs may have a very light twist and care is required, when stripping the cable sheath and fanning out the pairs, that the mates do not separate from their primary colours and get mixed up.

Note 2: At installation, each of the whippings should be tied around each bundle at the end of the cable sheath to maintain the bundle identification.

Source: *AS/CA S009:2020*, Appendix B, Table B5, Communications Alliance Ltd 2020

It is important to understand the colour codes for data cable as this will determine how the actual cable is terminated onto its respective outlet. In a 4-pair cable, an easy way to remember the colour-coding system is:

BLUE = sky
 ORANGE = sun
 GREEN = tree
 BROWN = trunk.

With a bundle of 20, 50, 100 or more cables the arrangement can be quite messy (see **Figure 19.10**). Thankfully, the type of cable shown in **Figure 19.11** is no longer installed.

There are two main systems of terminating data cable, named 568-A and 568-B. They are a subset of a much larger standard that the average installer will usually never encounter. In Australia and New Zealand 568-A is the recommended method, which is reflected in *AS/CA S009:2020*. In other parts of the world the 568-B system is commonly used. There is no mechanical or electrical difference between the two systems. The installer may encounter either method on the same job site. These two systems are shown in **Figures 19.12** and **19.13**.

Cablers must pay particular attention to cable colour codes when re-terminating multi-pair cables during an upgrade or change-over of an installation. **Figures 19.14** and **19.15** show an example of two similar yet different colour-coded cables. If the installer is not paying attention when carrying out this task, it would be easy for the blue cable bundle from the blue whipping to be interchanged with the orange whipping, causing problems when later trying to locate a specific pair. This confusion can be compounded when you realise cables from *AS/CA S009:2020*, Tables B3 and B4 can also be included, leading not only to lost cable bundles but also to lost cable pairs and even cable mates.

TABLE 19.8 Colour code for up to 200-pair cables (10-pair units) as outlined in *AS/CA S009:2020, Appendix B, Table B6*

Pair number	A leg (L+)	B leg (L-)	Pair range	Whipping colour
1	White	Blue	1–10	Blue-White
2	White	Orange	11–20	Orange-White
3	White	Green	21–30	Green-White
4	White	Brown	31–40	Brown-White
5	White	Grey	41–50	Grey-White
6	Red	Blue	51–60	Blue-Blue
7	Red	Orange	61–70	Orange-Orange
8	Red	Green	71–80	Green-Green
9	Red	Brown	81–90	Brown-Brown
10	Red	Grey	91–100	Grey-Grey
			101–110	White-White
			111–120	Red-Red
			121–130	Yellow-Yellow
			131–140	Violet-Violet
			141–150	Black-Black
			151–160	Blue-Red
			161–170	Orange-Red
			171–180	Green-Red
			181–190	Brown-Red
			191–200	Grey-Red

Note 1: The cable pairs may have a very light twist and care is required, when stripping the cable sheath and fanning out the pairs, that the mates do not separate from their primary colours and get mixed up.

Note 2: At installation, each of the whippings should be tied around each bundle at the end of the cable sheath to maintain the bundle identification.

Source: *AS/CA S009:2020, Appendix B, Table B6*, Communications Alliance Ltd 2020

A newer type of fibre used in specialist connectors uses 16 fibres and four extra colours: 13–Olive, 14–Magenta, 15–Tan, 16–Lime. Further information on cable colour codes can be found at www.thefoa.org/tech/ColCodes.htm. It is worth noting that *AS/CA S009:2020, Appendix C, Figures C2 and C3* and *Table C2 and C3* refer to the older style of telephone systems, and since they are no longer supported by the NBN, they are not discussed in this chapter.

TABLE 19.9 Optical fibre colour code as outlined in *AS/CA S009:2020, Appendix B, Table B7*

Fibre number	Colour
1	Blue
2	Orange
3	Green
4	Brown
5	Grey
6	White
7	Red
8	Black
9	Yellow
10	Violet
11	Pink
12	Aqua

Note 1: This colour code applies to both loose tube and tight buffered fibre.

Note 2: For stranded (multiple) loose tube construction, the tube colour sequence is the same as the fibre colour sequence.

Source: *AS/CA S009:2020, Appendix B, Table B7*, Communications Alliance Ltd 2020

TABLE 19.10 8P socket contact/pair assignment and cable colour code as outlined in *AS/CA S009:2020, Appendix C, Table C1*

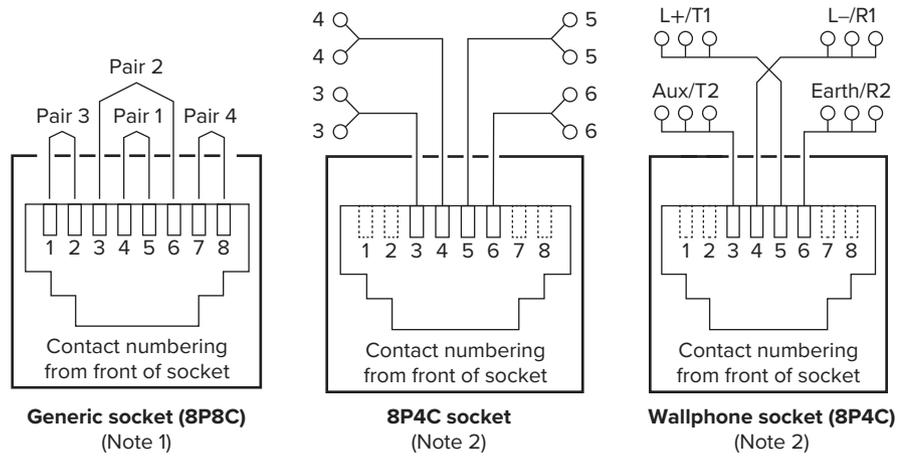
Contact designations			Pair no.	4-pair cable colour code variations			3-pair cable	2-pair cable
L+	T1	5	1	White	White-Blue	White-Blue*	White Blue	White Blue
L-	R1	4		Blue	Blue	Blue-White*		
Aux	T2	3	2	White	White-Orange	White-Orange*	Red Black	Red Black
Earth	R2	6		Orange	Orange	Orange-White*		
—	—	1	3	White	White-Green	White-Green*	Orange Green	—
—	—	2		Green	Green	Green-White*		
—	—	7	4	White	White-Brown	White-Brown*	—	—
—	—	8		Brown	Brown	Brown-White*		

*The first-named colour is the predominant colour

Note 1: With bus-wired (e.g. telephone) outlets, only working pairs should be connected to the socket (e.g. pair 1 for one line). With generic cabling (i.e. cabling star wired from a distributor), all pairs should be terminated on the socket.

Note 2: This table provides detail on the A and B designation as to polarity and purpose. It also indicates which terminal on an 8P8C connector the cable is terminated on.

Source: *AS/CA S009:2020, Appendix C, Table C1*, Communications Alliance Ltd 2020



Note 1: Recommended 8P8C socket pair assignments (T568A) for generic cabling are shown.

Note 2: With 8P4C sockets, only the inner 4 contacts are fitted, which allows 2 conductor terminations to be provided per contact spring to support bus wiring of outlets.

Note 3: The terminals for wallphone-mounting outlets may be marked with line designations as shown, rather than with the socket contact numbers.

FIGURE 19.9 8P modular socket contact numbering as outlined in *AS/CA S009:2020, Appendix C, Figure C1*

Source: *AS/CA S009:2020, Appendix C, Figure C1, Communications Alliance Ltd 2020*

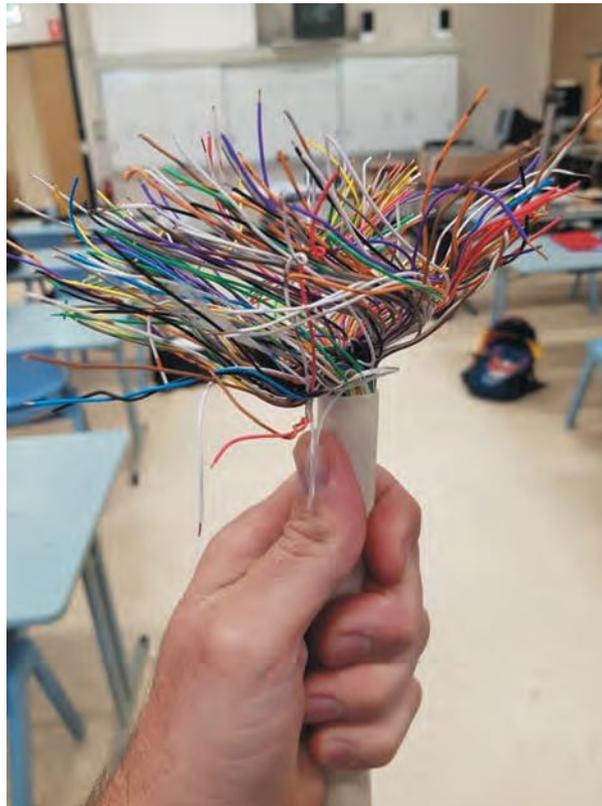


FIGURE 19.10 Multi-pair telephone cable

Graham Hand



FIGURE 19.11 1200-pair underground telephone cable

Robert Wickstead

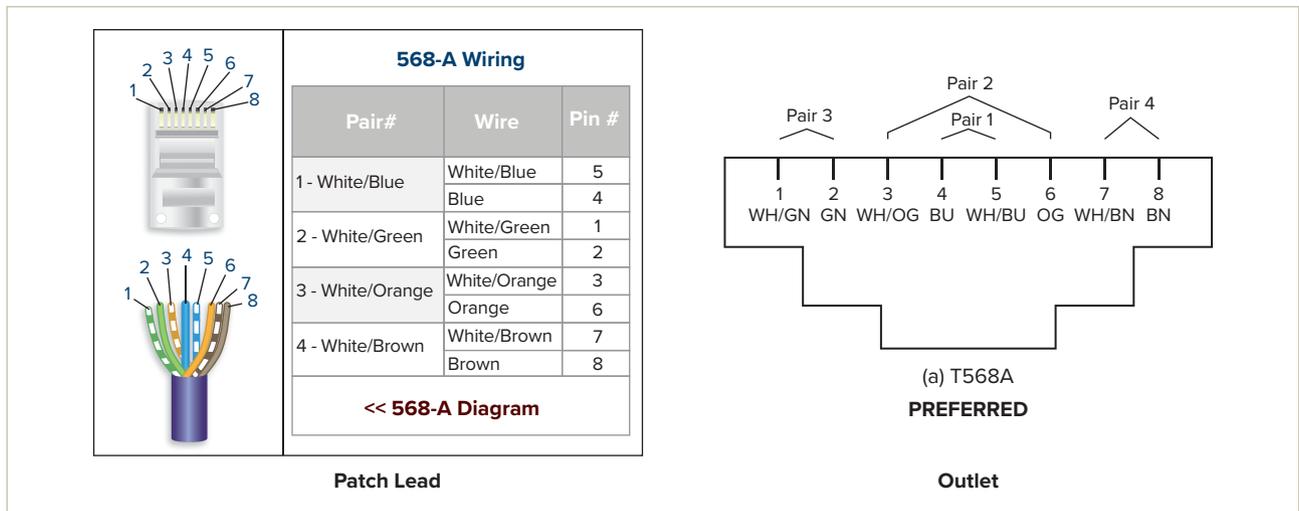


FIGURE 19.12 Wiring standard for field termination with TS568A

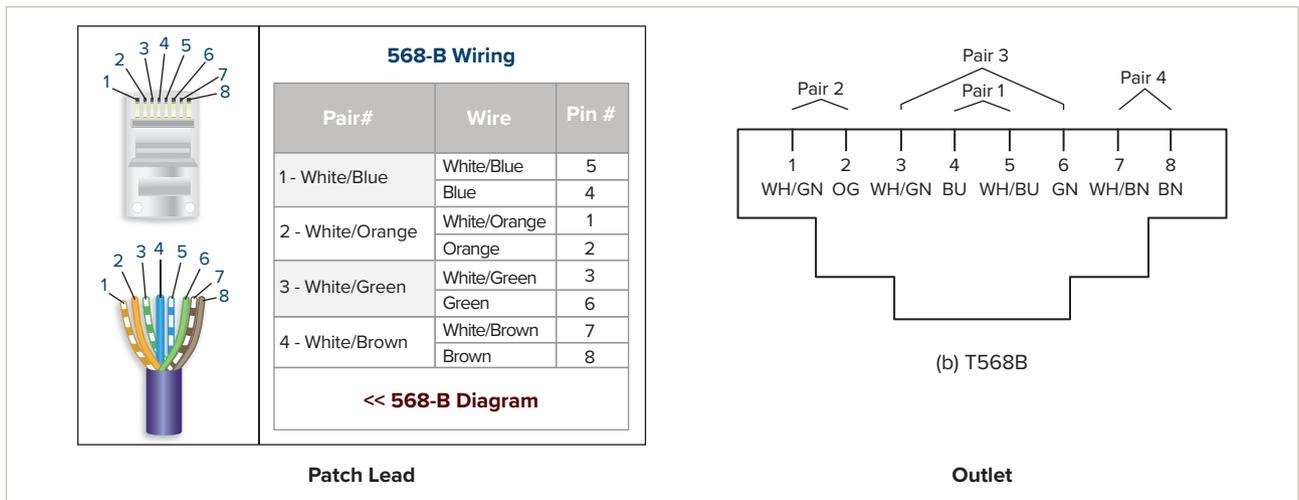


FIGURE 19.13 Wiring standard for field termination with TS568B

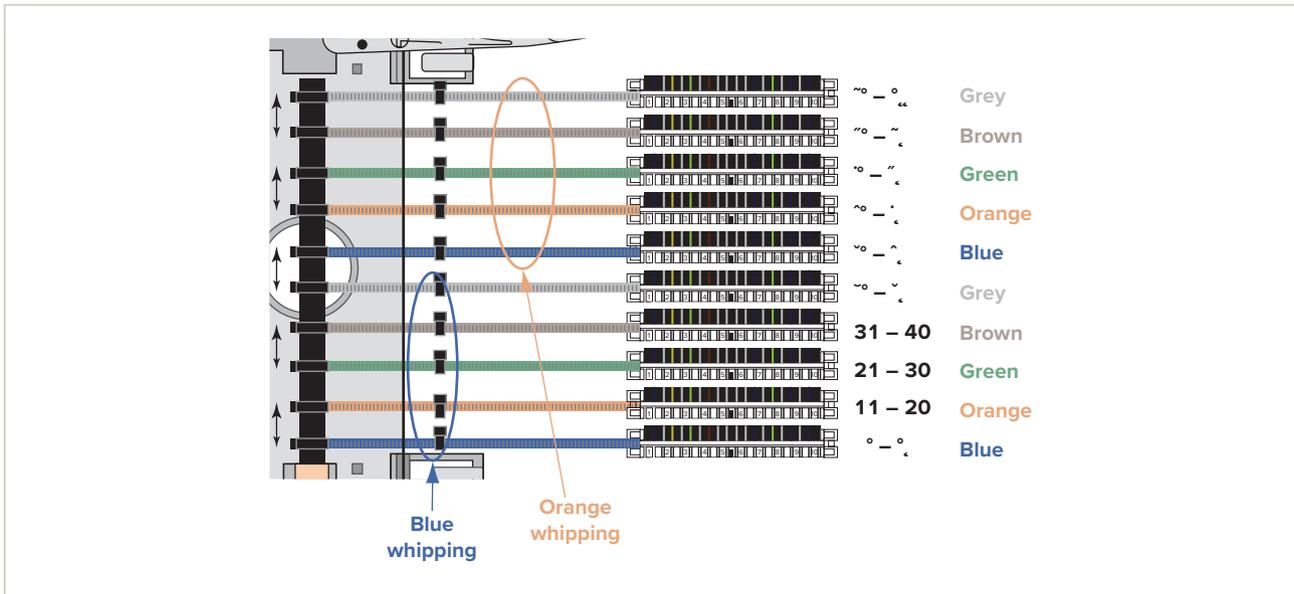


FIGURE 19.14 Example of a cable loom using AS/CA S009:2020, Table B5 colour codes

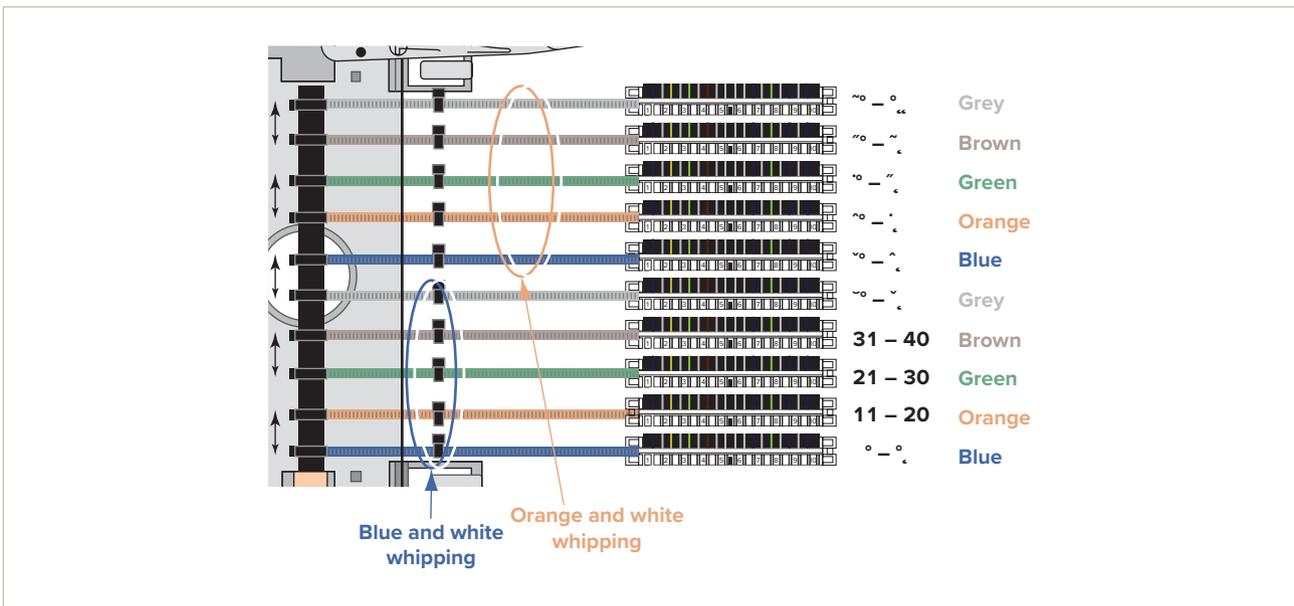


FIGURE 19.15 Example of a cable loom using AS/CA S009:2020, Table B6 colour codes

19.2.5 Optical fibre

Optical fibre cabling is typically used to carry guided light for both telephone and data signals end to end. Typically, optical fibre sends digital signals over great distances. Optical fibre is made from glass and does not contain any electrical components, unless it also has a metallic shield for protection or a metallic strength member. A typical cross-section of a fibre optic patch cord is shown in **Figure 19.16**.

The light is reflected off the boundary between the core and cladding of the cable. The buffer is used to protect the cladding and provide a method of colour-coding the fibre. The sheath is used when there are bundles of fibres to make a single cable. In underground fibres, there will be coloured tubes housing a group of fibres (sometimes up to 144 fibres in one tube and 12 tubes in the fibre cable).

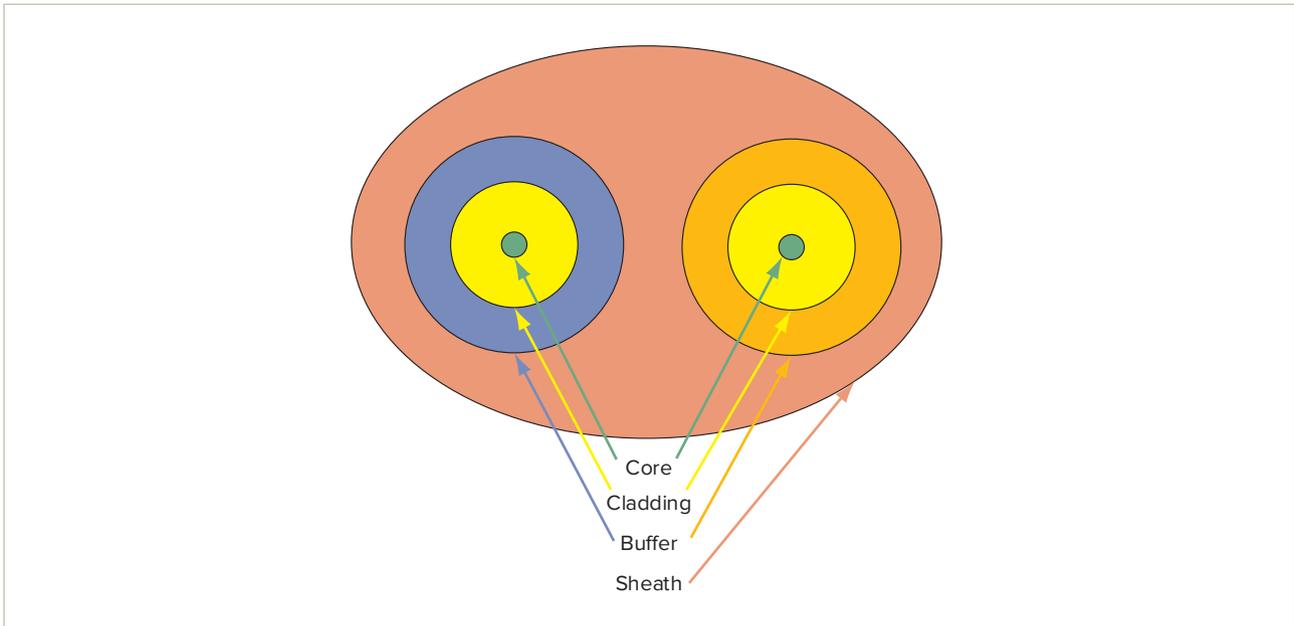


FIGURE 19.16 Typical optical fibre construction

One advantage of optical fibre is its low attenuation and insensitivity to electronic interference. Optical fibre is immune to radio-frequency interference (RFI) and low-frequency interference (LFI). RFI and LFI are interrupting frequencies that can affect metallic cables; as optical fibre has no metal parts it does not affect or disturb the signals. Optical fibre can carry signals great distances without data loss, making it an ideal medium for transmitting high amounts of data communication.

Optical fibre transmission has a strict requirement for the way the light is 'inserted' into the actual fibre. Ideally it will be parallel to the core; however, it can tolerate a slight angle (referred to as the insertion angle). The larger the angle, the more loss in the fibre, and there is a point in the insertion angle where the light does not reflect at all, meaning no data can be transmitted. This requirement means cablers must take care to avoid sharp bends when installing optical fibre.



CAUTION

Fibre optic light is at the infrared wavelength—the human eye cannot see this light.

Carrier-grade fibre optics use very strong lasers that can cause permanent damage or blindness in a very short amount of time.

NEVER look down a fibre optic cable or connector—always use an infrared-sensitive camera to check for a light source.

Single mode and multimode are the two main types of optical fibre. They are loosely defined by the types of light they can carry.

AS/NZS 11801:2019 (Parts 1 and 2), Table F.3 Supported applications using optical fibre (previously *AS/NZS 3080:2013*) shows every ratified fibre standard to date, with the distances and fibre types over which they can be carried. In addition, active equipment manufacturers specify supported distances of their products on datasheets, which may improve on those stated in *Table F* because of the design of the active components.

Single-mode optical fibre

Single-mode optical fibre (SMOF) uses a laser light source and is used for distances over 2 km or in high-bandwidth applications. Single-mode fibre has a core diameter of about 9 microns and a cladding diameter of 125 microns (a micron is 1 millionth of a metre, or a micrometre, and is symbolised by a μ). The cladding is slightly larger in diameter than a human hair (see **Figure 19.17**). It utilises a laser for transmission and is normally used as a backbone cable to supply services between distribution centres such as telephone exchanges.

SMOF relies on the accurate alignment of the transmission laser, which makes the equipment more expensive and the cable harder to work with. These problems are overshadowed by the amount of data (referred to as throughput) that can be transmitted and the distances the cable can be used for.

Currently, a large portion of the NBN makes use of SMOF, usually to a pit or pillar in the nature strip, but sometimes even into clients' premises. All carrier fibre is part of the carrier system and the registered cabler is not legally authorised to disturb the cable.

Using SMOF for commercial purposes is gaining popularity, mainly due to the long distances a signal can travel without major distortion or loss of power, and the amount of data that can be transmitted. A cabler must hold the endorsement for optical fibre to carry out this type of work.

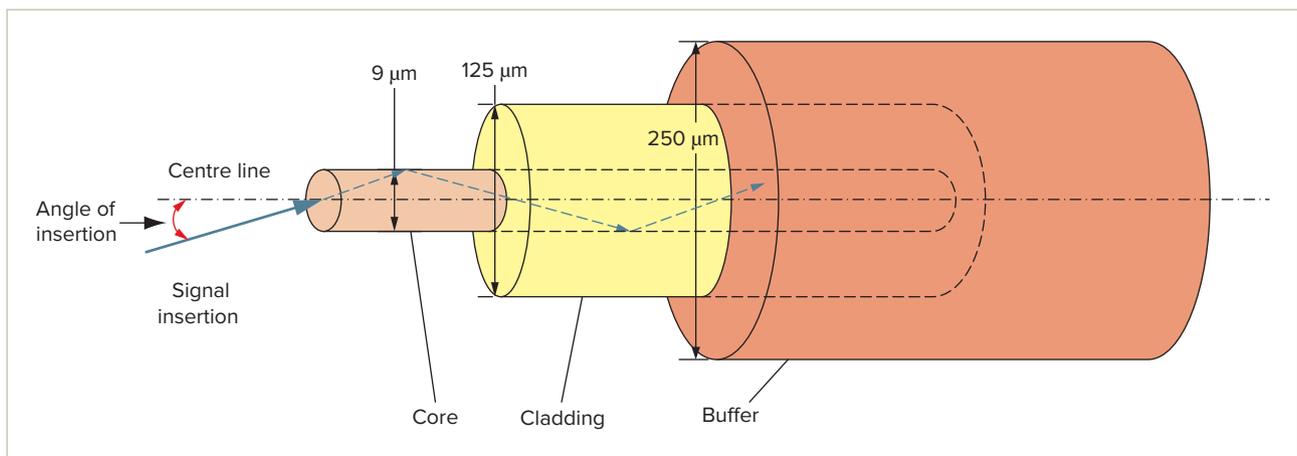


FIGURE 19.17 Single-mode optical fibre

Multimode optical fibre

Multimode optical fibre (MMOF) uses a LED light source or similar and is used for distances under 2 km. Multimode optical fibre has a core diameter of 50 microns and is used to transmit multiple types of media at the same time. It has a wide angle of insertion from a (relatively) wide light source, hence the name *multimode*. This would be similar to using a LED panel light to transmit instead of a laser pointer (as used for single mode); see **Figure 19.18**.

MMOF is designed to be more tolerant of alignment inaccuracies and to work under a less arduous alignment system but suffers from having to take a multitude of different light frequencies (wavelengths) at different insertion angles, reducing its distance and throughput capacity. It is normally used as a backbone cable to supply services between distribution centres within a building.

AS/CA S009:2013, Section 11 covers the installation requirements for optical fibre systems. The section is mostly concerned with safety issues for cabling providers and users of the system.

19.2.6 Coaxial cabling

A coaxial (coax) cable has an inner conductor surrounded by a tubular insulating dielectric, surrounded by a tubular conducting shield. The term *coaxial* comes from the fact that the inner conductor and the outer shield share a geometric axis (e.g. are round and centred); see **Figures 19.19** and **19.20**.

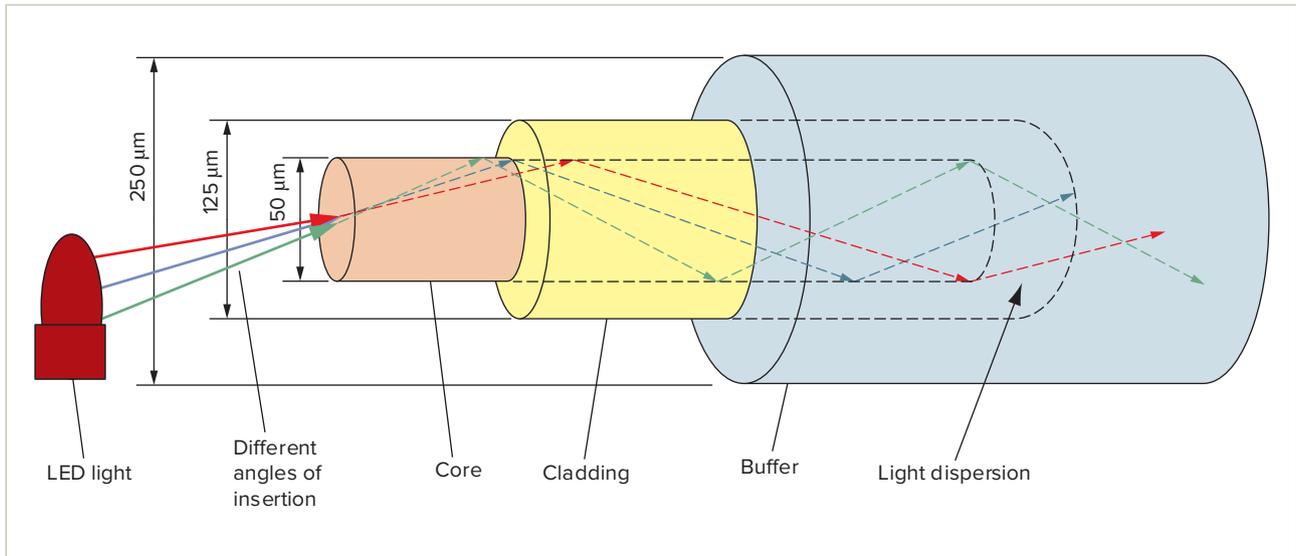


FIGURE 19.18 Multimode optical fibre

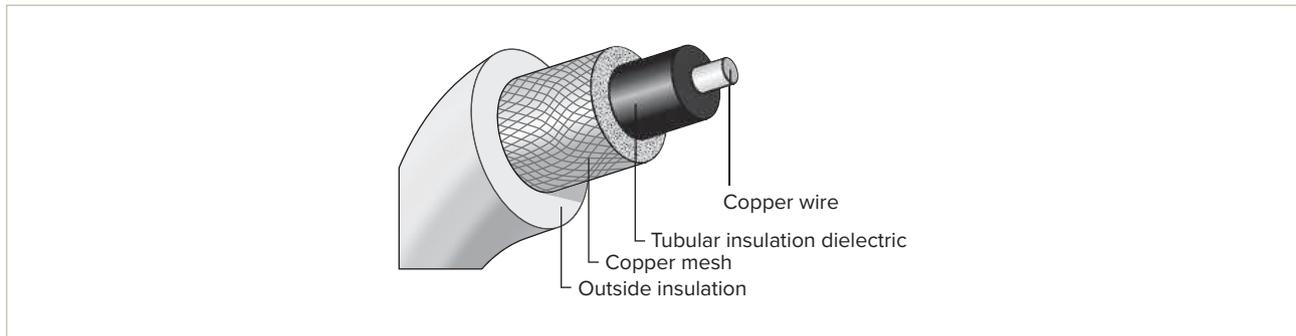


FIGURE 19.19 Coaxial cable



FIGURE 19.20 Close-up of coaxial cable used for high-powered radio transmission showing centre conductor and dielectric (the AA battery has been included for scale)

Robert Wickstead

Coaxial cabling is primarily used for basic television services such as:

- ▶ cable television or CATV/MATV
- ▶ closed-circuit television (CCTV)
- ▶ free-to-air television (FTA)
- ▶ satellite television services (SAT).

Coaxial cable was the medium used for data transmission prior to the introduction of the unshielded twisted pair (UTP) but has almost (if not totally) been superseded by copper twisted pair.

Chapter 20 explores data cable and coaxial cable in greater depth.



CHECK YOUR UNDERSTANDING

6. When installing underground conduits, how should the conduit be labelled and coloured?
7. Why should a cabler not use conduit marked *electrical* or of an orange colour?
8. Which type of cable is primarily used for television services?
9. What is the above-ground clearance for aerial cable over any commercial/industrial driveway or private roadway in accordance with the *Wiring Rules AS/CA S009:2020*?
10. A cable you are installing does not have an approved compliance notice on it. Can you legally install this cable?

19.3 Terminations

The type of cable used for a particular service will dictate the type of connector or socket used for that cable. The type of connector will then likely dictate the type of termination used. A coaxial cable system will need to terminate on a coaxial cable socket, using proper coaxial cable termination methods; likewise for optical fibre cables. Copper cables, on the other hand, can be terminated on a wide variety of sockets using a wide variety of termination methods. For instance, a telephone 2-pair cable can quite easily be terminated onto a socket designed for Category 6 and still function at rated speeds.

However, the cable installer must keep in mind that using different ratings of components in an installation will only provide the lowest category of performance. For example, a telephone cable installation system that contains a 1 gigabit socket will not perform at the higher 10 gigabit data rate expected of such a system. Since clients demand that their cable installation performs at an expected level, it is important to carry out testing on the telecommunications system; testing is covered in more detail later in the chapter.

NOTE: *AS/CA S009:2020, Clause 8.2.1* states that ‘customer cabling shall not be secured to a cable, conduit, or pipe of another service (e.g. a power cable/conduit or water/waste pipe)’. This includes *not* attaching telecommunications cables or supports to suspended ceiling hanging rods or other supporting structures.

Always install telecommunications cables using their own support means.

19.3.1 Telephone

Horizontal cabling, or field cabling, is the cable that goes from a floor distributor to the telecommunications outlet. Field cabling typically has no more than four pairs of wires and is usually UTP or shielded twisted pair (STP) cable.

Preparing cable for termination in the field will depend on the the type of cable. It will be much easier than backbone cabling but takes the same skills and techniques to fit off. The most common horizontal cable is UTP 4-pair cable, which is terminated on modular 8P8C (commonly called RJ45 sockets) connectors or 8P4C (commonly called telephone sockets) connectors.

The basic steps to terminate cable include:

- ▶ remove sheath
- ▶ place wires into position
- ▶ terminate cable.

The most used field outlets are:

- ▶ modular (8P8C or 8P4C)
- ▶ 610 socket
- ▶ 611 socket
- ▶ telephone wall socket.

Telephone wall socket, 610 socket and 611 socket are no longer supported or used (see **Figure 19.21**).

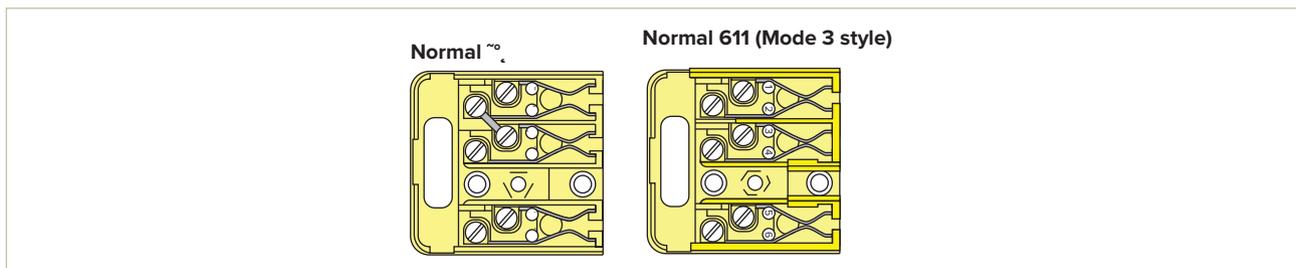


FIGURE 19.21 600 series telephone socket

NOTE: The telephone wall socket, 610 socket and 611 socket are legacy telephone sockets and are no longer used or supported. However, there are tens of thousands, if not hundreds of thousands, of these sockets installed throughout Australia; see **Figure 19.22**.



FIGURE 19.22 610 and 611 telephone socket and plug

Robert Wickstead

The NBN will not terminate the incoming lines onto these types of sockets and the installer must ensure they are not used when preparing a site for the NBN.

The NBN has issued a document, *Authority to Alter Facilities in Residential and Small Business Premises*, detailing how installers can prepare a site to be NBN compliant. This includes replacing all 600 series telephone sockets. The document can be downloaded from www.nbnco.com.au

Preparing cabling for field outlets is significantly easier than it is for distributors. Cabling should be cut to length and stripped to allow for screw terminal termination or simply cut to length for modular outlet termination, as these use insulation displacement-type terminations.

Cabling is usually labelled at either end prior to hauling so that it can be placed into position ready for termination. The manufacturer's guidelines should be followed when fitting cabling as individual requirements may need to be met to comply with the *Wiring Rules*; it may also be necessary to satisfy the recommended methodology for warranty purposes.

The Krone 8P4C media outlet, as shown in **Figures 19.23** and **19.24**, became the standard telephone socket early this century, mainly due to its ability to handle the higher frequencies demanded by the different internet services. Currently, most major manufacturers (e.g. Clipsal, Commscope, HPM, Amdex) also make a version of this socket for use as carrier sockets for the internet (when provided via a twisted pair of wires). This level of cabling is often referred to as Category 3.

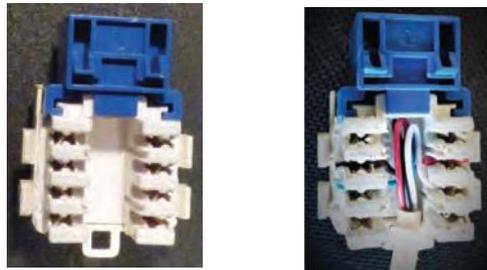


FIGURE 19.23 Krone 8P4C telephone socket detailing the connections and termination of a two-pair

Robert Wickstead

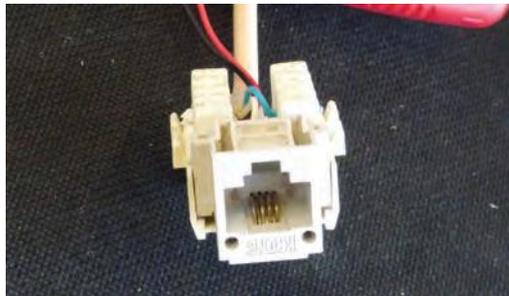


FIGURE 19.24 Nose of a Krone 8P4C socket; note the RJ45 shape (yet only four pins are installed)

Robert Wickstead

This type of socket, while being suitable for NBN connections, is not to be used for any ethernet type of system: it is only to allow an NBN modem to connect to the NBN system. The modem will then have an output that is ethernet and the installer will need to cable and terminate to this standard using the 8P8C sockets, Category 5 or above. This will be covered in further detail in **Chapter 20**.

19.3.2 Distributors

AS/CA S009:2020 (Section 4.2.34) defines a distributor as:

- ▶ a collection of components used to terminate cables, which:
 - ▶ provides for cross-connection of cables or cable elements; and
 - ▶ excludes an assembly of sockets used for connection, using cords, of no more than six telecommunications outlet cables to other cables or equipment.

The hierarchy for distributors through a telecommunications cabling system flows from carrier to the end user. *AS/NZS 11801.1:2019* discusses the use of distributors in a structured cabling system. Essentially, the campus distributor is also known as the main distribution frame (MDF). This is the frame that houses the carrier's lead-in cable and provides distribution to the customer's cabling.

The four most used termination blocks are:

1. ADC/Krone disconnect
2. 110 system
3. patch panel
4. pair management (highband).

These termination blocks are collectively known as a distributor and, depending on their location, will either be an MDF, a building distributor or a floor distributor. It is important to comply with the carrier's requirements and choose only ADC/Krone termination block types (sometimes known as an insulation displacement connection (IDC) system) to terminate the lead-in cable; all other types of termination blocks can be used on the customer's side.

Preparing a backbone cable for termination

The steps in terminating backbone cables are as follows:

1. remove the sheath
2. secure the end of the cable to maintain pair integrity by using a cable tie around the cable and form a tree if the cable is over four pairs
3. crank the individual wires so that the pair is ready for termination if needed
4. place the cable onto the termination position
5. terminate and fix the cable into place.

SHEATH REMOVAL

The removal of the sheath is typically done with a specialised cable stripper. When stripping cables, at least 350 mm should be removed from the sheath in order to expose the cable pairs. It is of great importance that the ends of the cable pairs are secured and tied together to avoid losing the pairs. If the ends of the cable are not secure there is a risk of losing the cable mates. If the pairs are disturbed it is difficult to determine which white mate goes with which coloured wire.

SECURING CABLES

The ends of the cables need to be secure to maintain pair integrity. Wrap cable ties around the cable bundles to form a tree. Crank individual wires to maintain the pair ready for termination. Place the cable onto the termination position then terminate and fix the cable into place.

CABLE LOOMING

As the cabling is split into groupings of ten pairs, it is important to make it easier to terminate by looming the cable into ten even groups of ten. Refer to **Figure 19.14** for an example of a cable loom.

CRANKING PAIRS

To crank a pair, twist in the end of the cable to ensure that the pair is kept together and is not lost. It is imperative that the A and B wires do not get split up (see **Figure 19.25**).

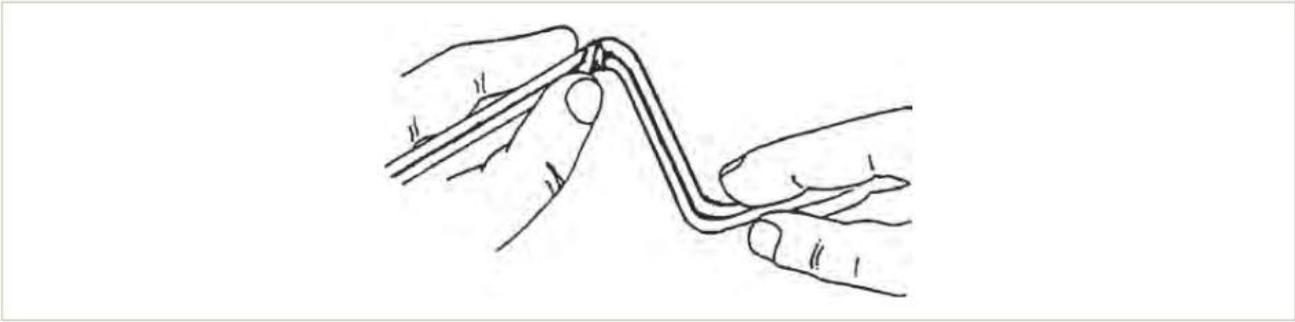


FIGURE 19.25 Cranking pairs

PUTTING CABLE INTO PLACE

The cable should be put in place in the order of the colour code. Pairs should go from left to right, starting at Pair 1. The A wire goes first and the B wire second (see **Figure 19.26**).

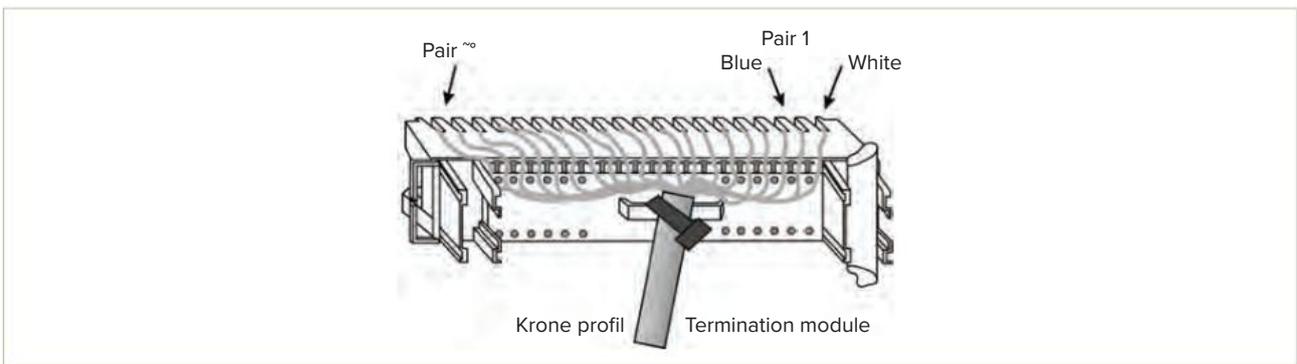


FIGURE 19.26 Placing cables in position

Cabling providers have to learn how to prepare and terminate up to 50-pair cables. Learning the 50 pairs first enables cabling providers to prepare and terminate all types of telephone backbones, from the smallest up to 100 pairs.

As manufacturers design and construct UTP and STP cables differently, it is always best to consult the manufacturer's guidelines when terminating twisted pair cables. As a general guide, the steps to prepare and terminate the cable in place are as follows:

1. remove the sheath with cable strippers
2. remove any separator or braid to expose the pairs
3. place the pairs onto the outlet following the colour-coding system
4. punch down the pairs with an appropriate termination tool
5. check the position of the pairs and polarity.

In all cases of cable termination, the manufacturer's twist rate is required to be maintained up until the actual connection is made. As an installer, it might be a good idea to remember *Twist is King*.

NOTE: Fixed cabling for backbones and client cabling should always be installed on the top of the distribution module. Always start with the A leg wire (mate) on the left terminal followed by the B leg wire (coloured) next to it.

Terminating the cable

The appropriate tool should be used to fix the cabling into place ready to terminate. The two styles of termination, ADC/Krone and 110 system, require two different tools. It is extremely important that the correct tool is used

for the job as using the incorrect tool may compromise the integrity of the telecommunications equipment. It is common for installers to use credit cards or flat-blade screwdrivers to terminate cabling in place at both the field and distributor. However, this damages the equipment and voids warranty. The ADC/Krone tool uses an IDC. The tool pushes into the module with the scissors facing down; these then push the wire pair down into place and chop off the excess conductors. The most common type of termination found in legacy telephone systems is that of the 10-pair disconnect module, commonly called the Krone module.

Once a cable has been hauled and prepared for termination it is time to terminate the cabling to allow for distribution from the active to the passive side. The carrier will always terminate on the active side of a distributor, from the top of the module. The bottom part of the module is to allow the installer to terminate jumper wires to connect in-house services to the carrier. This module is commonly referred to as a Krone 10-pair module (see **Figure 19.27**). The disconnect module allows the carrier to plug in test equipment and isolate the incoming and outgoing cables. The carrier's lead-in cable will terminate on the black side (e.g. on top) of the module (see **Figure 19.28**).

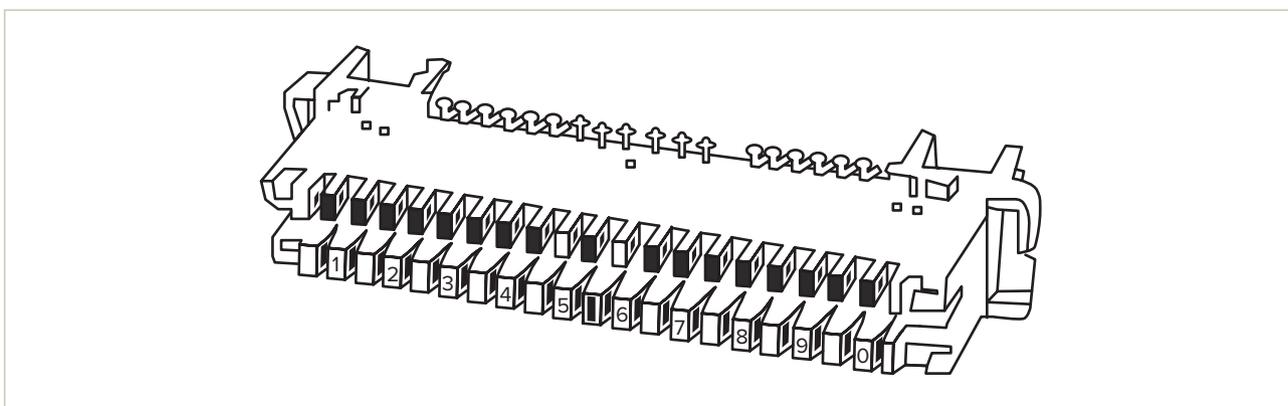


FIGURE 19.27 10-pair disconnection module



FIGURE 19.28 Using the Krone tool on a disconnection module (note there is a very slight tilt into the cut)

Robert Wickstead

When terminating these modules, it is vital that the installer allows enough slack in the cable, both before and after terminating, to allow for fault finding and pair identification. Cabling will be terminated at two ends; backbone cabling will usually terminate in the same style at either end. Cabling for field outlets may terminate from a distributor and then at the field on various types of outlets. Termination types can be split into two categories: distributor and field.



CAUTION

It is important that cabling providers choose the correct style of termination type to suit clients' and carriers' requirements. The carrier mandates the use of the Krone 10-pair disconnect module for any twisted pair lead-in cable termination. The carrier's requirements are mandatory and installers need to match the termination type to the client's specifications and requirements.

Cabling beyond the carrier's demarcation point can terminate on any permitted type of termination equipment. Typically, cabling providers will match the style of termination module for the incoming and outgoing cabling to keep a uniform standard throughout the voice hierarchy.



CHECK YOUR UNDERSTANDING

11. According to *Table 2 in Section 9 of AS/CA S009:2020*, telecommunications outlets require separation from LV power cable by a permanent rigidly fixed barrier of durable insulating material or earthed metal between the two services. What is the minimum termination separation required for compliance?
12. According to *Section 4.2.34 of AS/CA S009:2020*, what are the two results of using a distributor to terminate cables?
13. When terminating multiple-pair cable onto a 10-pair ADC/Krone module, what is the correct termination sequence for the pairs?
14. A 20-pair cable is used for small backbone links from a distribution frame to a floor distributor. What would be the A and B wires of the fifteenth pair of a 20-pair internal cable?
15. What is the only termination block to be used for the carrier's incoming line?

19.4 Cabling systems

A cable is only as good as the connector on it, and the connector is only as good as the equipment it services. So, installers need to ensure the cable matches the connector (socket) for the system in use and is fit for purpose. Installers cable an installation using one of two systems: the horizontal system or the backbone (vertical) system.

NOTE: *AS/CA S009:2020 (Section 5.2)* states that cable and equipment installed for connection to a carrier's telecommunications network shall be installed:

- (a) in accordance with the manufacturer's instructions, including, in the case of cable, such things as cable bend radius, tension, cable tie pressure, colour code, etc.; and
- (b) in accordance with the instructions of the manufacturer or supplier of any equipment to which the cable or equipment is to be connected.

19.4.1 Legacy cabling systems

Older wiring systems involved separate cabling for telephone and data. The data cabling was usually installed by installers certified by individual companies, allowing those companies to then install their equipment and use the cable, with a good level of success. This cable was usually Category 5.

Telephone cabling was performed either by Telecom (precursor of Telstra) or by a licensed sub-contractor of Telecom. This was done to allow Telecom telephones to be installed and to ensure they worked properly. When deregulation hit fully, the carrier was restricted to supplying the incoming telephone wiring and the cabler then installed all the field wiring. This system involved a series of distribution systems (mainly distribution frames revolving around the Krone system), with cabling having a top-down approach. This system, called pre-structured cabling, still relied on different connectors, distributors, cables, techniques and so on, making it quite difficult to interface between the two (see **Figure 19.29**).

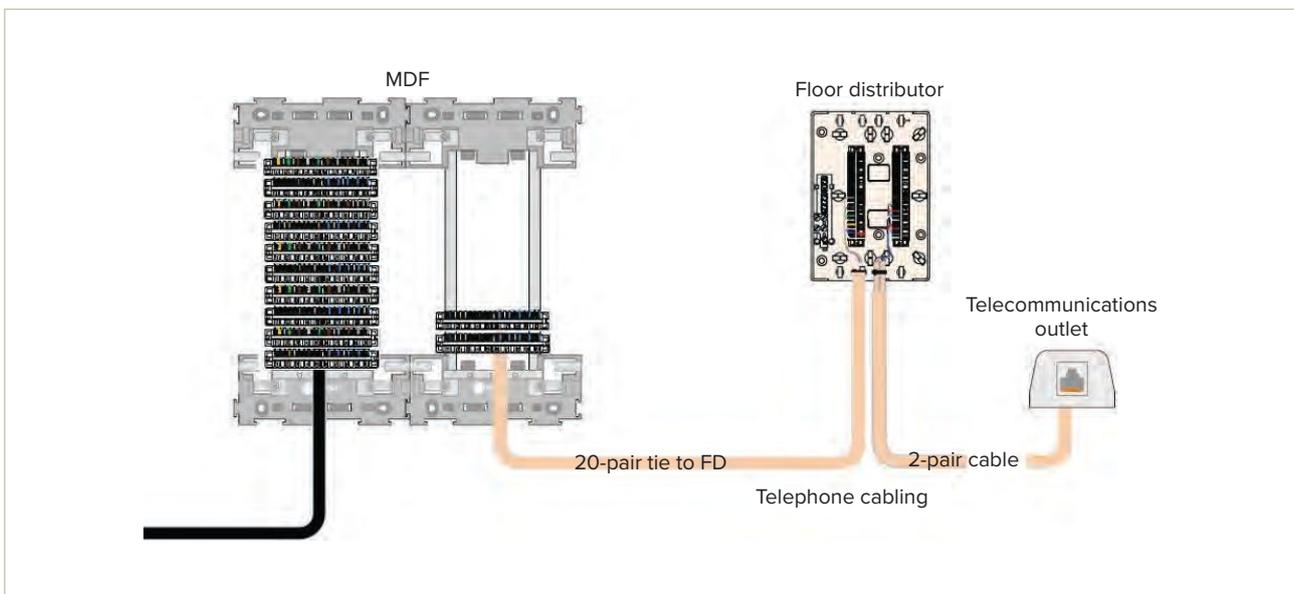


FIGURE 19.29 Pre-structured cabling

As electronics, skills, equipment and knowledge improved, the industry rapidly migrated to a system that allowed a multitude of equipment to use one system of wiring and communications and provide a method of interfacing different technologies together. For instance, Category 6 cable can be used for data, facsimile, printing, data storage, CCTV, electronic security, access control, process engineering and controls, among other uses, with only one type of connector and cable. This system is commonly referred to as structured cabling and is the most widely used system for cabling in the commercial area.

Structured cabling actually makes the installer's job much easier as complexity is minimised and the installer can concentrate on doing one job (supplying and installing high-speed data cabling) at a very high level without having to worry about interfacing. It also makes the client's ongoing tasks much easier to manage and keep track of, as they decide what they want the cable to do and what plugs into it. And this is without having to get the installer involved (in most cases). See **Figure 19.30**.

This system will be discussed in more detail in **Chapter 20**.

19.4.2 Horizontal cabling

Horizontal cabling (sometimes referred to as field cabling) is a term used to describe the cables, supports, terminations, equipment to be plugged in, and the users' needs, all rolled into one system. Essentially, horizontal cable is cable

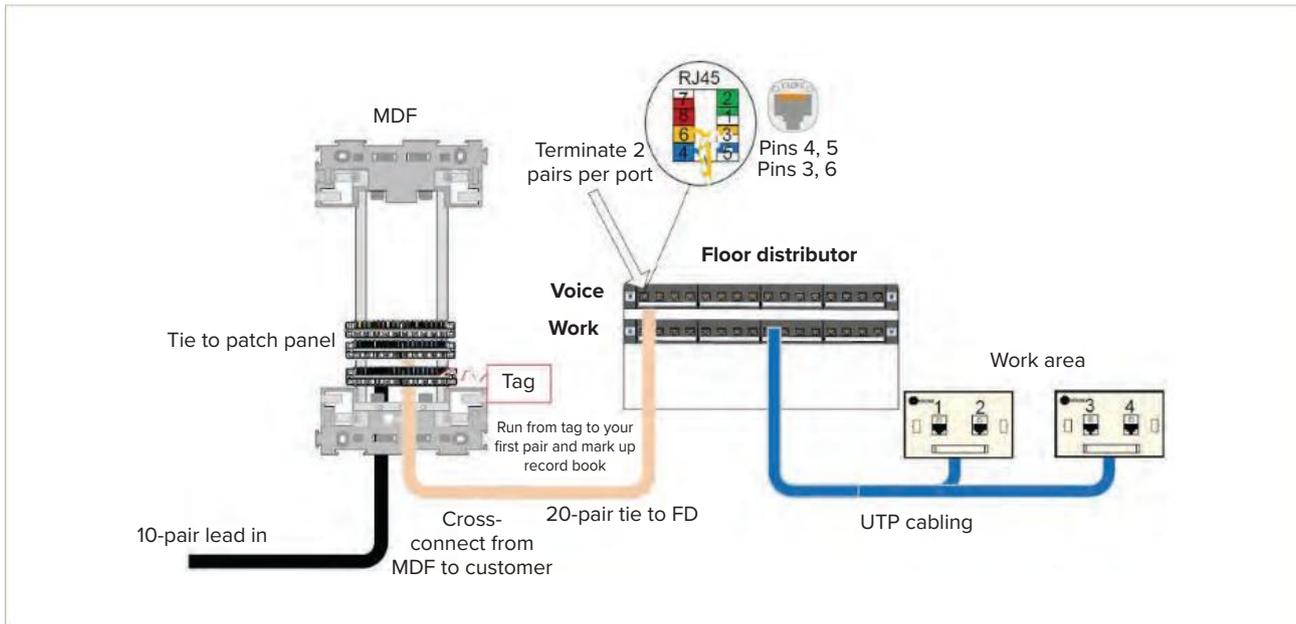


FIGURE 19.30 Structured cabling

originating from a point where a service can be accessed to the actual equipment terminated to that cable. This is diagrammed in **Figure 19.31**.

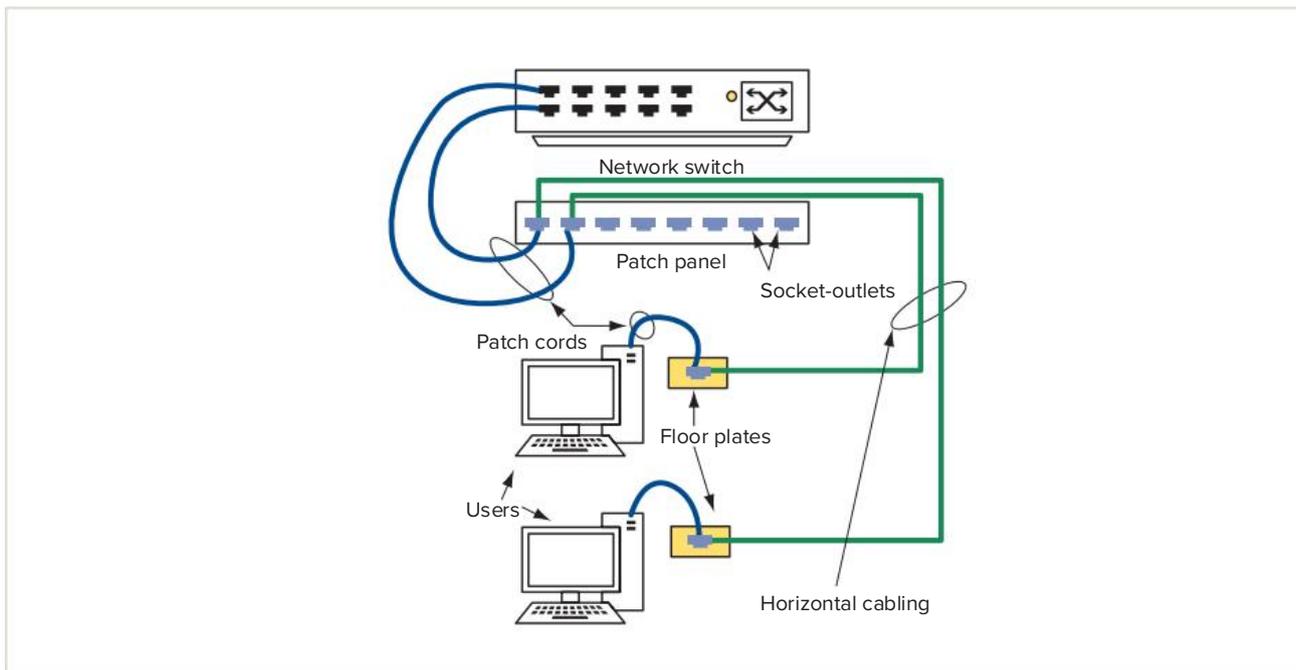


FIGURE 19.31 Horizontal cabling

Historically, horizontal cabling was composed of a combination of 2-pair telephone cable and 4-pair data cable (pre-structured cabling). This complicated the installation as there were quite often multiple parties involved in the project. Now, horizontal cable is mainly comprised of 4-pair Category 6 (or higher) cable and connectors, supplied and installed by a single contractor (structured cabling). This contractor would also be responsible for testing and certifying the installation and providing any guarantees required.

19.4.3 Vertical cabling

Vertical cabling (sometimes called backbone cabling) is used when there are a large number of users needing to access a small number of services, such as:

- ▶ internet
- ▶ email
- ▶ printing
- ▶ storage
- ▶ telephone.

With a standard NBN connection to a premises, some system has to be in place to allow the different users to share the connection and other services. Equipment like a switching hub and patch panels allow the different users access to these services by allocating space to the data traffic, much like merging onto a freeway. Historically, vertical cable has been a combination of multipair telephone cable and various high-speed copper cable. Currently, copper is being replaced by fibre due to its ability to carry large data streams with little loss across long distances. When there is a requirement to distribute a video signal to multiple locations (e.g. Foxtel or free-to-air), a coaxial cable will be used for this backbone cable.

The NBN (as the carrier) cannot possibly allocate individual connections to each person, especially if that connection is only used for a small fraction of the total possible time. So equipment is installed to allow this sharing to take place. To make the system more user-friendly, this equipment is spread out to different areas and then interconnected. The different areas could be wiring closets on each floor and users would be connected to the closets with horizontal cabling.

In order to allow the users to access the different services, the various closets are then interconnected, allowing transfer of information between them and also access to the NBN system. The cabling interlinking all these areas is vertical cable and is usually run in a purpose-built riser system in buildings but can be as simple as a high-speed copper link (e.g. Category 6A or Category 8.1). See **Figure 19.32**.

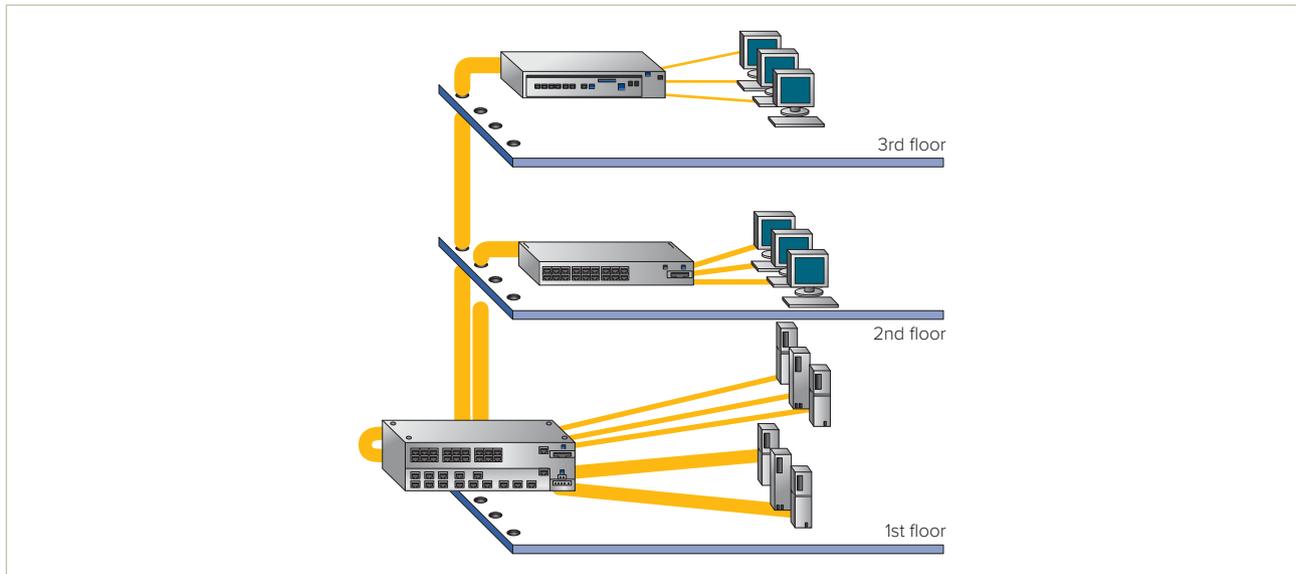


FIGURE 19.32 Vertical or backbone cabling

A rule of thumb is to have a backbone system that is capable of transmitting 10 times the average user's needs between devices (i.e. telecommunications closets, switching hubs, wireless access points, etc.). For example, a standard Category 6 horizontal cabling system would need a Category 6A vertical cabling system.

Commercial establishments will typically use MMOF as the backbone, and the NBN would use SMOF coming in from the street. Various pieces of equipment would then be used to change the signal from single mode to multi-mode to copper and distributed to the different users.

Domestically, it is not common to have a backbone cabling system due to the short distances the horizontal cable is required to run. However, anything greater than about 80 m would require a backbone distribution system.

Vertical cabling is discussed in further detail in **Chapter 20**.



CHECK YOUR UNDERSTANDING

16. What name is given to the cable that goes from a distributor to an outlet?
17. What is the other name given to the modular field outlet for NBN modems?
18. What is the cable that connects two distributors together?

19.5 Earthing

Earthing is a general electrical term that indicates being connected to the general mass of earth, which is used to ensure the safety device will operate in the event of a fault to earth. This is quite common in low-voltage and high-voltage systems. A more detailed discussion of earthing is given in **Chapter 12**.

In general, the telecommunications system relies on much lower voltages, which are referred to as *extra-low voltages* (ELV). *AS/CA S009:2020* discusses these different voltages in *Section 4.2.65* and *Table 2*. However, the Standard equates the voltages to a level of danger, as outlined in *Section 9.3*. For the sake of discussion, the term *ELV* will be used.

As with any a.c. voltage, a magnetic field will be generated and any metallic item in that field will then generate a secondary voltage due to magnetic conduction. This also occurs in a telecommunications system and many different steps are taken to minimise or exploit this magnetic field. These include:

- ▶ using transformers to step down the voltage to allow 5 and 12 V d.c. supplies
- ▶ using isolation transformers to disconnect the source from the device
- ▶ using testing to indicate a satisfactory level of discrimination.

There are other steps that can be taken to try and rid the system of unwanted voltages generated from magnetic coupling. These include:

- ▶ shielding cables to prevent the ingress of the magnetic fields
- ▶ shielding cables to keep information secure and minimise the egress of data signals
- ▶ twisting the cables to minimise the effect of external voltages on the data.

This is discussed in further detail in **Chapter 20**.

AS/CA S009:2020, Section 20 provides an in-depth system for helping to reduce the effect of these outside voltages, some aspects of which are briefly discussed in the following sections. Cables should have a solid understanding of *Section 20* to ensure the safety and performance of the systems they install.

19.5.1 Communications earthing system

The communications earthing system (CES) covered in *AS/CA S009:2020, Section 20.12* describes the earthing system of the telecommunications installation, which is kept separate and distinct from the main electrical earthing installation. Connecting to earthing points other than the telecommunication bonding points is not recommended. This is in order to maintain the integrity and safety of the installation.

The CES will have one equipotential bonding connection to the communications earth terminal (CET) and the earthing system of the electrical installation. A good electrical earthing connection from the earthing system of an electrical installation will ensure any over-voltage conditions or surges will have a clear path to earth (see **Figure 19.33**).

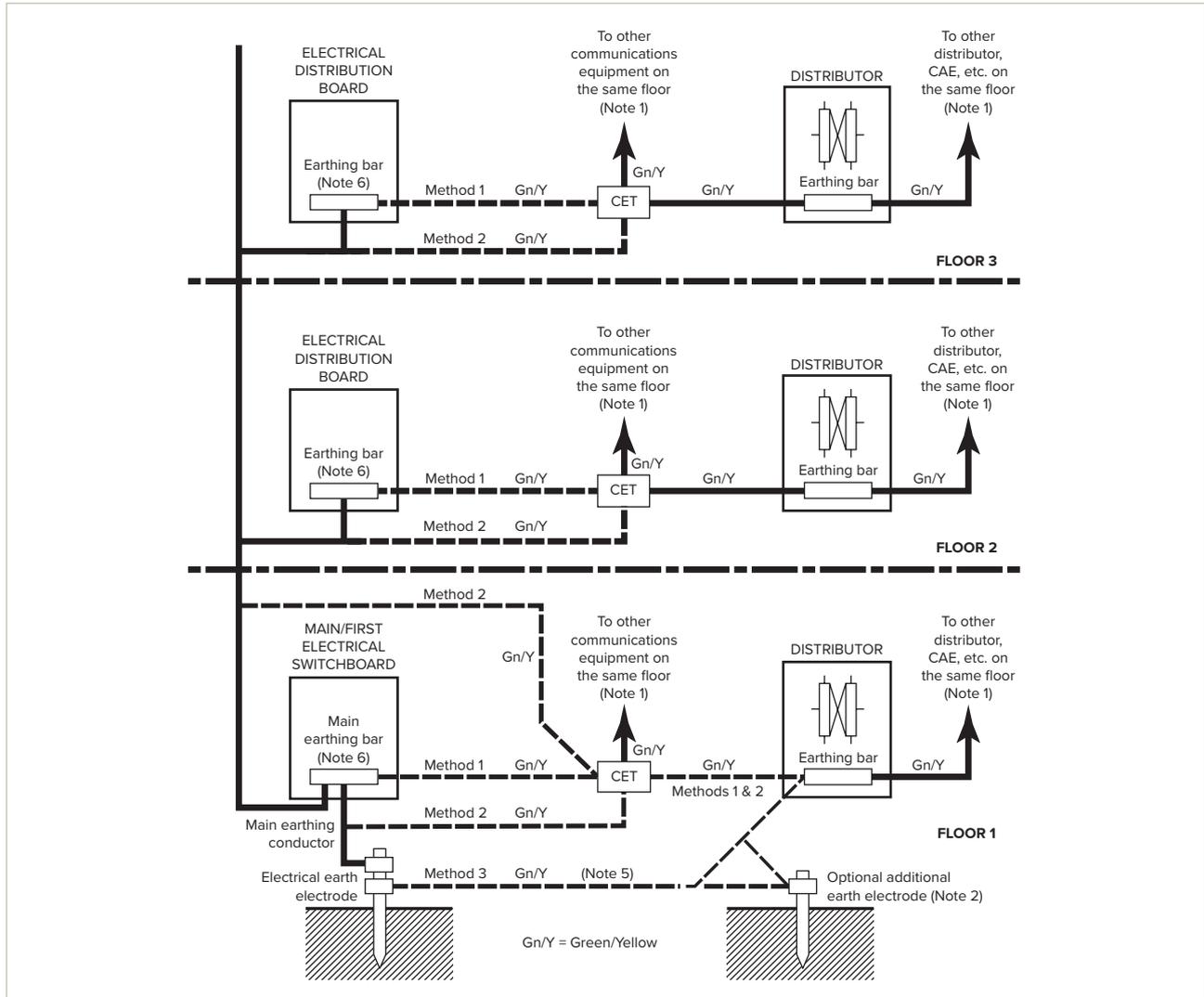


FIGURE 19.33 Typical CES for a commercial building

Refer to *AS/CA S009:2020* for a description of the Notes.

Source: *AS/CA S009:2020, Section 20, Figure 4*, Communications Alliance Ltd 2020

19.5.2 Definitions

Some definitions are provided below to help make the CES easier to understand.

Multiple earthed neutral system

The multiple earthed neutral (MEN) system is the building electrical earthing system used and installed by electricians. As defined by *AS/NZS 3000*, the MEN system is a system of earthing that shall be deemed to satisfy the requirements of *Clause 5.1* in which the parts of an electrical installation required to be earthed are connected to the general mass of earth. They should also be connected within the electrical installation to the neutral conductor of the supply system.

Communications earthing conductor

The CES is used for both protection and functional purposes and is wired using a stranded conductor cable, the communications earthing conductor (CEC) with Green/Yellow insulation. *AS/CA S009:2013, Table 7* notes the CES sizes. The CES will have one equipotential bond from the CET to an earth bar/link bar, which connects to the

building's protective earth; the size is 6 mm² Green/Yellow insulation. Earthing is installed on an as-needed basis. The only mandatory earth required on an installation is when a distributor requires surge suppression. All other parts need not be earthed.

General requirements of the CES

The connection from the surge suppression device to the electrical switchboard should be as short as is practical, ideally no more than 10 m and preferably 1.5 m or less.

Resistance

The resistance of the earthing conductor between the point of connection to the earthing system of the electrical installation and the earthing bar or terminal at any MDF, network termination device, distributor or customer access equipment should not exceed 1 Ω .

Telecommunications reference conductor

AS/CA S009:2020, Section 20.13.1 describes the telecommunications reference conductor (TRC) as 'a functional earthing system that is Connected to an earth reference at one point only in a Building to minimise noise and emanates from a TRC link bar located at the nearest Distributor to the main or first electrical switchboard in the Building'. The TRC is used to minimise noise and stray voltages that may be encountered on cables. The TRC is *not* a safety earth and is installed with this in mind. Fortunately, it is not used much in modern communications systems as the concept of the TRC can be confusing.

Some installation practices relating to the TRC are:

- ▶ its resistance limits should not exceed 5 Ω
- ▶ it must be star wired and must not be cut at any point
- ▶ it must have one equipotential bond at only one point in the system
- ▶ it must be violet in colour.

It is important to consider the following from *Clause 20.13.1* of *AS/CA S009:2013*:

Note 1: On TRC systems installed before October 1990, the TRC was coloured red.

Note 2: The TRC is generally considered to be a live conductor, comparable to the neutral conductor of an a.c. mains supply system, i.e. earthed at the source only.

For safety reasons, it is especially important to note that red is used as an active conductor for power and that the TRC should not be disconnected at any point without removing the link to the equipotential bond.

Where necessary, a TRC may be used; however, a TRC is generally an optional addition to a building's cabling system.

Earthing cabling

Earthing cabling to be used in a telecommunications cabling system is not mandatory except in situations that require surge suppression. The need for earthing is subject to the requirements of the site. It is good practice, however, to install recommended earthing systems to allow for future needs. As a minimum, the CES system should be installed. This will require a cable from the main electrical switchboard to a CET. Earthing cables for communications use should be stranded and comply with the Telecommunications Labelling Notice. The sizes and colours of earthing cables should follow the requirements of *Table 7* of *AS/CA S009:2020*.

Insulation resistance

It is important that the sheath material around conductors can withstand not only environmental conditions but also mechanical and electrical conditions. To find out the quality of the insulation around each conductor, cable providers need to measure the dielectric strength of the insulation.

An ohmmeter will not provide a voltage high enough to stress the insulation; instead, installers need to use an insulation resistance tester (IRT), also known as a megohmmeter or megger. The IRT is similar to an ohmmeter

except that it outputs a much higher test voltage and the reading is in milliohms. The test voltage is typically 500 V d.c. but some testers have a selectable voltage of 250 V d.c. up to 1000 V d.c.

As the IRT outputs these voltages, any misuse places operators at risk of electric shock. The tester does not normally produce enough current to cause serious damage but the shock itself would cause discomfort. Furthermore, after testing with an IRT, installers need to place a short across the cable conductors to discharge any residual charge due to the capacitive nature of the cable.

Low insulation resistance may be due to damage to wire insulation. It could also be more noticeable in an underground cable after wet weather—moisture in the cable means the insulation around the conductors is less effective. For telephony services, low insulation resistance faults may appear as crossed lines or cross-talk because there is a low-resistance path between adjacent telecommunications circuits.

Labelling earthing cable

Labelling of earthing cable should be carried out in accordance with *AS/CA S009:2020, Section 20*. The two mandatory labelling requirements for earthing are as follows:

- ▶ designated distributor
- ▶ telecommunications functional earth electrode.

Other labelling of earthing cable should fit into the structured cabling system design and labelling requirements of the site.

Designated distributor

The designated distributor is a distributor, near the main or first electrical switchboard in the building, designated by the cabling provider as the most appropriate option for distribution of a TRC system. This distributor is typically the MDF or the first readily accessible distributor closest to the main electrical switchboard.

Figure 7 of AS/CA S009:2020, Section 20 shows the possible connections from the main switchboard to the CES and the connection to the CET:

- ▶ Method 1: The cable is brought from the main earth bar to the CET. This connection must be conducted by a licensed electrician and is the preferred method.
- ▶ Method 2: The cable has a soldered T connection from the feed from the earth electrode to the CET. This method may be carried out by a registered cabling provider.
- ▶ Method 3: The cable is brought directly from the earth electrode to the earthing bar of the designated distributor.

The possible connections are illustrated in **Figure 19.34**.

Of the three methods discussed in *AS/CA S009:2020*, the safest and most reliable is Method 1 as this is the only one with reliable connection to the building earth. This is especially important as a lot of new installations now rely on a buried earth electrode system, which not easily accessed outside of the main switchboard.

Telecommunications functional earth electrode

The telecommunications functional earth electrode (TFEE) should be permanently labelled *telecommunications electrode* at both ends of the installation. The TFEE is used when the main earth electrode is too noisy. In modern data systems, the TRC and the TFEE are not necessary or used. However, there is a good probability of both being in place in legacy systems.

Power distribution current limiting

Where customer cabling is used for power feeding other than power derived from a carriage service, the cabling should be protected from excessive current flow that may cause damage or fire. This can be done by means such as fuses, circuit-breakers or current-limiting circuitry. It is quite commonly done by the device supplying power itself. For instance, when using power over ethernet (PoE), the voltage needed by the device is generated and regulated by the switch or injector.

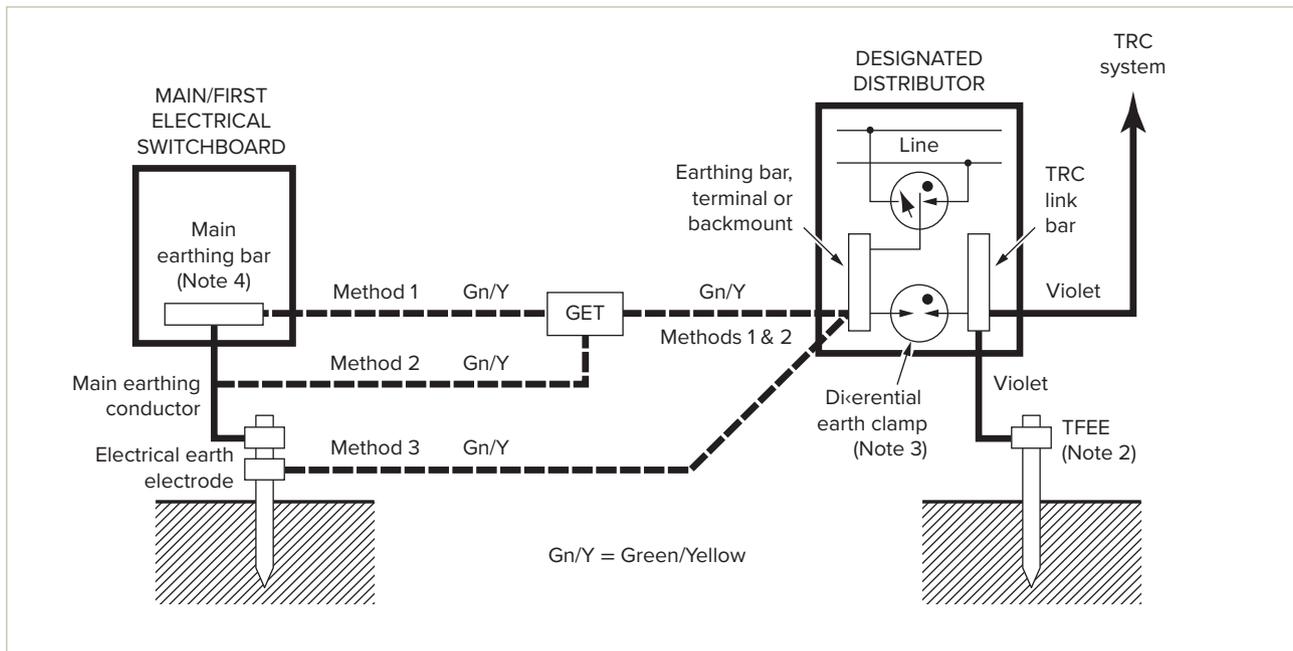


FIGURE 19.34 Equipotential bonding of the TRC to the electrical earthing system

Refer to *AS/CA S009:2020* for a description of the Notes.

Source: *AS/CA S009:2020, Section 8, Figure 7, Communications Alliance Ltd 2020*

Note: This includes single-core conductors or busbars used for an ELV (d.c. or a.c.) power supply system used to power telecommunications equipment. However, the PoE cables should be treated as any other live TRC conductor and power removed and made safe prior to working on the cable.

Alterations

From time to time, as businesses expand, it may be necessary to extend an earthing system or to move or change an existing set-up. It is important for cabling providers to maintain the integrity of the earthing system and to be mindful of adding cabling to the installation while still maintaining compliance with the Standard.

As earthing systems have resistance limits, it is important when adding cabling to an earthing system to consider the size of the conductor of the existing cable and work out what size of new earth cable is required in order to maintain compliance with the Standard. *Table 6 of AS/CA S009:2013* sets out the resistance limits of conductive earth cable per km.

Extra-low-voltage direct current

The extra-low-voltage direct current (ELV d.c.) is a system whereby positive or negative conductors of a d.c. supply are used to distribute earth to the equipment.

Extra-low-voltage direct current system installation

Installations in restricted-access locations operating an ELV d.c. power supply system may provide for d.c./earth return paths in accordance with *AS/NZS 3015*. With this system, the earth may be distributed to equipment via the positive or negative conductor of the d.c. supply.

The ELV d.c. system requires that the safety of the cabling provider and general public is maintained through adequate labelling and the installation of current-limiting devices such as circuit breakers to protect the circuit. A d.c. earth return circuit may be required where continuous direct current (d.c.) will be discharged to earth. Such circuits require the installation of a dedicated earth electrode to prevent damage to the electrical earthing system. Earthing conductors used for this purpose have violet insulation and are labelled at each termination point. For example, from the earth bar at a distributor you could connect an earth cable to a cable tray to allow for protection from accidental bonding. Another example is connecting an earth cable from the earth bar up to a customer's private branch exchange to protect the technicians working on the system from static discharge or over-voltage conditions.

NOTE: The professional cabling installer should be quite familiar with *AS/CA S009:2020*. It is highly recommended that students study this Standard before attempting to gain their open cabling registration. Studying individually and in small groups can be advantageous.



CHECK YOUR UNDERSTANDING

19. Given the resistance between the building protective earth and the CET is negligible, what is the maximum resistance between the CET and a distributor?
20. A telecommunications-only tray is to be used to support a bundle of cables. This tray is required to be earthed. To what system should the cabler connect the earth?
21. What is the colour and size of the communications bonding conductor connection between the CET and the building protective earth?
22. The CES should only have one equipotential bonding connection to the building earthing system. What is this common connection called?
23. What is the minimum size and colour of the conductor cable connecting the TFEE to the TRC?

SUMMARY

- ▶ The Australian Communications and Media Authority is responsible for administering the telecommunications industry in Australia.
- ▶ The Australian Communications and Media Authority has developed a range of rules, standards and legislation to assist cabling installers to work safely in the industry.
- ▶ There are many different types of cables and conduits in use, including:
 - ▶ indoor
 - ▶ riser
 - ▶ outdoor
 - ▶ underground
 - ▶ aerial.
- ▶ There are accepted colour codes in use to assist cablers to identify systems and connections.
- ▶ Specialist cables such as fibre optic, coaxial and high-speed copper have different uses.
- ▶ There is a wide variety of termination types designed to maximise throughput.
- ▶ Three basic cabling systems are in use:
 - ▶ legacy (older telephone types)
 - ▶ horizontal
 - ▶ vertical.
- ▶ There is a comprehensive system of earthing, grounding and bonding in use in the telecommunications industry that cablers need to be familiar with.

REVIEW QUESTIONS

1. Who is the ACMA and what is its role?
2. What standards must installers use for cabling? What other standards can cable installers use?
3. Explain what TCA1 and TCA2 forms are used for and who receives each form.
4. Explain how to become an open cabling provider.
5. Briefly describe the main sections in *AS/CA S009:2020*.
6. Describe a basic cable construction.
7. Describe the different properties needed for:
 - ▶ indoor cable
 - ▶ outdoor cable
 - ▶ underground cable
 - ▶ aerial cable.
8. Outline the prohibited conduit colours prescribed by *AS/CA S009:2020* and the service each colour is associated with.
9. Where in the *AS/CA S009:2020* can you find information about the colour coding of multipair cables?
10. Draw and identify the main components of a fibre optic cable.
11. Draw and identify the main components of coaxial cable.
12. Describe the most common type of field outlets currently in use.
13. Describe how a carrier will terminate cable on a distributor.
14. Describe the different cabling systems in use.
15. Describe the CES system.
16. Describe the TRC system.
17. What colour cables will be used in each of the following?
 - a. CEC
 - b. TRC
 - c. d.c. earth return.
18. When connecting the CET to the main building earthing system, what is the preferred method outlined in *AS/CA S009:2020*?

CHAPTER 20

Install, modify and verify coaxial and structured communication copper cabling

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ identify different categories and classes of cables
- ▶ recognise the importance of different network layouts
- ▶ explain the different types of cables
- ▶ identify different types of coaxial cables
- ▶ recognise physical faults in cable routes
- ▶ identify different testing parameters for cables
- ▶ understand the importance of earthing and grounding
- ▶ identify basic National Broadband Network components.

This chapter is all about performance and speed. As with performance vehicles, performance data requires specialised and dedicated paths to run properly. While a normal telephone cable can handle some internet traffic, to gain the advantage of high-speed data, the telephone pathway (e.g. the cable and equipment) will need to be upgraded to the minimum standard required for the system being installed. As with a special racetrack to accommodate the anticipated performance car, a Category 6 (Cat 6 or C6) system requires the cable, connectors, patch cords, switches, computers and other pieces of equipment to be able to operate at Category 6 levels. With correct cable connections, a normal telephone can use this system but will be more expensive relatively speaking—much like a typical family car can use a racetrack but will not be cost-effective.

High-speed data uses high-frequency transmission signals for transmission. In some twisted-pair systems, this frequency can be as high as 500 Megahertz (500 MHz or 500 000 000 cycles per second). As the frequency is so high, different methods and technology are required such as twisting the cable pairs tightly together, having special insulation and sheathing, inserting separators between the cable pairs or even using shielded cables.

Any data cabling installed by an electrotechnology worker, whether copper, coaxial or fibre optical, must comply with the established *Wiring Rules* and *AS/CA S009:2020*. *ISO 11801.1* and *11801.2* must also be adhered to.

20.1 High-speed data networks

The cable installer is key to ensuring high-speed data works reliably in a network. If the installer does not connect properly, or damages a cable, attempting to use the high-speed data will be like trying to drag race over a road covered with potholes and speed bumps!

Open Systems Interconnection uses a model to describe the seven layers that systems use to communicate over a network. According to this model the installer operates at Layer 1 in the process (see **Figure 20.1**). Layer 1, the physical layer, is concerned with the physical cables and connections in an installation, and is where cable and data cable terminations play a fundamental part. If the cable, as the foundation of the network, is robust, the functionality of the entire network will be strong. If the foundation is weak, the rest of the network will be unstable.

Layer 7	Application layer	Provides protocols that enable software to send and receive data to/from users: HTTP, Windows, Internet Radio, VoIP, MacOS, etc.
Layer 6	Presentation layer	Prepares data for the application layer by defining how devices encode, encrypt and compress data so that it is received correctly at the other end: ASCII.
Layer 5	Session layer	Creates communication channels between devices, opening them while data is being transferred and closing them when communication ends; assists with continuous data transfer.
Layer 4	Transport layer	Transmits data; checks whether data was received correctly and if not, requests it again; and acknowledges packets received: TCP.
Layer 3	Network layer	Breaks up segments into packets and reassembles the packets on the receiving end; establishes the best path across a physical network: AppleTalk, IPv4 and IPv6; traffic control.
Layer 2	Data link layer	Establishes a connection between two devices on a network; places bits into frames.
Layer 1	Physical layer	Defines the technology connecting devices and transmits raw data as bits: xDSL, USB and Bluetooth; defines the physical medium: cables and connectors.

FIGURE 20.1 Open Systems Interconnection 7-layer model

Source: Adapted from <https://www.imperva.com/learn/application-security/osi-model>

20.1.1 Construction of data cables

The design of data cables centres around several core concepts, one being twisted pairs. Twisting data cables allows them to perform better at longer distances, up to a point. The twisting of data pairs helps to cancel out signal electromagnetic force (or field) (EMF) between conductors. Every cable carrying a voltage will generate a field. This EMF affects the surrounding cables. When cables are twisted, this helps cancel the EMF by reversing the field force (as field made or received by one wire is identical and opposite in the other) allowing high-frequency signals to be transmitted without interference by nearby cables. The other cables also have twists and manufacturers go to great lengths to ensure these twists are different between different pairs in the cable, avoiding mutual interference (i.e. crosstalk). This twist rate variation is vital and must not be altered more than necessary during termination.

EMF crosstalk is also minimised by separating pairs, which is a frequent practice in Category 6 or Category 6A cables (sometimes displayed as C6 or C6A), by having the individual pairs in a separate compartment of the cable. This compartment is made by including a four-compartment separator (star) in the cable, where each pair has its own section. To further combat the EMF crosstalk problem, this separator is also twisted inside the cable, resulting in the pairs having a further twist (several twists in a metre). Sometimes, in high-speed cable (e.g. C6A or C7A), the separator is not equal in section, leading to an oblong cable. The oblong cable then adds yet another limiting factor to the EMF crosstalk, allowing even more data throughput (and more speed).

For a Category 5 cable (sometimes called C5E), the twist rate, separation and internal twisting are not as stringent as that of a C6A. As the frequency of the data transmission rises, so does the EMF crosstalk being generated, and therefore the quality of construction must rise too.

Different cable constructions are shown in **Figure 20.2**.

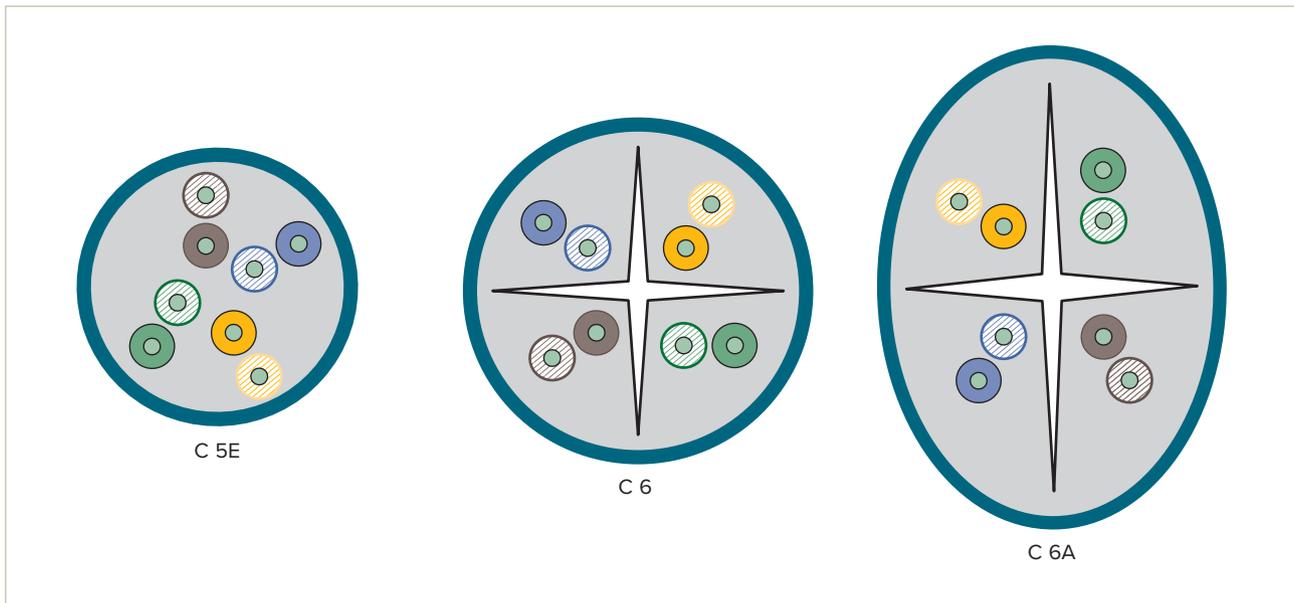


FIGURE 20.2 Cross-sectional view of different data cables

An outer sheath protects the cable wires from mechanical damage. It lacks electrical characteristics but may be designed to resist tearing, piercing, friction burns and vermin among other things. It may also be formulated to resist UV light and to peel open during termination. Powder may be added to allow wire pairs to slip against it during cable laying.

Insulation

A primary purpose of the insulation around a conductor is to keep it mechanically separated from other conductors or from creating an electric shock hazard to people. This is useful for wires carrying low-voltage power and lighting, and to a limited extent for high-voltage power. However, as data cables tend to operate at voltages below the low-voltage range (often lower than 48 V d.c. or 24 V a.c.), the electrical insulation properties are not as important.

The insulation around conductors in high-speed data is very different from that of power wiring cables, as the insulation effects play a vital role in the speed the data cables can work at. As such, insulation tends to be designed with a specific lower dielectric constant (to perform better at the expected higher frequencies) and across the expected temperature ranges the cables may encounter (e.g. in fire-rated areas, outdoor areas, freezers etc.).

Insulation compounds include fluorinated ethylene propylene (FEP), polyethylene (PE), polypropylene (PP), cross-linked (XL) and ethylene chlorotrifluoroethylene (ECTFE). Each one is designed to suit a different environment so as to protect the conductors' ability to transmit the data at the expected rates. Category 5 cables will perform differently from Category 6A cables, even if used for the same purpose. More information on different types of insulation can be found in *AS/NZS 3008.1.1*.

It is important that both the insulation and outer sheathing on cables be kept as free from damage as possible, and that the sheath is kept as close to the connections as possible. This is also a requirement of the manufacturers.

20.1.2 Installation of data cables

Installation of data cable requires checking pathways, hauling cables, ensuring the correct pathways are put in place, removing obstacles to data transmission such as kinks, and terminating cables.

Checking the pathway

There are two scenarios in which a cable installer is required to check the pathway: when a new pathway is needed or when there is a previously established pathway on an existing installation.

In the first instance, where an installation requires a new pathway to be installed, it is easy to check the access conditions for cabling. The installer should check that the new passage for cabling is clear and free from sharp burrs or edges on any metalwork and that other cabling—if used in a shared pathway—will not impede the drawing through of cabling. In the second instance, where an existing installation has an established pathway, the installer must ensure the pathway will support the new cabling and that the installation of the new cabling will not impede on or upset any existing infrastructure.

When installing within a ceiling or floor space lacking any clear pathway and support system, the cabler must install the new cabling in such a way that access to other services, such as gas, water, power and plumbing, is not blocked by the new cabling.

Hauling

Hauling is to drag or pull with force. When used in relation to cabling it refers to the pulling or drawing in of cabling with (limited) force from one point to another. Some cables are specially designed to tolerate this activity. Depending on the type and amount of cabling, the hauling process may require the use of other equipment attached to the cabling to install it on the pathway. This may include hauling eyes, cable grips/socks, rods, rope, rollers, lubricant, benders and any other items used to make sure the haul goes smoothly. Other factors, such as cable specifications, play a key role in determining the hauling capabilities of suitable cable. These include:

- ▶ allowable pulling tension
- ▶ allowable bend radius
- ▶ maximum distance permitted in a length
- ▶ outside diameter of the cable
- ▶ conduit capacity and future growth.

As an installer, it is imperative that not only is the cabling installed in a manner that follows the manufacturer's guidelines but also that the electrical capabilities of the cable are not compromised during installation, impacting cable performance.

Most, if not all, indoor cable cannot tolerate large strong pulling forces. To avoid pulling forces (which can stretch the cable to breaking point in some cases), it is advisable to adopt the gentler method of *placing the cable*. This implies the absence of pulling force, ensuring the cable does not undergo stretching.

Cabling pathways

Cabling pathways refer to the support systems used for cabling within ceilings or under-floor. These protect both the cables and other nearby fittings (or people) while making cables easier to service. A pathway for cabling should cater not only for the immediate cabling needs but also cabling needs for future growth. It is crucial when designing a pathway to ensure that the pathway for both 'vertical' (backbone) and 'horizontal' (local termination) cabling is considered.

Types of pathways

Common pathways include:

- ▶ solid fixings (e.g. conduit, duct and surface-raceway)
- ▶ cable trays
- ▶ ladder trays
- ▶ mesh/basket trays
- ▶ shared trays
- ▶ catenary supports.

Under the mandatory requirements of *AS/CA S009:2020, Section 10*, cables must be secured and supported in the ceiling and under floors, and protected from reasonable harm. It is not permissible to attach cabling to ceiling

hangers or rods within a ceiling or to use any other services as an attachment that have not been installed specifically for use with telecommunications services.

Bearing in mind the number of cables to be supported and the potential future expansion requirements, a system that fits the budget and future needs of the building should be chosen. Manufacturers will provide guidelines for cable bundles.

NOTE: *AS/CA S009:2020, Clause 8.2.1* states that ‘customer cabling shall not be secured to a cable, conduit or pipe of another service (e.g. a power cable/conduit or water/waste pipe)’. This has important safety implications.

SOLID FIXINGS

Common solid fixings include conduit, duct and surface-raceway. Conduit fixing is typically a solid length of hollow material into which cables can be placed. It is available in bendable (i.e. flexible/corrugated) form and is often made of tough/inexpensive PVC plastic. It can also be made from UV-resistant material (black, to resist sunshine), metal (to resist damage or provide electrical shielding) or any convenient soft or moulded shape (e.g. for under-carpet work). Some examples of conduit fixing are shown in **Figure 20.3**.

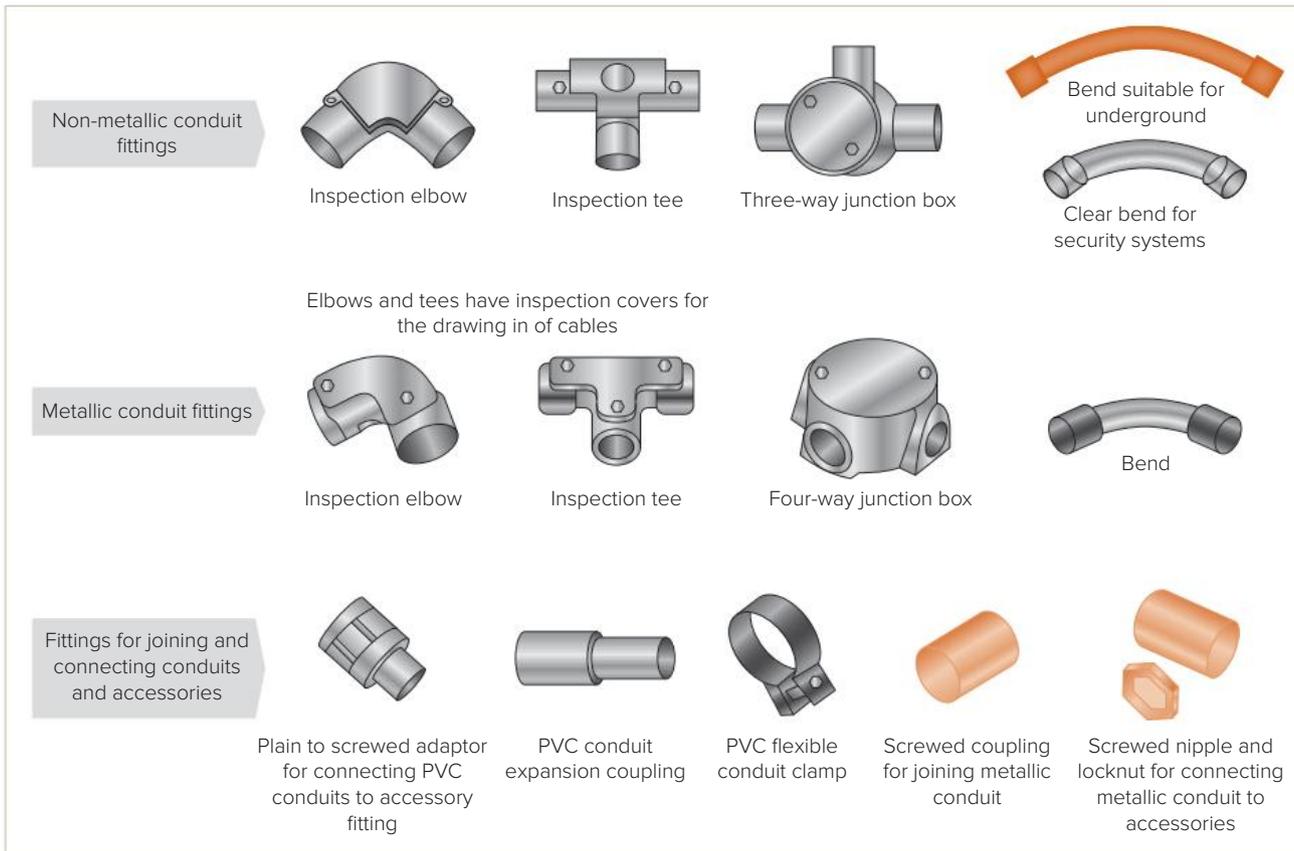


FIGURE 20.3 Examples of conduit fixings

Lids are provided on proud-mounting surface-raceway, or lengths of duct embedded into a surface like a wall. This makes installation, service and upgrades easier. Some convenient support shapes include:

- ▶ umbilicals—useful for cabling suspended from a ceiling, typically to a desk
- ▶ J-hooks—useful for wall-mounting cables
- ▶ girder-clips—for suspending below I-beams
- ▶ cable-management systems—for use within racks
- ▶ slotted (finger) duct—for rack cable distribution.

CABLE TRAYS

A cable tray is a rigid, perforated, mild-steel structure that is typically around 3 m in length. Cable trays are usually installed on walls, ceilings and floors to support multiple cables. They come in various widths, ranging from 100 mm (about the length of the long edge of a credit card) to 500 mm (about half the length of a baseball bat). **Figure 20.4** shows a cable tray installed on a ceiling.



FIGURE 20.4 A cable tray installed on a section of ceiling

Lemau Studio/Shutterstock.com

LADDER TRAYS

A ladder tray is connected by individual transverse members and is designed for use with larger cables and as a backbone cable support system. Typically, such trays are in the shape of a ladder, with a large gap between supports. Ladder trays are used for heavy-duty backbone cables and are supported by solid anchoring to ceilings or floors as shown in **Figure 20.5**.



FIGURE 20.5 Example of a ladder tray

© EzyStrut

MESH/BASKET TRAYS

Basket trays are wire metal basket-style products suited to interior installations (see **Figure 20.6**). They allow for cable drops anywhere along their run. This helps make them an ideal solution for working around complex sites such as computer server rooms or other areas where there is complex machinery. The advantages of basket trays are that they are affordable and allow for growth and expansion.



FIGURE 20.6 Example of a basket tray

SVshot/Shutterstock.com

SHARED TRAYS

It is common for telecommunications services and electrical services to share the same common tray. Shared trays will have a separation between services based on the requirements of *AS/CA S009:2020*. Separation of systems must be in accordance with relevant standards and manufacturers' guidelines. Some manufacturers will not warrant cabling performance if a shared tray system is used and a physical barrier is not installed to ensure segregation. Manufacturers will often require a separation distance which means the use of separate trays and baskets. It is best practice to err on the conservative side and install one's own support structures.

CATENARY SUPPORTS

Catenary support systems are independent wires installed into solid fixings in a ceiling or floor (see **Figure 20.7**). The wire is usually fixed with hooks and eyelets and independently hung to minimise sag and support the weight of the intended load. Catenary wire systems are usually installed to support up to half the maximum load of the fixings, in accordance with the manufacturer's guidelines. Catenary wire should follow the requirements of *Clause 19.4* of *AS/CA S009:2020*.

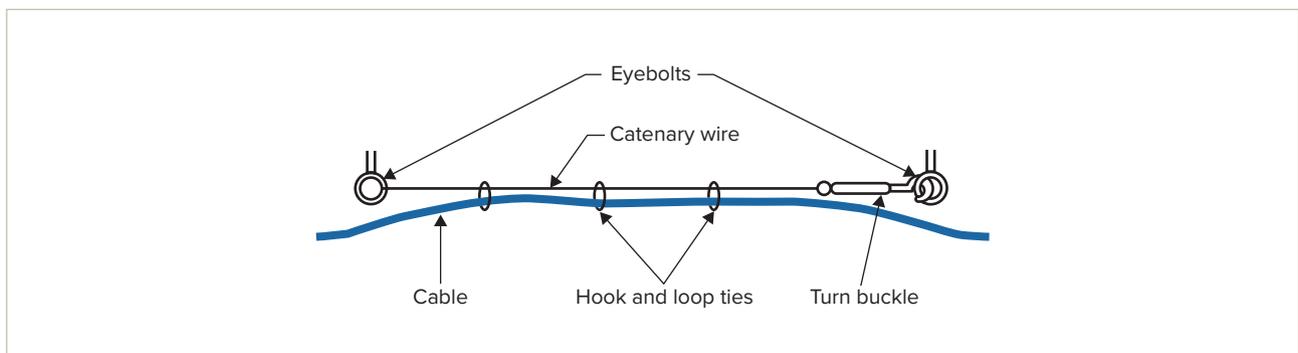


FIGURE 20.7 Example of catenary support system

Some manufacturers recommend a maximum number of cables that can be supported, to ensure not only the safety of the installation but also the electronic capabilities and performance of the cable. Catenary support wires should be installed in such a way that:

- ▶ they are attached to permanent building structures
- ▶ they have an adjustment for tensioning (a turnbuckle)
- ▶ they are strong for the weight of cables attached to them
- ▶ they are located so that access to the area is not obstructed
- ▶ they are at least 75 mm clear of false ceiling tiles and support structures.



CAUTION

Avoid creating pressure points along the cable. Hook and loop support methods should be used for any soft-sheathed indoor cables.

Avoid the use of cable ties wherever possible for indoor cabling.

NOTE: Cabling manufacturers quite often state that for data cabling within a wall space, additional protection is required to ensure the physical separation between the cable and other services—by means of a barrier of durable insulating material placed between them.

As these manufacturers warrant their systems for the lifetime of the cabling system, it is important that the installer is registered with them so that they can ensure proper training and compliance is maintained for the integrator.

Most cabling manufacturers will have warranty programs that involve additional manufacturer training, through either a TAFE or other registered training organisation. This ensures installers are qualified and professionally trained in the correct installation for their product.

Kinking

Kinks in data cables can cause massive restrictions in data flow, much like a kink in a water hose. Unlike a water hose, however, loosening up the kink in a data cable does not always lead to restoration of the data flow. Kinks cause data signal reflections to occur at the position, leading to internal data corruption. Corruption can cause up to 90 per cent constriction of data flow.

To avoid kinks, always ensure cables are not pulled hard out of their boxes and are laid out flat when installing. Kinks can also occur when going around tight bends or when using cable ties. Best practice is to always keep the bend radius at least 10 times the cable diameter. For example, a Category 6 cable of 8 mm nominal diameter should have a bend radius of 80 mm, similar to the size of a wiffle ball or soft ball (see **Figure 20.8**).

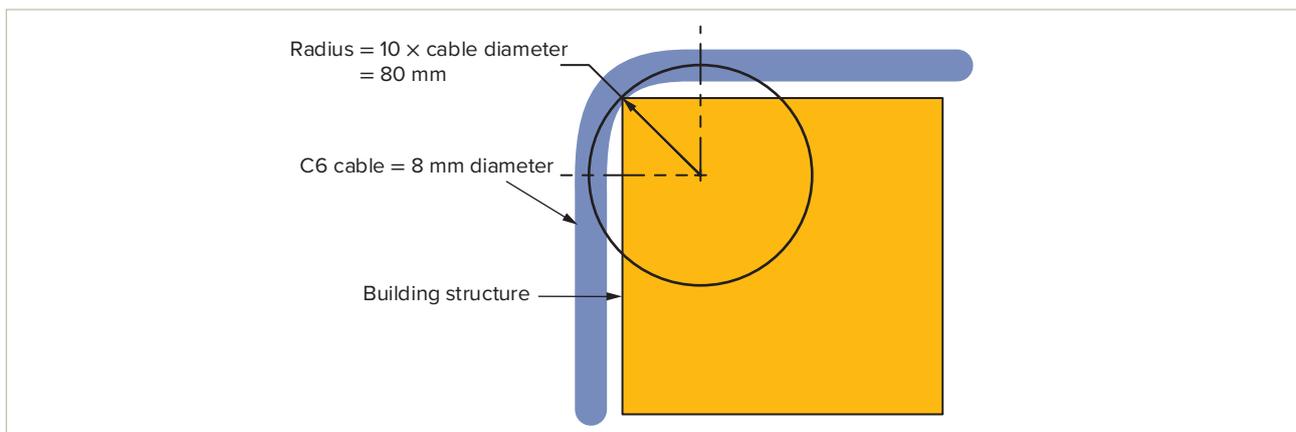


FIGURE 20.8 Example of a suitable cable bend radius

Terminating data cables

When terminating cables, it is important to keep the twist rate constant up to the point of attachment—this is often referred to as punching down the cable (punching down is when the terminating tool is used to push the cable into the connector and then cut the cable flush). Do not untwist the cable any more than necessary to get the cable pairs into their respective slots ready for punching down. While a slight over twist can be tolerated, untwisting the cables can lead to excessive noise being imposed onto the cables, translating to noise and a lower data rate when equipment is used. This is discussed later in the chapter. **Figure 20.9** shows a cable termination.

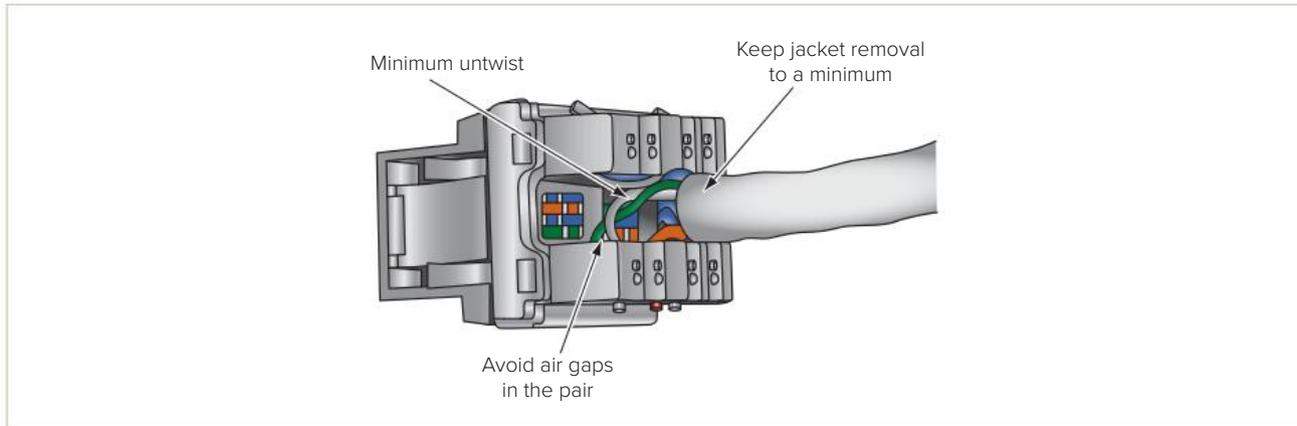


FIGURE 20.9 Example of a cable termination

Source: Adapted from <https://www.flukenetworks.com/knowledge-base/applicationstandards-articles-copper/terminating-category-6-5e-and-5-connector>

20.1.3 Purpose of data cables

By paying careful attention when installing and terminating data cabling in particular, the cabler ensures the optimum performance and lifespan for that cable, allowing it to do the best job it has been designed to do. Examples of where it is particularly important to ensure the optimum functioning of data include the following:

- ▶ *Smart buildings*, which rely on consistent data connections between devices to allow the devices to best control their environment. In such buildings, light levels need to be monitored and lighting adjusted to maintain a constant level throughout the working day while conserving energy where possible. Air-conditioning and ventilation are also monitored. It is of little use detecting the number of people in a room if that data cannot be sent to the receivers properly.
- ▶ *Power over Ethernet (PoE) devices*, such as CCTV cameras or wireless access points (WAPs), which depend on the ability of the data cables not only to transmit the signals correctly but also to get enough operational voltage to the devices, thus allowing them to be powered from their local switches. This reduces the need for low voltage 230 V a.c. plugs at the device or for power packs, which provide power to the data cabling transmitted from the source. Advantages of this set-up include:
 - ▶ less wiring (there is no separate power wiring needed)
 - ▶ higher reliability (fewer wire connections with the potential to fail)
 - ▶ fewer power socket-outlets required
 - ▶ increased safety (less mains wiring is used)
 - ▶ smaller looms (as separate power wiring is removed)
 - ▶ easier control via the local Ethernet switching hub
 - ▶ power backup of all data devices is possible if there is backup for the switches.
- ▶ *Data transfer and file storage devices*, which are quite often shared between several, if not hundreds, of users so need to have a reliable connection to ensure reasonable speeds for all users ensuring there are no bottlenecks slowing down the entire system. It is quite frustrating to travel along a multi-lane freeway and to then have to stop at a one-lane intersection—the same thing happens when (fast) file storage devices must cope with inadequate data speeds.

For PoE devices and file storage systems, a good rule of thumb is to have their data cable feeds run at the next highest level. An example of this would be a WAP on a standard Category 6 system needing a Category 6A link (i.e. cable, connectors, terminations etc.) in order to have the required bandwidth to service the users.

NOTE: Wireless access points often upgrade to data-hungry new technologies so they are best supplied with the fastest cable type possible; for example, C6A in a Category 6 environment.



CHECK YOUR UNDERSTANDING

1. Sketch the Open Systems Interconnection 7-layer model for data communications. Provide a brief explanation of this model.
2. According to the Open Systems Interconnection 7-layer model for data communications at what point does the professional data cabler have the most impact?
3. Describe the main differences between a Category 5 cable, a Category 6 cable and a Category 6A cable.
4. Describe how using the correct bend radius factor for data cable can prevent kinks. Sketch an example of a suitable bend radius.
5. Why is it important to maintain the twist rate when terminating cables?

20.2 Twisted pair cables

20.2.1 Plugs and socket-outlets

There are three distinct styles of plugs that can connect to socket-outlets:

- ▶ 4-positions plug
- ▶ 6-positions plug
- ▶ 8-positions plug.

All three plugs will fit into a standard data jack. Only the 8-positions plug is used in a structured data distribution system; 4-positions plugs and 6-positions plugs are reserved for use by the carrier or in a telephone and will not be discussed here.

The 8-positions modular plug is the standard for data and voice applications. This jack is usually referred to as an RJ45. The plug body is often supplied with all eight gold-plated contacts and should be correctly referred to as 8P8C. For basic voice-line cords, the plug may be loaded with only the centre two or four gold contacts and referred to as either 8P2C or 8P4C. For data applications, several colour-coding sequences are used for the conductor pairs. In Australia, the most widely used system is known as T568A, which is shown in **Figure 20.10**.

A round plug should always be used when terminating Category 5 or other round cords to ensure that the jacket and conductors are not crushed during termination. Flat cord plugs must be used to ensure adequate cord strain relief of flat cord. Flat cord is not as popular as round cord.

NOTE: Best practice places the contacts above and the locking clip below to limit dust contamination.

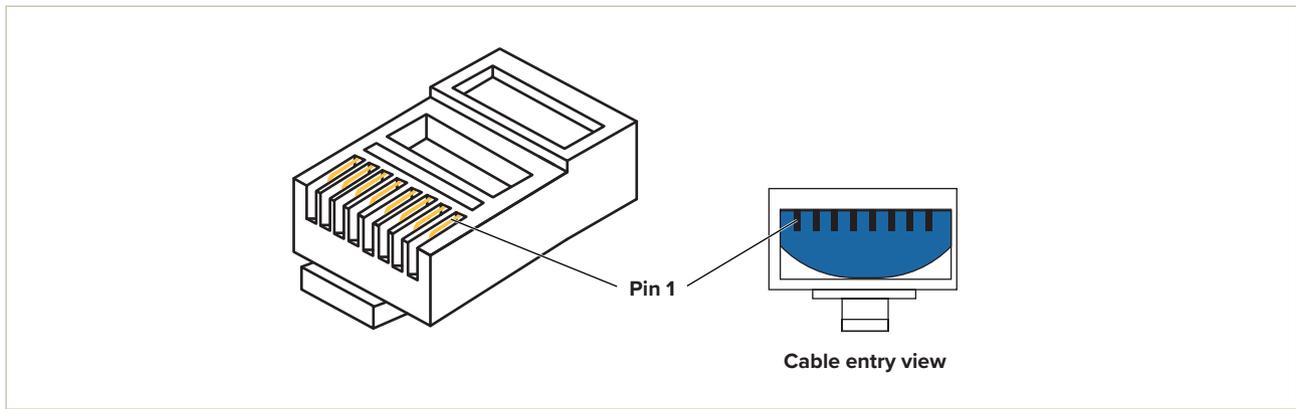


FIGURE 20.10 An RJ45 plug

The insulation displacement contact connection section of the contacts can be designed for either solid conductors or stranded (flexible) conductors. Plugs for solid wires have a three-pronged contact for each wire that forks over the solid conductor, while the contacts for a stranded conductor have two spikes that penetrate between the strands. Failure to use the correct contact type may result in unreliable terminations.

Unshielded twisted pair cable

Unshielded twisted pair (UTP) cable is used in most buildings to distribute both telephone and data cabling. UTP cable follows a technical standard from the EIA/TIA. EIA/TIA Standard 568 specifies the termination pattern of an 8-wire RJ45 cable. Options 568A and 568B are functionally identical but use different wire colours for identification. Installers should always terminate the same field outlets and floor distributions using the EIA/TIA TS568A colour code for Australia, unless to keep a site consistent with previous standards (i.e. the systems must match). If TS568A wiring is used for the field outlet, TS568A must also be used for the floor distributor. Do not mix ends—terminating one end differently may cause misoperation; for example, using TS568A wire for the floor distributor and TS568B for the field outlet will result in a wiring configuration problem.

Field end

As the EIA/TIA has two wiring standards for a field outlet, it is important to note that in Australia TS568A is the preferred standard as it is in most of Europe, while TS568B is typically used in commercial applications in North America. The patch panel end should also be terminated in the same standard; for example, using TS568A at both ends (for Australia).

NOTE: Special patch-cables (known as wired null-modem or cross-over cables) are used to connect some terminals. Wired 568A at one end and 568B at the other, these often have special cable or connector colours to warn that they are wired in a non-standard way. These cables are not often used in newer installations.

While cabling used for telephone usually only requires a single pair of wires (on pins 4 and 5 of an RJ45 socket), to conform to the structured cabling system of wiring, all wires are terminated into their own terminal. This can be seen in good detail in **Chapter 19** and *Appendix C* in *AS/CA S009* (specifically *Figure C1* and *Table C1*). To assist the installer, **Figure 20.11** lists typical colours and abbreviations as used in the cabling industry.

Common colours	Abbreviation	Additional colours	Abbreviation
Blue	BU	Grey	GY or GR
Orange	OR	Purple	PU
Green	GN	Turquoise	TQ
Brown	BN	Lime green	LM-GN
Slate	SL	Pink	PK
White	WH	Olive	OL
Red	RD	Magenta	MG
Black	BK	Tan	TN
Violet	VT or VI	Beige	BG
Yellow	YE	Chocolate	CH
Rose	RS	Dark green	DK-GN
Aqua	AQ		

FIGURE 20.11 Typical colours and abbreviations used in the cabling industry

20.2.2 Categories and classes of twisted-pair cables

ISO 11801 classifies cables using classes and categories as shown in **Table 20.1**. For instance, a channel classified as Class A is known to provide the minimum transmission performance to support Class A applications. Similarly, Class B, C, D, E and F channels provide the transmission performance to support Class B, C, D, E and F applications, respectively. Links and channels of a given class will support all applications of a lower class. Class A is regarded as the lowest class.

The category classification refers to actual components. Category is the more common referral for a system designed to work at a certain speed; for example, Category 6 is describing a Class E system. **Table 20.1** is intended as a guide only as any matching of cable class and category must factor in cable length to be accurate (Class D and above shown in **Table 20.1** are accurate for cable lengths up to approximately 100 metres).

NOTE: For commercial viability, cables that guarantee data performance are preferred.

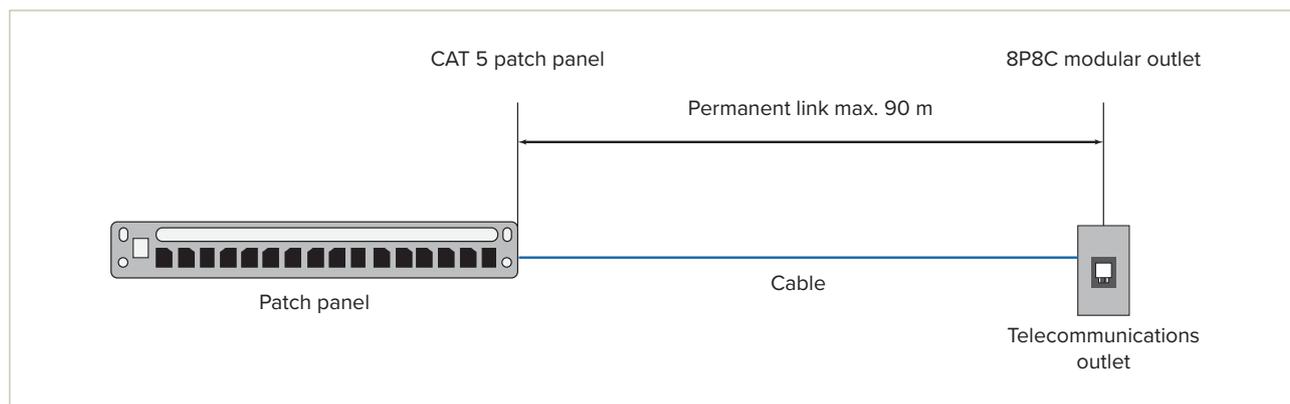
20.2.3 Links

Permanent link

A permanent link is a fixed piece of cable from a distributor to a telecommunications outlet. It is part of the cabling system fixed in place. The maximum length recommended for a fixed horizontal (local) cable is 90 m. This is the most common method of installing data cable in Australia (see **Figure 20.12**).

TABLE 20.1 Classes and categories of twisted-pair cables

Class	Category of cable	Transmission frequency	Typical use
A	1	100 kHz	<ul style="list-style-type: none"> Security detectors, doorbells
B	2	1 MHz	<ul style="list-style-type: none"> Analogue telephones
C	3	10 MHz	<ul style="list-style-type: none"> Early data communications 10 Mbps at a guaranteed 100 m run
	4	16 MHz	<ul style="list-style-type: none"> Token ring (no longer used)
	5	100 MHz	<ul style="list-style-type: none"> Early Ethernet using two pairs of wires Up to 100 Mbps at a guaranteed 100 m run
D	5E	100 MHz	<ul style="list-style-type: none"> Ethernet using four pairs of wires, typically domestic only Improved Category 5, able to handle 1 Gbps over shorter distances
E	6	250 MHz	<ul style="list-style-type: none"> High-speed Ethernet, commercial minimum desktop standard 1 Gbps at a guaranteed 100 m run, up to 10 Gbps (at 35 m) Currently the most common system in use
E _A	6A	500 MHz	<ul style="list-style-type: none"> Data servers, WAPs, HDMI and HDBaseT 10 Gbps at a guaranteed 100 m run, up to 40 Gbps (25 m) Often shielded cabling is used Used in high-security sites where high speed is necessary (e.g. Australian Taxation Office, Medicare, etc.)
F	7	600 MHz	<ul style="list-style-type: none"> Data centres (used infrequently) Individually shielded pairs allow independent functions on different pairs at the same time
F _A	7A	1000 MHz	<ul style="list-style-type: none"> Data centres, tends to be proprietary and live video
Class I	8 and 8.1	2000 MHz	<ul style="list-style-type: none"> Data centres, 30 m and 40 Gbps max Can use RJ45 components
Class II	8.2	2000 MHz	<ul style="list-style-type: none"> Data centres, 30 m and 40 Gbps, non-RJ45 compatible connectors

**FIGURE 20.12** A permanent link

Channel link

The channel link incorporates the permanent link and adds up to 10 m of patch leads. The maximum channel length for most applications is 100 m, as shown in **Figure 20.13**.

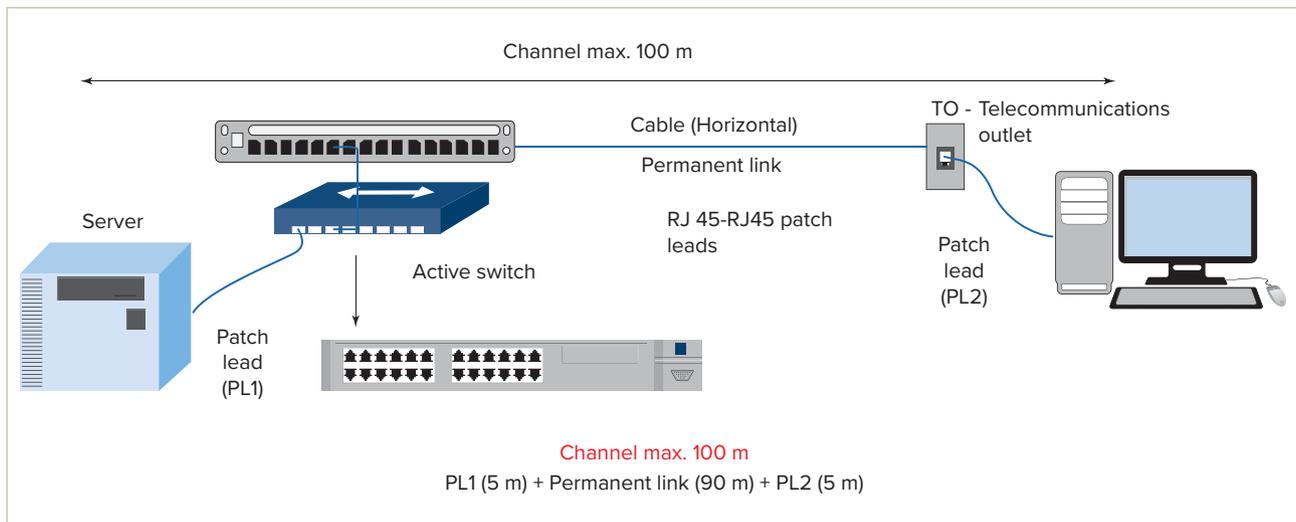


FIGURE 20.13 A channel link



DID YOU KNOW?

90 + 10 Rule

The channel link is sometimes called the 90 + 10 Rule. It refers to the 90 m of cable fixed into the wall (permanent link) and the 5 m of patch cables plugged into it at each end.

Lengths beyond these limits are not within standard and therefore may not always work for paying customers.

20.2.4 Shielding

A shield protects a cable from the mitigating effects of electromagnetic interference (EMI) and radiofrequency interference (RFI). The effects of EMI and RFI (including crosstalk) on a cable will disrupt telecommunications voice and data transmission signals.

Electromagnetic interference and radiofrequency interference

EMI is wide-frequency spectrum interference of all types. Usually, EMI is from the electrical power cables in a building. When it occurs within the radiofrequency spectrum (high frequency), it is called RFI. Static electricity is another damaging form of EMI. Either way, EMI/RFI is a disruption to the electromagnetic field of one device by the radiofrequency generation of another device. For example, when in use an arc welder generates radiofrequency signals that can interfere with the electromagnetic field surrounding a telecommunications cable. A change in that electromagnetic field produces a corresponding change in current flow within the signals on nearby telecommunications cables.

EMI/RFI can be generated by other large electrical equipment such as electric motors and can also emanate from telecommunications cables. Therefore, high-performance class E_A cabling (also generally called Category 6a) is laid randomly rather than neatly side by side, so that the EMI emanating from one cable does not interfere with adjacent cables.

Crosstalk

Crosstalk occurs when the signal on one set of wires affects the signal on another set of wires. This may be within a cable or between separate cables ('alien' crosstalk). The changing electrical signal on a wire creates a changing magnetic field. This changing magnetic field, should it surround another wire, will affect the current flow of the electrical signal on that wire. That is the inter-connected nature of magnetic and electric fields.

Twisting pairs of wires together has the effect of cancelling out this crosstalk. Each wire in the twisted pair carries an equal amplitude but opposite phase signal. Any disturbance (crosstalk) that occurs evenly on the pair has the same (but opposite) amplitude, so the destination equipment can cancel the net effect by adding the signals together. This works better if equal pickup is assured by twisting to differentiate between signal and interference and therefore cancel out the interference using electronic techniques.

Ideally, cable wires should not interfere with other wires and there should be no crosstalk. Methods used to reduce crosstalk include tightly twisting pairs of wires, separation, shielding and screening. A shield may be placed around cable pairs in the form of a braided aluminium barrier. Shielding may be improved with solid metal surrounding but can be done cheaply with aluminium foil. A drain wire allows grounding of the shield by pressure against the fragile aluminium foil at multiple points along the cable.

In high-performance cabling (such as Category 7 and Category 7a cabling), each pair may have an individual shield, with all pairs being wrapped again and an overall drain wire wrapped around all the pairs. The two types of shielded cables are shielded twisted pair (STP) and foil twisted pair (FTP). These are sometimes hard to distinguish from one another. Braiding of thicker copper wires works well at strong lower frequencies, while a complete surface of foil works better for higher frequencies (see **Figure 20.14**).

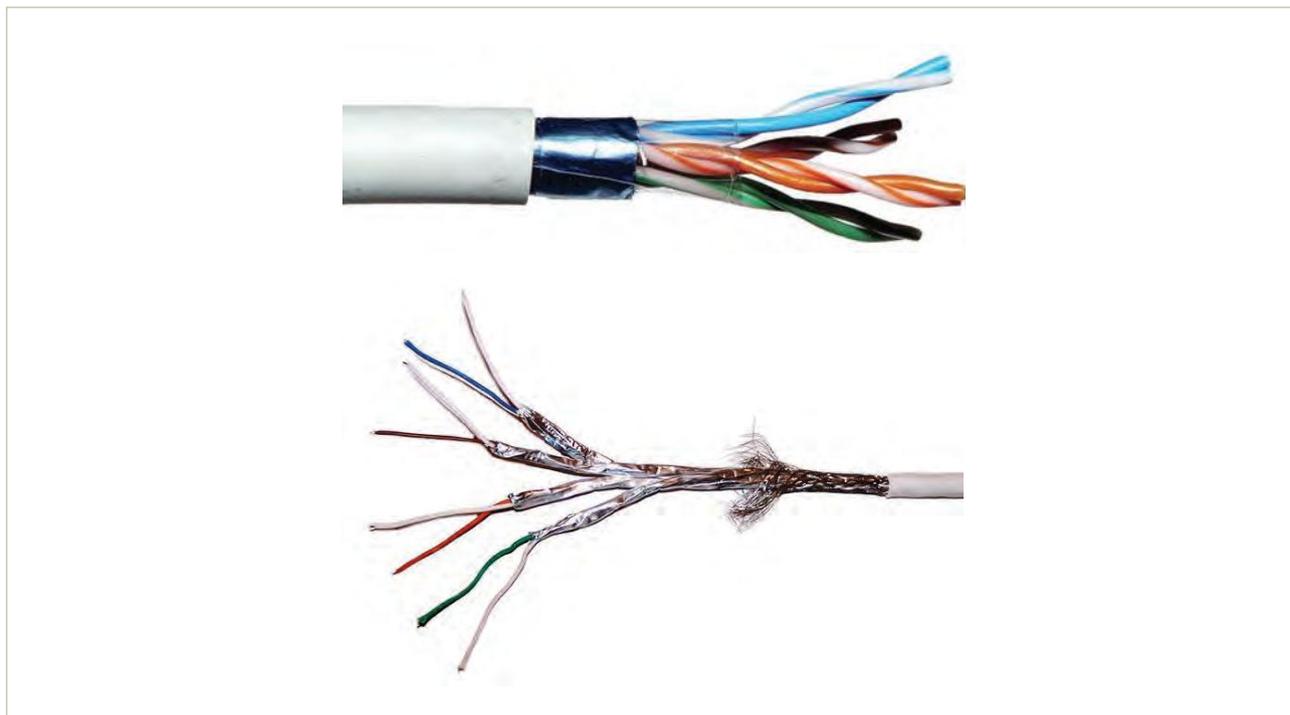


FIGURE 20.14 Example of cable shielding; note the tiny drain wire beside the foil

Graham Hand

NOTE: Shielding the cabling will reduce the likelihood of crosstalk being transmitted by EMI/RFI fields, whether inside or outside noise sources.

Shielded cable

FTP has a cable comprising one or more insulated electrical conductors, which are collectively covered by an overall foil shield. The shield may also take the form of a braid STP or a combination of foil and braid (SFTP). It is important to note that shielded cables are manufactured differently. For example, a shielded cable can be manufactured with one foil over all of the pairs, or with individual foils over each pair. **Figure 20.15** defines the different types of cables.

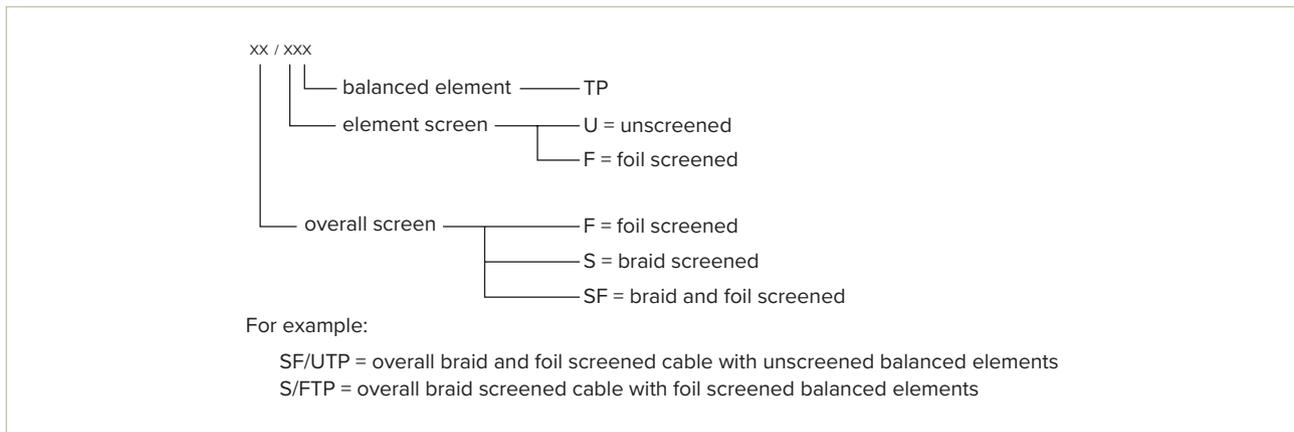


FIGURE 20.15 Types of shielded cables

The advantage of shielded cabling is the immunity from electrical interference it provides for signals, allowing a better performing cable. Disadvantages are:

- ▶ thicker diameter of the cable
- ▶ larger minimum bend radii
- ▶ more difficult termination processes
- ▶ more expensive termination connectors.

It also requires a bond to earth, which is more time-consuming than for a simple UTP installation. With the industry demanding more performance and higher bandwidth, customers and manufacturers will shift from UTP, the industry standard, to FTP or SFTP, the next generation of structured cabling, along with fibre technologies (extremely high noise-reduction and much longer runs). The normal cable installed for most commercial premises is Category 6 UTP but that will change to Category 6a FTP in time. Note that not all Category 6a cable is shielded.



CAUTION

Never connect both ends to an earth connection, as doing so could allow a current to flow between the two ends. This electrical point current could result in a difference in potential that could cause harm to you, others or equipment.

20.2.5 Labelling

Cables

Labelling of telecommunications cabling is done at the time of hauling. Cabling should be labelled at either end so that cables are readily identifiable within a cabling system. Cable labels should be unique—that is, no two cables should share the same label. In a structured cabling system, a consistent naming system (nomenclature) should be set up prior to running cables. This ensures that no two cables within an infrastructure are labelled the same.

Optical fibre

Optical fibre panels and enclosures should be labelled to warn of the potential presence of hazardous laser levels. Each optical connector, splice box or other part emitting radiation when opened should be marked, for example, with a label, sleeve, tag or tape. Optical fibre labels should be coloured black on a yellow background as shown in **Figure 20.16**. The warning marking should consist of a warning label that meets the requirements of *Figure 1* of *AS/NZS IEC 60825.1—Safety of laser products: Equipment classification and requirements* plus an explanatory label that meets the requirements of *Figure 2* of *AS/NZS IEC 60825.1*.

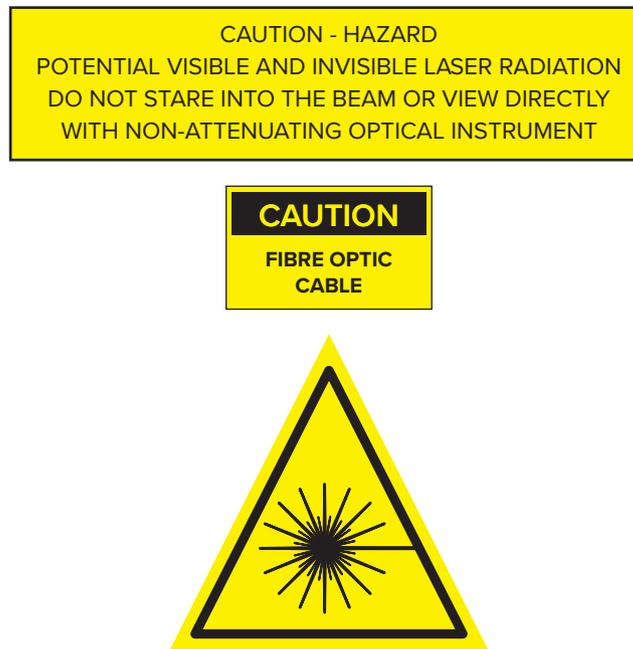


FIGURE 20.16 Sample fibre optic labels

Distributors and data racks

Labelling of distributors and data racks should follow the guidelines of *AS/CA S009:2020*. The main distribution frame should be clearly labelled as follows: the vertical columns of jumperable terminations (verticals) should be alphabetically indicated, from left to right, omitting the letters *I* and *O*. This is because *I* and *O* may be confused with 1 and 0.

Socket-outlets

The marking of telecommunications socket-outlets should be visible and legible and be able to be seen without the use of special gear. It is recommended that computer-printed labels are used in place of hand-drawn labels. Cabling hardware should be identified and labelled in accordance with *AS 3085*, which is adopted from *ISO/IEC 14763-1*. It should be installed and designed in accordance with *ISO/IEC 14764-2*.

Labelling of extra-low-voltage d.c.

There are a lot of devices that use power transmitted over the data cables, referred to as PoE. Among these common devices are:

- ▶ wireless access points
- ▶ voice over IP telephones
- ▶ CCTV IP cameras.

Standards allow up to 30 W of power to be transmitted on a Category 5e or Category 6 cable, and this will soon rise to 100 W. For instance, if a device needs 30 W to run, this will translate to 150 mA per pair, if all four pairs are used. Some devices rely on this to be on just one pair of wires, translating to 600 mA on one pair of cables. If someone were to cut into this wire, they could receive an electric shock, cause equipment failure, or even fall off a ladder. With any PoE devices, the system needs to be labelled to indicate there is power on cables and for installers to take extra care when working around them.

Where customer cabling is used for power feeding other than power derived from a carriage service, the cabling should be protected from excessive current flow that may cause damage or fire, by such means as fuses, circuit breakers or current-limiting circuitry. Most manufacturers will build this protection into their devices, but one should not rely on safety devices activating for initial protection. Installations that make use of this process should be labelled accordingly.

Horizontal cabling

The label on the UTP cable in **Figure 20.17** shows that the cable originates from floor distributor 1, uses cable pathway 1 and is the first cable in that communications room. All elements of a cabling system should be readily identifiable; that is, the cables, the pathways and the spaces where the cabling is installed. According to *AS 3080:2014*, a unique identifier should be assigned to every cable, distributor, termination point and space (e.g. name, number and/or string of characters).



FIGURE 20.17 Example of labelling on a horizontal cable



CHECK YOUR UNDERSTANDING

6. Sketch and label the correct wiring colour codes for the T568A (Australia/Europe) connection system.
7. Describe the differences between Category 6 and Category 6A cable.
8. What is the difference between a permanent link and a channel link?
9. Apart from shielding, what is the other method manufacturers use to cut down on crosstalk?
10. State the advantages and disadvantages of using shielded cable over unshielded cable.

20.3 Earthing telecommunications networks

20.3.1 Necessity of earthing telecommunications networks

It is not a mandatory requirement for metallic parts of a telecommunications system to be earthed. The main reason for not earthing too many parts of the telecommunications system is to avoid accidental exposure to hazardous voltages. If all parts of the electrical installation are earthed and they happen to feed from various sources, the earth loops and differences in potential could be hazardous, resulting in electric shock.

Metallic distributor frames, back mounts and enclosures, cable trays, conduits, trunking, and steel wire armoured cables should not be connected to the telecommunications reference conductor (TRC) other than at a communications earth terminal (CET) or to the bar, terminal or back mount at the designated distributor where

the Green/Yellow equipotential bonding conductor is connected. Metallic distributor frames, communications cabinets, back mounts and enclosures, cable trays, conduits, trunking and SWA cables may be connected to a protective earthing conductor or the communications earthing system (CES). The TRC is not commonly used in structured cabling systems.

As a minimum, a CES should be installed. This will require a cable from the main electrical switchboard to a CET. Earthing cables for communications use should be stranded and comply with the Telecommunications Labelling Notice. For more information on TRCs and CESs, see **Chapter 19**.

Choosing the size of the cable

The type and size of cable are dependent on the type of earthing system to which the cabling is connecting. The requirements in terms of type and size of cable are laid out in *Table 7 of AS/CA S009:2020*. The relevant resistance limits are based on *Table 6 of AS/CA S009:2020*. The CES uses Green/Yellow insulation with multistranded copper wire. The typical size is 6 mm², with 2.5 mm² normally being used for other connections. Larger sizes may be needed for operational purposes. A sample of a typical earthing conductor is shown in **Figure 20.18**.



FIGURE 20.18 Earthing wire

Graham Hand

The CES will have one equipotential bond between a CET and an earth bar, in accordance with *AS/CA S009:2020*, and have a resistance limit of 1 Ω. Equipotential bonding is required when installing a CES. This means that a CES needs to be connected to a premise's protective earth system. This connection must occur at one point only and is done to prevent differing voltage potentials between the two systems which otherwise could be a hazard.

Requirements for compliance

Earthing cable must follow the requirements of *AS/CA S009:2020, Section 20* and those of the manufacturer. As earth cable is used for protective purposes, steps should be taken to ensure electrical continuity and the sheath should be tested to meet insulation resistance requirements.

Basic checks to carry out when earthing telecommunications systems include:

- ▶ continuity
- ▶ correct colour of insulation
- ▶ correct use of termination techniques
- ▶ acceptable resistance limits
- ▶ insulation resistance check
- ▶ physical connection in tunnel terminals
- ▶ secure and fastened.

Hazards

As the earthing installation will connect to a protective earth, it is essential that the proper precautions are taken when working on the earthed part of a telecommunications installation. During installation, the cabling provider must ensure that the earth cable is installed in such a way that it does not encounter any live parts and that no

hazardous voltage is present on any section of the earthed installation. This may be done using a multimeter and may also be passed off to a qualified electrician.

Labelling earthing cable

The labelling of earthing cable should be carried out in accordance with *AS/CA S009:2020, Section 20*—this labelling is further discussed in **Chapter 19**.

20.3.2 Purpose of earthing telecommunications systems

Earthing of telecommunications cables is done to minimise the effects of low-frequency induction and high-frequency induction.

Low-frequency induction

In the case of parallel runs with (mainly) high-voltage (HV) power lines, it is necessary to evaluate the level of low-frequency induction (LFI). This can also be a problem with low-voltage (LV) systems. If the level of induction exceeds the permissible limit (i.e. 430 V a.c.), the installation should proceed only on the basis that customer cables that contain electrically conductive elements should not be installed in the vicinity of an HV power line. Where there are 50 Hz induced voltages under normal or fault conditions that may exceed 430 V a.c. in the customer cabling, an engineered solution must be carried out in consultation with the carrier.

It is necessary, in cases of parallel runs with underground or aerial HV power lines, to evaluate the level of low-frequency induction. If the level of induction exceeds the permissible limit, the installation should proceed only on the basis that an engineered design has been prepared in compliance with the relevant codes.

To minimise the effects of low-frequency induction, data cables should be run as far away as possible and should not run parallel with power cables. It is common to exceed the requirements of *AS/CA S009:2020* by many times to limit the effect of LFI (e.g. instead of having a 50 mm gap between data and LV cables, the gap would be 300 to 400 mm).

NOTE: LFI is the generation of current in a telecommunications line due to inductive coupling with a power line carrying large, unbalanced currents, for example during a fault on an HV power system (see **Figure 20.19**). Refer to *Clause 4.2.64* of *AS/CA S009:2020*.

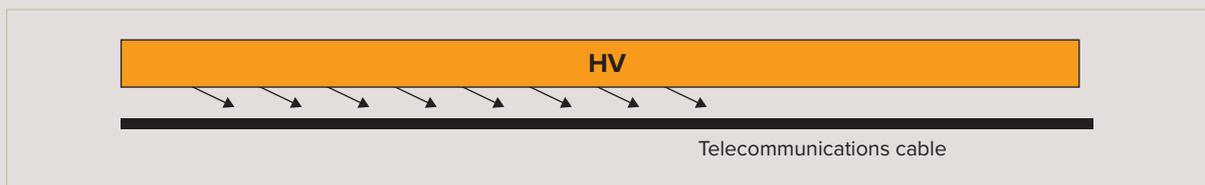


FIGURE 20.19 Low-frequency induction

NOTE: A classic example of LFI and telecommunications cabling is HV transmission lines. It is often the case that induction from HV travels through the ground and promotes crosstalk and interference on telecommunications cabling. That is why it is especially important never to install telecommunications cabling in parallel runs close to HV sites or transmission paths. It is always best to take a geographically diverse route, away from that of the power cables, to eliminate the risk. LFI can also be generated from LV power cables running close to data cables.

High-frequency induction

Data cables are susceptible to magnetic interference coming from sources other than power cables. LED drivers, active detectors, neon signs and even other cables in the bundle can all contribute to high-frequency induction (HFI). This is commonly referred to as radiofrequency induction, or radiofrequency (RF). Even individual conductors in one cable bundle can cause unnaturally elevated levels of HFI if not properly terminated. As the transmission frequency increases, so does the HFI from every cable and conductor.

To prevent HFI (or RF) from causing data loss, it is highly recommended that any metallic component associated with high-speed data be earthed to the CES. This applies to metallic ducts, cable trays, cable ladders, data cabinets, patch panels and so on. This especially applies to the use of shielded cables, but only at the originating or data centre end. Keeping the twist rate of data cables tight is another method of minimising RF, especially at the terminations.

HFI is one reason typical data runs are less than 90 m (permanent links), to ensure the HFI does not overwhelm the data signal in the other cable pairs. It is vital the installer realises that an earthing system for the telecommunications network needs to originate at one point only. If the installer connects a cable shield to another earthing point (e.g. on another floor or building), currents can (and will) circulate on the earth cable connecting the two points.



CAUTION

Do not connect the field end of a shielded cable to an earthed piece of equipment. Use a non-shielded patch cord of the same category to connect the equipment up to the field outlet. If you do, Ohm's Law will come into effect, and you will end up with unwanted circulating currents on your data wires (earth loops).



CAUTION

Before making an insulation resistance test, you must be sure the cable you are testing is not in service and does not have a voltage present.



CHECK YOUR UNDERSTANDING

11. Explain the condition referred to as low-frequency induction.
12. What is one solution to minimise or prevent low-frequency induction?
13. What are some of the sources of radiofrequency?
14. How can radiofrequency be minimised in data cables?
15. What is the minimum size and required colour of the communications earthing system connection cables?

20.4 Coaxial cable

20.4.1 Construction of coaxial cable

Coaxial cable (also known as coax) is a cable system using only one wire to transmit a signal. The one wire is surrounded by a spacer insulator (called the dielectric), which is wrapped (coaxially) in a system of shields made

from either copper (foil or weave), aluminium, steel or a combination of all these. The cable may then be covered in a protective insulation layer, depending on the environment it will be installed in. These protective layers may include:

- ▶ stainless steel, to stop birds and animals chewing through the cable
- ▶ sacrificial sheath, to stop insects and rodents chewing through the cable
- ▶ flooded cable (i.e. cable filled with a water-repellant gel), to stop moisture getting into the cable.

The term *coaxial* comes from the fact that the inner conductor and the outer shield share a geometric axis. Coax is an unbalanced cable system because one conductor carries the signal and the return conductor (shield) is grounded (or earthed). The construction helps determine the high-frequency impedance of the coax (characteristic impedance). Pay TV and NBN use a 75 Ω cable exclusively. Radio transmission (e.g. two-way radio) sometimes uses 50 Ω impedance cable. **Figure 20.20** shows a coax example.

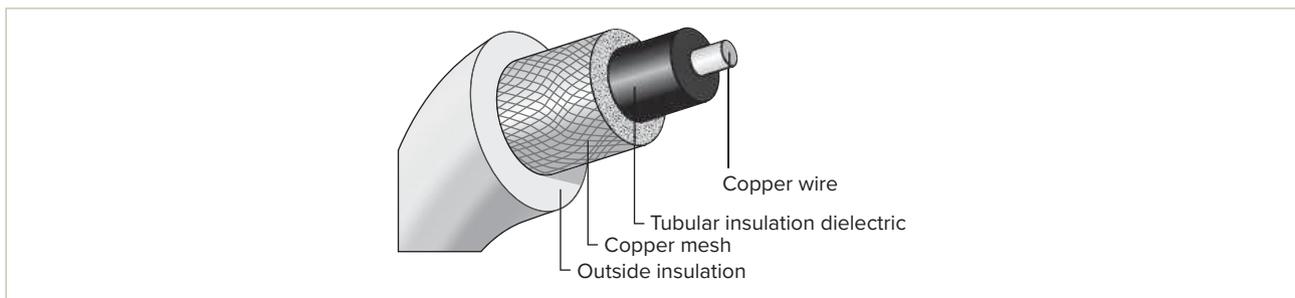


FIGURE 20.20 Coaxial cable

CAUTION

The impedance of the coax determines how the signal will behave in the cable. 75 Ω coax will not work well with radio, and 50 Ω coax will not work well with video due to high signal loss because of impedance mismatch.

Watch your cables! Crushing or bending cables sharply alters their characteristic impedance, often distorting the signal. Gentle support and pathing are critical for best performance.

Coaxial cabling is used for cable television/cable internet (known as hybrid fibre coax or HFC), legacy CCTV (closed-circuit television), free-to-air television and satellite television services. Coax cable was previously used for data transmission, prior to the introduction of UTP. While the HFC network heavily relies on a coax connection to the house, and has been reliable and very fast, Foxtel and NBN are actively migrating their clients off coax and onto either satellite or fibre to the curb (kerb) (with a twisted pair of wires supplying the last 50 m). The reasoning is the HFC network is beyond economical maintenance and the upgrade to handle the new Foxtel IQHD4 (4K Sports) is driving this change-over. However, with hundreds of thousands of connections involved, it will take many years yet.

When installing coax cable, most data cable practices apply: there should be no kinks, sharp bends or cuts in the outer insulation, and separation from hazardous services (especially separation from LV cabling) must be achieved. Cablers must also ensure that the outer sheath is suitable for the environment in which it will be installed and that the cable will meet the required power needs (power is lost due to length *and* frequency). Coax comes in a variety of sizes and types including:

- ▶ microwave transmission
- ▶ satellite reception and transmission
- ▶ mobile phone towers
- ▶ radio and television transmission towers

- ▶ two-way radio communications
- ▶ internet connections
- ▶ television antennas.

Each coax has its own method of equipment connection, including the method of terminating connectors onto it. **Figures 20.21** and **20.22** show examples of coax cables.



FIGURE 20.21 Examples of coaxial cable used in the Pay TV industry: top—RG6 with built-in bearer wire (Foxtel); middle—CX50 (NBN distribution with solid shield); bottom—foam-insulated Heliax (microwave)

Robert Wickstead



FIGURE 20.22 Cross-section of Heliax (or hardline) coaxial cable; note the foam insulator (AA battery included for scale)

Robert Wickstead

For more technical information on coaxial cable, see *AS/NZS 1367:2016*.

20.4.2 Shielding

Shielding with tightly-woven copper wire works well against noise pickup at lower frequencies with high interfering currents, but less well at very high frequencies, which tend to use solid copper or aluminium foils. Woven wire on foil optimises all these outcomes but may be more costly. Running a shield over the shield (with isolated earth connections) will help to stop noise currents in the shield. RG6 Quad-shield cable is one type (quad = four different cables: two foil and two braid).

20.4.3 Skin effect

Figure 20.23 shows the large coaxial cable is made from three different parts. The inner hollow conductor is on a low-dielectric white plastic spacer shape, used to keep the cable shape and an even impedance between it and the outer sheath. The outer part of the conductor is a thin copper pipe. These thin copper pipes carry the signal between devices, with minimum dielectric (capacitor) losses between them due to the minimal plastic spacer content.

The reason thin copper pipe is used relates to the phenomenon called skin effect, where a high-frequency signal will travel mainly on the outer edge of a conductor. Manufacturers do not need to use thick conductors, so they fill the inside with a less-costly inner member to keep the shape, which is sometimes hollow. This is very common in high-powered and high-frequency transmission systems, and can even be seen in the Pay TV network.



FIGURE 20.23 Cross-section of high-powered and high-frequency coaxial cables; note the hollow centre conductor (AA battery included for scale)

Robert Wickstead

In **Figure 20.23**, the coaxial cables on the right use a less expensive system to provide mechanical support via a foam plastic fill instead of inserting spacers. This bubbled plastic fill has increased dielectric losses but not as much as solid plastic would have. Low-loss plastics like Teflon or polythene are used at these high frequencies (up to 10 GHz or more). Many strong cheap plastics like PVC are unusable as they absorb moisture.

Installers will probably not come into contact with this type of cable but if they do it is worth keeping in mind that it does not bend easily.

20.4.4 Pay TV

Cablers running high-speed data in commercial buildings will encounter what is commonly called Pay TV cable (sometimes referred to as Foxtel cable). This cable uses a more flexible construction and is much easier to prepare and terminate. The coax is 75 Ω impedance. However, using the wrong size of 75 Ω coax will compromise performance. It is important to understand the common types of 75 Ω cable in use.

For commercial video distribution, it is quite common to use an RG6/U cable (radiofrequency grade, government-approved use, government-assigned approval number, universal specification). RG6/U will transmit a television signal many dozens of metres before the signal becomes unusable. This degradation is measured in decibels (dB) per metre.

20.4.5 Signal measurement

The dB is used to measure and indicate signal losses in a cable. The dB is used to reflect the difference in the source signal level (at the antenna) and the final signal level (usually at the television outlet). It is the gain or loss represented as a multiplying factor. In this application of radio power, energy or field strength signal measurements, dB is an abbreviation of deciBel microvolts (dB μ V). It is the standard unit of measurement for radio power and is a convenient method engineers use to indicate power loss. A very important detail to note is that dB μ V measurements are measured on a logarithmic scale, not a linear scale, as shown in **Table 20.2**.

The practical application for this is in measuring signal losses in a transmission system. If the power level at the source, such as a free-to-air television antenna or the output of a launch amplifier for an MATV system, is measured at say 75 dB μ V, and at the other level it is measured as 72 dB μ V, there is a 3 dB μ V loss in that signal. This does not sound like much, but

TABLE 20.2 Attenuation rates for RG6/U and RG11/U coaxial cable

Frequency MHz	Maximum cable attenuation dB/100 m at 20 °C	
	Series 6 (RG6)	Series 11 (RG11)
5	1.9	1.3
45	4.6	2.8
100	6.6	4.1
170	8.8	5.4
230	10.4	6.5
520	15.6	9.7
600	16.7	10.4
750	18.7	12.0
820	19.5	12.8
862	20.1	13.2
950	21.2	13.9
1000	21.7	14.3
1450	27.0	17.5
1800	30.3	19.7
2000	32.0	20.8
2150	33.3	21.7
3000	39.8	26.0

Source: AS/NZS 1367:2016 Coaxial cable and optical fibre systems—Section 5 Passive equipment

this 3 dB represents 50 per cent of the signal being attenuated or lost. Another 3 dB represents a further 50 per cent of the remaining signal. If for some reason there was a 10 dB loss, this would represent a further 166.6 per cent signal loss.

Fortunately, common electronics can cope with a lot of loss and still show good picture quality. Provided the signal strength is matched with signal quality, a poor-quality signal can be amplified (e.g. BER and MER signal quality). For a basic signal, anything between 55 dB μ V and 75 dB μ V will allow a high-definition movie to play properly.

One method to minimise the signal loss is to utilise a powered splitter if more than one point is going to be installed. Using quality cable and approved connectors, and employing correct cable-laying techniques and shorter cable runs will also help.

NOTE: The best way to ensure that a good signal is provided to a television is to use a signal strength meter to ensure you have good signal strength and good signal quality.

Using a passive (non-powered) splitter will further contribute another 3 to 4 dB signal loss through each splitter. If a bad connector or improperly terminated connector is also in the installation, the signal loss can be quite substantial.

If the cable run is very long, or the final signal level is too low to work, a larger cable or a launch amplifier may be needed (see **Figure 20.24**). Usually, this larger cable is an RG11/U, roughly twice the diameter of the RG6/U cable.

However, twice the thickness does not equal twice the length. A rule of thumb is to only add half the length to the new cable to achieve a working level. This is shown in **Table 20.2**.

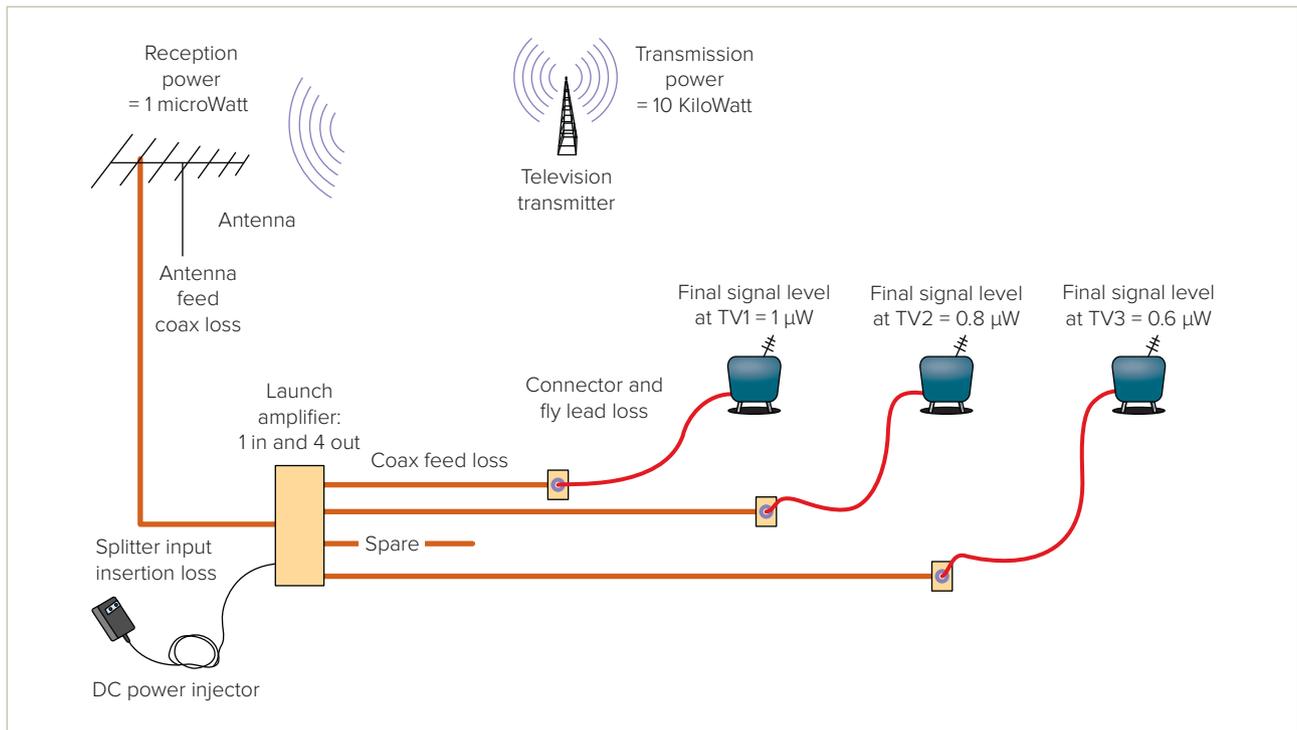


FIGURE 20.24 A launch amplifier in a typical free-to-air television system

Using **Table 20.2**, we can see that at a frequency of 100 MHz (100 000 000 cycles per second), an RG6/U cable loses about 6.6 dB for every 100 m. At 600 MHz, this loss is 16.7 dB at the same distance. If a television needs a signal level of 60 dB to work (at 600 MHz), the source must put out more than 77 dB for this frequency. If the source is only 70 dB, the television may not work on some channels, if at all.

By using an RG11/U coaxial cable, the loss is only about 10 dB for the same distance, and this would be adequate for the television to work. However, this will be more expensive and could cost more than installing an amplifier instead.

As the radio frequency increases, so do the transmission signal losses (i.e. it is not a linear or straight-line increase). For the frequencies which Foxtel currently uses for transmitting its intermediate frequency (IF) signal from a satellite dish to a decoder box (950 MHz at the time), RG6 Quad is only usable for approximately 40 m. This is shown in **Figure 20.25**.

NOTE: RG59 coaxial cable, once good for basic CCTV and analogue television transmission, is no longer suitable for use in the digital television environment due to its high loss, low power rating and susceptibility to ingress of unwanted RFI.

RG59 coax should be replaced with a good-quality RG6 Quad shield coax when completing any free-to-air television upgrade, and with Foxtel-approved RG6 Quad if provisioning for a Foxtel installation.

20.4.6 Connections

Coaxial cable must be properly terminated to ensure the shielding is maintained up into the connector. If there is even a small gap, it will allow noise into the cable and the signal loss could be enough to prevent the television from working properly. For termination of coaxial cables, the recommended sequence is as follows:

- ▶ Remove the insulation around the shield.
- ▶ Remove the shield from around the dielectric.



CHECK YOUR UNDERSTANDING

16. Sketch a coaxial cable and identify its basic components.
17. What is the main difference between using a 50 Ω coaxial cable and a 75 Ω coaxial cable?
18. Explain the term *skin effect*.
19. Explain the effect of higher frequencies on RG6/U and RG11/U coaxial cable.
20. Refer to Table 20.2 to answer the following questions.
 - a. A free-to-air television signal needs to get to an outlet at 60 dB strength. The source of the signal is 65 dB strength. The maximum frequency is 520 MHz. The length of the cable run is 30 m. Will the television work adequately at this distance?
 - b. If the above system is now to carry a Pay TV signal at 950 MHz, what will be the maximum distance an RG6/U cable can be used?
 - c. If the outlet cannot be moved (e.g. 30 m from the source), what are possible solutions?

20.5 The National Broadband Network

20.5.1 What is the National Broadband Network?

In its own words, the National Broadband Network (NBN) provides the means for retail providers to connect to internet services in Australia. On 9 April 2009 the Australian Government established NBN Co with the purpose to design, build and operate the country's wholesale broadband access network. As a publicly owned corporation NBN Co reports to two shareholder ministers: the Minister for Finance and the Minister for Communications. NBN Co is also known simply as nbn.

NBN's primary objective is to ensure that all Australians have access to fast broadband, at an affordable price and at least cost. By February 2020 NBN announced that 6.7 million businesses and homes were connected to plans over the NBN network.

To achieve its objective, NBN has been structured as a wholesale-only, open-access broadband network. NBN provides broadband access predominantly to retail service providers, which then on-sell access to residential and business customers. The intent was to level the playing field in Australian telecommunications, creating competition within the industry and providing choice for consumers.

The NBN does not interface with the general public: that is the internet service provider's (ISP) role. However, as a cabling provider, you will need to be familiar with what your client will be connecting to, and why you need to provide a good network for them.

There are different ways the NBN connects to premises, and the method will depend on the infrastructure already in use. The system already in use is called multi-technology mix (MTM). The speed of connection is part of the ISP system and is negotiated by the customer. While there are advantages and disadvantages of each, this is left to the client and/or installer to research.

NOTE: As the NBN is considered the area of the carrier, the installer is not allowed to alter any of the NBN assets without prior written permission.

20.5.2 NBN connections

Fibre to the premises

Fibre to the premises (FTTP) was previously known as fibre to the house. In this type of connection, the NBN installs a single, underground fibre optical cable to the utility box, where the underground fibre is changed over to a more indoor-friendly fibre. The fibre will connect to the NBN connection box where the ISP will then connect its equipment; see **Figure 20.27**. FTTP connection is common in areas being built from the ground up, known as green fields. It is important to remember that this link is usually shared with up to 30 other users. The technology is beyond the scope of this chapter.

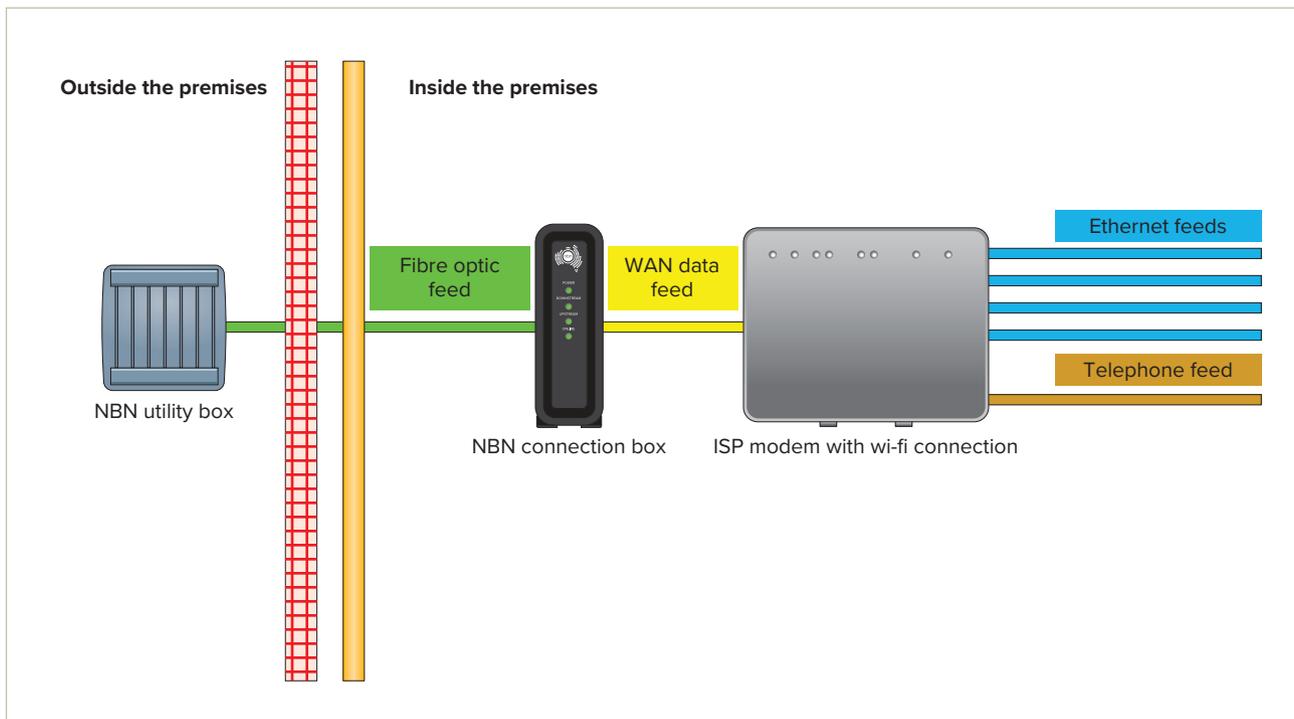


FIGURE 20.27 Fibre to the premises NBN connection

Fibre to the building

Fibre to the building (FTTB) is sometimes referred to as fibre to the basement. This system is used to bring multiple services into a building (e.g. apartment, shopping centre, unit block) using the existing telephone line from the

building's main distribution frame. It is important for cabling providers to be aware of how jumpering is done in these areas (see Chapter 19). Figure 20.28 shows an FTTB connection.

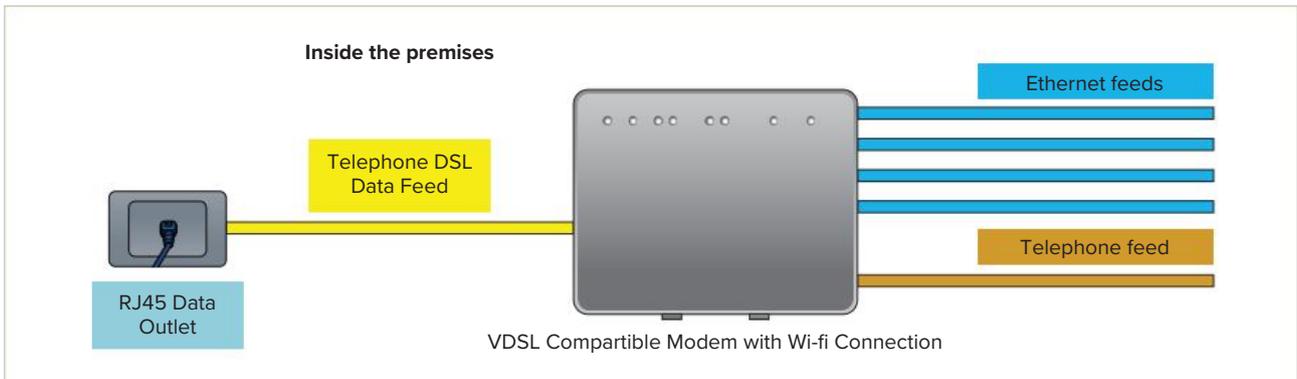


FIGURE 20.28 Fibre to the building NBN connection

Hybrid fibre coaxial

A hybrid fibre coaxial (HFC) system uses the existing Foxtel network as installed in the area. A fibre cable brings the service to a fibre node, where it is then changed to the cable television system (called data over cable service interface specification), commonly referred to as Foxtel (see Figure 20.29).

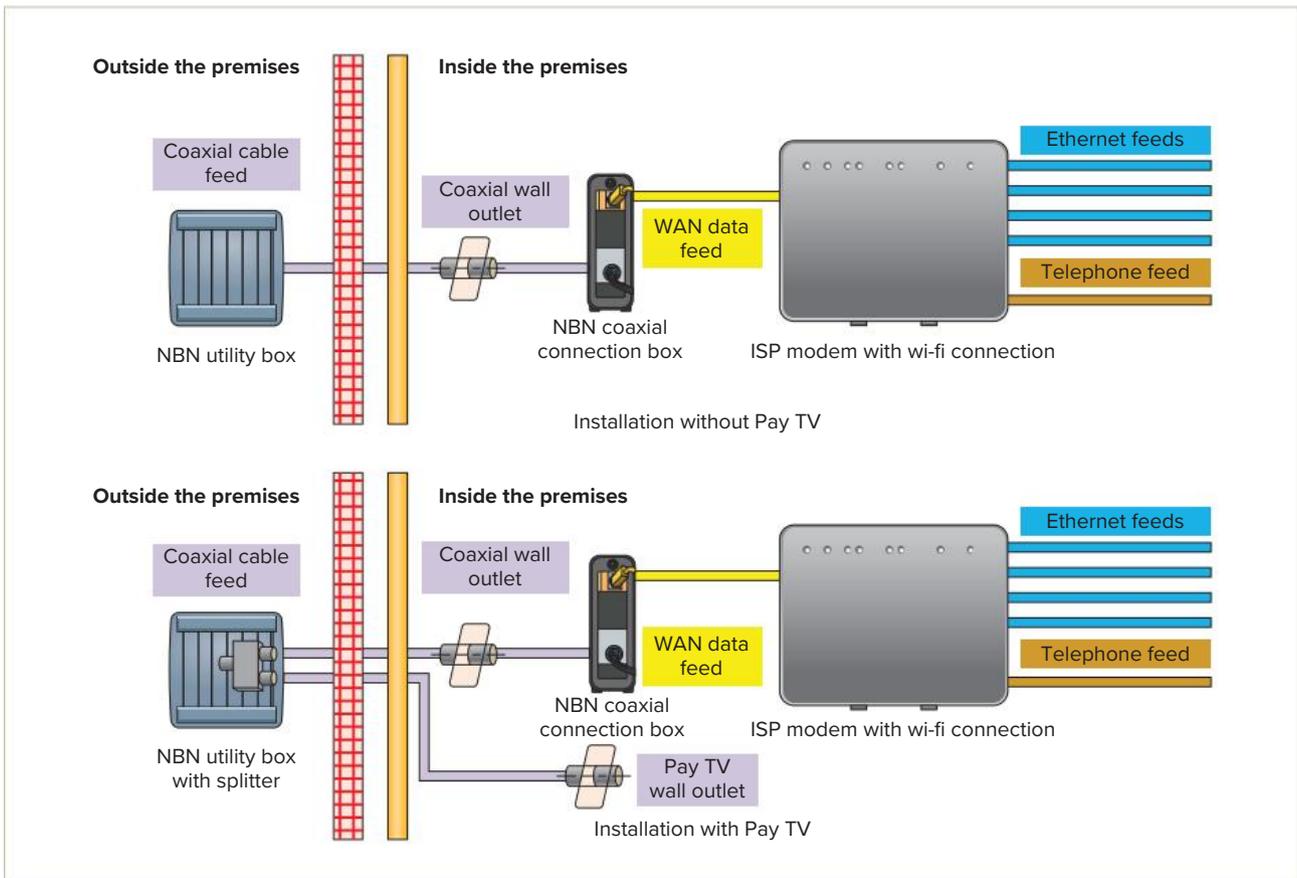


FIGURE 20.29 Hybrid fibre coaxial (HFC) connection

Figure 20.30 shows how the HFC network is connected. The different items may be several hundred metres apart, and the optical node (where the fibre optic cable terminates) may be several kilometres from the local exchange. The output from the taps is then run into the premises. The taps are selected to ensure the correct power level at the house, usually about $0 \text{ dB}\mu\text{V} \pm 10 \text{ per cent}$ at the outlet.

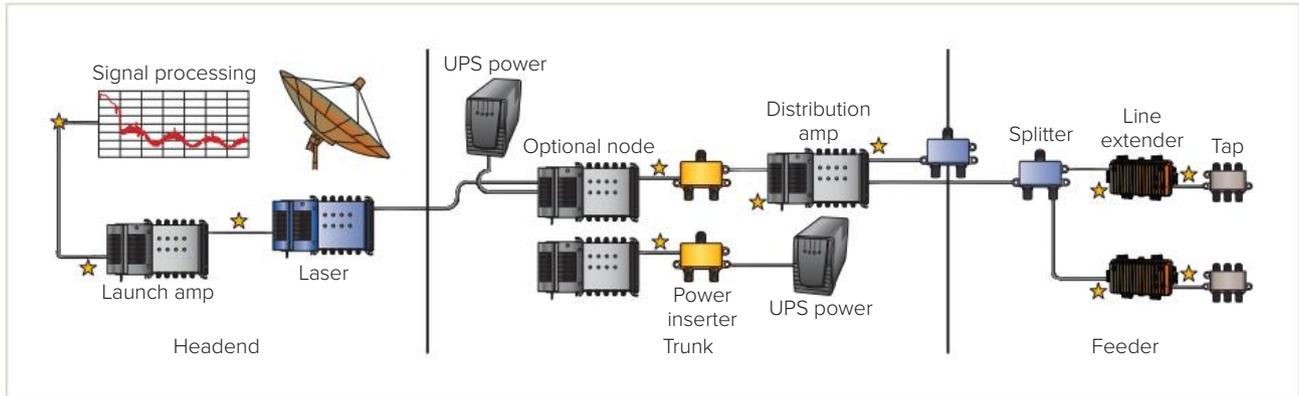


FIGURE 20.30 Connections within a hybrid fibre coaxial system

Source: Adapted from https://telecomtest.com.au/wp-content/uploads/2016/12/CM3000_Series_D05-00-062P_A00_LoRes.pdf

Figures 20.31 and **20.32** show the front and back view of a hybrid fibre coaxial NBN connection box.



FIGURE 20.31 The back of a hybrid fibre coaxial NBN connection box; note the single Ethernet port (UNI-D)

Robert Wickstead

The Ethernet port from the connection box needs to go to a router (which is usually supplied by the ISP) in order for computers and wireless devices to connect to the internet. **Figure 20.33** shows the connection from the NBN to the ISP router in yellow, and the computers and other devices on the network connected in blue.



FIGURE 20.32 Front lights of a hybrid fibre coaxial NBN connection box

Robert Wickstead

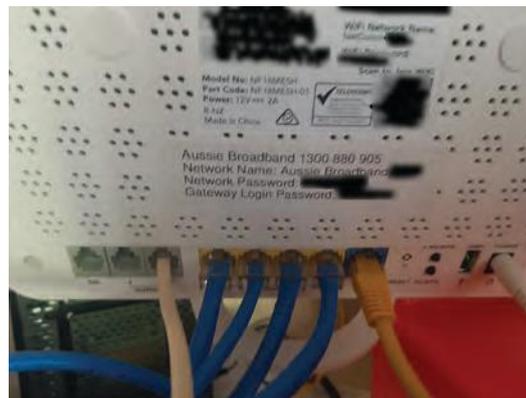


FIGURE 20.33 ISP-supplied router cable connections; note the cream telephone connection on the left; this system has an attached telephone going through the hybrid fibre coaxial network via the user network interface–telephone

Robert Wickstead

Fibre to the curb

A fibre to the curb (FTTC) connection runs a fibre from the pit closest to the premises and a small device is used in the pit to connect to an existing telephone line to bring the NBN into the building. The connection must be on a compatible socket-outlet (covered in **Chapter 19**). The customer is responsible for any costs associated with upgrading the socket-outlet. If there are multiple outlets in the place, all but one must be removed from the circuit.

What is unusual about this system is that the customer supplies power via the telephone line to the pit. The device in the pit will not work unless there is power from the house. Some pits may have as many as eight different devices connected, all being powered from different houses. This can lead to electric shock if care is not taken; see **Figure 20.34**.

Fibre to the node

Much like in the FTTB connection, in a fibre to the node (FTTN) connection the fibre is run to a cabinet on the nature strip, usually within about 300 m. Here it is then converted to run on the existing telephone line to the premises. The cabinets are powered from the street LV system, so the client is only powering their own equipment (refer to **Figure 20.28**). The four different NBN connections are shown together in **Figure 20.35**.

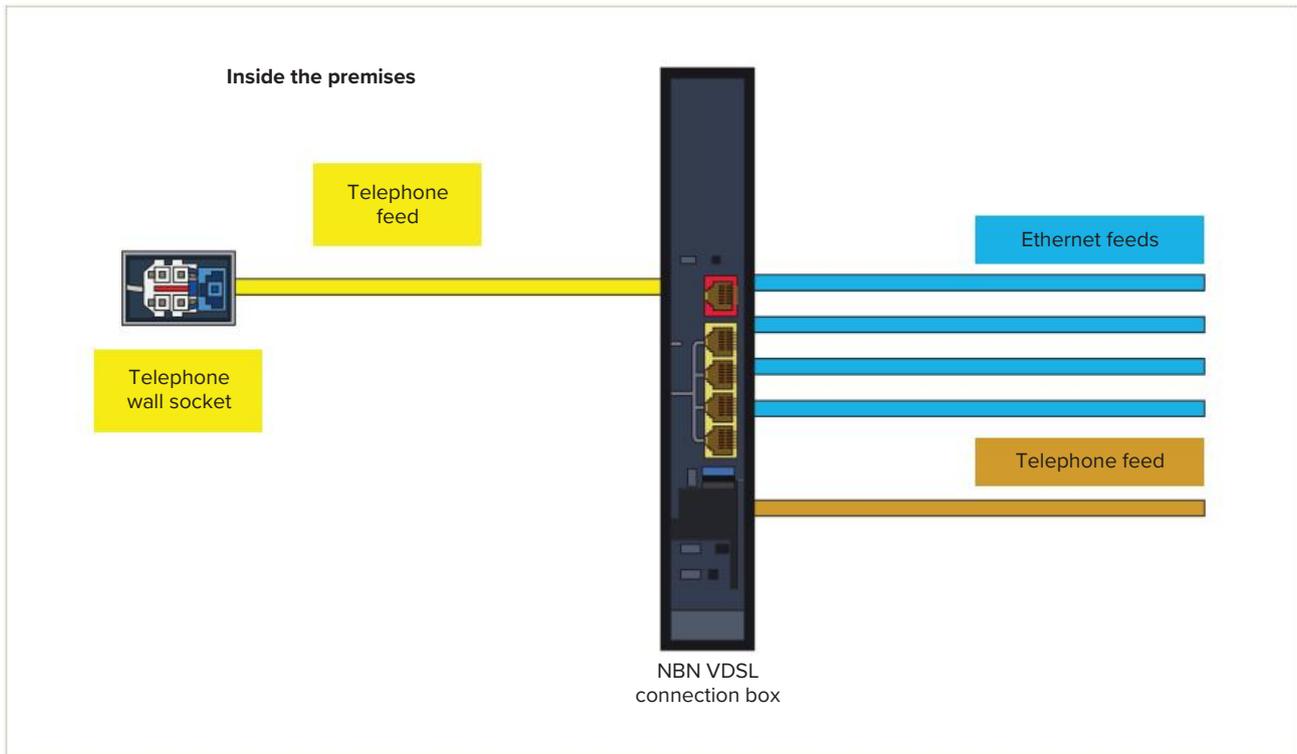


FIGURE 20.34 A fibre to the curb NBN connection

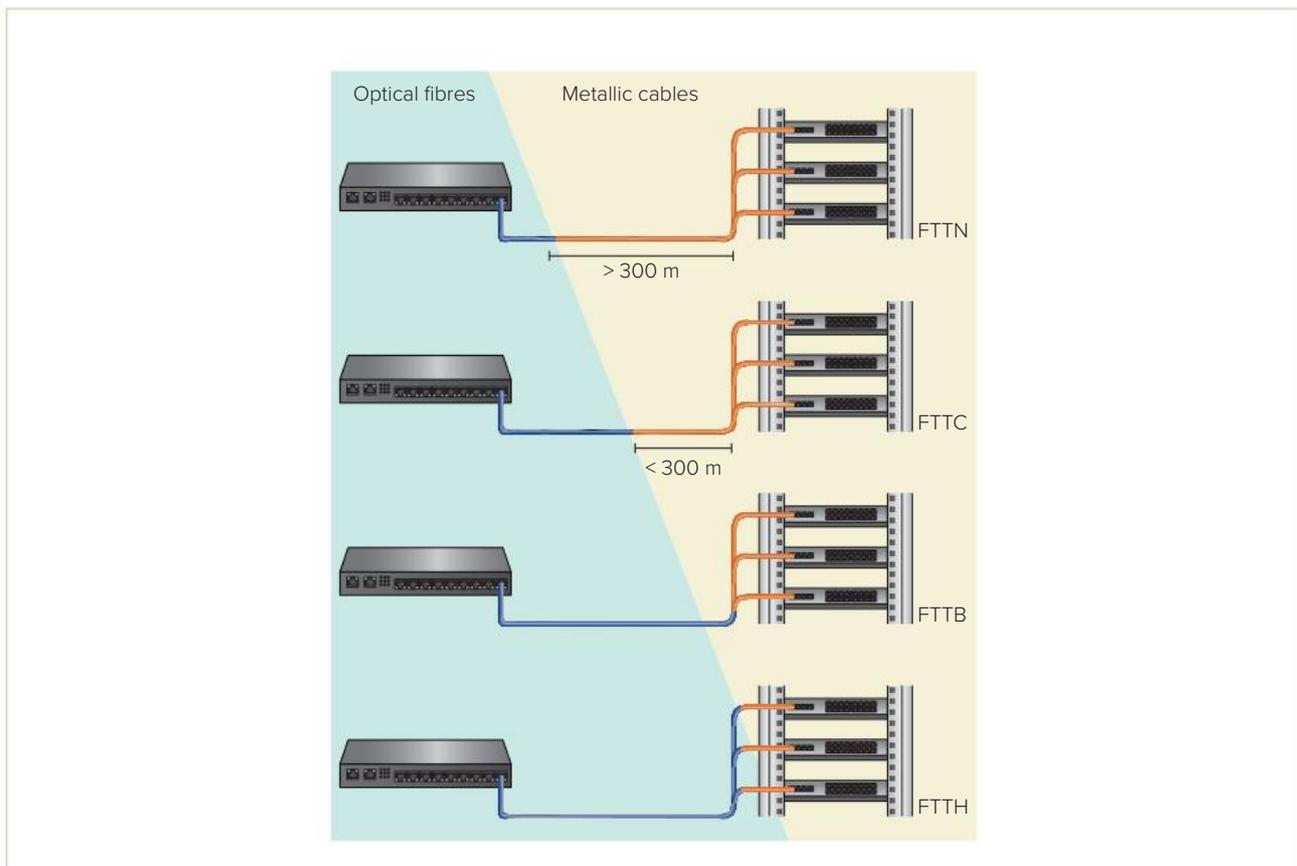


FIGURE 20.35 Common NBN connections

Fixed wireless

Data is relayed to a fixed wireless antenna mounted outside the building and pointing to the closest tower (usually many kilometres away). The antenna system requires power to operate and the connection box may be inside or outside the premises. If mounted outside, there will be an additional outlet installed for the Ethernet connection. There may be a requirement for additional surge protection as well, depending on local weather conditions (see **Figure 20.36**).

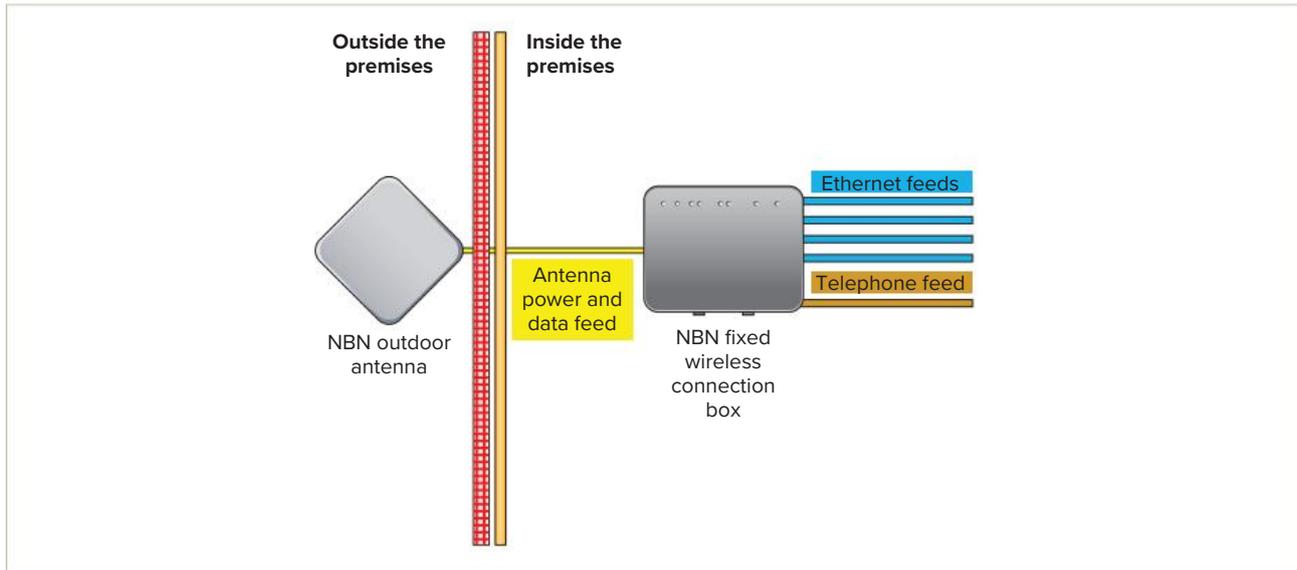


FIGURE 20.36 Fixed wireless NBN connection

Sky Muster™ Satellite

The Sky Muster™ satellite connection is much like the fixed wireless connection, only a much larger receiver antenna is needed—a satellite dish antenna. This system is designed for remote areas of Australia such as Central Australia, Norfolk Island, Christmas Island, and rural Tasmania (see **Figure 20.37**).

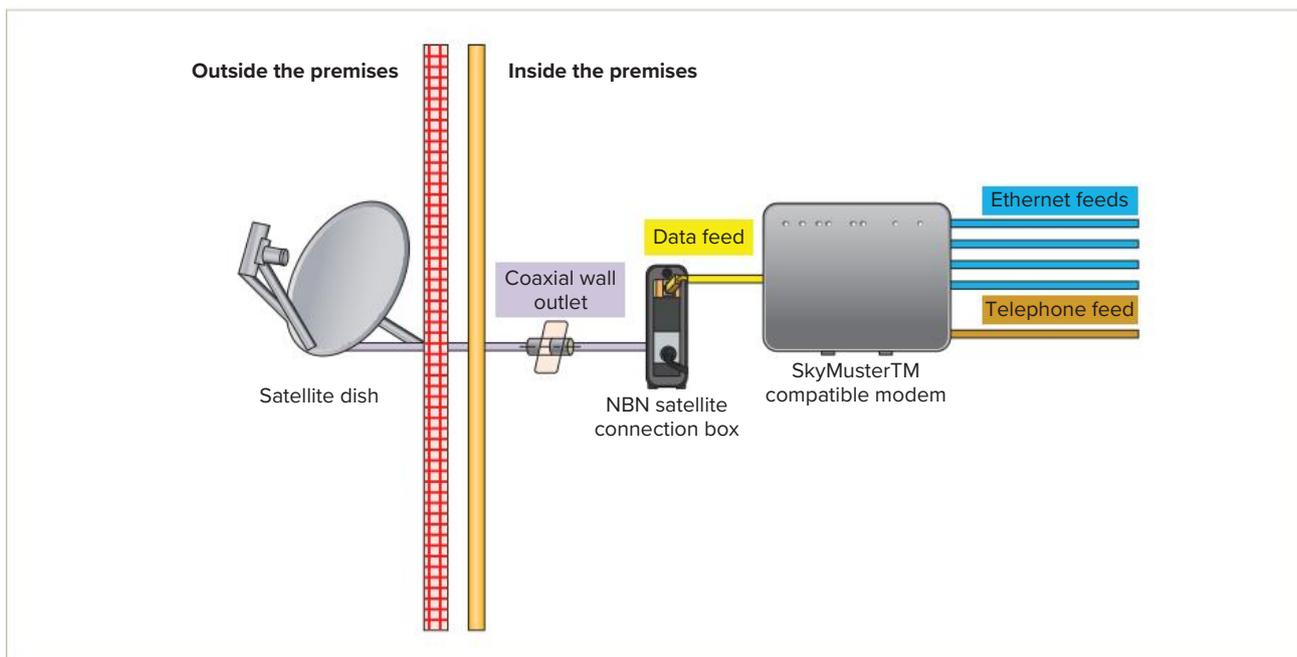


FIGURE 20.37 Sky Muster™ satellite NBN connection

The NBN connection box will vary depending on the technology used but will resemble that shown in **Figure 20.38**. The ports shown on the box are where the ISP modem (router) will plug in, usually with a short Ethernet cable. Only one of the ports is used but in larger installations where another ISP is used, a second port will be activated.

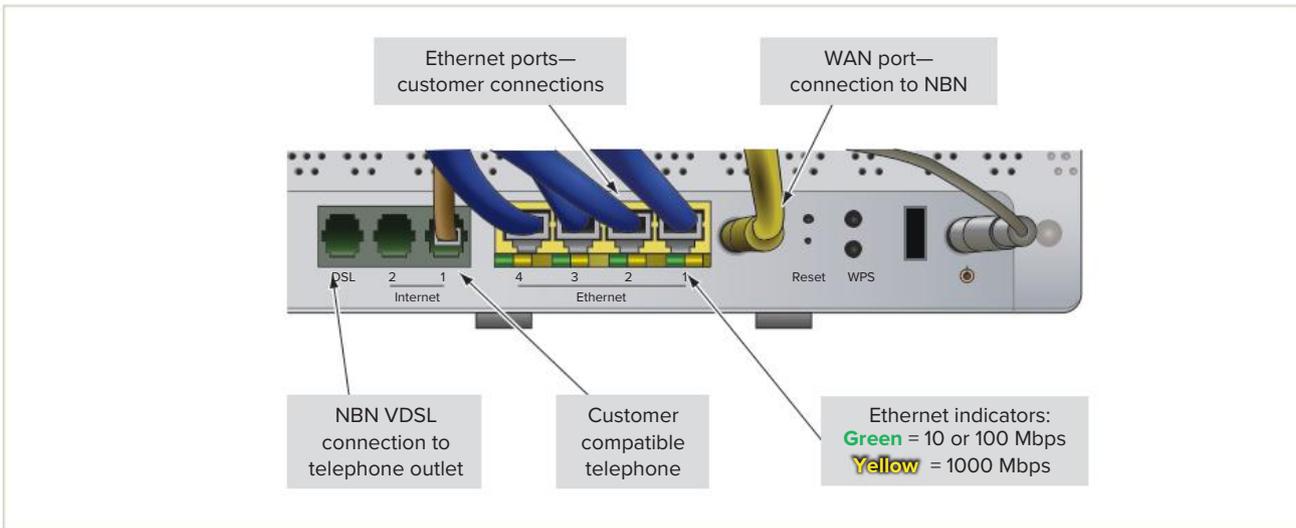


FIGURE 20.38 Typical NBN compatible modem connections

All these systems depend on a reliable LV supply being available. In the event of a power outage, the NBN system will *not* work unless the client has installed a battery backup. Sometimes this battery may be enclosed in the connection box or power supply but the more common method is for the client to connect the power to a dedicated uninterruptible power supply containing one or more standby batteries. This will keep the system operational for a period of time.

20.5.3 Testing the Foxtel/NBN network

Cable modem network analysers can test the functionality of cable networks. The results of a series of tests on the Foxtel network are shown in **Figures 20.39** to **20.43**. The tests were conducted on the author's cable system several years before the NBN was connected. A more technical discussion of these analysers and their testing capabilities can be found at <https://telecomtest.com.au/product/cm3000cm3800>.

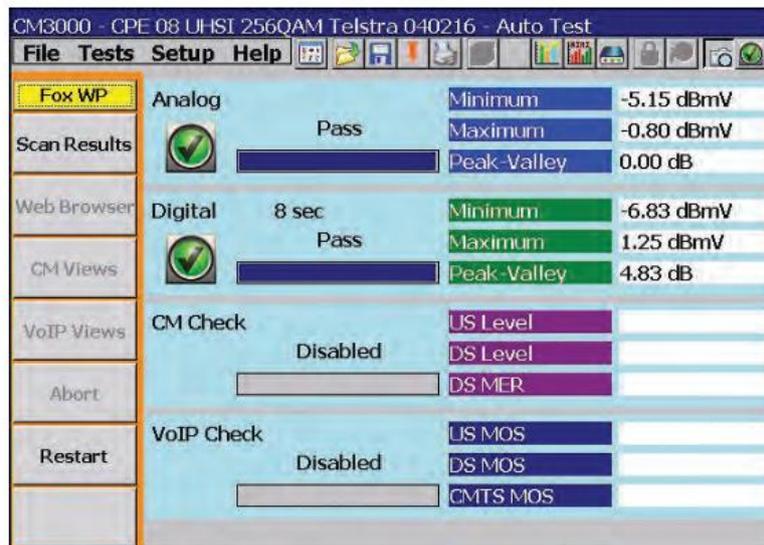


FIGURE 20.39 QAM test showing power levels recorded

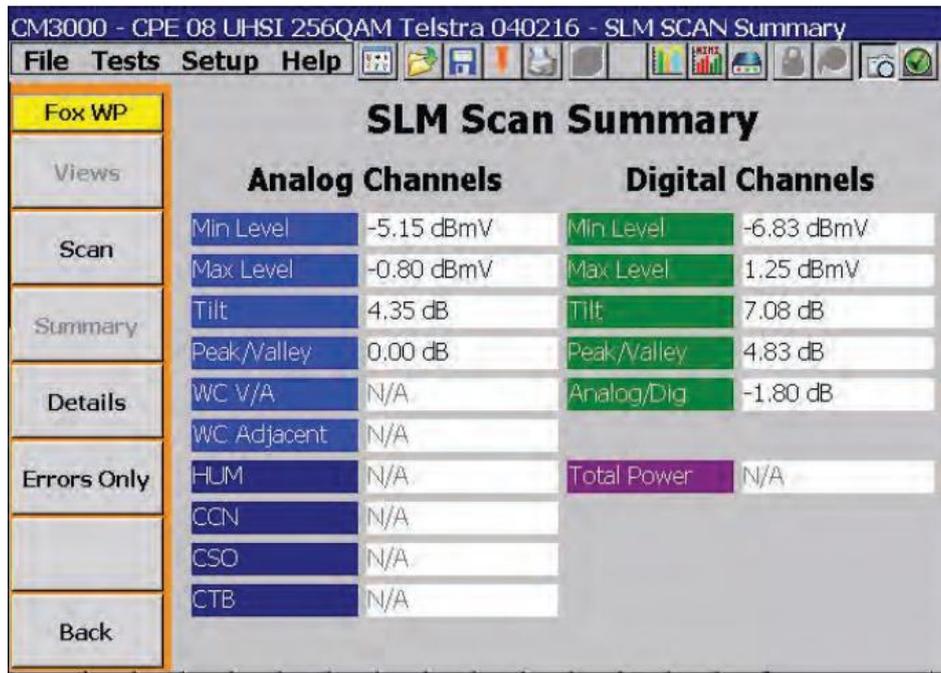


FIGURE 20.40 Signal level meter test; shows more detail than the QAM test
Robert Wickstead

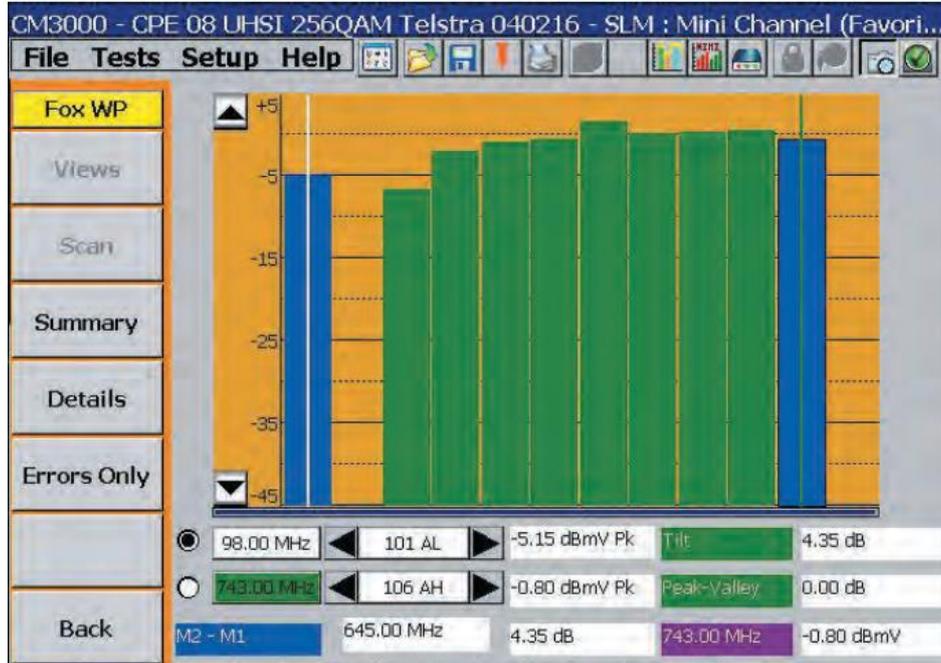


FIGURE 20.41 Signal level meter mini-scan test; shows key channel levels
Robert Wickstead



FIGURE 20.42 Signal level meter detail of mini-scan test

Robert Wickstead

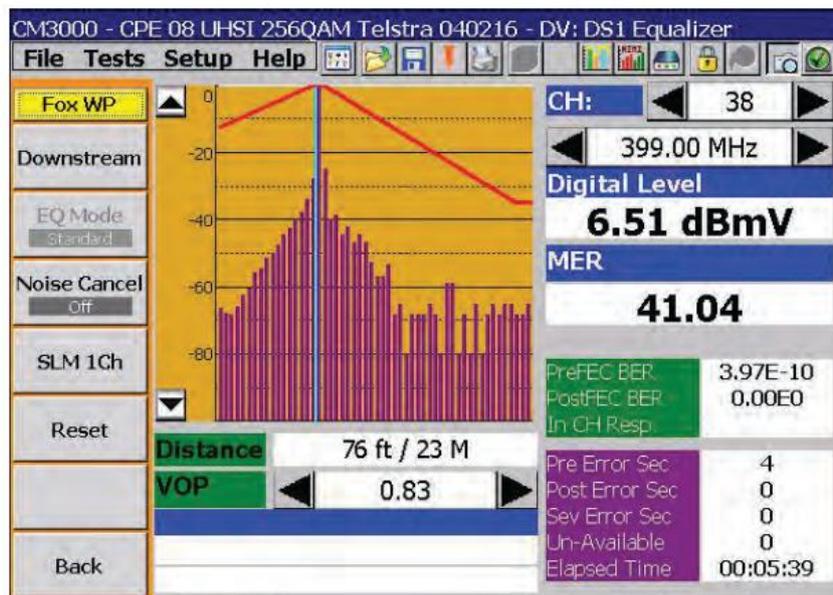


FIGURE 20.43 Equaliser test; the peak (the location of the outside coaxial connecting with the inside coaxial) indicates the connection is 23 m from the tester

Robert Wickstead

20.5.4 NBN installation

A sample FTTP/FTTH installation is shown in **Figure 20.44**. The installer is responsible for installing the P23 conduit from the premises connection device (PCD) location to the network termination device (NTD) location, and any LAN cables needed from the ISP modem. The NBN (via the ISP) is then responsible for the cable from the street, the PCD (install and connect), the power supply unit and the NTD. The ISP will supply the modem and the internet cable, connecting the ISP to the NBN. It is advisable to have an uninterruptable power supply for the NBN and ISP equipment to plug into, to prevent problems during power outages.

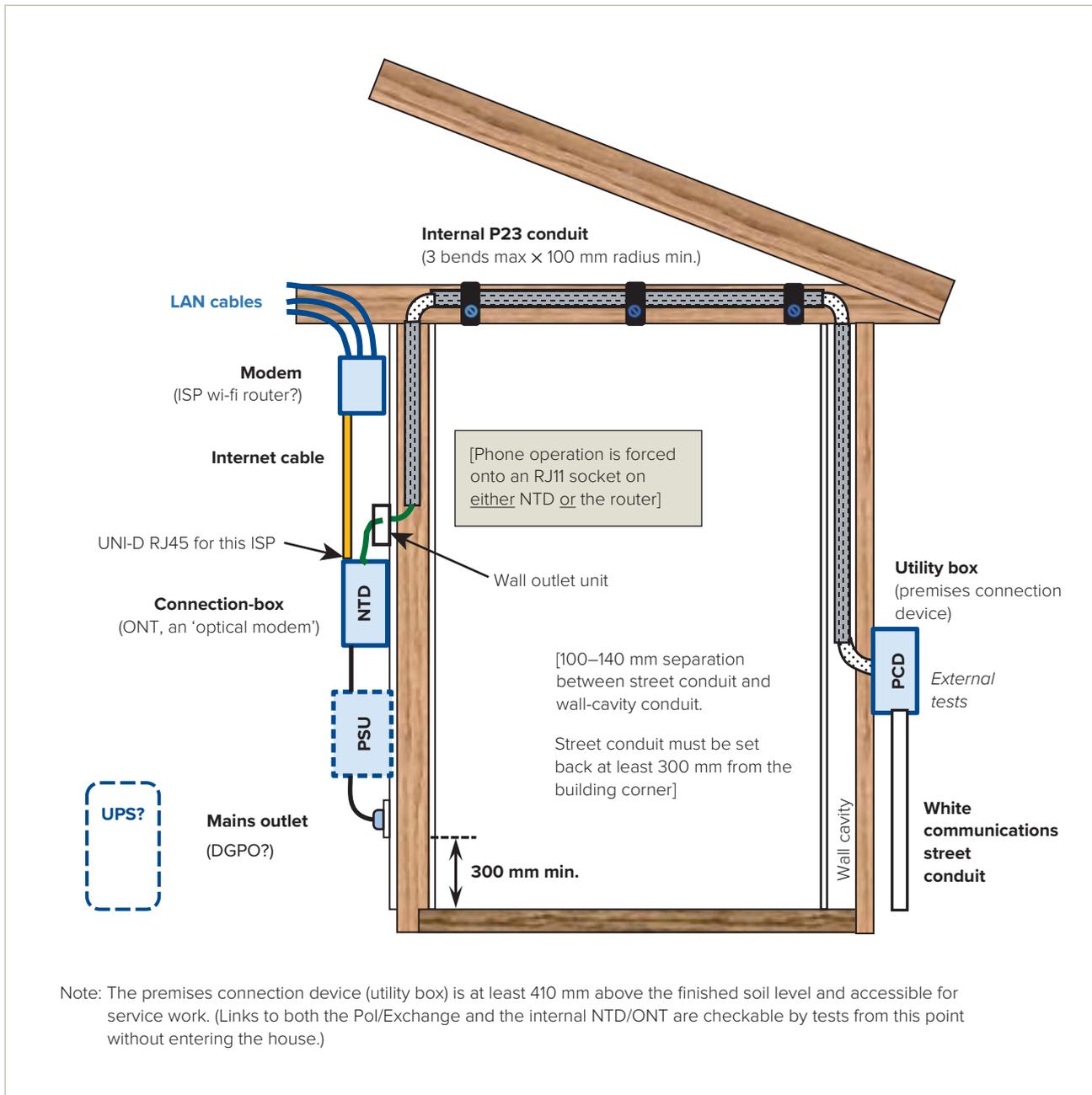


FIGURE 20.44 Sample domestic FTTP/FTTH installation

Source: Rob Bernard



CHECK YOUR UNDERSTANDING

21. What are the different NBN connection systems? Provide a brief explanation of each.
22. What is the hybrid fibre coaxial network?

20.6 Testing cable networks

Quality control is a way to maintain standards in manufactured products by testing a sample of the output against the specification. Within telecommunications, quality control is measured by testing the installation in relation to a manufacturer's testing specifications or checklists. Companies sometimes have quality assurance staff who assess and check work on a progressive basis. This ensures that the installation is done to their company's specifications. It also means that when an installer gets to the end of an installation, they will not find that a critical product did not meet required expectations and/or performance levels, forcing them remove it and start again.

As some manufacturers offer extended warranty on products, the cabling provider must produce tests, evidence and results of installed cabling systems, which are submitted to the manufacturers for testing. On the completion of terminating cables, a checklist or job sheet may incorporate some quality-control measures to ensure that an employee is aware of the expectations concerning the quality of their work. Some companies attach pride tags to their work and keep other documents to demonstrate high-quality work.

20.6.1 Testing twisted pair cables

One of the requirements of Standard *AS/CA 2009:2020, Clause 13.13.4(a)* is that the appropriate tool is used when terminating cables. This avoids damaging the terminals and cable. Along with basic hand tools, the installer will be expected to have basic testing devices, and sometimes, more complex ones.

Cabling providers must test the installation of cabling products to ensure compliance with relevant Standards and manufacturers' requirements. The need for testing equipment will depend on job tasks but most installers performing basic installation work will need to have the following testing equipment available for daily use:

- ▶ digital multimeter
- ▶ function set (F-set)
- ▶ buttinski (for telephone work only)
- ▶ basic cable tester (wiremap)
- ▶ insulation resistance tester
- ▶ LSA (Krone) tool
- ▶ 110 tool.

Data installers and cabling specialists may also have access to or carry the following test equipment:

- ▶ cable performance scanner
- ▶ optical time domain reflectometer
- ▶ light source and power meter.

In some circumstances when testing cabling products and equipment outside, a functional test of the live equipment may be needed. In other words, if an installer is testing that a cable pair is fit for use, they may connect a live line from the carrier on the cable pair and install the equipment to be left in place. This is the aim when trying to get a telephone circuit working. This type of test is called a working service test.

Ideally, it is always good practice to test and confirm cabling and cabling products are fit for use and application prior to installing equipment. Failure to test cabling for incorrect termination may affect manufacturer warranty and compliance issues. If a cabling provider fails to perform basic checks on cabling and it is connected to the carrier's network, the carrier may disconnect and cease to supply service to the installation if the cabling has not been terminated correctly and in accordance with *AS/CA S009:2020*.

20.6.2 Simple tests of cable networks

Organisations that use telecommunications networks tend to rely heavily on the networks to conduct their day-to-day business. Many failures can be eliminated by performing simple but thorough tests on the cabling system

after installation. It is the responsibility of the cabling provider to test all installed cabling to ensure not only that it complies with installation requirements but also that it functions correctly. There is a broad range of sophisticated test equipment available for testing metallic conductor cabling systems. However, it is possible to discover many cable faults using simple testing techniques and low-cost testing instruments.

Examples of simple tests

End-to-end continuity testing is a simple and effective way to detect miswiring and shorted or open conductors. Measuring the resistance of the cable insulation can be achieved by connecting an insulation resistance tester to the isolated conductors.



CAUTION

Never touch the ends of the probes while performing an insulation resistance test.

Before conducting any test on a telecommunications cable, installers need to determine its state. To do this, the voltage on the line must be measured. Start by measuring the a.c. voltage. If this indicates zero, then measure the d.c. voltage: this too needs to be zero. Always start with the voltmeter set at a voltage of about 500 V and work down the selector to be sure there is no voltage present.



CAUTION

Never presume you already know the state of any cable.

Ideally, the traditional copper public switched telephone network line should measure 48 V d.c. when idle. Note that NBN fibre optics do not carry a voltage and the NBN VDSL over copper has only a very minute d.c. voltage.

Category 3 or voice-grade cabling must pass a continuity test. Some basic tests used for Category 3 cables are open, short and miswired cable pairs.



CAUTION

- ▶ Always exercise care when testing communications circuits.
- ▶ Know your electrical safety rules and follow your work health and safety procedures—refer to your company's safe work method statements prior to commencing work.
- ▶ Know how to assist an electric shock victim—keep your first aid training up-to-date and know how to assist in an emergency.
- ▶ Be tidy.

SINGLE-PAIR CABLES

A basic continuity test will ensure the correct pairing of A and B legs of the cable pair. A common basic test performed on installed multipair cables is a pair identification test. This test is performed by sending a warbling tone down the pair and reading the warbling tone with a probe. The device used for such testing goes by the colloquial name *F-set*.

An F-set is a battery-powered device that uses an oscillator to transmit the tone and a receiver probe to home in on the signal. Such units normally have an LED, which shows the correct line polarity. Today there is more than the standard Aegis F-set on the market and companies such as Fluke produce multi-testing equipment that can perform basic tests as well as pair identification. **Figure 20.45** shows an example of one such instrument.



FIGURE 20.45 Fluke Networks IntelliTone tone and probe set

Reproduced with permission, Fluke Corporation

A basic pair identification test on a multipair cable would be conducted as shown in **Figure 20.46**. Line polarity is where the correct termination is performed at the socket-outlet, the NTD and the exchange—that is, the L– and L+ are terminated on the correct pins. Line polarity is not crucial to the functioning of most equipment but it is good practice to wire it the correct way around.

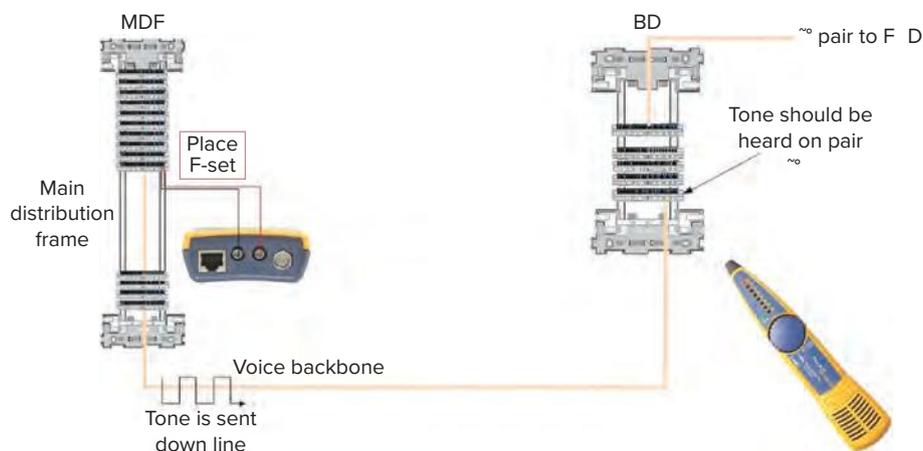


FIGURE 20.46 Basic pair testing

MULTIPAIR CABLES

Multipair cables need to be tested for correct pairing and continuity on all the cables. Testers are available on the market that test multiple cable pairs, commonly referred to as LAN testers. A LAN tester can find any of several simple faults on cable pairs, such as:

- ▶ open-circuit pair
- ▶ short-circuit pair
- ▶ split pair
- ▶ reversed pair
- ▶ crossed pair.

A LAN tester is a two-part tester: the sender or master and the receiver or remote. Using a simple Ethernet cable at each end, simple and quick tests can be done between the patch panel and floor outlet. LEDs will provide a visual indication of correct or incorrect pair terminations. Many different brands produce such testers and they are available for a relatively low cost. **Figure 20.47** shows a simple LAN tester.



FIGURE 20.47 Simple LAN tester unit

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- ▶ An open-circuit pair exists when one or both conductors in the pair are not electrically continuous. This fault will appear as a loss of telecommunications signal at either end of the pair. See **Figure 20.48** for an example. Potential causes of faults in a cable include:
 - ▶ wires connected to the wrong pins at the connector or terminating modules
 - ▶ faulty connections
 - ▶ cables routed to the wrong location
 - ▶ wires broken by stress at connections
 - ▶ damaged connector
 - ▶ cuts or breaks in cabling.
- ▶ A short-circuit will have the conductors of the A wire and the B wire touching somewhere along its length. This type of fault appears as a loss of telecommunications signal on the pair. Short-circuits can be from the same faults as open circuits. It is hard to find the exact position of a short-circuit in a cable without special test equipment. It may be possible to use an ohmmeter to gauge a rough distance to the short-circuit, but it depends on the actual resistance of the short (most are not 0Ω). To do this, measure the unlooped resistance of the pair from either end. If both conductors are open, there is a good chance the entire cable is damaged. See **Figure 20.48** for an example.

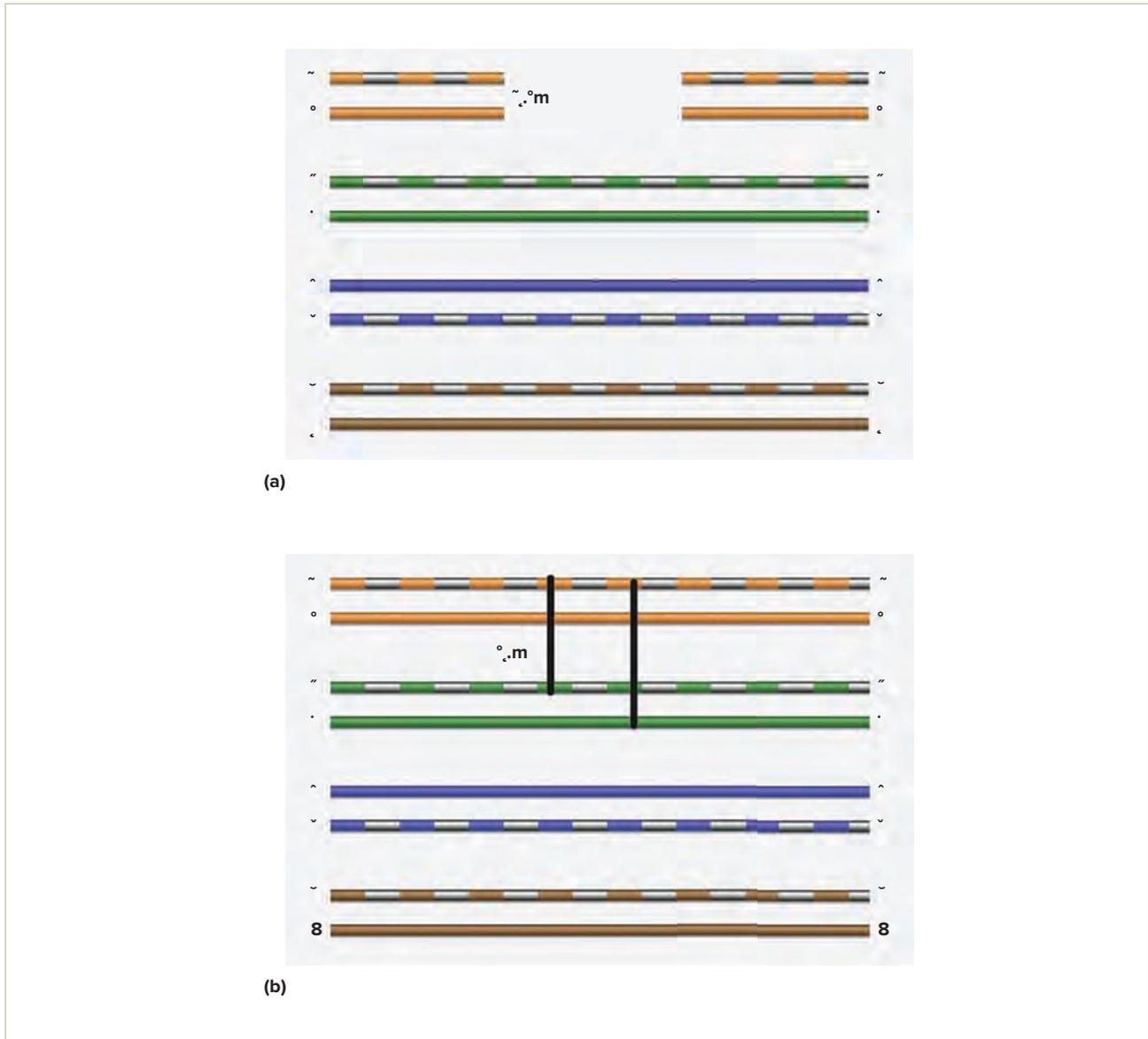


FIGURE 20.48 Screen display of cable faults from a LAN tester: (a) open-circuit pair and (b) short-circuit pair

- ▶ A split pair arises when one wire from a cable pair untwists and terminates from a wire in a different cable pair. Split pairs most frequently result from miswires at termination modules and cable connectors. For example, the A wire of Pair 1 is paired with the B wire of Pair 2, while the B wire of Pair 1 is paired with the A wire of Pair 2. Split pairs cause bad crosstalk as the signals in the twisted pairs come from different circuits. In telephone circuits, you may notice excessive crosstalk when using a test telephone. Detection of split pair wiring is done with a simple wire map tool—usually only a sophisticated tester will pick up this problem.
- ▶ Reversed pair wiring occurs when, for example, the A wire terminates in the correct position at one end but terminates in the position for the B wire at the other end, and vice versa. This situation will have little or no effect on a simple telephone service but it is important on systems requiring correct polarity. High-speed Ethernet will not work at all if there are reversed pairs in the installation.
- ▶ Crossed pair wiring occurs when the A wire and B wire of a pair terminate in the correct position at one end but terminate in the position of the A wire and B wire of another pair at the other end, and vice versa.

Split pair, reversed pair and crossed pair faults are illustrated in **Figure 20.49**.

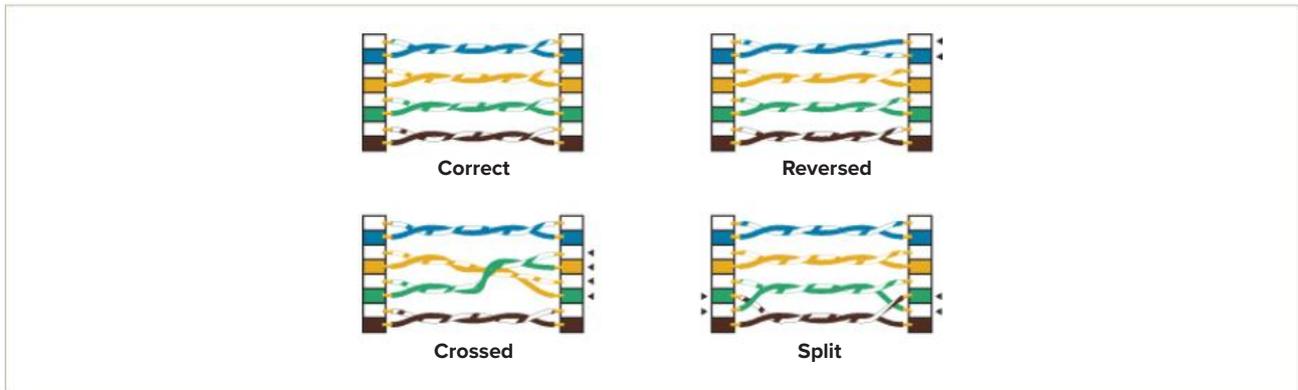


FIGURE 20.49 Common termination faults

20.6.3 Advanced testing of cable networks

In addition to carrying out basic tests, installers may be required to conduct compliance testing and certification for manufacturers. Cabling providers may be required to hire or purchase advanced testers to perform further tests on the cable to check its performance. It is important that cabling providers check with the manufacturer prior to certification to ensure their testing instrument is compliant and calibrated. These high-level testers are sometimes referred to as certification testers. They are the only ones that can provide a Pass or Fail on the tested link when tested using industry standards (TIA/EIA, ISO, AS, etc.).

These testers also check for proper twist rate at the connectors using the time domain reflection function and provide feedback on length, resistance and propagation delay (how long it takes a signal to go from one end to the other). These testers check each pair of wires against the other pairs of wires in the cable over several hundred MHz (250 MHz for Category 6). Examples of advanced testers include:

- ▶ Fluke Networks DSX CableAnalyzer™ (see Figure 20.50)
- ▶ WireScope 350
- ▶ Lantek.



FIGURE 20.50 Fluke DSX-5000 CableAnalyser main unit

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Advanced testers of this type are complex, expensive and require much experience in order to properly read their results. Manufacturers and wholesalers offer training in the use of these testers, at varying levels. A data cabler doing this type of installation would be wise to gain competency in testing (there is a cabling endorsement for this, too).

Industry standards give a minimum performance level by which clients, manufacturers and installers can rate their installation and see how well (or not so well) their cables and connections perform. Advanced tests can check for:

- ▶ propagation delay
- ▶ delay skew
- ▶ d.c. loop resistance
- ▶ insertion loss (attenuation)
- ▶ return loss (RL)
- ▶ near end crosstalk (NEXT)
- ▶ far end crosstalk (FEXT)
- ▶ alien crosstalk (AXT).

Apart from wire map, the most common fault is crosstalk, where the signal on one cable interferes with the signal on another cable. This usually happens at the termination points and can only be picked up with a certification meter. Manufacturers are quite adamant about maintaining the correct twist rate up to the connections and the entire cable must pass for certification to be granted.

A printout from a Fluke DSX-5000 CableAnalyser for a Category 6 cable using the TIA permanent link standard is shown in **Figure 20.51**.

20.6.4 Testing coaxial cable

Carrying out testing on coaxial cable is slightly different from testing on data cable. A simple multimeter can check for short circuits and open circuits but will not indicate whether a coaxial cable is usable. The only way to determine this is by transmitting a known signal down the cable to a receiver and comparing the information received with minimum standards of operation. For free-to-air television, using the signal from a properly installed digital antenna will provide known signal levels for the installer to check. A minimum signal level is required for attached equipment to function properly. This is usually measured as dB μ V. A test sample is shown in **Figure 20.52**.

The meter in **Figure 20.52** indicates the test is on RF Channel 12 (i.e. ABC in Melbourne, Australia, transmitting from Mount Dandenong), showing typical results for free-to-air reception at the socket-outlet. This meter will also check the power level for most Pay TV coaxial cable but will not test satellite reception (frequency is in the 2+ GHz range).

Figure 20.53 provides an example of a domestic Foxtel installation to three socket-outlets with a free-to-air antenna. Note how most of the cabling is RG6/U coaxial cable or 6 mm² earth.



CHECK YOUR UNDERSTANDING

23. What cable faults can be found using a LAN tester?
24. Explain the difference between a crossed pair and a split pair.
25. A certification meter can test for what type of faults?
26. What is the purpose of testing a coaxial cable for signal strength?
27. What are some testing tools the installer may require?



Cable ID: TYLER AND DEC C6 CP

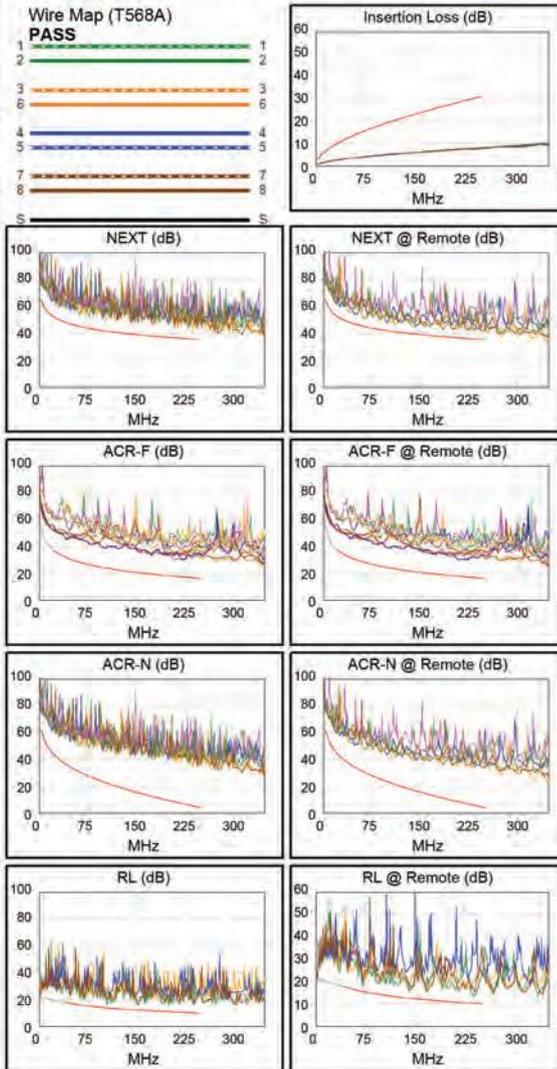
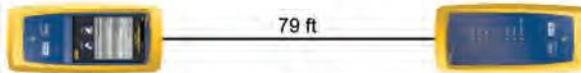
Test Summary: PASS

Test Limit: TIA Cat 6 Perm. Link
 Limits Version: V7.5
 Date / Time: 08/03/2021 11:28:49 AM
 Operator: BIG NUG
 Headroom 4.9 dB (NEXT 1,2-3,6)
 Cable Type: Cat 6 U/UTP
 NVP: 69.0%

Main: Versiv
 S/N: 20520290
 Software Version: V6.5 Build 5
 Calibration Date: 04/08/2021
 Adapter: DSX-5000 (DSX-PLA004)
 S/N: 21112161

Remote: Versiv
 S/N: 20520288
 Software Version: V6.5 Build 5
 Calibration Date: 04/08/2021
 Adapter: DSX-5000R (DSX-PLA004)
 S/N: 21112162

Length (ft), Limit 295	[Pair 7,8]	79
Prop. Delay (ns), Limit 498	[Pair 4,5]	122
Delay Skew (ns), Limit 44	[Pair 4,5]	6
Resistance (ohms)	[Pair 4,5]	4.09
Insertion Loss Margin (dB)	[Pair 3,6]	22.4
Frequency (MHz)	[Pair 3,6]	241.5
Limit (dB)	[Pair 3,6]	30.5



	Worst Case Margin		Worst Case Value	
	MAIN	SR	MAIN	SR
PASS				
Worst Pair	1,2-3,6	1,2-3,6	1,2-3,6	3,6-4,5
NEXT (dB)	7.4	4.9	7.4	6.1
Freq. (MHz)	238.5	110.5	238.5	250.0
Limit (dB)	35.7	41.1	35.7	35.3
Worst Pair	1,2	3,6	1,2	3,6
PS NEXT (dB)	8.6	5.0	8.6	5.3
Freq. (MHz)	238.5	110.5	238.5	234.5
Limit (dB)	33.0	38.6	33.0	33.2
PASS				
Worst Pair	3,6-7,8	7,8-3,6	7,8-3,6	3,6-7,8
ACR-F (dB)	12.5	12.3	12.7	12.7
Freq. (MHz)	211.0	211.0	223.5	223.5
Limit (dB)	17.7	17.7	17.2	17.2
Worst Pair	3,6	3,6	3,6	3,6
PS ACR-F (dB)	13.0	12.9	13.8	13.5
Freq. (MHz)	10.0	11.8	221.5	222.0
Limit (dB)	41.2	39.8	14.3	14.3
N/A				
Worst Pair	1,2-7,8	1,2-7,8	1,2-3,6	1,2-3,6
ACR-N (dB)	13.1	13.5	29.6	27.8
Freq. (MHz)	3.1	3.0	238.5	234.5
Limit (dB)	61.9	61.9	5.4	5.8
Worst Pair	7,8	1,2	1,2	3,6
PS ACR-N (dB)	13.8	14.2	31.2	27.3
Freq. (MHz)	3.9	7.8	238.5	234.5
Limit (dB)	58.5	52.4	2.8	3.2
PASS				
Worst Pair	3,6	3,6	3,6	3,6
RL (dB)	2.7	2.6	4.4	3.4
Freq. (MHz)	105.5	69.8	200.5	241.5
Limit (dB)	13.8	15.6	11.0	10.2

Compliant Network Standards:
 10BASE-T 100BASE-TX 100BASE-T4
 1000BASE-T 2.5GBASE-T
 ATM-25 ATM-51 5GBASE-T
 100VG-AnyLan TR-4 ATM-155
 TR-16 Passive TR-16 Active

LinkWare™ PC Version 10.9

Project: 18A10
 18A10.flw



FIGURE 20.51 Printout of a Category 6 cable certification test from a Fluke DSX-5000 CableAnalyser; the green tick indicates a pass

Robert Wickstead



FIGURE 20.52 Meter reading of signal power level from a free-to-air antenna

Robert Wickstead

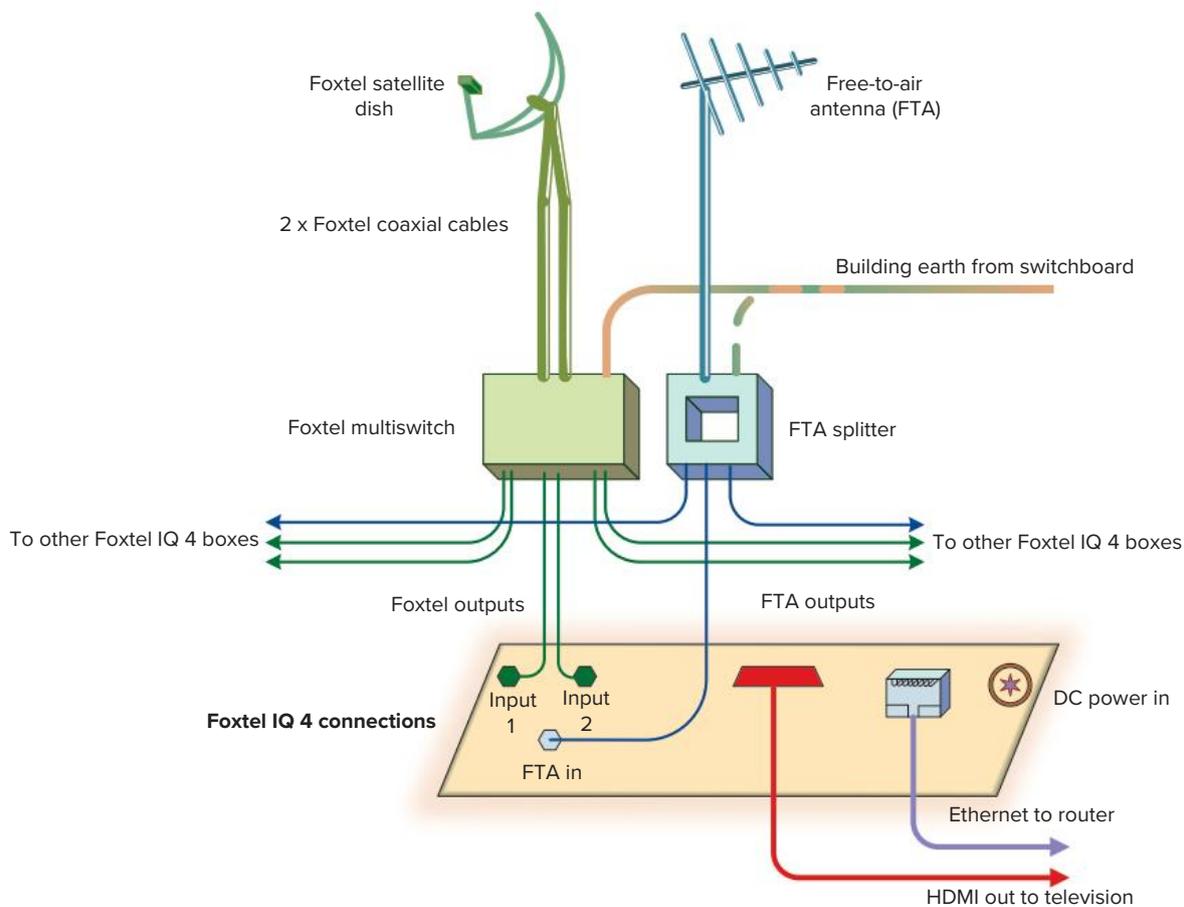


FIGURE 20.53 Example of a domestic Foxtel installation

SUMMARY

- ▶ Open Systems Interconnection uses the 7-layer model to describe the layers that systems use to communicate over a network. According to this model the installer operates at Layer 1 in this process and is key to ensuring the network is robust.
- ▶ Common cable pathways include solid fixings, cable trays, ladder trays, mesh/basket trays, shared trays and catenary supports, and all must be installed according to the mandatory requirements of *AS/CA S009:2020, Section 10*.
- ▶ Cables must be correctly terminated to ensure the network functions at its full capacity.
- ▶ *ISO 11801* classifies cables according to classes and categories.
- ▶ Crosstalk occurs when the signal on one set of wires affects the signal on another set of wires and can be prevented by shielding cables.
- ▶ Cables, optical fibre, distributors, telecommunications socket-outlets and cables transmitting extra-low-voltage d.c. should be labelled according to the relevant Standards.
- ▶ Earthing of telecommunications cables is done to minimise the effects of low-frequency induction and high-frequency induction. Earthing cable must follow the requirements of *AS/CA S009:2020, Section 20* and those of the manufacturer.
- ▶ Coaxial cable uses only one wire to transmit a signal. The one wire is surrounded by a spacer insulator which is wrapped (coaxially) in a system of shields, made of either copper, aluminium, steel or a combination of all these. The decibel is used to measure and indicate losses in a cable, which can be mitigated by using quality cable and approved connectors, employing correct cable-laying techniques and installing shorter cable runs.
- ▶ The National Broadband Network provides the means for retail providers to connect to internet services in Australia. There are different ways the NBN connects to premises, and the method used will depend on the infrastructure already in use. Common connections include fibre to the premises, fibre to the building, fibre to the curb (kerb) and fibre to the node.
- ▶ Cable installations should be tested to ensure compliance with relevant Standards and manufacturers' requirements. Common faults to test for include open-circuit pairs, short-circuit pairs, split pairs, reversed pairs and crossed pairs.

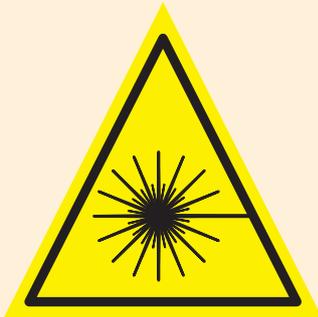
REVIEW QUESTIONS

1. What are some considerations when hauling cables that the installer must keep in mind?
2. Can an installer use existing services or supports for telecommunications cables?
3. Are cable ties recommended for use on indoor cables? Why or why not?
4. Why is it problematic to have excessive untwisting of cables when terminating?
5. Can you terminate a cable with 568A on one end and 568B on another? Why or why not?
6. Why should all four pairs of a phone link be terminated if only the Blue pair is used?
7. Complete the following table.

Class	Category of cable	Transmission frequency	Typical use
A			Security detectors, doorbells
	2		Analogue telephones
C	3		

Class	Category of cable	Transmission frequency	Typical use
			Token ring
	5		
		100 MHz	Ethernet using four pairs of wires, typically domestic only Improved Category 5 Adequate for handling 1 Gbps over shorter distances
	6		
E _A		500 MHz	
		600 MHz	Data centres (occasionally) Individually shielded pairs allow independent functions on different pairs at the same time
	7A	1000 MHz	
		2000 MHz	Data centres, 30 m and 40 Gbps maximum Can use RJ45 components
Class II			

8. Explain the *90 + 10 Rule*.
9. Describe *crosstalk*.
10. What types of cables are denoted by the following letters: TP, U, F, S, SF?
11. In what situations would an installer use the following warning sign? What does it mean?



12. Can an installer with an open cabling registration make an earthing connection in a switchboard?
13. Give examples of basic checks an installer needs to perform on an earthing system.
14. Should the earth wire from a switchboard be labelled? Why or why not?
15. Explain the following terms:
 - ▶ sacrificial sheath
 - ▶ flooding the cable
 - ▶ unbalanced, RG6 Quad.
16. What are some of the installation practices an installer should follow?
17. Briefly explain the seven different NBN connections.
18. How often should LAN testers and certification testers be tested?
19. Describe the common fault that causes crosstalk.
20. What signal level is recommended for a free-to-air domestic television?

CHAPTER 21

Working in the energy sector

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ list energy sector vocations and relevant peak bodies
- ▶ understand the requirements of working in the energy sector
- ▶ prepare to work in the energy sector
- ▶ carry out work activities in the energy sector
- ▶ understand how to problem solve and address unplanned situations
- ▶ check and confirm work activities are completed
- ▶ develop apprentices as resources
- ▶ understand self-help and employee assistance
- ▶ seek employment in the energy sector
- ▶ prepare for workplace interviews.

The energy sector in Australia employs thousands of electrotechnology workers including trainees, apprentices, tradespeople and other professionals. Vocational education and training qualifications for the majority of these workers range from Certificate II through to Diploma. Working in the energy sector, like any other sector, involves preparing to work, carrying out work activities, problem solving and completing required work activities.

In addition to providing information about industry stakeholders and the careers within it, the chapter looks at the development of apprentices as valuable assets for organisations and the industry at large. It also includes a section on employee health and wellbeing, which applies to apprentices and all electrotechnology workers in general.

The chapter also provides general information about getting work experience and preparing for job applications and interviews. This information is relevant to those seeking an apprenticeship, award interviews and promotions, as well as to those applying for a job after completing a traineeship or apprenticeship.

21.1 The energy sector

The electrotechnology sector includes the design, installation, maintenance and repair of electrical and electronic equipment. Energy sector vocations are found in the industries of mining, manufacturing, communications, construction, renewables, domestic and commercial refrigeration and air-conditioning, and industrial refrigeration and air-conditioning. The electrical services industry involves electrical wiring and installation of fittings in buildings and other construction projects, and repair and maintenance of existing electrical equipment and fixtures. The refrigeration and air-conditioning industry is concerned with the design, construction, installation, commissioning, service, repair and maintenance of cooling and heating systems for food preservation and human comfort.

21.1.1 Energy sector vocations

The electrotechnology industry comprises six main sectors, as shown in **Table 21.1**.

TABLE 21.1 Electrotechnology industry sectors and career paths

Industry sectors	Vocational education and training career pathways	
<ul style="list-style-type: none"> • Electrical services (electricians) • Electrical engineering • Industrial control • Electronics and computers • Refrigeration and air-conditioning • Renewable and sustainable energy 	<ul style="list-style-type: none"> • Appliances and entertainment • Computer systems • Data communications/communications • Electrical instrumentation control and switch gear • Fire and security systems 	<ul style="list-style-type: none"> • Rail • Refrigeration and air-conditioning • Renewable, photovoltaic and sustainable energy • Systems electrician • Systems support

21.1.2 Industry organisations and advisory and regulatory bodies

Stakeholders in the industry include employers, group training organisations (GTOs), industry regulators, electrical wholesalers, trade schools and registered training organisations (RTOs), trade unions, industry training advisory bodies (ITABs) and industry and skills councils (ISCs). Some ITABs and ISCs are still active, although most have been phased out in recent years, with their functions being performed by industry reference committees (IRCs) and skills service organisations (SSOs). New industry cluster arrangements are being planned by the Commonwealth Government to come into place in 2023. These new industry clusters will replace SSOs and IRCs.

Employer groups in the electrotechnology sector include the National Electrical and Communications Association, Master Electricians Australia, the Refrigeration and Air Conditioning Contractors' Association and the Australian Rail Track Corporation. The National Electrical and Communications Association is run by contractors, for contractors, and represents members in all states and territories of Australia. It is the peak industry body representing the interests of the electrical and communications contracting industry across the country. The services that they offer their members include guidance on industrial relations, legal advice, assistance and representation.

Master Electricians Australia is a dynamic and modern trade association that connects electrical contractors with local services to build business success, providing industry development and representation across Australia. The Refrigeration and Air Conditioning Contractors' Association is a not-for-profit organisation that represents the interests of a wide range of refrigeration and air-conditioning contractors across Australia.



CHECK YOUR UNDERSTANDING

1. Name five stakeholders of the electrotechnology industry.
2. What are the six main electrotechnology industry sectors in Australia?
3. Give four examples of advisory bodies in the electrotechnology industry.
4. Identify four employer groups in the electrotechnology sector.
5. What is the role of the Refrigeration and Air Conditioning Contractors' Association?

21.2 Working in the energy sector

Working in the energy sector requires workers to have skills and knowledge to successfully perform work activities, such as preparing for work, carrying out the work required and checking the quality of work completed. Work activities can be made up of specific tasks in a planned arrangement of tasks and sequence of activities.

21.2.1 Licensing

Successful completion of a Certificate III in Electrotechnology Electrician qualification is recognised nationally and is the main requirement for an electrical licence application in all states and territories. Other recognition processes exist and vary in different jurisdictions.

Essential Performance Capabilities Required for Licensed Electricians are a set of competencies as safety outcomes for licensing purposes. These were agreed by the National Uniform Electrical Licensing Council and are consistent across Australia. The competencies are embedded in the electrotechnology training package qualifications, and can be found at https://www.commerce.wa.gov.au/sites/default/files/atoms/files/essential_requirements_0.pdf.

21.2.2 Wages and employment conditions

Trade unions

Unions play an important role in the workplace and according to the Australian Government Fair Work Ombudsman, some of the key roles of unions include being a voice for employees, working with management to help resolve workplace issues and acting as a representative during bargaining negotiations.

Awards

An award is an enforceable document containing minimum terms and conditions of employment in addition to any legislated minimum terms. They identify conditions over and above the minimum required by legislation. Awards cover issues such as pay, overtime rates and conditions, special leave arrangements, special allowances and hours of work. Awards set minimum standards an employer in industry is allowed to pay for work.

Awards are handed down by an organisation called Fair Work Australia, which is the tribunal set up by government to perform this function. Fair Work Australia has responsibility for making and varying awards in the national workplace relations system.

Enterprise Bargaining Agreements

Modern awards are based on the National Employment Standards (NES), which are the 11 minimum employment entitlements of all employees. They cover a whole industry or occupation and provide a safety net of minimum pay

rates and employment conditions. Enterprise agreements are collective agreements tailored to meet the needs of a particular enterprise, and they are made between employers and employees.

An Enterprise Bargaining Agreement (EBA) is generally arrived at through negotiation between the employer and the union, and must be endorsed by Fair Work Australia. In general, an award applies to employees in a particular industry or occupation and is used as the benchmark for assessing enterprise agreements before approval. All the conditions that are in an award and included in an EBA apply. An EBA must leave an employee better off overall when compared with the relevant award or awards. Where there is an EBA, it overrides the award and may provide additional or changed conditions.

21.2.3 Employability and core skills frameworks

Employability and core work skills are also critical components of the required skill set that employers will consider in engaging capable, reliable workers. The Australian Chamber of Commerce and Industry (ACCI) and Business Council of Australia (BCA) conducted research in 2001 to determine the employability skills needs of industry. Key generic employability skills and a number of valued personal attributes were identified. Employers argued that employees should have these generic skills along with the job-specific or relevant technical skills. In 2006, the Meyer Key Competencies were replaced by the Employability Skills Framework in vocational education and training (VET) packages.

The Employability Skills Framework also found that teachers and trainers needed more guidance in how to teach employability skills in a structured way. The Australian Government funded the development of a Core Skills for Work Framework (CSfW). The CSfW aligns with the Employability Skills Framework but its approach is broader and it is targeted at educators, trainers, practitioners and those developing training packages (see **Table 21.2**).

TABLE 21.2 Generic skills frameworks

Employability Skills Framework (2002)	Core Skills for Work Framework
Communication Teamwork Problem solving Self-management Planning and organising Technology Learning Initiative and enterprise	Cluster 1: Navigate the world of work a. Manage career and work-life b. Work with roles, rights and protocols Cluster 2: Interact with others a. Communicate for work b. Connect and work with others c. Recognise and utilise diverse perspectives Cluster 3: Get the work done a. Plan and organise b. Make decisions c. Identify and solve problems d. Create and innovate e. Work in a digital world

21.2.4 Career paths

Australian Qualification Framework

The Australian Qualification Framework (AQF) is the national framework of qualifications in the school, VET and higher education sectors. It was developed in 1995 and has been revised a number of times, with the most recent major revision taking place in 2011 with full effect from January 2015. It is an agreed policy of Commonwealth, state and territory governments. Qualification paths within the AQF range from Certificate II and include Certificate III and IV, Diploma and Advanced Diploma in the Electrotechnology classifications. A chart of these qualification paths is shown in **Table 21.3**.

TABLE 21.3 Australian apprenticeships job pathways: electrotechnology

Sector vocation	Certificate II	Certificate III	Certificate IV	Diploma	Advanced Diploma
Appliances and entertainment	Electrotechnology trainee	Business equipment technician Custom electronics installations technician Electrical fitter	Audiovisual installation technician		Electronics engineering technical officer
Computer systems	Electrotechnology trainee	Computer systems technician	Computer systems technical officer	Computer systems senior technical officer	Computer systems engineer Electronics engineering technician
Data communications /communications	Electrotechnology trainee Data and voice communications cabler	Data and voice communications technician Electronics and communications tradesperson	Electronics equipment technician Data and voice technician	Electronics and communications technical officer	Telecommunications engineer Electronics engineering technical officer
Electrical instrumentation control and switch gear	Electrotechnology trainee	Business equipment technician Custom electronics installations technician Electrical fitter	Instrumentation and control electrician Industrial electronics electrician Industrial electronic technician Instrumentation and control technician	Instrumentation technical officer Electronics and control technical officer	Electronics and control engineer Instrumentation and control senior technical officer
Fire and security systems	Fire alarm technical assistant Electrotechnology trainee	Fire protection technician Security system technician	Senior fire protection technician		
Rail	Electrotechnology trainee		Rail signalling electrician Rail communications technician		

(Continues)

TABLE 21.3 Australian apprenticeships job pathways: electrotechnology (Continued)

Sector vocation	Certificate II	Certificate III	Certificate IV	Diploma	Advanced Diploma
Refrigeration and air-conditioning	Air-conditioning and heat pump installer Electrotechnology trainee	Air-conditioning and refrigeration mechanic	Air-conditioning technician Air-conditioning and refrigeration servicing technician Energy management control technician Refrigeration and air-conditioning mechanic	Refrigeration and air-conditioning technician Refrigeration and air-conditioning technical officer Electronics engineering technologist	Air-conditioning and refrigeration senior technologist Air-conditioning and refrigeration engineer
Renewable, photovoltaic and sustainable energy	Electrotechnology trainee Renewable energy trainee	Renewable energy tradesperson	Energy management technician Renewable energy technician Renewable energy electrician Solar electrician Electrical energy efficiency technician	Renewable energy technical officer	Renewable energy engineer Renewable energy technologist
Systems electrician	Electrotechnology trainee	Electrician Electrical appliance technician	Installation technician Electrician (special class) Energy management technician Lift electrician Electrical contractor Electrical fitter mechanic	Electrical engineering technical officer Electrical maintenance engineer	Mine electrical engineer Electrical engineering technician Electrical maintenance senior engineer
Technical support	Computer assembler Electrical component assembler Antennae installer Remote area power supply operator Security installation assistant Electrical trades assistant Electronics servicing worker Electrotechnology trainee		Installation technician Energy management technician Hazardous area electrician		Explosion protection senior technical officer

Source: Information from Australian Apprenticeships Pathways, <https://www.aapathways.com.au/job-pathways/chart/electrotechnology-use/47d298cd-232a-4462-89ad-39da9822808d>

Becoming an electrical apprentice

To become an electrical apprentice requires entering into a contract of training through an Australian Apprenticeship Support Network (AASN) and undertaking training in the Certificate III in Electrotechnology Electrician training course. This contract of training formalises an arrangement between:

- ▶ you as the employee (apprentice/trainee)
- ▶ the employer who agrees to employ you, pay your wages and train you, including releasing you for off-the-job training
- ▶ either an approved training provider/registered training organisation (RTO) or the RTO you and/or your employer have chosen.

The chosen RTO will receive a Notification of Business once the training contract is processed and approved by the state training authority in the relevant state or territory. One employment path to consider for an electrical apprenticeship is through a group training organisation (GTO).

Traineeships and apprenticeships are a form of vocational training where trainees and apprentices earn a wage, learn about the industry and the job and work towards gaining a qualification. An Australian apprenticeship provides a nationally recognised qualification and on-the-job experience.

Australian School-based Apprenticeships (ASbAs or ASBAs) are available for high school and college students in some states and territories. Students need to negotiate their attendance at work and training with their school. These can be arranged through an AASN. Further details are available at <https://www.australianapprenticeships.gov.au/school-based-apprenticeships>.

21.2.5 Energy sector apprentices

A National Code of Good Practice for Australian Apprenticeships has been developed to assist employers and apprentices to enter into a training contract with a clear understanding of each other's obligations and expectations. The employer is expected to meet their legal obligations, provide a safe working environment and support structured training. The apprentice is expected to be aware of and make a commitment to fulfil their work and training responsibilities including:

- ▶ attending work
- ▶ performing work in a professional and courteous manner
- ▶ respecting the rights of others in the workplace, as well as workplace property and resources
- ▶ attending training sessions, supervised workplace activities and taking advantage of learning opportunities
- ▶ making all reasonable efforts to undertake any training and assessment required.

21.2.6 Pre-apprenticeship programs

Funded programs are provided in states and territories to assist in developing knowledge, awareness and skills for future workforce apprentices. The following describes two such programs.

Background

The following case study is based on two funded pre-apprenticeship programs: the first program, Women In Power, is part of the Women In Trades initiative. The second program, which is open to males and females, was developed by the Future Skills for Future Jobs program. These pre-employment programs were designed to prepare candidates for future job opportunities by providing a blend of communication, team work, emotional intelligence and practical skills through a range of structured activities. Participants received instruction about hand and power tools, basic trade maths, industry orientation and safety in the workplace. They were provided with all relevant PPE (some of which can be seen in **Figure 21.1**).

Practical tasks involved using hand and power tools to measure, mark and cut timber, to assemble and erect timber frames for roughing in cable and stripping and preparing cable for terminations at socket-outlets, light switches and batten fittings. **Figure 21.2** shows program participants engaged in these activities.



FIGURE 21.1 Pre-apprenticeship program participants

Tony Jones



FIGURE 21.2 Pre-apprenticeship program participants erecting frames, sheeting and fitting off accessories

Tony Jones

Participants achieved their First-Aid Certificate, industry-recognised White Card and asbestos awareness training, and they also undertook an electrotechnology LLN Readiness Assessment. On completion of the program, participants left prepared with the knowledge, skills and confidence to assist them in seeking employment opportunities.

Communication and emotions

Potential apprentices require an awareness of the workplace, expectations and the skills needed to survive working with other people. Communication is key to achieving positive outcomes in these areas and involves talking with each other, clarifying work instructions, working together and asking questions. For this reason, this was a focus of the pre-apprenticeship programs.

In the programs, the initial presentation included opportunities for questions and answers, followed by the practical tasks of measuring, marking, cutting and assembling timber-frame walls. Participants were provided with the necessary tools and building materials, given task instructions and then supervised (for safety) with no further instructions.

Participants found themselves in an unfamiliar situation much like starting a new job, where they would be meeting co-workers for the first time, or entering a workplace without friendships or established working relationships. As expected, the results were poor performance, restricted interpersonal communication and very little collaboration. Groups were observed closely and an intervention was made before any psychological damage or harm could occur from frustration, anger, anxiety or embarrassment. In some situations personalities emerged to take control of the work, manage the team and ask for guidance or job task clarification.

Intervention was critical in order to turn a situation that was beginning to create confusion and frustration into:

- ▶ a carefully structured positive experience
- ▶ awareness of what was happening
- ▶ strategies for how to deal with the situation.

Participants were encouraged to vent their feelings and their views about what went wrong. All the participants expressed surprise at being validated and their experience then became one of empowerment and awareness.

The presentations and discussions on workplace communication became of greater importance. Points raised with each group included the questions:

- ▶ Did you know what to do?
- ▶ Did you ask?
- ▶ Did you seek advice/clarification?

The discussions highlighted the importance of asking questions, cooperation and collaboration. Foundations of teamwork were established and the task of building timber wall structures resumed with greater productivity and significant progress. A recap on each day's activities reinforced confidence and focused on improvements, achievement and success.

Each program created a safe space for making mistakes and learning from those mistakes.

Emotional intelligence

The activity intervention was designed to highlight the importance of emotional intelligence because the emerging factors were triggered as a result of poor cooperation, collaboration and communication. Emotional intelligence is a measure of our awareness of how our emotions—especially the negative ones—and the non-verbal cues caused by those emotions affect others. In the context of the energy sector, apprentices and potential apprentices particularly can be affected. Answering the question 'How does that make you feel?' was underpinned with awareness of what was happening and how to deal with the situation.

Key to the program was the building of confidence and positive self-image, as was taking on board the important message that it is okay to get upset or to be happy, angry or sad. These are all normal emotions, and it is important to manage them appropriately in the workplace to avoid becoming anxious, upset or depressed. Identifying unacceptable workplace behaviour such as bullying and harassment and the relevant OHS/WHS legislation and model codes of practice were addressed during the program.

The pressures placed on supervisors, managers, other apprentices and co-workers, and an awareness of how they may respond under pressure, was also discussed. Workplace behaviour, whether intentional or reactive, has a reason. Some of the 'sting' from others' frustrations, anger or comments can at least be understood with an awareness of what they are going through. It was emphasised, however, that this type of behaviour is not acceptable and should not be tolerated. The point was also shared that when one gets upset and argues with others, an angry word cannot be taken back, and this can impact workplace relationships.

This part of the program combined guidance and support for the participants, asking them questions to promote an awareness of who they were as individuals, how they felt, other people's reasons for being on the program and ways of working together effectively. Emphasising the themes of cooperation, collaboration and communication provided the program participants with a structure for the development of self-awareness, emotional intelligence and resilience.

Diversity and inclusion

Participants left the program with awareness, tolerance and an understanding of what to expect in the workplace. They emerged better prepared for seeking employment and with increased confidence. One former participant described the program thus:

A number of exercises, activities and discussions on diversity and inclusion, our differences and similarities, backgrounds and culture, work culture, our feelings and self-help, dealing with other people, their expectations, dealing

with customers and clients, tolerance all tied in with emotional intelligence and our work ethic through cooperation, collaboration and communication with each other in the workplace.

Skills

In addition, course participants learnt building frame terms such as top plate, bottom plate, studs and noggin. They were taught how timber frames would be assembled, how to line up each piece, and drill and screw join together. The participants also learnt about pilot and clearance hole sizes, drilling holes for cables, different types and sizes of drill bit and how to select and use battery-powered drill-driver/impact drivers.

21.2.7 Apprentice skill activities

Working in the energy sector requires a number of skills. Some skills are considered a minimum requirement by employers while others are learnt on the job. Two sets of skills that are very useful for new workers are what are termed soft skills and hand skills.

Soft skills include developing emotional intelligence, awareness (thinking and problem solving), communication and team working skills; these are integrated into work task activities. The pre-apprenticeship case study provides insight into the application of these soft skills. Hand skills involve the use of various hand and power tools and the application of skills needed to carry out routine work activities. Hand skills involve knowing how to use tools such as:

- ▶ power tools, such as drop/compound saws, drill drivers with hammers, impact drills and screwdrivers (battery and electric), heat guns, angle grinders (corded and cordless), drill presses and bench grinders
- ▶ hand tools, such as multigrips (vice, pipe), spanners, sockets, wire strippers, various types and sizes of screwdrivers (flat blade and Phillips Head), pliers (combination (linesman), diagonal (side-cutters) and long (needle) nose); different types of pliers are used for cutting, insulation stripping and joining conductors
- ▶ measuring and marking tools, such as pens, pencils or scribes for marking, a steel rule or tape measure for measuring and marking and a set square or straight edge for marking and cutting
- ▶ wallboard saws for cutting openings in plasterboard/Gyprock for recessing socket-outlets and switches.

Hand skills also include:

- ▶ knowing how to drill into different types of materials to create pilot holes for tapping and clearance holes. Tapping a pilot hole creates the thread needed for securing and bolting items, for example, pilot holes in timber allow the screw threads to cut directly into the hole and reduce the risk of splitting or causing cracking of the timber.
- ▶ knowing when a clearance hole is large enough to allow the thread of a screw or a bolt to pass through a material without the threads biting into the material. Clearance holes (not too big) are drilled to permit cable access through noggin and top and bottom plates.
- ▶ ensuring the head size of a screwdriver or Allen key exactly matches that of the bolts and screws to prevent damage by burring or stripping of the screw head.

This is just a small list of required hand skills, provided to indicate the skills an apprentice should seek out for development through work experience, project activities, Try-a-Trade days and pre-apprenticeship programs.

21.2.8 Apprentice supervision guidelines

Supervisors must be available at all times on a worksite to provide an appropriate level of supervision and support. What constitutes an appropriate level of supervision and support is based on an apprentice's:

- ▶ knowledge
- ▶ experience
- ▶ level of skill
- ▶ type of work activity.

The appropriate level of supervision must be determined by the supervisor, and the employer must be satisfied the supervisor has the necessary supervisory skills. There are three levels of supervision:

- ▶ Direct supervision—constant, general supervision. This type of supervision is provided at all times within visual contact and/or earshot (audible range). It is supervision that provides specific and constant guidance to the apprentice.
- ▶ General supervision—broad, intermittent supervision. This means being under instruction and direction for tasks being performed. The apprentice does not require the constant attendance of the supervisor but they must remain on the same worksite as the apprentice and be readily available.
- ▶ Broad supervision—regular/occasional supervision. This is supervision provided as periodic face-to-face contact throughout the day, or work cycle, to check that the apprentice's work complies with technical and safety requirements. The apprentice at this level of supervision must be able to demonstrate electrical knowledge and skills relevant to the task.

In various jurisdictions and work areas, limits are set on the number of apprentices being supervised. These limits are expressed as a ratio of supervisor to the number of apprentices. Strong restrictions apply to apprentices working on or near energised equipment. The concept of apprentice supervision for de-energised work is fairly consistent across states and territories. Supervisor-to-apprentice ratios and minimum supervision levels may vary slightly across jurisdictions and between different trades (e.g. electrical and refrigeration and air-conditioning apprentices).

21.2.9 What is the difference between an apprenticeship and a traineeship?

The main difference between an apprenticeship and a traineeship is that a traineeship can be within a broader range of occupations and is run either part-time or full-time, and trainees are employed and trained for typically between one to two years. An apprenticeship on the other hand covers skilled trades and takes around four years to complete.

21.2.10 Qualification requirements

Qualifications comprise units of competency, elements, performance criteria, skills and knowledge. The Certificate II Electrotechnology (Career Start) and Certificate III Electrotechnology are electrician qualifications made up of Units of Competency (UoC) or competencies. These need to be undertaken and successfully completed to achieve the qualification.

The Australian Skills Quality Authority (ASQA) defines units of competency as the specification of the standards of performance required in the workplace. It defines competency as:

The consistent application of knowledge and skill to the standard of performance required in the workplace. It embodies the ability to transfer and apply skills and knowledge to new situations and environments.

ASQA defines qualifications as:

Formal certification, issued by a relevant approved body, to recognise that a person has achieved learning outcomes or competencies relevant to identified individual, professional, industry or community needs.

Units of Competency are structured to contain the following components:

- ▶ Unit of Competency Code (e.g. UEECD0009—old code UEENEEE148A)
- ▶ Title (e.g. Carry out routine work activities in an energy sector environment)
- ▶ Application (formerly Descriptor)

- ▶ Elements (e.g. UEECD0009), which describe the essential outcomes:
 - ▶ prepare work activity
 - ▶ carry out work activity
 - ▶ check completed work.
- ▶ Performance Criteria, which describe the performance needed to demonstrate achievement of the element.

As well as satisfying the Elements and the Performance Criteria, assessment requirements for electrotechnology units of competency also need to address Performance Evidence and Knowledge Evidence. Electrotechnology-specific Performance Evidence and Knowledge Evidence must be, or be able to be, linked as the qualification evidence to meet the Performance Criteria.



CHECK YOUR UNDERSTANDING

6. Explain the acronym AQF.
7. State the work and training commitments for apprentices.
8. Identify three soft skills required for workplace activities.
9. What are two methods of drilling holes in timber frames?
10. List the three elements for the UEECD0009 Unit of Competency.

21.3 Prepare to undertake routine work activities

Routine work activities can be thought of as collections of smaller, specific work tasks. Work activities like projects have a start, a finish and a purpose. They involve a range of tasks, each requiring specific knowledge and skills. All work activities encompass working safely, to a quality standard and with a minimum of waste.

Work tasks, activities and projects involve planning, preparation, organisation and ongoing checks through to completion. The stages of performing routine work activities in the electrotechnology industry are identified as:

- ▶ prepare to undertake routine work activities
- ▶ carry out work as instructed
- ▶ check results of the completed work.

Work activities therefore involve communication, working to standards and safe operating practices, using tools and equipment, and awareness and understanding of where tasks fit into the work purpose or project.

21.3.1 Instructions, communication and understanding

Instructions for work tasks and activities require everyone to know what needs to be done and just as importantly, understand how to do the job. This understanding is in the form of guidance and instruction required to undertake the work activity.

Instruction can be given face-to-face, over the telephone/mobile and text messaging. More often the required tasks will be in a written form, either paper based or available via an electronic medium. Sometimes instruction might be set out in an email. In all situations the communication needs to be clear, concise and unambiguous. Workplace instruction involves advice, guidance and direction on working safely. Direction can also exist in the various forms of workplace literacy as signs, schedules, posters and safe work procedures.

Communication is a two-way process between two or more people. If communication is only one way, by reading something or being told, important detail can be left out and the intended message and work requirements not fully conveyed.

Is the message clear?

When someone is conveying information either verbally or in a written form there are three things to consider:

1. the message intended by the person giving the instruction
2. the message conveyed
3. the interpretation and understanding of the instruction or message.

Preparing to undertake routine work activities and then performing and completing them combines three specific communication skill areas for understanding:

1. reading and interpretation
2. talking and listening
3. writing, record keeping and reports.

Reading and interpretation

Every workplace contains three types of knowledge: tacit knowledge, implicit knowledge and explicit knowledge. Every workplace has its own unique culture. Workplace culture, communication and behaviour are influenced by what individuals know and understand, what is in their head (tacit knowledge), what is assumed and accepted as a group (i.e. the way we do things around here, which is implicit knowledge) and formalised work expectations (explicit knowledge).

Documentation, written instructions, emails, signs and notices, manuals, drawings and diagrams are all categorised as explicit knowledge and information. What you read and interpret for understanding is *communication that needs to be clear, concise and unambiguous*.

Talking and listening

Communication is a two-way process between everyone in a workplace. We find out what is going on and how to do things by talking with our workmates. Listening is a crucial skill to use and develop. Carrying out work tasks requires workers to listen to instructions given by those who instruct us and tell us how and what needs to be done.

Attending toolbox talks and workplace meetings to hear about changes and discuss safety issues requires listening skills. Going to training and information sessions where we listen to trainers, presenters, supervisors and managers and ask questions to clarify the message requires both talking and listening skills.

Confirm understanding by asking questions to clarify what is required, what is expected and what needs to be done. Listening and asking questions is essential to carrying out routine work activities.

Record keeping and report writing

Throughout all phases of work activity, certain documentation will need to be accessed, checklists followed and activity reports completed. Examples include:

- ▶ ordering materials
- ▶ following work lists and schedules
- ▶ performing pre-start hazard checks
- ▶ risk assessments
- ▶ other work-related checklists.

Paperwork skills and activities are documentation processes that may involve using computers, tablets and smartphones for work records, goods and material ordering, purchasing, email communication, following and completing checklists and recording work activities.

21.3.2 Understanding WHS/OHS policies and procedures

Safe Work Australia is an Australian Government statutory agency that develops national policy to improve work health and safety (WHS) and workers' compensation arrangements across the country. These policies are aimed at reducing the incidence of work-related death, injury and illness, and exposure to hazards and risks in the workplace.

WHS/OHS policies and procedures are communicated and confirmed to ensure they are understood and apply to the carrying out of all work activities. Occupational Health and Safety (OHS) legislation was updated and passed as the *Work Health Safety (WHS) Act 2011*. Since that time, references to OHS have been assumed to refer to WHS legislation. To work safely in the electrotechnology industry it is important to follow written communications such as:

- ▶ *Electrical Safety Act*
- ▶ *Work Health Safety Act 2011*
- ▶ codes of practice that cover:
 - ▶ high-risk work—working at heights, working with asbestos, working near electrical apparatus
 - ▶ safe work practices and procedures—manual handling, noise, managing electrical risks in the workplace
 - ▶ guidelines, policies and codes of behaviour—bullying and harassment
- ▶ standard/safe operating procedures—for using hand tools, power tools and operating plant and machinery
- ▶ workplace rules—site rules, policies, work procedures, safe work method statements (SWMS) and written material that forms part of inductions.

Standard work procedures

Standard work procedures are sometimes referred to as standard operating procedures or safe operating procedures and are commonly called SOPs. They are written guidelines or instructions for working safely and for the correct operation of plant and equipment. It is important that workers take notice of the SOPs so that work processes are carried out correctly.

- ▶ To follow SOPs you need to be able to read and/or understand them.
- ▶ You should also think about why there is an SOP near equipment and machines.
 - ▶ Would wrong use make the machine dangerous?
 - ▶ Could you hurt yourself or others?
 - ▶ Could you damage the machine?
 - ▶ Should you use it in a certain way to get the best results?
- ▶ Corded and battery-operated tools and equipment also have manufacturer instructions, safety recommendations and, in most workplaces, specific SOPs for safe use and care.

21.3.3 Identifying necessary tools, equipment and personal protective equipment

All tools, equipment and personal protective equipment (PPE) necessary for the work must be identified and checked to ensure they work correctly as intended and are safe to use in accordance with established workplace procedures and guidelines. Tools, instruments and equipment that are poorly maintained, inappropriately used or not fit for purpose can cause injuries. On job completion or when moving to another location, tools and equipment again need to be checked for wear and damage and they also need to be cleaned and stowed correctly.

Managing electrical risks in the workplace requires that:

- ▶ workers must be trained and competent in the safe and effective use of tools and equipment
- ▶ electrical workers must be appropriately trained and competent in test procedures and in the use of test equipment.

Ladders, scaffolds and similar equipment

Metallic or wire-reinforced ladders and scaffolds are electrically conductive, can create an electric shock path and may pose electrical risks. These items should not be used in close proximity to equipment where an electrical hazard may result from their use. Metallic, wire-reinforced or otherwise conductive ladders should be avoided for any kind of electrical work.

Basic ladder safety use and inspection should include checking that the ladder is non-conductive, meets relevant Standards and on visual inspection:

- ▶ has no loose, damaged or missing parts
- ▶ is properly erected and secure, top and bottom
- ▶ extends at least 1 m above the landing place

- ▶ is set at the correct angle (a ratio of 1:4)
- ▶ is even on firm ground.

When ascending or descending a ladder, in other words going up or coming down, there must be three points of contact with the ladder *at all times*, (i.e. two feet and one hand/two hands and one foot). Tools are to be carried in a tool belt/holster and *not* in the hands. A high number of recorded accidents (not including falling from a ladder), have occurred when stepping onto or off the first rung.

Checking test instruments and devices

Apprentices are introduced to certain test instruments and devices throughout their training. However, they are not permitted to take direct voltage measurements during the first three years of training or work on live equipment under any circumstances. Supervision guidelines need to be followed. Apprentices learn about the various test instruments, how to check them for signs of damage and how to use them safely. This includes using voltmeters and multimeters to measure extra-low voltage d.c. and a.c. values under direct supervision in controlled situations, such as off-the-job technical training or on test benches specifically designed for learning and practical tasks.

During an apprenticeship/traineeship, testing might include basic resistance measurements, testing of switches for normally open and normally closed states and continuity testing of unconnected cables. Also included (under supervision) will be insulation resistance (IR) checking of unconnected cables and instruction on how to use an IR tester. The training includes knowing what test instrument is to be used for different testing situations, identifying and following safe work procedures and safe operating procedures, understanding the safety category ratings (Cat II, III, IV) for test devices and checking manufacturer guidelines. These procedures help ensure the correct operation of testing devices. The student/apprentice must ensure that test instruments are checked, tested and calibrated before use. Under supervision, they should also visually inspect test instruments to ensure:

- ▶ the test device complies with *AS 61010* (it should be embossed on device) and is rated at the correct category for intended use
- ▶ the device is clean and in good condition, undamaged and with no cracks in the casing or insulation
- ▶ the device has suitably insulated leads (with the correct Category Rating), intact insulation and connection probes
- ▶ the device's clips are in good condition and undamaged.

The purpose of this visual inspection is so that test instruments can be connected to electrical equipment for measurements with minimal risk to the operator. It is also important to calibrate/check the testing device is working before use by making sure that:

- ▶ the internal energy source is sufficiently charged and the batteries are not flat or leaking
- ▶ the test instrument SOP and manufacturer instructions are checked and followed
- ▶ ohmmeters (multimeters, IR and continuity testers) are tested for correct operation, including:
 - ▶ zeroing for continuity by touching the test probes together
 - ▶ measuring known resistances by setting range on the test device and using test probes to confirm values using a resistance calibration box
 - ▶ being calibrated against known resistances, 1 m Ω , and 10 m Ω .

Trainees and apprentices working in the energy sector will learn about energising and de-energising procedures, isolation and Lock-out Tag-out procedures. Although these procedures are the responsibility of supervisors or supervising electricians, training will involve observing how these procedures are performed including:

- ▶ testing voltmeters (digital multimeters) on known supply sources (this may require a proving unit)
- ▶ testing for voltage and that equipment is de-energised by completing the following steps:
 - ▶ first, checking the test instrument with a known voltage source
 - ▶ second, testing the circuit and ensuring equipment is de-energised
 - ▶ third, re-checking the test instrument with the same voltage source to confirm the tester is still working.

Chapter 15 covers the use of testing devices in more detail.

21.3.5 Arranging resources and materials for the job

Solid communication skills are necessary for the three main tasks needed to prepare to undertake work activities, which are:

1. confirming the required resources and materials
2. scheduling the required resources and materials
3. obtaining the required resources and materials.

Preparing to undertake routine work activities involves providing work quotations, obtaining quotations from suppliers and procuring resources and materials needed for undertaking the work. The process requires technical and employability skills to perform these job tasks and keep to timeframes and work schedules. Dealing with clients, suppliers and other key personnel, including employers and colleagues, requires workers to develop and use CSfW skills.

Confirming the required resources and materials

The three-bedroom structure scenario in **Section 21.3.4** requires interpreting the floor plan, identifying the symbols and confirming what needs to be sourced, as well as liaison and communication to confirm the required resources and materials. In this scenario, the kitchen, bathroom and laundry require supply and installation of a stove, ceiling/exhaust fans and a hot water system, all of which need to be ordered. Other electrical materials and accessories including conduit, cable (of various types and sizes), switches, socket-outlets (of various types) and light fittings also need to be specifically itemised for ordering.

Scheduling the required resources and materials

When a job is due to start or work activities commenced, materials and resources need to be scheduled. Materials, equipment, workers and worksite access need to be coordinated and the work schedule planned. Workers and staff involved in some way count as a resource and their availability needs to be factored into the scheduling.

Obtaining the required resources and materials

Display catalogues with details for goods and materials are readily available online. Whether purchases are made over the counter or as an order added to an account, at some point digital technology is involved. Nearly all enquiries and transactions involve some form of technology to source or purchase items. **Chapter 22** references the three-bedroom structure scenario, ordering and receipting of goods and materials in greater detail.

21.3.6 Confirm work tasks, instructions and WHS requirements

Preparing for work activities requires awareness of what needs to be done and, for apprentices, supervision and instruction on how the work is to be carried out. Information including safe working practices, organisational policies and procedures has to be sourced, as do the tools, equipment and materials, which need to be available when necessary. If a trainee or apprentice is ever in a situation where they are unsure of what to do or how to do it, they should ask someone.

Personal protective equipment

Personal protective equipment (PPE) includes the following:

- ▶ safety helmets (hard hats)
- ▶ noise protection (ear muffs)
- ▶ face shields
- ▶ eye protection
- ▶ electrical insulation gloves for protection from electric shock
- ▶ appropriate clothing and footwear.

PPE must fit correctly and be maintained in good working order. Training must be provided in how to select and fit the correct type of equipment, as well as training in the use and care of the equipment so that it works effectively. PPE for electrical workers must be properly tested, regularly checked and suitable for the work. Safe work practices, operating procedures and codes of practice all play a role in properly maintaining tools, equipment and PPE, and the management of plant and equipment.

Tools, equipment and materials

Hand and power tools should always be used correctly and in the manner they were designed for. Power tools and equipment should have SOPs as guidance for safe use. In some states and territories safe work practices are used instead of SOPs. Instructions for the selection and need for specific tools, equipment and materials for work tasks should be clearly stated and confirmed by your tradesperson, supervisor and/or employer.

Further information about safety and WHS procedures appears in **Chapter 2** and the use of tools in **Chapter 3**.



CHECK YOUR UNDERSTANDING

11. What does SOP stand for (provide two possibilities)?
12. State three specific communication skill areas for understanding and confirming instructions.
13. What should you do if you are unsure about a job task?
14. Who could confirm work tasks and OHS/WHS requirements?
15. Briefly explain the need for PPE training.

21.4 Carry out work activities

Work activities include tasks ranging from reading floor plans and wiring schedules, roughing-in cable and installing lighting and power systems. Carrying out routine work activities can also include reading instructions and communicating with appropriate personnel such as other electricians, project supervisors, customers and suppliers.

Work tasks can also include making authorised phone calls, reading and sending emails, and ordering parts, goods and materials. Knowledge of who to contact, speak with and what to do involves research and an understanding of the work environment. Work activities therefore involve communication, working to standards, applying safe operating practices, using tools and equipment and having awareness and understanding of where tasks fit into the work purpose or project.

21.4.1 Work task and activity management

During work experience or an apprenticeship many work tasks and activities will be undertaken. Later in an apprenticeship and after progressing onto trade supervision roles, workers will be involved in arranging the work tasks and activities. These activities fit into the wider work breakdown structure of small, medium and large projects.

Project management is concerned with the implementation of planned work activities and examples include using project management book of knowledge principles and PProjects IN Controlled Environments (PRINCE2). Implementation is about process-based project management approaches that focus on organisation and control over the entire project, from start to finish. Implementing work schedules and activities involves planning, decision making and problem-solving processes.

21.4.2 An example of a work activity

An example of a work activity is roughing-in cable for light and power in an office. The activity requires a number of tasks, as well as knowledge and skills including:

- ▶ measuring and marking out where to drill holes in a timber frame, metal or masonry wall
- ▶ selecting the right tool to drill holes in timber, masonry or metal
- ▶ identifying and selecting the correct drill bit type and size
- ▶ setting up the drill, impact drill and clutch settings
- ▶ using the drill correctly and safely
- ▶ wearing appropriate PPE
- ▶ adhering to codes of practice.

This breakdown of each task may seem as oversimplification of the activity or micro-managing simple tasks—and we have yet to consider the cable type, size or length. Work activities involve information about the work task and an explanation of what needs to be done by whom, where, when and how.

The roughing-in activity for a new installation needs to be finished before wall sheeting. The next electrical installation task would be the fitting off socket-outlets, light switches and lighting points. These activities form part of a work schedule known in projects as the work breakdown structure and need to be carried out in a particular sequence, in this case roughing in then wall sheeting then fitting off.

21.5 Problem solving and unplanned situations

Decisions at work are made daily, ranging from selecting appropriate tools and equipment or deciding what steps to follow for a process or procedure. Decision making is an important part of problem-solving strategies. Some decisions are straightforward and involve only a two-step process of problem identification, followed by implementing a specific action or solution. An example would be deciding whether a socket-outlet should be single or two gang and whether it should be mounted in a horizontal or vertical orientation.

More complicated problems require a logical approach to decision making, combining inductive and deductive reasoning. They may require more sophisticated methods of problem solving such as the four-phase Plan—Do—Check—Act (PDCA) cycle, which involves multiple steps, particularly for identifying and defining problems in the planning phase of the cycle.

21.5.1 Plan—Do—Check—Act

The standard scientific method of hypothesis—experiment—evaluation was adapted in 1939 to the Shewhart Cycle, which runs as specification—production—inspection in a continuous cycle, creating a dynamic process for acquiring knowledge. The cycle was modified as the Deming Wheel (1950) and used as the basis for rebuilding industry in Japan after World War II. The Deming Wheel, or Cycle, was modified and implemented as the PDCA, Plan—Do—Check—Act. Deming later modified this to Plan—Do—Study—Act (PDSA).

The PDCA and PDSA are considered to be effective project management implementation and continuous improvement models. Versions of the PDCA are adapted as logical system approaches designed for decision making and problem solving.

21.5.2 PDCA and unplanned events

Proper and effective planning helps to prevent problems from occurring during a job. However, sometimes problems and unplanned events may occur that require processes and procedures for risk mitigation and problem solving. Examples include:

- ▶ item availability and delivery time issues
- ▶ work schedule delays, such as those caused by supply availability, weather conditions, approvals and site inspections and the impact of accidents, injury or illness on staffing and work schedules

- ▶ incorrect delivery location, products or materials
- ▶ changes and alterations to job specifications or requirements
- ▶ sourcing products, parts or materials from alternative suppliers or alternative products, parts or materials.

Figure 21.4 presents a simplified view of what can be a more complicated problem-solving process. Identifying the root cause of a problem in some situations is straightforward; however, misidentification of the cause can in itself create other problems. Complicated and challenging issues can present with a number of symptoms. Correctly analysing these problems requires identifying the difference between symptoms and symptom causes from the root cause of the problem.

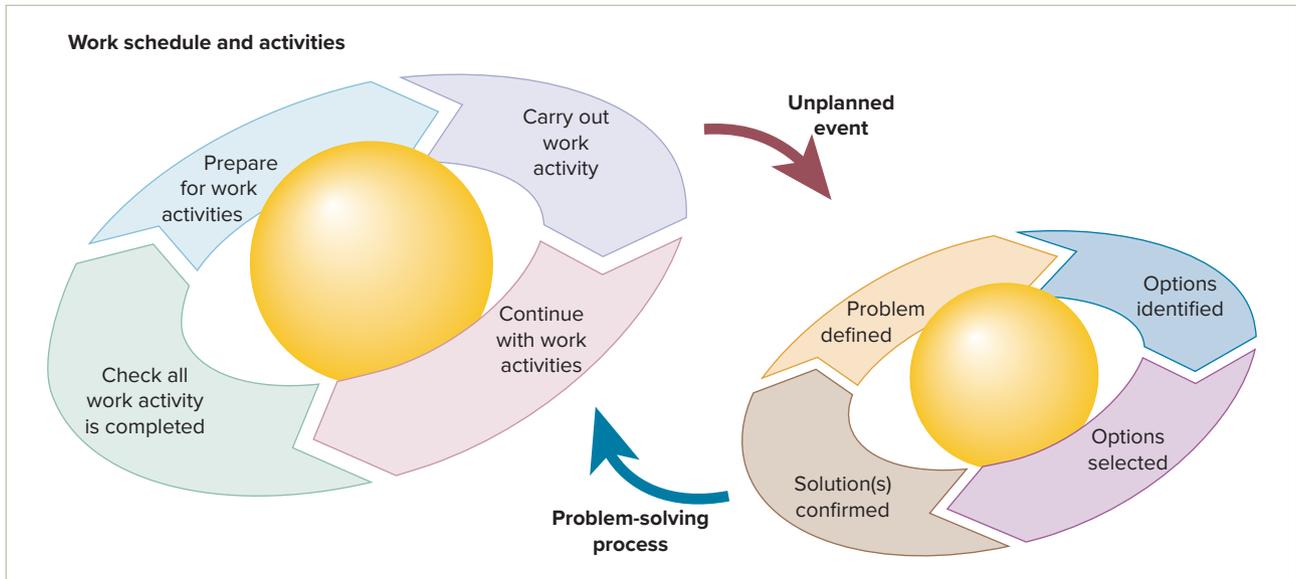


FIGURE 21.4 Problem-solving process for unplanned events that occur during work activities

Source: Adapted by author from <https://www.bulsuk.com/2009/02/taking-first-step-with-pdca.html>

Evaluating the effectiveness of the solution

Dealing with individual symptoms may be effective in complex situations. However, three questions need to be addressed during the Check phase of the PDCA:

1. Did the plan or solution meet the goal set?
2. Did the implemented solution eliminate (solve, correct or mitigate) the problem?
3. Were any new problems created?

The answers to these three questions provide an evidence and information gathering exercise for the Act phase of the PDCA. Should new problems emerge or effects of the problem remain, as represented in **Figure 21.5**, the acquired knowledge is used to repeat the six logical system steps provided in **Table 21.5**

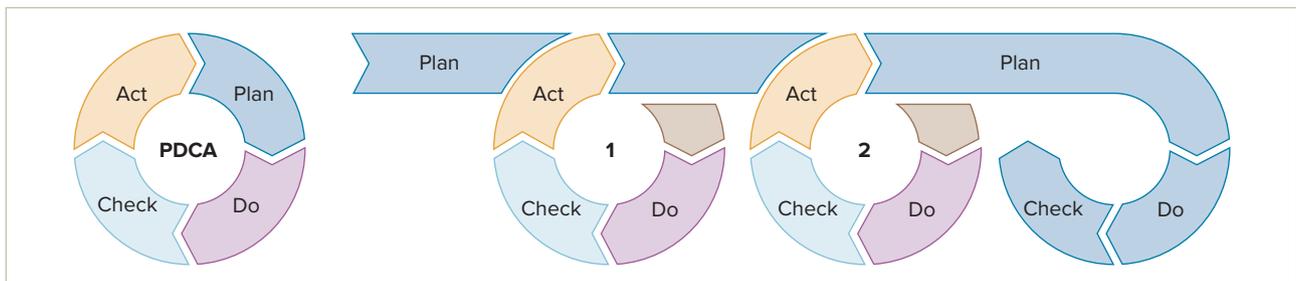


FIGURE 21.5 PDCA continuous cycle for problem solving

Source: Adapted from <https://commons.wikimedia.org/wiki/File:PDCA-Multi-Loop.png>, Christoph Roser, AllAboutLean.com

TABLE 21.5 Problem-solving comparison

Logical systems approach steps	PDCA cycle phases
1. Identifying and defining the problem 2. Analysing and fully understanding the problem 3. Generating ideas and possible solutions 4. Choosing a solution and course of action to take	Plan
5. Implementing the solution	Do
6. Evaluating the effectiveness of the solution	Check

In **Figure 21.3**, an unplanned event or problem (1) is identified and the six logical system steps of **Table 21.5** are carried out. Additional or separate problems are represented in **Figure 21.3** as (2) and are also managed following the logical system steps.

EXAMPLE 21.1: PROBLEM SOLVING A CONVEYOR OVERLOAD

The following example shows the PDCA problem-solving method in action.

A conveyor comprising multiple sections, each with its own motor, contactor and overload, began to continually trip in multiple sections after more than twelve months of use. It was discovered that, during that period, some of the motor overload setting ranges required adjustment. The overloads were initially set to their minimum setting and over time needed to be readjusted to compensate for increased motor current. More than half of the motor overloads were set to their maximum setting.

After tong testing each of the affected motors, a section of conveyor was thoroughly cleaned of dust and dirt build-up and retested. Cleaning had the effect of significantly reducing the motor current and the overload was reset to its original minimum setting (solution identified—Plan). The cleaning process was carried out on each conveyor section (Do). Once each section had been cleaned, the result was the same, with each motor drawing less current and overloads adjusted to their original settings (Check).

Despite manufacturer specifications and maintenance recommendations being followed, additional maintenance routines were implemented to prevent the same situation from occurring in the future (Act). The root cause for the motor overloads tripping was an unforeseen maintenance requirement for the conveyor track system and not a fault with the motors or motor control.

21.5.3 Tools for problem solving

In the Planning phase of PDCA, tools are needed to identify, define and analyse the root cause of problems. Two observation and analysis tools useful in determining what has gone wrong are the Toyota Five Whys technique and Ishikawa cause-and-effect (fishbone) diagram. Getting the right information about any problem or fault condition is about asking the right questions, making observations and obtaining facts and reliable data. The problem may be about ordering processes, material delivery delays or equipment failure.

Constructing cause-and-effect or Ishikawa fishbone diagrams

Cause-and-effect diagrams provide an effective visual representation of possible causes of a problem. The purpose is to find and address the causes, not the symptoms. The process can assist with complex situations where there may be multiple problems, each having a separate root cause.

The cause-and-effect diagram or Ishikawa fishbone diagram provides a powerful tool to analyse and solve problems, and is useful for planning or controlling project quality. Kaoru Ishikawa, who developed the diagrams,

was influenced by a series of lectures given to Japanese engineers and scientists in 1950 by W. Edwards Deming. The Ishikawa fishbone diagram comprises a number of steps (see **Figure 21.6**):

- ▶ Step 1: Draw a long line with an arrow pointing to the problem. The line represents the fish spine.
- ▶ Step 2: Choose a set of cause categories (see Step 4 for examples). These categories will be the basis of the Five Whys analysis.
- ▶ Step 3: Continue adding the major categories as ribs of the fish spine.
- ▶ Step 4: Brainstorm the problem using the Five Whys technique to complete the primary and secondary causes across all of the categories. (Note: continue asking the Five Why questions for each response.)

It is not uncommon during this process to discover other underlying problems or that the identified problem may be actually a symptom of the real problem.

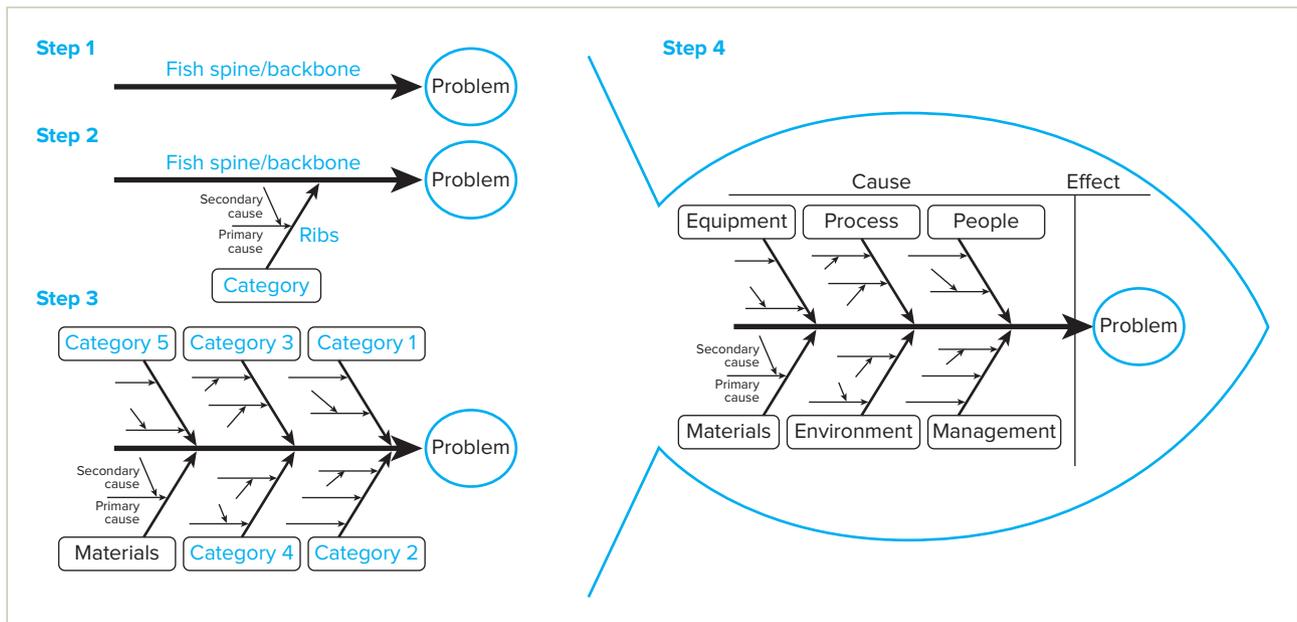


FIGURE 21.6 Building an Ishikawa fishbone diagram



CHECK YOUR UNDERSTANDING

16. Name two models for management implementation and continuous improvement.
17. What is the basic quality tool named after Kaoru Ishikawa?
18. List two observation and analysis tools useful in determining the root cause of problems.
19. In Example 21.1, what action resulted from the PDCA Check phase?
20. What do the spine and ribs of the cause-and-effect fishbone represent?

21.6 Check and confirm work activities are completed

Work tasks and activities need to conform to job instructions and job requirements. These may be specified within contracts, the project scope of works and work schedules. Ongoing work checks are carried out throughout the project. On completion of work a final inspection is carried out to ensure all work is complete, meets specifications and the outcome is fit for purpose.

21.6.1 Communication with customers and clients

Any person employed in a workplace will have some form of communication with appropriate personnel and clients. Appropriate personnel may include the workplace supervisor/team leader, work staff, business owner, other tradespeople and business customers. Clients can be internal or external customers:

- ▶ internal customer—you provide a service or complete a task for another person or department within the organisation that you work for
- ▶ external customer—you provide a service or complete a task for a person or business outside the organisation that you work for.

In all cases, it is important that you are polite and use verbal and non-verbal communication to respond to the client's requests in an appropriate manner. You should also consider cultural differences in your communication processes.

21.6.2 Work disruptions

The customer/client needs to be informed about when the disruption/isolation is to take place, what equipment will be affected and for how long the power will be unavailable. In the case of electrical work causing power disruption in a workplace, it is important to keep appropriate personnel informed about progress and completion of work. Any power disruption to their workplace or routine will have a cost factor. Their staff may have been allocated to different work tasks/activities pending your work completion.

Client work activities, schedules and the recommencement of normal operations will be relying on the restoration of light, power and/or equipment function. Keep the customer informed and updated and advise them when power is to be restored or the work finished.

21.6.3 Completion of projects and work activities

On the completion of a job, a final check is needed to identify any outstanding issues requiring correction. Electricians should:

- ▶ confirm work conforms to instructions
- ▶ confirm work conforms to job requirements
- ▶ carry out a visual inspection and testing of electrical installation work to ensure it is complete.

21.6.4 Changes and variations

Changes and variations to the original scope of works may have been required due to unexpected events or client requests. Variations usually involve additional work to be carried out and in turn additional costs for the customer/client. These variations would have required agreement by the client and it is important to check and confirm these amendments have been carried out.

21.6.5 Work completion and final checks

Completed electrical work requires mandatory testing before restoring power to a piece of equipment, final sub-circuit or installation. These tests are specified in *AS/NZS 3000* and the methods that should be used to carry them out have been covered in previous chapters. Electrical safety and function are not always obvious to a customer or client.

In addition, electrotechnology workers should carry out the following final tasks.

Visual inspection (electrical and non-electrical)

On completion of the work, the electrician should consider:

- ▶ Has the specified work been carried out as per instruction?
- ▶ Has the installation of accessories, fittings, fixtures, apparatus and equipment been carried out, completed and tested as per the schedule?
- ▶ Are switches, socket-outlets, surface conduits, surface-mount items and other items all fixed and secured symmetrically (i.e. level, even and not crooked) and in an aesthetically appealing manner?

Advising the client of completion of work

Completion of service or repair work involves communicating to the customer or client that the work is finished. Communication on-site may be face-to-face (i.e. verbally), involve a phone call and require a signature on a worksheet or electronic device once the appropriate personnel have been informed.

Preparing documentation

Payment for services rendered will also be part of the completion process and involves billing and providing formal documentation, such as invoices, to clients. Invoices are typically mailed through the post or sent electronically via email notification.

Some form of documentation will be part of the process of notifying appropriate personnel that work is completed. There will need to be some record kept by both the electrician performing the work and the client, detailing what work was performed, goods and materials used, costs and pricing.



CHECK YOUR UNDERSTANDING

21. Who would be regarded as appropriate personnel?
22. Briefly explain why variations to an electrical installation would require agreement by the client/customer.
23. Identify the two types of customers.
24. What would you consider from the perspective of a customer or client in a visual inspection?

21.7 Developing apprentices as resources

What do Olympic athletes and apprentices have in common? They possess the similarities of potential, a goal, preparation and development. Over an approximately four-year period, these athletes and apprentices are trained to develop their skills to ultimately reach their goals. Apprentices and athletes also deal with health and wellbeing needs and the emotional, mental and physical challenges involved in achieving success. At the end of their preparation athletes go on to compete at national, international and Olympic events, while apprentices evolve as highly skilled tradespeople in the electrotechnology industry, wiring light and power in homes and working on building sites, in factories and commercial premises.

21.7.1 Injuries: physical, mental and emotional

Many physical injuries in the workplace could be avoided through proper management and care by both employer and employee. During an apprenticeship, like an athlete preparing for competition, the risk of injury is ever present. The majority of apprentices are between the ages of 18 and 21, still developing physically and susceptible to muscular injury. As in the case of the athlete in training, a good physical training and exercise routine can assist in developing strength and meeting the physical demands of performing strenuous work tasks and activities.

Codes of practice are in place to promote safe work practices and assist in preventing injury to all electrotechnology workers. If something is too heavy to be lifted by one person, ask for assistance, use a trolley or lifting device. Trying to impress others by lifting, carrying or moving items that may cause arm, hand, back injury or hernia can result in lost time injuries, medical treatment and possibly surgery.

21.7.2 Mentoring programs

Over the past decade a number of specific mentoring programs have been trialled to support apprentices over an extended period of time. As many as one in four first-year electrical apprentices nationally leave their apprenticeship within their first year, this figure increasing to approximately 45 per cent by the end of the second year. Mentoring programs have been instigated to support apprentices, especially in the first two years of their training, to increase retention rates and improve completion rates. Three examples are described below:

- ▶ *Mentoring Australian Apprentices Program (MAAP)*. This program screened, engaged, trained and matched voluntary mentors to support apprentices across different trades.
- ▶ *Electrotechnology Industry Managing Apprentice Progression (EIMAP)*. This joint initiative between NECA and EE-Oz sought to deliver a national Energise Oz pilot program for electrical apprentices. The program included maths and learning support resources, mentors for apprentices and a learning management system to integrate apprentice learning and assessment.
- ▶ *Industry Specialist Mentoring of Australian Apprentices (ISMAA)*. This national program targeted specific apprentice groups with mentors who were trained and qualified in the same qualification as the apprentices being mentored.

21.7.3 Mentoring apprentices

Good mental health and wellbeing can mean different things to different people but many agree that ways to help improve them include:

- ▶ consuming a healthy and balanced diet
- ▶ taking regular exercise and establishing a routine
- ▶ introducing relaxing activities into one's daily routine
- ▶ getting good-quality sleep
- ▶ setting aside time for friends, family and socialising
- ▶ establishing a balance between lifestyle and study time.

During an apprenticeship events can happen that are largely (or completely) out of our control and which we need to talk about or get help with. These events may be trouble at home, with family, a relationship, illness of a close friend or family member, money problems, living away from home, loneliness, death of a loved one, struggles with studies, long work days or bullying issues at work.

Mentors of apprentices need to be good listeners and sounding boards, helping mentees to draw on their own experiences and strengths to talk, ask questions and make their own decisions with confidence. A mentor can be someone employed through a specific program, a supervisor or a tradesperson. The type of questions that a mentor might ask could include:

1. How are you going?
2. Are you eating well, sleeping well and feeling okay?
3. How are things at home?
4. How are things going at tech?
5. How are things at work?
6. Is there anything you need or want to chat about?

These questions are more often asked in person and occasionally as follow up by phone. In most situations there are supplementary questions based on non-verbal cues by an apprentice, such as facial expressions or pauses to

reflect on some questions. Ask yourself these questions and rate yourself on a scale out of five. If you are scoring three or less on a number of these questions it might be a good idea to chat with your employer, mentor if you have one, teacher or family member for support.

Sometimes it is a good idea to seek other services available or ask your employer to arrange a chat with a health and wellbeing support group such as that featured in the following example.

OZHELP AND ACT SERVICES

OzHelp is a community-based mental health support organisation with a focus on suicide prevention, which supports people in the workplace to stay well, resilient and confident in managing life's challenges. This is achieved through health screening, education and one-on-one confidential conversations. This can be the first step in referral to counselling or other services that may be needed. An example is OzHelp's 15-minute interactive workshop site visit designed to assist people in understanding how they can improve their health and wellbeing.

Other organisations doing similar work include:

- ▶ *Mates in Construction* whose focus is to improve the mental health and wellbeing of people working in the construction industry.
- ▶ *Menslink* which was established to meet the needs of young men and their families in the community, providing intensive short-term counselling and long-term mentoring support from positive male role models.
- ▶ *Incolink* which is a support organisation for the construction industry in Victoria.

21.8 Self-help and employee assistance

Help is available to everyone with access to a telephone, mobile phone or computer with internet. Sometimes we may need to speak to someone about a problem or just read up and research our thoughts, feelings or something we are going through at home or work. Various organisations, support sites and crisis contacts are available to provide help at such times. **Table 21.6** provides details of a number of support services available to young adults.

TABLE 21.6 Support services for young adults

Support service	Services offered	Website
Centre for Clinical Interventions: Looking after Yourself	Provides workbooks and modules with information sheets and worksheets as self-help resources for mental health problems	https://www.cci.health.wa.gov.au
This Way Up	Suite of practical online tools developed by a team of experienced mental health professionals located at the Clinical Research Unit for Anxiety and Depression (CRUFAD), a joint facility of St Vincent's Hospital and the University of New South Wales. Provides online courses to manage mental health based on cognitive behavioural therapy (CBT), which can help treat anxiety and related mental health conditions	https://thiswayup.org.au

TABLE 21.6 Support services for young adults (*Continued*)

Support service	Services offered	Website
Moodgym	Interactive program designed to help in improving wellbeing and reducing depression and anxiety symptoms in users Features interactive modules which include various self-help exercises and quizzes Was originally developed and evaluated at the Australian National University and is free to Australians through funding from the Australian Commonwealth Department of Health and Ageing	https://moodgym.com.au
Black Dog Institute: MyCompass	Free online self-help program developed by the Black Dog Institute that teaches cognitive behavioural techniques and strategies to manage your mood	www.mycompass.org.au
MindSpot	Free national online mental health clinic that offers psychological assessment and treatment for people experiencing stress, worry, anxiety and depression The Mood Mechanic Course consists of five lessons over eight weeks to help young adults aged 18–25 years learn to manage symptoms of depression and anxiety. During the course you can choose to receive weekly therapist support or to contact the clinic when you need to Based at Macquarie University, Sydney, it is funded by the Australian Government and contracted by the Department of Health as a regulated clinical service for people aged 18 and over	https://www.mindspot.org.au/

In addition, there are several national crisis telephone services that can be accessed 24 hours a day, seven days a week for support (see **Table 21.7**).

TABLE 21.7 National telephone crisis support services

Support service	Services offered	Contact details
Lifeline	National charity providing access to 24-hour crisis support and suicide prevention services for Australians experiencing emotional distress	13 11 14
Kids Helpline	Confidential 24/7 online and telephone counselling service for young people aged 5 to 25 All calls are free (even from a mobile)	1800 551 800
Suicide Call Back Service	Nationwide 24/7 telephone and online counselling services provided to people affected by suicide	1300 659 467
MensLine Australia	National telephone and online support, information and referral service staffed by professional counsellors, experienced in men's issues, for men with family and relationship concerns Available to men of any age	1300 78 99 78
Beyond Blue	24/7 contact service for information and support about mental health to help everyone whatever their age and wherever they live. Website provides information about anxiety, depression and suicide to the Australian community	1300 224 636

State-based mental health crisis telephone support services are shown in **Table 21.8**.

TABLE 21.8 State-based mental health crisis telephone support services

State service	Contact details
ACT—Mental Health Triage Service	1800 629 354
NSW—Mental Health Line	1800 011 511
NT—Top End Mental Health Service	08 8999 4988
QLD—13 HEALTH	13 43 25 84
SA—Mental Health Assessment and Crisis Intervention Service	13 14 65
TAS—Mental Health Services Helpline	1800 332 388
VIC—Suicide Help Line	1300 651 251
WA—Mental Health Emergency Response Line	1800 676 822

21.9 Seeking employment in the energy sector

Pursuing an apprenticeship or a job in the energy sector will require research to search for a job, prepare a resume (also known as a curriculum vitae or CV), make an application and prepare for a job interview. The Australian Apprenticeship Pathways (AAP) website is one avenue of research for individuals pursuing a career in electrotechnology: www.aapathways.com.au/industries/electrotech.

21.9.1 Research, writing and methods of application

The electrotechnology sector includes the design, installation, maintenance and repair of electrical and electronic equipment. Energy sector vocations are found in the industries of mining, manufacturing, communications, construction, renewables, domestic and commercial refrigeration and air-conditioning.

The AAP website includes detail about job pathways and career charts for electrotechnology from Certificate II to Advanced Diploma level for students and employers. The website provides information about industry providers and regulators, occupational videos, interviews, job search sites, group training providers and apprenticeship network providers.

21.9.2 Employability skills, attributes and core skills for work

Employability skills identify core skills and desirable, personal attributes of workers. These attributes are what an employer might be looking for in their workers as qualities and indicators of a potential job seeker's work ethic.

When researching and preparing for a job application, promotion or interview, consider whether examples that demonstrate these attributes can be provided to potential employers. Consider the influence of these attributes on relevant skills and abilities as part of preparation, application and interview presentation. **Table 21.9** provides examples of employability skills attributes, core skills for work influencing factors and skill areas for you to consider for your job application.

21.9.3 Preparing for job applications

Employers seek candidates who will be the *best fit* for their organisation and who have the potential for developing the skills and knowledge required by the business. The selection process may look for attributes and characteristics

TABLE 21.9 Employability skills attributes and core skills

ACCI/BCA Employability skills	Core skills for work developmental framework	
Attributes	Influencing factors	Skill area
Commitment	The nature and importance of this attribute is determined by <i>cultural and value-based factors</i> May also be an outcome of <i>degree of motivation</i>	Specific references in <i>Connect and Work with others (Cooperate and collaborate)</i> Also underpins <i>Plan and organise (Plan and organise workload and commitments)</i>
Reliability	The nature and importance of this attribute is determined by <i>cultural and value-based factors</i> May also be an outcome of <i>degree of motivation</i>	Underpins <i>Plan and organise (Plan and organise workload and commitments)</i> Also underpins <i>Connect and work with others (Cooperate and collaborate)</i>
Common sense	The nature and importance of this attribute is determined by <i>cultural and value-based factors</i>	Underpins <i>Work with roles, rights and protocols</i> Also underpins <i>Make decisions and Identify and solve problems</i>
Ability to deal with pressure	May be an outcome of <i>self-belief and resilience</i> Also influenced by <i>external factors</i>	An outcome of <i>Plan and organise</i> May be an outcome of <i>Connect and work with others (Understand self)</i>
Adaptability	May be an outcome of <i>self-belief and resilience</i>	Specific references in: <i>Make decisions</i> <i>Identify and solve problems</i> <i>Plan and organise</i>

Source: Department of Employment, Skills, and Education, BRIDGING DOCUMENT – CORE SKILLS FOR WORK, 2013, CC BY 4.0, <https://creativecommons.org/licenses/by/4.0>

considered as key to employment. While a number of these may be identified as employability or core skill framework skills, the application and interview process seek to identify suitable employees.

Interview questions may be asked to determine potential employees':

- ▶ skills
- ▶ work experience
- ▶ demonstrated abilities
- ▶ strengths
- ▶ weakness.

The participants in the pre-apprenticeship case study discussed earlier were involved in an activity about workplace expectations and were presented with a list of words to review and reflect upon. Course participants were asked three questions about themselves to prepare for job applications and work interviews. From the list provided they were asked:

- ▶ Which five words best describe attributes you possess?
- ▶ List any of the remaining words which describe the skills or abilities you should develop.
- ▶ Pick five words from the full list which best describe, skills or attributes needed for work.

Five of the most frequently identified words pre-apprenticeship participants associated with employer expectations as positive attributes for job applicants were attitude, awareness, interest, initiative and listening. An employee or job applicant who has a poor attitude, no interest or will not listen to instructions will experience difficulty in gaining or keeping a job.

Initiative is more than just a word

Initiative is being aware and interested in a job, not waiting to always be told what to do. One point of caution: initiative is good if you are aware of what needs to be done and have the skills and knowledge to do the task. If you do not know what to do or do not have the knowledge or skills needed, then ask someone for help, direction or advice.

An example of initiative was demonstrated by some pre-apprentice course participants who asked if they could take home overnight a pair of pliers and cable offcuts to practice cable stripping and joining. A number were experiencing difficulty in that they were nicking the copper strands when stripping insulation or breaking strands when twisting and joining cables for terminations into socket-outlets, switch and lamp accessories. This initiative demonstrated their interest and perseverance to source the cable and pliers and practise what they had learned.

21.9.4 Skill development programs and courses

Opportunities for work experience and pre-apprenticeship programs can assist in developing knowledge and skills. Other opportunities include Try-a-Trade days arranged at schools, trade centres and training centres for school-age students. Certificate II Electrotechnology (Career Start) is a course viewed by some employers as an indication of how well an applicant can handle learning off the job with some completed units of study being considered for credit transfer or recognition of prior learning towards an apprenticeship. For two or more applicants vying for an apprenticeship, an applicant who has undertaken the Certificate II, participated in pre-apprenticeship programs or pursued work experience may have an edge over other candidates without that experience.

21.9.5 Job advertisements and applications

Writing an application or CV alone will not be enough to secure an advertised job—applicants will likely be asked to also submit a written application. Advertisements may ask applicants to separately address a number of criteria or to write one general statement expressing their claims for a job. The job description will help applicants understand the responsibilities and tasks required of that position. When preparing a resume and job application, potential employers will be looking at what applicants can bring to their organisation. Whether writing a CV, a job application or answering questions at an interview, the STAR approach is a great way to structure examples.

The STAR model

The STAR model is one way of presenting information against selection criteria. It helps employers evaluate what skills, qualities and experience job applicants have and how they might fit with the job, company or workplace. STAR is an acronym for:

- ▶ *Situation.* Explain the situation that you were in. Set the context by describing the circumstance or environment (e.g. factory, construction site, commercial premises) where you used the skills or qualities and gained the experience.
- ▶ *Task.* What was your role? Give an overview to briefly explain what you had to do. The task may be installing a hot water service or installing light and power in an industrial, commercial or domestic environment. If you were working as a member of a group, explain the group's task but be clear about your own role.
- ▶ *Activities.* List the various activities involved with the task, like filling in a work journal, or profiling. State what you had to do and how you did it. The activities of the task may be drilling holes to surface mount conduit, light fittings and accessories such as switches and socket-outlets, pulling in cable, terminating cables or testing circuits.
- ▶ *Results.* What was the end result and what did you achieve? How does it relate to the job you are applying for? For example, a response might be 'Project task was completed on time and on budget to specification'.

21.9.6 Preparing a CV

Skills will develop, knowledge will grow and experience will widen during the course of a career so it is important to update CVs over time to make the most of career opportunities. Identifying experiences and examples of applying knowledge and skills in workplace situations using the STAR method is a way to assist in this process. The exercise will also be good preparation for the interview process where job applicants will meet with the interview panel in person or via technology mediums such as Zoom or Microsoft Teams where they can present examples of what they have done.

Sometimes a potential employer or selection panel may request a CV be a specific or maximum length or that certain details be included. Otherwise, a CV would typically include:

- ▶ personal details—name and contact details such as email address and phone number. There is no need to include age, gender or marital status.
- ▶ education—details of relevant education and qualifications.
- ▶ work experience—employment history, which should be listed in chronological order, starting with the most recent and including actual dates of employment. Main responsibilities and achievements relevant to the job being applied for should be highlighted.
- ▶ other experience—such as activities, interests or volunteer/community work that may be relevant, highlighting what was gained from that experience. Hobbies that aren't relevant to the job should not be included.
- ▶ referees—name and contact details of people who can confirm claims and support your application.

21.10 Workplace interviews

Workplace interviews can take the form of meetings, progress reviews and job and promotion interviews and can involve the interviewee, the interviewer (potentially a future employer) and the interviewee's performance. There are three critical factors to bear in mind for these situations: preparation, presentation and evaluation. A well-written job application demonstrates an applicant has prepared well, as they consider the job position and address the selection criteria, showing that they have the potential or skills that merit meeting with a potential employer. The interview provides an opportunity for the interviewer to meet with an applicant, which helps them to decide whether to offer an applicant the job.

It is important to prepare for an interview and to consider how to present yourself and make a strong claim for the position. The STAR model is a useful tool for such preparation.

Not all interviews are successful, and in cases where they are not there are lessons to learn from the experience by evaluating one's performance. Often it is difficult to decide who should be successful as the quality of candidates who applied was high. Following an interview, particularly if an applicant was not selected for the position, it can be useful to ask for feedback about the interview, which can help prepare for future opportunities and provide an added edge for an applicant's next interview. Applicants may also engage in evaluation after the interview through self-evaluation on how the interview went.

The following sections look more closely at various types of workplace interviews: a job interview, a performance review and finally a promotion.

21.10.1 Job interviews

Once a job interview has been set up, applicants must take steps to secure the role. They need to show prospective employers they have the aptitude, qualities and presentation skills worthy of the position or apprenticeship. This also applies to those undertaking or having completed the Certificate II Career Start. Progress results will indicate to prospective employers whether applicants can handle the off-the-job course work to undertake an apprenticeship. Some basic tips apply to meeting with customers, clients, apprentice of the year award interviews and job interviews. Presentation tips that are relevant to all meetings and interviews are provided later in this section.

21.10.2 Performance or progress reviews

Progress reviews can take different forms and are an opportunity to discuss work performance, which at times may be viewed favourably and at other times not. They offer the chance to discuss matters such as the progress of off-the-job courses and studies. An employer may take the opportunity in such interviews to discuss common workplace concerns to try and determine what is causing the problem. For example, an employer might be concerned about an employee who is regularly late for work or taking days off. They may use a performance review to determine if the absenteeism or tardiness is due to illness, fatigue, poor diet, poor timekeeping or something more sinister.

Occasionally apprentices, like any other employee, may experience difficulties that reflect in their work performance and reliability. An employer may need to talk with these employees to determine what is going wrong and whether the employee requires any help or assistance. Reasons may include wage and budgeting problems, relationship and/or personal issues or being unable to handle the course 'tech' work.

Severe workplace situations may involve intimidation, bullying or harassment and must be reported immediately. Persons conducting a business or undertaking (PCBUs) and employers are required by law to act on such incidents and employees need to let them know of any instances. Trust, openness and honesty are required in these situations and underpin an employee's presentation of the incident—withholding details and not explaining what has happened, how it made them feel or what they are going through places employers at a disadvantage where they are unable to take the action needed to remedy the situation.

Organisations may engage the services of a mentor, health and wellbeing officer or welfare officer trained and qualified in providing advice and support. They are often included in review meetings to support the apprentice. Preparing for this type of interview may involve some soul searching and reflection. It is important for employees to consider how they present in review meetings, especially if their work performance is causing concern and getting back on track is the focus.

21.10.3 Promotions

A promotion may be due to the completion of a Certificate II or III course work and apprenticeship. When applying for a promotion, presentation of claims, examples of attributes, key employability skills such as problem solving and teamwork and evidence of work skills will all be considered.

Applicants must address job selection criteria in their application, update their CV and prepare for the interview, ideally using the STAR model. The information provided in **subsections 21.9.5** and **21.9.6** can be useful when preparing for promotions. Examples of common selection criteria include:

- ▶ demonstrated capacity to communicate effectively
- ▶ good administrative and organisational skills
- ▶ proven ability to work as part of a team
- ▶ well-developed customer service skills
- ▶ proven ability to manage projects.

Check for any organisational requirements relating to dress codes and presentation. Although the workplace should be one of diversity, acceptance, tolerance and respect, the interviewer(s) may be impacted by first impressions or expectations, either intentional or unintentional.

An impression will be formed about the applicant within the first five to seven seconds based on facial expressions, posture, mannerisms and body language. Many interviewers and panels may look past this with understanding and appreciate an interview may be challenging and candidates could suffer from nerves. It is a good idea to practice for an interview with family members, friends and colleagues, during which time applicants can run through their personal presentation and interview preparation.

Presentation is also about being punctual, clean and appropriately dressed for the interview. Hair should be neat, clean and fingernails trimmed. Dirt under fingernails can be off-putting to an interviewer as they will be gauging your appearance in the context of how it will appear to their customers and clients.



CHECK YOUR UNDERSTANDING

25. Briefly explain the four parts of the STAR model.
26. Provide four reasons that might prompt an employer to arrange either a performance or progress interview.

SUMMARY

- ▶ Work in the electrotechnology sector includes the design, installation, maintenance and repair of electrical and electronic equipment.
- ▶ Successful completion of a Certificate III in Electrotechnology Electrician qualification is recognised nationally and is the main requirement for an electrical licence application in all states and territories.
- ▶ Stakeholders in the electrotechnology industry include employers, group training organisations, industry regulators, electrical wholesalers, trade schools and training organisations, trade unions, industry training advisory bodies and industry and skills councils.
- ▶ Pay, overtime rates and conditions, special leave arrangements, special allowances and hours of work are covered by industry awards. Awards set minimum amounts that an employer in industry is allowed to pay for work.
- ▶ A traineeship can be within a broader range of occupations, either part-time or full-time, typically between one to two years. An apprenticeship takes around four years to complete.
- ▶ Routine work activities are collections of smaller, specific work tasks and, like projects, have a start, a finish and a purpose.
- ▶ Tools, equipment and personal protective equipment necessary for work should be checked to ensure they work correctly and are safe to use.
- ▶ Workplace instruction involves advice, guidance and direction on working safely and can be provided in the form of workplace literacy such as signs, schedules, posters and safe work procedures.
- ▶ Two observation and analysis tools useful in determining 'what went wrong' are the Toyota Five Whys questioning technique and Ishikawa cause-and-effect (fishbone) diagram.
- ▶ The Ishikawa cause-and-effect (fishbone) diagram is one of the seven basic tools of quality providing a powerful tool to analyse and solve problems.

REVIEW QUESTIONS

1. What is the basis of development for what are known as *foundation skills*?
2. What are the training contract expectations for employers?
3. What is emotional intelligence?
4. State the ASQA definition of competency.
5. List the tools required for measuring and marking.
6. Explain what is meant by a *pilot hole*.
7. What is meant by the term *direct supervision*?

8. Identify five positive attributes of job applicants that employers might look for.
9. Identify two observation and analysis tools used for problem solving.
10. What is STAR an acronym for?
11. Briefly explain what is meant by the core skills framework Cluster 2: Interact with others.
12. State the three levels of apprentice supervision.
13. What documentation is used in some states and territories instead of SOPs?
14. State the purpose of visual inspection of test instruments.
15. Provide two reasons for having an SOP near equipment and machines.
16. Identify four items to look for when conducting a visual inspection of test instruments.
17. List three employability skill attributes.
18. List the five skills of the Core Skills for Work skills cluster relating to *Get the Work Done*.
19. List the sequence of steps to test for voltage and that equipment is de-energised.

CHAPTER 22

Components, accessories and materials for energy sector work

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you should be able to:

- ▶ understand how to locate, schedule and obtain resources and materials required for electrical work
- ▶ describe workplace policies, procedures, instructions and relevant documentation
- ▶ identify and access materials and parts used in electrical work
- ▶ use relevant part and component identification and information
- ▶ understand how to select electrotechnology parts, components, accessories and materials
- ▶ discuss how to confirm the selection of components, accessories and materials
- ▶ identify part codes, prices, goods and services tax (GST) and delivery costs
- ▶ explain ordering procedures, including customer approval, supplier requirements and job requirements
- ▶ understand receiving/dispatching procedures
- ▶ explain how to deal with unplanned situations.

Knowing how to identify, select and confirm the components, accessories and materials needed to carry out energy sector work is an essential part of an electrotechnology worker's job. It is important to understand how to identify items available from manufacturers and suppliers, and how to order and receive the supplies needed. It is also important to know how to deal with unplanned events and situations, such as receiving incorrect parts or delivery delays. Familiarity with the types of documentation encountered when ordering parts and accessories is necessary, as is an understanding of manual handling and storage practices, and the OHS/WHS and organisational policies and procedures needed to perform these tasks safely.

22.1 Locating, scheduling and obtaining resources and materials required for electrical work

Electrotechnology workers need to know how to prepare to carry out electrical activities, work safely and schedule work tasks to carry out installations correctly and in a timely manner. They also need to be able to locate and obtain resources to ensure that these tasks can be done.

22.1.1 Preparing for work activities

Preparing for any work activity requires having the appropriate knowledge and skills as well as a schedule of the work to be undertaken. This ensures that work tasks are performed safely (according to safe work practices), in an agreed timeframe (following the proposed schedule), to a quality standard (meeting specifications and standards) and with a minimum of waste (applying sustainable work practices).

Preparing for work activities involves providing a quote for the work, and procuring the necessary parts and materials needed to perform required tasks. Materials, parts and components must be confirmed, scheduled and obtained in accordance with workplace procedures.

Efficient project management is essential when preparing for work activities and identifying components, accessories and materials needed for work activities. **Chapter 21** provides further details about useful methods for planning work activities, such as the Plan–Do–Check–Act (PDCA) approach (see **Figure 22.1**), which is also useful as a problem-solving approach to deal with unplanned events.

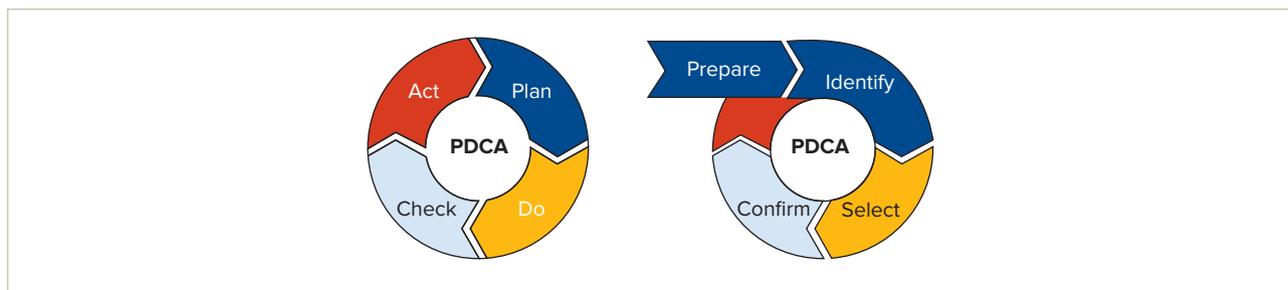


FIGURE 22.1 PDCA model for energy sector work activities

The process of planning and preparing for electrical work requires technical, organisational, communication and customer service skills as the electrotechnology worker liaises with clients, suppliers and colleagues to determine schedules and acquire the necessary parts and materials. Poor planning, preparation and scheduling can lead to workplace stress, poor performance and outcomes, and unsatisfied clients.

22.1.2 Working safely

Legislation details requirements for workplaces to ensure the safety of electrical workers, and codes of practice provide guidelines for dealing with specific work hazards. Organisational policies and procedures are put in place to deal with work conduct, working with others and the ways of performing work activities, in order to work safely. These include conducting risk assessments, preparing safe work method statements for high-risk work, training in correct use of personal protective equipment (PPE), and isolation, energising and de-energising procedures. Electrical workers must be able to access these resources in order to carry out their activities. **Chapter 2** and **Chapter 21** examine work safety practices in further detail.

22.1.3 Schedule of work

A schedule of work allows electrotechnology workers to carry out activities in a timely manner. It is typically determined by the work instructions. Required work activities may range from performing planned and preventive

maintenance tasks, to carrying out repairs to electrical installations, and testing commissioning or plant and equipment installation. Maintenance task schedules may be daily, weekly or monthly, while electrical installations will have a specified start and completion date. Work instructions are based on:

- ▶ manufacturer specifications for maintenance and repairs
- ▶ client specifications
- ▶ electrical standards, rules and regulations.

Installation, maintenance and repair work requires sourcing and obtaining parts and accessories, and larger electrical installations projects will require a degree of project planning. These electrical work activities need to be scheduled, with defined start, duration and finish times. Preparing a schedule of work involves following steps to identify, select and confirm components, accessories and materials for work activities (see **Figure 22.2**).



FIGURE 22.2 Steps in preparing a schedule of work

Identification

Work instructions for electrical work are determined by the client and job specifications. For example, in the case of a service call or a request to repair electrical equipment, the job specification is to return equipment, machinery or devices to an operating condition. In the case of an electrical installation, there are more factors involved and decisions to be made. Components, accessories, tools, PPE and materials required to undertake work activities are identified based on the job requirements.

Selection

The schedule of work is followed and the required parts and accessories are ordered from suppliers. (Refer to **Section 22.6** for further information on ordering.) Some work schedules may have a degree of latitude or flexibility within the timeline, referred to as slip and float within the critical path. *Critical path* is the term for the necessary sequence and scheduling of work activities without slippage. Examples illustrating this are cable rough-in and fitting-off: ordering and purchasing cable is important but actually having the cable is essential for roughing-in tasks. Roughing-in cable needs to be carried out before fitting-off switches, lighting points, socket-outlets and other appliances.

Confirmation

Checks are made to ensure the schedule and work instructions are followed, and that the correct goods have been ordered, received and verified. (Refer to **Section 22.8** for receiving and dispatch procedures.) It is important to note that when carrying out electrical work, electrotechnology workers are a human resource that also needs to be scheduled and worker availability needs to be factored in. Materials, equipment, workers, worksite access, inspections and deliveries all need to be effectively coordinated and scheduled to enable work to take place.

22.1.4 Standards, specifications and sources of information

Knowledge of relevant standards is essential for carrying out electrical work. Electrical installations must comply with the *Wiring Rules* and *AS/NZS 3008.1 Electrical installations—Selection of cables*, *Service and Installation Rules 2014 (SIR)* and other standards, such as those mentioned in other chapters. Access to job specifications and information is

also necessary and this comes in the form of architectural electrical drawings and floor plans, which show the layout and position of lighting points, switches and socket-outlets based on client requirements and installation specifications.

Other sources of information required for work are manufacturer and supplier documentation, equipment specifications, service and maintenance manuals, parts lists, circuit diagrams and manuals. These provide details of components, parts and accessories found in electrical and electronic devices, equipment and machinery, and provide electrotechnology workers with the necessary details, guidance and recommendations about maintenance procedures, adjustments and repair work instructions.

22.1.5 Obtaining resources and materials

Electrotechnology workers typically review supplier catalogues when they seek to obtain parts and accessories for work activities. Catalogues are usually available online on supplier and wholesaler websites. Today, most purchases are made online, unless an item is required urgently, which prompts an in-store visit. Nearly all enquiries and transactions involve some form of technology to either source or purchase items. Obtaining resources, goods and materials will involve setting up an account with a supplier. Terms and conditions apply to accounts, particularly in regard to timeframes and methods of payment. These can assist suppliers, electrical contractors and businesses with cash flow, billing and lines of credit flexibility. If terms and conditions are not met an account could be suspended, halting deliveries and resulting in unwanted delays, disruption to workflow and scheduling.

22.1.6 Tools, equipment and personal protective equipment

Workers need to be able to identify and select appropriate tools and equipment to use across a variety of electrotechnology tasks. Repairs, maintenance and installation activities will vary; however, all require hand tools such as pliers and screwdrivers of various types and sizes. Testing activities require continuity and insulation resistance testers for installations, multimeter LCR and ESR testers for electronic components. All electrotechnology workers will require some form of digital literacy and skill with using computers and digital hand-held devices.

Electrotechnology workers directly involved with warehousing, distribution, receiving and dispatch docks and electrical wholesale workplaces use different tools and equipment from that of installation, repairs and servicing work such as manual lifters, pallet jacks and forklifts. Other resources include knowledge of processes, procedures and technology used for processing and preparing orders, inventory management and supply chain logistics, such as label printers and hand-held barcode scanners used to automate and streamline work processes and logistics. Warehousing and delivery personnel utilise this technology for scanning QR codes and barcodes on parcels and package labels for inventory management, logistics and delivery work activities.

PPE requirements will vary across work locations and environments. Regardless of the type of equipment, tools or PPE required, they need to be checked for damage, correct operation and condition before use, during and after use. Computer programs and systems along with all forms of equipment and machinery have recommended start-up and shut-down procedures to be followed.

Example: locating, scheduling and obtaining resources and materials to carry out service and repair work in the hospitality industry

Small business and commercial operations in the hospitality and service sectors depend on service industry contractors to service and repair equipment. These include cafés, bistros, bars, pubs and restaurants, which require maintenance and repair to equipment such as glass washers, ovens, meat room bandsaws and delicatessen food warmers among many other items. When such equipment needs repair or maintenance, a service call is made to a service technician. A service technician called out to perform such activities would set about identifying and sourcing components, accessories and materials for such work using the following steps (illustrated in **Figure 22.3**):

- ▶ Customer call—The process begins with a call from the customer who details a problem with their equipment that needs to be fixed.
- ▶ Site visit—A site visit is then conducted, where the service technician checks the equipment to diagnose, identify the cause and confirm the problem.

- ▶ Order placed—On some service calls, generic electrical items, known as van stock, can be used to rectify the problem. Often though a replacement part is required and needs to be ordered from the manufacturer or supplier. The component, accessory and any materials required are identified and an order is placed with the relevant manufacturer supply agent. When looking at replacing a part a service technician will either source a direct replacement or attempt to obtain a *like for like* component for the job. This will include the correct ratings such as, voltage, amperes and wattage.
- ▶ Goods received—The necessary parts and accessories are sent by the manufacturer or supplier, delivered to the service technician and the customer is called to say the parts have arrived.
- ▶ Installation repair or replacement—A follow-up site visit is arranged and the equipment is fixed, tested and returned to service.



FIGURE 22.3 Service call process steps

The process duration may be anywhere from a 24-hour turnaround up to a week from the initial call to job completion. Delays and availability of items that might impact the process are mentioned later in the chapter. A service technician may make anywhere from five to 10 or more different site visits every day. Initial site visits where parts need to be ordered may take anywhere from 15 to 60 minutes. A call-out fee is charged to the customer and in some cases may include the first 15 minutes of diagnosis and repair work. The follow-up call-out is usually only charged for the time taken to undertake the repair. A single invoice for both site visits will be provided to the customer with details including the time, date, description of work activity, parts used and cost involved.



CHECK YOUR UNDERSTANDING

1. List four objectives for preparing for work activities.
2. What is a possible consequence of breaching terms and conditions that apply to a supplier's payment of accounts?
3. List the steps a service technician would follow when responding to a service call to repair electrical equipment or installations.
4. Identify the range of tools and equipment required for warehousing, distribution, receiving and dispatch dock work areas.

22.2 The supply chain

The following section gives an overview of the difference between purchasing and procurement, the supply chain and logistics, e-commerce, quality, sustainability and the Rs of purchasing and procurement.

22.2.1 Purchasing and procurement

Purchasing and procurement are terms sometimes used interchangeably. *Purchasing* refers to the process and functions associated with buying accessories, parts and materials. Purchasing is part of the procurement process. *Procurement* refers to the steps and activities that happen before, during and after acquiring goods and services.

22.2.2 Supply-chain networks and logistics

Supply-chain networks vary according to industry and the products or services provided. They include manufacturers, producers, suppliers, vendors, wholesalers and retailers. A supply chain represents a network of people and businesses following a series of organisational steps and activities needed in getting products or services to the customer or final buyer. The steps and processes in achieving this can be described as logistics and play an integral part in the chain.

Logistics was a term initially applied to the movement of military equipment and supplies to various troop deployment locations. Today the term is closely associated with supply chains and networks. An important aspect of supply-chain management, logistics is concerned with warehousing, transportation and distribution centres. A variety of information management, warehouse and e-commerce systems are required and include inventory management, purchasing and invoicing. Due to technological advancements and e-commerce, logistics and supply-chain management are now one of the world's fastest-growing and widely used industries in its own right.

22.2.3 E-commerce

E-commerce and online ordering are electronic commercial transactions, for the purposes of buying and selling goods and services. These transactions include electronic banking and electronic transfer of funds wirelessly and over the internet, using computers or other types of smart devices such as laptops, tablets and mobile phones. Online ordering, purchasing and payments have become quicker, easier and more efficient due to technological innovation, giving rise to e-commerce and resulting in the rapid growth of online ordering and the development of supply-chain networks and logistics. The three main types of e-commerce commonly referred to are business-to-business, business-to-consumer and consumer-to-consumer. These can be considered as a basis to identify transactional relationships between businesses and links in the supply chain.

22.2.4 Total quality management and the three Ps

Sustainability and quality have intersecting and overlapping roles in supply-chain management and logistics. Quality and the principles of efficiency and productivity for many years focused primarily on costs, sales and profit. Quality was considered as something intangible and perceived in the eyes of the beholder. The quality of the product was linked to brand names, reliability and the reputation of the manufacturer, price, seller and distributor. The concept of quality is today integrated with the quality of products, the quality of service to the customer and the quality of business and transactional relationships. Quality should permeate every area of the supply chain. Total quality management principles are put in place through policies, procedures and practices in all areas of management, communication, processes and relationships to ensure this is achieved.

Environmental awareness and a realisation of the need to protect and preserve the environment have caused a significant shift in recent years towards sustainability and the three Ps: people, planet and profit (sometimes called the triple-bottom-line). Each of the three Ps has different business goals, values and measures, which vary between organisations, but all are concerned with eliminating waste and better utilising resources more efficiently. Over time, these approaches to quality and sustainability have been adopted as the more correct way of carrying out business activities.

22.2.5 The Rs of purchasing, procurement and logistics

The Rs of purchasing, procurement and logistics refer to what is required in ‘getting it right’. Most models refer to quantity, quality, place, time and price:

- ▶ Right product or service—Parts and accessories identified, selected and ordered are as described, and correct in terms of specification, colour, size and quantity.
- ▶ Right condition—Parts and accessories are delivered intact, undamaged and fit for the purpose intended.
- ▶ Right place (and customer)—This primarily refers to the location of the customer or the delivery destination. Other place considerations include sources in the chain, places from which materials are acquired and the location of other activities involved in the supply-chain network.
- ▶ Right time—Consideration is given to the lead-time required for materials and products, time management, time spent with suppliers and achieving minimal delay between ordering and delivery.
- ▶ Right price—Price considerations include the amount paid for materials or products, GST, shipping and handling costs, the cost of acquisition as well as sustainability considerations, the price to society and the price to the environment.

To achieve these ‘rights’ businesses need to embrace new technologies as well as the processes and checks required. Each of these checks helps to provide tracking, traceability and accountability for the supply chain. These checks include process documentation in the form of electronic systems or paper-based records, or a combination of the two.



CHECK YOUR UNDERSTANDING

5. What is a supply chain?
6. What is e-commerce?
7. List three items that customers link to product quality.
8. What is the term given to the steps and processes in a supply chain?
9. Provide three examples for the Rs of purchasing and procurement.

22.3 Workplace documentation, policies, procedures and instructions

22.3.1 Documentation and work procedures

Documentation and work procedures can be paper-based or electronic and are considered here in three separate areas:

- ▶ OHS/WHS legislation, standards, codes of practice and safe work practices (see **Section 22.1.2**)
- ▶ manufacturer and supplier documentation, equipment specifications, service and maintenance manuals, parts lists, circuit diagrams and manuals (see **Section 22.1.4**)
- ▶ organisational policies, work instructions, workplace procedures incorporating ordering, receiving and dispatching procedures, and workplace records.

These common forms of documentation are the background for ordering procedures, material management processes for work, manual handling and storage for components, accessories and materials for electrical industry work activities. It should be noted that they can vary from one organisation to another, with differences in procedures and financial arrangements from one country to another. Large organisations may have a dedicated administration department or staff in an accounts department who process invoices, and manage sales, purchasing and payments.

22.3.2 Goods and services tax

Goods and services are subject to a goods and services tax (GST). This tax applies to goods produced for sale, and for services provided to clients and customers. Goods and services can be considered as products and solutions that can be sold to meet a customer's needs. There are various definitions and descriptions for the terms *products*, *goods* and *services*. Grouping these descriptions into a single definition for 'what is a product' encompasses all forms of goods and services.

A product is an object, item, commodity, system or service, in either physical, virtual or cyber form, offered for sale to meet the need or want of a customer. Products can be components, accessories and materials. Services can include work activities to fix and repair or to replace items of equipment, perform adjustments, or to test, measure and install electrical services. For example, a house alarm is a product. The act of installing the house alarm system is a service. Both would be subject to GST.

Table 22.1 notes the characteristics of goods and services.

TABLE 22.1 Goods and services in the electrical industry

Goods	Services
<ul style="list-style-type: none"> • An item produced or resulting from labour • An item offered for sale • Physical items such as a tap or tap washer • Computer components, video cards and RAM • Electrical accessories: lights, switches, socket-outlets • Components, accessories and materials required to perform work activities 	<ul style="list-style-type: none"> • Outcomes provided by labour or work performed • Something (a service) offered for sale • Replacing a tap or tap washer • Assembling or replacing RAM or a video card • Installing electrical accessories such as lights, switches, socket-outlets • Identifying, selecting and performing work activities with components, accessories and materials

A house alarm system, while being a product, attracts a charge or fee when used as an externally monitored system and can also be regarded as a service subject to GST. Most goods and services are subject to GST, although some are specifically exempt. The GST details of goods and services need to be recorded either electronically or physically in workplace documentation.

In Australia, GST is a broad-based tax of 10 per cent on most goods and services. In New Zealand, GST is a consumption tax of 15 per cent on all goods and services.

22.3.3 Invoices and receipts

An invoice serves as a formal agreement between the seller and buyer and relates to a sale or transaction for (products) goods and/or services. An invoice can be electronic or paper-based and is a business document record listing details of the type of product or service provided, quantities, agreed price and method of payment.

An issued invoice confirms that goods have been shipped and requests payment to the supplier or account holder. The seller is giving up ownership of assets as inventory to a different form of assets as accounts receivable. Generally goods and materials will be shipped or handed over to customers after payment is received. An invoice for services provided is more commonly issued to the customer with terms requesting payment.

According to the Australian Competition and Consumer Commission (ACCC), a receipt can be in the form of a GST tax invoice, a cash register or a handwritten receipt. Tax invoices will often provide details of payment total inclusive of shipping and GST, the amount paid and balance due.

The Australian Taxation Office (ATO) identifies three types of invoices: regular invoices, tax invoices and recipient created invoices. Businesses not registered for GST provide regular invoices without the words *tax invoice*. Businesses

registered for GST provide tax invoices. In special cases the buyer can provide recipient created tax invoices. Tax invoices must include at least seven pieces of information:

- ▶ document title or indication that the document is a tax invoice
- ▶ seller's identity
- ▶ Australian Business Number (ABN) of seller
- ▶ date invoice was issued
- ▶ brief description of items sold, the quantity (if applicable) and price
- ▶ GST amount (if any) payable, shown separately or with a statement which says 'Total price includes GST'
- ▶ indication for sale amount as GST inclusive.

Tax invoices of \$1000 or more also need to show the buyer's identity or ABN. **Figure 22.4** shows these components as they might appear on a typical invoice.

<p>Seller identity</p> <p>ABC Computer Parts <i>From Us to You</i></p> <p>ABN: 56 641 078 319 Australian Business Number (ABN) of seller</p> <p>123 Silicon Vally Place EVATT ACT 2617 Phone 02 62040404 Fax 02 62140404</p> <p>SOLD TO: R. U. Okay EWP 1313 Mockingbird Lane Beverley Park Sydney 2217 Phone: 02 687 02 49</p> <p>COMMENTS OR SPECIAL INSTRUCTIONS:</p>	<p>Document title or indication as Tax Invoice</p> <p style="text-align: center;">TAX INVOICE</p> <p style="text-align: right;">INVOICE #: MGH12345 DATE: JANUARY 6, 2022</p> <p style="text-align: right;">Date invoice was issued</p> <p>SHIP TO: R. U. Okay EWP 1313 Mockingbird Lane Beverley Park Sydney 2217 Phone: Somebody Okay</p>																												
<p>Brief description of items sold, the quantity (if applicable) and price</p>																													
<table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <thead> <tr> <th>QTY</th> <th>UNIT</th> <th>CODE</th> <th>DESCRIPTION</th> <th>UNIT PRICE</th> <th>TAX</th> <th>TOTAL</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>ea</td> <td>SDSSDA-120G-G27</td> <td>SanDisk SSD PLUS 120GB 530MB/s SATA 2.5" SSD</td> <td>\$37.00</td> <td>10.00%</td> <td>\$37.00</td> </tr> <tr> <td>1</td> <td>ea</td> <td>WDS250G2BOA</td> <td>WD Blue 3D NAND 250 GB 550MB/s SATA 2.5" SSD</td> <td>\$52.00</td> <td>10.00%</td> <td>\$52.00</td> </tr> <tr> <td>1</td> <td>ea</td> <td>WDS500G2BOA</td> <td>WD Blue 3D NAND 500 GB 550MB/s SATA 2.5" SSD</td> <td>\$105.00</td> <td>10.00%</td> <td>\$105.00</td> </tr> </tbody> </table>		QTY	UNIT	CODE	DESCRIPTION	UNIT PRICE	TAX	TOTAL	1	ea	SDSSDA-120G-G27	SanDisk SSD PLUS 120GB 530MB/s SATA 2.5" SSD	\$37.00	10.00%	\$37.00	1	ea	WDS250G2BOA	WD Blue 3D NAND 250 GB 550MB/s SATA 2.5" SSD	\$52.00	10.00%	\$52.00	1	ea	WDS500G2BOA	WD Blue 3D NAND 500 GB 550MB/s SATA 2.5" SSD	\$105.00	10.00%	\$105.00
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<p>Shipped Via: XYZ, Couriers + Insurance Cover</p> <p>Shipping Cost \$14.95</p>																													
<p>SUBTOTAL: \$194.00</p> <p>GST INCLUSIVE: \$19.00</p> <p>SHIPPING & HANDLING: \$14.95</p>																													
<p>GRAND TOTAL: \$208.95</p> <p>AMOUNT PAID: \$208.95</p> <hr style="border: 1px solid black;"/> <p>BALANCE DUE: \$0.00</p>																													
<p>PAYMENT OPTIONS Cheque, Direct Bank Deposit or Internet Transfer</p> <p>Make all cheques payable to ABC Computer Parts If you have any questions concerning this invoice, contact Nobody Maybe</p>																													
<p>THANK YOU FOR YOUR BUSINESS!</p>																													

FIGURE 22.4 Example of a tax invoice

22.3.4 Digital and electronic invoices (e-invoicing)

A tax invoice can be in paper or electronic form (e-invoice), typically in portable document format (PDF). Alternatively, an e-invoice process may use the supplier's and buyer's software systems for automated direct exchange of invoices. Paper and email-based invoicing are manually intensive and prone to human error.

22.3.5 Purchase orders

A purchase order is a document sent by a buyer or vendor to a seller and indicates the types and quantities of goods they wish to purchase. It differs from a tax invoice, which is a document distributed from a seller to a vendor. *Vendor* is a general term to describe any supplier of goods or services; they may sell products or services to other companies and/or to individual customers.

Purchase orders are useful for businesses to document the purchase of products and services from suppliers. Each purchase order has a unique number that helps suppliers and customers track delivery and payment. While each business' processes and documentation may differ, a typical purchase order will contain the following information:

- ▶ company and vendor name (supplier name and address information)
- ▶ purchase order number and customer or reference number
- ▶ delivery location (shipping details) and billing address
- ▶ delivery date
- ▶ product or service being purchased
- ▶ brand names, stock-keeping unit (SKU) item codes or model numbers and description
- ▶ price per unit and quantity being purchased
- ▶ payment terms (e.g., payment upon delivery or within 30 days).

Purchase orders can be handwritten or electronic; however, in the past decade the process has been transitioning towards e-purchasing or what is now referred to as e-procurement. Australia and New Zealand have recently taken a step closer towards eliminating paper bills by creating trans-Tasman standards for electronic invoicing. By adopting e-invoicing the two nations hope to achieve more streamlined payments and are projected to save an estimated \$30 billion over 10 years.

22.3.6 Preparing goods for delivery

Picking and packing lists are documents used in the supply chain and logistics to assist suppliers and warehousing staff prepare goods and materials for customers. They may be used as customer pack lists to streamline the process of picking items for delivery to customers, a way of cross-checking selected items and reducing duplication of paperwork. Common documents include:

- ▶ picking list
 - ▶ used when selecting items for packing
 - ▶ contains the list of items, goods or materials picked from a customer order and made ready for packing and shipping or dispatch
- ▶ packing list
 - ▶ confirms items for dispatch
 - ▶ gives details of items to be packed on pallets or in boxes for delivery to the customer
- ▶ packing slip
 - ▶ contains details about an order to be shipped to a customer
 - ▶ sometimes referred to as a packaging slip, shipment slip or an order slip.

The packing slip is what the customer will often see when goods are delivered. Two warehouse shipping documents often confused with each other are the packing slip and the shipping label. Both documents are created by the shipper.

The difference between a packing slip and a shipping label is that a packing slip indicates information relevant to the order, while a shipping label is used by carriers and provides shipping information.

22.3.7 Delivery of goods and materials

Delivery costs and charges are included on tax invoices like the one shown in **Figure 22.4**. These costs may often be referred to as freight charges, shipping or shipping and handling. Delivery costs and charge amounts are sometimes included in other documents. Various documents are prepared when an item is shipped including:

- ▶ consignment note
 - ▶ prepared by the shipper for the company delivering the goods
- ▶ shipping slips
 - ▶ contain information couriers need to deliver packages to customers
 - ▶ generally used for tracking and smooth flow of delivery fulfilment
- ▶ packing slip
 - ▶ a printed list of inventory items included with a dispatched order
 - ▶ contains details about the items inside the package that is shipped
- ▶ delivery note
 - ▶ describes what is being delivered and received and the quantity included
 - ▶ accompanies a shipment or delivery of goods and serves as a formal document providing proof of delivery for the buyer and/or seller.

The terms *delivery note* and *delivery docket* are sometimes used interchangeably. Variations of these are referred to as a packing list, waybill, bill of parcel or unpacking note. The delivery note enables the seller to share exactly what is included in the delivery for the buyer to agree to and accept. All delivery notes should include:

- ▶ docket number, which is generated from document management software
- ▶ sender (supplier) and receiver (customer) name and address details
- ▶ purchase order number or customer reference number
- ▶ order date and delivery date
- ▶ contents of the delivery details including quantity ordered, item codes and description of goods.

The delivery note goes to the customer, while a signed copy is returned to the supplier as proof of delivery. Where confirmation cannot be obtained, a card with delivery and contact details will be left, advising the delivery was attempted and the goods taken back to the depot. Where prior consent has been provided for goods to be left, the courier will take a photo of the delivered goods being left as instructed and identifying the location in the photo.

Businesses and larger organisations with a reception area, delivery dock or loading bay on premises can have staff trained as receiving officers and authorised to accept deliveries and receipt goods. **Section 22.8** provides more detail on receiving officer duties and what is required to check deliveries.

Recent changes to legislation and advancements in innovation and technology are expected to further improve delivery processes. An increasing trend with online purchasing is that of businesses using parcel post and e-parcel deliveries, which allow for labels to be printed off and attached to parcels, with barcodes and QR codes for scanning by dispatchers and delivery drivers. These are useful for deliveries of small electrical components and parts. The contents are not specifically listed but the article reference number can be used as a cross-reference for goods receipt.

In addition to a QR code and barcode, the label details include:

- ▶ delivery instructions (e.g. please leave at front door)
- ▶ sender (supplier) and receiver (customer) name and address details
- ▶ consignment note number
- ▶ article identification number for cross-referencing with other documentation
- ▶ reference number.



CHECK YOUR UNDERSTANDING

10. What is the difference between packing lists and shipment lists?
11. Who should be given a copy of an invoice?
12. What documentation wouldn't normally contain item prices, the total amount owing or GST?
13. What is the difference between a purchase order and an invoice?
14. List four pieces of information that will be found on a delivery note.

22.4 Part identification and access

Part identification can involve a variety of methods and varies from situation to situation. Parts, components and assemblies may be illustrated and identified from circuit diagrams and schematics, exploded view drawings or service manuals in either hard copy, electronic copy or online. In some situations, items might be identified from details listed on previous purchase orders and similar documentation. Generally, electrical parts and components can be identified by:

- ▶ a picture, illustration or drawing
- ▶ a description of the item or function
- ▶ a code or part number.

If these resources are not available a call to the supplier or manufacturer could be made. It may also be possible to take a photo of the part to be identified or replaced using a smartphone, which can be sent to the supplier for identification and ordering. Alternatively, a sketch of the part may be required or a drawing showing the location in the equipment where the part is in relation to other parts and components.

Identifying accessories for electrical installations from online wholesaler and supplier websites is an easy way to identify, select and confirm the type, shape, style, colour and specification details of items.

22.4.1 Type, number and ratings of typical components

Electrical components, parts and accessories have ratings specific for installation, operation and manufacturer requirements and recommendations. These ratings can be based on wattage, current, temperature and voltage. Resistors, capacitors and diodes have a voltage specification and peak inverse voltage in the case of Zener diodes.

Section 22.5.3 provides an example of a three-bedroom residence with kitchen, bathroom, laundry and outdoor areas. All of the installation switches, socket-outlets, fittings and apparatus need to meet the required voltage and current rating specifications to conform to safety and industry standards. The example also looks at the type and number of electrical accessories required for the installation.

22.4.2 Part codes

Part codes, also referred to as part numbers, are specified in manufacturer documents, service manuals, printed and online catalogues. Exploded view and assembly drawings identify the various parts and components and include a legend or listing to reference the specific part number. Part codes and numbers are required for specific identification,

selection and ordering of parts and accessories. The tax invoice in **Figure 22.4** shows the supplier part (code) number for different types of components.

22.4.3 Manufacturers and manufacturer's supply outlets

Manufacturers and suppliers carry listings of parts and can be contacted about part availability and part number based on the description supplied. Service technicians can provide the supplier with an observation of the item, its physical location and function (if known) and the supplier can align this with the part description. Exploded view diagrams are useful for this task (see **Figure 3.12**).

22.5 Part identification and ordering

22.5.1 Identification from an electrical diagram

Most schematic diagrams will either label the individual components or have a legend or symbol key for component identification.

22.5.2 Example: parts selection for a computer upgrade

The following is an example of a computer upgrade for a customer based on their identified performance requirements. The process can be as advice and information provided to the customer for their consideration or based on computer parts and performance specifications provided by the customer. **Figure 22.5** shows the parts identified for the computer upgrade. The customer already has a suitable monitor, keyboard and mouse to use with the computer upgrade.

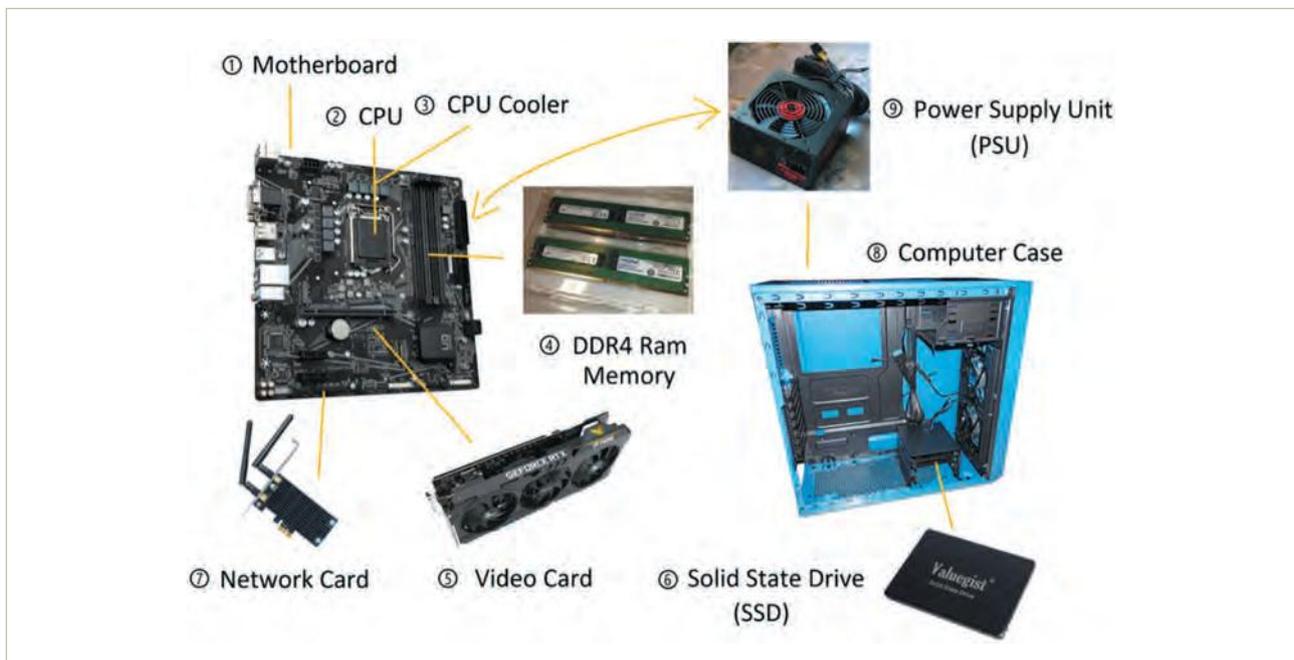


FIGURE 22.5 Identified computer components

Performance requirements would include a suitable motherboard for the central processing unit (CPU) and plug-in components, CPU speed, ram type, voltage and capacity, hard disk drive type, read and write access performance, screen refresh rate and resolution output of the video card. Physical assembly of the parts is one thing, suitability and compatibility so the assembled components function correctly, to specification and desired performance is also required.

Documentation required for the total cost to supply and assemble the computer, software installation and testing for this example includes:

- ▶ a list of suggested components and price quotation for the customer
- ▶ purchase order from EBM to the supplier
- ▶ customer tax invoice.

Figure 22.6 shows the three documents for this example. Pricing for items in a retail environment will be made up of the wholesale cost with business operating costs as mark up. The quotation in this example shows the retail pricing included but not GST. The tax invoice for this example shows the GST portion of the total price and the total price including GST.

22.5.3 Example: identifying, selecting and confirming accessories required for an electrical installation

Chapter 6 covers aspects involved in the installation design and planning for a ground floor flat. An architectural floor plan is drawn up marking the locations of switches and socket-outlets. A list of materials for the installation is also drawn up. Parts and accessories must be identified, confirmed and selected. The following three-bedroom residence example shows how this is done, as it needs to be planned out in the same way. In this example, electrical materials and accessories need to be identified and selected as part of this planning phase. The kitchen, bathroom and laundry areas also require item sourcing, ordering and supply for installation of a stove, ceiling/exhaust fans and hot water system.

Identifying the accessories

Sale of a three-bedroom residence off-the-plan had fallen through and has been recently purchased by a different client. Construction has not commenced and is in the early phase of planning. The company you work for has agreed to take on the electrical installation work and meet with the new owner to discuss changes and inclusions. Based on the architectural electrical drawings, the initial floor plan proposed locations for electrical apparatus, lighting points and controls, socket-outlets, TV and telephone outlets. The floor plan shown in **Figure 22.7** was provided purely as an indication of layout by the builder for the original client.

The preliminary list of materials as shown in **Table 22.2** was compiled by an apprentice from the architectural floor plan. The listing of materials exercise requires interpreting the architectural electrical floor plan, identifying the symbols and confirming what accessories need to be sourced.

From the floorplan layout and materials list, you and the tradesperson discuss possible improvements to suggest at the client meeting. These include:

- ▶ changing the fluorescent light in the kitchen to an energy-efficient Slimline LED batten double
- ▶ converting the fixed bayonet batten holders to energy-efficient LED downlights
- ▶ changing from single to double socket-outlets.

The tradesperson also suggests identifying different types and styles for light switch controls and socket-outlets to show the client. (Refer to **Figure 22.8** for light switch type and style.) The item part codes in **Figure 22.8** can be found in **Figure 22.9**.



Shop 3/31-35 Nettieford St, Belconnen, ACT, 2617
 Phone: (02) 6253 2668
 Email: sales@ebm.net.au

Quote

Customer Name: I.M. Client
 Address: 123 Crescent Street, Suburb STT, 0980
 Contact Details: 0421 335 789
 Date: 24 December 2021 Reference: 24122021_525

QTY	Description	Unit	Price
1	Motherboard Gigabyte B560M D3H-4DRG		
1	CPU Intel i7 11700 4.9GHz 8 Core		
1	CPU Cooler DeepCool Gammaxx GTE V2 Black Air Cooler		
1	RAM Crucial DDR4 3600 16GB (2x8GB) Ballistix		
1	SSD Crucial MX500 1TB SSD		
1	HDD		
1	Video Card Asus TUF RTX 3060 Gaming 12GB		
1	Optical Drive		
1	Network Card TP Link Archer T6E AC1300 Dual Band PCIe Card		
1	Keyboard/Mouse		
1	Monitor		
1	Software MS Windows 10 Home		
1	Case Corsair Carbide 110R Mid Tower TG Case Black		
1	PSU Corsair CV750M 750W 80+ Bronze Modular		
1	Audio		
1	Access Point		
1	Labour		
1	Other Items		

Deposit Paid: \$3,060
 Outstanding Owed: \$3,060
 Total Price: \$3,060
 Sales Representative: Roger

System Packages usually take 2-5 Business Days to assemble. Delays are uncommon, we will try to keep you informed if they occur.
 System Packages have a 2 Year Back-to-Back Warranty, and a 5 Year Labour Guarantee.
 All Quotes require payment of their below parts are ordered. Once placed with our supplier, orders cannot be cancelled.

(a) Customer quotation

FIGURE 22.6 Examples of documentation

Source: EBM Computers



Shop 3/31-35 Nettieford St, Belconnen, 2617
 Phone: (02) 6253 2668
 Email: sales@ebm.net.au

Tax Invoice

ABN: 65 720 018 239

Customer Name: I.M. Client
 Address: 123 Crescent Street, Suburb STT, 0980
 Contact details: 0421 335 789
 Date: 24 December 2021 Reference: 24122021_525

QTY	Description	Unit	Price
1	Motherboard Gigabyte B560M D3H-4DRG		
1	CPU Intel i7 11700 4.9GHz 8 Core		
1	CPU Cooler DeepCool Gammaxx GTE V2 Black Air Cooler		
1	RAM Crucial DDR4 3600 16GB (2x8GB) Ballistix		
1	SSD Crucial MX500 1TB SSD		
1	HDD		
1	Video Card Asus TUF RTX 3060 Gaming 12GB		
1	Optical Drive		
1	Network Card TP Link Archer T6E AC1300 Dual Band PCIe Card		
1	Keyboard/Mouse		
1	Monitor		
1	Software MS Windows 10 Home		
1	Case Corsair Carbide 110R Mid Tower TG Case Black		
1	PSU Corsair CV750M 750W 80+ Bronze Modular		
1	Audio		
1	Access Point		
1	Labour		
1	Other Items		

Name: EBM Computers
 BSB : 023-002
 Acc No : 380 222 885
 Ref : 24122021_525
 Sub-Total: \$2,781.82 GST: \$278.18
 Total Price: \$3,060

System Packages usually take 2-5 Business Days to assemble. Delays are uncommon, we will try to keep you informed if they occur.
 System Packages have a 2 Year Back-to-Back Warranty and a 5 Year Labour Guarantee.
 Spare Parts include a 12 Month Back-To-Base Warranty.

(c) Customer tax invoice

Purchase Order

Customer Name: I.M. Client
 Address: 123 Crescent Street, Suburb STT, 0980
 Contact details: 0421 335 789
 Date: 24 December 2021 Reference: 24122021_525

QTY	Description	Unit	Price
1	Motherboard Gigabyte B560M D3H-4DRG		
1	CPU Intel i7 11700 4.9GHz 8 Core		
1	CPU Cooler DeepCool Gammaxx GTE V2 Black Air Cooler		
1	RAM Crucial DDR4 3600 16GB (2x8GB) Ballistix		
1	SSD Crucial MX500 1TB SSD		
1	HDD		
1	Video Card Asus TUF RTX 3060 Gaming 12GB		
1	Optical Drive		
1	Network Card TP Link Archer T6E AC1300 Dual Band PCIe Card		
1	Keyboard/Mouse		
1	Monitor		
1	Software MS Windows 10 Home		
1	Case Corsair Carbide 110R Mid Tower TG Case Black		
1	PSU Corsair CV750M 750W 80+ Bronze Modular		
1	Audio		
1	Access Point		
1	Labour		
1	Other Items		

Price: \$3,060
 Deposit: \$3,060
 Owing: \$3,060
 Expected Pick up date: 31 December 2021
 Sales Representative: Roger

System Packages usually take 2-5 Business Days to assemble. Delays are uncommon, we will try to keep you informed if they occur.
 System Packages have a 2 Year Back-to-Back Warranty and a 5 Year Labour Guarantee.
 All Quotes require payment of their below parts are ordered. Once placed with our supplier, orders cannot be cancelled.

(b) Purchase order for parts

(c) Customer tax invoice

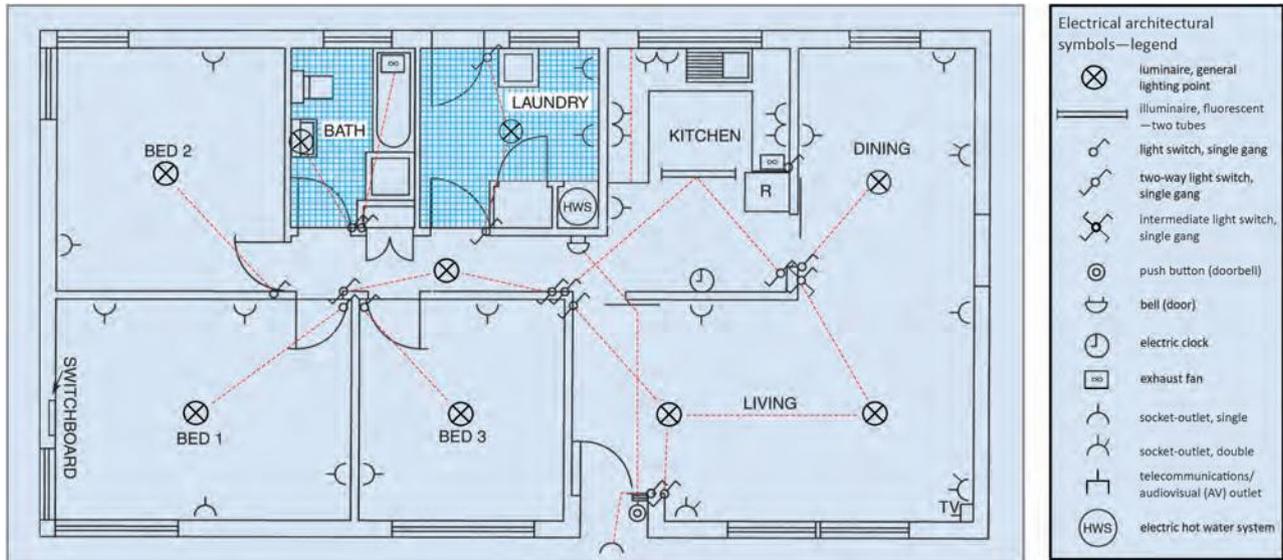


FIGURE 22.7 Architectural floor plan and symbol legend

TABLE 22.2 Listing of materials

Item	Quantity	Category	Code/Part no.
Batten holder	9	Lighting	530WE
Lamp (downlights)	13	Lighting	SYA S9141TC/WH
LED flood light 24 watt	2	Lighting	LEDFL24W
Twin fluorescent luminaire diffused	1	Lighting	PIE MECOLED40CSLS
Switch single-gang (horizontal)	6	Lighting	CLI 3041HA-VW
Switch two-gang (horizontal)	7	Lighting	CLI 3042HA-VW
Plaster C-clip NLS		Lighting	30015
Metal stud mounting bracket (Clipsal)	24	Socket-outlets	155
Socket-outlet 10A (single)	18	Socket-outlets	CLI 3015-VW
Socket-outlet 10A (double)	3	Socket-outlets	CLI 3025-VW
Smoke detector (Clipsal)	1	Surface or flush	CLI 755PSMA4 CLI 755PFM4
Exhaust fan	2	Airflow	ce250
Telephone wall plate	1	Cabac	40RJ12WP
Cable 1.5 mm ² thermoplastic sheathed twin (100 m)	1	Cable	PIR FT2C7050
Cable 1.5 mm ² thermoplastic sheathed twin and earth (100 m)	2	Cable	PIR FT2CE7050
Cable 2.5 mm ² thermoplastic sheathed twin and earth (100 m)	2	Cable	PIR FT2CE7067



FIGURE 22.8 Light switch type and style

Legrand Australia Pty Ltd (images at right and centre) and Schneider Electric (image at left)

Selecting the accessories

At the client meeting, the client requests that one of the bedrooms be converted into an office area and asks for advice as to whether bedroom two or three would be the more suitable. Ultimately, bedroom two is chosen. During this meeting it is also noted there needs to be provision for outside lighting, security lighting and external power. A number of other client changes are put forward which would impact the construction and electrical installation. These changes include:

- ▶ construction of a patio entertaining area to be built at the rear of the house
 - ▶ this is to extend from bedroom two across to the dining room
 - ▶ the dining room window is to be changed to a door for entertaining area access
- ▶ installation of external lighting, bunker and security sensor floodlighting
- ▶ installation of external speakers and outdoor socket-outlets
- ▶ connection of a three-phase switchboard (8 KW solar panel system)
- ▶ installation of underfloor heating in the bathroom
- ▶ installation of two double socket-outlets each with USB in bedroom two (the new office).

Confirming the accessories

A quick turnaround from ordering to supply and fit-out of the installation will be required for this installation. The electrical contractor has a good working relationship with local suppliers and arranges for the revised material list to be sent to two suppliers, Middy's Electrical and Legrand. A separate purchase order will be sent to each supplier based on the quotations provided, client budget and availability of the required electrical materials and accessories.

22.5.4 Price, discounts and delivery costs

A benefit of opening an account and registering a business with an electrical wholesaler can include discounts, promotional prices and product specials. Free product and material delivery or discounts may also be available. In **Figure 22.9** the quotation provides details of part numbers, part descriptions, unit prices and total costs per item excluding GST. The quotation also provides a total cost excluding GST of \$4335.65, the total GST amount of \$433.57 and the total cost price including GST of \$4769.22



Legrand Australia Pty Ltd
ABN 31 000 102 661
Building 4, 43-47 Lyn Parade
Prestons NSW 2170
www.legrand.com.au

Improving lives by transforming the spaces where people live, work and meet, with electrical and digital infrastructures and connected solutions that are simple, innovative and sustainable

QUOTE TO:

Company: **Legrand Trade National Quotes**
Attention: **CPQ Internal Quotes National**
Phone:
Email: tosh.bourke@legrand.com.au

QUOTE FROM:

Name: Project Quotations
Phone:
Email: projects.quotations@legrand.com.au

DATES:

Original Date: 23/12/2021
Current Date: 23/12/2021
Expiry Date: 30/06/2022

QUOTE DETAILS:

Job Name **Apprentice Training Module CANBERRA ACT 2601, AUSTRALIA**

Quotation No **Q-639651** **Revision No** **1** **Expiry Date** **June 30, 2022**

Account Manager **Jason Billing** **Phone** **Email**

NOTES **EXAMPLE USE ONLY**

All details listed within this quotation is based on the information provided and our interpretation of that data. This quotation is governed by our Terms & Conditions of Sale that can be viewed at www.legrand.com.au. Legrand Australia reserves the right to alter the details of the quotation upon written notification.



Company: Legrand Trade National Quotes **Job Name:** Apprentice Training Module CANBERRA ACT 2601, AUSTRALIA
Attention: CPQ Internal Quotes National **Expiry Date:** June 30, 2022

Quotation No: Q-639651
Revision No: 1

LINE NO.	SPEC NO.	QTY	PART NO.	DESCRIPTION	U/M	UNIT PRICE (EXCL. GST)	EXT. PRICE (EXCL. GST)
1		9	366WE	BATTEN HOLDERS WHITE	EA	\$ 7.50	\$ 67.50
2		1	LBL034KWE	HPM ELLIPTICA BUNKER OUTDOOR WALL LIGHT COOL WHITE WHITE	EA	\$ 106.82	\$ 106.82
3		1	M5FD228LED	LED Slim Linear Fixture 4K	EA	\$ 103.05	\$ 103.05
4		1	WL787USBCG	AQUA LIFE SGPO w USB CH. TYPE A 2.4A+C 15W 2 PORTS CEME GREY	EA	\$ 99.18	\$ 99.18
5		1	WL77754CG	AQUA LIFE DBL POWERPOINT 10A IP54 SURFACE MOUNT CEMENT GREY	EA	\$ 55.78	\$ 55.78
6		1	ED7774WE	E-DED 10A QUAD POWERPOINT WHITE	EA	\$ 56.37	\$ 56.37
7		2	ED777USB2ACWE	EXCEL LIFE DGPO with USB CH. TYPE A 2.4A+ C 12W 2 PORTS WHITE	EA	\$ 87.28	\$ 174.56
8		17	ED777WE	E-DED 10A DOUBLE POWERPOINT WHITE	EA	\$ 19.48	\$ 331.16
9		3	ED787WE	E-DED 10A SINGLE POWERPOINT WHITE	EA	\$ 10.31	\$ 30.93
10		1	630SM01WE	MÓVEMENT SENSOR MANUAL OVERRIDE SURFACE MOUNT	EA	\$ 83.54	\$ 83.54
11		2	643085	PHOTOELECTRIC SMOKE ALARM SURFACE MOUNT 240V a.c.	EA	\$ 137.40	\$ 274.80
12		1	HLC24S Loaded	3 Phase 24 Pole Board Loaded		\$ 800.00	\$ 800.00
				3P Main Switch 3 x 10A RCBO's 3 x 16A RCBO's 3 x 20A RCBO's 1 x 4P 20A RCBO 1 x 3P Surge Diverter			
13		13	ED7701HWE	E-DED 16A 1-GANG HORIZONTAL SWITCH WHITE	EA	\$ 7.35	\$ 95.55
14		5	ELTVD2WE	Excel Life TV + Data Outlet White		\$ 21.46	\$ 107.30
15		1	BH2DWE	3-IN-1 HEAT FAN LIGHT DUCTED 2-LAMP WHITE	EA	\$ 299.85	\$ 299.85
16		1	EF200SQWE	200MM NON-DUCTED CEILING EXHAUST FAN SQUARE WHITE	EA	\$ 69.26	\$ 69.26
17		1	315512	DOOR ENTRY KIT VIDEO 4 WIRE HANDSFREE 7 240V a.c.	EA	\$ 330.00	\$ 330.00
18		25	DLI90TRIWE	DLI 90mm 3K/4K/5K Dimmable L&P	EA	\$ 20.00	\$ 500.00
19		25	DLI90BTWE	DLI LED 7W CONNECTED DOWNLIGHT TRI COLOUR WHITE FINISH 90MM	EA	\$ 30.00	\$ 750.00
				BLUEOOTH LED TRI COLOUR DOWNLIGHT - Controlled by HPM App			
						Sub Total	\$4,335.65

COMMENTS:

Total excl GST	\$ 4,335.65
GST	433.57
Total Incl GST	\$4,769.22









Minimum quantities apply and Legrand Australia reserves the right to alter the details of the quotation upon written notification. A copy of our Terms & Conditions of Sale can be viewed at www.legrand.com.au and special care should be taken with regards to our return policy before placing orders.

FIGURE 22.9 Apprentice Training Module quotation by Legrand

Note: prices given for educational purposes only

Source: Legrand Australia Pty Ltd



CHECK YOUR UNDERSTANDING

15. List three changes or improvements that could be made to the original floor plan or electrical accessories identified by the apprentice in the listing of materials.
16. On the architectural floor plan shown in **Figure 22.7** the kitchen entry from the lounge-dining room has two light switches with another on the other side of the wall for the kitchen light. From the examples given in **Figure 22.8** what product would have all three switches on the one plate? Provide the brand, model and product code in your answer.
17. Identify three details found on the quotation in **Figure 22.9**.

22.6 Ordering procedures

Pricing lists are made available by electrical manufacturers for identifying, selecting and ordering parts, components, accessories and materials. Prices for goods are subject to change so would need to be checked to confirm they are correct. Ordering from a price list requires the buyer checking:

- ▶ that the goods are available and in the quantities required
- ▶ that the prices are correct
- ▶ payment terms, conditions and charges
- ▶ delivery options.

Contacting an electrical supplier before ordering is a good practice because some unforeseen availability or delivery issues can be identified early on before placing an order. Small orders might be easy to confirm over the phone subject to creating an order request. Suppliers may also be able to offer solutions and alternative products. Ordering procedures require customer approval and meeting supplier and job requirements.

22.6.1 Customer approval

Before ordering, an initial client meeting is needed to identify and select accessories required for an electrical installation. The style, colour, number and layout of light switches, socket-outlets and other accessories need to be discussed and options confirmed. Once these decisions are made, orders can be placed with suppliers and a schedule of work activity planned.

22.6.2 Supplier requirements

Ideally, carry out online research regarding available products using an electrical supplier's website before making an enquiry, and if not registered as a trade client, request a quote for required parts. Electrical parts and accessories can be purchased as cash sales or on credit if an account has been set up. Invoiced goods should usually be paid for within 30 days of the date on the invoice, unless agreed otherwise.

22.6.3 Job requirements

Job requirements can be finalised after meeting with clients to discuss the selection of electrical accessories for installation. In some cases, additions may be requested by the client and must be accommodated. In the example

in **Section 22.5.3** one of the requested client changes was to have outdoor weatherproof socket-outlets as shown in **Figure 22.10**, one for the outdoor speakers and another for charging USB devices. These two options could have been shown to the client on the contractor's laptop, discussed and agreed on as part of the installation.



FIGURE 22.10 Weatherproof socket-outlets for patio area

Source: Legrand Australia Pty Ltd



CHECK YOUR UNDERSTANDING

18. From the example in **Section 22.5.3**, identify three variations between the original floor plan material list and the client requested changes. Identify the line number, quantity, part number and item description from the quote provided in **Figure 22.9**.
19. Describe the similarities and differences between the two outdoor weatherproof accessories shown in **Figure 22.10**.

22.7 Dealing with unplanned events or situations

Proper planning, preparation and defined work schedules help create a smooth workflow and prevent problems. Contingency planning provides a cushion for dealing with unplanned events and situations. This may be in the form of allowing some flexibility in the budget, to ensure available cash flow to pay for parts and accessories, or allocating resources to align with the arrival of goods and materials. Such measures can prevent delays with larger building, construction and installation projects. But even with proper planning unexpected events can occur, which have the potential to impact an electrical installation. These may be delays in receiving goods, lengthy product delivery times, unavailable parts and accessories, receiving incorrect parts or components, or clients requesting alterations.

An effective problem-solving strategy can assist in dealing with unplanned situations. Early problem identification and response are crucial in keeping projects running on time. Often the problem-solving approach is a two-step problem identified/problem solved approach. Unfortunately, not all problems have quick-fix solutions and may need to follow the problem-solving process outlined in **Figure 2.4**.

22.7.1 Availability and delivery times

When placing an order for electrical materials the two important questions to ask are about item availability and delivery time. An initial call to an electrical supplier may be needed to request information about item availability:

- ▶ Do you have any ...?
- ▶ When can you get some in for me ...?

If parts and accessories are not in stock, are unavailable or will not arrive in time, alternative arrangements need to be made prior to placing an order. Good job planning, preparation and ordering items for installations ahead of time for the scheduled work can help prevent or mitigate availability and delivery time issues.

22.7.2 Delays

Delays can present in many ways ranging from a delay in receiving payment for completed works to delays in receiving materials and deliveries. Delays can result from supplies being unavailable and other external factors such as bad weather, approvals and inspections processes, staffing issues and accidents, injury or illness. Delays can occur anywhere along the supply chain. In **Figure 22.11** the arrows indicate potential points of delay in the supply line, from the initial planning through to job completion.

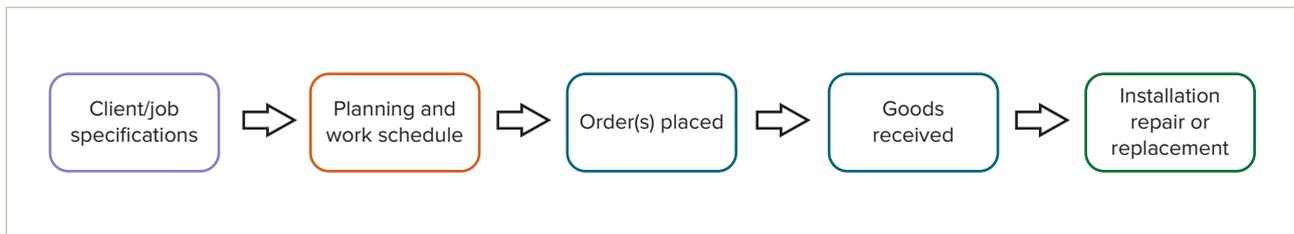


FIGURE 22.11 Supply line points of delay

Not meeting account terms and conditions with suppliers, as mentioned earlier in the chapter, can result in goods not being released or delivered, resulting in disruption to the work schedule. Service technicians can save time through van pickups, which involve going to the supplier's physical store to pick up ordered parts and items needed for service repairs as required throughout the day. Time is saved by picking up components, parts and materials from the supplier when they arrive instead of waiting for them to be delivered by a third party—this enables the service technician to fix or repair customer equipment as soon as possible. Even a matter of a few hours saved through van pickups between jobs will reduce a client's potential operating losses resulting from broken-down equipment.

22.7.3 Incorrect delivery, products and materials

At times, deliveries may be incorrect; deliveries may have been sent to the wrong address, which may occur when job activities are at different stages of progress and across multiple locations. Occasionally the incorrect part or accessory gets delivered. Products and materials for one job may be incorrectly delivered to the wrong location. Or a wrong address may have been given to the supplier.

Quality work processes for goods tracking and delivery involve computerised logistics management systems to prevent incorrect delivery situations. The use of printed labels for delivery dockets, barcodes and QR codes assist in tracking and delivery. Errors can still occur from wrong information being provided and printed on the label or human error. Using item tracking and updates by email or mobile text messaging can be useful in identifying potential delivery problems. Contacting the supplier by telephone regarding delivery issues early on can sometimes result in a quick response and solutions to these problems.

suppliers will have difficulty predicting all emergency order needs or anticipating poor planning by contractors. In such cases, alternative parts and accessories need to be obtained. This is an example where developing quality relationships with suppliers is good work practice.



CHECK YOUR UNDERSTANDING

20. What two important questions should you ask an electrical supplier prior to placing an order for electrical parts and accessories?
21. Give two reasons why goods and materials may be delivered incorrectly.
22. State three reasons why there may be changes to original goods and materials orders.
23. What is the benefit of having printed delivery docket labels?

22.8 Receiving/dispatching procedures

Receiving electrical parts and materials is a process that requires documented procedures to be followed. Guidelines for workers to follow, such as checklists and ways of recording activities, are required to show confirmation of parts and electrical accessories received. It is the responsibility of the receiving officer or authorised person to obtain copies of delivery dockets, receiving slips or packing lists as proof of delivery.

Once goods have arrived, the courier will require proof of delivery by way of signature on the delivery docket. The delivery docket will require signatures by both parties to serve as proof of delivery for the buyer and/or seller. The delivery docket can be either paper-based or electronic. Providing a signature is confirming the electrical goods have been delivered.

Small businesses with only one or two staff would follow the steps outlined below. There may be additional steps for larger businesses with a receiving dock officer, warehouse and administration staff.

22.8.1 Checking deliveries

A delivery docket, packing list consignment note or tax invoice should accompany any goods being delivered. The staff member responsible for receiving goods would check:

- ▶ that the business name and address on the delivery docket are correct
- ▶ that the number of cartons received corresponds with the number of cartons on the delivery docket
- ▶ whether any cartons or packages are damaged
- ▶ that the goods have not been tampered with, opened or show any signs of interference.

If all is correct the receiving officer would sign for the delivery. A good work practice includes making a record with additional information such as date and time the delivery was made, details of any discrepancies and the name(s) of staff receiving and checking the delivery.

22.8.2 Processing incoming electrical goods

A receiving bay or workspace should be set aside where incoming orders can be placed for checking. Opening and unpacking boxes, and checking and counting electrical orders need to follow prescribed work procedures and safe work practices. A safety knife should be used to open all packaging, cutting away from the body to prevent accident

or injury and to prevent damage to contents. Packing material needs to be removed as rubbish or recycling. The area needs to be kept clear of packing material and free of any trip hazards. A clear, clean area makes the checking and inspection of goods and materials quicker, easier, safer and more efficient.

Once the goods have been unpacked:

- ▶ check the parts and accessories received against the supplier documents, purchase order or invoice
- ▶ arrange payment to the supplier if the order is correct and the information on the purchase order matches the information on the invoice
- ▶ if the order has already been paid for, check the tax invoice against the packing slip
- ▶ inform the supplier if the order is not correct.

When checking the tax invoice for goods received attention should be paid to ensuring it shows the correct:

- ▶ name and address of the business
- ▶ items, accessories and materials
- ▶ quantities
- ▶ item prices
- ▶ GST
- ▶ total costs.

Businesses and organisations that regularly receive goods use some form of warehouse management system or electronic inventory system.

22.8.3 Returns

Any electrical materials that are damaged, different from the original order or incorrect may need to be returned to the electrical supplier. In this case, the supplier will need to be contacted by phone or email to make arrangements for the damaged/incorrect goods to be replaced. Details including item or part numbers, item costs and descriptions of damage may need to be given. It is important to ask the supplier about their policies and procedures for returning and replacing parts and accessories.

22.8.4 Manual handling and storage practices

Correct manual handling techniques must be followed when unpacking and handling orders to prevent injury. Training in safe lifting techniques and operation of mechanical lifting devices, pallet jacks and forklifts should be provided and be kept up to date. When lifting, carrying and moving heavy items assistance from colleagues must be sought. Lifting devices, mechanical aids, trolleys and pallet jacks should be made available, maintained and used correctly and when required.

Electrical parts and materials should be sorted, allocated for planned work and stored appropriately as soon as they have been received. Heavy items should be stored on lower levels and shelves, and not stacked on top of lighter or fragile items. Fragile items need to be allocated adequate storage locations to prevent damage or breakage.



CHECK YOUR UNDERSTANDING

24. What four things should be checked before signing for and receiving goods?
25. Name three safe work practices for manual handling and storage.
26. What actions are required when unpacking and checking goods received?
27. List four items that should be checked on a tax invoice you have received.

SUMMARY

- ▶ Work tasks need to be performed safely (following safe work practices), in an agreed timeframe (following a schedule), to a quality standard (meeting specifications and standards), with a minimum of waste (applying sustainable work practices).
- ▶ Work instructions are determined by client and job specifications.
- ▶ Proper planning, preparation and defined work schedules assist in creating a smooth workflow and help prevent problems occurring during an electrical installation.
- ▶ Preparing a materials list requires interpretation of architectural electrical floor plans, identifying the symbols and confirming what accessories need to be sourced.
- ▶ Part codes, also referred to as part numbers, are specified in manufacturer documentation, service manuals, and printed and online catalogues.
- ▶ Electrical parts, components and assemblies may be illustrated and identified from circuit diagrams and schematics, exploded view drawings and hard copy or electronic service manuals.
- ▶ Electrical components, parts and accessories have ratings specific for installation, operation and manufacturer requirements and recommendations.
- ▶ A packing slip provides information relevant to the order. A shipping label provides shipping information used by carriers.
- ▶ A purchase order is a request for materials sent to the supplier or vendor; it differs from an invoice, which is an official payment request (or tax invoice) sent by the supplier to the buyer.
- ▶ Tax invoices provide details of payment total inclusive of shipping and GST, any amounts already paid and balance due.
- ▶ When opening and unpacking boxes and checking and counting electrical goods it is important to follow prescribed work procedures and safe work practices in order to avoid injury and damage to goods.
- ▶ Correct manual handling techniques must be followed when dealing with heavy electrical parts and accessories to prevent injury.

REVIEW QUESTIONS

1. List the types of skills that are required in preparing for work activities associated with identifying and confirming components, accessories and materials.
2. What is the difference between a packing slip and a shipping label?
3. Name three undesirable results of poor planning and work scheduling.
4. Identify four examples of working safely.
5. Work instructions are typically based on what factors?
6. State the five steps in preparing a schedule of work.
7. Name the four-step problem-solving process that can be used to deal with unplanned events.
8. Explain what is meant by the term *critical path*.
9. What project term is used to describe work activity starting later in a project timeline?
10. State the benefit of opening an account with a supplier.
11. What does the term *van pickup* mean to servicing technicians?
12. Briefly explain how van pickups can reduce delays.

13. The quotation in **Figure 22.12** lists three line items. For one unit from each of the line items, calculate the total item cost, GST payable and total cost GST inclusive.
14. Give three examples of electrical goods and materials.
15. Give three examples of an electrical service.
16. What sources of information are available to help identify identify and select electrical materials, parts, components and accessories?
17. What type of information could you expect to find in electrical manufacturer documentation?
18. Identify three ways that electrical parts, components and equipment assembly can be identified.
19. How might an electrical installation job be affected by unexpected changes or alterations?

ACRONYMS

A	amp	HVDC	high-voltage direct current
a.c.	alternating current	IEC	International Electrotechnical Commission
ACIF	Australian Communications Industry Forum	IDC	insulation displacement connection
ACMA	Australian Communications and Media Authority	IP	International Protection
ACSR/GZ	aluminium conductor galvanised steel reinforced	IPCC	Intergovernmental Panel on Climate Change
AEMC	Australian Energy Market Commission	ISP	internet service provider
APR	acoustic performance rating	ISO	International Organization for Standardization
AS	Australian Standard	JSA	job safety analysis
ASCC	Australian Safety and Compensation Council	LAN	local area network
AS/NZS	Australian Standard/New Zealand Standard	LOBAC	low-voltage aerial bundled cable
BCA	Building Code of Australia	LPG	liquid petroleum gas
CAD	computer-aided design	MEN	multiple earthed neutral
CEC	Clean Energy Council	MIMS	mineral-insulated metal-sheathed
CES	communications earthing system	MMOF	multimode optical fibre
CET	communications earth terminal	MW	megawatt
CETO	This is not an acronym but the name of a West Australian company and its wave energy technology. For more information see www.ceto.com.au .	MΩ	megaohm: unit of electrical resistance equal to 10 ⁶ ohms
CLFR	compact linear Fresnel reflector	N	neutral
CPR	cardiopulmonary resuscitation	NBN	National Broadband Network
CPRs	<i>Telecommunications Cabling Provider Rules</i>	NECA	National Electrical and Communications Association
d.c.	direct current	NEM	National Electricity Market
DOL	direct-on-line	NEMMCO	National Electricity Market Management Company Limited
EL-001	The <i>Wiring Rules</i> Committee	NEXT	near-end crosstalk
ELV	extra-low voltage	NZBC	New Zealand Building Code
EMC	electromagnetically compatible	NZS	New Zealand Standard
EMF	electromagnetic force (or field)	OCR	open cabling registration
EMI	electromagnetic interference	OPGW	optical ground wire
ERAC	Electrical Regulatory Authorities Council	PCB	polychlorinated biphenyl
FRL	fire resistance level	PoE	Power over Ethernet
GP	general purpose	PE	protective-earth
GST	goods and service tax	PELV	protected extra-low voltage
HD	heavy duty	PEN	protective-earth and neutral
HFT	halogen-free, temperature-stable (PVC)	PILC	paper-insulated lead-covered
HRC	high rupturing capacity	PLC	programmable logic controller
HSE	<i>Health and Safety in Employment Act</i> (New Zealand)	PPE	personal protective equipment
HVAC	high-voltage alternating current	PV	photovoltaic
		PVC	polyvinyl chloride
		RAPS	remote-area power supply
		RCD	residual current device
		RCM	regulatory compliance mark

SELV	separated extra-low voltage	TPS	thermoplastic sheathed cable
SDI	single double-insulated	TRC	telecommunications reference conductor
STP	shielded twisted pair	UTP	unshielded twisted pair
SMOF	single-mode optical fibre	UV	ultraviolet
SPDT	single-pole double-throw	VSD	variable speed drive
SPST	single-pole single-throw	VVVF	variable-voltage variable-frequency
SWA	steel wire armour	WAP	wireless access points
SWER	single-wire earth-return	WHS	Work Health and Safety
SWMS	safe work method statements	XPLE	cross-linked polyethylene

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