

17

Switchboards and control panels

Accessories used for the control and protection of circuits are installed at the commencement of the circuits they control or protect, and are usually assembled on a switchboard or control panel.

This chapter introduces you to:

- wiring rules relevant to switchboards and control panels
- domestic and multiple domestic switchboards
- switchboards for non-domestic installations
- testing and inspection of switchboards.

A number of other modules are available for the above switchboard, to suit a wide variety of needs for a domestic or small non-domestic installation. They all provide a great deal of flexibility for mounting a variety of equipment. These switchboards may be installed either inside a domestic dwelling or on a panel in a standard meter box located outside the building. As they are neat and unobtrusive in appearance, there is an increasing tendency to mount them inside a dwelling, particularly in multiple domestic situations such as flats and townhouses. AS/NZS 3018 recommends their installation inside all single domestic dwellings.

In the case of a single dwelling, a standard meter box is normally used outdoors, its dimensions being specified by the energy distributor in each region it supplies.

Hinged switchboard panels are the most commonly used type in domestic installations, and a typical combined meter box and switchboard of this type intended for external use is shown in Figure 17.6(a). Included is

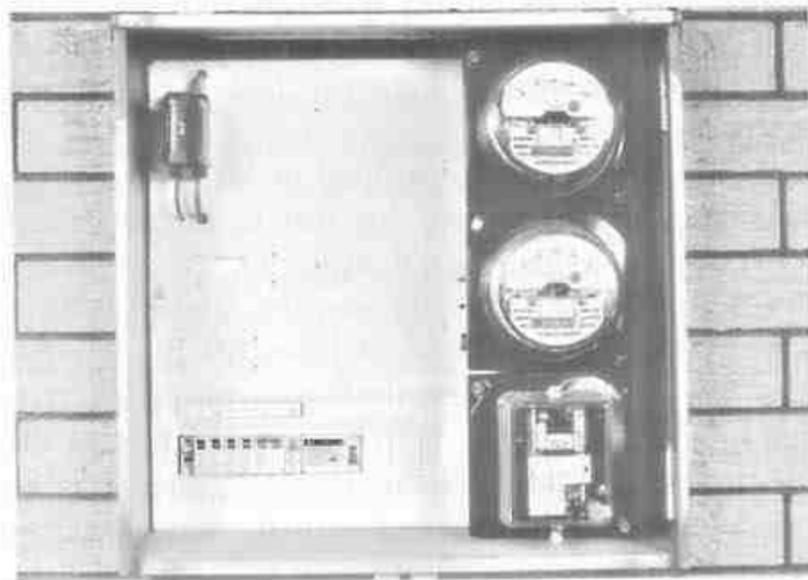


Fig. 17.6(a) Typical meter box equipped for single-phase supply with meter for domestic tariff, and time switch and meter for off-peak tariff ENERGY AUSTRALIA

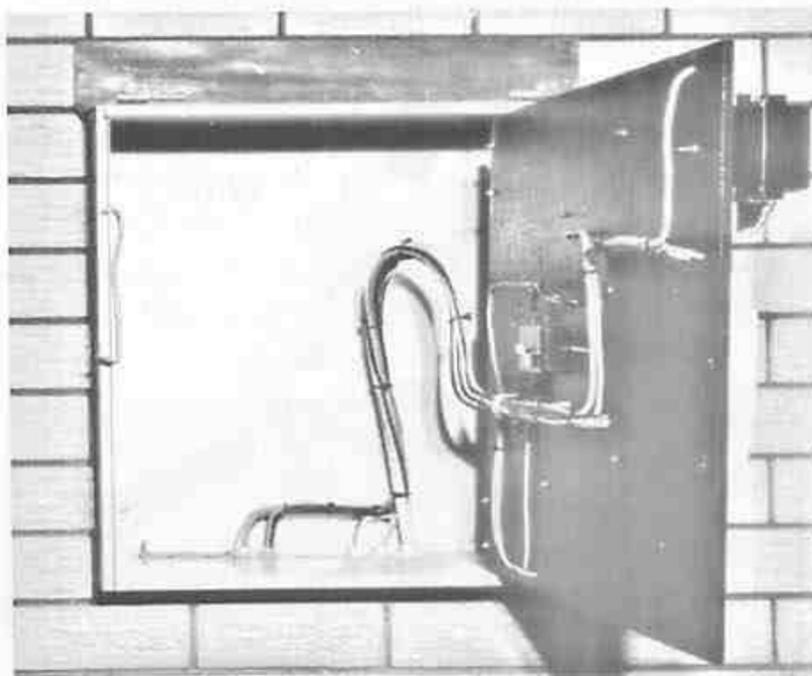


Fig. 17.6(b) Easy access to rear of hinged panel (note neutral link) ENERGY AUSTRALIA

a self-contained consumer's board, the provision of a meter for the domestic tariff and an audio-frequency relay for switching a controlled hot-water system. This relay is adapted to a plug-in base mounted on the bottom right-hand corner of the panel. Figure 17.6(b) illustrates a hinged panel swung out at 90° for easy access to the rear of the panel. The energy distributor in this case employs back-of-panel mounting for the supply neutral link. The consumer's link is front-mounted. This type of switchboard is commonly used in NSW.

An exterior combined meter/switchboard box, which is supplied with a predrilled panel to suit Electricity Trust of South Australia specifications, is illustrated in Figure 17.7. It is fitted with an earth/neutral bar assembly and a full-length full DIN rail to permit the easy mounting of MCBs, RCDs and other auxiliary equipment.

Energy distributors generally specify their requirements for switchboards in the distribution areas under their control. These requirements vary between states and between different areas within a given state. With the increasing privatisation of the electrical supply industry these differences will become greater.

In areas where plug-in-type meters and controlled audio-frequency injection relays are used, it is usually necessary for the contractor to purchase the meter bases, mount them on the switchboard and wire them up, so that the energy distributor's officer may simply plug in the meter or relay after the installation has been approved for connection to the supply. Figure 17.8 shows the standard hinged metering panel of Figure 17.6(a) as it is required to be left by the contractor before lodging a 'completion notice' and test certificate.



Fig. 17.7 Exterior meter/switchboard GERARD INDUSTRIES

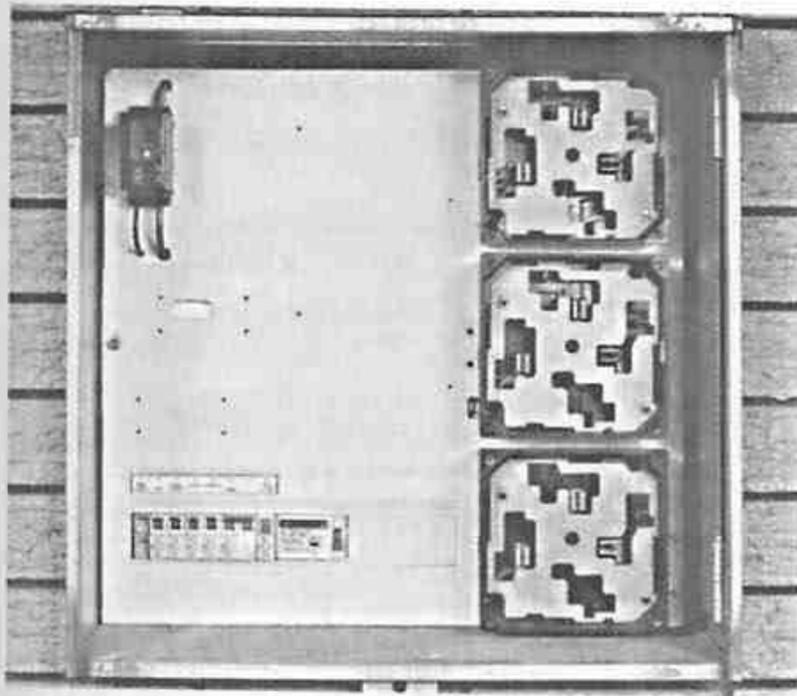


Fig. 17.8 Panel of Fig. 17.6(a) as required to be left by contractor before lodging a notice of completion and testing ENERGY AUSTRALIA

With self-contained-type switchboards, the onus is on the manufacturer to comply with all relevant AS 3000 and AS 3439 rules. However, when a switchboard is custom-built, such as the multiple domestic types, an example of which is shown in Figure 17.10, the electrician must ensure that the layout, mounting of equipment and clearances comply with all the rules discussed in section 17.2 of this chapter.

Switchboard layout, wiring and marking

Switchboard layout and wiring exercises are covered by practical instruction in an electrical trades course, but Figures 17.9(a) and (b) are included here to illustrate some of the basic principles involved.

Referring to Figure 17.9(a), check the following:

- *Note A:* This refers to the thickness of the insulating panel mentioned in section 17.2 of this chapter and in *Clause 2.22.2.3* and *Table 2.9* of the Rules. It was seen that increasing the number of points of support permits the reduction of panel thickness. Check back on section 17.2 and AS 3000 in regard to clearance behind the panel for hinged boards, fixed switchboard spacings and switchboards with other types of access such as removable panels.
- *Note B:* Again check section 17.2 and AS 3000 with reference to spacing and grouping to show the relationship of equipment.
- *Note C:* Although the requirements for the marking of domestic switchboards are not as demanding as the requirements for marking other types, it is good practice to mark them fully. In the small board of Figure 17.9, suitable and complete neutral-link marking would be earth, main neutral, range (or stove), power C2, C3, C4, light C5, C6, HWS C7.

- *Note D:* MCBs must be fixed to the panel by bolts, metal thread screws engaging nuts or tapped holes in metal, or by other equivalent approved means such as a DIN rail. This rule applies to all accessories mounted on the board (see *Clause 2.23.4.3*). The MCBs adjacent to each other on the switchboard should be marked with the MCB rating and the circuit identification (e.g. range 30 A, general-purpose outlet (GPO) 16 A). An alternative is to number each circuit, mark its current rating, and supply a legend either on the panel or firmly attached to the switchboard. If the legend is printed or typed on paper, it should be properly mounted and protected by glass, clear plastic or similar material; for example:

Circuit no.	Rating	Remarks
1	30 A	Range — kitchen
2	16 A	7 GPOs — west wing
3	16 A	8 GPOs — back section and garage

- *Note E:* The main switch must be marked for easy identification to allow prompt operation in an emergency. If there is more than one main switch, each must be marked to indicate which portion of the installation it controls.
- *Note F:* These two circuits are protected by combined RCD/MCBs. The unprotected power circuit, if supplying GPOs, may be used only to connect refrigerators and food freezers (see Chapter 14).

If use is made of self-adhesive labels on a switchboard, they must be of an approved type and be fixed to a suitable surface. For example, they are **not** suitable for fixing to the commonly used bituminous-based materials used for the manufacture of domestic-type panels. They may, however, be fixed to suitable backing material and the assembly screwed or pinned to the panel.

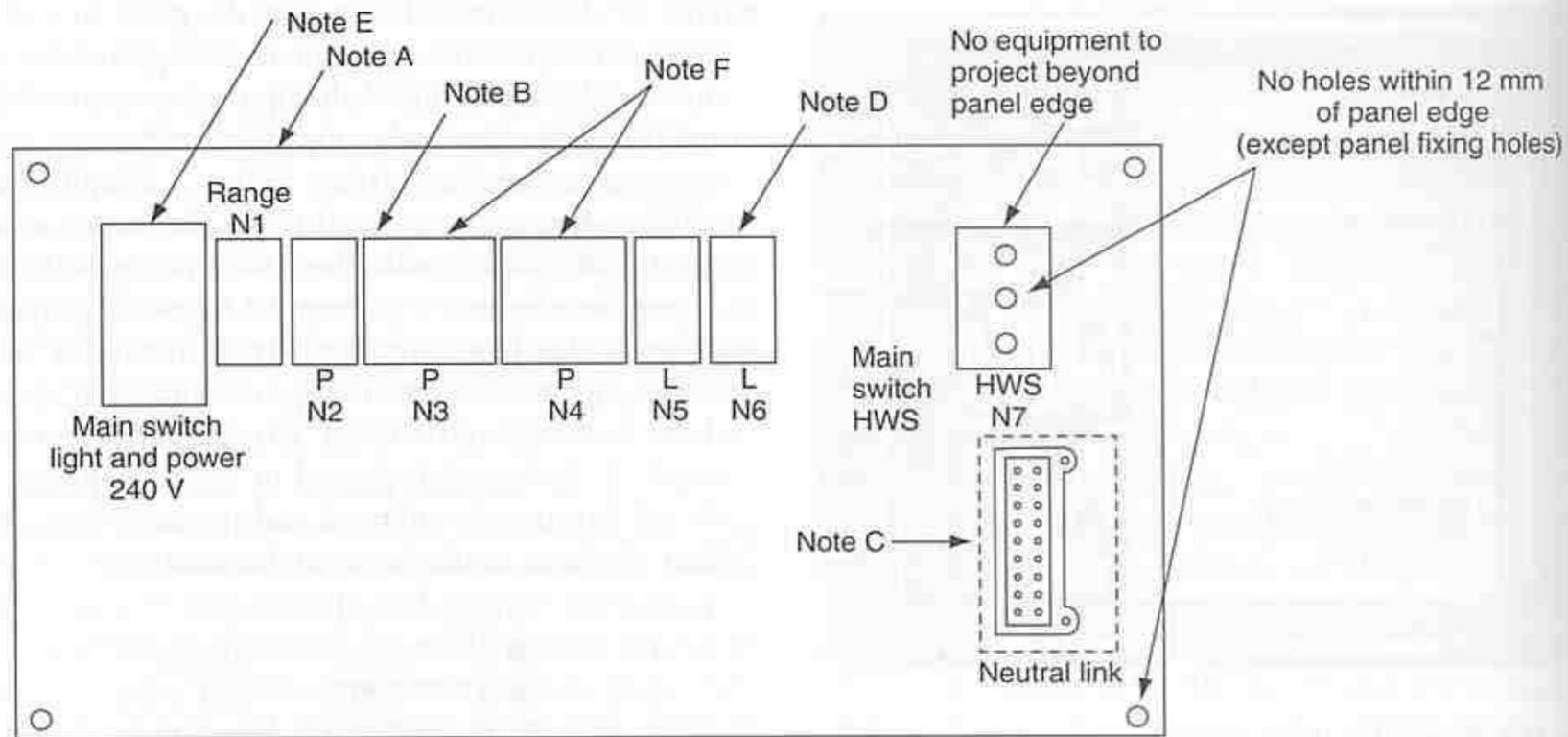
The self-contained modular switchboard shown in Figure 17.4 is provided with a set of self-adhesive labels. These may be readily attached to the moulded plastic casing to identify each circuit control device fitted to the DIN rail.

Figure 17.4(c) is a wiring diagram for the above-mentioned switchboard. You should identify the circuit components and relate these to Figure 17.4(b).

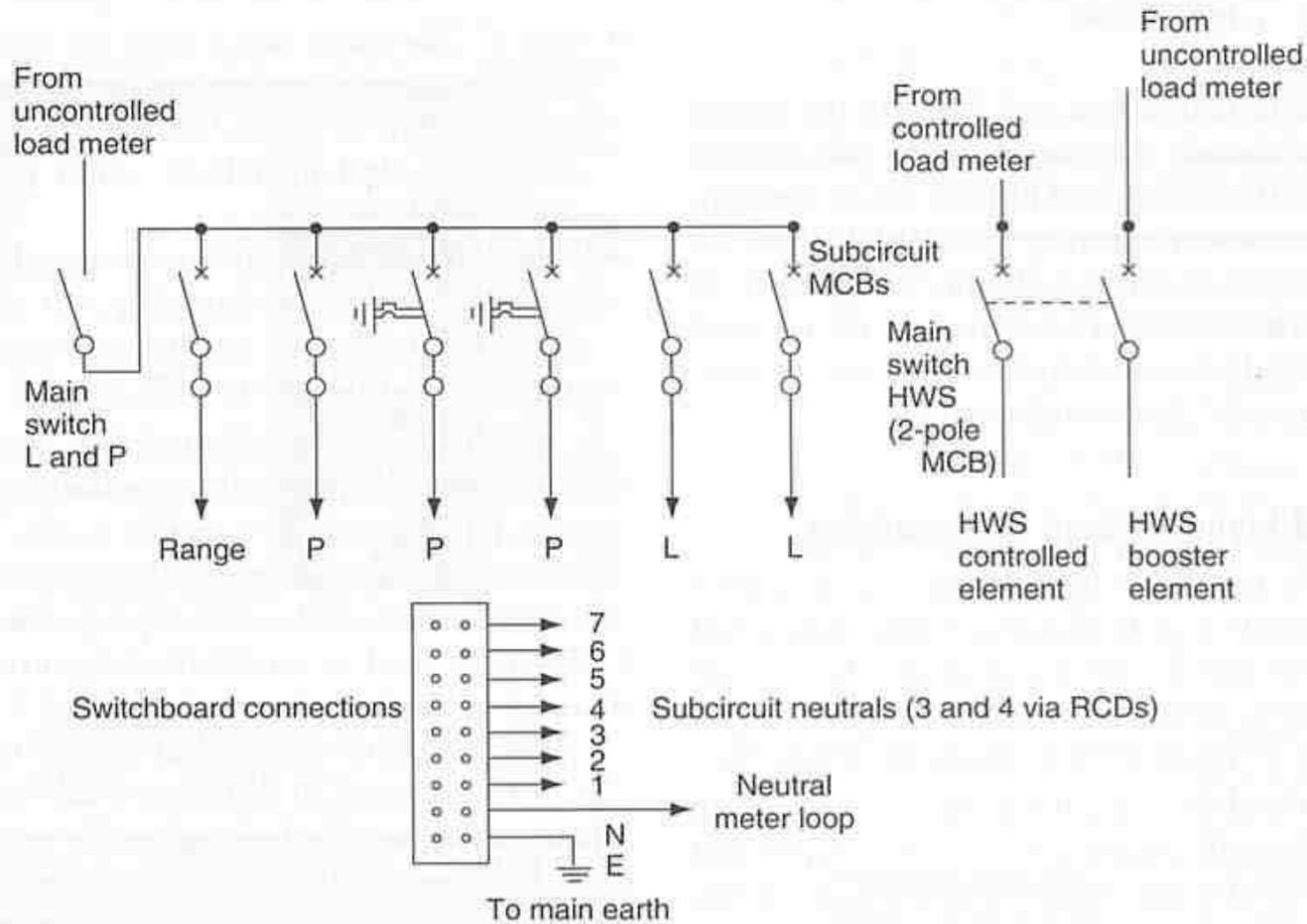
Multiple domestic situations

Multiple domestic dwellings (e.g. home units and flats) range from small groups of, say, four units in a suburban block to high-rise buildings containing perhaps 200 flats ('Greenway', a huge high-rise block in North Sydney, has 309 all-electric), each unit having a separate domestic installation.

In the first example, if the arrangement is compact, one main switchboard containing metering, main switches and subcircuit protection for each of the four



(a) For notes A, B, C, D, E and F, see text



(b)

Fig. 17.9 Small domestic switchboard (panel and frame) layout and wiring

portions may be installed at a central position accessible to all consumers.

In the second case, there will still be a main switchboard, but from it will originate many submains and/or rising mains (usually unmetered) to feed various sections, where further distribution will occur. The whole installation must be arranged so that each individual domestic installation is under the control of the consumer or user of the equipment, and so that the control equipment in the main switchroom is accessible from a public area (see section 17.2 in this chapter and the relevant AS 3000 Rules).

Provision must also be made for common services such as public lighting and air conditioning, and this type of load is usually supplied from the main switchboard. Figure 17.10 shows a switchboard on which are mounted the main control circuit breakers for twelve individual units. The main metering panel is not shown; the meter in the photograph is for community services.

A metering panel for a multiple domestic dwelling of twenty-four units is shown in Figure 17.11. Protective blanks are installed on the plug-in meter bases for units yet to be completed. On completion of these units, the electrical contractor will test the installation and

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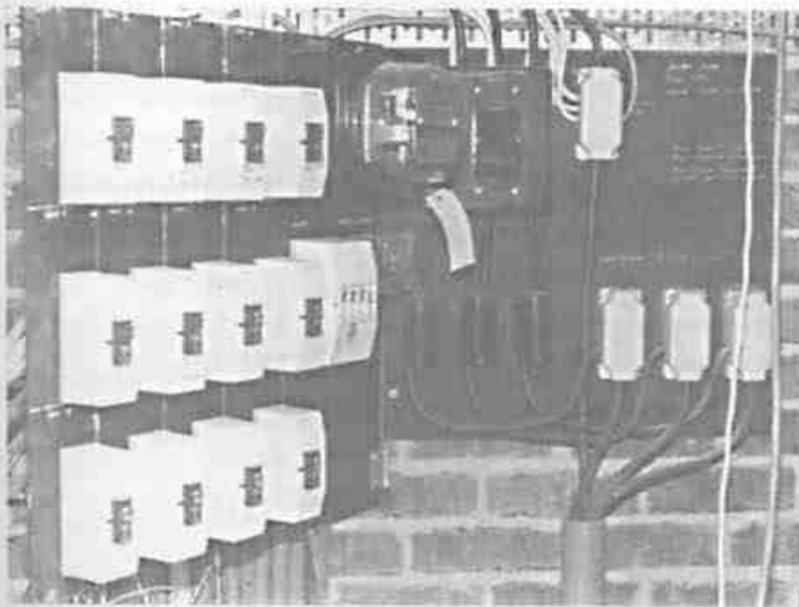


Fig. 17.10 Switchboard for a multiple domestic installation

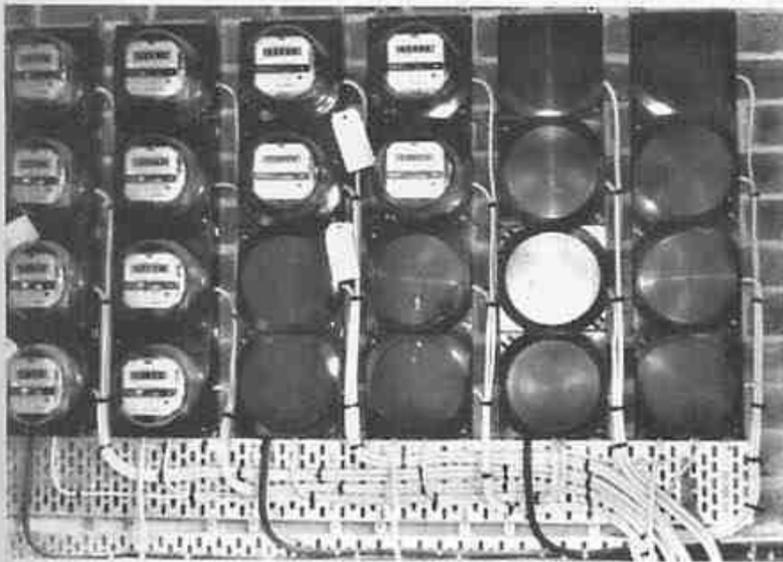


Fig. 17.11 Metering panel for a multiple domestic installation

lodge a test certificate with the local energy distributor. The distributor will then arrange for meters to be installed and for the installation to be connected to the supply. As pointed out in Chapter 11 (Volume 1), most energy distributors will require a new installation to be checked and tested before connecting it to their mains.

The switchboard of Figure 17.10 and the metering panel of Figure 17.11 are both housed in lockable switchrooms. You should note that metering and wiring requirements vary greatly in different parts of Australia and New Zealand. The open wiring shown would not be permissible, for example, in Victoria.

17.4 Switchboards for non-domestic installations

With commercial- and industrial-type installations, and in common with most other installation types, the consumer's mains terminate at a main control point. In

most cases this is the main switchboard, and for convenience this is usually the metering point also.

The nature and electrical rating of the load, and its location within the building or buildings, determine the number and location of the various distribution centres necessary. For small industrial and light commercial installations, typical examples are the switchboards discussed in section 17.3, which would be installed as distribution boards fed by submains or which could be the main switchboard of a small factory or commercial installation.

The type and size of an industrial or commercial switchboard vary with the type and size of the installation, and they are either custom-built by the electrician or switchboard manufacturer or purchased as a self-contained unit. Typical of the latter is the Panel Board manufactured by Cutler-Hammer, shown in Figure 17.12, and the three-phase metal 80 A switchboard shown in Figure 17.13.

The Clipsal switchboard may be supplied with a 150 A three-phase main switch and is also available as a single-phase unit. It is made with eight modules of full DIN and thirty modules of clip rail as shown, but is also available in horizontal configuration with forty-four modules of full DIN rail mounting only.

Self-contained switchboards are extremely adaptable, as there is a wide variety of options available—the switchboard illustrated in Figure 17.12, for example, being manufactured with busbar ratings from 150 A to 400 A tested for 16 kA and 20 kA. Single-pole or multi-pole circuit breakers may be fitted without any alterations to the mounting system or busbar connections, and a main switch can be fitted at the top, bottom or centre of the panel. Special boards that incorporate time switches, metering equipment and so on also are easily produced from standard basic components.

For small- and medium-sized assemblies, the alternative to a manufacturer's standard panel is a switchboard custom-built in the electrician's workshop or sometimes on the job, in which case it becomes necessary to keep in mind all the pertinent regulations. The board usually consists of an insulating panel and surround, the panel being hinged or fixed according to expediency; the assembly is similar to the small domestic switchboard shown in Figure 17.9. For larger boards made up by the electrician or manufacturer, the basic layout and principles are the same as for the smaller-sized boards.

With increasing size and rating, it is important to ensure that the design of the switchboard and the equipment that it supports are capable of handling the prospective fault current in the event of a low-impedance short circuit close to the supply source.

The panel and layout must be in accordance with the regulations, and the finished product should present a professional appearance that reflects credit on the

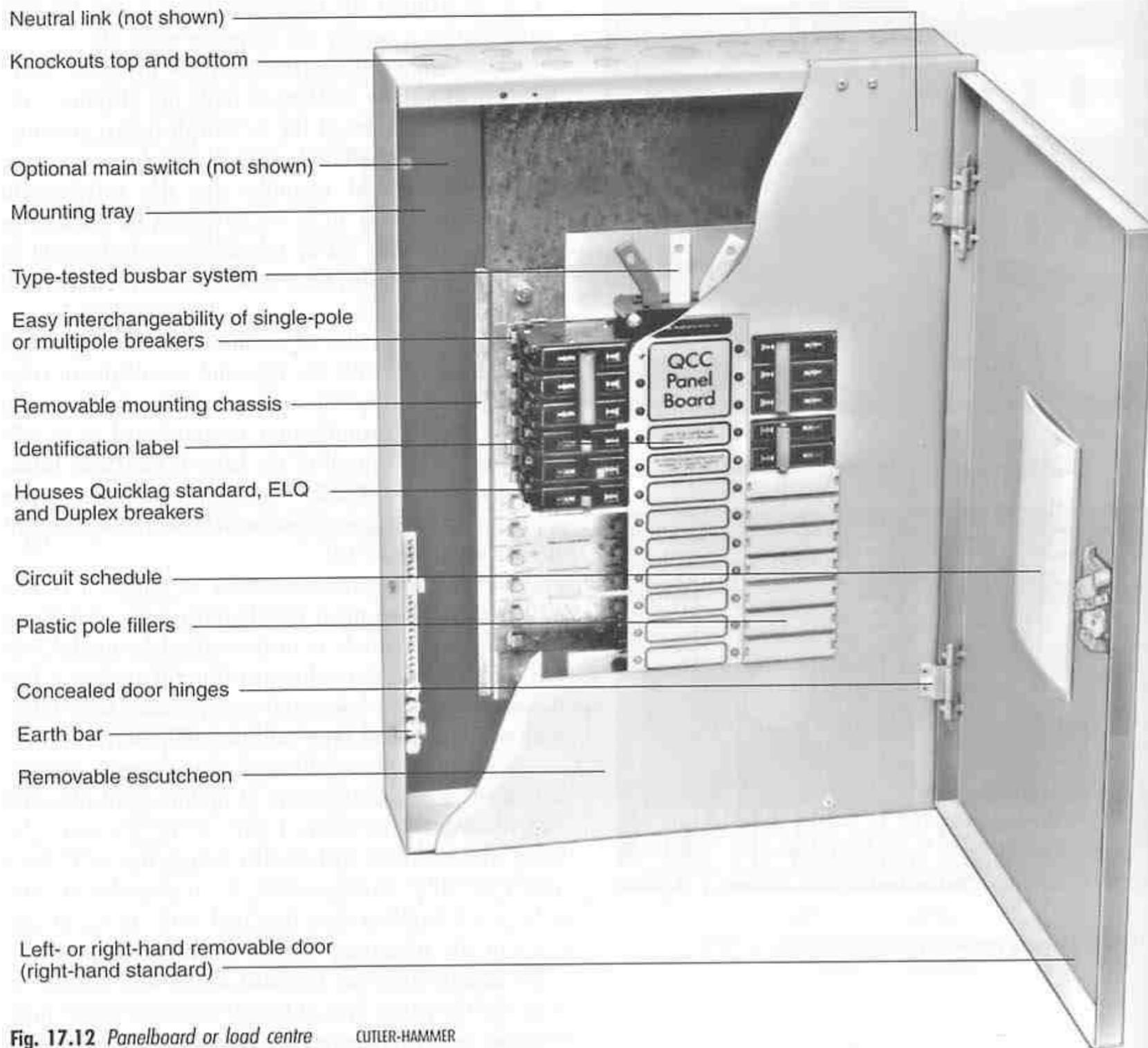


Fig. 17.12 Panelboard or load centre CUTLER-HAMMER

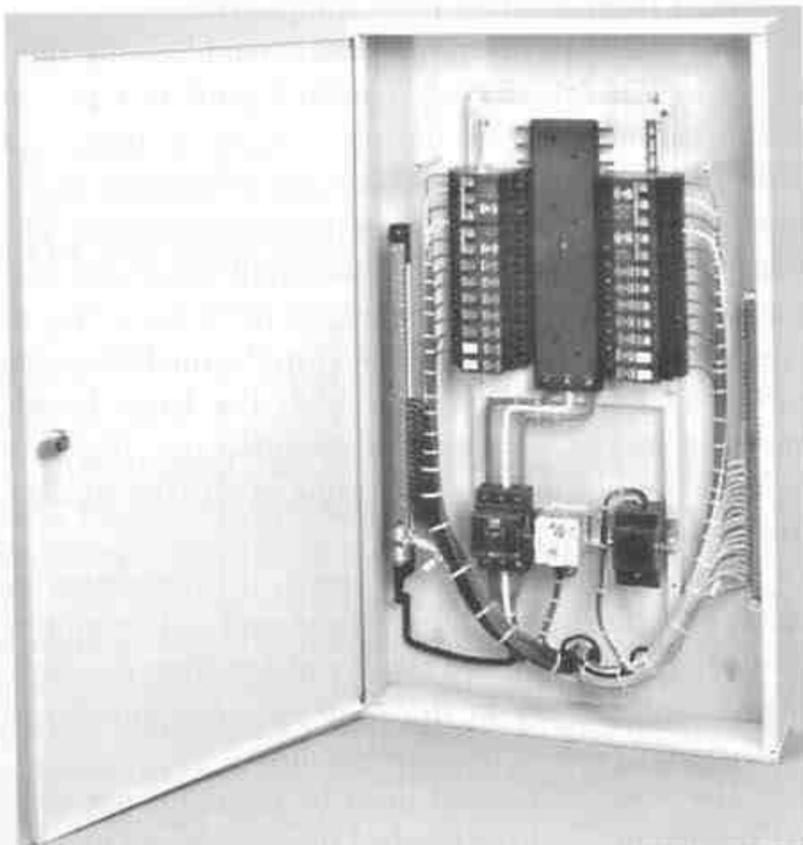


Fig. 17.13 Three-phase switchboard GERARD INDUSTRIES

electrician making up the board. The Rules of AS 3000 must all be observed, and in addition the specifications of AS 3439 apply, especially for commercial and industrial switchboards and controlgear assemblies.

Australian Standard AS 3439, mentioned in section 17.1, contains a list of definitions classifying switchgear and controlgear assemblies into six types: open, dead front, enclosed, cubicle type, desk type and box type. There are further classifications, and many other terms are in use for these assemblies, but all are switchgear and controlgear assemblies (SCAs) by definition and so must conform to the requirements as set out in AS 3439 and the current AS 3000 Rules.

Various tests for the units illustrated are described, with specific test conditions laid down. Perhaps two of the most important are a test of the unit's ability to withstand stresses produced by heavy short circuit currents, and a test of its ability to withstand the arc, flame and explosive pressure that occurs with an internal arcing fault. There are other tests, but these two have

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17.1 Introduction

By this stage, you must have realised 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 AS 3000 in general and AS 3439.1 in particular for most types, the latter specifications being most relevant to manufactured switchboards.

AS 3439.1—1993 *Low Voltage Switchgear and Controlgear Assemblies* defines an 'assembly' as:

a combination of one or more low voltage switching devices together with associated control, measuring, signalling, protective, regulating equipment etc. completely assembled under the responsibility of the manufacturer with all the internal electrical and mechanical interconnections and structural parts.

This is a very broad and encompassing definition, and covers nearly all manufactured and custom-built assemblies, such as those known in the trade as switchboards, panelboards, control panels, control centres or load centres. The various parts and their interconnection usually require reference to additional codes and specifications, such as AS 3100—1994 *Approval and Test Specification—General Requirements for Electrical Equipment*, and many others.

Many large switchboards in current use and some older types have been made up on the job or in the contractor's workshop. However, the modern approach to a large switchboard is to have a reputable switchboard manufacturer build the switchboard to specifications and compliance with the many and complex codes, or to use a ready-built board of standard design, if available. This approach is even used for small switchboards, such as single domestic, for which self-contained units are available in many types and ratings and which are widely used (see section 17.3).

17.2 AS 3000: relevant rules

The *SAA Wiring Rules* specify only three types of **switchgear**: self-contained, enclosed and partly enclosed, and these are briefly described in section 3.6 of Chapter 3, Volume 1. Reference to AS 3000 will reveal that a **switchboard** may be a main switchboard (*Clause 0.5.85*) from which the supply for the whole of the installation originates, or a distribution board controlling and/or protecting a portion of the installation fed by a submain (*Clause 0.5.39*).

Either board may be the origin of a final subcircuit or of submains, and both types are distinct from **control**

panels (*Clause 0.5.68*), which, although providing control and protection similar to switchboard functions, are installed for an individual appliance or group of appliances.

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. It may be seen that 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.

Location and access

Because the switchboard is an assembly of protective devices and controls, such as fuses, circuit breakers and switches, the Rules of AS 3000 relating to switchboards must be studied in conjunction with the Rules appropriate to the equipment making up the switchboard.

As an example, *Clause 2.16.1.3* specifies the location and accessibility requirements for a main switch, and this obviously also limits the location and accessibility of the main switchboard on which the main switch is installed. To comply with the Rule, the main switch must be readily accessible as defined by *Clause 0.5.2*, and the means of operating it must not be higher than 2 m above the ground, floor or operating platform.

If there is more than one occupier of a building, each occupier must have ready access to the main switch or to a control that will isolate the occupier's portion of the installation. In addition, the main switchboard must be located within the limits of one floor above or below the entrance and within easy access of it. A prohibited location is within a flat or living unit, but there are exceptions, such as:

- in the case of a switchboard for a single private dwelling or flat
- where specially approved by the inspecting authority.

The best location for a switchboard in a single domestic installation is inside the dwelling, because:

- access to main switch is easier, important in case of an emergency;
- circuit breakers and other controls such as timers are more convenient and safe to operate than they would be if located outside the building;
- where security devices or lighting are installed, unauthorised access is more difficult;
- final subcircuit runs are shorter, resulting in less voltage drop and a saving in cable. In some cases these advantages may be offset to a certain extent by the length of the consumer's mains.

A switchboard should not be located in a bathroom, toilet, laundry or kitchen of a domestic installation. AS/NZS 3018: 1997 *Electrical Installations—Domestic Installations* specifically prohibits its location inside a

bathroom. However, a switchboard may be installed in a kitchen, laundry or lavatory, provided it is enclosed in a cupboard with a close-fitting door (see Fig. 17.1). The cupboard must be designed specifically for its enclosure and the switchboard must be mounted towards the front of the cupboard. This is so that items that could impede ready access to the switches and protection devices cannot be stored in front of the switchboard.

Considering the switchboard as a whole, its location must be dry, well-ventilated, accessible and where access is not obstructed by the building or its contents (see *Clause 2.21*). Some prohibited locations for a switchboard are listed in *Clause 2.21.1.4*. Check this clause, and particularly note the restrictions with regard to switchboards located within a cupboard, which are clarified by Figure 17.1.

Clause 2.21.1.4(a)(i) specifies that the switchboard must not be installed within 1.2 m above the floor, ground or platform, unless special provisions are met. Note also that a domestic switchboard must exceed 0.9 m above the ground, floor or platform irrespective of its type, and that energy distributors often specify minimum and maximum mounting heights for their metering equipment, which may affect the switchboard mounting height.

The prohibited and restricted locations are those deemed to require special mention, but there are many other locations which would not be considered 'suitable places' for a switchboard as required by *Clause 2.21*. To clarify the prohibited and restricted locations of switchboards in relation to the ground, floor or platform, a table in *Doc. 3000 R/1—1991 Rulings to SAA Wiring Rules (AS 3000—1991)* is included. The table is part of Ruling C.721/91 to *Clause 2.21.1.4* of AS 3000, and should be studied by you. *Doc. 3000 R/1* is part of a rulings and amendment service provided by Standards

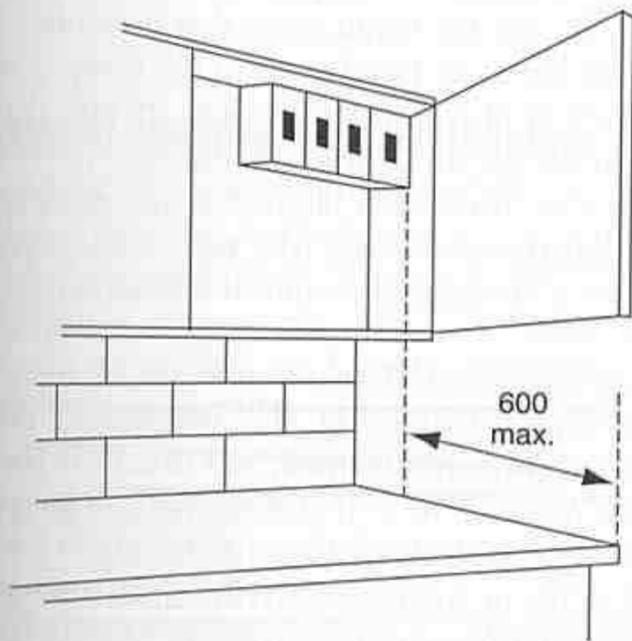


Fig. 17.1 An example of a switchboard located in a cupboard with a close-fitting door. The distance between the front of the switchboard and the edge of the bench must not be greater than 600 mm (see *Clause 2.21*)

Australia for a fee. It should also be held in most technical college libraries.

If a room has been specially allocated to house a switchboard, it must comply with the provisions of *Clause 2.21* with regard to doors, lighting and access. This is necessary to facilitate the safe and effective operation of controls, the replacement of fuse elements and other equipment, and general maintenance. For similar reasons, access is required to the switchboard wiring and equipment at the rear of the switchboard or within cubicles or enclosures. The provisions for this access will vary depending on the switchboard type and design.

Exit facilities are also necessary, at least one being required in all cases. For switchboards having a length exceeding 3 m, two exits spaced well apart should be provided unless a clear space of 3 m or more surrounds the switchboard and its equipment.

Within the provisions of *Clause 2.21*, specific requirements are detailed to allow access for switchboard wiring and equipment, covering:

- walk-in access, or access by doors (*Clause 2.21.3.2*);
- access by removable or hinged panels. Study *Table 2.11* 'Installation methods', and note how the area of the panel affects the clearances at the back of the panel and the rules regarding support and fixing;
- access to fixed switchboards via the edges (*Clause 2.22.2.6*). See *Table 2.10*, and note how the distance from any point on the switchboard to the nearest access point, and the space available at the access point, governs the clearance behind the board;
- access to the rear of fixed panels (*Clause 2.22.2.5*). This clause covers the requirements for passageways and access thereto at the rear of switchboards. Particularly note the requirements of *Clause 2.21.2.3*, which includes provision for both access and exit.

Briefly, the whole of the equipment on any switchboard must be accessible for maintenance or replacement, and this includes the removal or replacement of any conductor or item of equipment that is part of the switchboard while the switchboard is dead (see *Clause 2.23.3*).

Fire and shock hazard

In common with other electrical equipment, the twin hazards of fire and shock must be provided against. *Clause 2.22.1* deals with fire hazard. In effect it specifies that the enclosure or sheath of conductors must continue into the switchboard surround to leave no exposed wiring. However, short lengths of exposed wiring are permissible where cables pass through the panel for connection to equipment. Three exceptions are a switchroom containing no flammable material, self-contained switchgear incorporating its own surround, and a fixed switchboard clear of flammable material. Permissible

material for use as switchboard cases and surrounds, three of which are non-flammable and one of which is wood with a non-flammable lining, are also specified.

Specific reference is made to the prohibition of exposed live parts on a domestic switchboard, where the only live metal allowed would be a fuse contact that becomes exposed on removal of the fuse wedges (see *Clause 2.23.4.4(c)*). Should it be necessary to remove covers to facilitate access to fuses, live parts (other than fuse contacts) must not be exposed. Other switchboards must not have exposed live parts unless protected by an enclosing case, and are not considered to be exposed until the enclosing case is removed. However, this does not apply to switchboards in a special compartment or switchroom with access to authorised personnel only.

Another factor affecting shock hazard is that the space behind a switchboard must be such as will permit working on the wiring or equipment without the risk of electric shock.

Clause 2.22 also is relevant to shock and fire hazard, in that it specifies the materials for switchboard construction and the mounting of equipment so as to provide 'safe and effective operation and handling'.

A self-contained switchboard may be mounted on any surface, while the support for other types must be non-flammable. In addition, switchboard panels must be durable, non-hygroscopic and non-flammable. Metal falls within the scope of these definitions; but if metal panels are used, live parts must be insulated. Also, where conductors pass through the metal panel, the holes must be bushed or so shaped that they will not cause mechanical or electrical failure by way of abrasion of the conductor or its sheathing, as required by *Clause 1.4.7*. All holes for cables should be close-fitting and preferably sealed to prevent the spread of a switchboard fire into the building structure.

The usual panels for small switchboards are made from a composition of bitumen-impregnated fibrous cement and are sold under various trade names, such as Lebah, Miscolite and Zelemite.

The laminated phenolic of *Table 2.9*, column 3, of AS 3000 is usually a bakelite-resin-impregnated laminated paper board, which is superior to, but more costly than, the former panel material, marketed under trade names such as Formatese, Formica, Spauldite and Synthane.

In *Table 2.9* of AS 3000, panel types X and Z are insulating panels, while types A and B are non-insulating. All types must conform to the requirements and strict tests of AS 1795 *Sheets and Boards for Electrical Purposes, Part 1*. Other modern panel materials have been developed, all of which fall within the scope of AS 1795.

Panel thickness for the insulating-type panel depends on the distance between supports and the material used, and a study of *Table 2.9* will reveal that

panel thickness may be reduced if more support is provided. Figure 17.2, representing a 600 mm × 400 mm type Z or B panel, illustrates this point. If the panel is supported at the four corners only, the greatest distance from any point on the panel to the nearest point of support will be approximately 350 mm. From *Table 2.9*, the minimum panel thickness that may be used is 10 mm. If two additional points of support are provided as shown, thus reducing the distance to approximately 245 mm, panel thickness may be reduced to 6 mm.

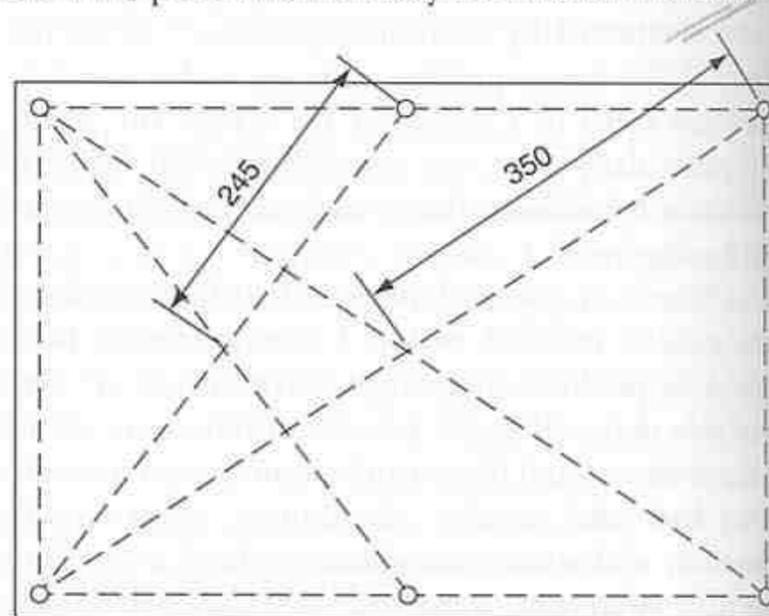


Fig. 17.2 Determining the thickness of a non-metallic panel

Mounting of equipment

No equipment must project beyond the edge of the panel, and no holes other than those by which the panel is fixed should be within 12 mm of the panel edge (see Fig. 17.9).

Arrangement of equipment on switchboards

Mention is made in Chapter 13 of rewirable fuses marked 'R' and the requirement that no earthed metal be introduced to or be adjacent to the fusing chamber. The necessity of maintaining at least 25 mm clearance between R-type fuse bodies of different potential or phase is also mentioned. However, fuses manufactured for unrestricted mounting (the more commonly used U-type) may be mounted immediately adjacent to each other.

Fuses and circuit breakers must also be arranged so that a person looking at the switchboard can see instantly their interrelatedness, and to achieve this they must be mounted in a similar manner and grouped in such a way as to indicate their relationship.

No fuses or circuit breakers are allowed at the back of a switchboard, with the exception of small fuses in instrument circuits or fault current limiters.

Clause 2.23.6 specifies rigid fixing and support for bare conductors or live parts of a switchboard, so as to maintain a minimum clearance between them and any

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uninsulated metal or other live parts of different polarity or phase. *Table 2.12* is included in the clause as a guide.

Neutral links

The minimum size for a neutral link is 40 mm^2 in cross-section and 3 mm thick, but in any case its current-carrying capacity must be at least that of the incoming neutral to which it is connected. Two or more interconnected links may be regarded as a single link, provided that they are connected by a conductor of appropriate current rating. Important provisions with regard to connections at neutral links are enumerated in *Clause 2.23.4.5*. These include the provision that the incoming neutral connections be of a type that:

- cannot be inadvertently open-circuited and hence cause unstable phase voltage conditions in a three-phase system and shock hazards on the multiple-earthed neutral (MEN) system (as the neutral current will now be carried by the earth wire);
- enables each circuit conductor to have an individual and separate connection to the link;
- has an approved connector that will prevent spreading of the strands of any stranded conductor, such as the incoming neutral and the main earthing conductor (on the MEN system); when neutral conductors are connected into tunnel terminals of a neutral link, the terminals must be of a type having at least two clamping screws.

Clause 2.23.4.5(f) favours front-mounted neutral links, but does not prohibit back-of-panel mounting where there is provision for access to the link by virtue of the panel's being hinged or, in the case of a fixed panel, where there is clearance of 0.8 m from the back of the panel or where a removable escutcheon plate or cover is provided.

Marking of equipment on switchboards

All marking of equipment on switchboards must be legible and indelible, and links must be marked to indicate whether they are active or neutral. Each terminal of all equipment such as links, fuses and circuit breakers must also be marked to identify the corresponding circuit connections. One exception is on the MEN system, where the main neutral and earth need not be marked at the neutral link if the main earth connection is at one end of the link with the incoming neutral main at the adjacent terminal (see *Clause 5.9.3.2*).

The relationship of equipment such as switches and fuses or circuit breakers to various parts of the installation must be marked on the switchboard or adjacent to it. In addition, the main switch or switches must be distinctly marked and grouped to permit prompt

operation in an emergency. If the manufacturer's marking on a fuse base does not correctly indicate the rating of the circuit it protects, the correct circuit rating must be marked on a non-detachable portion of the fuse or on the switchboard immediately adjacent to it. This must be done in such a way that the marking is clearly visible. For example, a 30 A fuse may be used on a circuit having a rating of 20 A, provided that the 20 A rating is clearly indicated.

Wiring of switchboards

Unless all switchgear is of the self-contained type in a fire-resistant enclosure that does not have to be opened to operate any switch, the wiring must be run at the back of the switchboard panel. Any cables brought through the panel must pass through close-fitting holes as close as practicable to their connecting terminals (see *Clause 2.22.1.3*). This requirement also applies to the wiring of any front-connected equipment on the switchboard panel.

Clause 2.23.7.3 requires that where wiring is located behind a fixed switchboard panel there must be sufficient space behind the panel to permit the manipulation of the wiring. In the case of hinged or removable panels, there should be sufficient slack left on all conductors to permit movement to a position that enables any work to be done on and behind the switchboard.

Although *Clause 2.22.2.7(b)* specifies that the panel must be capable of being swung through an angle of 60° from its original position, most electricians in practice allow for a 90° swing. In addition, to ensure flexibility of the cables, the minimum distance required from the back of the panel to a wall or other immovable structure is related to the size of cables used behind the panel (see *Table 2.11*).

Anchorage of the cables at the panel must be such as to prevent any strain on the terminal connections, and this may be achieved by using a suitable saddle or strap, firmly fixed to the panel in a suitable position.

Ratings of switchboard equipment

The ratings of fuses and circuit breakers on outgoing circuits are considered in Chapter 13, where interrupting capacity (rupturing capacity) also is considered. Usual fault-level capabilities are 1.0 kA for rewirable fuses, 1.5 kA for the 'plug-in' circuit breaker that substitutes for a fuse element in the corresponding fuse base and 8.0 kA for miniature circuit breakers (MCBs).

High-rupturing-capacity (HRC) fuses manufactured to AS 2005 are type tested to withstand prescribed short circuit currents; for example 415 V ac industrial types have a fault-level capability of up to 50 kA.

Control and layout

An installation is controlled by a main switch or switches mounted on the main switchboard. The switch or switches must control the whole of the installation, other than consumers' mains and any equipment classed as 'emergency equipment' (such as fire protection and lift circuits). These must be connected to the supply side of the main switch or switches.

The maximum number of main switches permissible is six, but these do not include:

- switches that control fire protection, lifts and essential building services;
- switches that control closing devices for main switches and associated equipment that is required to be connected on the supply side of the main switches; or
- a number of main switches controlled from a remote position.

Note the provisions of *Clause 2.16.1.5* with regard to the remote control of main switches, and consider the difference between a remote control switch (on/off) and a trip circuit (off only) as a means of opening a main switch by remote control.

Check also the requirements of *Clause 2.16.2* 'Additional switches', which outline the conditions under which additional switches are required for separate buildings and multiple installations. The Rule also specifies that a separate switch be provided on the switchboard for every circuit to a separate building with a distribution board having a rating exceeding 100 A per phase.

For control of an installation using any of the three accepted earthing systems—direct earthing, the MEN system and the voltage-operated earth-leakage circuit-breaker (ELCB) system—switches must operate in all the active conductors. In the rare instance of a supply system that is not solidly earthed at the source, control and protection are required in all conductors (active and neutral). In this case a multipole switch that includes a contact intended for connection in the neutral must be arranged so that the neutral cannot be open when the active switch contacts are closed.

Layout of the switchboard will in general be affected by all the preceding factors, together with metering requirements, which sometimes include the use of current transformers, and the service rules of the local energy distributor. In particular layout will depend on the type of switchboard: domestic, industrial or commercial. Specific factors affecting the layout of domestic and commercial/industrial switchboards are discussed in sections 17.3 and 17.4 respectively.

The main point to keep in mind when considering the rules and requirements discussed here is that the control and layout design of the switchboard must be such as will provide safe and effective control, and protection of the installation.

Alterations and additions

Should additions or alterations be contemplated at the time a switchboard is first installed, provision would be made for future extensions. However, this is seldom the case, and any subsequent alterations or additions to a switchboard could render it inadequate to provide safe and effective control and necessitate its replacement or removal to a more suitable position. *Paragraphs H4.4.1 and H4.4.2 of Appendix H* advises on both these eventualities. They both commence with the phrase, 'If, in the opinion of the inspecting authority . . .', which indicates where an opinion should be sought if any doubt arises.

Another situation that could result in perfectly sound switchboard equipment's becoming inadequate would be that caused by an increase in the fault-level capacity of the supply. For example, a small factory or industry taking supply from its own indoor substation may have wiring extensions made that double its kVA load. This will double the kVA rating required at the supply transformers, resulting in a possible increase in the available short circuit current at existing switchboards. The problem cited is sometimes overcome by the use of HRC fault-current limiters (see *Clause 2.4.4*).

An electrician often avoids the necessity of making alterations to an existing switchboard by installing a separate switchboard (such as a self-contained type) close to and fed from the first. This practice is satisfactory, provided that the new switchboard complies with the accessibility requirements of *Clause 2.21*, discussed on page 119. An extension of this idea would, however, result in an untidy appearance; so its use is limited.

Control panels

The installation of control panels is governed by similar rules of access for operation and maintenance as those for switchboards (see *Clause 2.26*, in which frequent reference is made to appropriate switchboard rules). Most control panels are manufactured or custom-built; any panel outside this category would be rare or very old.

An electrical mechanic's job includes installation of the main supply circuit and the circuit wiring between the control panel and the controlled equipment. It also includes connecting up the mains, control panel and equipment ready for operation, and any final adjustments required to the control equipment where these have not been preset.

The above remarks also apply to the overlapping categories of control panels known as 'motor control centres', 'motor control boards', 'control assemblies', 'control centres' and 'protection and control units' etc.

17.3 Domestic and multiple domestic switchboards

Requirements so far discussed relate to all switchboard types. *Clause 2.23.4.4(c)*, however, relates specifically to a domestic switchboard and prohibits the exposure of any live part. See also *Clause 2.22.1.4* concerning access to live parts behind metallic access covers and escutcheon plates.

Rules other than those of AS 3000 that particularly affect the installation of domestic switchboards are those contained within the service rules of local energy distributors. It is here that variations occur due to differing tariff structures and metering, different earthing arrangements, switchboard enclosures or meter boxes, and different methods for the protection of consumers' mains and metering equipment.

To ensure uniformity within a supply area, many energy distributors adopt a standard meter box or a combined meter board and switchboard (main switchboard). Minimum standards are set for the manufacture of the box and panel; a list of manufacturers whose boxes have been checked, tested and approved for compliance is published; and the boxes are permanently marked to indicate that they comply with the standard. Many energy distributors have adopted the standard box and panel and have specified their use in the local service rules.

A typical standard meter box is shown in Figure 17.6(a), where the consumer's equipment is mounted on a defined area at the bottom left-hand corner of the switchboard.

Marking

The interpretation of *Clause 2.23.5.2* (which requires that 'the relationship of switches, fuses and similar equipment to the various sections of the installation shall be marked on or adjacent to the switchboard') in relation to domestic boards is that the marking may indicate the use or application of the circuit: for example, lighting circuits as L1, L2 and so on, power as P1, P2 and so on, hot-water service as HWS, and wall oven as WO.

The main switch should be identified as such, and also any other main or control switch, such as that for the water heater, should be suitably marked. Neutral links may be marked N/L with the outgoing neutral terminals marked, for example, E, N, L1, L2, P1, P2, HWS and WO. Alternatively, terminals may be arranged to identify the corresponding active and neutral connections for each circuit, say by numbering and by logical sequence of connecting conductors.

If the main earthing conductor is connected to a terminal at one extreme end of the neutral link, and the

incoming neutral main is connected to the adjacent terminal, the marking for these may be omitted.

It is preferable to spend extra time to ensure the clear identification of circuits in a domestic installation. This is better than leaving it to the householder's imagination to identify a fuse, circuit breaker or switch; the consumer in a domestic or multiple domestic situation is usually not familiar with trade terms.

Switchboards installed prior to July 1976 may have circuits marked 'sub-installation', 'sub-installation mains' or 'sub-installation switchboard'. These terms are not in current use, as what was previously termed a 'sub-installation' is now a 'portion' of an installation or an 'individual domestic installation' in a 'multiple installation' and will be supplied by 'submains'. The electrical worker should be aware of current terminology to avoid confusion.

The switch or circuit breakers controlling domestic installations that form part of a multiple installation, such as in a block of flats, must be clearly marked and identified in such a way that they may be easily located in an emergency. They must also be readily accessible to the owner of the portion (of the multiple installation) controlled. They do not, however, have to control the submains supplying the domestic installation. (See *Clause 2.16.2.2*.)

Switchboard types

As mentioned in section 17.1, recent trends are towards 'packaged' units that are self-contained and only require mounting and the connection of incoming supply and outgoing circuits.

Wide acceptance of these units has led to some degree of standardisation and uniformity of design, with trade names such as Clipsal, Federal, Siemens and Cutler-Hammer, although custom-built boards are also still widely used. With the self-contained assembly, many types and variations are available; so it is possible to select one from stock that is suitable for a particular job.

Packaged switchboards using rewirable fuses have been known for many years, but most manufacturers have moved away from the production of these units in Australia in favour of units using MCBs. As the use of residual current devices (RCDs) is mandatory for some power circuits in domestic installations and on construction sites in most states in Australia, the use of MCBs to protect the remainder of the installation seems logical.

One factor that has made the rewirable fuseboard virtually obsolete is the minimal differential in cost between MCBs and rewirable fuses. However, there are considerable numbers of rewirable fuseboards in existing domestic and industrial installations. The rewirable fuses themselves will, therefore, continue to be used to replace existing fuses.

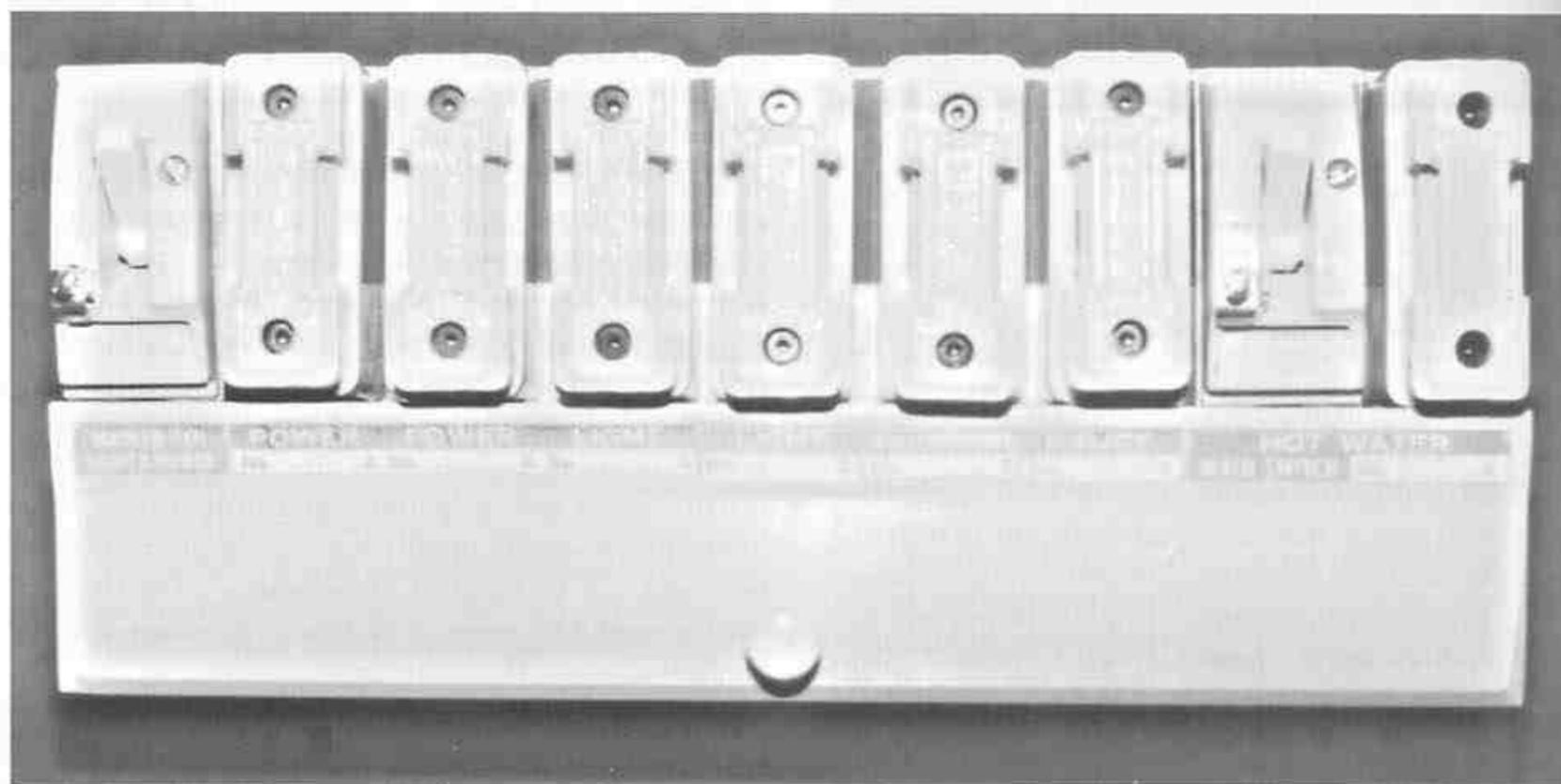


Fig. 17.3 Domestic two-tariff switchboard using rewirable fuses (no RCD protection provided). Common in existing installations, not recommended for new installations

Packaged rewirable fuseboards (see Fig. 17.3) are designed in such a way that fuse ratings and switches may be varied, time switches or other controls fitted, and the board arranged for one, two or three phases. The switch control may be omitted and the space occupied by more fuses (e.g. to make a fuseboard suitable for use as a distribution board).

Cartridge-type HRC fuses with a classification of 33 kA may be substituted for the rewirable type if desired but a conversion kit available from the manufacturer will be needed. A circuit breaker designed to replace the rewirable fuse is also available, but may only be fitted subject to certain conditions in some supply areas (see Chapter 16, Fig. 16.1).

The same packaged-unit approach is evident with self-contained circuit breaker boards or 'load centres'. However, the range of options for these units is considerably greater than the range for packaged switchboards using rewirable fuses.

AS/NZS 3018: 1997 *Electrical Installations—Domestic Installations* recommends that all final subcircuits in a domestic installation be protected by miniature circuit



Fig. 17.4(a) Switchboard with surround and cover fitted
HPM INDUSTRIES

breakers. The switchboard shown in Figure 17.3 will therefore not be desirable in single domestic premises, but the one shown in Figure 17.4 is typical of that recommended for new domestic installations. It is a single-phase switchboard, and in Figure 17.4(b) its moulded plastic surround and cover is removed to illustrate the range of options available from the manufacturer.

The switchboard is intended for surface mounting but this type of unit is readily available with a flush-mounting enclosure. It is provided with a DIN rail for mounting the MCBs and other accessories. The three separate earth bars and neutral links enable separate neutral links to be used for protected and unprotected circuits.

Devices mounted on the DIN rail of the switchboard from left to right are:

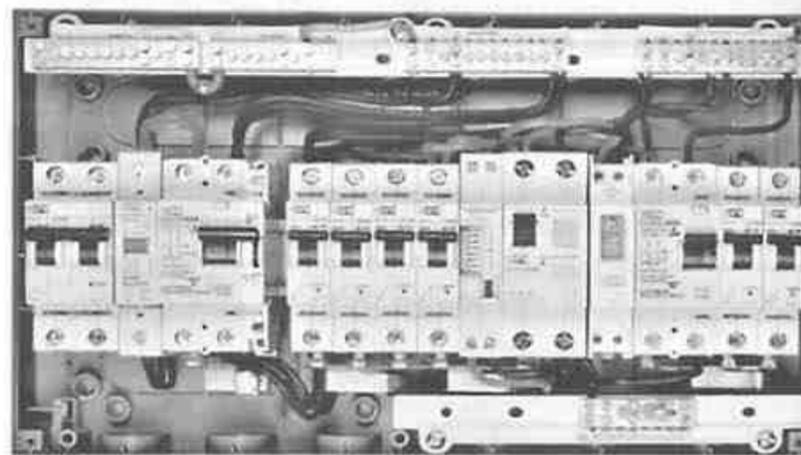


Fig. 17.4(b) Two-tariff switchboard with moulded surround and cover removed. This switchboard features an earth bar, an unprotected neutral, a neutral link for type IV RCD protection and a neutral link for type II RCD protection
HPM INDUSTRIES

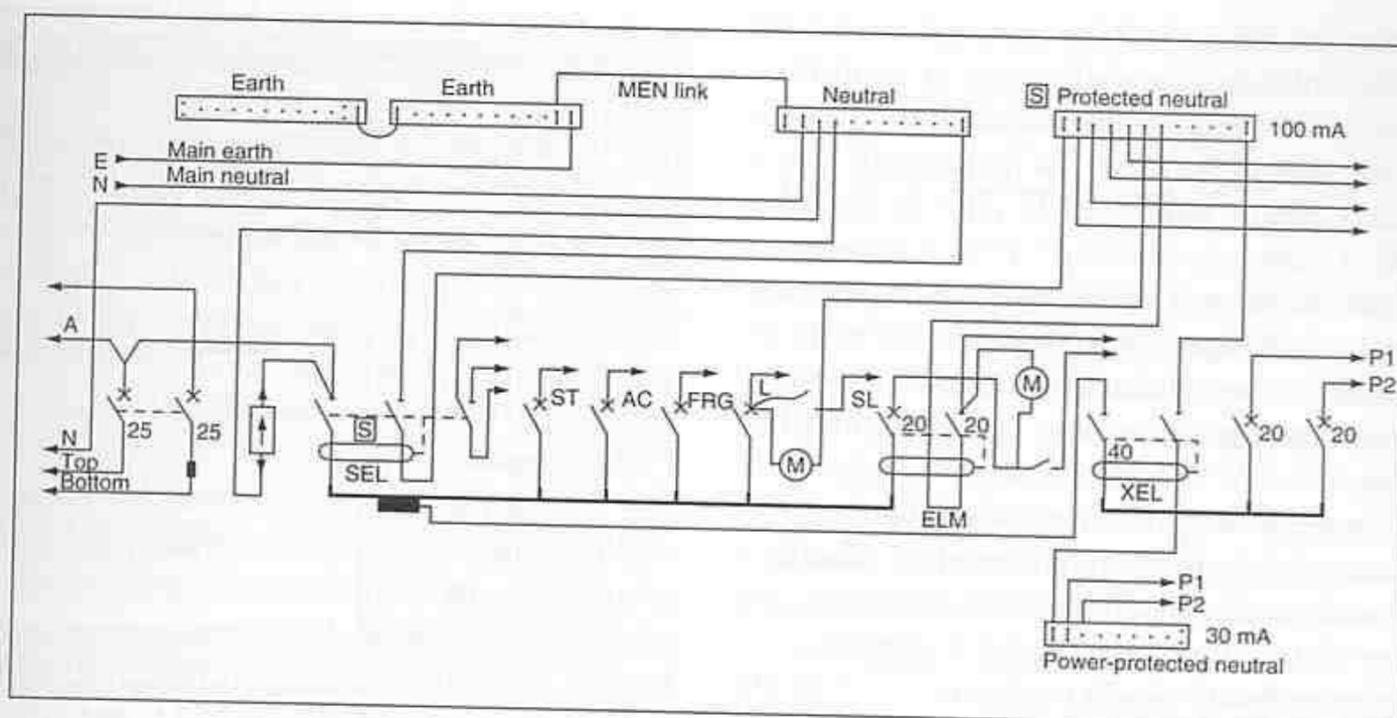


Fig. 17.4(c) Wiring diagram for switchboard of Fig. 17.4 HPM INDUSTRIES

- double-pole 25 A MCB for two-element water heater
- surge diverter protection for the installation
- 80 A/100 mA selective RCD with 500 millisecond delay sensitivity as main switch
- auxiliary switch to be connected to main switch, to set off alarm or security device in the event of power failure
- single-pole 32 A MCB
- single-pole 16 A MCB
- single-pole 20 A MCB
- single-pole 16 A MCB
- 24 hour timer for pool or spa
- two-pole 20 A/30 mA MCB/RCD
- digital timer for security lighting
- single-pole 20 A/30 mA RCD
- single-pole 20 A MCB
- single-pole 20 A MCB.

At the top of the switchboard from left to right are two linked earth bars, a MEN-linked neutral, and a protected neutral for the 100 mA RCD. Another protected

neutral link (for the 30 mA RCD) may be seen at the bottom right-hand corner of the switchboard.

The circuit wiring for the switchboard can be seen in Figure 17.4(c).

Because the DIN clips fitted to MCBs and other modules are spring-loaded, they may be simply clipped into position on the DIN rail. Figure 17.5(a) shows how the spring-loaded DIN clip may be released with a screwdriver to remove one or more MCBs or other modules, and 17.5(b) shows the busbar connections provided. When the busbar is in place at the base of the MCBs, access to the DIN clips is still available, permitting an MCB to be removed with the busbar still in place.

Supply can be connected to the top or bottom of the MCBs using cable in lieu of the busbar. However, as can be seen in Figure 17.4(c), internal wiring of the switchboard is simplified by using the busbar provided by the manufacturer.

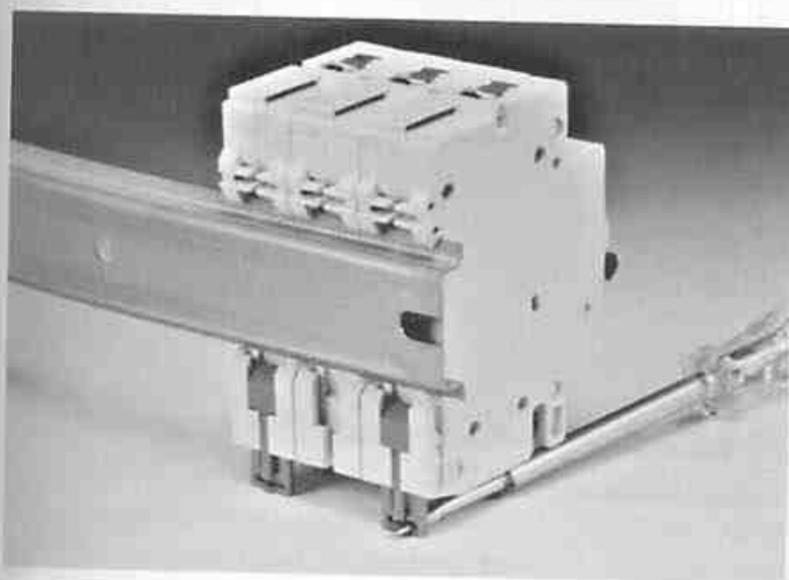


Fig. 17.5(a) Removal of MCBs from DIN rail HPM INDUSTRIES



Fig. 17.5(b) Busbar connections HPM INDUSTRIES

been mentioned to underline the 'hands-off' rule when wiring or connecting up these units, to ensure that the original design is not modified or interfered with.

Large switchboards are built by switchboard manufacturers and constructed to comply with all the relevant Rules and to the engineering and electrical specifications for the individual job. Many of these manufacturers are a division or subsidiary firm of a large electrical contractor.

A number of firms have developed standard designs and layouts and have submitted prototypes of these to a recognised testing authority for tests and approval. Once the design has been type-tested and approved, it

may be incorporated in the manufacture of many built-in or custom-built switchboards produced by the firm. This leads to economies and a degree of design standardisation for the switchboards of the particular manufacturer.

However, the costs associated with the testing of switchboards are high and would be prohibitive unless the firm was assured of continuing work. This means in practice that, although custom-built switchboards are manufactured in large sizes and high ratings, there is a limit above which it becomes uneconomical to produce them. Figures 17.14, 17.15 and 17.16 show three custom-built switchboards.



Fig. 17.14 This 2500 A switchboard installed in a flour mill in Papua New Guinea is an example of modular construction. It has been type-tested as complying with AS 3439
K.E. BROWN ELECTRICAL SWITCHBOARDS

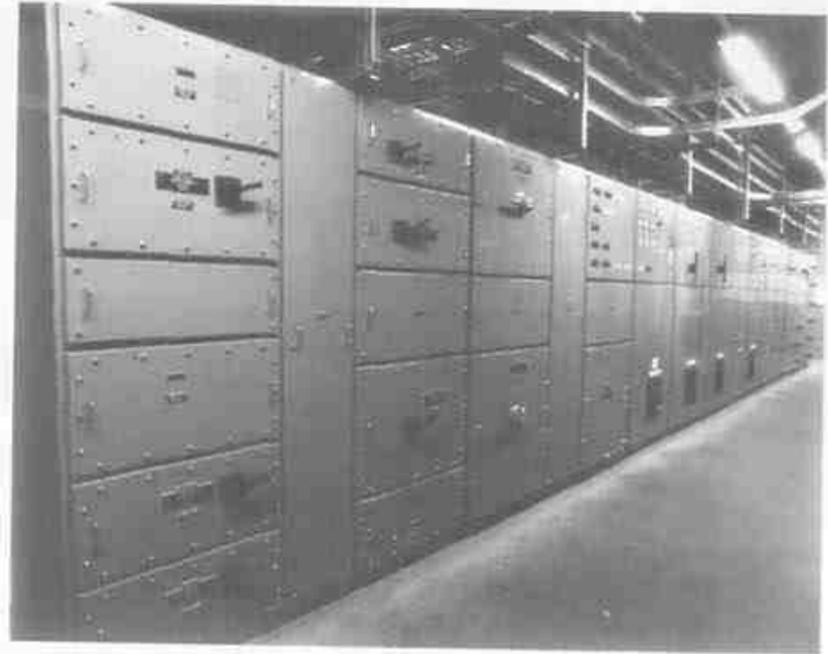


Fig. 17.15 Custom-built 5000 A switchboard: built to customer's as well as relevant energy distributor's specifications
K.E. BROWN ELECTRICAL SWITCHBOARDS

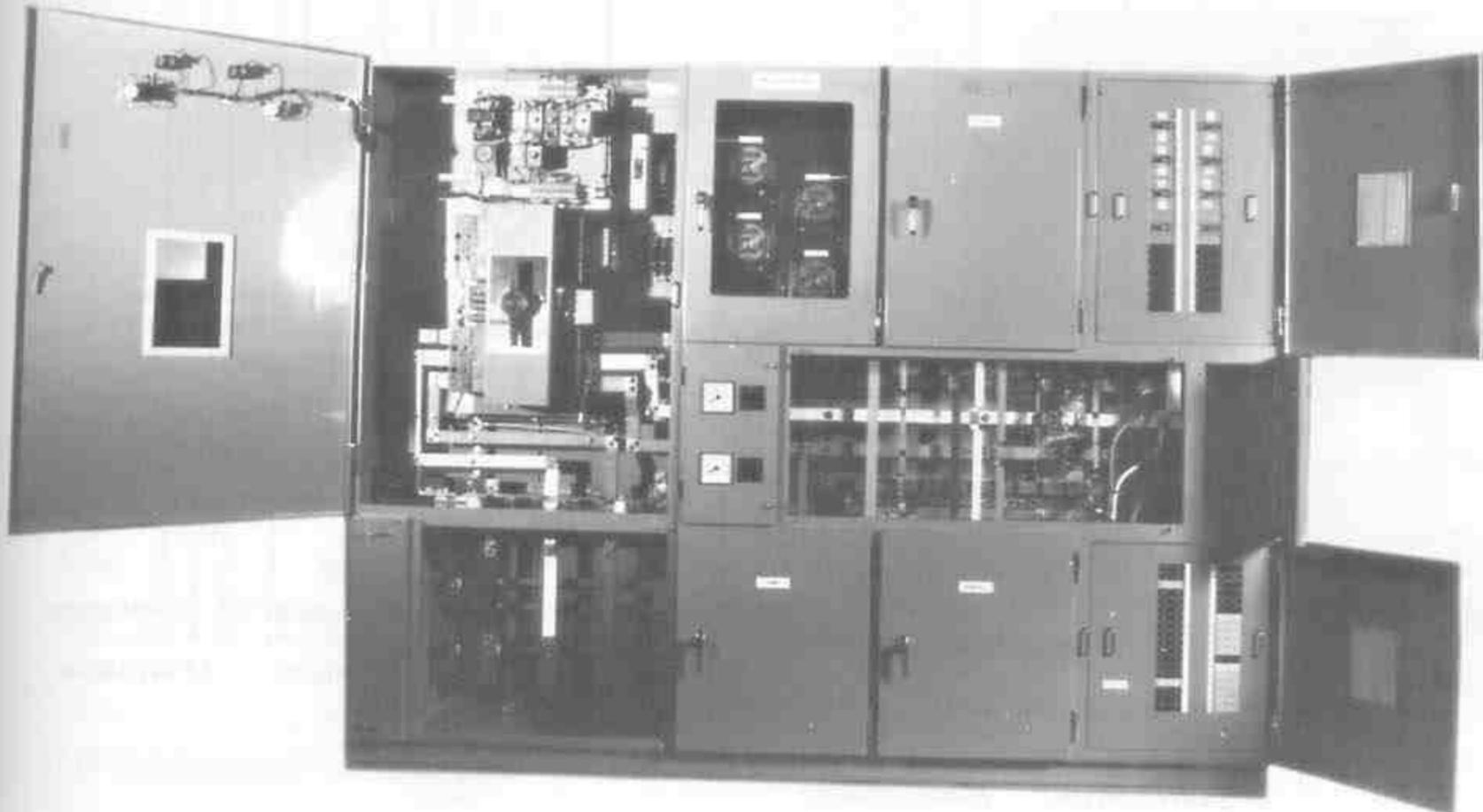


Fig. 17.16 Typical main switchboard CUTLER-HAMMER

The manufacture and supply of switchboards having still higher ratings are confined to large and usually international firms, such as General Electric, Siemens and ASEA Brown Boveri, which have an international market large enough to support their own research and development laboratories. A modular construction to specified requirements is almost invariably used to build up the switchgear and controlgear equipment, the size of which may vary in all dimensions.

However, the variation of dimensions is in standard increments, and the standard size modules, for both the equipment and the cubicles in which it is housed, permit an arrangement to suit nearly any load and protection requirement. Figure 17.17 illustrates this concept in an arrangement for a motor control and power distribution centre. The modules with starters and fuse switches pull or rack out for service or adjustment in a similar way to the modular low-voltage switchboard of Figure 17.18, which features a dead front multicubicle type of SCA with three separate compartments, comprising:

- a circuit breaker compartment;
- a busbar compartment, which accommodates the

circuit breaker connections and the horizontal and vertical busbars; and

- a cabling compartment, with facilities for incoming cables and connections and for earth and neutral bars.
- The whole assembly is free standing with front and rear access and is extendable on both sides. Figure 17.19 illustrates a similar concept in a motor control centre.

AS 3439 *Low-Voltage Switchgear and Controlgear Assemblies* describes desk-type SCAs and box-type construction; these types are not illustrated here. The desk-type is popular for control panels in heavy industry and powerhouses, while the robust box-type is often used in industrial substations and in metalliferous mines. The box-type is also made in explosion-proof and flameproof versions for use in hazardous situations, such as oil refineries and coal mines.

To sum up: the switchboard types considered in this section could be broadly placed in three groups: those of small to medium ratings, those of relatively high ratings, and those of extra-high ratings insofar as their prospective short-circuit current capabilities are concerned. These short-circuit current capabilities may,

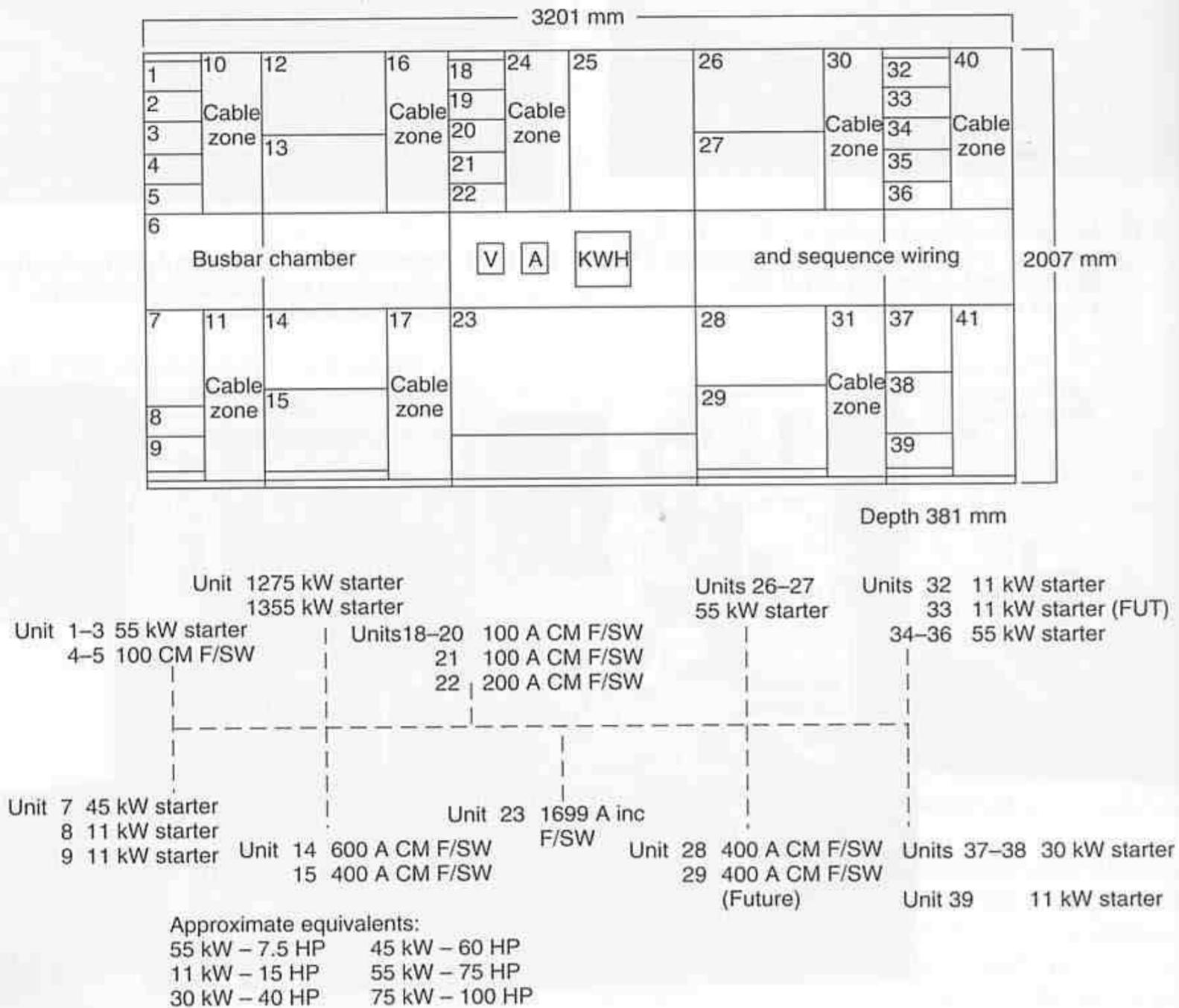


Fig. 17.17 Arrangement of a typical motor-control and power distribution centre GEC AUSTRALIA

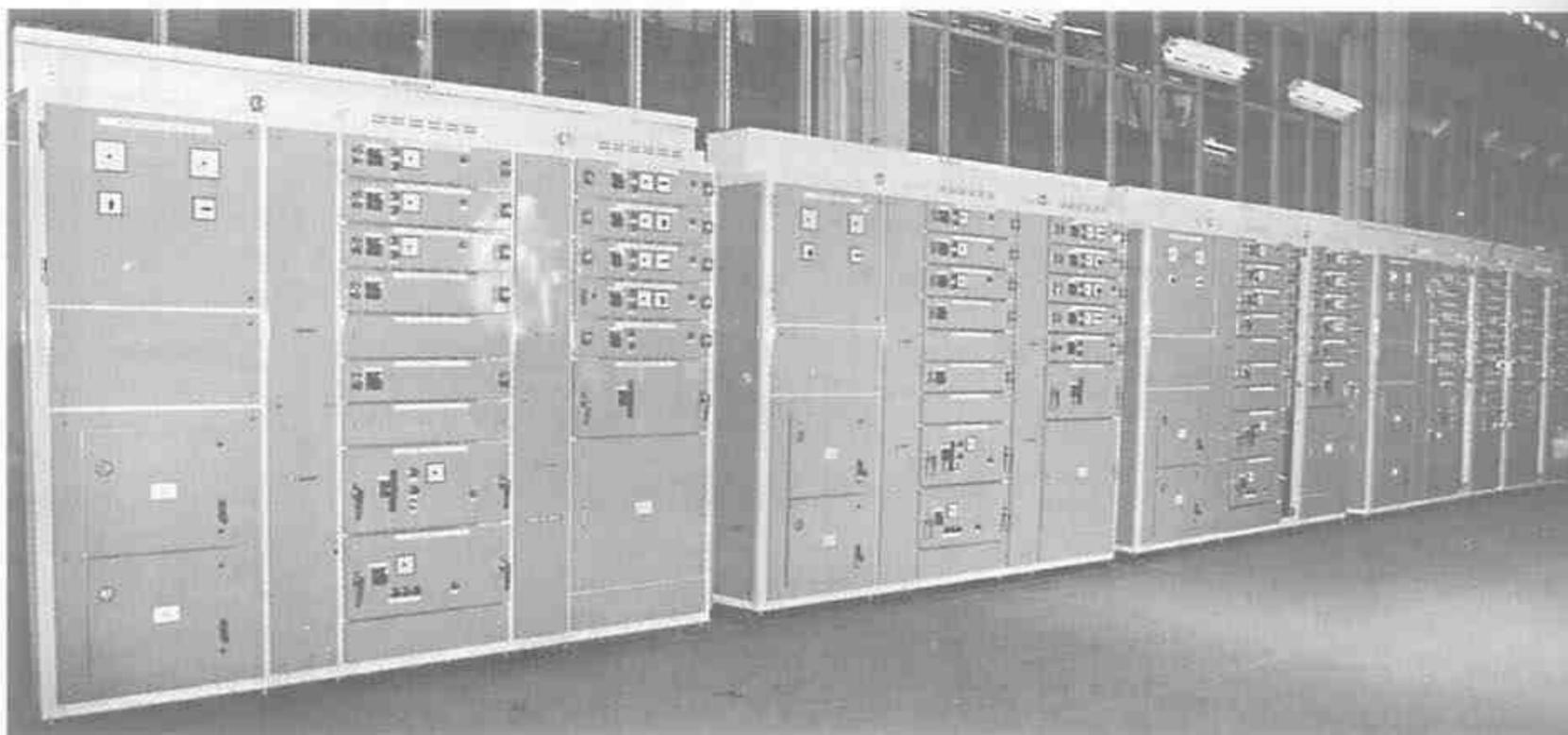


Fig. 17.19 Motor control centres CUTLER-HAMMER

however, be modified by the use of HRC fuses as current limiters.

Switchboards in the first group would be found installed in light industrial and commercial premises. Switchboards in the second group would be found in large factory and industrial situations and would usually be manufactured in Australia or New Zealand to standard specifications, using equipment and sometimes complete modules of local or imported manufacture. Switchboards in the third group, with really high ratings, would be confined to the power supply industry or heavy industry such as steelworks or automobile manufacturers.

With the latter group the modules and equipment are invariably imported but are assembled in Australia or New Zealand by firms of international status with sophisticated testing facilities. The international firms also often compete in other switchboard areas.

The classification of switchboards into 'domestic' and 'non-domestic' types is to illustrate the typical arrangements for the different types of installation. This does not mean that a typical non-domestic switchboard could not be installed in a domestic dwelling. Many large luxury houses require a switchboard that resembles that for, say, a small factory. Inner-city living has become more popular in recent years, resulting in the development of large high-rise apartment buildings. The main switchboards for these installations are similar to those for any large high-rise buildings. Ultimately, the design, arrangement and protection required of a switchboard will depend on the load of the installation.

17.5 Testing and inspection

The switchboard position and its facilities for the isolation and control of circuits are used as a means for carrying out tests on the whole or on any part of the installation that commences at the switchboard. Checking of the switchboard or SCA itself must also be done to ensure that it complies with all the rules of AS 3000, AS 3439 and the local energy distributor.

A visual examination of the switchboard should be made to check design requirements such as front clearance, rear panel clearances and access, spacing, logical layout and grouping of equipment, and accessibility of wiring and equipment. As pointed out in section 17.2, if a hinged panel is used, it should be possible to swing it out at an angle of at least 60° to inspect wiring at the rear of the switchboard.

Panel marking should also be inspected for legibility and correctness, and each circuit should be checked to ensure that it is connected to the correct control and protection equipment and that the marking corresponds to the circuit connections. Serious accidents have been caused by incorrect connections or cross-connections between circuits.

Equipment on the board is always supplied by manufacturers and built to comply with relevant codes; so the only tests required on equipment are to see that its voltage, current and fault level ratings are correct, to check it for correct operation, and to make any adjustments required such as overload or time-delay settings.

With regard to factory tests on equipment supplied

by the manufacturer, these are well outside the scope of the practising electrician, but a check should always be made that equipment is of an approved type and that ratings are adequate or as specified. The significance of these tests should also be realised so that nothing is done during installation that would negate or alter any of the characteristics of the equipment supplied. AS 3439 requires that type tests be carried out on a sample of SCAs manufactured to the same or a similar design.

As an indication of the extent of these tests, they include the verification of:

- segregation of circuits
- temperature rise limits
- dielectric properties

- short circuit capacity
- clearance and creepage distance
- mechanical operation
- degree of protection
- protective (earthing) circuit.

They also include type-approval tests and routine tests to detect any defects or poor workmanship. Tests are also carried out on all components, but many of the tests can be performed only in properly equipped testing laboratories in accordance with the test procedures set out in the above Standard.

The current edition of AS 3000 (*Appendix J*) provides guidelines for the assessment of both tested and untested switchgear assemblies.

SUMMARY

- The *SAA Wiring Rules* (AS 3000—1991) specify three types of switchgear: self-contained, enclosed, and partly enclosed.
- A main switch must be readily accessible and not less than 2 m above the ground, floor or platform.
- The best location for a switchboard in a single domestic installation is inside the dwelling, for accessibility, convenience and safety.
- Switchboards must not be installed within 1.2 m of the floor or platform. A domestic switchboard must be more than 0.9 m above ground, floor or platform.
- Some prohibited and restricted locations of switchboards are given in AS 3000 and are further explained in *Doc. 3000 R/1 Rulings to SAA Wiring Rules*.
- Entry and exit requirements for switchrooms are covered by *Clause 2.21* of AS 3000.
- Provision must be made to prevent fire and shock hazards, and there must be no exposed live parts on a domestic switchboard.
- Switchboard panel thickness depends on distance between supports and panel material used. No equipment mounting holes should be within 12 mm of the panel edge.
- Fuses and circuit breakers must be grouped so as to indicate their relationship to each other and to the circuits they control.
- Neutral links must have adequate current-carrying capacity, and connections must be secure.
- Equipment on a switchboard must be properly marked.
- Wiring is normally run at the back of a panel, adequate space is required, and it must be possible—in the case of a hinged switchboard—to swing the panel through an angle of at least 60°.
- An installation is controlled by a main switch or switches mounted on the main switchboard; the maximum number of main switches permitted is six, excluding those controlling essential services such as fire pumps.
- All switches must operate in the active conductors and provide safe and effective control.
- The installation of control panels is governed by similar rules of access for operation and maintenance to those for switchboards.
- Many energy distributors specify the use of standard meter boxes for meters and consumer's equipment.
- Circuits must be clearly and indelibly identified in a domestic installation.
- Packaged switchboards using MCBs have displaced rewirable fuseboards. *AS/NZS 3018: 1997 Electrical Installations—Domestic Installations* specifies the use of MCBs for all single domestic installations.
- DIN clips fitted to MCBs enable their easy fitting and removal.
- Hinged switchboard panels are still commonly used and many use plug-in-type meters.
- A small multiple domestic installation may have only one main switchboard accessible to all consumers. However, it must have separate metering and main switches for each of the four consumers. Requirements may vary between different energy distributors.
- Larger installations will have submains to feed individual switchboards for each consumer.
- Provision may be made for common services, such as separate metered public lighting.
- Packaged switchboards similar to the domestic boards described in section 17.3 may be used for small industrial and light commercial installations.
- Larger panel boards or load centres (see Figs 17.12 and 17.13) may be used for larger installations. Alternatively they may be custom-built, particularly for very large installations (see Fig. 17.15).
- Checking of a switchboard or switchgear and controlgear assembly (SCA) must be done to ensure that it complies with the requirements of AS 3000, AS 3439 and the energy distributor.
- A visual inspection of design requirements such as front clearance, rear panel clearance and access, spacing, layout, grouping of equipment and accessibility of wiring should be made.
- Panel marking and circuit identification must also be checked.
- Tests should take in type approval segregation of circuits, temperature rise limits, dielectric properties, short circuit capacity, clearance and creepage distances, mechanical operation, degree of protection, and the protective (earthing) circuit.



REVIEW QUESTIONS

Where the answer to a review question is numerical or requires reference to the SAA Wiring Rules, the answer is given at the back of the book. These questions are marked ★.

- ★ 1. Explain the difference between a switchboard and a control panel.
- ★ 2. A main switch must be readily accessible. What is meant by the term 'readily accessible'?
- ★ 3. List some prohibited locations for switchboards.
- ★ 4. What access must be provided to a switchroom?
- ★ 5. Is it necessary for the sheath or enclosure of conductors to continue into a switchboard surround?
- ★ 6. May a domestic switchboard have exposed live parts accessible without the use of a tool?
- ★ 7. On what does the thickness of a switchboard panel depend?
- ★ 8. State the minimum distance permissible from a fuse body to the edge of a switchboard panel.
- ★ 9. Under what conditions may a neutral link be mounted on the back of a switchboard?
- ★10. May a 30 A fuse be used on a circuit having a maximum demand rating of 15 A?
- ★11. Is it necessary to provide a separate control switch on the switchboard at which a 105 A circuit originates?
- ★12. A domestic installation forms part of a multiple installation. Must it be provided with its own readily accessible switch to control the whole of the domestic installation?
- ★13. What conditions would make it necessary to move a switchboard to a new position after additions or alterations had been made to the switchboard?
- 14. An electrician avoids the necessity of altering an existing switchboard by installing a separate switchboard close to and fed from the existing switchboard. Under what conditions is this permissible?
- ★15. How is the relationship of switches, fuses and so on to various sections of an installation shown on a switchboard?
- 16. In areas where plug-in-type meters and audio-frequency injection relays are used for controlled loads, is it usually necessary for the electrician to mount the meter bases on the switchboard and wire them up?
- ★17. How must equipment be fixed to a switchboard panel?
- 18. Would self-adhesive labels be acceptable for labelling switchgear mounted on a bituminous-based switchboard panel?
- 19. List six classifications of switchgear and controlgear assemblies.
- 20. What are the advantages of modular construction for large industrial switchboards?
- 21. Where are desk-type SCAs used?
- 22. When testing or examining a completed switchboard, what visual checks should be made?

21

Electrical heating

This chapter introduces you to electrical heating equipment by outlining the principles and applications of some common types of appliances. More specifically, it looks at:

- some *SAA Wiring Rules* that apply to water- and space-heating installations
- principles and types of heating control devices
- instantaneous and storage-type hot-water systems, and how they are controlled
- space-heating equipment
- electrical production of heat for various industrial processes
- commercial and domestic kitchen equipment.

Because this type of heater is unvented and operates at mains pressure, it may be and most commonly is installed at floor level. The fitting of a pressure and temperature relief valve in the hot-water outlet pipe is compulsory on all unvented storage water heaters. If this valve is functioning correctly, it eliminates the risk of an explosion such as that illustrated in Figure 21.1. The relief valve should be hand-operated to ensure that it releases water through its outlet pipe at least twice a year. A typical relief valve on systems above 160 litre capacity is one set to operate if water pressure exceeds 850 kPa.

Should mains water pressure be too high, a pressure-reducing valve should be fitted by a plumber into the inlet line. Note that it is normal for some hot water to be released during the latter part of the water-heating cycle; but should leakage persist, this is an indication that inlet water pressure is too high or that the relief valve is faulty. In some states, a cold-water expansion valve is fitted to the cold-water inlet and set to drip continually during the heating cycle.

Applications and locations

If the storage capacity is large enough, and the heater supplies a multipoint installation, the arrangement is described as a 'hot-water system'. Figures 21.10(a), (b), (c), (d) and (e) illustrate some storage-heater types suitable, if sufficiently large, for hot-water systems. In Figure 21.10(f), two smaller-type storage units are shown, and these would be installed at the bath and over the sink respectively for the supply of hot water at the installed position only. All storage-type water heaters are thermostatically controlled to keep water temperature approximately constant within the delivery rating of the heater.

In the small storage system, the unit is located at the hot-water outlets to be supplied; with the larger unit supplying multipoints, the location is as close as possible to the outlet most often used. In a domestic installation, this is usually the kitchen sink. The location of a large tank is influenced by the type of building structure, which also influences the type of heater used. Figure 21.11 illustrates some possible locations and types.

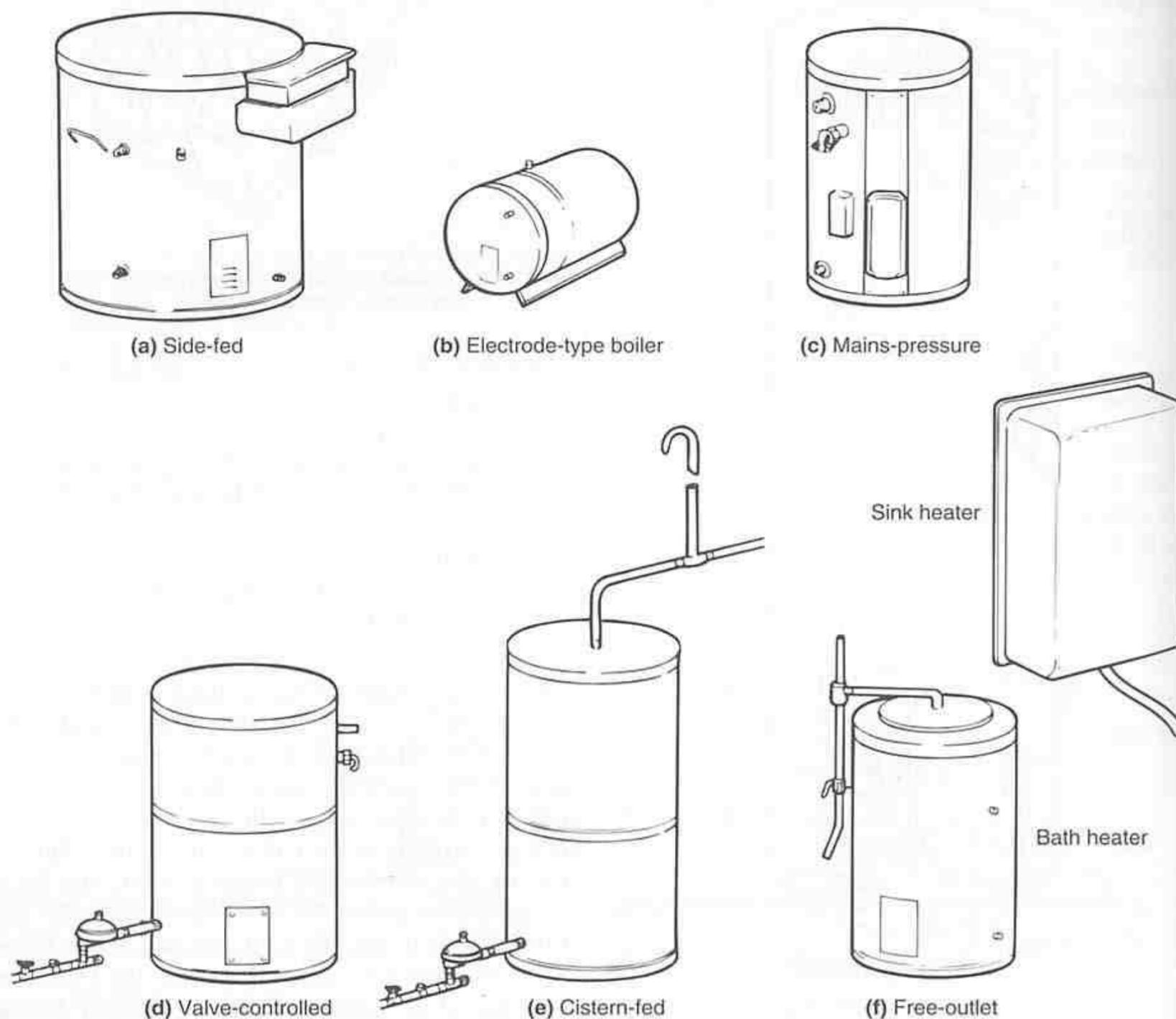


Fig. 21.10 Types of hot-water systems

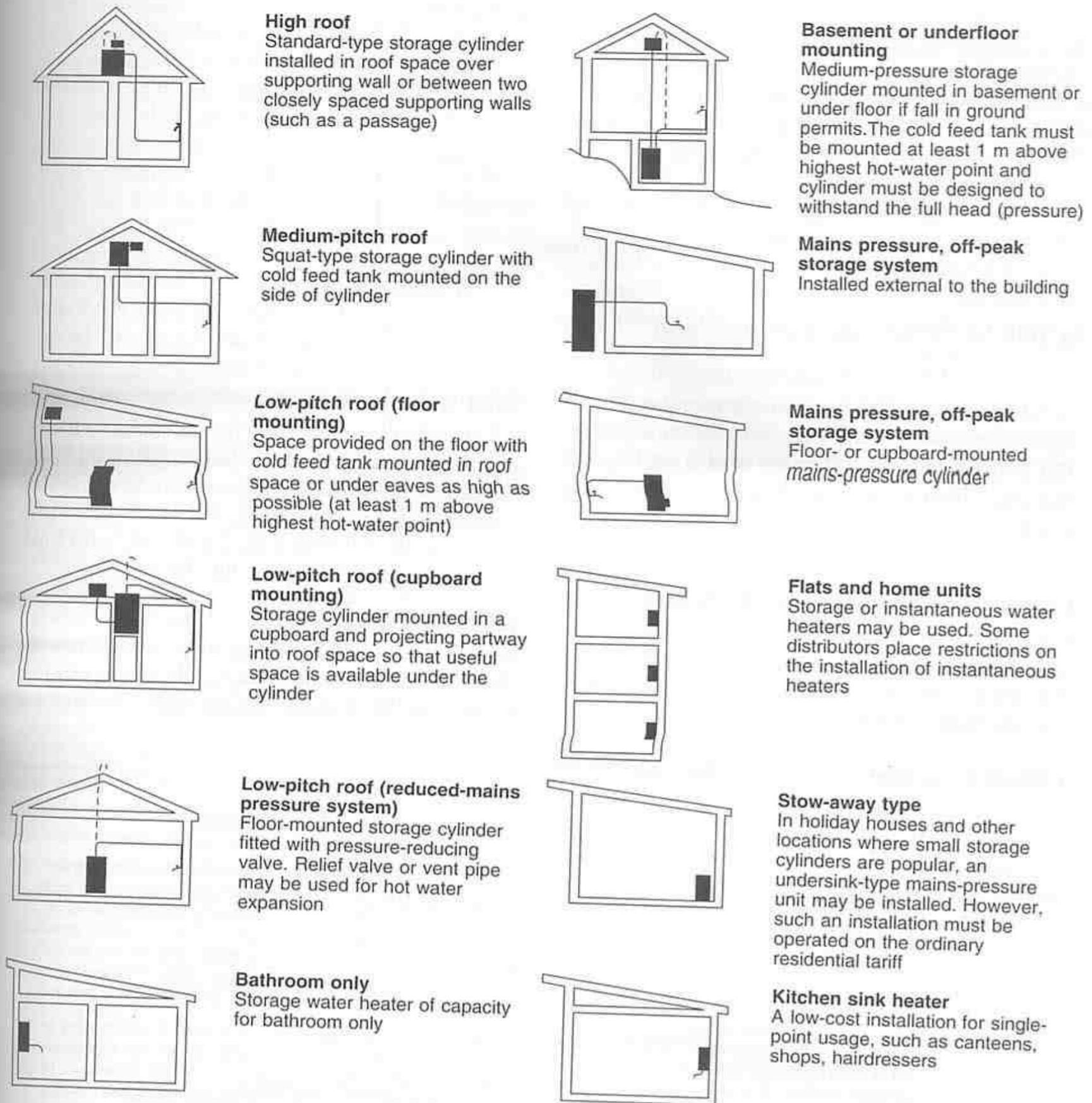


Fig. 21.11 Location of various types of water heaters

The storage-type hot-water systems discussed above are all used in domestic and other situations, the type used being dependent 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. (See the table in Chapter 18, p. 142, relating minimum heater size to house size, in order to qualify for *off-peak rate 1—automatic boosted tariff*.)

Displacement types of 6820 litres and falling-level types of up to 13 638 litres are used in commercial and industrial installations. The falling-level type is normally used only for large sizes in locations where water pressure

is poor; its maximum draw-off is governed only by the size of the hot-water pipes and the height of the storage tank, whereas that of the displacement type is limited by the inflow rate through the ballcock and cistern.

The quick-recovery mains-pressure type of storage heater is not manufactured above a size of 400 litres; so in many commercial and industrial applications, where large quantities of hot water are used, multiple storage tanks are common. Sometimes each tank is located where it supplies an area of high demand, thus eliminating long runs and consequent heat losses. Alternatively, the heaters may be used in parallel banks employing a common hot-water outlet and a common cold-water inlet manifold (see Fig. 21.12).

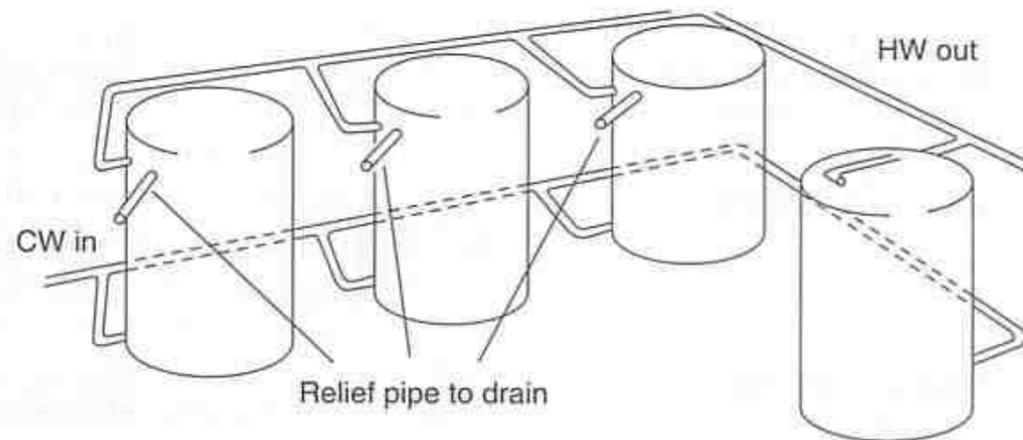


Fig. 21.12 Typical bank of mains-pressure storage heaters STATE ELECTRICITY COMMISSION OF VICTORIA

A six-element 400 litre heater is manufactured for applications where demand for hot water is high. Elements for this heater are normally rated at 4.8 kW each and arranged for star connection to a 415 V three-phase supply.

Comparison of instantaneous and storage water heaters

Table 21.1 compares off-peak continuous storage and instantaneous water heaters for commercial and industrial applications; most of the remarks are relevant to domestic installations also.

Table 21.1 Comparison of commercial- and industrial-type water heaters

	Storage		Instantaneous
	Controlled-load (off-peak)	Continuous	
Operation	Provided that the storage cylinder is of adequate capacity, this system will provide hot water without requiring daytime boosting. If necessary, an automatic booster element may be added to cover contingencies in demand.	Supply continuously available. Higher rating elements capable of heating large quantities of water quickly are used; so smaller cylinders may be employed to provide large volumes of hot water.	Cold water passes through a flow switch, automatically turning on the elements only when a hot tap is opened. The cold water is immediately heated as it passes over the elements; none is stored. Temperature is controlled by a constant flow device.
Location	In the roof, on the floor, under the floor or out of doors if vented. If unvented, cannot be located in the roof or any unfrequented location.	In the roof, on the floor, under the floor or out of doors if vented. If unvented, cannot be located in the roof or any unfrequented location due to necessity to operate exercising lever regularly, but can often be closer to hot-water outlets because of smaller size.	Physically small, and therefore easily located on any wall. Approximately 33 mm high × 20 mm wide × 10 mm deep. Extremely simple plumbing.
Economy	Most economical to operate where there is a regular and fairly uniform daily demand for hot water.	More economical than off-peak in terms of space requirements, where space is at a premium.	Most economical to operate for small or irregular hot-water demands.
Application	Hotels, motels, offices, shops, restaurants, factories, pavilions, or any commercial business requiring economical, reliable supply of hot water. Permits high flow rates without drop in temperature. Most suitable where ratio of maximum to minimum daily demand for hot water does not exceed about 2:1.	Suitable where regular daily use is assured or when all of the daily hot-water requirements cannot be stored overnight. Mains-pressure units are ideal for such applications. Falling-level-type boiling-water units are used for tea and coffee making in commercial quantities. Capacity of boiling water units ranges from 9 to 450 litres and may supply water continuously at 98°–99°C.	Public showers, ablution blocks, communal laundries and motel rooms. May be easily coupled with coin-in-the-slot meters. Used either alone or in association with other heaters for booster applications—up to 16.5 kW. Largest instantaneous heaters may take the form of electrode boilers, which can be used for hot-water supply and space heating in large commercial or institutional buildings, with or without hot-water storage.

21.1 Introduction

In wiring work, the heating effect due to current in the conductors is considered a disadvantage, and must be kept to a minimum as it represents a loss of energy. However, the heating effect of an electric current is utilised in a large variety of heating appliances employed in domestic, industrial and commercial installations. In considering this utilisation of heat energy, it is helpful to revise some basic theory relating to heat, temperature and heat transfer.

Heat

Heat is a form of energy that is equal to the total kinetic energy of the molecules or atoms of a system. A movement of electrons from atom to atom in a conductor (an electric current) such as in the element of an electrical appliance will produce heat that may be calculated thus:

$$H = IRt$$

where H = amount of heat produced by the element in joules

I = current in amperes

R = resistance of element in ohms

t = time for which current flows in seconds.

Temperature

Temperature may be defined as the degree of hotness of a body. It determines the direction in which heat flows, which will always be from a hotter to a colder body. The rate of heat transfer will be largely dependent on the temperature difference between the two bodies.

Heat energy transfer

Heat energy is transferred in three ways:

- **Radiation** is the transmission of heat energy away from an object in a way that involves no material means of transfer. Heat is transferred as an electromagnetic radiation. As its transmission is in straight lines similar to light, it may be directed or focused by suitable reflectors. A bright or polished surface reflects and does not absorb most of the radiant energy that falls on it, and is also a poor radiator of heat. A matt black surface is the best absorber and radiator of heat, and the quantity of heat radiated rises rapidly as the temperature rises. Radiant heat is transmitted from a hotter to a colder body without appreciably heating the air through which it passes.
- **Convection** involves the transfer of heat by the circulation of a fluid, either liquid or gas. In space heating, for example, air is the common medium for transfer. If the transfer is caused by the natural motion

of the air due to density differences, it is termed 'natural convection'. An electric element causes heated air to rise, establishing natural convection currents that circulate gradually through a room. On the other hand, if the heated air is made to move by a fan, the transfer is termed 'forced convection' and better heat distribution results. However, too high a velocity of air movement may cause a sensation of cold due to moisture evaporation from the skin. Convection currents escaping through doors and windows, ducts and cracks are a major source of heat loss in buildings.

In a storage hot-water system, molecules of water in intimate contact with the element are heated by the element, become less dense and rise. Colder, denser molecules move in to take their place, establishing convection currents which carry the heated water to the top of the storage tank.

- **Conduction** is transmission of heat directly from one body to another. A common application is the electric blanket. The method is rarely used directly in space heating, but it is used indirectly in convection heaters, as in this case the air is heated by direct contact with the heating element.

Thermal conductivity

Thermal conductivity is a measure of the rate at which the heat will be transferred through a material, for example from the inner water container of a storage HW system through the insulation wrapped around this container and through the outer metal casing to the surrounding air (refer to Fig. 21.9(a)). The resulting heat loss will be dependent on the temperature difference between the hot water and the outside air, thickness of the insulation, type of insulation, and surface area of the container.

21.2 Water- and space-heating installations: general

Any equipment designed for space heating or process heating is of necessity an energy-consuming device, and is therefore classed as an electrical appliance as defined by *Clauses 0.5.7 to 0.5.11* inclusive. The circuitry, control and protection of an appliance is governed by its type and rating, the degree of control required and the environment in which it operates.

Relatively low-rated, portable heating equipment (e.g. jugs, toasters, radiators and small urns) generally require no special wiring. The usual low-power rating of 2.4 kW or less allows them to be plugged into an ordinary 240 V general-purpose outlet (GPO).

Some appliances, if rated at 20 A or more, such as a 5.2 kW air conditioner or a large hot-water urn, may

have to be supplied by their own separate subcircuits, as indicated by *Clause 2.9*. If the loading of an appliance is such that a socket outlet rated at 20 A or higher is necessary, it is essential that the appliance plug be of the higher rating to prevent accidental connection to a 10 A or 15 A socket outlet.

Fixed heating appliances such as strip heaters may be permanently connected to or plugged into circuits containing GPOs, but the number of points per circuit must be in accordance with *Tables 2.5* and *2.6* of the Rules.

These two tables, together with their respective footnotes, should be carefully studied. In non-domestic buildings incorporating permanently installed space-heating or -cooling equipment (not necessarily electric), the assumption is that their installation makes the use of portable heating or cooling appliances unnecessary. Because of this, the number of GPOs on circuits comprising only GPOs and protected by circuit breakers or high-rupturing-capacity (HRC) fuses may be increased, as indicated in column 3 of *Table 2.6* and in column 7 of *Table 2.8*.

When a **single** heating appliance is supplied by its own subcircuit, the current rating of the circuit and hence the cable used are determined by the nameplate rating of the appliance. For example, a heater rated at 240 V, 20 A would be supplied by cable rated at 20 A or higher. There are only two exceptions to this Rule, as far as heating equipment is concerned:

- if a 'duty cycle' can be established to the satisfaction of the energy distributor (see *Clause 2.9.2*);
- in the case of a range in a **domestic** installation where *Clause 2.9.4.2* applies.

Because mains and submains do not supply a single appliance but supply a number of different appliances that are used in diverse ways and at various times, the loading is determined by a 'maximum demand' calculation, and the cable rating is usually less than that of the total connected load rating. The 'diversity factors' applied in the calculation of maximum demand are given in *Tables 2.3* and *2.4* of AS 3000. The subject of maximum demand is discussed in Chapter 16.

The requirements of *Clause 4.18* apply to appliances in general, while other Rules apply to particular appliance types. *Clause 4.20* applies specifically to water heaters, and requires that unvented water heaters be installed in such a way that access to the terminals of the protective devices, such as pressure-relief valves, thermostats and overtemperature cut-outs, is readily available for inspection and adjustment. A water heater should also be arranged so that the elements can be removed as necessary for replacement.

Warning: With any unvented water heater, under no circumstances should a thermostat or a protective device be 'bridged out' to complete the circuit to the element (see Fig. 21.1). It is also important to note that



Fig. 21.1 Damage to buildings caused by the explosion of an unvented storage water heater SYDNEY ELECTRICITY

an unvented water heater should **never** be placed in service without the thermostat or protective cut-outs properly fitted and connected and the heater filled with water. Some older-type heaters may be found fitted with a thermostat only, and advice should be immediately obtained from the manufacturer or the energy distributor on the most suitable method for fitting the necessary protection.

In general, the weight of a water heater should be carried by its own supporting structure, bracket or hob, but *Clause 4.20.3.1* provides that the energy distributor may accept a water heater supported by water pipes, dependent on the size and construction of the heater and arrangement and fixing of the pipes. Support by conduit, however, is prohibited.

Note that all appliances must be directly earthed and that *Clause 4.20.5* specifies that conduit near a water heater must be arranged so that water issuing from a faulty heater cannot remain in the conduit.

Clause 4.20.7 regarding the control of water heaters is important, because it requires the following:

- The heater must be controlled by an independent switch **in addition to** any automatic control.
- The heater control switch may be adjacent to the heater or at the switchboard. A position adjacent to the heater is usually preferred for servicing, as this allows tests at the heater to be made without the necessity of repeated trips to the switchboard, but the Rules permit either position.

- The control switch should have silver or silver-coated surfaces. This provision is necessary on any switch controlling an appliance where the switch may not be operated for long periods, because most contact materials require the wiping action of the contacts to keep their contact resistance low. This does not apply to silver contacts.

Clause 4.21 deals with the special requirements for heaters and steam generators which have electrode-type elements; many of these operate on high voltage. This heater type is normally used for 'boilers' or steam generators, where the turbulence keeps the electrode plates clean. This cleaning action, however, does not take place at lower temperatures, and most energy distributors will not permit the use of this type for other than special purposes.

One practical difficulty is that the water sediments tend to deposit on the plates, reducing the effective distance between them and causing high currents that exceed the heater rating. The pertinent point is that many special provisions must be met before this type of heater may be installed.

21.3 Principles of heating control devices

With most heating appliances, it is necessary to have some measure of control over the temperature, for example room temperature, oven temperature, incubator temperature or the temperature of an annealing furnace.

The required control may be achieved:

- manually, by switching; or
- automatically, by some form of control device.

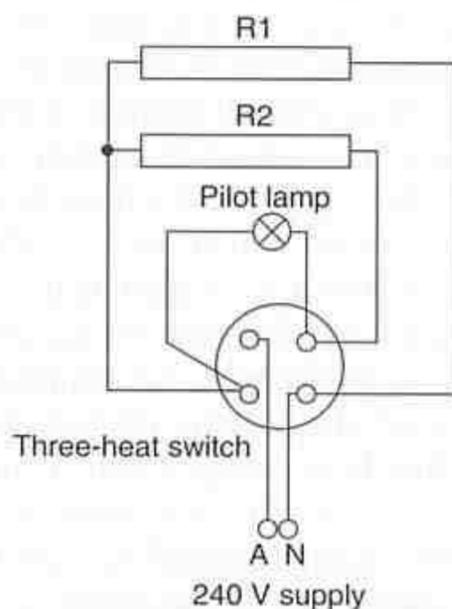


Fig. 21.2 Single-pole three-heat switch with pilot light fitted

Manual control

The simplest form of manual control is the switch on a GPO supplying a portable appliance such as a radiator, which is switched off when the appliance is not required. Some radiators have two elements that may be switched in or out of circuit at will by operating single switches to achieve a crude form of control. An improvement on this method of control may be found on some older hot-water urns and is termed 'multiheat' or 'three-heat' switching. This form of control is shown in Figure 21.2. You should examine the various switch positions, noting that 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.

A pilot lamp is sometimes connected in a three-heat control circuit, especially on urns as shown. The lamp indication is 'bright' for the high and medium switch positions, but is 'dim' in the low position. Trace out the circuit and observe the reason for this.

Three-heat switching is now virtually obsolete and has largely been replaced by thermostatic control. However, it is a good exercise in circuitry for the electrical student and has been retained here for this reason.

The principle of being able to select alternative heat positions of either high or low heat is illustrated in Figure 21.3, applied to a three-phase instantaneous water heater.

The switching arrangement of Figure 21.4 is still used on some domestic room heaters. An interesting exercise for you 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.

All the preceding manual controls, which are representative of the many types available, are 'on-off' or 'stepped-control' types. As they are manually set or controlled, control relies heavily on the judgment of the

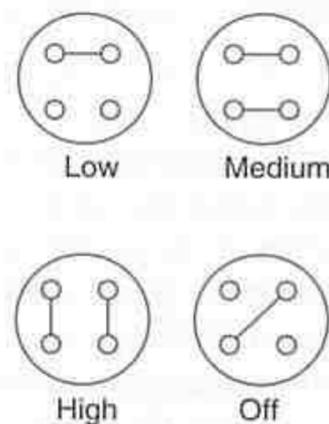


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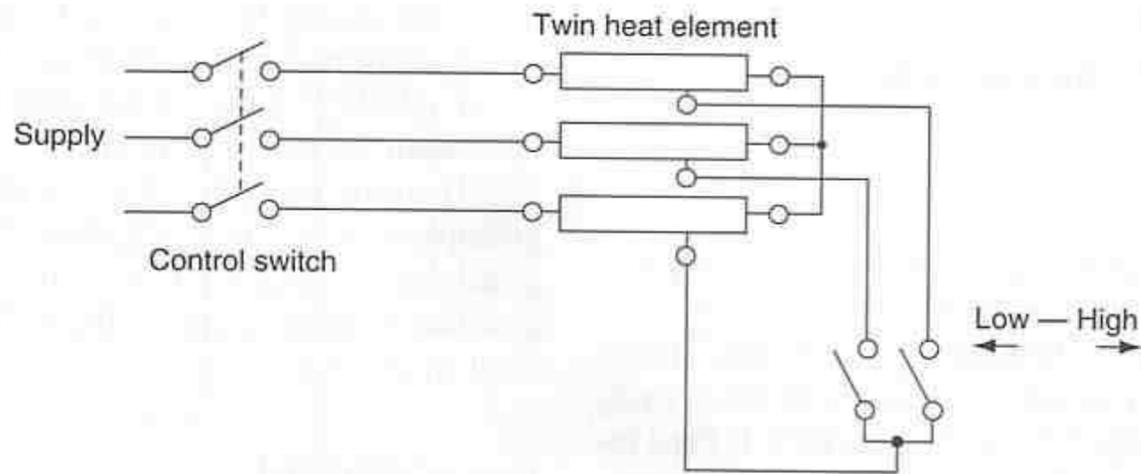


Fig. 21.3 Water heater with twin heat element

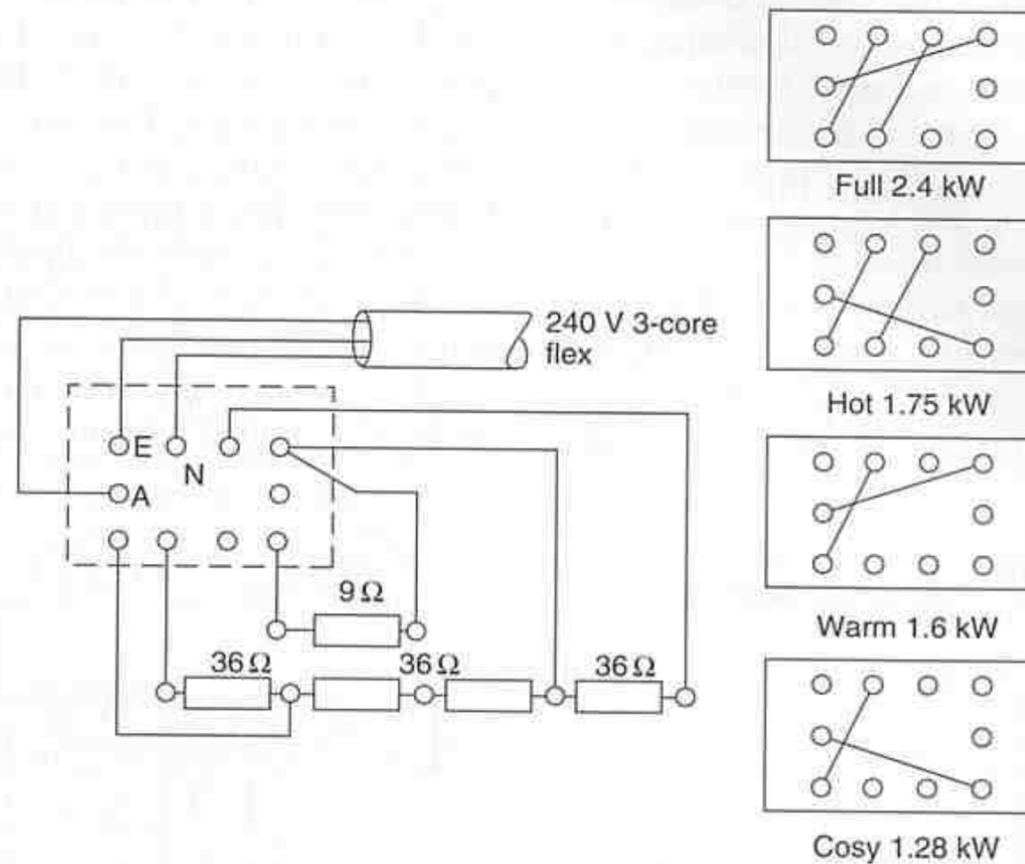


Fig. 21.4 Four-heat control of a convection-type room heater

operator. However, because manual control is relatively simple and inexpensive, it is commonly used on many heating appliances. If more precise temperature control is required, automatic control devices are used.

Automatic control

For automatic temperature control, there are two main groups of control devices:

- thermostatic control, which maintains the temperature between upper and lower limits, termed the 'differential'. Temperature is maintained between the two temperature limits by automatically switching off at the upper limit and back on at the lower limit as the thermostat senses the temperature;
- simmerstatic or energy regulator control. This is a proportional control device, constant heat output of the electric element that it controls being achieved by

regulating the on and off periods in such a way that the average energy input is maintained at the desired level.

It is important to know the difference between a thermostat and a simmerstat. A **thermostat** senses the temperature to be controlled and controls it according to the thermostat setting; that is, it is essentially a feedback system. The **simmerstat**, on the other hand, is not a feedback system; once set, it continues to supply energy to the load, irrespective of temperature.

Thermocouples and thermistors commonly used for temperature indication may be incorporated in control circuits to form a third group of control devices; but, as they usually require expensive accessories such as amplifiers and other electronic circuits, their use is confined to rather sophisticated circuitry and control. Only thermostatic and simmerstatic control are considered further here.

Thermostatic control

There are three main types of thermostat:

- bimetal
- expanding tube
- vapour pressure.

These have many design variations, but the basic principles of each type are illustrated in Figure 21.5.

In Figure 21.5(a), the bimetal helix is fixed at one end to the supporting stem but is free to rotate or twist within its length. The other end of the helix is fixed to the operating rod, which is also free to rotate. A temperature change causes the helix and the operating rod to which it is attached to twist, thus opening or closing a set of contacts. The rod itself is made of Invar, which is an alloy having a negligible coefficient of expansion.

The brass tube shown in Figure 21.5(b) changes length with temperature change, as for the bimetal thermostat. The operating rod is made of Invar, and, being attached to the tube at one end but free to move at the other, it moves and operates the contacts.

In Figure 21.5(c), the liquid in the phial attached to the end of the capillary tube is sensitive to temperature change, and the internal pressure within the phial varies. Pressure change is transmitted through the cap-

illary tube to the bellows, which flex and actuate the switch contacts. The advantage of this type is that the sensor (phial) and the control head may be some distance apart, as in an electric oven.

There are many design variations, especially on the principles used in Figure 21.5(a) and (b), and the same principles are often used in protective devices for the detection of temperature rise due to overheating in electrical equipment.

Simmerstatic control

The simmerstat consists of a heater that causes a bimetal strip to bend, thus closing or opening contacts with a 'snap' action. If the circuit of Figure 21.6 is studied, it may be seen that with the switch in the original closed position both the load and the heater are energised, as they are both connected across the terminals RL and G. The current in the heater generates heat, warming the bimetal strip, which bends and opens the switch contacts. This action interrupts supply to both the load and the heater element, the bimetal strip cools and the switch contacts close again to repeat the cycle.

The rate or ratio of 'time on' to 'time off' may be adjusted by turning the cam to adjust pressure on the

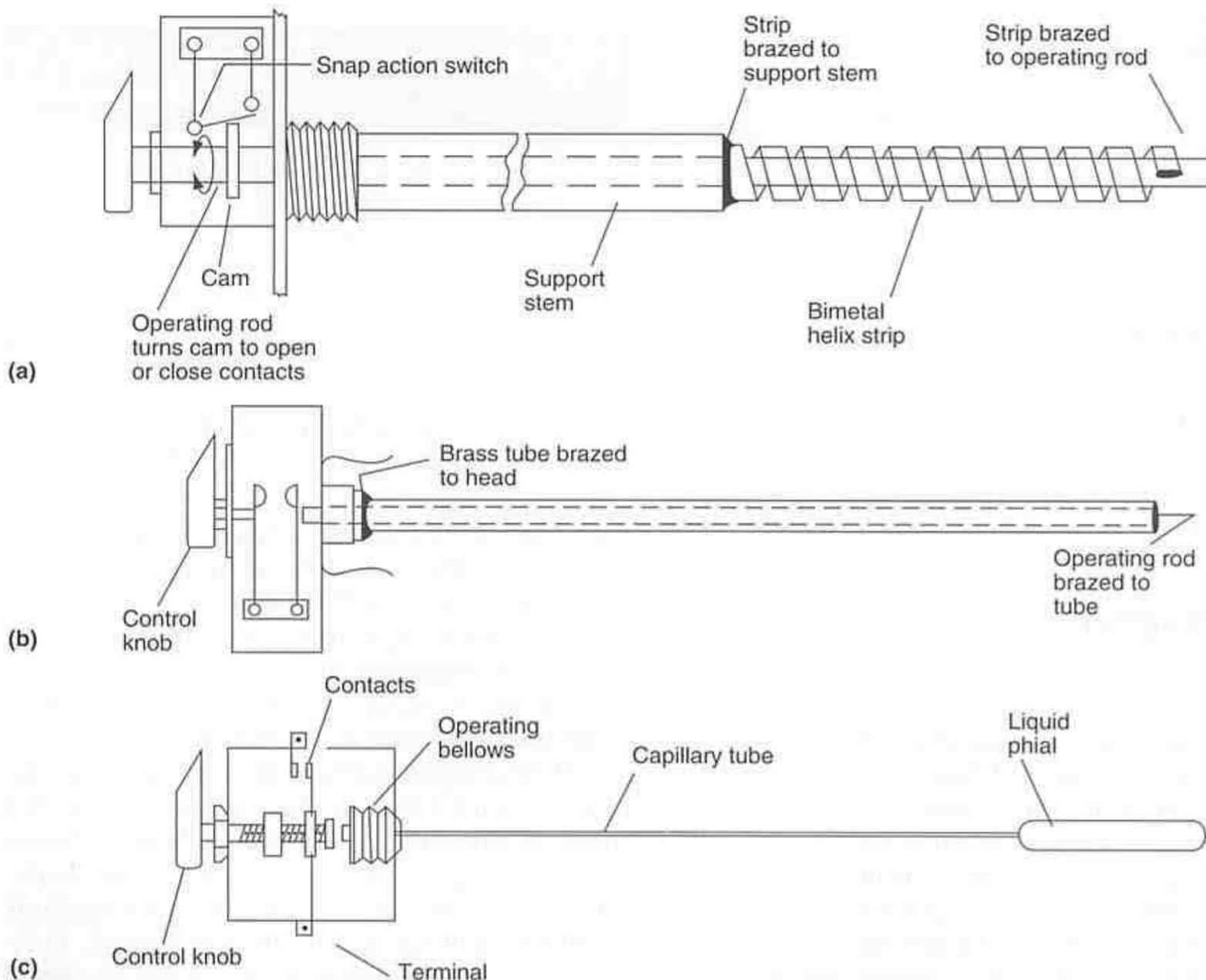


Fig. 21.5 Principles of typical thermostat types: (a) bimetal; (b) expanding tube; (c) vapour pressure

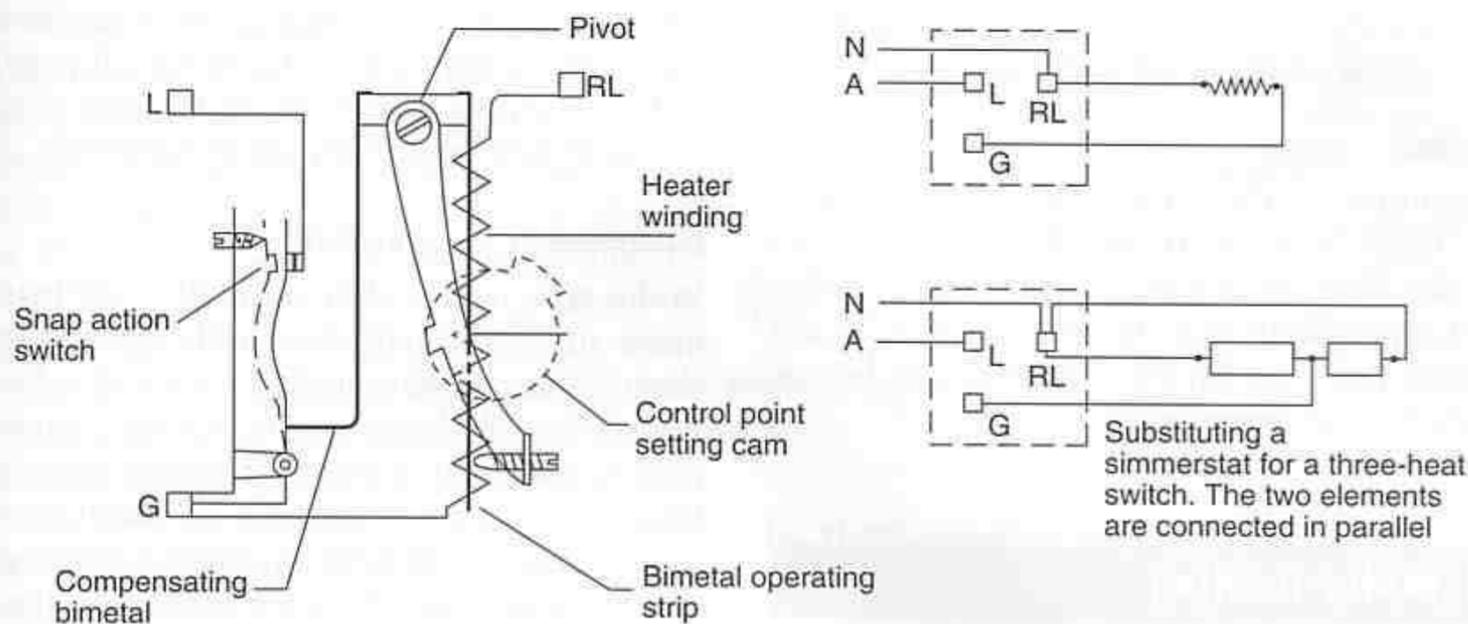


Fig. 21.6 Simmerstat control

bimetal pressing. A compensating bimetal strip adjusts for any variation in the ambient temperature; and because the heater and the load receive the same voltage, any variation in supply voltage does not affect the heat produced.

The three-phase automatic instantaneous type of water heater has no temperature control, water temperature being governed by rate of water flow, but the

heater element is automatically switched on and off by a hydraulic diaphragm switch whenever a hot-water tap is operated (see Fig. 21.7).

As the only method of regulating the water temperature is by varying the water flow, most modern heaters have a 'high-low' switch fitted (see Fig. 21.3) to allow for the difference in ambient water temperature throughout the year. A diagrammatic section of this type

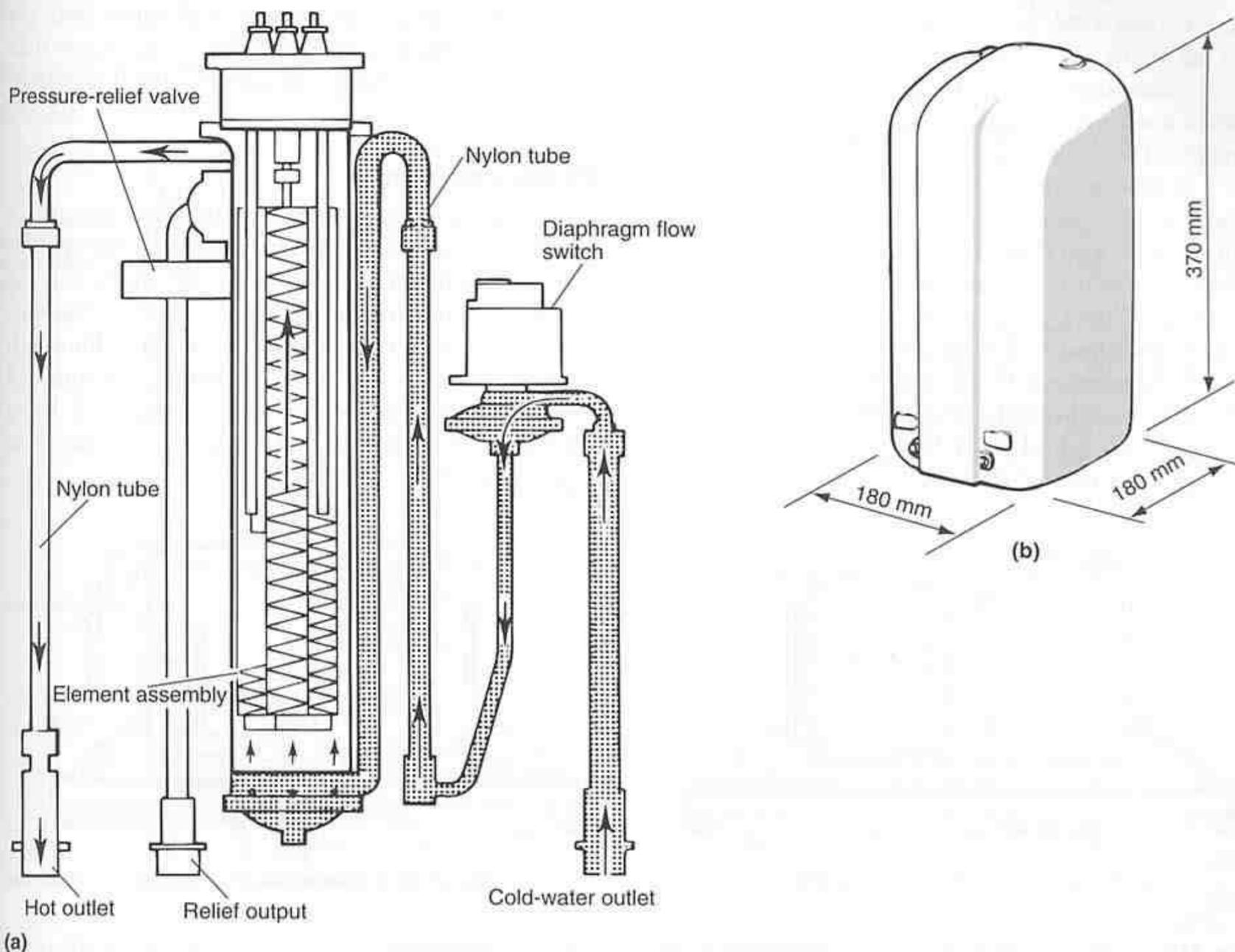


Fig. 21.7 Three-phase instantaneous water heater: (a) diagrammatic section; (b) typical dimensions

of heater is shown in Figure 21.7, with typical heater dimensions to illustrate the small overall size.

Other controls

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 encounter others.

21.4 Water heating

Classification of water heaters

Whether the installation is domestic, industrial or commercial, water heaters may be grouped into:

- instantaneous heaters; and
- storage heaters, which may be further classified according to their use and tariff rating into load groups of
 - (a) continuous water heaters, and
 - (b) controlled-load or restricted-hours water heaters.

These classifications are used for maximum demand assessments (see *Table 2.3*, column 1, load groups E, F and G; and *Table 2.4*, column 1, load groups C and G of AS 3000).

Instantaneous water heaters are switched on only when hot water is required, and are usually arranged for supply at normal tariff rates.

Continuous water heaters are in circuit continuously, as their name implies, and have a storage capacity. In common with the instantaneous type of water heater, they are supplied on normal tariff. Because of the water stored as reserve, continuous water heaters represent a much lower load on the supply system (compare three-phase instantaneous 13 kW with 80 litre continuous at 3.6 kW), and thus fall into a different load category.

Controlled-load water heaters usually have greater storage capacity than the continuous type, as they are

energised for only a restricted period when demand on the supply is low, that is, during the off-peak period. Although storage heaters are on for long periods, the water temperature is controlled by thermostat.

Instantaneous water heaters

In this type, illustrated in Figure 21.7, the heating elements are enclosed within a small copper container of about 0.8 litre capacity, making it essential to have water flowing through the heater when the elements are energised. On-off control may be manual or automatic; and because the automatic-instantaneous water heater utilises mains-pressure water flow to activate a diaphragm flow switch that connects the heater elements to the supply, mains pressure to operate the switch must be over 83 kPa.

Instantaneous water heaters are generally available as a three-phase unit fitted with elements rated at 18 A per phase (Victoria, 23 A). Two-heat models are fitted with a 12 A and 18 A element (Victoria, 23/18 A). Because of the high demand on the supply system and the necessity for a three-phase supply, most energy distributors discourage the installation of three-phase instantaneous water heaters. Instead they prefer to encourage the installation of off-peak hot-water systems, which make fewer demands on the supply system.

A 16.5 kW (23 A/phase) instantaneous water heater is capable of supplying approximately 6545 litres per day, but the heater cannot efficiently supply more than one tap at a time and will switch off if the flow is drastically reduced.

Storage water heaters

By the immersion of a bare or sheathed element in water, practically all the heat generated by the element of a storage heater is absorbed by the water, and the result is a more efficient heating device. A storage-type heater consists of an inner water container, within which is contained the water-immersed heating element, and an outer metal casing, the water storage tank being surrounded by a layer of heat insulation to reduce heat dissipation losses.

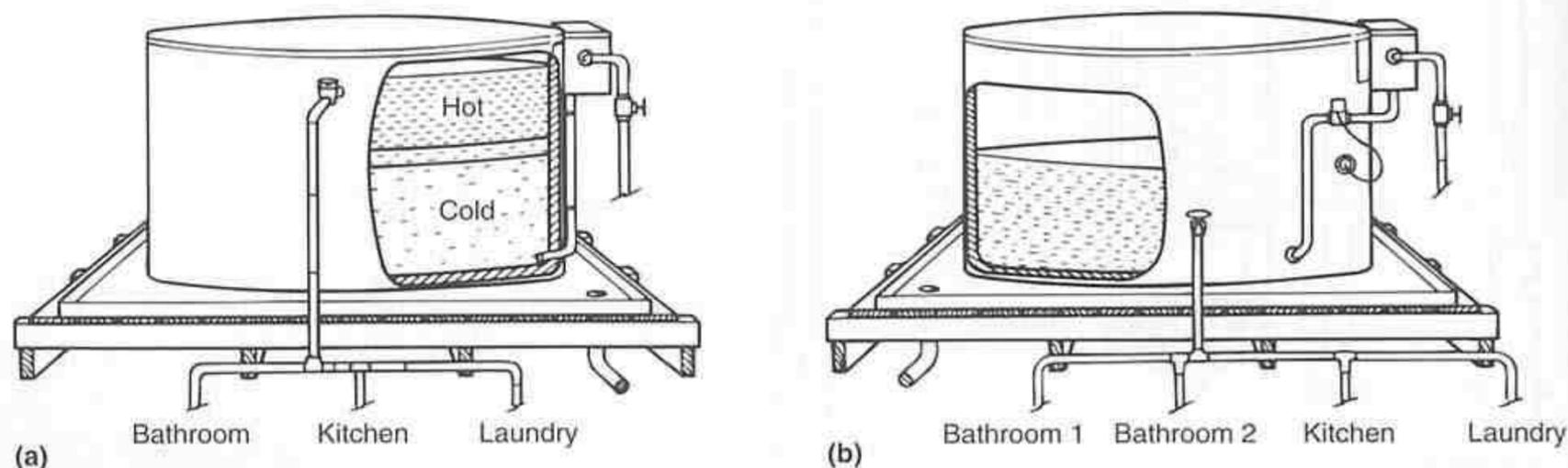


Fig. 21.8 Low-pressure water heaters: (a) displacement type; (b) falling-level type

Types of storage water heaters

As may be seen from Figure 21.11, there are several physically different storage-heater types, which, irrespective of their load groupings, could be classed as:

- displacement type, such as the one illustrated in Figure 21.8(a), in which cold water is fed into the bottom of the tank to displace the water drawn off the top. A disadvantage of this type is that, where cold-water pressure is poor, or where multiple hot-water outlets are being used (such as in the shower room of a factory), hot water may be drawn off at a faster rate than the cold water can replace it. The falling-level type described below overcomes this problem;
- falling-level type, such as the one illustrated in Figure 21.8(b), where the water level falls as the hot water is drawn off, in a manner somewhat similar to a large urn. The cold water inlet has a magnetic valve con-

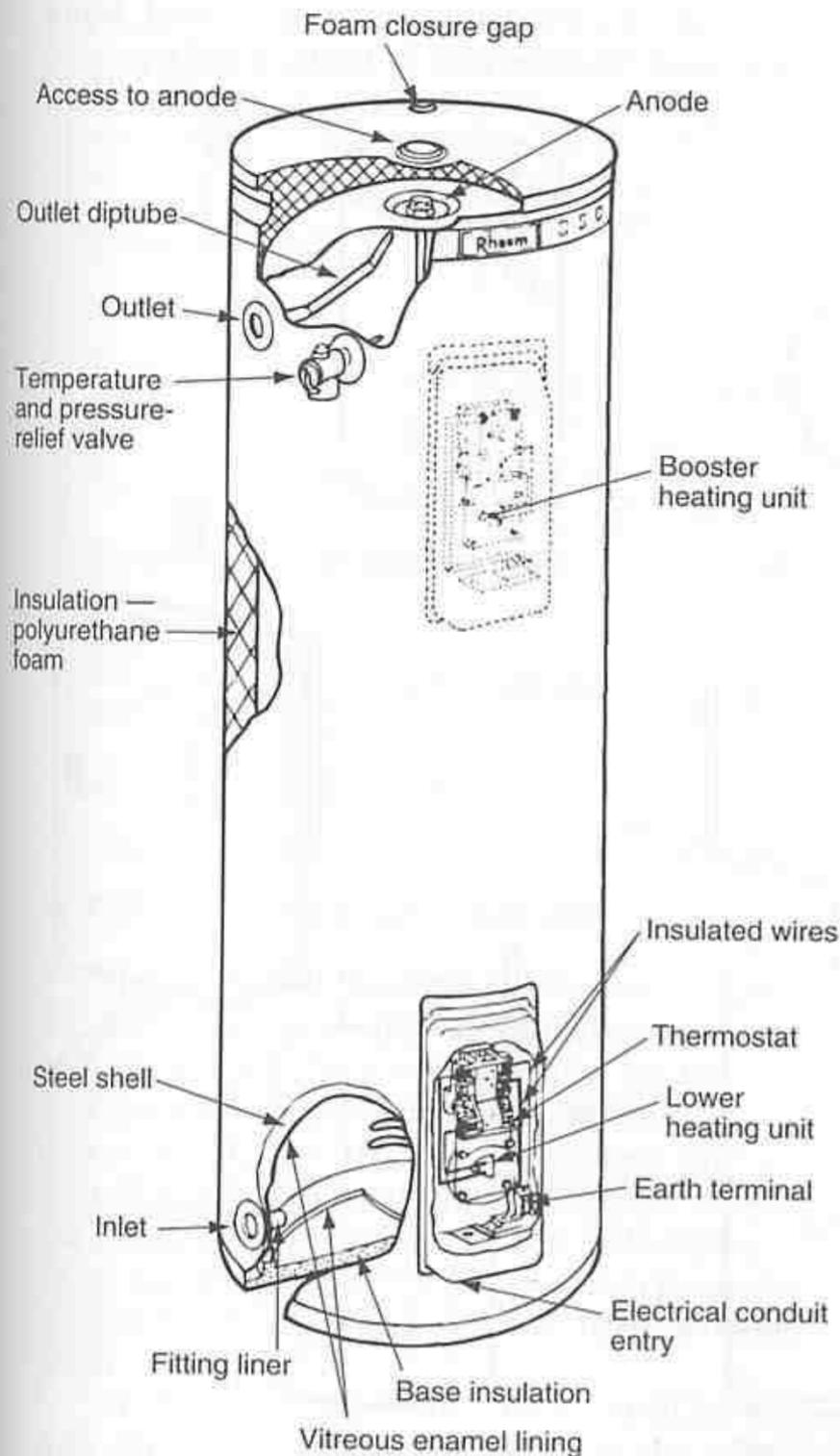


Fig. 21.9(a) Cutaway section of heater SOUTHCORP WATER HEATERS

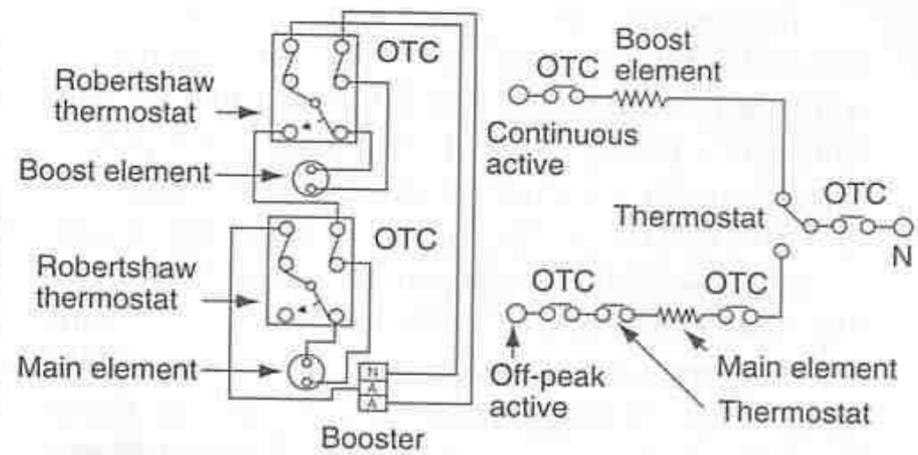


Fig. 21.9(b) Robertshaw control to two elements
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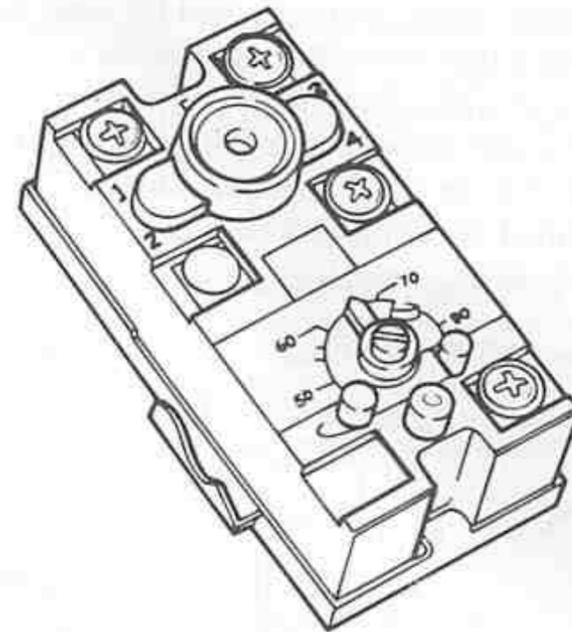


Fig. 21.9(c) Combined thermostat and overtemperature cut-out
STATE ELECTRICITY COMMISSION OF VICTORIA

nected so that it will not allow cold water into the heater until the water in the heater has reached a predetermined temperature;

- mains-pressure type, which has no feed tank, is unvented and is connected direct to the cold-water main for
 - (a) operation at full mains pressure, or
 - (b) operation at medium pressure with a pressure-reducing and pressure-relief valve.

Figure 21.9(a) illustrates a typical mains-pressure storage water heater, which is fitted with a booster element installed near the top of the cylinder. As explained in Chapter 18, the two heater elements must be wired for non-simultaneous operation. One common method of wiring to achieve this requirement is shown in Figure 21.9(b) and is termed 'Robertshaw control'. Another common method utilises a Thermodisc thermostat and a separate Klixon overtemperature cut-out (OTC). In both cases the top thermostat should be set 10°C lower than the bottom thermostat. The OTC that forms part of the thermostat assembly of Figure 21.9(c) is to prevent the water, in case of thermostat failure, from exceeding 95°C .

collector are usually close-coupled. Water in the collector is heated by solar radiation, flows to the upper part of the storage tank and is replaced by cooler water from the bottom of the tank. Extra structural timbers are normally required in the roof to support the weight of any close-coupled system.

If desired, a split system may be used, in which case the storage tank is mounted at ground level. A magnetically coupled pump circulates water from the bottom of the tank to the solar collector panels on the roof, where it is heated. A thermostatic controller prevents water from being pumped into the tank until it has reached the required temperature.

One type of close-coupled thermo-siphon solar water heater uses a 'closed circuit system' containing a non-corrosive fluid to absorb heat from the solar collector. It has an inner and outer tank, and the fluid heated at the collector panel is circulated around the outside of the inner tank, from which the hot water to be utilised is drawn. The unit, marketed as the 'Black chrome miracle', is illustrated in Figure 21.13.

A booster element is fitted to all of the above solar hot-water systems and is necessary to provide for times when insufficient solar energy is available.

To avoid the booster elements being left on indefinitely, which would nullify the benefit of solar heating, a special relay rated at 20 A, 240 V is available (see Fig. 21.14). When water is cold, an indicator neon lights up, prompting the householder to press a push-button switch to connect supply to the booster element. When the water temperature reaches the required level, a thermostat automatically turns off supply to the booster element, returning the system to normal solar operation.

Quantum system

Another type of solar hot-water system, marketed as the Quantum domestic hot-water heater, is in effect a solar-boosted heat pump. It works on the same principle as a refrigeration circuit, drawing heat out of the one space and transferring it into another. The system is available as a 'split' or a 'compact' system.

In the split system (see Fig. 21.15), a water storage tank is located at ground or floor level inside or outside the house, and the solar evaporator plate assembly is mounted on the roof. Mounting on a vertical wall is also acceptable. Although it is not essential, evaporator plates roof-mounted and oriented towards the north maximise the available solar contribution to water heating.

With the compact system the evaporator plates are formed around and permanently bonded to the water storage tank; that is, the evaporator plates form an integral part of the whole hot-water system. The unit may be located anywhere, but is more efficient if located with a northward orientation.

In operation, the evaporators absorb available heat energy from the surrounding medium (sunshine, wind, rain or air), and this energy vaporises the refrigerant, which has an evaporation point of approximately -30°C . The vapour is then compressed to raise its temperature and pressure. This high-temperature vapour is pumped through the pipes that are permanently bonded to the surface around the outside of the water storage tank; these comprise the condenser.

As the refrigerant vapour condenses back to its liquid form, it gives off its heat to the stored water. At the same time the condensed refrigerant liquid passes back to the evaporator plates, and the cycle is then repeated.

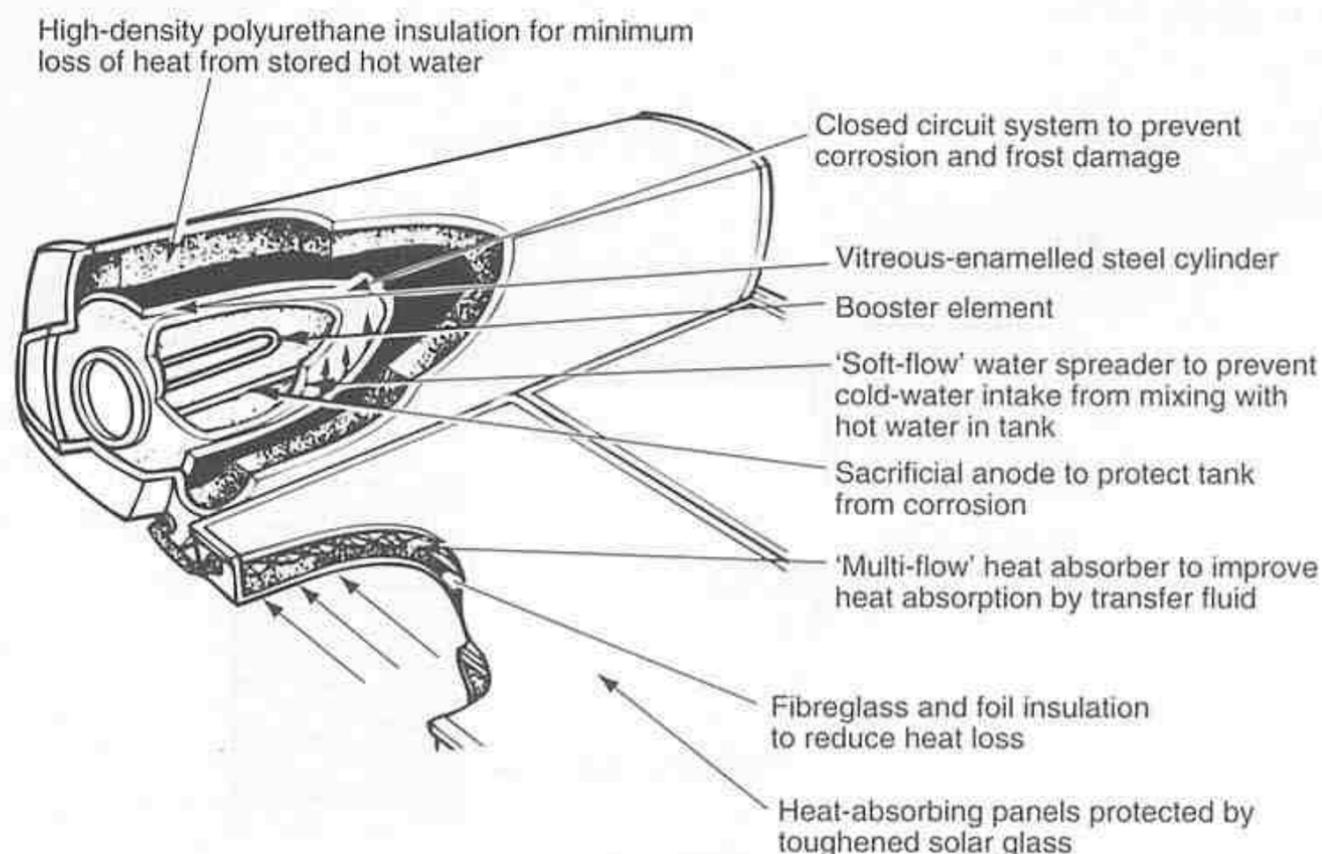
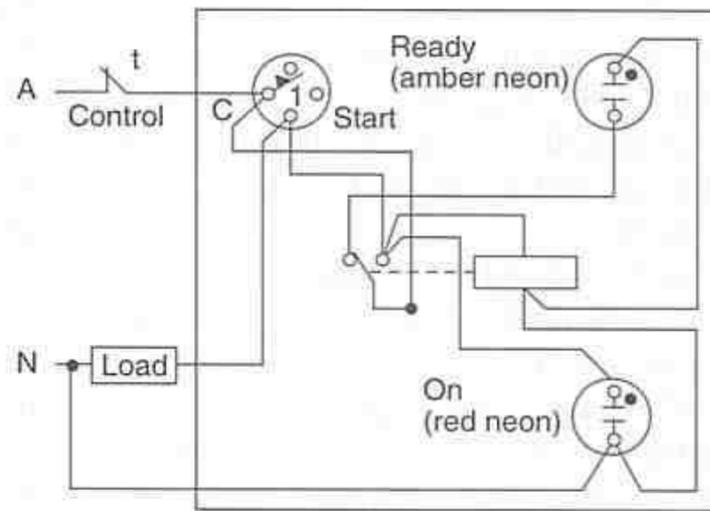
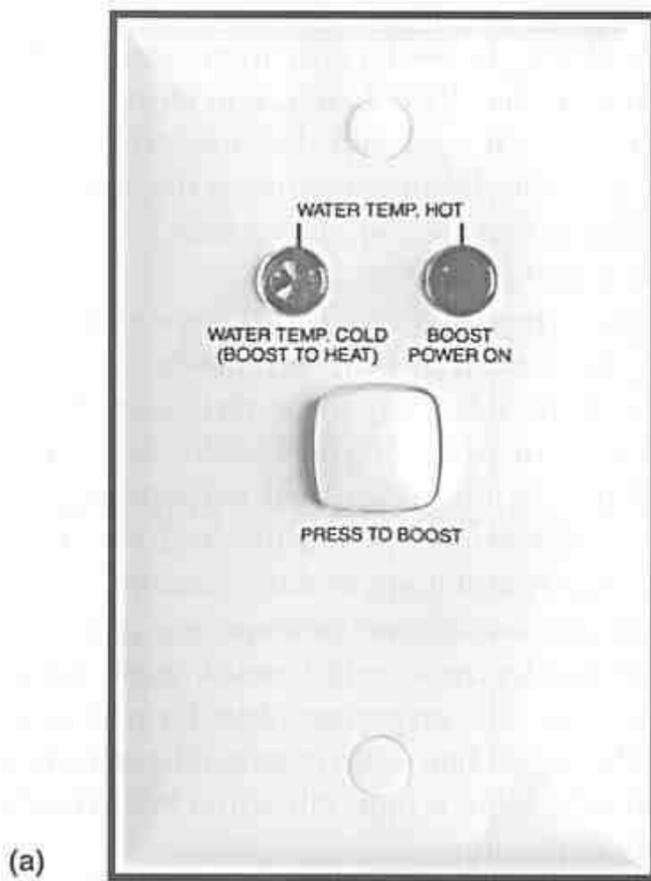


Fig. 21.13 'Closed circuit' solar hot-water system SOLAHART



- Amber neon on (e.g. thermostat closed, water cold)
- Press if boosting (one shot only) required
- Red neon on and amber neon off (e.g. hot-water booster element connected, via REL and water heating)
- No power to REL unit (e.g. water is hot and thermostat open); no operation possible until 'Ready' and 'Start' pressed for 'one shot' heating
- Must be fitted to insulate relay terminals from mounting bracket

Fig. 21.14 (a) 'One-shot' relay (b) Wiring diagram HPM INDUSTRIES

An advantage of the above system over the conventional solar water heater is that it can operate with or without sunshine; the collectors will absorb heat under practically any weather conditions and even at night. Some power is of course used by the compressor motor (typically 300–700 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. Savings in energy costs are therefore largely offset by this extra cost, at least in the short term.

The manufacturers of the Quantum system state

that it takes from 5 to 8 years to recover the extra initial cost compared with an off-peak electric system. The energy costs of running the system for an equivalent amount of hot water are less than one-third of the energy costs for off-peak storage heating and approximately 60 per cent of the costs of operating a conventional solar water-heating system.

Hot-water delivery temperatures

Most residential water heaters will deliver water at temperatures in the range 65° to 75°C. A temperature of

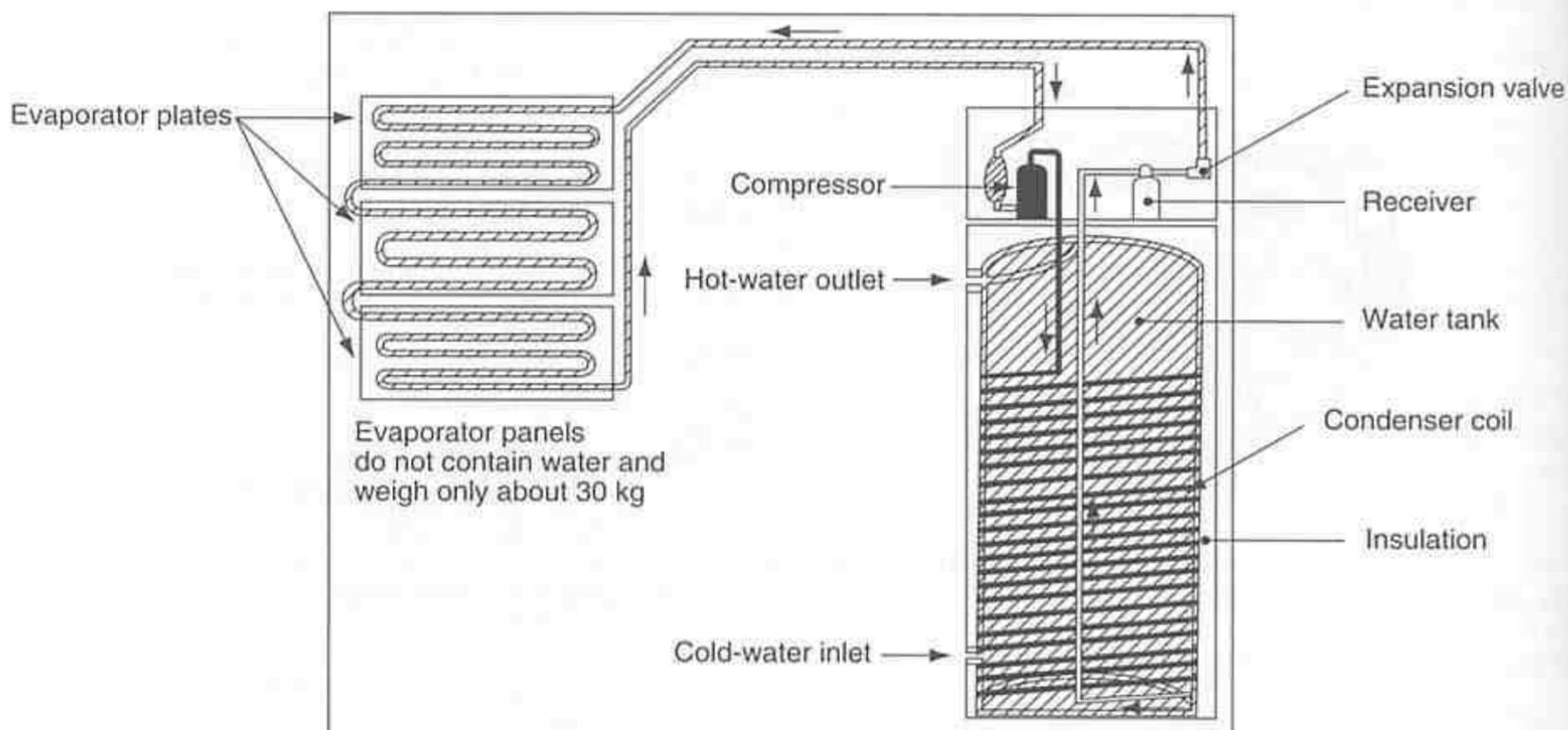


Fig. 21.15(a) Quantum split system



Fig. 21.15(b) Quantum split system SES WATER HEATERS

65°C is capable of producing third-degree burns on a child in one second. Most scalding accidents occur in the bathroom.

In September 1994, Standards Australia released a new standard (AS 3500—*National Plumbing and Drainage Code*) setting a maximum of 50°C temperature for hot water in residential bathrooms. However, in most states in Australia legislation has not been enacted that makes AS 3500 mandatory. A temperature of 50°C

raises scalding time to five minutes.

While AS 3500 sets the 50°C bathroom outlet temperature requirement in *Clause 1.10.2*, a storage temperature of 60°C minimum is required by *Clause 1.10.1*. There have been suggestions that the 60°C storage requirement be reduced to 50°C. At the same time, concern has been expressed that the reduced temperature may not kill bacteria such as *Legionella*, most of which cannot survive past 60°C. Some medical authorities

believe that the infection risk of storing water at 50°C is minimal. The matter is quite controversial.

The practising electrical worker needs to be aware that hot-water storage capacity decreases by about 10 per cent for every 5°C reduction in temperature. Dropping the temperature from say 65°C to 50°C in a 250 litre hot-water tank will reduce its effective hot-water delivery capacity to 175 litres. In addition, the thermostat's temperature differential may affect the delivery capacity. With the common use of twin-element water heaters, in effect being connected to supply 24 hours per day, the reduction in effective capacity will be less significant. If energy distributors agree to a lower storage temperature, the table mentioned earlier (from Chapter 18) relating minimum heater size to house size will no doubt need to be modified.

To achieve the existing requirements of AS 3500 (i.e. 60°C storage temperature and 50°C delivery temperatures at bathroom outlets), devices such as 'thermostatic' mixing valves or 'tempering' valves may be installed by a plumber. The thermostatic mixing valve is expensive but provides a high level of safety by accurately mixing hot and cold water in set proportions. It is readily adjustable and accurately controls outlet temperature. A tempering valve is much less expensive and may or may not be adjustable, the adjustable type permitting temperature control within plus or minus 5°C.

Tariffs for hot-water units

Energy distributors distribute electrical energy to hot-water systems and other suitable heating loads at three basic rates:

- continuous—energy is available for 24 hours per day;
- controlled continuous, restricted-hours or extended off-peak—supply is available for approximately 20 hours per day;
- off-peak or night—supply is restricted to about 8–10 hours per day, usually between 8 pm and 8 am.

Distributors differ with their regulations and conditions for connection of a unit to be supplied at a particular rate, and it is always necessary to check these requirements before installation. Some points to be checked are:

- What is the minimum storage capacity for connection on a certain tariff?
- What are the energy distributor's regulations regarding element power ratings?
- Are there any restrictions regarding the non-simultaneous operation of multiple-element units, such as an off-peak and booster element?
- What specific metering arrangements are required?
- What wiring is required to accommodate the particular type of control (e.g. time switch, relay)?

The continuous rate or normal tariff would apply to all instantaneous-type heaters, to small storage units, and to larger storage units where the demand was intermittent and where it was impractical or uneconomical to store sufficient water for a 24 hour demand. A common domestic storage unit for continuous tariff supply is a 3.6 kW, 80 litre heater having a 'recovery rate' of 55 litres per hour for 38°C temperature rise. Continuous rate requires no special metering arrangements, but the usual power ratings are such that a separate subcircuit is necessary.

Any storage system is suitable for off-peak rates, provided always that it meets local requirements and that its storage capacity is adequate. For example, in Victoria, a 160 litre hot-water heating capacity is generally the minimum size required to qualify for an off-peak rate. Some energy distributors, however, will not supply solar hot-water systems at the off-peak rate.

Where a controlled-load storage water heater for domestic use is fitted with a booster element, it is usual to operate this arrangement with two distinct circuits. The lower element could be on off-peak rate with separate metering, while the top element is connected to a circuit on normal rate controlled by the consumer's main switch. Sometimes, to reduce demand, an interlock arrangement is required between the two elements to prevent their being on simultaneously; this is usually incorporated into the storage heater unit. In some states, full off-peak rate is given 24 hours a day, subject to interlocking and a minimum-capacity storage tank in relation to the size of the household (see Chapter 18).

21.5 Space heating

The term 'space heating' describes the heating of building space to provide a comfortable and healthy work environment for people and satisfactory temperature conditions for goods and equipment. Most space-heating equipment in current use provides heat only, but it is known that other factors such as air flow, pollution and humidity have a bearing on personal comfort, and appliances such as air conditioners in some measure provide control over these.

Types and applications of space-heating equipment

Space-heating equipment may be broadly classified into three main groups:

- high-temperature radiant panels or radiators;
- low-temperature panels, convection and unit heaters;
- thermal-storage-type heaters.

The reverse-cycle air-conditioner or heat pump falls within a category of its own.

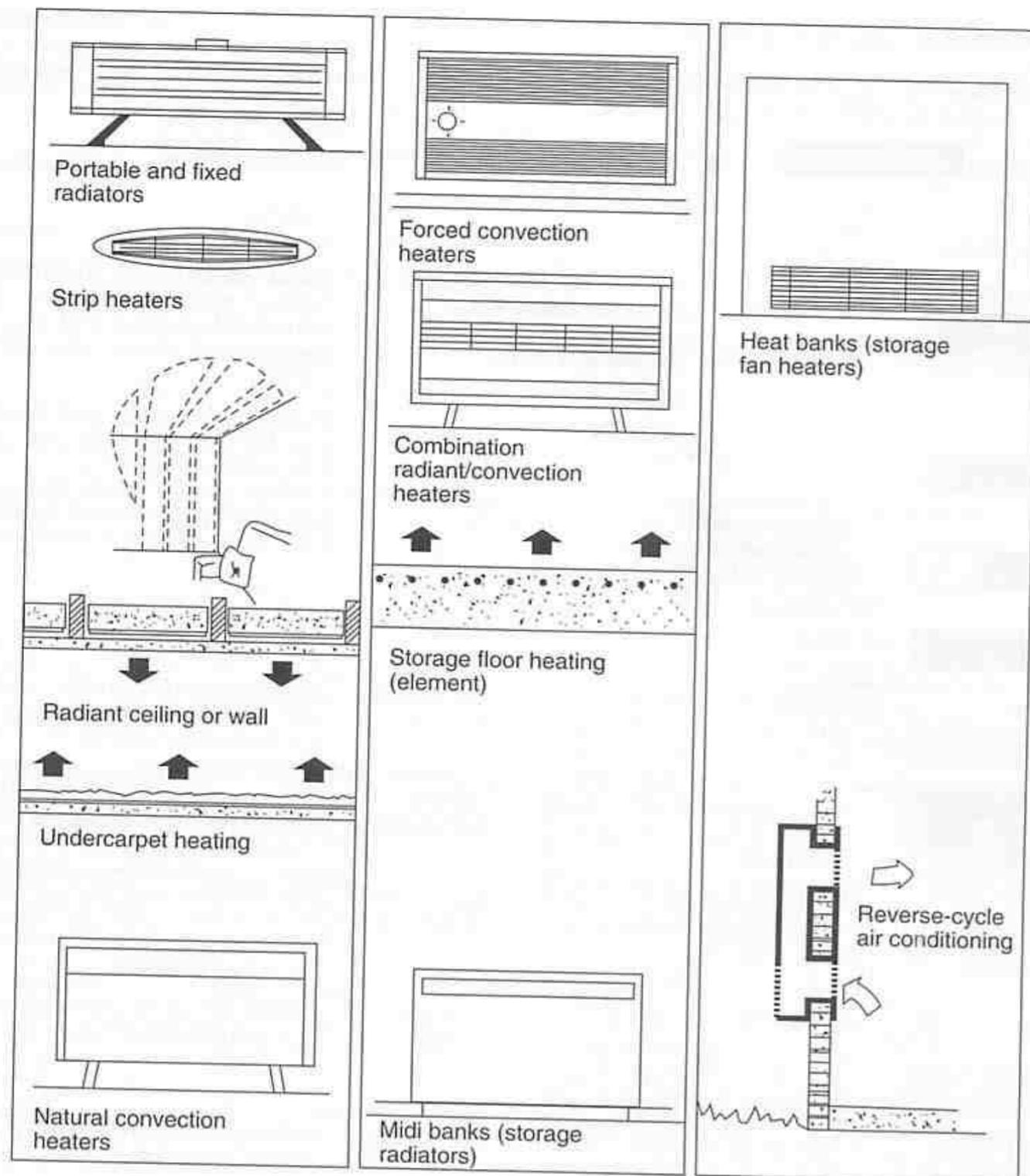


Fig. 21.16 Some types of space-heating equipment

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Figure 21.16 illustrates some types of space-heating equipment, and a summary of their properties and applications is given in Table 21.2.

The radiators and heaters have elements working at 1400°C to 1600°C , while the operating temperature for radiant wall and ceiling panels would rarely exceed 300°C . Many heating panels and fixed-heating-cable installations have a much greater area of heat dissipation, and the temperature is well below 300°C .

High-temperature heaters

Common types of portable and fixed high-temperature radiant heaters are included in Table 21.2 and Figure 21.16.

One type of radiant heater intended for commercial, industrial and institutional use is the halogen heater shown in Figure 21.17. It emits energy by radiation

giving 86 per cent radiated heat and requires no warm-up time. With radiant heat waves there is minimal heat loss through air, and when they strike a solid object such as a person's body they are converted to heat. The heater element, which is used in conjunction with an optical metal reflector, is a descendant of the linear tungsten lamp enclosed in a ruby red sleeve, and emits energy in the infrared range. The object of the sleeve is to reduce visual glare and to display a pleasant warm appearance. Lamp life claimed by the manufacturer is 9000 hours, and two lamp ratings are available (500 and 1500 W).

Mounting height for the units, which may be ceiling- or wall-mounted, is in the range 2.5 to 6 metres at a recommended angle to the vertical of 45° . If wall-mounted they are best mounted at intervals along opposite walls. When they are mounted to cover infrequently used areas, they may be used in conjunction with an

Table 21.2 Comparison of space-heating equipment

Heat dissipation percentage The rectangles in the table below represent the total heat output and the sections show the approximate proportions of radiation, convection and conduction from the different heat sources.

Type	Description	Application
Portable and fixed radiators 	Rod-type portable heaters from 750 W to 2400 W. Generally infrared rod types with element enclosed in silica tube. Permanently wired wall or console radiators for fixing to or recessing in a surround. Up to 3.6 kW.	Portable—for quick individual spot heating; for topping up other forms of heating during excessive cold periods; for heating in small rooms or rooms used intermittently. Heats the object in front of it by radiation.
Strip heaters 		As above, but particularly suitable for warming drying area of bathroom and out-of-the-way heating (e.g. kitchen, children's play areas).
Radiant wall 	Maintains comfortably warm conditions mainly by radiation, without directly raising air temperature. Safe, automatic control (if desired); completely invisible.	Flexible low-temperature panels or fixed heating cables laid on ceiling or concealed in wall.
Radiant ceiling 		
Undercarpet heating 	As above, and warmth at floor level gained by conduction is ideal where children play. Produces zero temperature gradient between floor and ceiling.	Specially insulated heating cable—mineral-insulated metal-sheathed—laid under floor covering but insulated from structural floor.
Natural convection heaters 	Cool air being drawn into the heater forces warm air upwards, providing continuous circulation without excessive air movement.	Small rooms and areas of low ceiling height where induced limited air movement is sufficient to heat all air in the room.
Forced convection heaters 	More rapid circulation of air ensures faster and more even heat distribution, which is particularly useful in large areas.	Either drum or propeller fans force air over heating elements before circulation. Available as small portable units, larger-capacity console heaters, or for building into wall or cupboards.
Combination radiant/convection heaters 	<ol style="list-style-type: none"> Two types of elements are included, one giving instant direct localised heating by radiation, the second providing heat by natural convection. Oil-filled panel and column heaters. 	Generally portable, yet large enough to provide basic heating of moderate-sized rooms.
Storage floor-heating element 	Heating cable embedded in concrete floor slab. Operated on low-cost controlled-hours tariff and heat-stored for use as required.	Central-type heating—whole buildings. In new buildings with concrete floor slabs.
Midi banks (storage radiators) 	Heating element embedded in the heat-storage core of a free-standing unit with free output characteristics. Operated on low-cost controlled-hours tariff.	Sole means of heating in dwellings with brick, masonry or concrete internal walls (providing adequate heat-storage capacity). Background heating where reinforced by auxiliary heating of other types in buildings of light construction.
Heat banks (storage fan heaters) 	An insulated storage core to which a fan has been added (operated either manually or by thermostat) to extract heat when required. Operated on low-cost controlled-hours tariff as above.	Buildings of any construction—new and existing.
Reverse-cycle air conditioning 	Mounted on an outside wall, it pumps heat either into or out of the building. It is designed to heat a room in winter and, by simple switching, cool it in summer. It will also reduce the humidity of the cooling cycle. Auxiliary direct elements may be needed in coldest weather.	Ideal for homes and flats, giving controlled comfort in winter and summer.

infrared motion detector (see Chapter 24) to conserve energy.

Manufacturers will supply recommended values of heating required in watts per square metre (W/m^2) for a specific application. For example, if the recommended value of heating for a factory in a light industrial area is given as $165 W/m^2$, how many twin ($2 \times 1500 W$)

heaters will be needed, given the area to be heated is 18×10 metres?

Area to be heated	$18 \times 10 = 180 m^2$
Recommended heating is $165 W/m^2$	
Total power required will be equal to	$180 \times 165 = 29\,700 W$

Each twin heater
requires 3000 W
Number of heaters
required $\frac{29\,700}{165} = 9.9$.

That is, 10 heaters will be required.

Low-temperature ceiling and floor heating

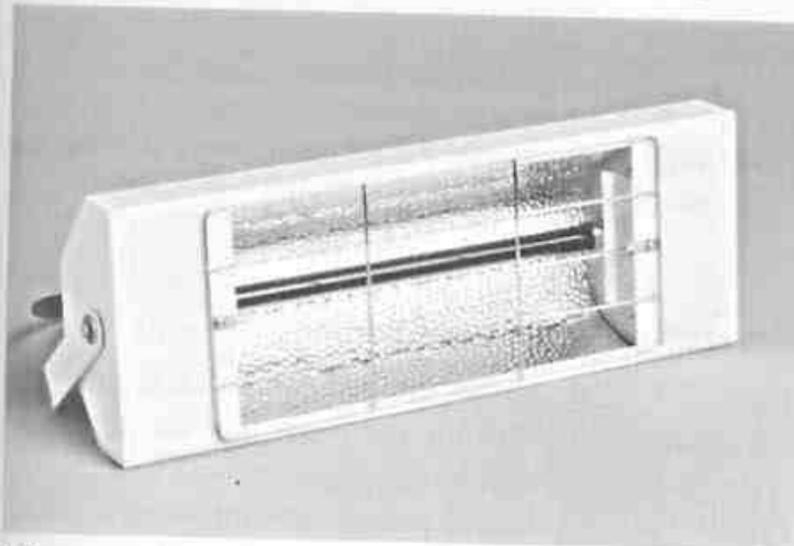
A typical heated ceiling is installed with mineral-insulated metal-sheathed (MIMS) heating cable. The heated ceiling or heated wall is a relatively expensive system to install and is not used as widely as undercarpet floor heating. Very little thermal storage capacity is possessed by either heating system, making them unsuitable for off-peak operation. A diagrammatic version of undercarpet floor heating, which is used mainly in domestic installations, is illustrated in Figure 21.18.

Electric-storage floor heating, which utilises heating cables installed in the concrete slab or tile bed prior to the finished floor surface or coverings being placed, has the advantage that it may be operated at the cheaper off-

peak rate. The cables (about 5 mm in diameter) consist of a central element embedded in an insulating material of compressed magnesium oxide encased in a polyethylene-served copper sheath. They may be fixed to an anchoring strip and installed in a pattern similar to that shown in Figure 21.19. Alternatively, they may be attached to the reinforcing mesh in a concrete slab, as shown in Figure 21.20(b).

Convection and thermal storage heaters

Convection heaters may be classified as either natural convection or forced convection units, using fans or pumps. This latter system for hot-air distribution is employed on controlled-output storage units (see Fig. 21.21), and has widespread applications in ducted systems using the reverse-cycle air conditioner as the central unit. Convection heaters also include the free-standing or built-in panel or tubular types, which may be water or oil filled and heated by an immersion element. They are often called 'radiators' and do actually radiate about 50 per cent of the heat produced.



(a) Fig. 21.17(a) Single-lamp halogen heater; (b) Halogen heaters in a workshop

THORN INDUSTRIES

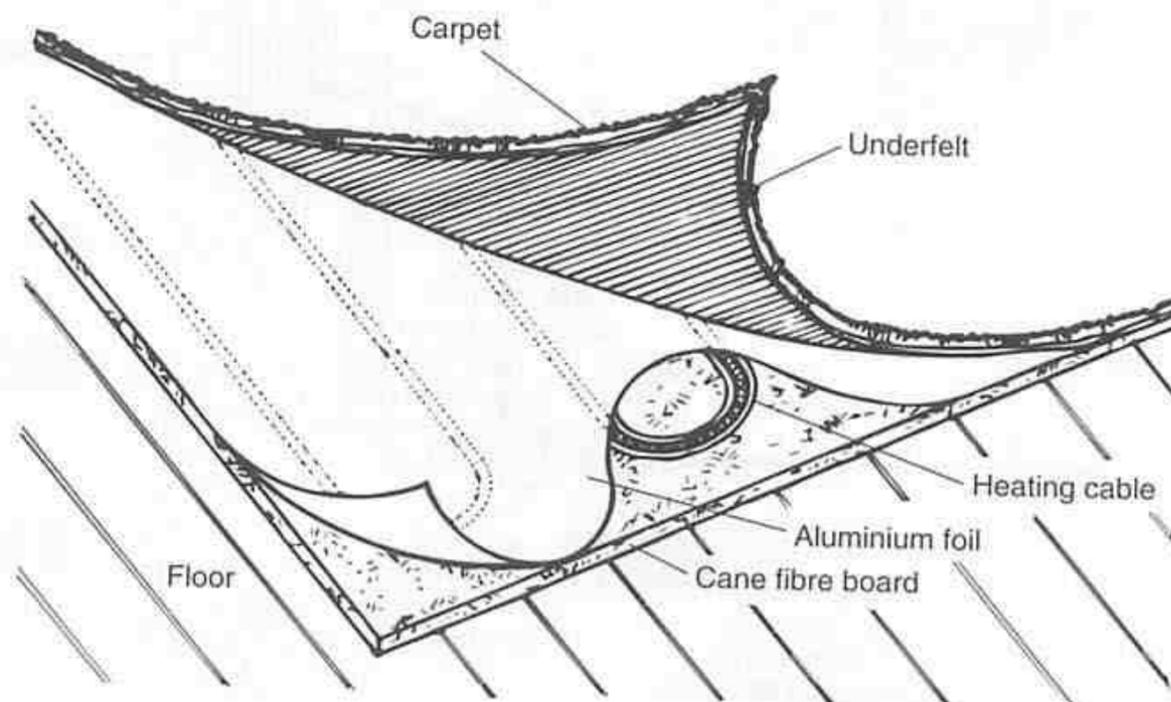


Fig. 21.18 MIMS heating cables may be used for undercarpet floor heating

MM CABLES PYROTENAX



Fig. 21.19 Concrete screed nearing completion covering heating cables that have been fixed to an anchoring strip
ELECTRIC HEATING SERVICE

All the storage heater types, if of sufficient heat-storage capacity, are suitable for off-peak tariffs, including concrete floor storage. Their use on off-peak tariffs depends on the energy distributor's approval.

The cross-section of a controlled-output storage-type heat bank is shown in Figure 21.21. 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.



Fig. 21.20(b) Cables embedded in the actual concrete slab. They are continually tested while concrete is being poured

Reverse-cycle air conditioning

Figure 21.22 illustrates the principle of a reverse-cycle air-conditioning unit, an appliance that on its cooling cycle pumps unwanted heat out of an area and that can have its cycle reversed to provide heating when required. Heating or cooling of the area is achieved by using a

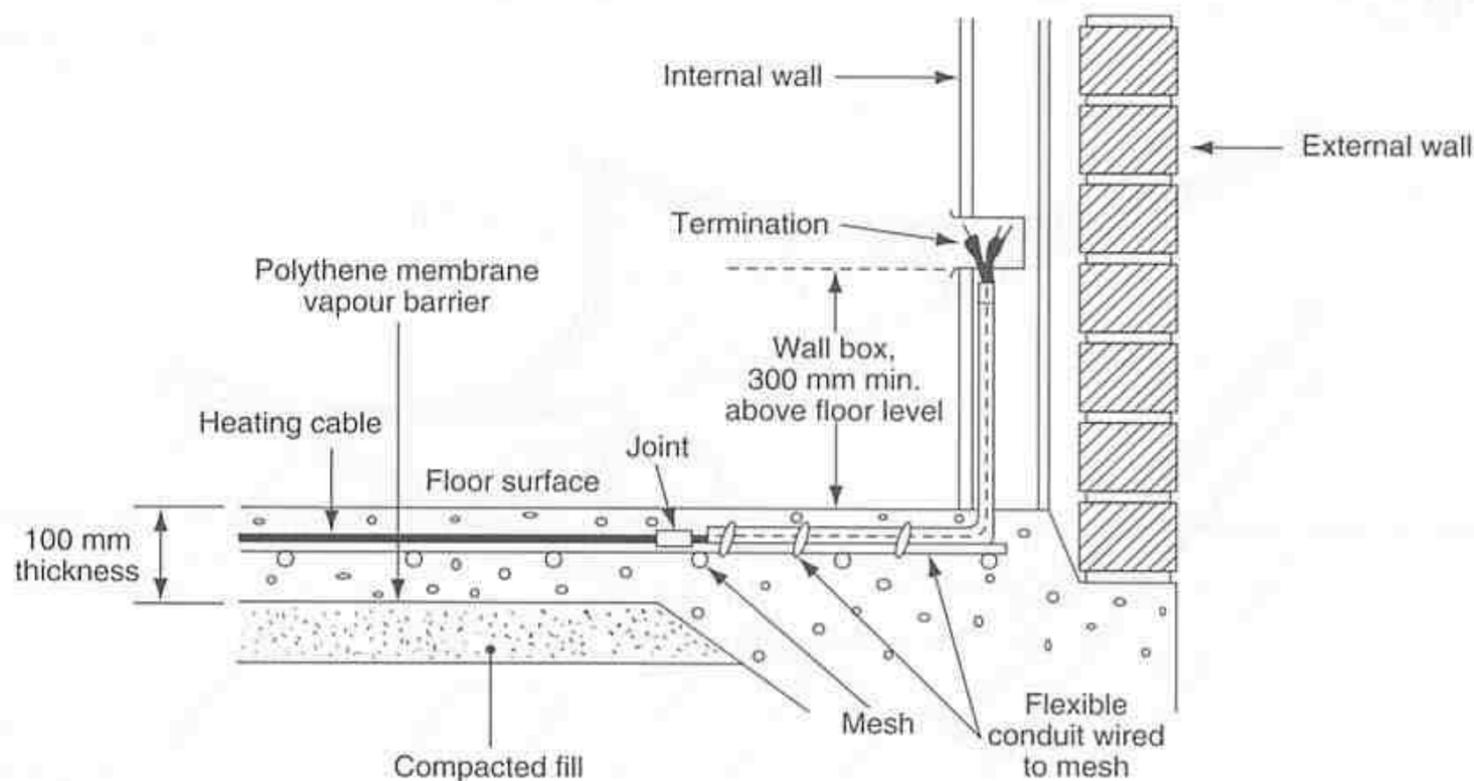


Fig. 21.20(a) Termination of heating cables

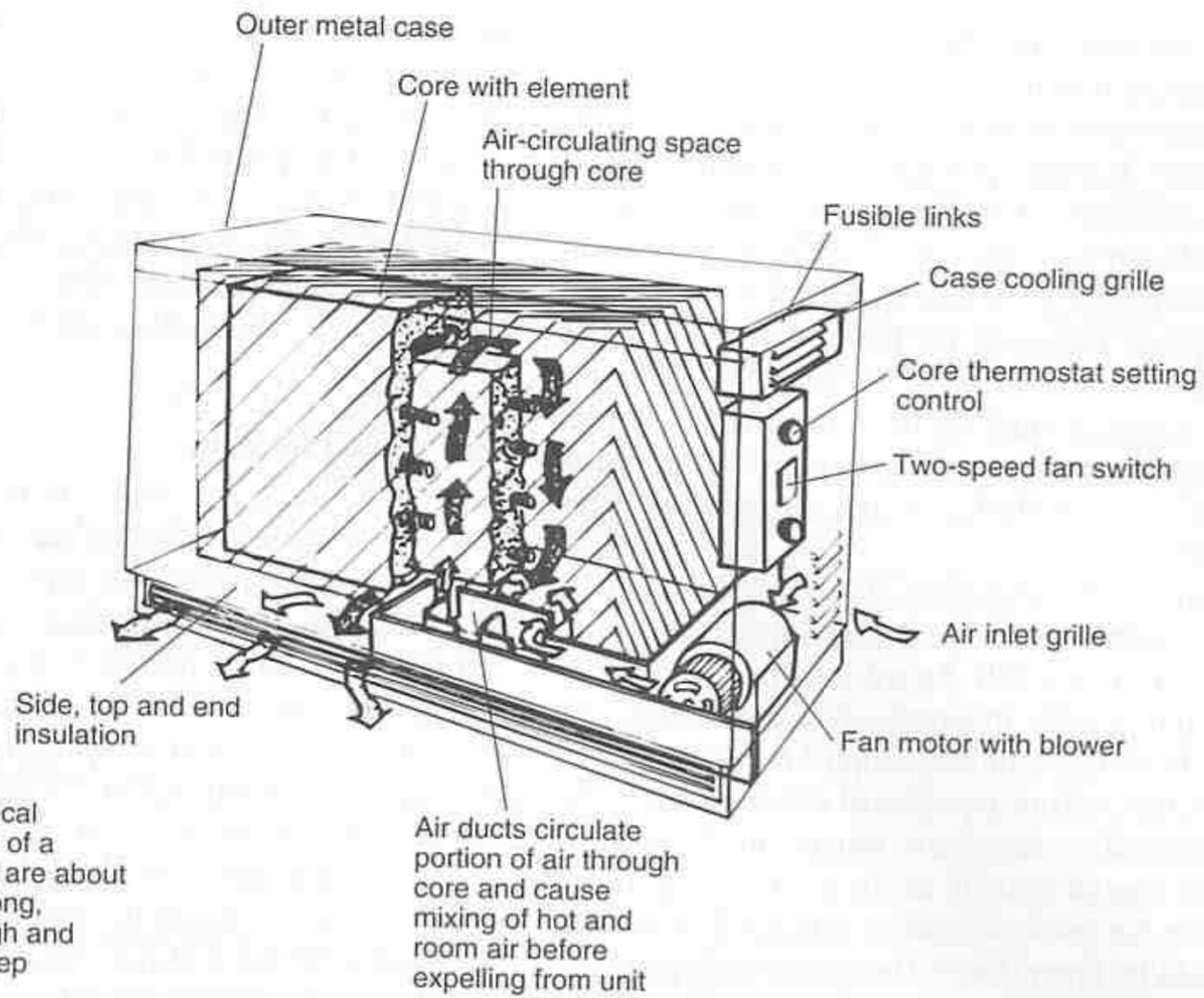


Fig. 21.21 Schematic cross-section of a heat bank STATE ELECTRICITY COMMISSION OF VICTORIA

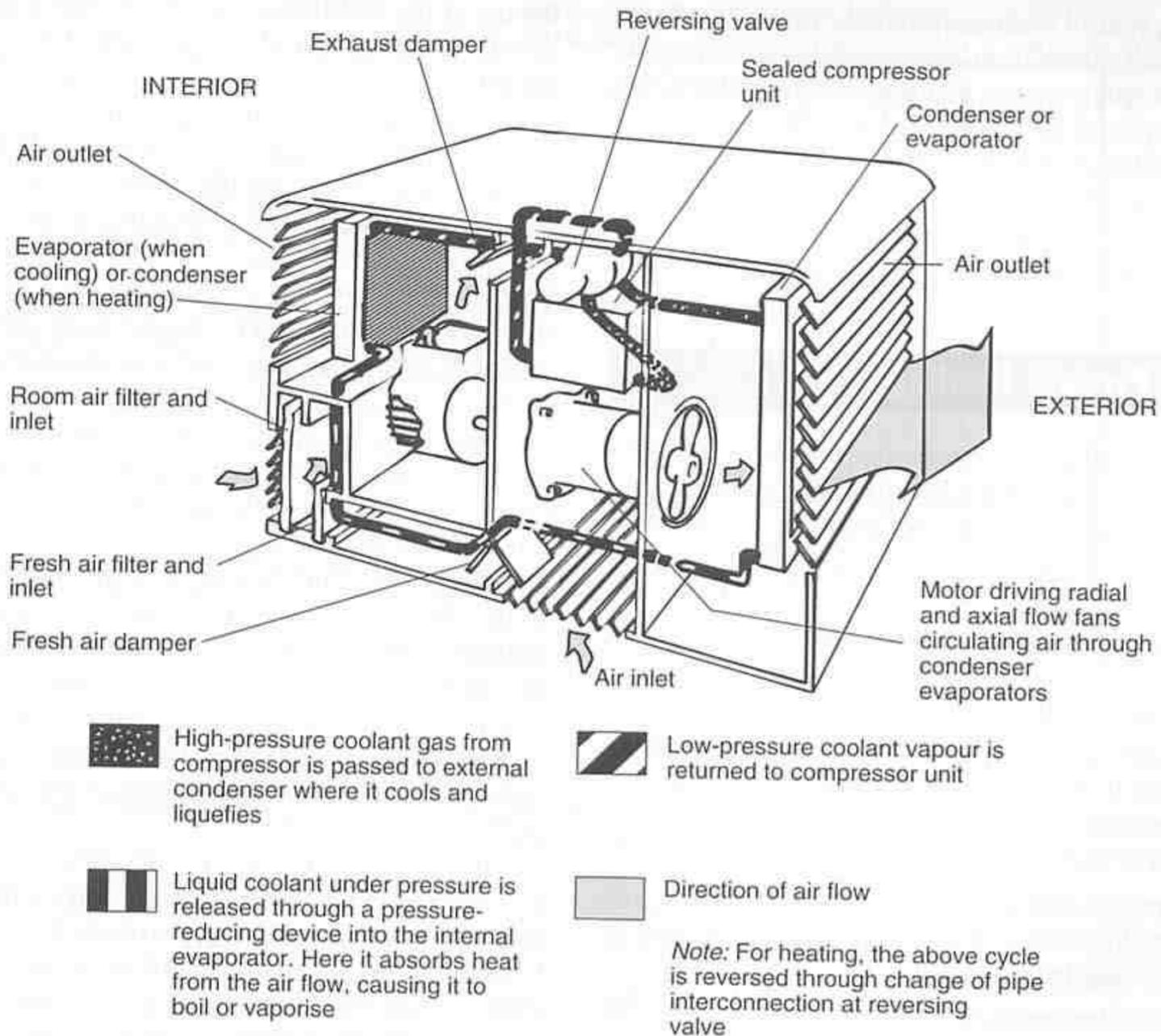


Fig. 21.22 Schematic arrangements of a reverse-cycle air conditioner STATE ELECTRICITY COMMISSION OF VICTORIA

refrigeration system to exchange heat between the internal and the external air.

The principle of operation is similar to that of the solar-boosted heat-pump type of hot-water system described in section 21.4. Heat exchange is effected by changing the pressure and therefore the temperature of a refrigerant fluid that has an extremely low vaporisation (boiling) point. Changing the fluid to vapour and vice versa enables heat to be given out or absorbed by the fluid. For example, under certain conditions 2 kW of (electrical) input energy may produce 3 kW of output (heat) energy, the extra heat being extracted from the ambient air.

The unit shown in Figure 21.22 could be mounted in a wall aperture or a window embrasure, as an individual unit or as a fully ducted system, with a larger-capacity unit usually mounted on a pad outside the building. The larger unit may supply heating (or cooling on the reverse cycle) to any selected section of the building, on manual or automatic programmed operation. The initial capital cost of an air-conditioning unit is higher than for most alternative systems, but running costs should be lower due to the reverse-cycle principle. The heat transference cycle may be manually or automatically reversed, and most units incorporate a thermostat to control room temperatures within close limits.

A modern trend is to 'integrate' lighting, heating and air-conditioning systems by using systems of ducts, fans and heat pumps on a controlled 'closed' network, thus utilising what used to be waste heat. As an example, the heat dissipated from the lighting installation of a large office building, even with fluorescent lighting, is sufficient to make a major contribution to the heating load.

21.6 Process heating

The use of electrical means for producing the heat required in various manufacturing and industrial processes is widespread because of the following advantages:

- Electrical heating is clean and makes for pleasant working conditions.
- With no open flames, the fire risk is lower.
- Temperature and automatic control of the heating process are precise and 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 from electrical energy to heat energy could be roughly classified as:

- resistance heating using some form of element;
- infrared heating from a source of infrared radiation, such as lamps or strip heaters;

- induction heating by inducing 'eddy currents' in the workpiece or the 'melt';
- dielectric heating of non-conductive material such as plywood or plastic by the use of an electric field to speed up molecular movement within the material;
- arc heating by using the heat generated in an electric arc, as in an arc furnace; electric welding may also be included in this classification.

Resistance heating

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 21.23 shows some resistance heater applications and some types of elements used in electric furnaces.

Temperatures up to 3000°C may be attained by the use of materials other than those illustrated. In some applications the direct resistance method is used, in which the workpiece itself becomes the heating element when a current is passed through it. This method is used in production for soldering, brazing, annealing and the preheating of steel bars for rolling or forging.

An important application of resistance heating is the use of the MIMS heating cable described in section 21.5 for industrial space-heating systems. It may be used for defroster heating elements in refrigeration, for drip tray heaters and for defrosting coldroom doors and display cabinets. It is also used for warming soil to assist in plant propagation and for greenhouse heating for commercial growers (see Fig. 21.24).

Trace heating in industry

Because mineral-insulated heating cable can operate at a continuous temperature of 600°C, it has a high watts per metre rating. Hence it may be used for maintaining the flow of viscous fluids through pipelines, as a controlled heat source for automated production lines, for plastic products, and for a number of other manufacturing processes.

Trace heating of pipes, valves and storage vessels for crude oil or petroleum byproducts is commonly used to maintain flow temperatures. Sometimes, trace heating of pipelines is used for frost protection (e.g. in hydro-electric installations). It is also used in the food and confectionery industry and includes keeping ingredients such as chocolate, toffee and syrup in liquid form in pipes, tanks and nozzles.

In the design of a trace heating system, two important factors must be considered: heat loss compensation, and raising and maintaining the required temperature. For example, a long pipeline will dissipate a considerable amount of heat to the surrounding atmosphere, and heat loss will also be affected by pipe diameter and the number of flanges and valves in the line. In addition, it

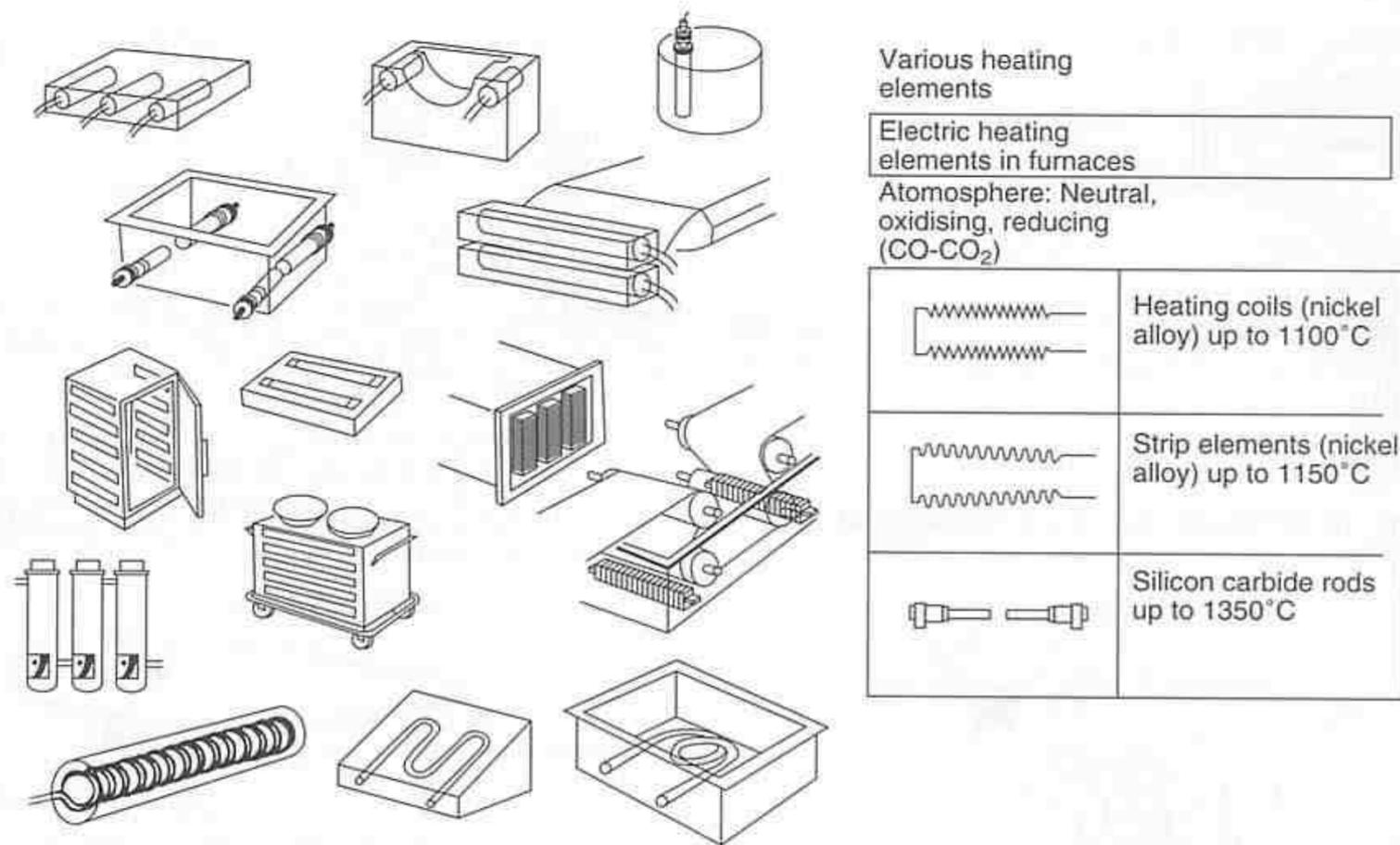


Fig. 21.23 Resistance heater applications and furnace elements

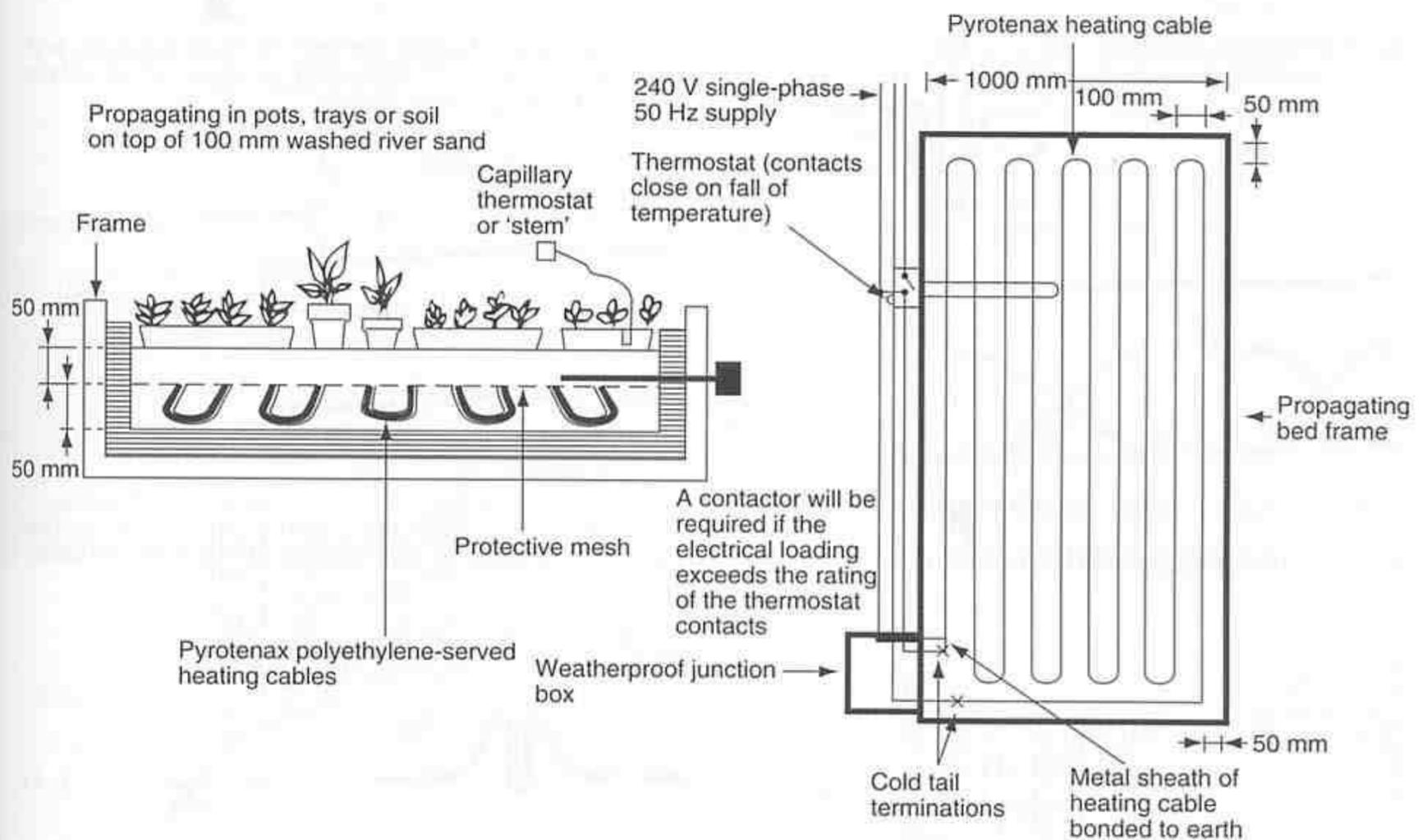
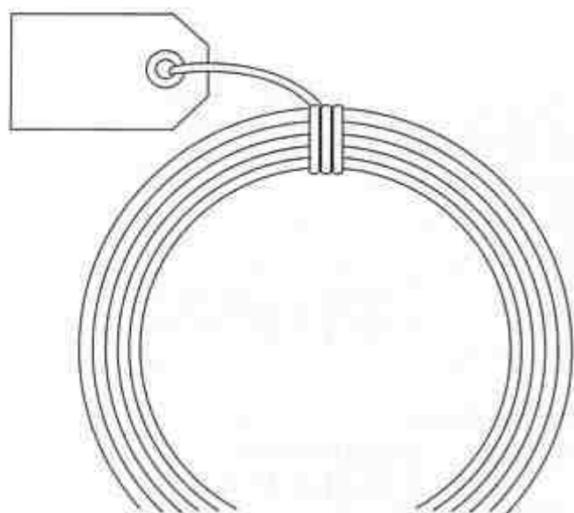


Fig. 21.24 Resistance heating for plant propagation MM CABLES PYROTEX

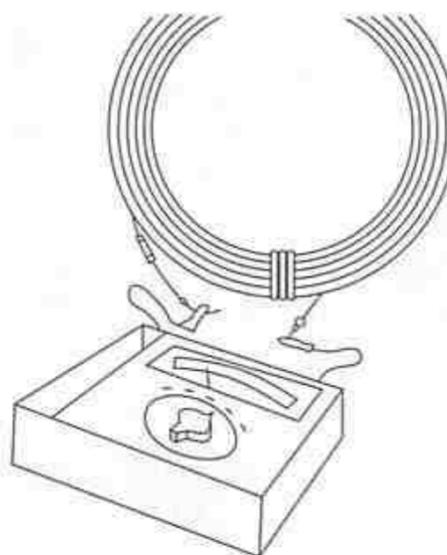
is essential to provide sufficient heat to raise the temperature of the material to the required level to enable the industrial process to be effective.

Manufacturers of mineral-insulated heating cables publish comprehensive data on the design of a trace heating system, by way of tables, graphs and formulae to

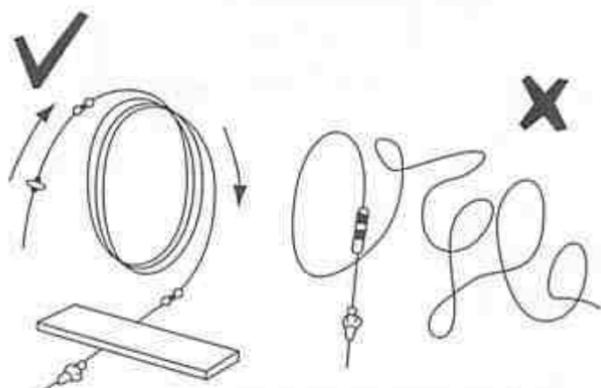
be used in assessing an installation requirement. These are readily available, together with any technical advice required on the use of the products. Design details are beyond the scope of this chapter, but an installation guide provided by the manufacturer of Pyroheat industrial electric heating systems is shown in Figure 21.25. This guide



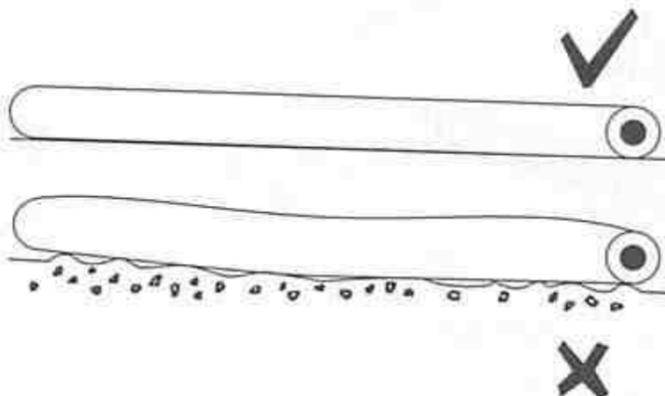
1. Check unit lengths and kW loading, site data and specifications



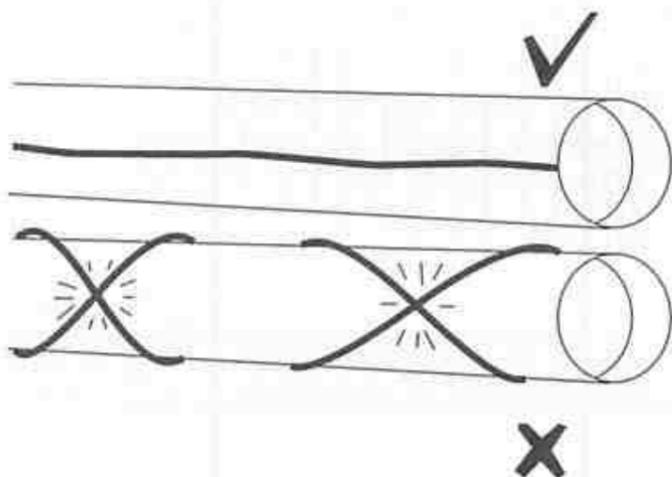
2. Test insulation and conductor resistance. An insulation value of infinity must be obtained



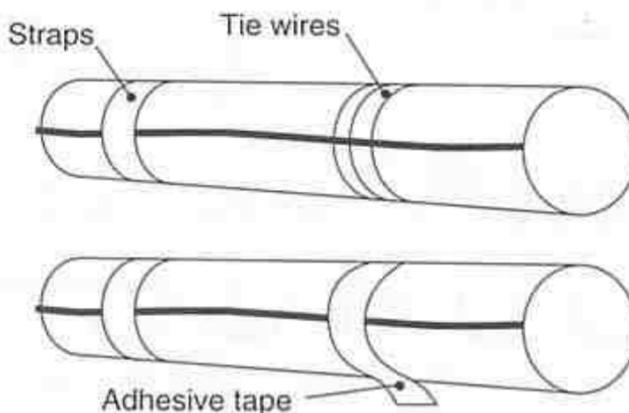
3. Unroll elements carefully, avoiding twists or kinks in the cable. DO NOT pull out into a spiral



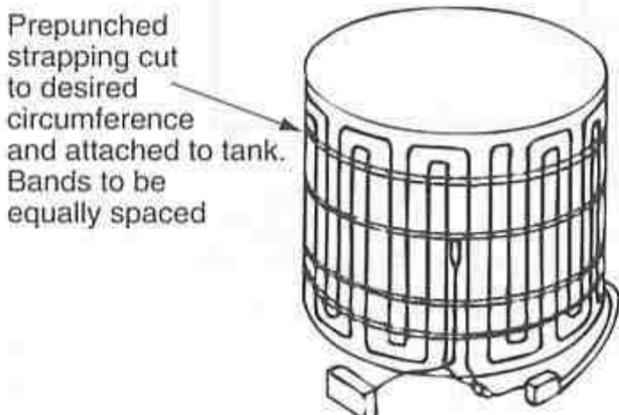
4. DO NOT install heating elements on rough surfaces, and take precautions over flanges, valve cases and sharp edges to prevent damage to the element



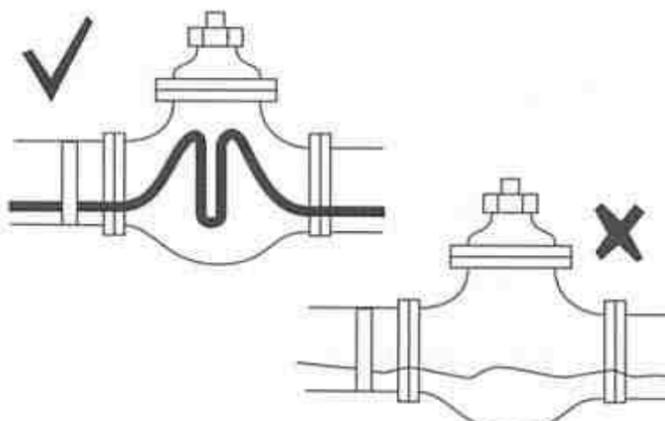
5. DO NOT let the elements touch or overlap



6. Recommended fixings for bare mineral-insulated cable onto pipes are stainless steel straps or copper tie wires. Use glass-cloth adhesive tape for served mineral-insulated cable



7. Pre-punched strapping or metal fixing tape should be used for tanks, vessels etc. Bands are to be equally spaced and attached to tank

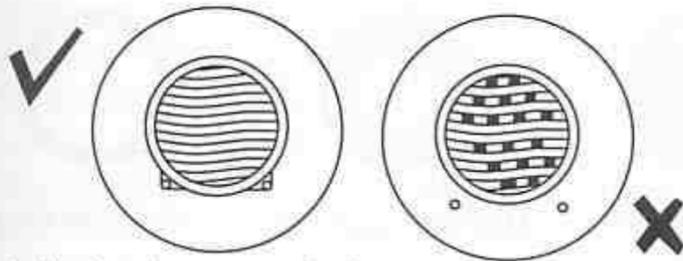


8. Additional allowance on unit length should be made to give the necessary coverage of valves and flanges and to allow for maintenance

Fig. 21.25 Installation guide for trace heating cables

MM CABLES PYROTEX

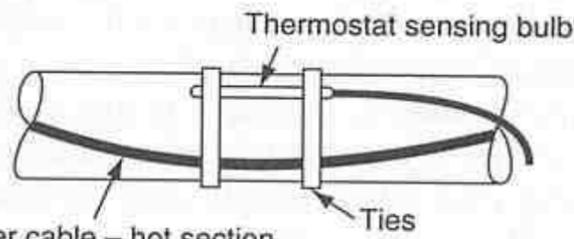
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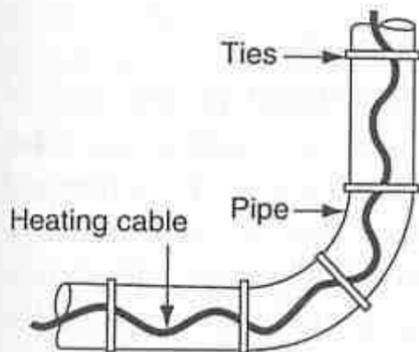
9. Heating elements must be kept in intimate contact with the surface to be heated for efficient operation. The cable should be covered with metal adhesive tape to prevent the cable from becoming trapped in the insulation. The tape **MUST NOT** get wet or entrap moisture at any time.

The heating cables may be encased in heat transfer cement. However, this **MUST NOT** contain constituents corrosive to the heating cable.

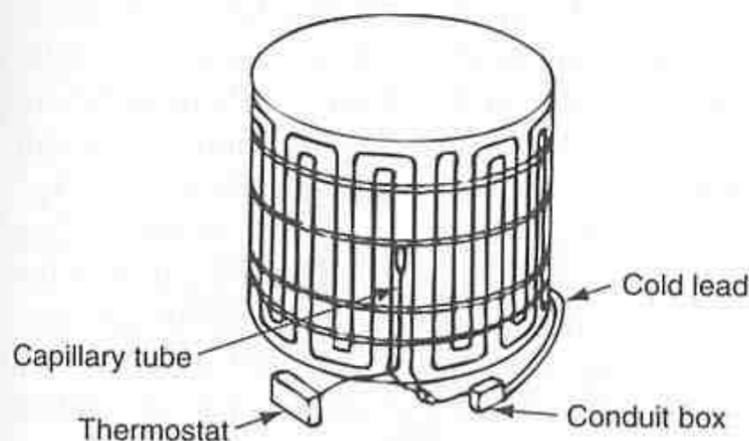
Spray-on polyurethane insulation must not be used with copper-sheathed heating cables



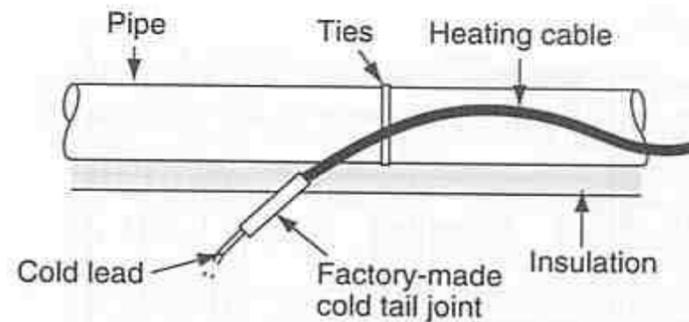
11. The thermostat sensor should **NOT** be positioned in direct contact with or be directly influenced by the heating unit. It should be located so that it monitors the point where the lowest temperature is likely to occur



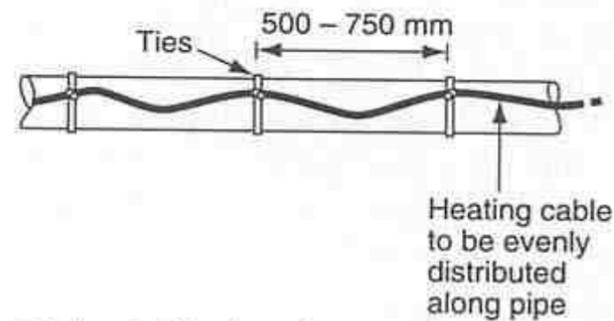
13. Installation at bends



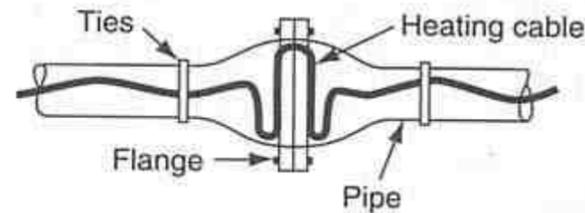
15. Layout of heating unit on tank



10. The cold tail joint should not be in contact with pipe. It should be located externally (outside of insulation) where it cannot be damaged



12. Layout of heating unit on straight pipe



14. Installation at flanges to allow for maintenance

Note:

- Thermal insulation and fixing materials **MUST NOT** get wet during installation. Outdoor applications should be weatherproofed.
- Installation examples show one side only. Opposite side is similar.
- Insulation is not shown in installation examples.

Fig. 21.25 (cont.) Installation guide for trace heating cables

MM CABLES PYROTENAX

provides some very useful information on the handling and installation of trace heating cables.

Infrared heating

This is a direct radiant heat method where the source of infrared may be lamps with internal reflectors, metal-sheathed strip elements in reflectors, or silica-sheathed

elements or quartz tube lamps in reflectors. Figure 21.26 is a sketch of one type of infrared oven.

Induction heating

In this system the metal workpiece of the material being heated becomes the 'core' of a coil that is energised from an ac source. Eddy currents are induced in the

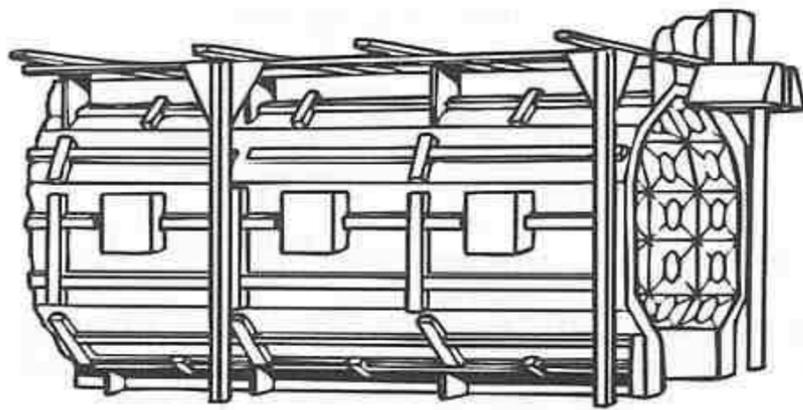


Fig. 21.26 Infrared oven

conductive workpiece, due to the alternating magnetic field of the coil, and the heat generated depends on the magnitude of the currents, the time and the resistivity of the material. Frequencies between the normal supply frequency of 50 Hz and 5 MHz are used, depending on the application. Although this system was originally introduced to melt metals, it is now used for heating, welding, brazing, soldering, case hardening and similar applications (see Fig. 21.27).

As the frequency of the supply to the coil increases, the induced eddy currents in the workpiece shift closer to the surface of the work ('skin effect'), and this phenomenon is fully used in applications such as case hardening (Fig. 21.28).

Dielectric heating

If a non-conductor such as wood, glue or a plastic material is placed between two electrodes and ac is applied

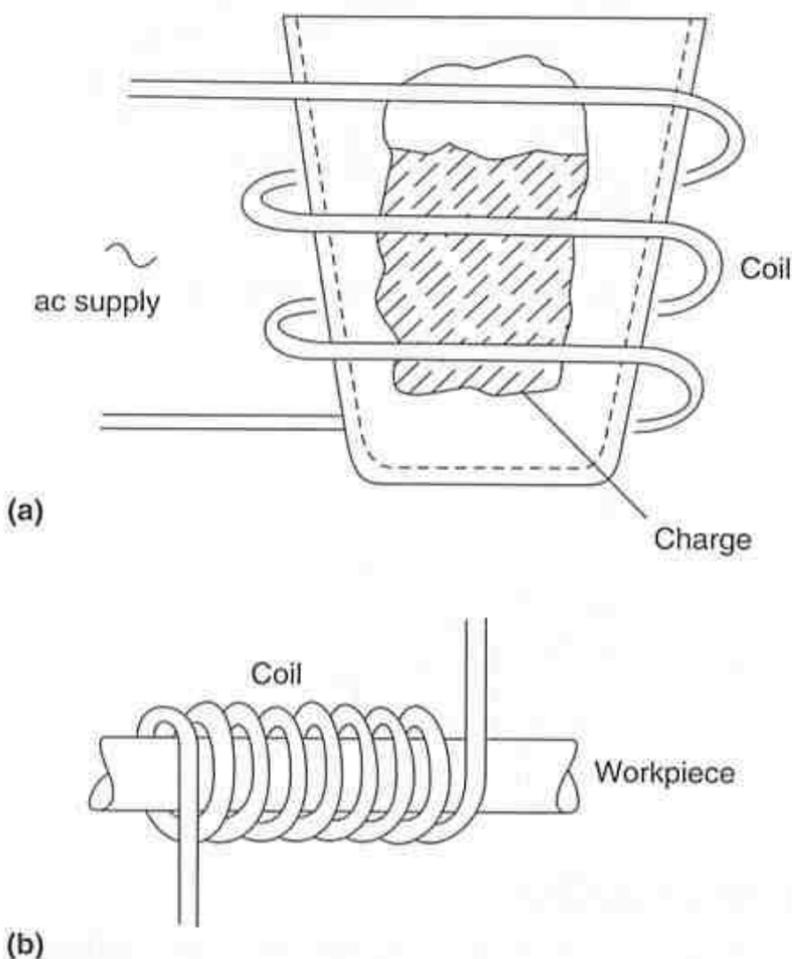


Fig. 21.27 Principles of induction heating: (a) melting; (b) heating

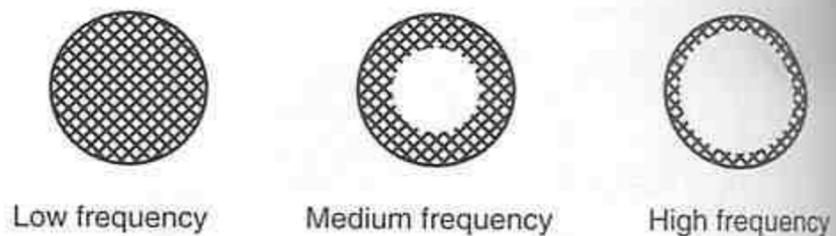


Fig. 21.28 Skin effect of ac utilised in the case hardening of metals

to the electrodes, the electrostatic field produced speeds up the movement of the molecules in the dielectric between the electrodes, and heats it.

This method is used extensively for the heating of thermosetting synthetic glues for the welding of plastics (e.g. in the manufacture of raincoats) and for the pre-heating of moulding powders and pellets.

Dielectric heating is also used in the foodstuff industry for defrosting, sterilisation and disinfecting and for the drying of breakfast cereals, dog biscuits and similar tasks. The microwave oven is an extension of the principle, where wave guides are used instead of electrodes. There are many other applications for this type of heating in industrial processes.

Electric arc

All the equipment so far mentioned in this section normally requires special circuits and installation. The arc furnace is also a specialised piece of equipment. Direct arc-type furnaces are used in the steel industry with melting capacities up to 150 tonnes, and in this type of furnace the arc takes place between electrodes and the 'melt' or 'charge'.

In the indirect arc-type or rocking arc furnace, the charge is heated by an arc established between horizontally opposed graphite electrodes connected to single-phase supply, and heat transfer is mainly by radiation. The furnace rocks continuously to ensure thorough mixing of the melt; capacity is from 2.25 kg to 45 kg.

The heat of an electric arc is used in arc welding equipment, and this equipment, in common with the other types described, requires special circuits and provision for installation. *Clauses 4.24 and 4.25* relate to the installation of welding machines and arc welding equipment.

Spot and seam welding are resistance welding techniques and use the direct-resistance heating method mentioned earlier in this section.

21.7 Commercial and domestic kitchen equipment

With the exception of microwave ovens and electrode-type boilers, nearly all cooking and water-heating

appliances in the kitchen utilise electric elements. Figure 21.29 is a flow diagram for a commercial kitchen and shows possible types and positions for some cooking and heating equipment. From the diagram it may be seen that, because of the concentration of equipment, most kitchens would best be served by a central distribution board or boards, the boards being fed by submains from the main switchboard or the switchboard serving the area. The site of a distribution board should be as close as practicable to the electrical centre of the load that it is feeding. Care must be exercised in the kitchen environment that the switchboard sites are not vulnerable to kitchen fumes, steam, water or humid conditions that could affect their operation (see *Clause 2.21*).

Most of the heating appliances in Figure 21.29 would require separate final subcircuits, and some of these circuits could be two- or three-phase, depending on the rating of the appliances.

The range of cooking and associated appliances available for both domestic and commercial kitchens is extensive, most of the commercial appliances being similar in principle to the domestic ones but designed to cater for a much larger number of people. Some commercial toasters handle up to 720 buns, sandwiches or slices of bread per hour, and rotisserie units designed to handle up to 45 chickens per load are common.

Other specialised equipment more likely to be found on commercial premises than in a domestic kitchen includes stockpots, deep-well fryers, pressure steamers, pastry ovens, food and pie warmers, *bains-marie* and large-capacity hot-water urns.

If the rating of a small appliance is 2.4 kW or less, it may be supplied from a GPO. Most of the appliances in a domestic kitchen except the range come within this category, but many of them are rated at 1600 W or more, and it is therefore wise to arrange the GPOs over two separate circuits to prevent overloading of the wiring. In any case the application of *Tables 2.5* and *2.7* with footnotes (e) and (d) respectively virtually make it necessary to install at least two separate circuits of power in a domestic installation; so it is logical to take advantage of this when planning the wiring of the kitchen outlets.

An electric range in any location other than domestic must be supplied by a cable rated to carry the full-load current of the range. For a domestic range a diversity is allowed, and the cable size may be reduced to the sizes indicated by the current ratings of *Clause 2.9.4.2*.

Some high-rated single-phase 240 V equipment such as large ranges may have to be balanced over more than one phase. The loading per phase is decided by the energy distributor, and will vary even within a distributor's area depending on the distribution system. Where there is any doubt about the phase loading in a particular area, the local service rules should be studied, and if necessary the distributor consulted for a ruling.

Just as it is wise to supply the concentrated load of the commercial kitchen by a distribution board or boards, so in a domestic installation a distribution board in the centre of the electrical load is also a wise and economical move where practicable. Wiring route lengths will be reduced, with a consequent reduction in voltage drop on the circuit wiring.

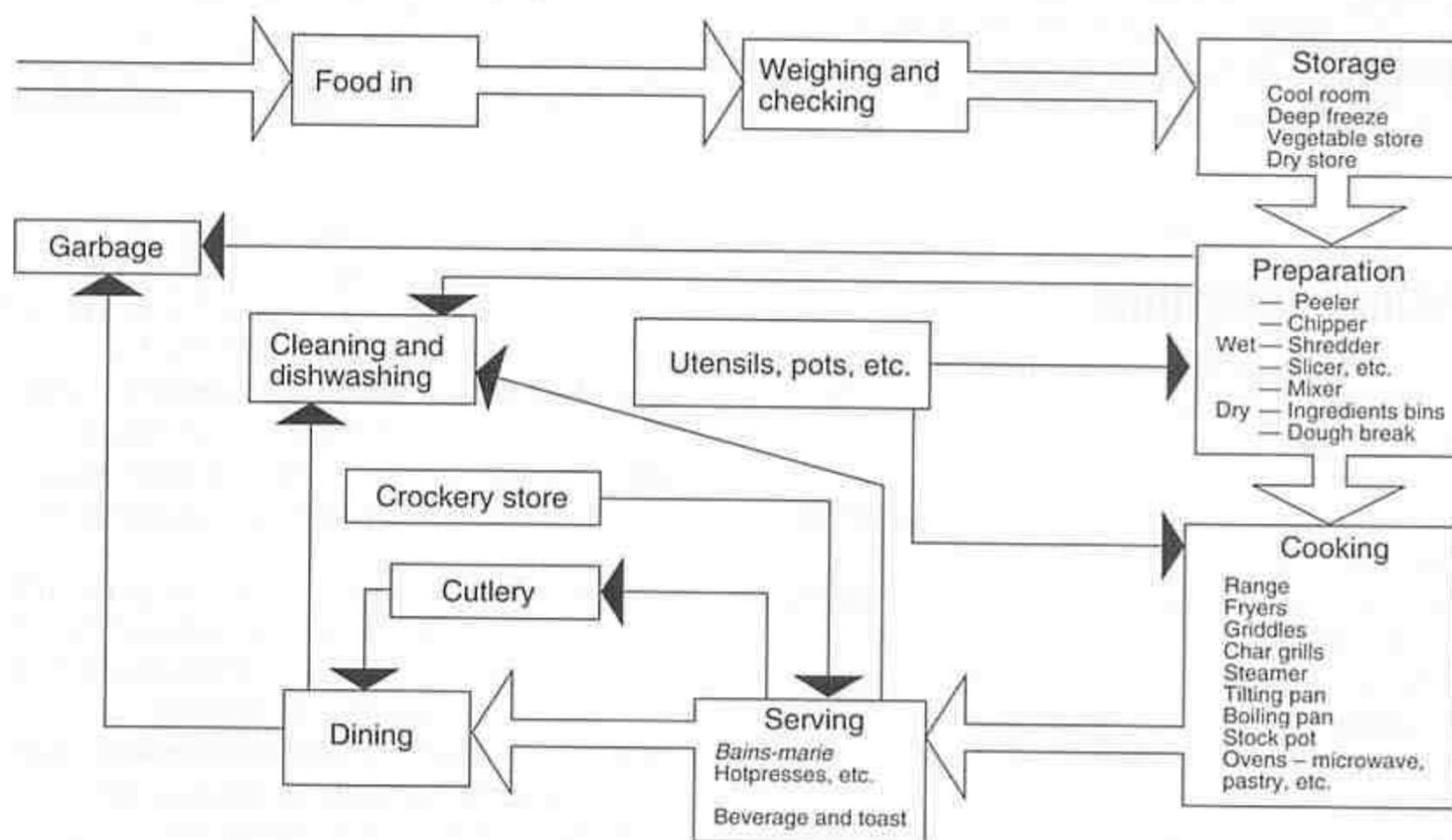


Fig. 21.29 Flow diagram of a commercial kitchen

SUMMARY

- Heat is a form of energy, and may be transferred by radiation, convection and conduction.
- Temperature determines the direction in which heat flows.
- Thermal conductivity is a measure of the rate at which heat will be transferred through a material.
- Some heating appliances need to be supplied by their own final subcircuit (see *Clause 2.9* of AS 3000).
- Control of heating appliances may be achieved manually by switching, such as three-heat and four-heat control.
- Automatic temperature control may be:
 - thermostatic, which maintains temperature between upper and lower limits and which may be a bimetal, expanding tube or vapour pressure type (see Fig. 21.5);
 - simmerstatic, which unlike the thermostat is not a feedback system; once set it continues to supply energy to the load, irrespective of temperature (see Fig. 21.6).
- Water heaters may be classified as:
 - instantaneous type, which are switched on only when hot water is required;
 - storage type, which may be on continuous tariff or controlled-load tariff, and which may be a displacement, falling-level (see Fig. 21.8) or mains-pressure unit.
- Solar energy is sometimes used to supplement heating of water in storage systems, and uses a collector panel, usually roof-mounted, as a solar collector.
- One type of solar hot-water system works on the same principle as a refrigeration circuit (see Fig. 21.15).
- Hot-water delivery temperatures are sometimes lowered to reduce the severity of scalding; this may affect the effective capacity of a hot-water system.
- Space heating may be provided by high-temperature radiant panels or radiators; low-temperature panels, convection and unit heaters; thermal storage-type heaters; or reverse-cycle air conditioners.
- Halogen heaters are a type of radiant heater intended for commercial and industrial use which emit energy in the infrared range and require no warm-up time.
- Ceiling heating systems using mineral-insulated metal-sheathed (MIMS) cable have minimal thermal storage capacity and are expensive to install; they are seldom used.
- Undercarpet heating using MIMS heating cables also has low thermal storage capacity.
- Heating cables installed in a concrete slab (see Fig. 21.19) yield a system with thermal heating capacity, and may therefore be operated at the cheaper off-peak rate.
- Convection heaters include free-standing or built-in panel or tubular types, which may be water- or oil-filled and heated by an immersion element. They are often called 'radiators', because they radiate about 50% of the heat produced.
- A storage heat bank draws energy on controlled-hours tariff. Heat is stored in an insulated heat storage core and extracted by a fan, which is controlled by a room thermostat.
- Reverse-cycle air conditioners effect heat exchange by changing the pressure and therefore the temperature of a refrigerant fluid. Changing the fluid to vapour and vice versa enables heat to be given out or absorbed by the fluid.
- Industrial process heating includes:
 - resistance heating, where heat generated in an element is transferred to the material being heated by radiation, convection or conduction. Trace heating is an application described by Figure 21.25;
 - induction heating, where eddy currents are induced in the workpiece by the alternating magnetic field of a coil;
 - dielectric heating, used to heat non-conductors placed between two electrodes to which ac is applied;
 - electric arc, such as in an electric arc furnace, where heat produced in an electric arc is used to melt a 'load' or 'charge', usually metal. The heat produced in electric arc is also used in arc welding equipment.
- Many commercial and domestic kitchen appliances use electric elements. Some exceptions are microwave ovens, electrode-type boilers, blenders and mixers.



REVIEW QUESTIONS

Where the answer to a review question is numerical or requires reference to the SAA Wiring Rules, the answer is given at the back of the book. These questions are marked *.

1. What is heat energy?
2. Outline briefly the process whereby heat is generated in an electrical element.
3. Name four methods used in electrical process heating for the generation and transfer of heat energy.
- * 4. Why are all electrical heating devices classed as appliances for the purpose of the *SAA Wiring Rules*?
- * 5. What is the maximum kilowatt rating for an appliance supplied by a GPO?
- * 6. How does the installation of air conditioning affect the number of GPOs on a subcircuit in a non-domestic installation?
7. Flexible cords attached to heating appliances sometimes require special protection. Why?
8. State specifically why a thermostat on an unvented water heater must never be bridged out.
- * 9. What are two alternative positions for a water-heater control switch (apart from the OFF position)?
- * 10. Switches used for the control of water heaters must be of a special type if operated infrequently. What type is this?
- * 11. Assume that a heating appliance has two 1000 W elements arranged for manual three-heat control. State the power rating of the appliance for the three switch positions of low, medium and high.
12. Explain the essential difference between control by a thermostat and control by a simmerstat.
13. What control is there over the water temperature with a three-phase instantaneous-type water heater?
14. List the three main thermostat types.

- *15. By reference to the *SAA Wiring Rules, Tables 2.3 and 2.4*, list the classes of load group applicable to water heaters.
16. State two heater types that would not normally qualify for off-peak tariff rates.
17. What is the name of the device usually fitted to storage water heaters for the purpose of temperature control?
18. State a common kilowatt power rating for a three-phase instantaneous water heater.
19. Where should a hot-water system storage tank be located, relative to the hot-water outlets?
20. Name the three main storage water-heater types.
21. Why is it usual to supply a water heater with its own separate subcircuit?
22. An examination of a main switchboard reveals that the hot-water system has its own separate main control and metering. What type of hot-water system is it?
23. What do you consider to be the main disadvantage of a solar hot-water system?
24. Name some common causes of heat loss from rooms using space-heating equipment.
25. State the type of space heating that would be suitable for off-peak supply rates.
26. How would room temperature be controlled in an undercarpet type of space-heating installation?
27. State one advantage of electric concrete-floor storage systems?
28. How is thermal energy stored in a heat bank?
29. What is meant by a closed or integrated heating system for a large building?
30. How does electrical process heating reduce fire risk?
31. Why is it common practice to have a distribution board close to an all-electric kitchen?
32. What is the ideal position for a distribution board in relation to the electrical load?
33. What particular conditions exist in kitchens that are likely to affect wiring, control equipment or switchboards?
34. Most of the equipment in a commercial kitchen would be supplied by individual separate circuits. Why are circuits of GPOs also necessary?
- *35. What is the necessary clearance, horizontally and vertically, from the edge of the water container of a sink to a GPO socket?
36. Why is it wise to distribute the GPOs in a kitchen over two circuits in a domestic installation?
37. On some domestic installations it is both wise and economical to provide an internal distribution board. Why?
38. List some applications of trace heating in industry.

14

Residual current devices

This chapter deals with the most widely used method of supplementary protection, the residual current device (RCD), and covers:

- the development of RCDs
- their operating principles
- RCD types and applications
- discrimination and dealing with nuisance tripping
- testing
- installation arrangements for RCD protection.

RCD protection, will help to avoid nuisance tripping due to this cumulative effect.

In a new domestic installation in Australia the use of a type I (10 mA) or a type II (30 mA) device is mandatory (*Clause 4.14.9*) for the protection of most GPOs. However, most manufacturers recommended the 30 mA RCD for this purpose.

Appliances that incorporate 'calrod'-type heating elements (e.g. cooking stoves, water heaters) can have relatively high leakage currents when new or after long periods of non-use, due to moisture absorbed by the element insulant. *Clause 1.5.2.4* of the *SAA Wiring Rules* permits the insulation between live parts and earth of appliances fitted with heating elements to be as low as 10 000 Ω . As an example, this represents a maximum permissible leakage current in a cooking range of:

$$\begin{aligned} I_L &= \frac{V}{R} \\ &= \frac{240}{10\,000} \\ &= 0.024 \text{ A (24 mA)}. \end{aligned}$$

Provided that the earthing requirements of AS 3000 are met, these levels of leakage current are quite acceptable and do not normally present any hazard. The circuits for the above appliances, which are usually permanently connected, can be provided with RCD protection by type III devices without encountering unwanted tripping due to standing residual current (see section 14.7).

In domestic installations, GPOs supplying refrigerators and food freezers are not required to be protected by an RCD. This is because these appliances can have high leakage currents from their defrost, evaporation and antifrost heating elements and the resultant nuisance tripping might cause food spoilage.

Standing leakage currents reach unacceptable levels generally through the deterioration of insulation or the ingress of moisture and other contaminants between live parts and earthed metal (e.g. dust, insects, spiders). Damage by vermin also is a contributing factor. This is a problem with older installations, particularly those with vulcanised india rubber (VIR) or tough rubber sheathed (TRS) wiring.

Before RCD protection is installed, the sources of leakage currents must be located and reduced to acceptable levels (see section 14.6). This may involve the replacement of circuit wiring or the cleaning, repair or replacement of accessories, light fittings or appliances.

Paths for residual current flow in appliances include:

- a build-up of breadcrumbs in a toaster;
- condensed moisture on the lint collected in a clothes iron, particularly a steam iron;
- carbon dust build-up on the commutator of a motorised appliance such as a vacuum cleaner or portable electric tool.

Damage to an installation during building repairs, alterations or additions is another common source of high leakage currents. Typical is a nail driven into wiring such that the neutral and earth conductor become short circuited. This would result in up to half the load current's returning via the earthing conductor. Obviously, such faults must be located and repaired.

Note: RCDs will trip without the presence of fault current in a circuit if the active and neutral conductors supplying the protected circuit do not pass through the toroidal core or do not pass through it from supply to load in the same direction (see Figs 14.4(a) and (b)).

Electrical disturbances

Disturbances to the normal line voltage can be caused by lightning strikes, switching transients in the supply system and switching off reactive loads such as motors, welding equipment and fluorescent lights. The standing leakage current at 50 Hz may be acceptably small, but switching transients are usually at higher voltage and frequencies. The higher frequencies reduce the capacitive reactance of the circuit, and leakage current increases;

$$X_c \propto \frac{1}{f} \text{ and } I = \frac{V}{X_c}$$

Note: The supply conductors separated from earth by insulation represent a capacitance between the conductors and earth.

Switching transients, in the form of a damped oscillation, are of short duration, and filtering components are usually incorporated in RCDs to help overcome nuisance tripping due to this phenomenon.

The consequences of lightning strikes on an electrical system are quite varied and complex, but they generally cause high-voltage and high-frequency transients of longer duration than switching transients. Although the modern RCD is equipped with filtering components and techniques to discriminate against transient disturbances in the supply lines, devices may trip when subjected to transients due to lightning strikes. In areas subject to frequent electrical storms, circuits that would normally be protected by type III devices may be more appropriately protected by the selective time-delay type IV RCDs to avoid some nuisance tripping (see Chapter 13 for protection against voltage surges and transients).

The inrush starting current of large motors can have a phase difference that may cause an RCD to trip during starting. In these cases, time must be allowed for the currents to settle down. Therefore, when providing residual current protection for these circuits, an RCD with selective time delay should be installed.

Installation practices and faults

Again, RCDs detect fault current by monitoring the supply and return currents of a circuit. Any connection

between neutrals of different circuits or between neutral and earth on the load side of an RCD will cause unwanted tripping. You will have realised that any such connection is contrary to the *SAA Wiring Rules* and is an installation defect. However, such connections may be found on existing installations that were not properly tested when the electrical wiring and equipment were first installed.

A typical fault is incorrect connection of the neutral and earthing conductors at a GPO or appliance cord (see Fig. 14.7). Also, an addition to an existing installation may be found to have the neutral for a new light point fed from a power circuit, usually for installation convenience (see Fig. 14.8). **Thorough testing of an installation is vital to the process of installing effective residual current protection.**

Note: Circuits that use the earth-sheathed-return system (Clause 3.21.6), and circuits supplying outbuildings or detached portions of an installation having a separate multiple-earthed neutral (MEN) connection (Clause 5.9.4), are not suitable for residual current protection.

RCDs can be affected by dc line components generated by equipment using phase control and rectifying devices such as light dimmers, speed-controlled power

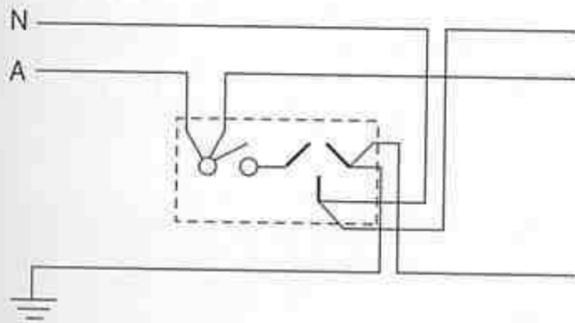


Fig. 14.7 The neutral and earth connections interchanged at a GPO will cause an RCD installed on the circuit to trip. Such a connection is one type of defect that may be found when testing an existing installation GERARD INDUSTRIES

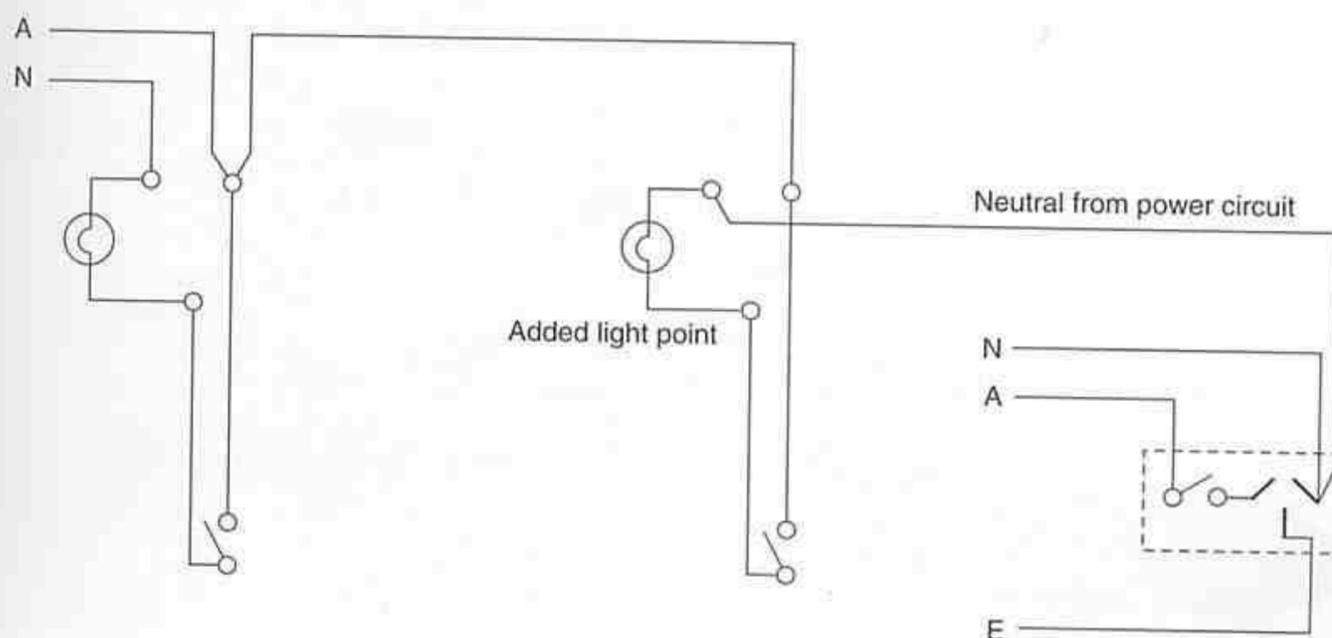


Fig. 14.8 Mixed neutrals from different circuits (a dangerous practice) will cause an RCD to trip GERARD INDUSTRIES

tools and food processors. The dc component tends to saturate the toroidal core, rendering the RCD ineffective at detecting leakage current. The problem is being addressed by the use of higher-permeability magnetic material in the toroidal core and higher-sensitivity detection circuits in the RCDs. Also, the approval standards for equipment incorporating phase control and rectifying devices limit the level of dc component that this equipment is permitted to generate.

14.6 Installation and RCD testing

In section 14.5 it is explained that high standing leakage current is responsible for the majority of nuisance tripping. Therefore, before installing RCD protection to an existing circuit, it is important to locate and rectify any source of unacceptable leakage current. If the insulation resistance of a circuit is known, the leakage current can be determined by:

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

Insulation testing of a complete installation is explained in Chapter 11, Volume 1. A similar procedure is used when testing for leakage current:

1. Turn off the supply.
2. Disconnect the main earth and main neutral from the neutral link.
3. Appliances can be connected or tested separately.
4. Test between the load side of the main switch and the main earth and between the neutral link and main earth. See Chapter 11, Volume 1, for testing techniques and procedures.
5. If a low reading is obtained, remove the fuse, or switch off the circuit breaker for the circuits not intended for RCD protection, and test again.

14.1 Introduction

Along with the development of electricity as a major energy source has been the development of systems for protection against electric shock. The early measures adopted were aimed at the avoidance of contact with live parts by insulating, providing barriers, enclosing live parts or locating live parts out of reach. This level of protection, however, does not offer protection from direct or indirect contact with live parts in the event of insulation breakdown, damage to the barriers or enclosures, or deterioration of these materials due to ageing.

To give protection against indirect contact with live parts, earthing systems were introduced. Together with appropriately sized fuses or circuit breakers, 'fault protection' methods evolved. As pointed out in Chapter 12, earthing systems fail in providing protection against the risk of electric shock when the earth fault resistance is high. To overcome this failing, **residual current devices (RCDs)** are being more widely used as a supplementary protection to the earthing system. This chapter covers the development, operating principles and application of these devices, initially introduced in Chapter 12.

14.2 Development of residual current protection

RCDs have been used as supplementary protection in some industrial activities, medical treatment areas and the construction industry for a number of years. These devices have also been known as 'core balance units' or 'current-operated earth-leakage circuit breakers'. More recently, through electrical-safety promotion programs particularly aimed at the domestic consumer, they have been referred to as 'safety switches'. Irrespective 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 current, at a level likely to cause physical harm, is leaking to earth. Protection against leakage currents likely to cause damage or start a fire can also be provided by RCDs.

In the early development of electrical systems, only limited protection against electric shock was provided, as little was known about the causes of death from electrocution and the factors involved. Research into the physiological effects of electricity has been parallel with 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 has been carried out by the International Electrotechnical Commission (IEC) and is documented in IEC Report 479: *Effects of Current Passing through the Human Body*. This information was essential to the development of effective techniques of protection against electric shock.

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. Ventricular fibrillation is the disruption of the normally coordinated rhythmic contraction and relaxation activity of the heart muscles so that pumping action becomes ineffective and blood circulation ceases. Under these conditions, permanent brain damage occurs within a few minutes followed by death within several minutes. Ventricular fibrillation is the main cause of death by electrocution involving low-voltage ac (50 V to 1000 V), while burns are a greater contributing factor in high-voltage electric shock (see Chapter 2, Volume 1, for the resuscitation of victims of electric shock).

The time-current effects on the human body are shown in Figure 14.1 and have been accepted as the international standard for the development of techniques of protection against electric shock. The characteristic curves a, b and c_1 form the boundaries of four zones representing the various time-current effects on the human body:

- zone 1: usually no effect
- zone 2: usually no harmful effect
- zone 3: muscular contraction; breathing difficulties; ventricular fibrillation not likely (0.5 per cent probability)
- zone 4 (including the effects of zone 3):
 - c_1 probability of ventricular fibrillation increased to 5 per cent
 - c_2 probability of ventricular fibrillation increased to 50 per cent
 - c_3 probability of ventricular fibrillation increased to above 50 per cent.

Further increase in current and time is likely to cause complete stopping of the heart activity (cardiac arrest) and breathing; burning may also occur. If the duration of current flow is below 200 milliseconds (0.2 seconds), ventricular fibrillation is likely only within what is known as the 'vulnerable period' of heart activity, if the relevant threshold current is exceeded. The vulnerable period can be seen on the electrocardiogram of a healthy heart (see Fig. 14.2) and is the T-wave portion of the curve.

This information on current effects on the human body has served as the basis for determining the oper-

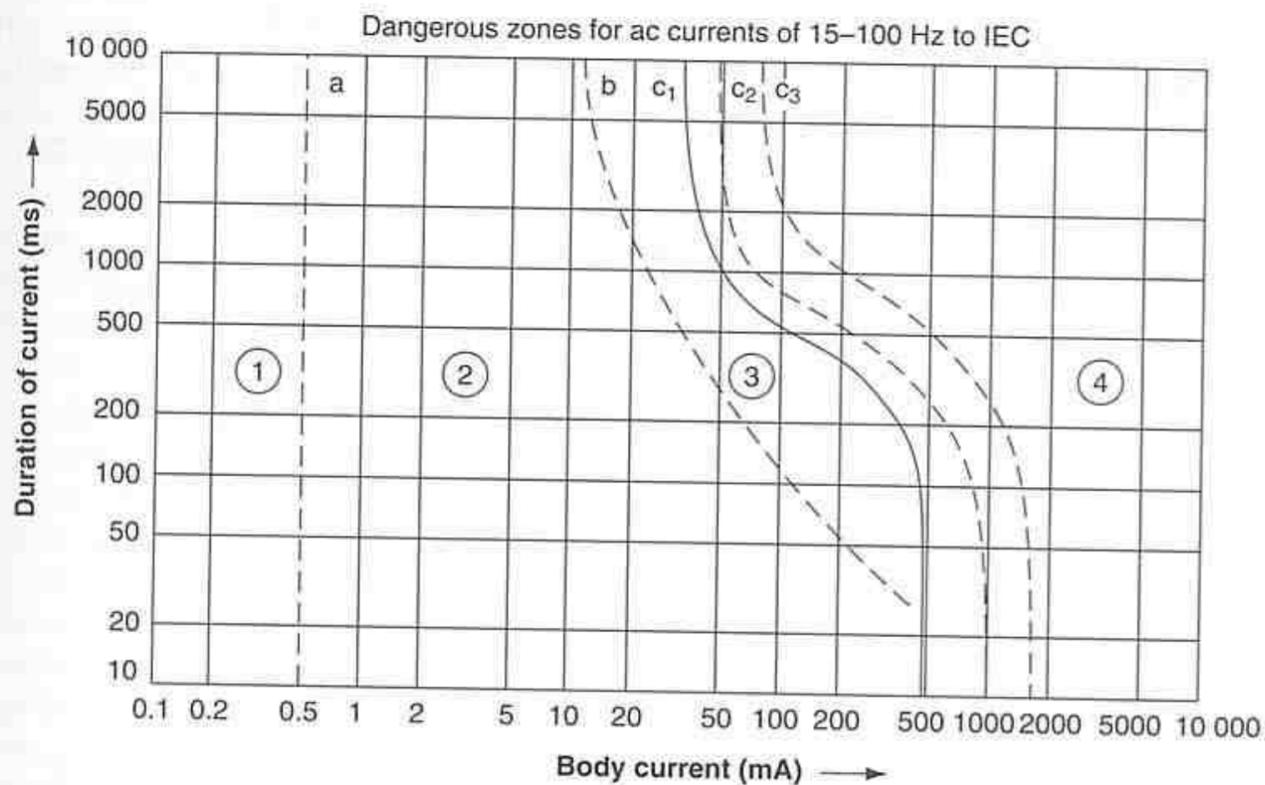


Fig. 14.1 Time-current zone effects on humans GERARD INDUSTRIES

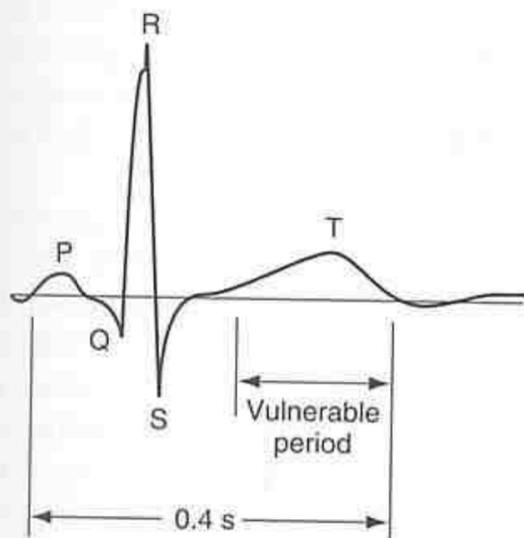


Fig. 14.2 Electrocardiogram shows the electrical activity of the heart over one heartbeat GERARD INDUSTRIES

ating characteristic for effective RCDs. By way of example, the shaded area in Figure 14.5(b) shows the range in which a type II RCD (30 mA) must operate as required by AS 3190: *Approval of Test Specifications—Residual Current Devices*. It can be seen that the RCD will trip the circuit that it is protecting well below the threshold of the probability of ventricular fibrillation (i.e. below c_1).

14.3 Operating principle

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 main contacts to switch off the circuit. The active and neutral conductors supplying the circuit to be protected are installed so that they pass through the toroidal core (see Fig. 14.3).

In the case of a single-phase circuit, the current that flows in the active conductor is normally equal to and opposite to the current flowing in the neutral conductor. Magnetic fluxes, related to currents in each conductor, are established in the toroidal core. Under normal conditions, the phasor sum of these currents is zero; the fluxes cancel each other, and so the resultant flux in the core is zero (see Fig. 14.4(a)).

Tracing out the path of the earth fault current in Figure 14.4(b), it can be seen that this represents a second current path from the active to the source, which bypasses the toroidal core. The current in the active conductor is now the sum of the load current and the earth fault current (i.e. current bypassing the toroidal core), while the current in the neutral is equal to the load current. Under these conditions, the phasor sum of the currents in the active and neutral conductors passing through the toroidal core will be equal to the earth fault current. A net resultant magnetic flux is established in the toroidal core by this fault current (i.e. a residual current).

Due to transformer action, the net flux in the core induces a voltage in the sensing (secondary) winding, which is then used to operate the trip relay to isolate the circuit.

In multiphase ac circuits, the phasor sum of the currents in all conductors is normally zero. This is the

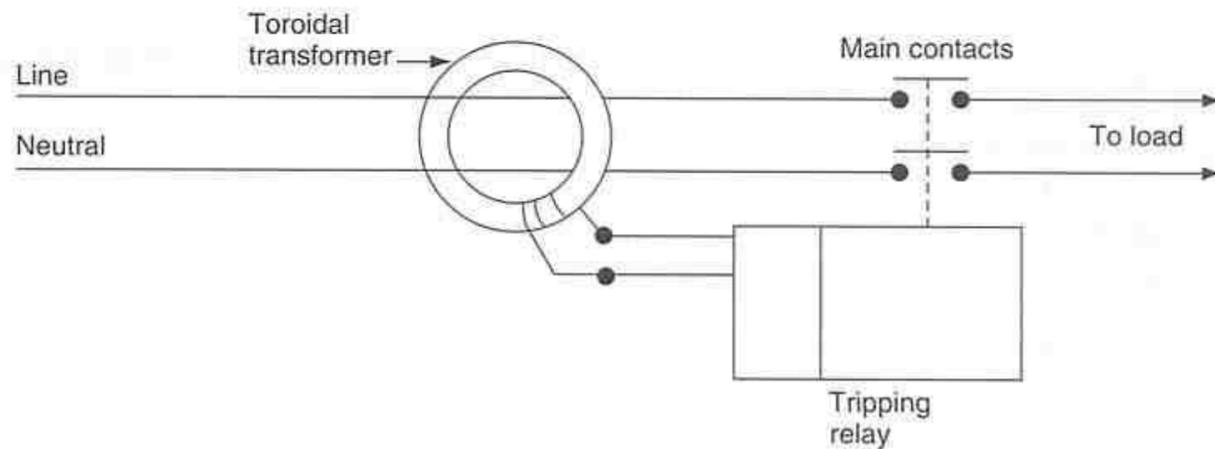


Fig. 14.3 Basic elements of a residual current device (RCD) GERARD INDUSTRIES

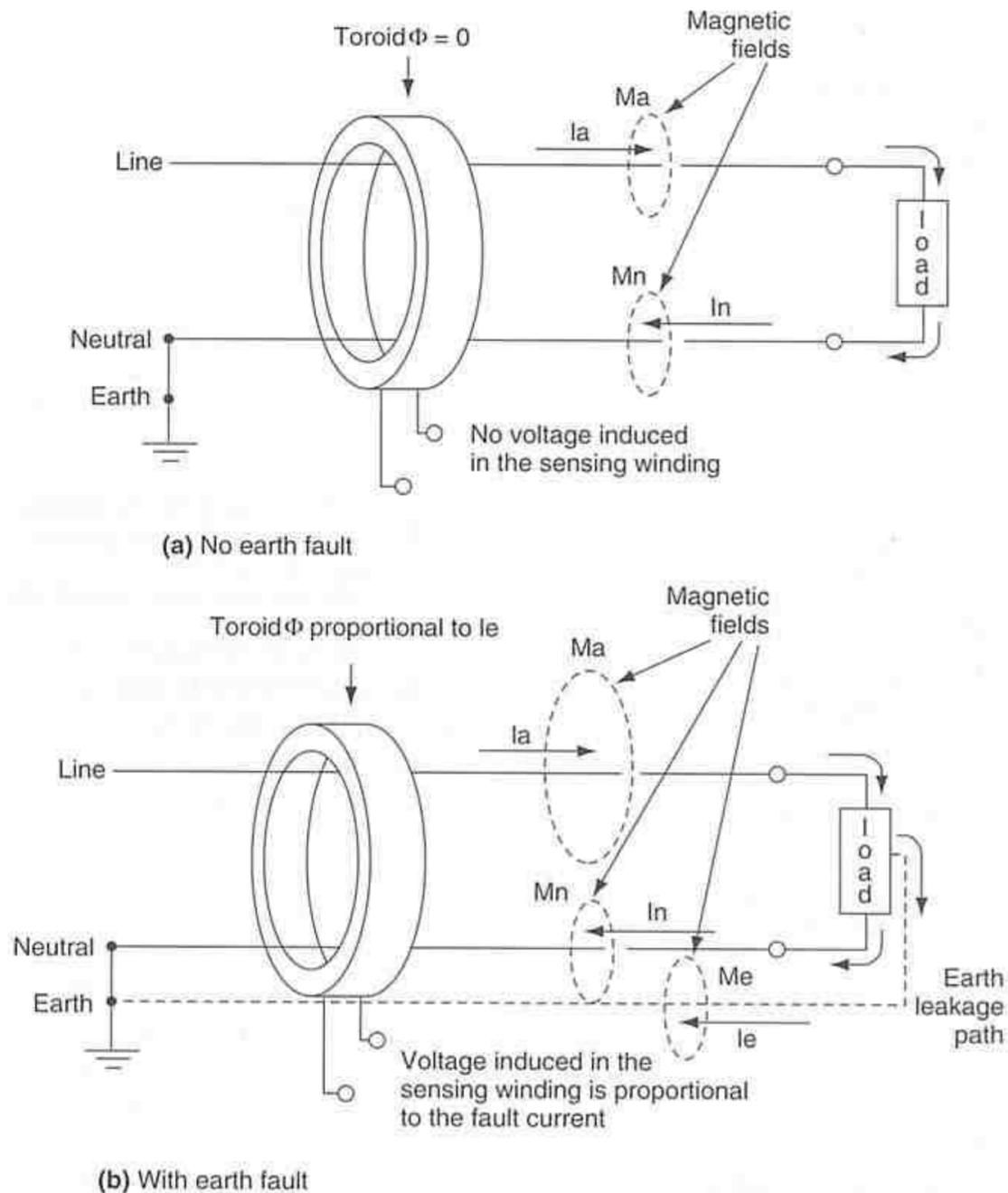


Fig. 14.4 RCD fault-current detection principles GERARD INDUSTRIES

case even when some phases are loaded more than others, as the out-of-balance current is carried by the neutral conductor. If all the conductors supplying a load are passed through a toroidal core transformer, any earth fault current will be detected by the sensing winding. Therefore the same operating principle applies as described for single-phase ac circuits.

It should be observed from Figures 14.4(a) and (b) that to detect earth fault current all the live conductors supplying a circuit (active/s and neutral) must pass through the device, from supply to load, in the same direction.

The term 'residual', meaning 'leftover', refers to the current left over as a result of the phasor sum of the

currents in all the conductors passing through the toroidal core. The terms 'earth fault current', 'earth leakage current' and 'residual current' are interchangeable.

The basic operating principle applies to all RCDs, and all use a toroidal current transformer to sense residual current. However, in practice there are variations in the other operating mechanisms, and these variations are mainly related to reliability and manufacturing cost.

The three main types of operating mechanism are described below.

- *Magnetically held trip relay:* The trip relay includes a permanent magnet, which holds a spring-loaded armature in the closed position. The sensing winding of the toroidal transformer is connected to the trip relay coil. An output from the sensing winding causes a disturbance in the magnetic circuit, which weakens the flux and releases the armature. The energy from the spring-loaded armature mechanically trips the main contacts. No connection between the trip circuit and the supply is required. There are two types of trip relays that use this same principle. One type is a polarised-type relay that only responds to the positive half-cycle of a fault current. The other is a saturation-type relay that responds to both the positive and negative half-cycles of a fault current, improving the response time by half a cycle or 10 milliseconds for a 50 Hz supply.
- *Electronic relay:* The small output signal of the toroidal transformer is used to trigger a silicon-controlled rectifier (SCR) or is amplified to operate a relay or shunt trip circuit to trip the main contacts. These types derive their operating energy from the mains supply.
- *Magnetically held relay with electronic time delay:* The circuit from the sensing winding in this type of relay includes filtering or delay elements to provide discrimination against unwanted tripping.

All RCDs must be provided with an accessible testing facility. This allows the user to test periodically the tripping operation of the device by pressing a test button located on the RCD. When the button is pressed, an artificial earth fault is created such that all of the components of the device are tested.

14.4 Types and applications

The Australian Standard *Approval and Test Specifications—Residual Current Devices* (AS 3190—1994) classifies four types of RCDs or residual current relays. The standard also covers portable RCDs. Note that under this standard a 'residual current device' is defined 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 facil-

ities and circuitry necessary to provide an output. The output can be connected to operate an external contactor or shunt-trip circuit breaker. Generally, throughout this text the term 'RCD' will include both of these devices, unless otherwise stated.

The rated residual current ($I_{\Delta n}$) of an RCD is the residual (fault) current at which tripping operation of the RCD is ensured. This is also known as the **sensitivity** of an RCD. The RCD must operate within a maximum rated time, and also must be able to distinguish between 'true' leakage current and other disturbances that may cause 'nuisance' tripping.

As well as tripping sensitivity rating an RCD has a maximum load-current rating. 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). However, AS 3190 classifies RCDs by their sensitivity rating.

The classifications of RCDs are:

- type I: residual current rating not exceeding 10 mA
- type II: residual current rating exceeding 10 mA but not exceeding 30 mA
- type III: residual current rating exceeding 30 mA but not exceeding 300 mA without selective tripping-time delay
- type IV: residual current rating exceeding 30 mA but not exceeding 300 mA with selective tripping-time delay.

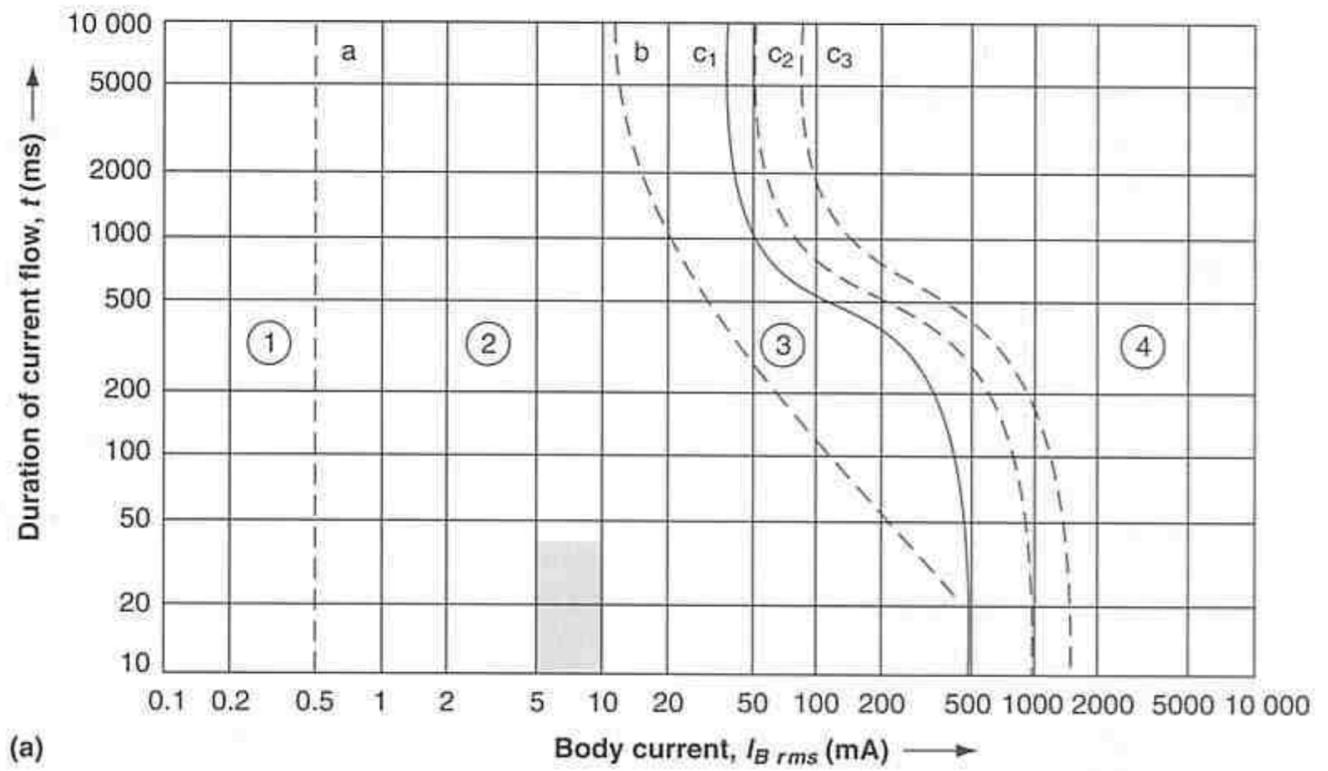
Portable RCDs are divided into:

- class L: single-phase portable devices primarily intended for household and similar general use
- class H: portable devices primarily intended for general industrial use.

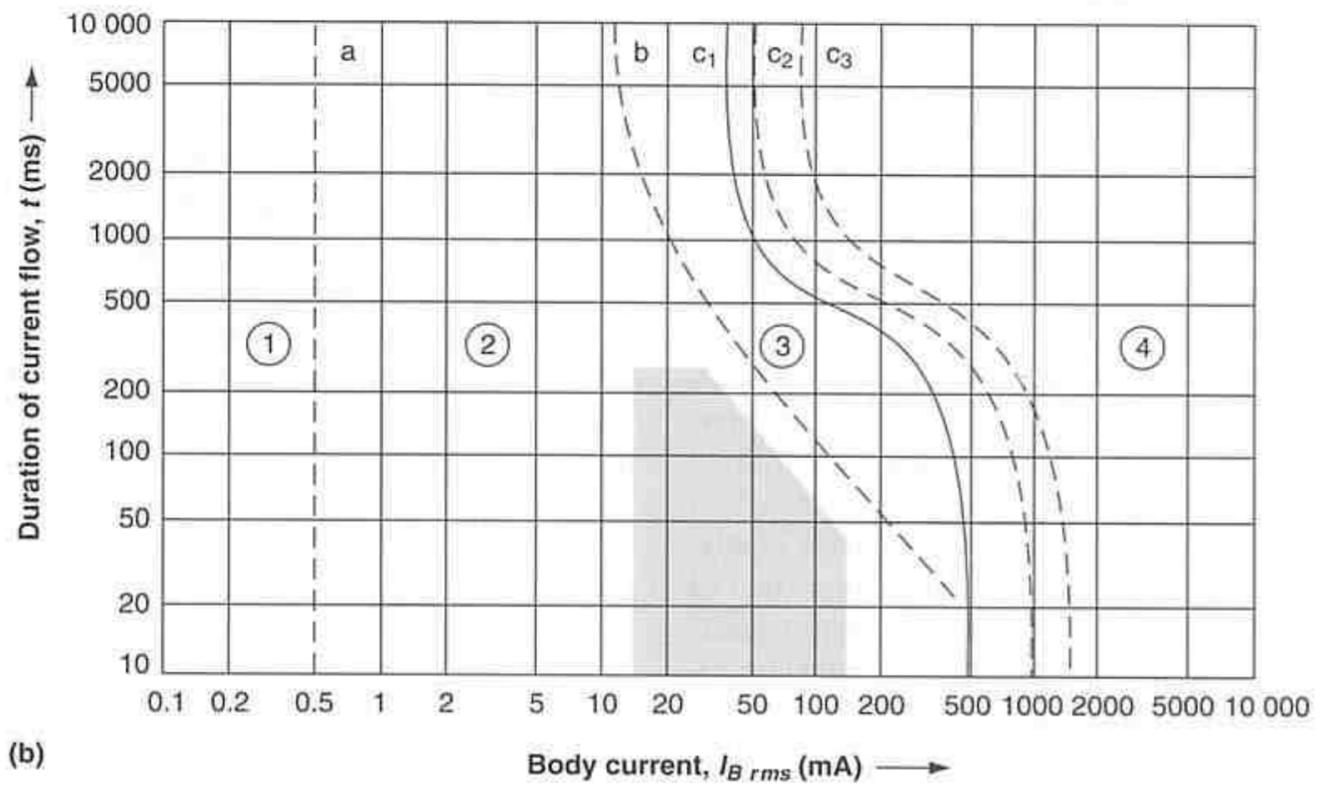
The type I RCD is specified for use in patient treatment areas by AS 3003—1985 *Electrical Installations—Patient Treatment Areas of Hospitals and Medical and Dental Practices*. This type is also suitable for use in research and educational laboratories. In hospital use, the RCD must trip on a leakage current of no more than 10 mA in a time of not more than 40 milliseconds. As medical equipment may also contain rectifying components, the type I RCD must also respond to dc pulses. The device must not trip on leakage currents less than 5 mA (see Fig. 14.5(a)).

Medical treatment quite often requires the patient to be connected to electromedical equipment, and some procedures may involve the insertion of electrodes into the body. Under these conditions, body resistance is lowered and the probability of fibrillation is greatly increased.

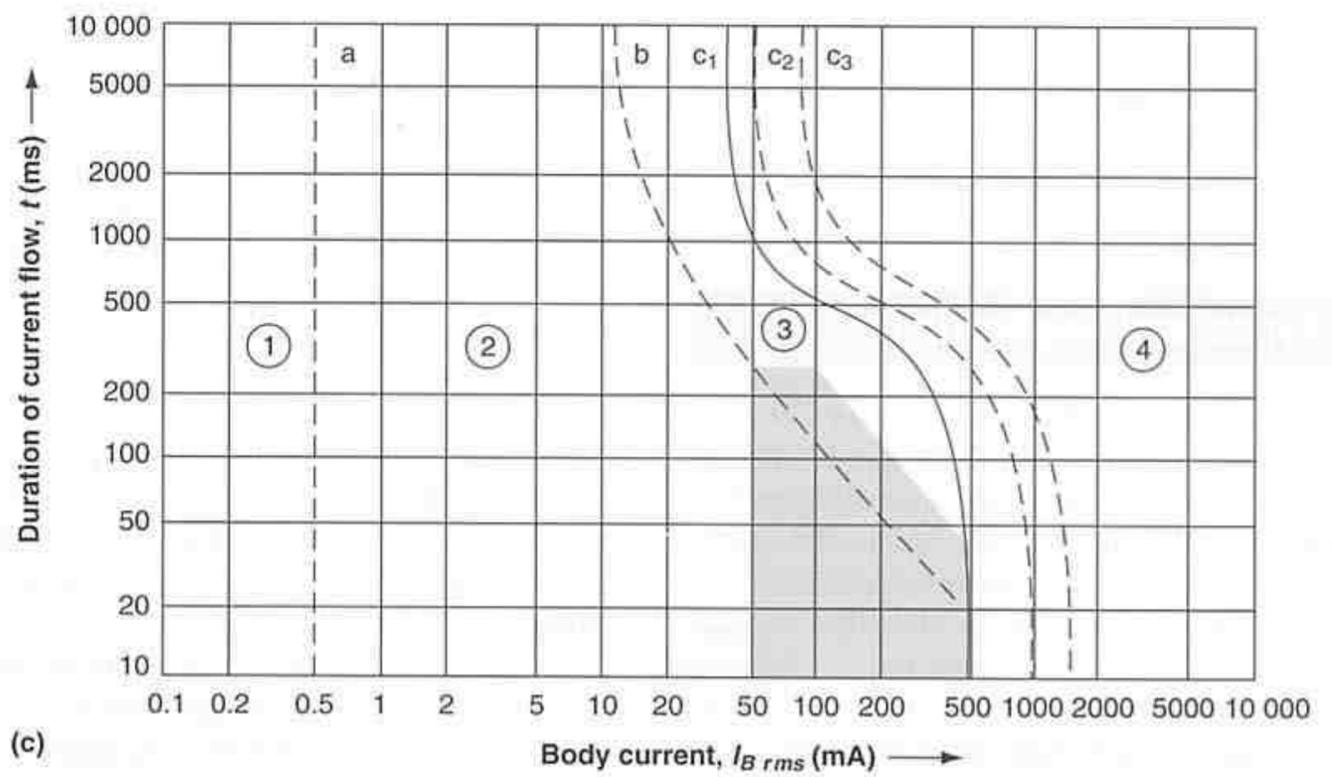
The maximum trip time for type I devices is derived from the duration of the vulnerable period of heart activity discussed in section 14.2. Electrical installations



(a)



(b)



(c)

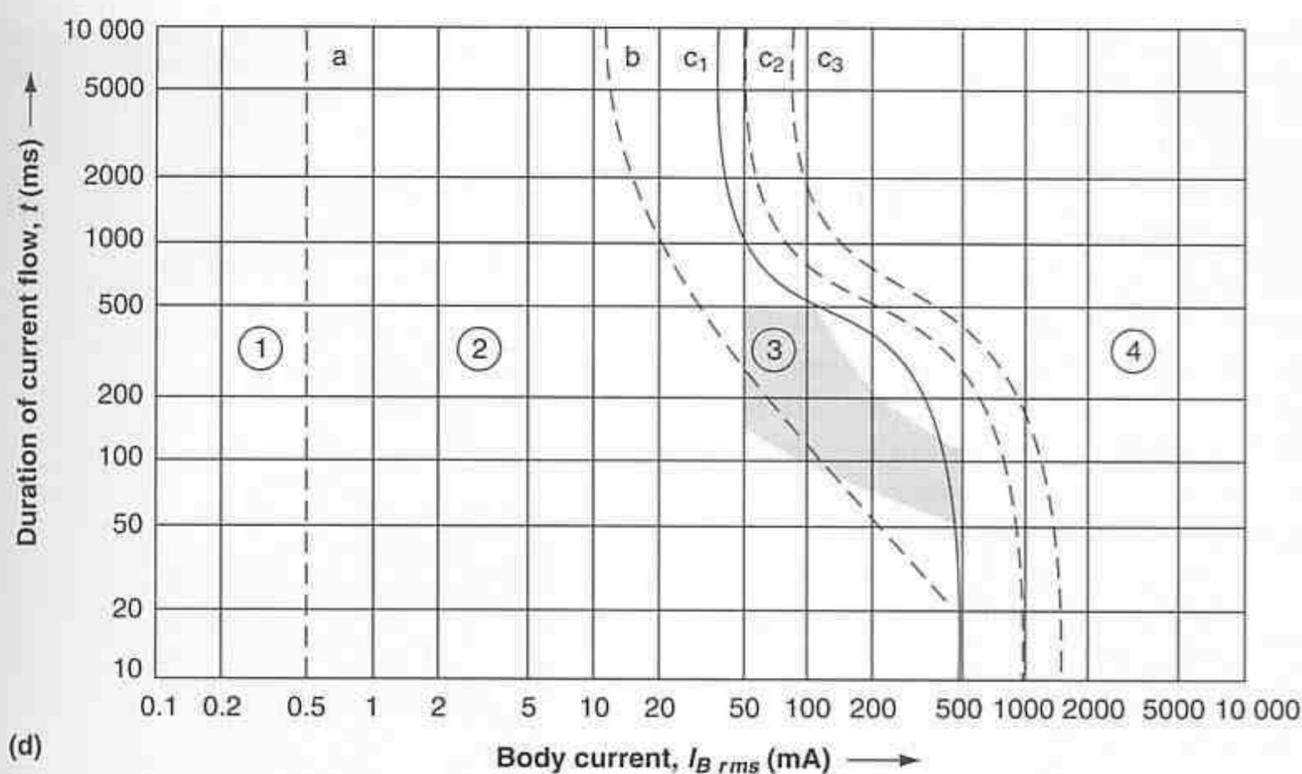


Fig. 14.5 Operating characteristics of approved types of RCDs as specified by AS 3190 are the shaded areas on the time-current zone effects graphs (refer to Fig. 14.1): (a) type I RCD (10 mA); (b) type II RCD (30 mA); (c) type III RCD (100 mA); (d) type IV RCD (100 mA) GERARD INDUSTRIES

and equipment in medical treatment areas are covered in greater detail in Chapter 19.

The type II RCD is required to operate within 300 milliseconds (250 milliseconds for residual current relays) at 30 mA leakage current and within 40 milliseconds at 150 mA leakage current. It can be seen in Figure 14.5(b) that this operating characteristic is well below the probability of ventricular fibrillation, and therefore this type of RCD will protect against direct contact with live parts. The device must not trip at leakage currents below 15 mA. In practice, a typical design point would be 22.5 mA to trip in less than 40 milliseconds.

Clause 4.14.9 of the *SAA Wiring Rules* requires all general-purpose outlets (GPOs) in a domestic installation to be protected by a type I (10 mA) or type II (30 mA) RCD. One exception is GPOs supplying refrigerators and food freezers. Another is additions and repairs to an existing installation. Note, however, that a new circuit of GPOs in a domestic installation must be RCD-protected (see Paragraph H2.6 of AS 3000). Type II devices would be the most suitable in the majority of cases, as type I devices may be subjected to a high degree of 'nuisance' tripping in the domestic installation.

At the time of writing (1997), the use of RCDs is recommended in New Zealand, but the mandatory requirement of Clause 4.14.9 does not apply. However, where a socket outlet is used to supply equipment outdoors in a damp situation in New Zealand, protection by an RCD with a maximum rated residual current of 30 mA is required. The RCD must be a type that responds not only to residual alternating currents but to any residual pulsating direct currents.

Types I and II are available in an RCD/circuit breaker combination providing circuit protection and residual current protection in one unit (see Fig. 14.6(d)). RCDs incorporated in a standard combination outlet assembly provide a convenient and economical method of installing residual current protection in an existing circuit (see Fig. 14.11).

Type III RCDs are manufactured with residual current ratings of 100 mA and 300 mA, with a maximum tripping time of 300 milliseconds (250 milliseconds for residual current relays) at the rated tripping current. Although the maximum operating characteristics (see Fig. 14.5(c)) 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 or where a high standing leakage current would cause a type II RCD to trip.

The only method of discrimination that can be incorporated into the operating characteristics of an RCD is one that uses different response times to a given fault. Fault current is independent of the RCD and is the result of the voltage and the fault path resistance:

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

Type IV RCDs (also known as S-type because they have selective tripping-time delay) are available with the same residual current ratings as type III (see Fig. 14.5(d)). However, the trip time response is 50 milliseconds to 150 milliseconds at maximum fault current, whereas the response time for types II and III

is 40 milliseconds, resulting in a minimum time delay of 10 milliseconds. Therefore, type IV devices can be used 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.

Portable RCDs incorporate type I or II devices, which protect one or more socket outlets, cord extension sockets or a combination of both. The requirements for these devices as specified in AS 3190 include limitations on the lengths of supply flexible cords for a given RCD load-current rating and cord conductor size. For example, a supply flexible cord with 1.0 mm² conductors and protected by a portable RCD with a load current not exceeding 10 A is limited to a length of 25 metres. The Standard stipulates maximum lengths for supply flexible cords with conductors up to 4.0 mm².

The Australian Standard AS 2081 *Electrical Equipment for Coal and Shale Mines—Electrical Protection Devices* covers, in part, earth-fault protection devices with rated tripping currents above 300 mA but not exceeding 500 mA. The Standard is used by the mining authority in each state to detail permissible earth leakage devices under local regulations. Devices usually require approval by the relevant mining authority before they can be installed.

In mining activities, earthing systems are required to be regularly monitored, and most cables are of the neutral-screened or armoured type, making protection necessary against indirect contact (i.e. the voltage between exposed metal and earth during an earth fault) only.

Residual current relays are used mainly in non-domestic installations such as hospitals, heavy industry and mining and 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 (see Figure 14.6(c)).

It is worth noting that RCDs are available in enclosures with appropriate international protection (IP) ratings (see Chapter 19) that allow their installation in harsh environments. Figures 14.6(a)–(e) show a variety of RCD types and styles.

14.5 Discrimination and dealing with nuisance tripping

An RCD must be able:

- to detect leakage current up to its rated value;
- to switch off the supply rapidly when such leakage current has been detected;



Fig. 14.6(a) Type I RCD intended for protection against electric shock in medical treatment areas GERARD INDUSTRIES

- to ignore leakage currents 50 per cent below its rated value; and
- to discriminate between leakage current caused by an earth fault and other line disturbances (i.e. avoid unwanted tripping).

The major causes of unwanted or nuisance tripping can be reduced to acceptable levels in the majority of cases. These causes are:

- 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'.

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. The initial standing leakage current can be as high as 5 mA for some cord-connected appliances (e.g. electric frypan, domestic clothes iron). When a number of these appliances are used on the same power circuit, the cumulative effect of their individual leakage currents could cause unwanted tripping of an RCD protecting the circuit. Arranging GPOs on separate circuits, each with separate

(b)

(c)

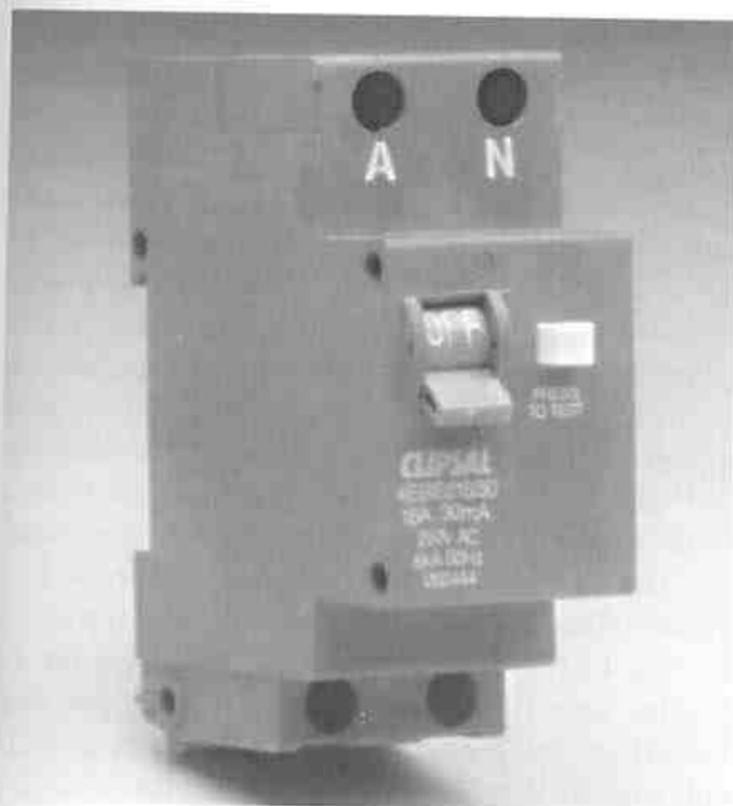
Fig.



(b)



(c)



(d)



(e)

Fig. 14.6(b)-(e) (b) Type II two-pole RCD HPM INDUSTRIES (c) Residual current relay CUTLER-HAMMER (d) Combination RCD/RCB GERARD INDUSTRIES (e) Type II four-pole RCD for multiphase or multicircuit application HPM INDUSTRIES

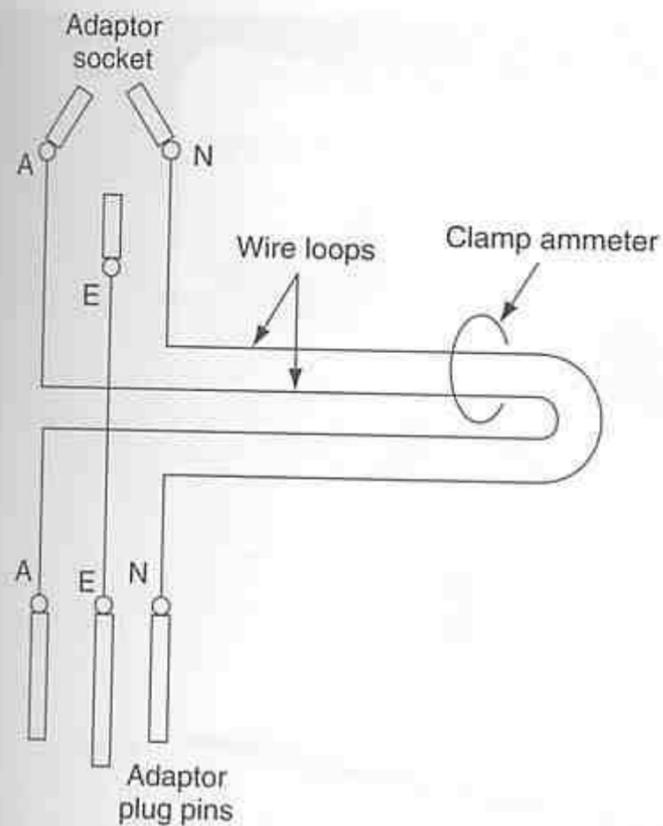


Fig. 14.9(b) Wiring diagram of the control adaptor arrangement



Fig. 14.10 RCD calibration tester GERARD INDUSTRIES

14.7 Installation arrangements for RCD protection

There are a number of installation arrangements for providing residual current protection. The factors governing these options are:

- the level of protection required by regulations;
- additional protection specified by the consumer;
- installation limitations; and
- overall cost.

The first three of these factors will be discussed here.

Level of protection required by regulations

Residual current protection is mandatory for most GPOs in new domestic installations in Australia (*Clause 4.14.9*) and for socket outlets in medical treatment areas (AS 3003). As mentioned in section 14.4, RCD protection for socket outlets supplying equipment in damp situations is mandatory in New Zealand. The installation arrangements in medical treatment areas are fairly well defined in AS 3003, which specifies the location of RCDs for easy access and restricts the number of outlets connected to an RCD-protected circuit (see Chapter 19 for more details on areas in which electromedical equipment is used).

In a domestic installation, a number of options are available for the provision of RCD protection to GPO circuits. Installing an RCD-protected socket outlet (see Fig. 14.11) in place of a standard outlet will also provide earth-fault protection on all GPOs installed downstream from the device. Figure 14.12 shows this arrangement where a GPO is left unprotected for the connection of a refrigerator or food freezer, both of which are exempt from a mandatory requirement, while all other GPOs are protected. In an existing installation it will be necessary to determine the location of the first GPO on a circuit, as any GPOs or wiring upstream of the RCD will not be protected.

The other options in a domestic installation involve the installation of devices at the main switchboard, and include the following:

- *Four-pole RCD installed on the load side of the circuit protection devices* (as shown in Fig. 14.13). This arrangement is easy to install, particularly in existing installations, as little modification to the switchboard is required. However, this setup is limited to protected installations with two protected power circuits only; any additional power circuit installed at a later date will require an additional RCD, unless it is a dedicated circuit for a refrigerator or freezer. Also, a fault on either circuit will trip both circuits.
- *Two-pole RCD installed on the line side of the circuit protection devices* (as shown in Fig. 14.14). With this arrangement, although circuits can be added later, the

6. With any further low readings, it will be necessary to test each circuit individually. Apart from old lighting points and power outlets, junction and terminal boxes are likely to be the main sources of leakage current, particularly those located in areas where the ingress of moisture is possible.

A reading of $1\text{ M}\Omega$ 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 $0.1\text{ M}\Omega$, the leakage current will increase to 2.4 mA , because current increases as resistance lowers.

The disadvantages with this method of testing for leakage current are that the installation has to be switched off during testing and that some wiring and/or equipment must be disconnected. Also, there is a risk of damaging equipment incorporating electronic components, if due care is not taken.

A simpler and more convenient method of testing for leakage current is with a clamp-type ammeter. The ammeter must be a low reading type, say 100 mA full-scale deflection. When the ammeter is clamped around the conductors (active/s and neutral) supplying a circuit, the reading will be the phasor sum of the currents in these conductors. In other words, the ammeter reading represents the leakage current of the circuit, the same as 'seen' by an RCD. In this manner the leakage current for a whole installation or individual circuits can be determined. With the use of a control adaptor the leakage current in cord-connected appliances (one of the

main offenders with regard to high leakage current) can be measured (see Figs 14.9(a) and (b)).

Note that any standing leakage current not eliminated from a circuit to be earth-fault protected increases the apparent sensitivity of the RCD. For example, a circuit with a 10 mA standing leakage current protected by a 30 mA RCD (with a tripping current of 25 mA) will trip on a 15 mA fault.

Once an RCD has been installed, it is important periodically to test the device, to ensure that it is functioning correctly. The consumer should be made aware of the test button located on the front of the RCD and should be advised on testing the device at regular intervals. An RCD should also be tested for calibration from time to time, to ensure that it operates within specified tripping currents and time. RCD testers are available that provide for the injection of a selected trip current, measurement of trip time, and enable positive and negative half-cycle testing to be selected. A typical RCD tester is shown in Figure 14.10.

Australian/New Zealand standard AS/NZS 3760—1996 *In-Service Safety Inspection and Testing of Electrical Equipment* sets out inspection and testing requirements for electrical equipment in use in various environments such as construction sites, factories and offices. The Standard includes testing criteria for RCDs and specifies how often tests are to be carried out. It has been adopted variously by regulatory authorities for electricity and occupational or workplace health and safety.

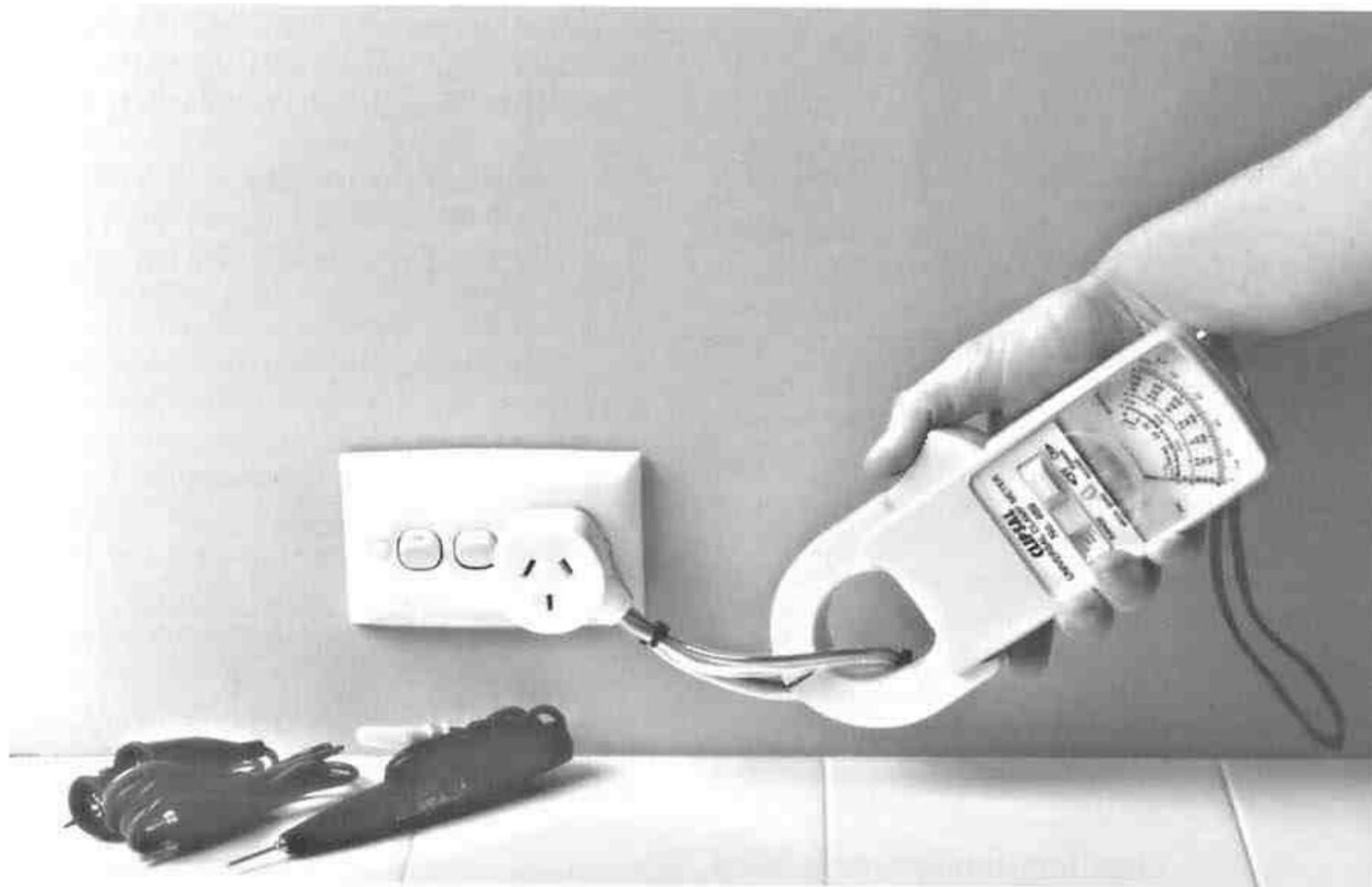


Fig. 14.9(a) Low-reading clamp ammeter used with a control adaptor to detect leakage current in an appliance

GERARD INDUSTRIES

Fig. 14

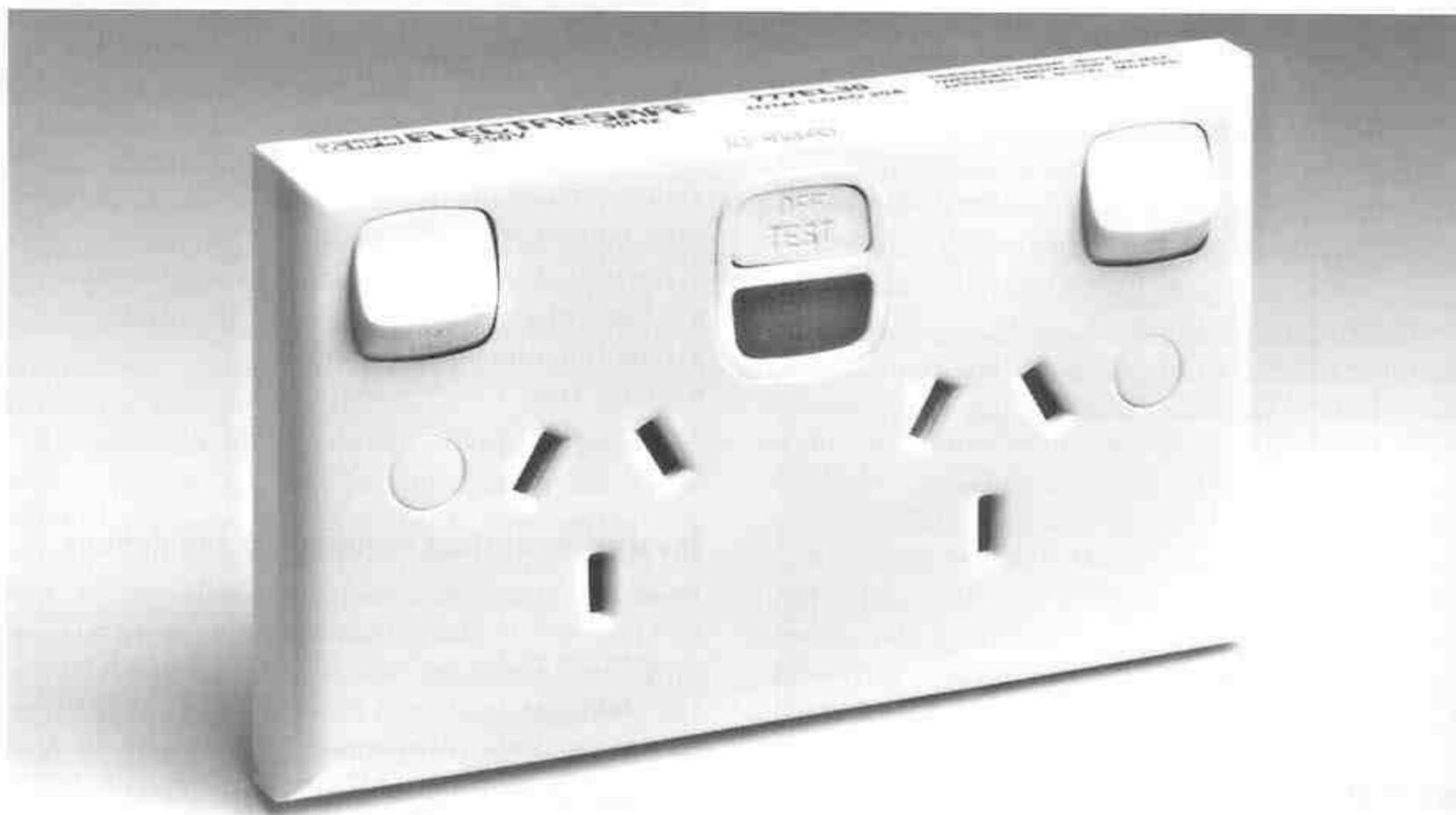


Fig. 14.11 RCD incorporated into a standard combination switch socket

HPM INDUSTRIES

device is susceptible to nuisance tripping due to the accumulated standing leakage currents of all the protected circuits. Also, a fault on any protected circuit will trip all protected circuits.

Where a separate RCD (i.e. not a combined RCD/MCB) is installed on the line side of the circuit protection device/s a separate neutral bar/link for the RCD-protected circuits is needed. This is the case for the arrangements shown in Figures 14.14 and 14.16. Generally, compact-type switchboards are supplied with a split neutral bar/link joined by a bridge connection. The bridge can be removed to provide separate unprotected and protected sections of the neutral bar/link.

In addition to the rated residual current an RCD must be rated for maximum load current (*Clause 2.4.3.1*). In the arrangement shown in Figure 14.14 this is the combined load current of the two power circuits protected by the RCD. For example, if each power circuit is protected by a 20 A circuit breaker, the rating of the RCD must be at least 40 A.

Another example is where a four-pole RCD is used to protect three single-phase power circuits. In this case, as the neutral pole of the RCD is to carry the current of all protected circuits, the RCD must be rated accordingly. Typically for these power circuits, if each is rated at 20 A, a 63 A rated RCD will be required. Also, when connecting a four-pole RCD, it is important that the neutral conductor/s be connected to the pole/s specified by the manufacturer. This is necessary because the internal test and trip

circuits are arranged across particular poles.

- *Combined RCD/overcurrent circuit-breaker unit for each circuit* (as shown in Fig. 14.15). This arrangement confines earth fault tripping to each individual circuit and is only required to cope with the standing leakage current of each circuit. It can be considered the most satisfactory of the three arrangements discussed here.

In most areas regulations require RCDs of type I or II for the protection of all fixed-wiring final subcircuits on construction sites, as well as the use of portable units for protection against earth faults in power tools. Local regulations should be consulted before undertaking installations related to construction activities.

For the mandatory requirements of earth leakage protection in mines, you should consult AS 2081 and local mining regulations.

Additional protection specified by the consumer

The electrical contractor's client is free to specify any earth fault protection additional to the mandatory requirements. In many non-domestic installations, these requirements are usually clearly documented in the job specification. The installations in many buildings include RCD protection for circuits supplying socket outlets and equipment in high-risk (earthed situation) areas. A typical example is RCD protection of socket outlets in laboratories and classrooms of educational institutions.

Fig. 14

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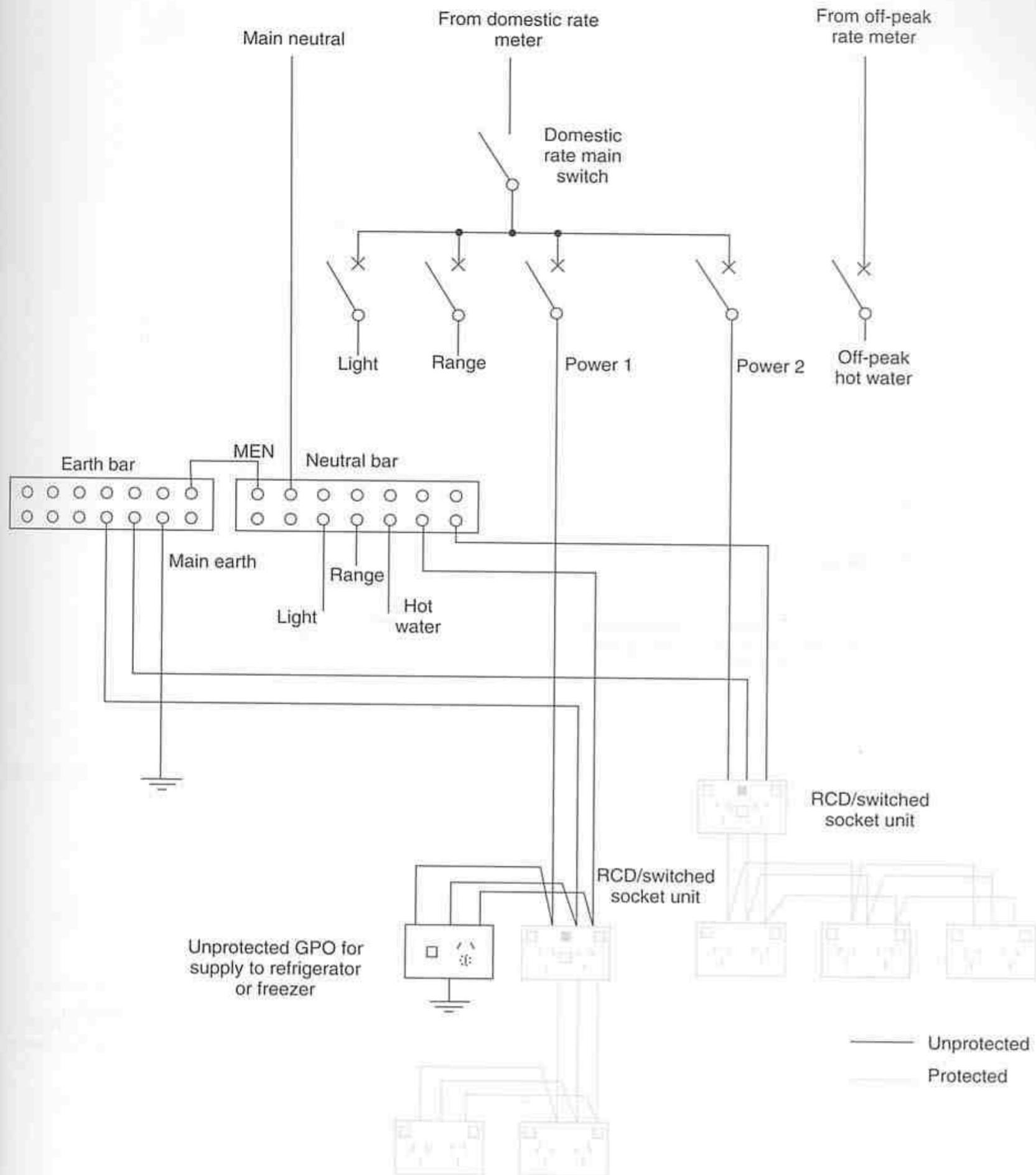
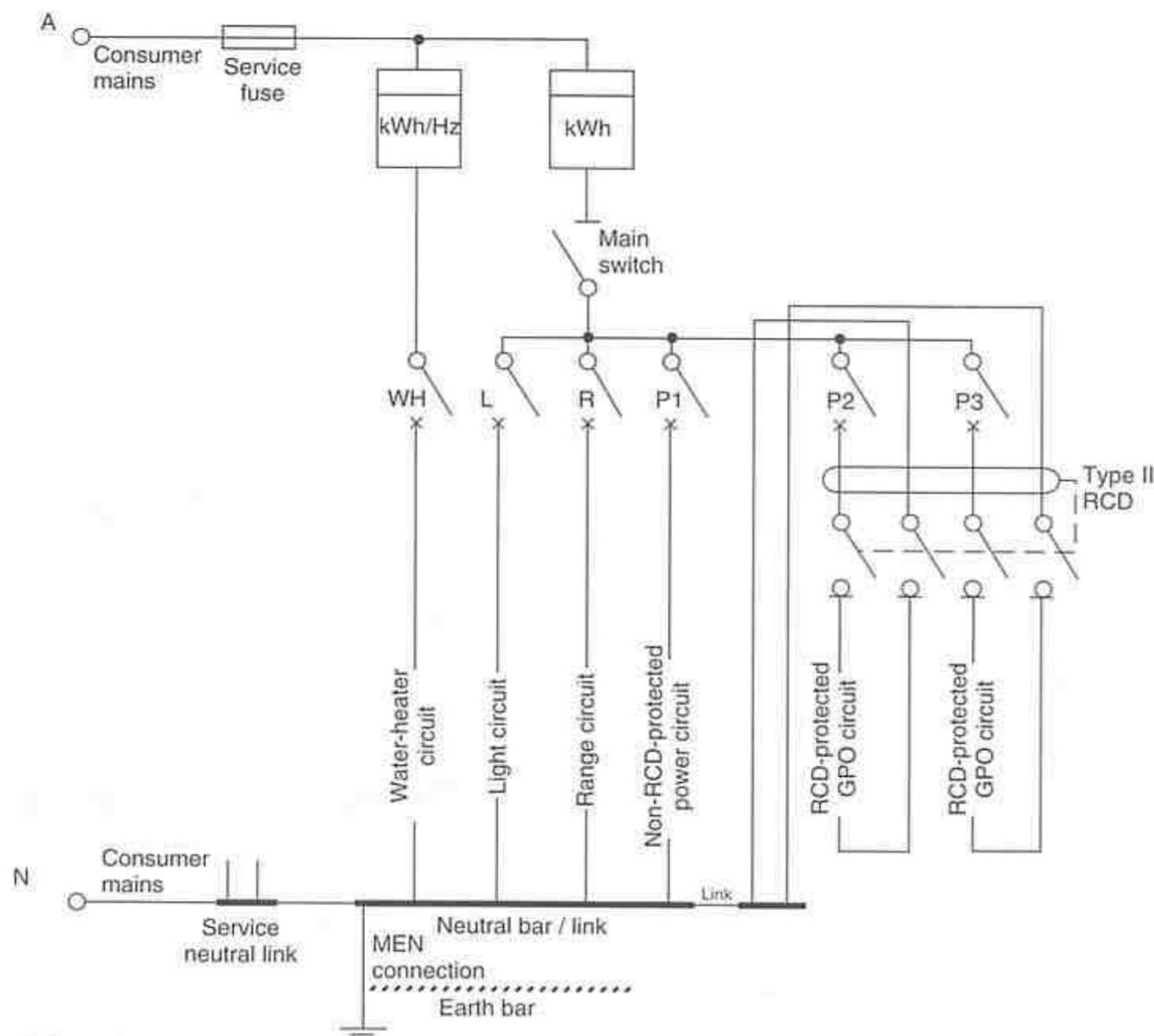


Fig. 14.12 Distribution arrangement in a single domestic dwelling for protection of power circuits using RCD/switched socket units. Note the unprotected GPO for connecting a refrigerator or freezer

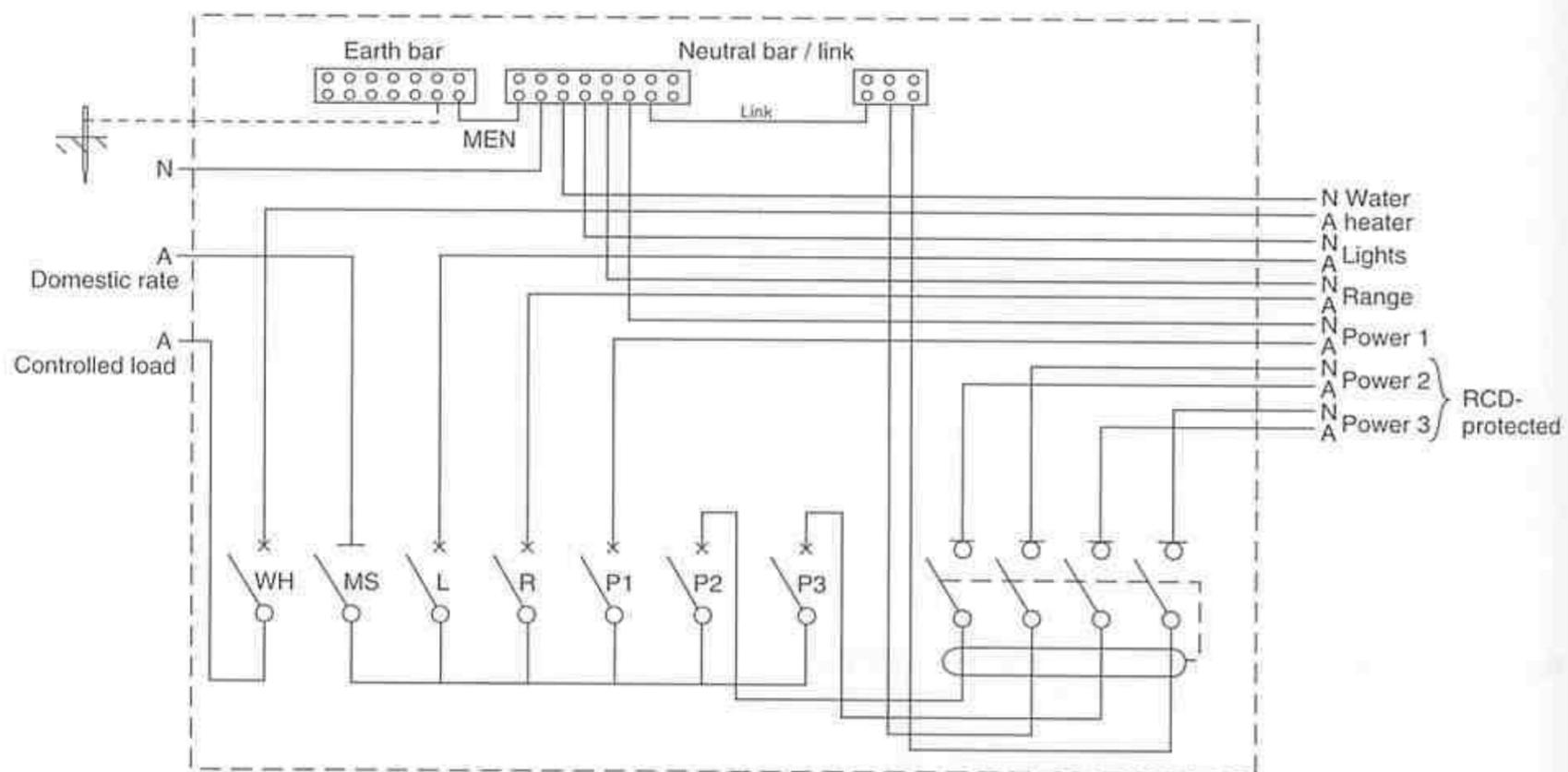
For domestic and small non-domestic installations the customer is likely to seek advice from the electrician on additional protection. The important consideration is to ensure that high-risk areas are protected in a configuration that will avoid nuisance tripping. The arrangement shown in Figure 14.16 gives both shock and fire protection for the whole installation except the water-heater circuit. Using individual RCD protection for each light and power circuit gives greater selectivity

in protection. The only circuit disconnected will be the one with the fault. This is not the case where a single RCD is used to protect more than one circuit. The following may be useful as a general guide in providing effective earth fault protection in domestic and small non-domestic installations.

A whole installation can be protected against damage or the risk of fire by a type IV (S-type) 100 mA unit installed on the supply side of all protected devices.



(a) Typical installation circuit arrangement



(b) Typical compact switchboard wiring arrangement

Fig. 14.13 Distribution arrangement in a single domestic dwelling for protection of two power circuits using one 4-pole RCD

Fixed appliances (e.g. cooking equipment, water heaters) can be protected against the risk of shock by type III 100 mA devices without being subject to nuisance tripping. However, as this equipment is considered low-risk, provided that it is correctly earthed, a more

economical but limited protection is achieved by the single type IV (S) 100 mA unit installed to protect the whole installation, as mentioned above.

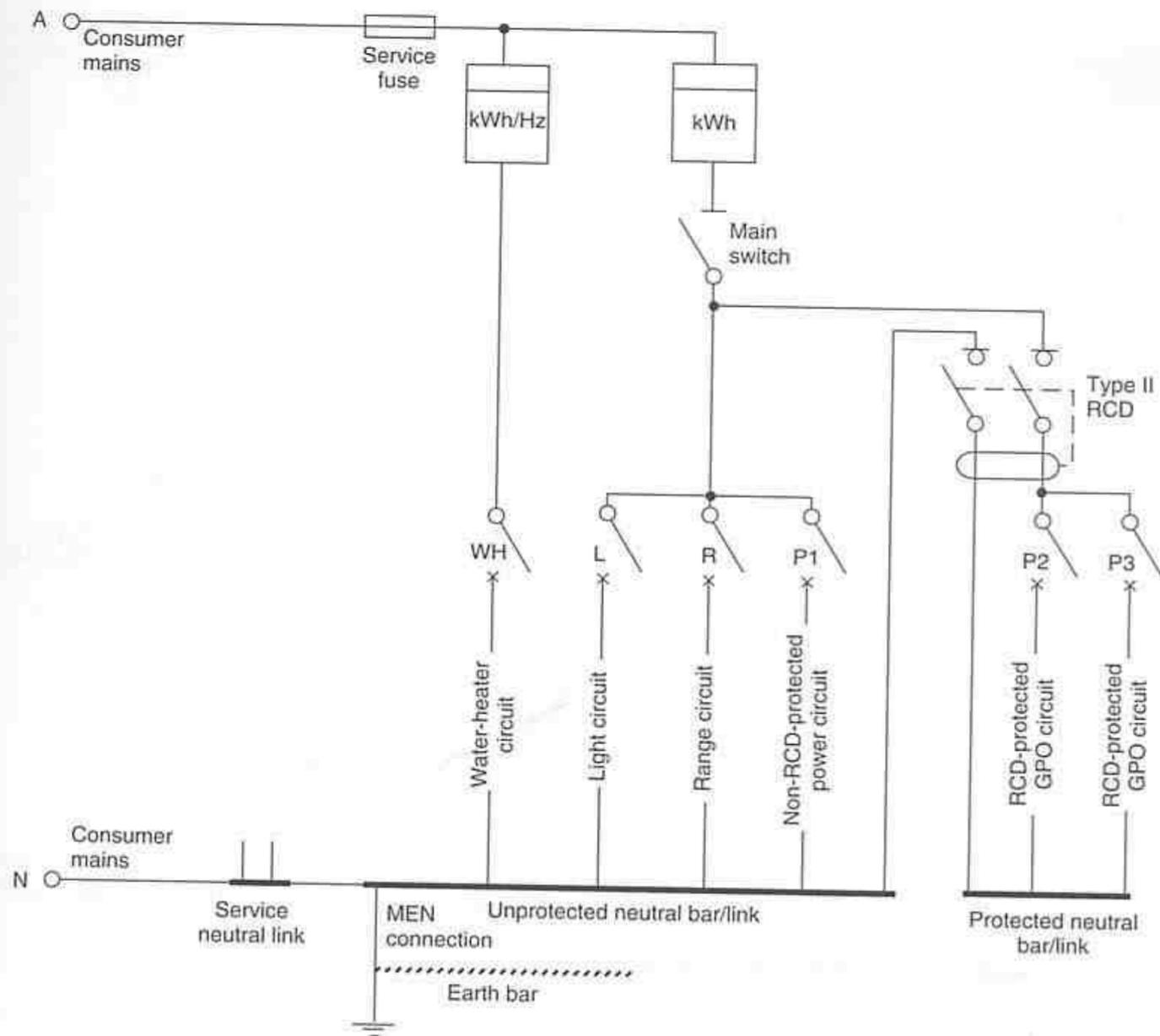
Lighting points in high-risk areas such as bathrooms, laundries, kitchens and outdoors should be pro-

(a) T

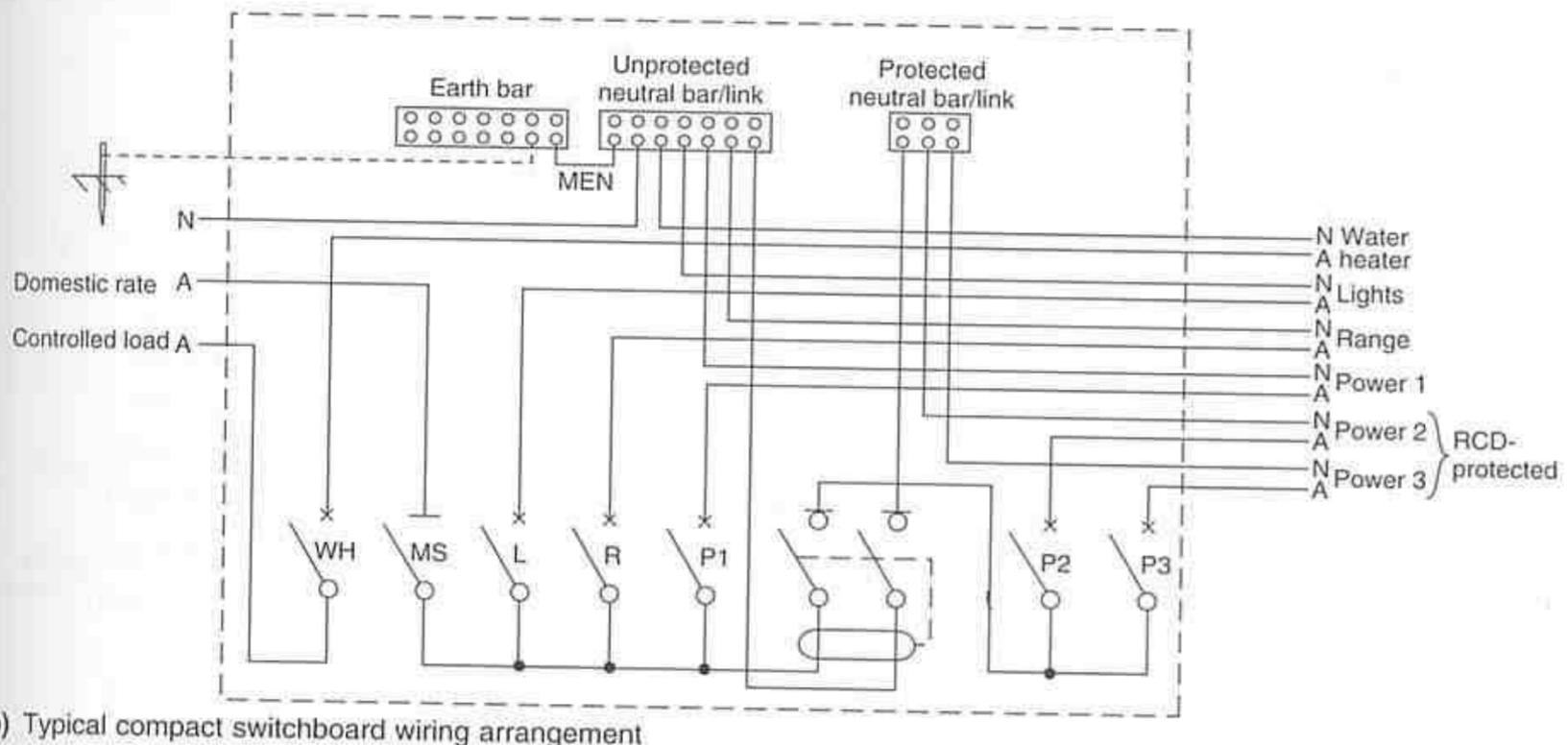
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(a) Typical installation circuit arrangement



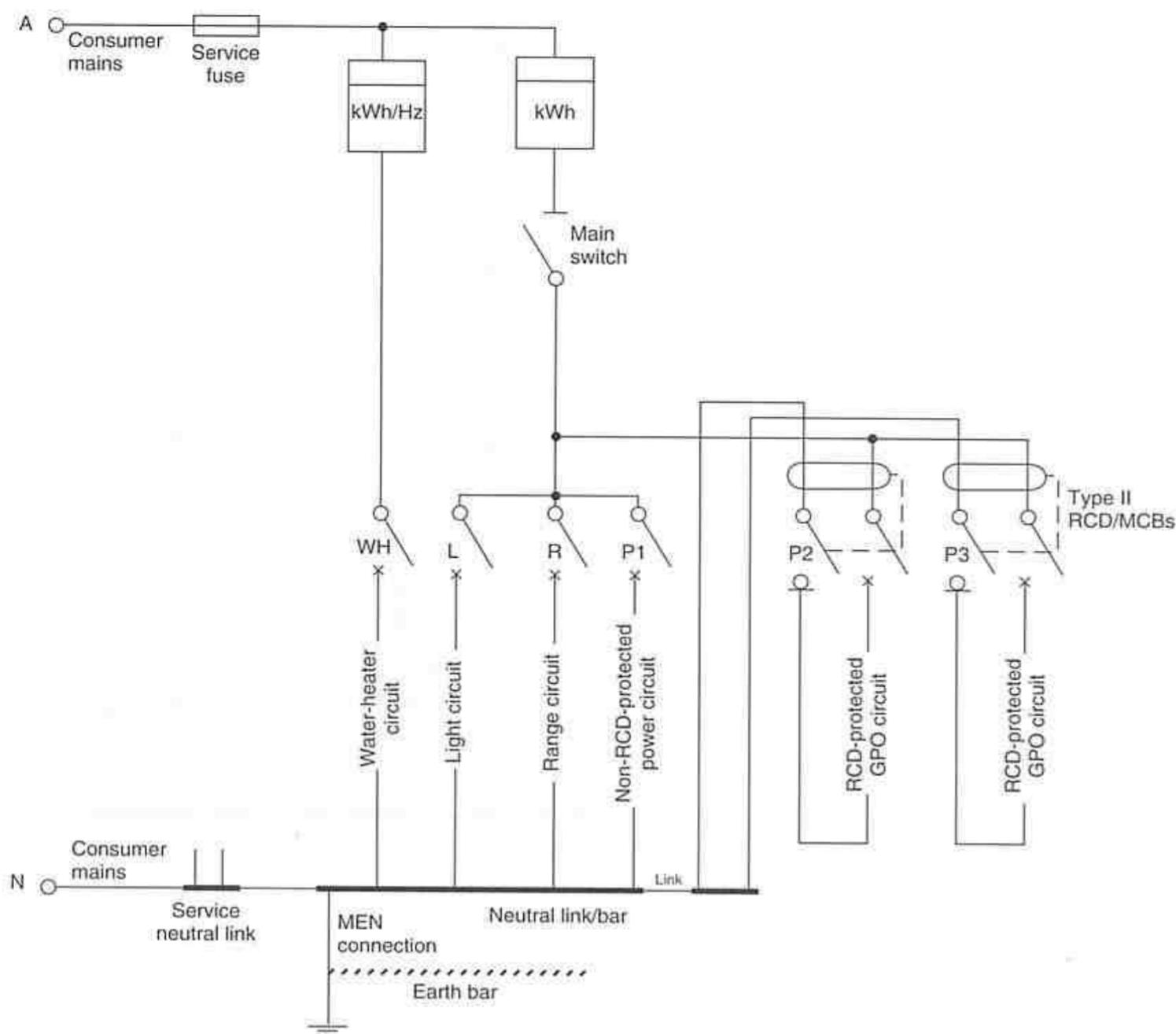
(b) Typical compact switchboard wiring arrangement

Fig. 14.14 Distribution arrangement in a single domestic dwelling for protection of two power circuits using one 2-pole RCD. Note the separate neutral bars/links for RCD-protected and non-protected portions of the installation

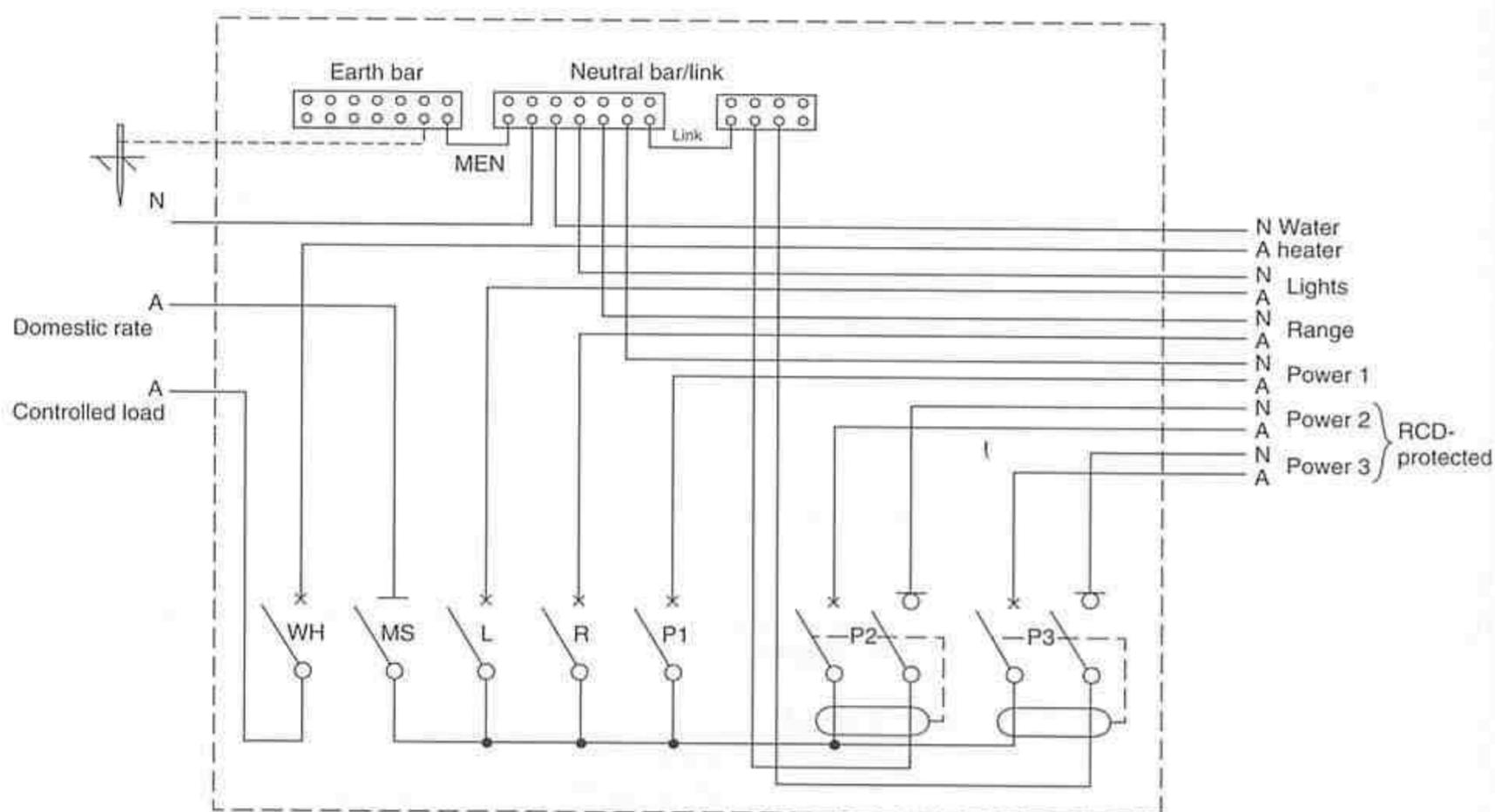
ected by a type II 30 mA device. The protection should be separate from any other circuit to avoid faults plunging the whole installation into darkness.

Circuits supplying equipment in spa or pool areas are usually protected adequately by type II 30 mA devices, as long as heating elements are not involved.

Figure 17.4 in Chapter 17 shows a switchboard equipped to provide RCD type IV as the main switch, RCD/MCB type II for pool area and RCD type II for two power circuits. The switchboard comes fitted with an earth bar and an unprotected neutral bar with terminals for the main earth, main neutral and MEN

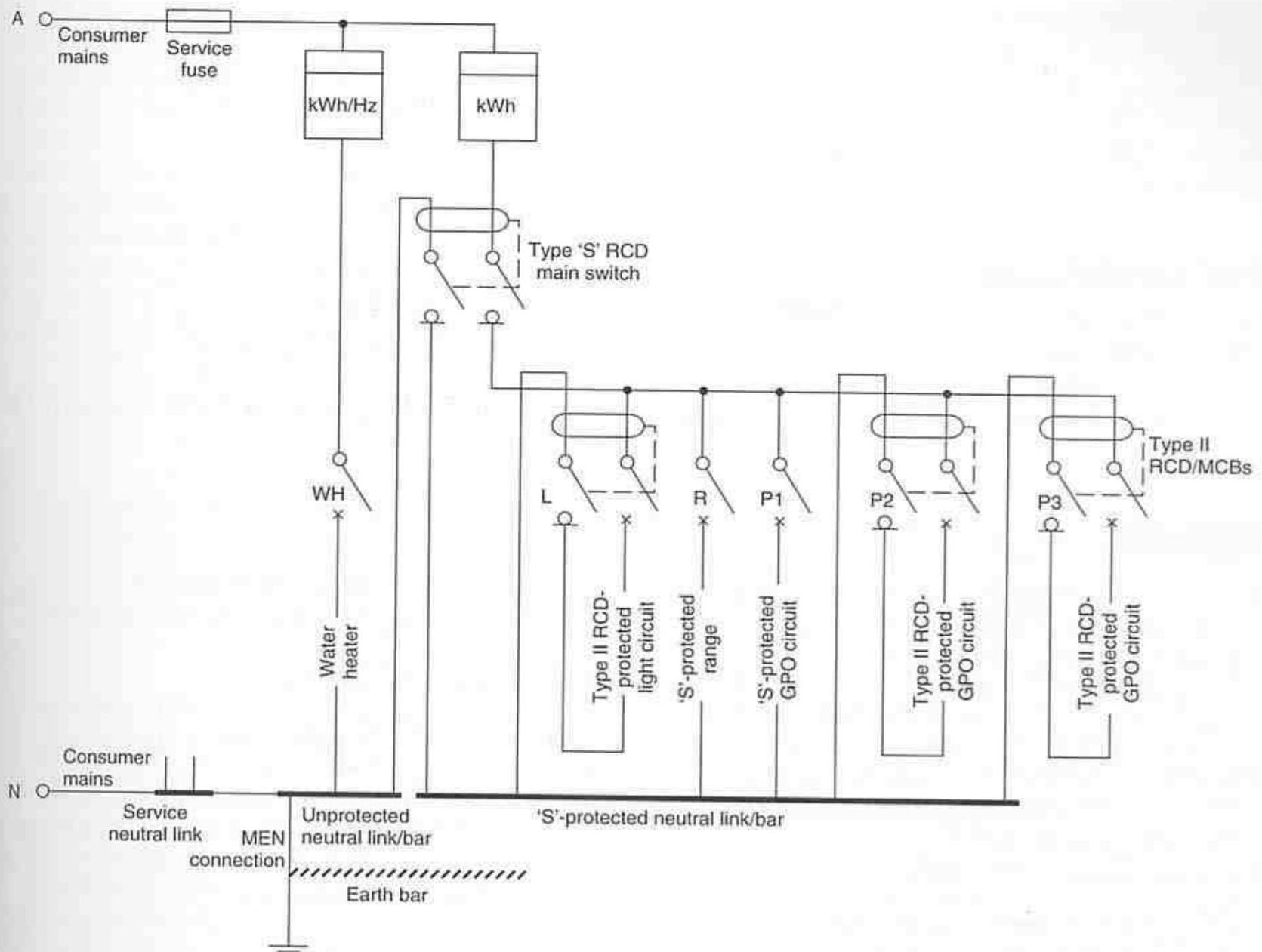


(a) Typical installation circuit arrangement

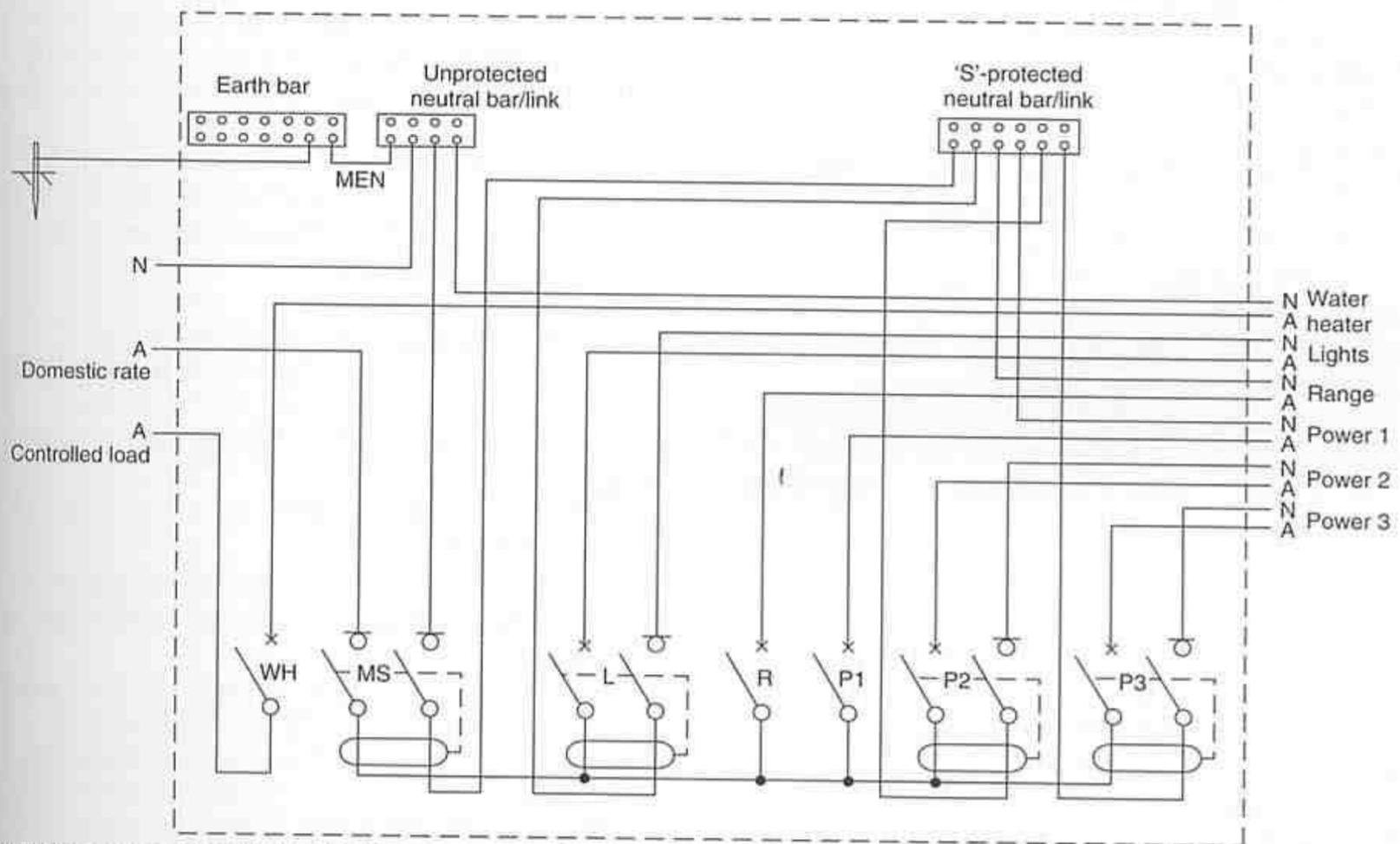


(b) Typical compact switchboard wiring arrangement

Fig. 14.15 Distribution arrangement in a single domestic dwelling for protection of two power circuits using two 2-pole combination RCD/MCBs



(a) Typical installation circuit arrangement



(b) Typical compact switchboard wiring arrangement

Fig. 14.16 Distribution arrangement in a single domestic dwelling for the protection of the whole installation, except the water-heating circuit, by a type 'S' RCD and combination RCD/MCBs for each light and power circuit

connections and separate neutral bars for type II and type IV protected circuits.

Manufacturers' data sheets and catalogues show many alternative arrangements for providing RCD protection and the special design features of their particular products.

Installation limitations

Circuits with long route lengths may present unacceptable standing leakage current due to their capacitive effect. This situation is more likely to arise in non-domestic installations and can be overcome by installing the RCD close to the equipment being supplied. With

this arrangement, protection is not provided for the circuit cable on the supply side of the device, which can be classified as low risk. The protection is confined to the area most likely to be at high risk, that is, the equipment and adjacent wiring.

Warning: RCDs **will not** provide protection against electric shock where there is no leakage current to earth, such as an electric shock caused from direct contact between active and neutral or between phases of a multiphase circuit. Even though a circuit may be protected by an RCD, a fatal shock is still possible or can be the cause of a secondary accident (e.g. falling off a ladder). **Safe working practices should be observed at all times.**

SUMMARY

- Residual current devices (RCDs) are used to rapidly cut off the power to a circuit when measured conditions in the circuit indicate that a harmful current is leaking to earth.
- The severity of the effects of electric shock depend on the magnitude of the current, the duration of the current flow and 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.
- Ventricular fibrillation is a disruption of the normal pumping action of the heart, causing blood circulation to cease, which will result in death if not rectified promptly.
- The research information on the effects of current on the human body has served as the basis for determining the operating characteristics of effective RCDs.
- RCDs use a toroidal transformer to detect any difference between the outgoing and return current in all live conductors of a circuit.
- The live conductors (active/s and neutral) for a circuit pass through the core of the toroidal transformer. The transformer acts much like a current transformer, responding to the resultant magnetic flux surrounding all live conductors.
- Under earth leakage conditions the imbalance in the outgoing and return currents, due to the leakage current, result in a net magnetic flux surrounding the conductors passing through the toroidal core.
- The net magnetic flux induces a voltage in the transformer winding. If the earth leakage current is sufficiently high, the induced voltage operates a trip mechanism to switch off the power to the circuit.
- The three main types of RCD operating mechanisms are:
 - magnetically held trip relay
 - electronic relay
 - magnetically held relay with electronic time delay.
- The classifications of RCDs are:
 - type I: residual current rating not exceeding 10 mA;
 - type II: residual current rating exceeding 10 mA but not exceeding 30 mA;
 - type III: residual current rating exceeding 30 mA but not exceeding 300 mA without selective tripping-time delay;
 - type IV: residual current rating exceeding 30 mA but not exceeding 300 mA with selective tripping-time delay.
- Portable RCDs are divided into:
 - class L: single-phase devices intended for household use;
 - class H: intended for general use.
- Typical applications of RCDs are:
 - type I: intended in areas where persons may be more sensitive to the effects of current, such as patients connected to electromedical equipment;
 - type II: intended for general protection against electric shock and particularly used for circuits supplying GPOs and socket outlets;
 - type III: useful where high standing currents would cause type II RCDs to trip;
 - type IV: intended as backup protection for type II RCDs and to protect against leakage current likely to cause a fire. Delay function is to prevent nuisance tripping.
- Residual current relays are used mainly in non-domestic installations. The output from a residual current relay can be used to operate the trip coil of a circuit breaker or other power circuit tripping device.
- An RCD must be able:
 - to detect leakage current below its rated value;
 - to switch off the supply rapidly when leakage current has been detected;
 - to ignore leakage currents 50 per cent below its rated value; and
 - to discriminate between genuine leakage current and other line disturbances.
- The main causes of nuisance tripping are standing leakage currents, electrical disturbances, and poor installation practices and faults.
- Before RCD protection is installed, sources of leakage current must be located and reduced to an acceptable level.
- Sources of unacceptable leakage current are deteriorated wiring insulation, moisture and contamination between live parts and earthed metal, particularly around terminals and in appliances.

- Electrical disturbances that may cause nuisance tripping are the result of lightning strikes on the system, switching transients or switching of reactive loads.
- Before an RCD is installed on an existing installation any defects resulting from poor installation practices must be rectified.
- Unacceptable level of leakage current can be detected through insulation resistance testing or by use of a low reading clip-on ammeter (see section 14.6).
- The tripping characteristic of an RCD should be checked periodically. This is done using a special residual current circuit breaker (RCCB) tester.
- Installation arrangements for providing residual current protection are governed by:
 - the level of protection required by regulations;
 - additional protection specified by the consumer;
 - installation limitations; and
 - overall cost.
- Residual current protection is mandatory in Australia (recommended in New Zealand) for most GPOs in new domestic installations and for socket outlets in medical treatment areas.
- Regulations require RCD protection for fixed-wiring final subcircuits on construction sites, as well as the use of portable units for protection against earth faults in power tools.
- Mining regulations also specify various requirements for earth leakage protection.
- Some installation arrangements for RCD protection are shown in Figures 14.12 to 14.16.
- RCDs will not provide protection against electric shock where there is no leakage current to earth, such as an electric shock caused from direct contact between active and neutral or between phases of a multiphase circuit.
- RCDs will not provide protection against overcurrent in a circuit, unless they are combination types offering both earth-leakage and overcurrent protection.

REVIEW QUESTIONS

Where the answer to a review question is numerical or requires reference to the SAA Wiring Rules, the answer is given at the back of the book. These questions are marked *.

1. What is the main cause of death from electric shock by low voltage?
2. Describe the purpose of an RCD.
- * 3. To what Australian Standard must types I, II, III and IV RCDs comply?
4. Explain how an RCD detects leakage current.
- * 5. (a) What are the SAA Wiring Rules requirements for providing protection against the possible risks of earth-leakage currents?
(b) What is the minimum load current rating for an RCD?
6. What is meant by the term 'residual current rating'?
- * 7. List the maximum residual current ratings for types I, II, III and IV RCDs.
8. Describe the meaning of 'standing leakage current'.
- * 9. Determine the standing leakage current for a circuit supplying GPOs if the resistance between live conductors and earth is measured as 5000 Ω .
10. What type of RCD is approved for the protection of patients in medical treatment areas?
11. Describe a procedure for testing an existing installation for leakage currents.
12. What problems could be encountered with a single RCD installed to provide protection on a number of circuits?
13. Name the tests that should be carried out regularly to ensure that an RCD is operating correctly.
14. Will an RCD provide absolute protection against a fatal electric shock?
15. What is the only effective method of protection against the risk of electric shock from active to neutral or between phases?
- *16. A new circuit of GPOs is to be added to an existing domestic installation. Is RCD protection of the new circuit required?
17. Complete the diagram on page 80 so that all circuits except the water heater are protected by an 'S'-type RCD and power circuits 2, 3 and 4 are protected by a type II four-pole RCD.

11

Testing and checking

In this chapter you will learn about testing electrical circuits and systems, including:

- reasons for testing
- testing principles and the difference between dead and live testing
- devices and accessories used in testing
- testing safely
- general requirements for testing an installation
- testing techniques
- appliance testing.

11.1 Introduction

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, thus avoiding costly repairs or adjustments later. Once the installation is complete, and prior to its connection to the supply, final testing and checking is a requirement of regulations and the 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 procedure for the isolation of the fault immediately. Tests are required again after repairs or after additions to an installation. Whatever the situation, the final outcome of testing and checking an installation is to ensure that the following apply:

- that the earthing system is complete and continuous, and its resistance is sufficiently low to meet requirements of the regulations. This is to ensure that the circuit-protection devices such as circuit breakers and fuses operate to cut off the supply in the event of a short circuit between active conductors and earth.
- that the installation resistance between all live parts and earth is adequate and sufficiently high to meet the requirements of the regulations. This is to ensure that people using the electrical installation cannot come in contact with live parts and receive an electric shock. Also, it helps protect against damage and fire due to leakage or short-circuit currents.
- that the active, neutral and earthing conductors are connected to the correct terminals throughout the installation. Incorrect connections can result in the earthing system becoming 'live' or the terminals of appliances, lampholders and the receptacles of socket outlets remaining 'live' when they are switched 'off'.
- that all circuits are connected correctly to ensure that there are no interconnections of live conductors between different circuits or short circuits between conductors. An installation where there is an interconnection of live conductors between different circuits may appear to operate correctly. However, an electrician working on the installation at some future time may be exposed to an electric shock, for instance when the neutral conductor of an interconnected circuit is open-circuited, such as at the terminals of a batten holder. This situation might arise even though isolation procedures appeared to prove that the circuit was 'dead' and safe to work on.
- that switchboard equipment is marked correctly, in particular that active conductors and their corresponding neutral conductors are identified. This is to help ensure the safety of personnel carrying out work in

the future on the installation or maintenance on equipment by identifying circuits and their protective devices for the purpose of isolating them from the supply.

- that the installation operates as intended. This is to ensure that all switches operate correctly; the rating of circuit protection devices, switches and control equipment is adequate; the current-carrying capacity of the circuit cables is sufficient; the voltage drop in the installation is not excessive; residual current devices operate under fault conditions; metering arrangements and connections are correct; and wiring and equipment are not damaged and are adequately protected against risk of damage.
- that the completed installation complies with the *SAA Wiring Rules*, local regulations, any relevant code, such as *AS 1735: SAA Lift Code* for example, and customer specifications.

This chapter is an introduction to simple methods used for testing and checking low-voltage installations.

11.2 Testing principles

Underlying the ability to test electrical circuits and find faults is a sound knowledge of Ohm's Law and the characteristics of series and parallel circuits, as well as a general understanding of how the wiring for the various types of circuits is arranged. All electrical testing methods employ the same basic principle of connecting an electrical energy source to a circuit to be tested and using electrical indicators or meters to observe how the circuit behaves. From these observations deductions are made as to whether a circuit is faulty, and if so the nature of the fault; or whether the circuit is sound, functions as intended and is safe to use.

For example, a battery and an audible device connected in series can be used to test that the conductors of a circuit are electrically continuous and have no open circuits. In this case the battery is used as the electrical energy source, with the audible device indicating whether a current is flowing in the circuit. If the device sounds, current must be flowing in the circuit and therefore the circuit must be continuous, and there is no open circuit in the conductor (see Fig. 11.1).

Many testing devices are designed with an inbuilt energy source and indicator or meter. For instance, an ohmmeter, used to measure resistance, has a battery as an energy source which is connected in series with the meter movement within the meter. An ohmmeter could have been used instead of the battery and audible device in the previous example. A zero reading on the ohmmeter indicates that the conductor is continuous.

Testing with audible devices or an ohmmeter to indicate whether a conductor or circuit is electrically

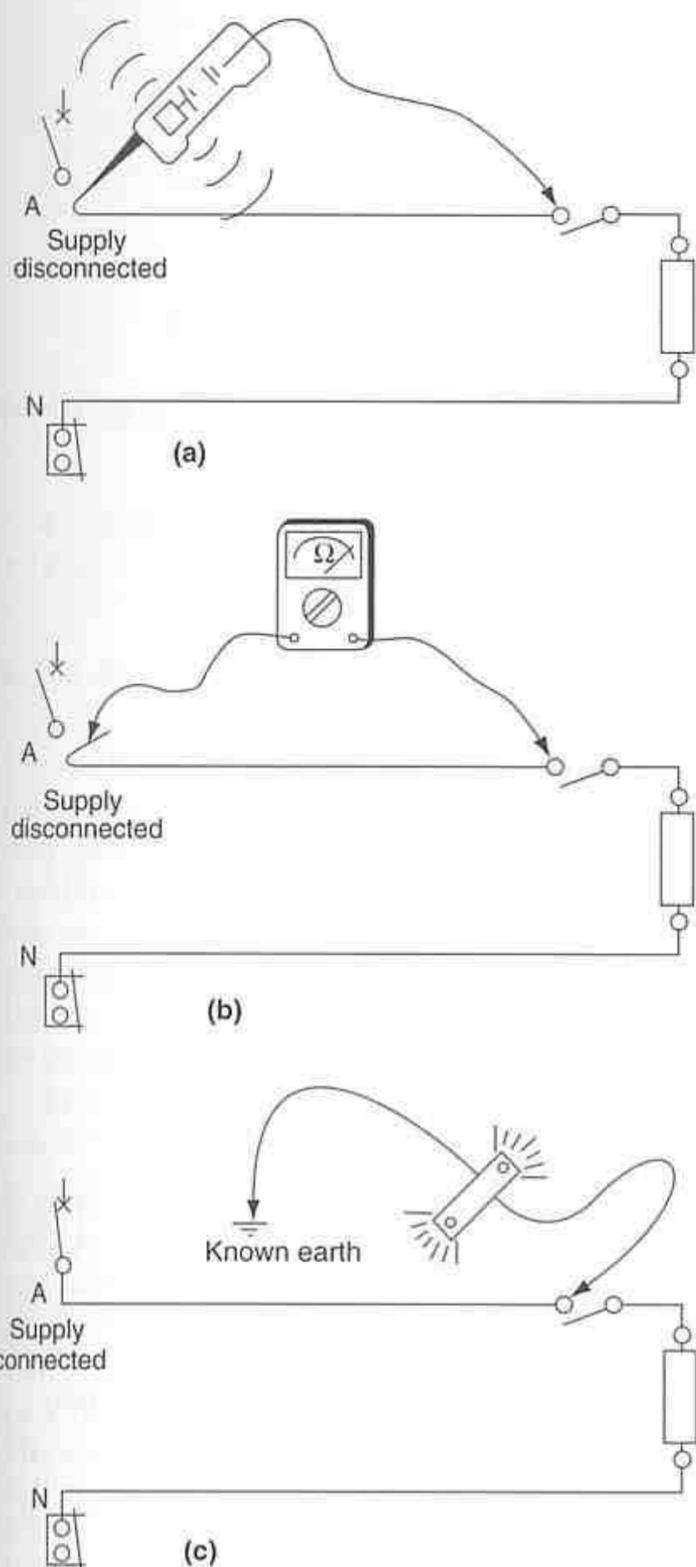


Fig. 11.1 Testing the continuity of a circuit conductor: (a) using a popular tester with inbuilt audible device and battery; (b) using an ohmmeter; (c) using an approved test lamp

continuous is referred to as **continuity testing**, and is used:

- to check that the earthing system is electrically continuous and of low resistance
- to identify active, control and neutral conductors prior to connecting them to an accessory or appliance
- to check that the wiring of a circuit is connected to the correct terminals at an accessory or appliance
- to check that there are no short circuits in a new installation or for locating a short circuit that may have developed in an existing circuit or equipment
- to check that there are no interconnections between circuits
- to identify a circuit by measuring its resistance

- to locate high-resistance connections that may have developed in a circuit while in service.

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-resistance tester', which has an inbuilt energy source that produces test voltages of 500 V dc or 1000 V dc. Testing devices with an inbuilt energy source are used with the supply disconnected from the circuit under test, and this method of testing is generally referred to as **dead testing**. Dead-testing methods are preferred by many authorities for testing new work prior to connecting to the supply.

Another energy source that is used in testing is the normal electricity supply itself. In this method of testing, the supply is connected to a circuit to be tested and voltage indicators, voltmeters or ammeters are used to observe how the circuit behaves. Once again, this time with the supply connected, a voltage indicator such as a test lamp can be used to test that the conductor is continuous. Testing undertaken with the supply connected to the circuit is referred to as **live testing**.

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 leads to the correct diagnosis of any fault. For example, a defect may occur in a circuit with no apparent effect on the operation of the circuit.

In Figure 11.2, the neutral conductor has developed a short circuit to earth at B and an open circuit at A. The circuit appears to operate in a normal fashion, but the condition is dangerous. Testing devices such as test lamps or measuring instruments must be employed before the faulty condition can be detected.

11.3 Testing devices

Visual indicators

The largest group of testing devices used by electricians comprises those that give a visual indication of the effect being tested. Perhaps the simplest and most useful for the practising electrician is the test lamp device of Figure 11.3, which usually consists of two 240 V lamps connected in series. It may be used:

- to detect the presence of a potential (i.e. whether the point being tested is live);
- to test polarity (i.e. the location of actives, neutral and earth terminals or supply points);
- to locate blown fuses;

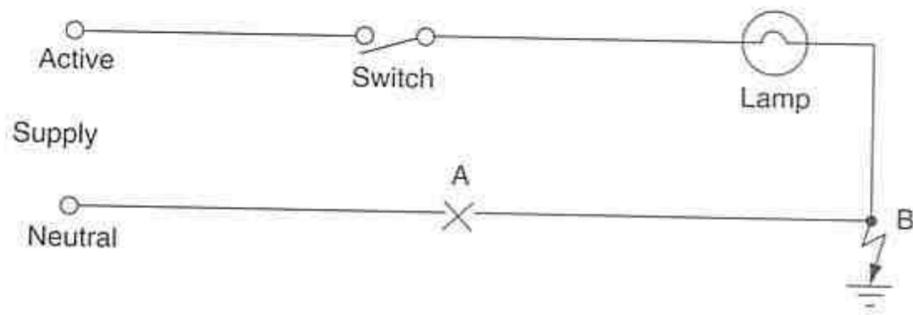


Fig. 11.2 Dangerous condition in a faulty circuit that appears to function normally



Fig. 11.3(a) 480 V test lamp QUEENSLAND ELECTRICITY COMMISSION

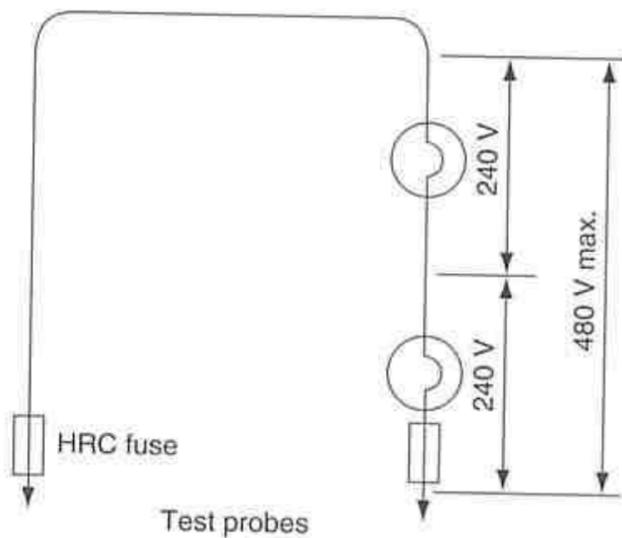


Fig. 11.3(b) The two 240 V lamps housed in the plastic moulding are connected in series

- for checking like or similar phases when 'phasing out' preparatory to paralleling two supplies;
- for other tests, dependent on the background knowledge and ingenuity of the electrician.

The lamp testing set illustrated comprises low-wattage lamps of equal power rating, not greater than 25 W per lamp, and fused probes. Because this set is designed for insertion into the socket terminals of a socket outlet, the metal exposed at the tips of the probes is greater than the 2 mm recommended and may need to be used with caution in some circumstances.

A single lamp type may be used when testing on ELV circuits such as 12 V or 32 V systems. A single 240 V lamp type should never be used, as it is dangerous to the user and may also give an incorrect interpretation of a fault condition, such as that shown in Figure 11.4. In this case a test of voltage to earth using a 240 V test lamp would indicate apparently normal conditions existing at the three load terminals. If the lamp leads were placed across the blown fuse in L_1 , the lamp would burn out violently, as a potential of 415 V would be impressed across the fuse terminals.

Approved test lamps, correctly handled, are a safe live testing device as their impedance and rating are such that a user cannot mistakenly cause a short circuit. One drawback is that when testing circuits with residual current protection they draw sufficient current to trip the device when testing between active and earth.

A device used for the detection of electrical potential or for polarity testing is the 'neon test pencil'. A simple form of this is shown in Figure 11.5, but it is manufactured in a variety of types and designs. Provision is usually made for a test lead to be attached to the cap of the neon test pencil, but this is rarely used because the neon tube will glow on contact with an active without the lead. The intensity of glow will increase if a finger is placed on the cap or if the cap is earthed.

Care should be taken to see that the tube is never used without the correct current-limiting resistor shown.

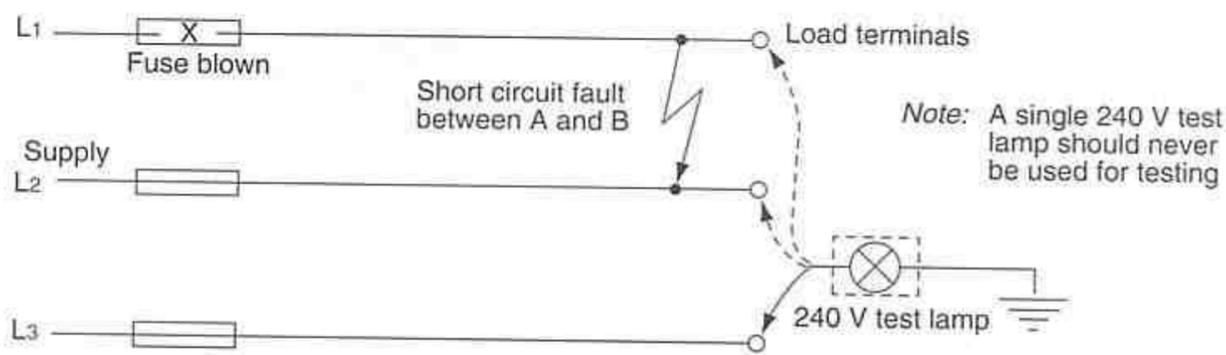


Fig. 11.4 The short circuit in this diagram causes misleading test results for the type of test shown

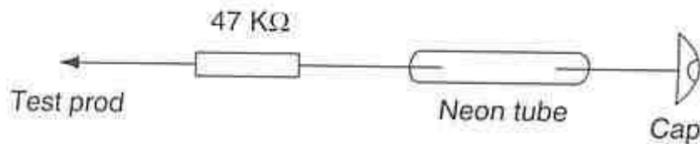


Fig. 11.5 Neon test pencil (diagrammatic representation)

It should also be noted that with this type of tester a faint glow is evident even on very low voltages, which could lead to misinterpretation—especially if the tester is used in a dark place. The authors do not consider the neon test pencil to be a particularly safe testing device, preferring the voltage indicator of Figure 11.6. However, a survey of some states indicated an extremely low incidence of accidents using a neon test pencil.

In common with most other testing devices, the neon tester may be damaged if it is dropped, and should be checked on a known live source before and after use to test for the presence or absence of voltage.

The high-impedance tester in Figure 11.6 gives an audible signal and a visual indication of the presence of voltage.

Note: Some light switches and power outlets incorporate a neon indicator, which is a visual indication of the presence of supply at the terminals of the switch or outlet. However, if the neon indicator does not glow, it cannot be assumed that there is no supply at the outlet; the neon indicator could be inoperative.



Fig. 11.6 High-impedance tester QUEENSLAND ELECTRICITY COMMISSION

Meters

It is appropriate at this point to make a brief comparison between analogue and digital instruments. Because an analogue meter operates by moving a pointer across a calibrated scale, the reading is subject to parallax error. The measured quantity on a digital meter is displayed as numbers and therefore not subject to this problem.

An inherent property of the analogue meter is that it provides an immediate visual indication through the movement of the pointer. This can be an advantage where an indication above or below a particular value is required and not a precise measurement. For example, full-scale deflection of the needle of an ohmmeter set to measure low resistance would show that the circuit or conductor under test is electrically continuous without the need to take an exact resistance reading. This can improve the efficiency of the testing process, and analogue meters are thus preferred by many electricians for testing new installations. However, when testing to determine a specific resistance, such as in fault-finding, the digital readout may be more suitable.

Voltmeters and ammeters

The voltmeter is another testing device that detects the presence of an 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 instrument must be suitable for the supply (ac or dc) and be set on the correct range or voltage rating. For example, an attempt to measure 240 V with a 10 V instrument will probably destroy the movement of the meter, which is expensive to replace and, more importantly, may produce a safety hazard.

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. Ammeters, in common with other measuring instruments, are made in a wide selection of ranges and designs. On ac circuits, both ammeters and voltmeters may have their range extended by the use of suitable current and voltage transformers respectively.

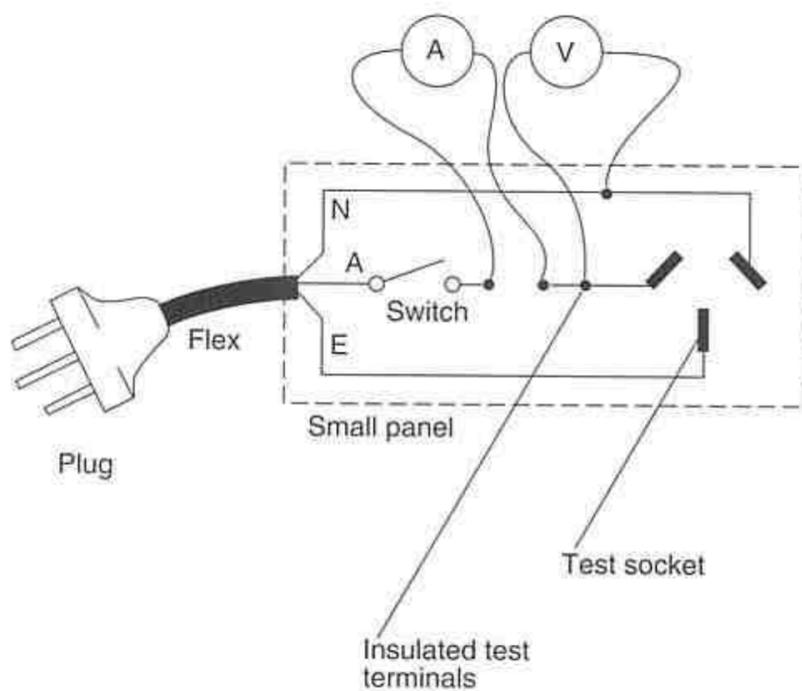


Fig. 11.7 Simple test panel for metering current and voltage on an appliance

Figure 11.7 shows the connection of an ammeter and voltmeter through a simple test panel. The appliance being tested plugs into the test socket, and the panel is in turn plugged into the supply outlet.

Provided that a portion of the circuit wiring is accessible, values of voltage, current and power in a single-phase or balanced three-phase circuit may be measured without disconnecting the circuit or disturbing the wiring, by the use of a clip-on type of instrument, such as that illustrated in Figure 11.8. This digital-type meter is provided with analogue output terminals as a standard feature, and in this versatile measurement and testing device the instrument transformer and the meter are combined in the one hand-held instrument. The clip-on meter is the most commonly used type of meter in field testing the load conditions of circuits and appliances.

Multimeters and ohmmeters

For convenience, the functions of several measuring instruments are sometimes combined and incorporated in the one instrument. This instrument has many trade names but is most widely known as a multimeter. A typical analogue multimeter, described by its manufacturer as a 'robust toolbag instrument', is shown in Figure 11.9. A wide range of voltage, current and resistance measurements is possible with the instrument shown.

Figure 11.10 illustrates a more expensive but very versatile type of testing instrument, termed an Insulation Polytester by its makers; it is included to illustrate the type of testing possible. The clip-on current transformer shown in Figure 11.11 is used in conjunction with the meter movement of the Polytester to measure ac. This is in effect a current transformer, which utilises the circuit conductor as the primary and has an ammeter connected across the secondary. Note the possible ranges



Fig. 11.8 Digital-type clip-on ac meter NILSEN INSTRUMENTS

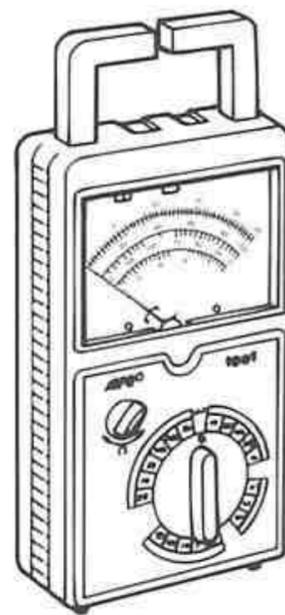


Fig. 11.9 Typical multimeter NILSEN INSTRUMENTS

of measurement shown below the appropriate diagrams included in Figure 11.11.

The measurement of resistance values in the field may be broadly divided into:

- measurements of relatively low resistance, such as earth-continuity resistance or the resistance of a heating element or motor winding;
- measurements of high resistance, typified by tests of insulation resistance.

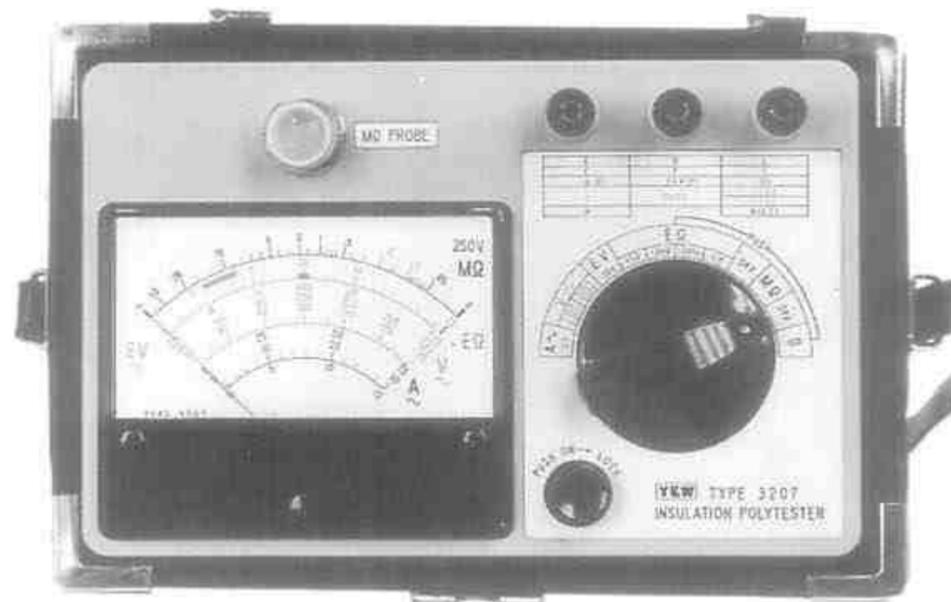


Fig. 11.10 Electronic multifunctional field tester capable of use for the five steps of measurement illustrated in Fig. 11.11 NILSEN INSTRUMENTS

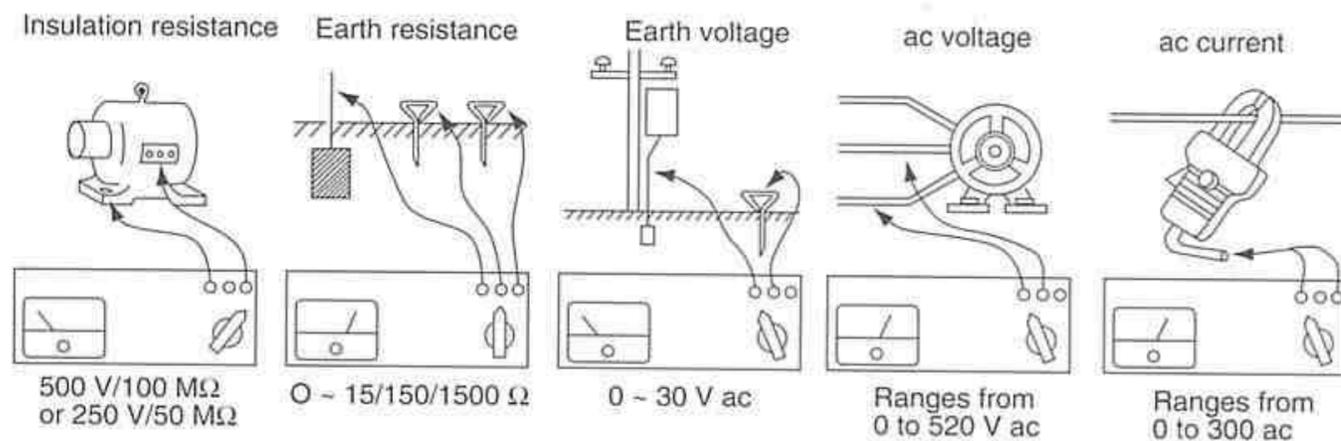


Fig. 11.11 Multifunctional field tester applications NILSEN INSTRUMENTS

A wide range of resistance measurement is possible with the multimeter-type instrument if it is used intelligently, with an appreciation of its practical limitations. It is pertinent here to point out the importance of electrical theory background, using the multimeter as an example.

The multimeter of Figure 11.9 is quite adequate for measurements of resistance, but does not necessarily test a circuit to the required or specified voltages. Insulation resistance of a 250 V circuit must be measured with the insulation under a stress of 500 V dc (see *Clause 1.5.2*). The type of multimeter illustrated rarely has a testing voltage of more than 9 V. The 500 V insulation tester shown in Figure 11.14 would be suitable for this test, or the Polytester illustrated in Figure 11.10, which can test at 250 or 500 V.

On the other hand, if a 500 V testing voltage were applied to the 'solid-state' components of a light dimmer, they would be ruined. Some electronic components can be destroyed by the application of a potential as low as 4.5 V if the potential is applied incorrectly, so it is important to check always that the instrument to be used is suitable for the test being carried out.

When a normal multimeter is used on the 'ohms' scales, the circuit is designed so that the movement of

the instrument is actually measuring voltage drop; however, the scale is calibrated in ohms, enabling resistance values to be read directly.

Insulation-resistance testers

In multimeters, a battery is used as the source of emf. A battery may also be employed as the energy source for a solid-state or transistorised circuit to supply an emf at higher voltages. The source of emf may also be in the form of a hand- or motor-driven generator. A well-known heavy-duty insulation-resistance tester is shown in Figure 11.12. It may be hand-cranked or connected to an ac mains supply and is designed for high-voltage heavy-duty work, such as the maintenance and servicing of large industrial installations. Models capable of applying test voltages up to 5000 V dc are available.

The digital insulation tester shown in Figure 11.13 is designed for testing large or complex installations at voltages up to 1000 V dc. It is auto-ranging and therefore gives a direct reading at all test voltages; no multiplication factors have to be applied. An internal battery supply is housed in the instrument casing.

Figure 11.14 shows a hand-driven 500 V insulation and continuity tester having insulation-resistance ranges



Fig. 11.12 Heavy-duty insulation-resistance tester NILSEN INSTRUMENTS

of 0–1000 M Ω and infinity. The instrument also has a voltage-measuring facility, range 0–300 V ac.

The electronic battery-operated type of instrument is very popular, because it is light and compact and may be held and operated in one hand, as there is no generator to turn. High testing voltage is produced by an electronic circuit, which uses an internal battery as an energy source. The instrument in Figure 11.15 has a range of 0–100 M Ω and infinity at a testing voltage of 500 V. It has the same voltage-measuring facility as the hand-driven insulation tester in Figure 11.14.

Another battery-operated tester suitable for measuring insulation resistance and continuity is shown in Figure 11.35 on p. 277.

For full descriptions of the instruments mentioned in this chapter, you are referred to trade literature pro-

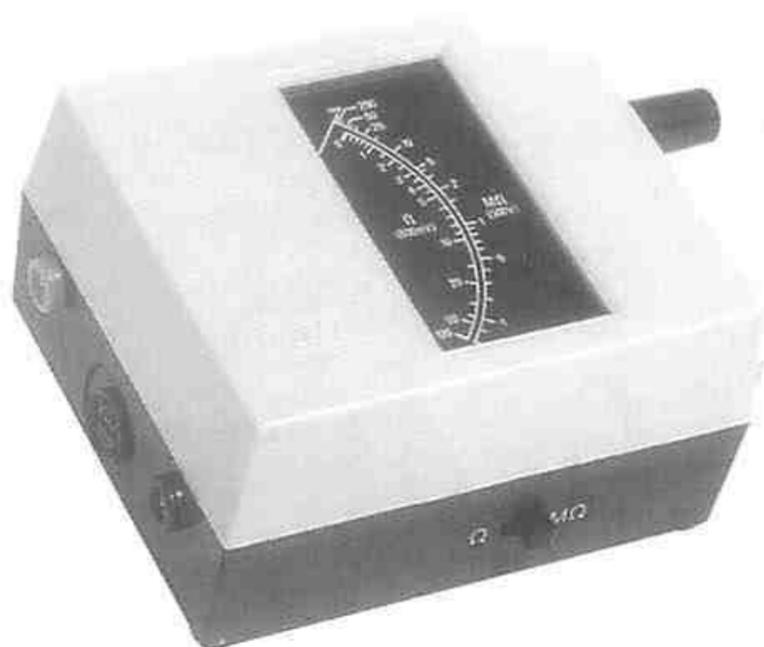


Fig. 11.14 Hand-driven insulation and continuity tester NILSEN INSTRUMENTS

duced by the instrument manufacturers and to textbooks on their construction, design and operation.

Testing accessories

A number of purpose-designed accessories and testing devices are used specifically to improve the accuracy and efficiency of testing an installation. This type of equipment has been used in the past by energy distributors' inspectors. More recently it has been adopted by many electrical contractors as a result of changes to legislation, requiring them to conduct safety testing of their installation and to ensure that the installation is safe to connect to the supply.



Fig. 11.13 Multivoltage digital insulation-resistance tester NILSEN INSTRUMENTS



Fig. 11.15 This battery-operated insulation-resistance tester is light and compact NILSEN INSTRUMENTS

Figure 11.16 shows equipment designed by Testing Inspection Services Pty Ltd for 'dead testing' the polarity of final subcircuits, transposition of earth and neutral, connections between circuits and the number of points on a circuit. The resistor box (a) provides six values of resistance to differentiate between the active and neutral conductors of three different circuits. It is used in conjunction with the Light Stix, dead (b) and the GPO tester, dead (c), each of which has a two-position switch for testing the connections of the active and neutral conductors. A trailing lead (d) is a useful testing accessory, and the probe (e), which is designed to plug into the earth receptacle of a socket outlet, enables connection with the earthing conductor on a final subcircuit.

A 'Light Stix' for 'live testing', with a built-in extension rod for testing earth connections and continuity at light fittings and other exposed metal, is shown as part (a) in Figure 11.17. The series lamp and flasher unit (b) are for connecting into a final subcircuit at the switchboard to differentiate between active and neutral conductors. The GPO tester (c) incorporates earth and neutral take-off terminals, earth-continuity testing, and testing for transposition of earth and neutral conductors. It also has a push button to test active to neutral and active to earth.

The 'installation test box' (Figure 11.18) provides functions for checking the continuity of test lamps, the accuracy of an ohmmeter used for earth-continuity testing and the output voltage of an insulation tester. Other functions include a load, a flasher, and a resistor for differentiating between conductors when conducting

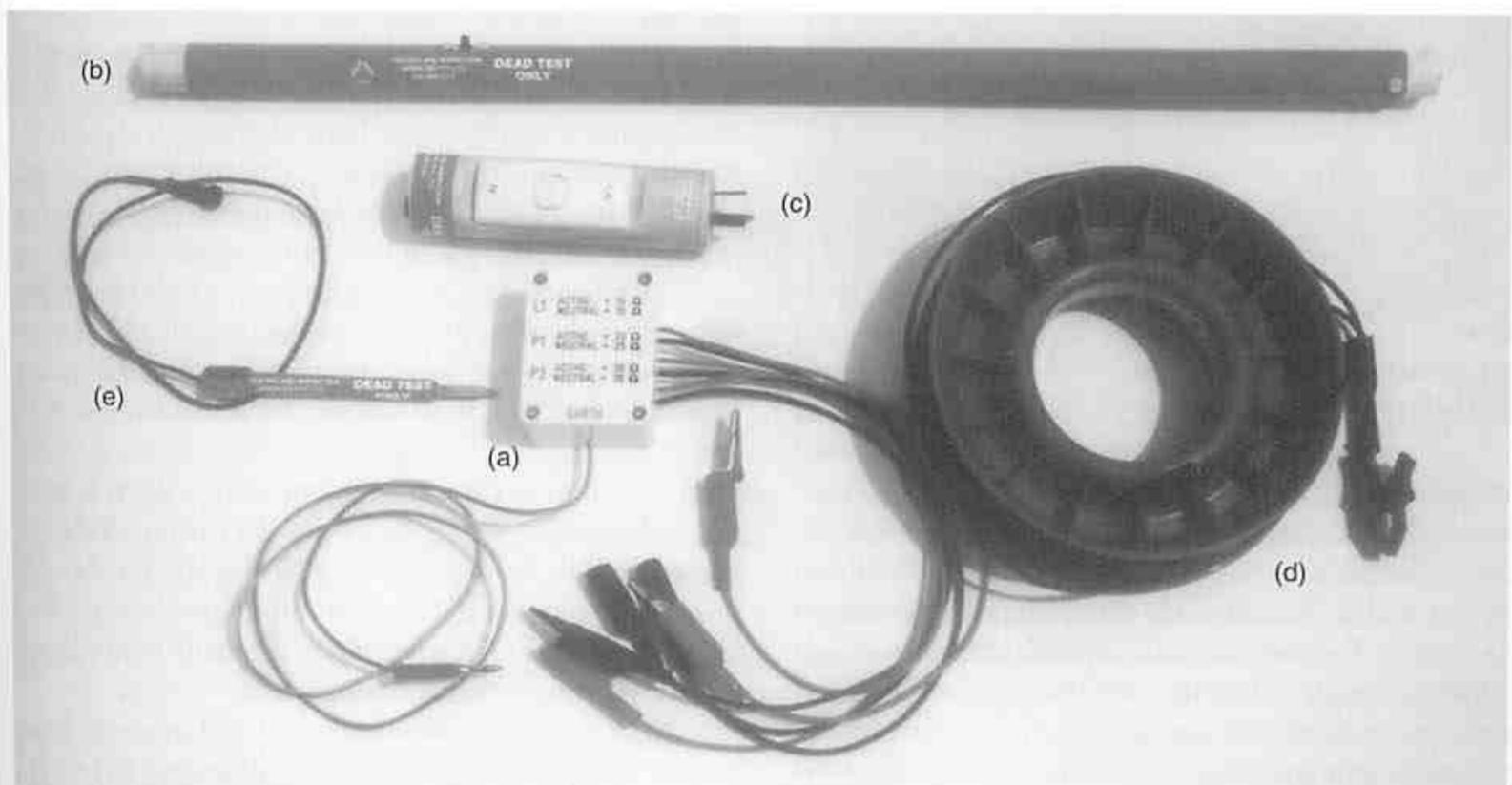


Fig. 11.16 Accessories designed to improve the efficiency and accuracy of 'dead testing': (a) resistor box for differentiating active and neutral conductors in three different circuits; (b) 'dead test' Light Stix; (c) 'dead test' GPO tester; (d) trailing lead; (e) probe used in testing earth receptacle at socket outlets TESTING AND INSPECTION SERVICES

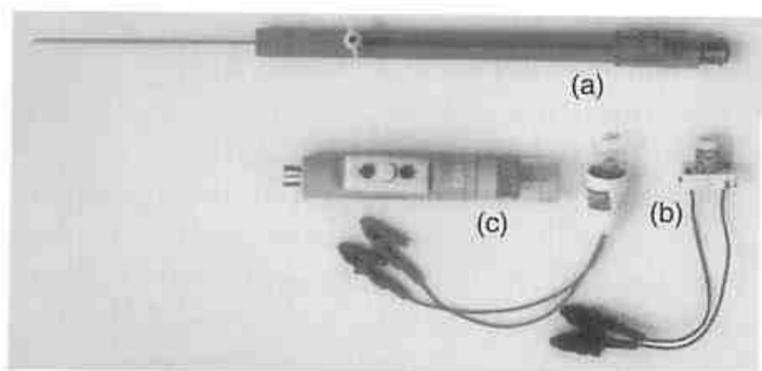


Fig. 11.17 Accessories used in 'live' testing: (a) 'Light Stix' with built-in extension rod for testing earth connections at lighting points and for testing exposed metal; (b) series test lamp and flasher unit for differentiating between active and neutral conductors; (c) GPO tester

TESTING AND INSPECTION SERVICES

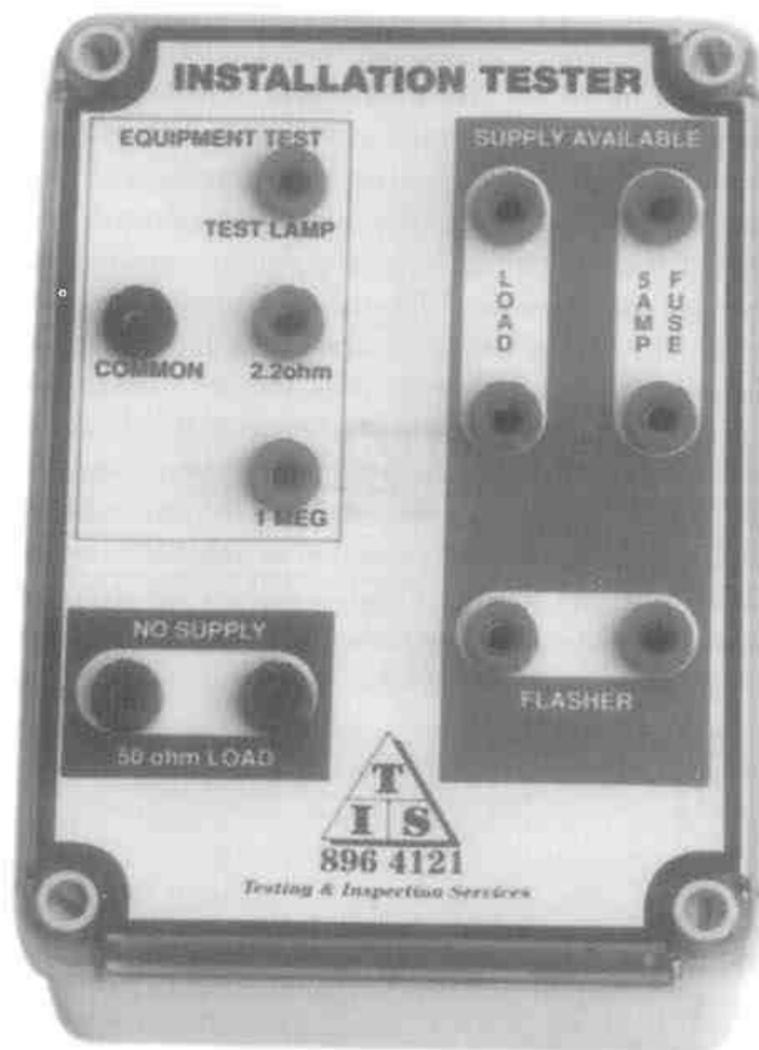


Fig. 11.18 Installation test box

TESTING AND INSPECTION SERVICES

various tests. Circuits protected by residual current devices (RCDs) present a difficulty when live testing, as a test between active and earth will cause the RCD to trip (as it should) and cause nuisance interruptions to the testing. To overcome this, the installation test box is equipped with a 5 A fuse for the purpose, bridging across the line and load terminals of an RCD to prevent nuisance tripping during live testing and at the same time ensuring that the circuit is protected.

It must be remembered that these devices are intended to help improve the safety and efficiency with which tests are carried out. The testing principles remain

the same and must be understood before the benefits of using such devices can be fully realised.

11.4 Testing safely

Like the many activities involved in electrical work, control measures adopted to limit the risk of death or injury must be followed—no more so than when testing electrical circuits and equipment. Dead testing is obviously safer than live testing and some tests, such as an insulation-resistance test, can be performed only with the supply disconnected. Most faults in circuits and equipment can, theoretically at least, be detected by dead testing. In some areas, for example in Victoria, mandatory testing of new or altered installation must be conducted with the supply **disconnected**. In any case, with new installations the supply may not be available at the time the tests are to be carried out. However, live testing is often preferred as it can be more efficient and may in some instances be the only effective way to diagnose a particular fault.

Risk factors in testing

Unless some caution is exercised when electricians are required to work on or near live conductors, injury due to electric shock or burns due to arcing may occur. Burns generally account for more serious accidents than electric shock when installations are being tested, and the arcing is usually due to 'flashover' caused by the use of unsatisfactory test probes. This applies particularly to installations with high energy levels, because once the arc has started it can, and often does, ionise the surrounding air, making the air conductive and providing a path to earthed metal in the vicinity of the arc. The risk is greater in confined areas, such as electrical equipment enclosures or small switchrooms with limited ventilation.

When testing an extra-low-voltage (ELV) installation, the risk of burns from arcing is minimal if the system energy level is low, but care still needs to be taken to avoid causing a short circuit. Storage batteries, for example, are capable of delivering high discharge currents to a short circuit; in addition, there is the risk that the hydrogen gas given off during the battery-charging process may be ignited by the arc. This may cause a cell to explode and cause chemical burns to anyone in the vicinity. The risk of electric shock is usually minimal in a dry environment when testing an ELV system.

All of the above risks can be reduced to a very low level by the electrical workers' developing their technical knowledge and skill and using suitable test equipment. They should start by considering the causes of accidents that can happen when testing live equipment. These causes include:

- using a test probe with excessive length of bare metal at the tip, which could bridge live conductors or a live conductor and adjacent metal. The probes and leads also may not be insulated for the voltage under test;
- setting multimeters on the wrong range when measuring voltage, or the maximum working voltage of the instrument exceeded. This has caused many accidents. It is preferable to use a suitable test lamp or voltage detector of correct voltage rating for the job, rather than a multimeter, where it is necessary only to establish the presence or absence of voltage;
- using testing devices with exposed live terminals;
- a lead coming adrift from a meter terminal while either the lead terminal or the meter terminal remains live.

Selection of equipment

The risks associated with testing installations can be considerably reduced by selecting equipment with the following features:

- For testing for the presence or absence of voltage, probes should be designed so that the exposed metal tip is the minimum size possible for the job, really 2 mm or less. They should be shaped so as to avoid inadvertent hand or finger contact with the live conductors under test. Note the finger barriers on the fused probes shown in Figure 11.19. The use of fused probes is strongly recommended when **detecting ac voltage** using a test lamp, voltmeter or voltage indicator on systems having high energy levels. It is advisable to use them for detecting voltage on any ac system; in Queensland the use of fused probes for this purpose is recommended for testing all installations.

High-rupturing-capacity (HRC) fuses having a low current rating are incorporated in the probes for protection against excess current; the ones illustrated have a category of duty of 440 V ac or 230 V dc and a maximum prospective overload of 33 000 A. Because they have a high impedance, fused probes are unsuitable for continuity testing.

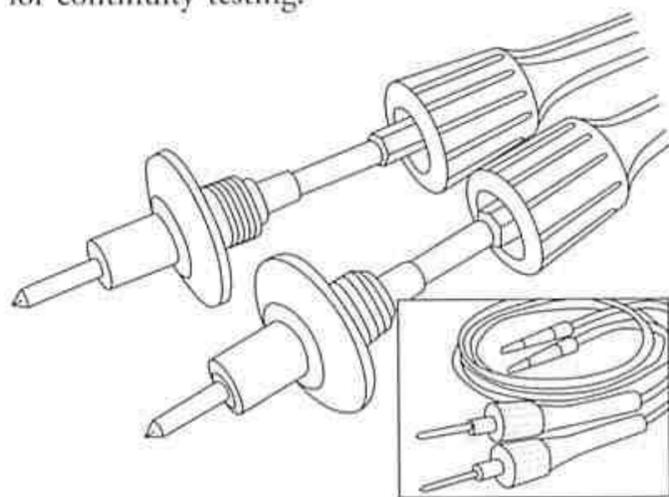


Fig. 11.19 Fused test probes NILSEN INSTRUMENTS

- Leads should be adequately insulated and coloured, usually red and black, to distinguish one from the other. They should be long enough for practical use but not long enough to be unwieldy. Their connection at the test device end should not be accessible for inadvertent contact with a person's finger if a lead becomes detached from the device or from a probe.
- Test lamps should be designed so that the glass bulbs are protected from mechanical damage (see Figure 11.3(a)).
- Terminals on a testing device should be shrouded or designed to avoid finger contact when being used for testing.
- Test lamps and any other devices used to detect the presence or absence of voltage should be marked to indicate maximum working voltage and, if applicable, any short time rating for the device.
- All testing equipment should be in good working order and be regularly inspected and tested.

Precautions

When carrying out electrical tests, always keep in mind the importance of safe working procedures and test with the circuit de-energised or 'dead' if this is at all practicable. For example, before conducting dead testing, circuits should be isolated, tagged and locked off in accordance with safe working procedures.

Whatever the testing device employed, **test for its correct functioning before the test and again after the test.** This precaution is particularly important when testing live circuits or equipment.

When using a test lamp, voltmeter or similar equipment, try to arrange the circuit so that any 'roving lead' is at earth or neutral potential or that a lamp or current-limiting resistance is in series with the lead to limit the current, should a fault occur (see Fig. 11.20 as an illustration of this point).

Note: Test probes in the diagrams used in this chapter are represented by arrowheads, and the HRC fuses used in some probes are not shown. **The use of fused probes with test lamps and other devices for detecting ac voltage is recommended, particularly where high energy levels exist.**

When testing de-energised wiring, the testing device should also be checked before and after the test; an insulation-resistance tester, for example, would give a reading of 'infinity' on all tests if a lead on the instrument were open-circuited.

Always check that the testing instrument selected is suitable for the job (e.g. voltmeter, ohmmeter), that it is suitable for the supply (ac or dc), and that it is set to the correct range. If a multirange instrument is being used and if it is practicable, set the range switch initially to the maximum range, and then switch down if necessary to the range most suitable for the quantity being

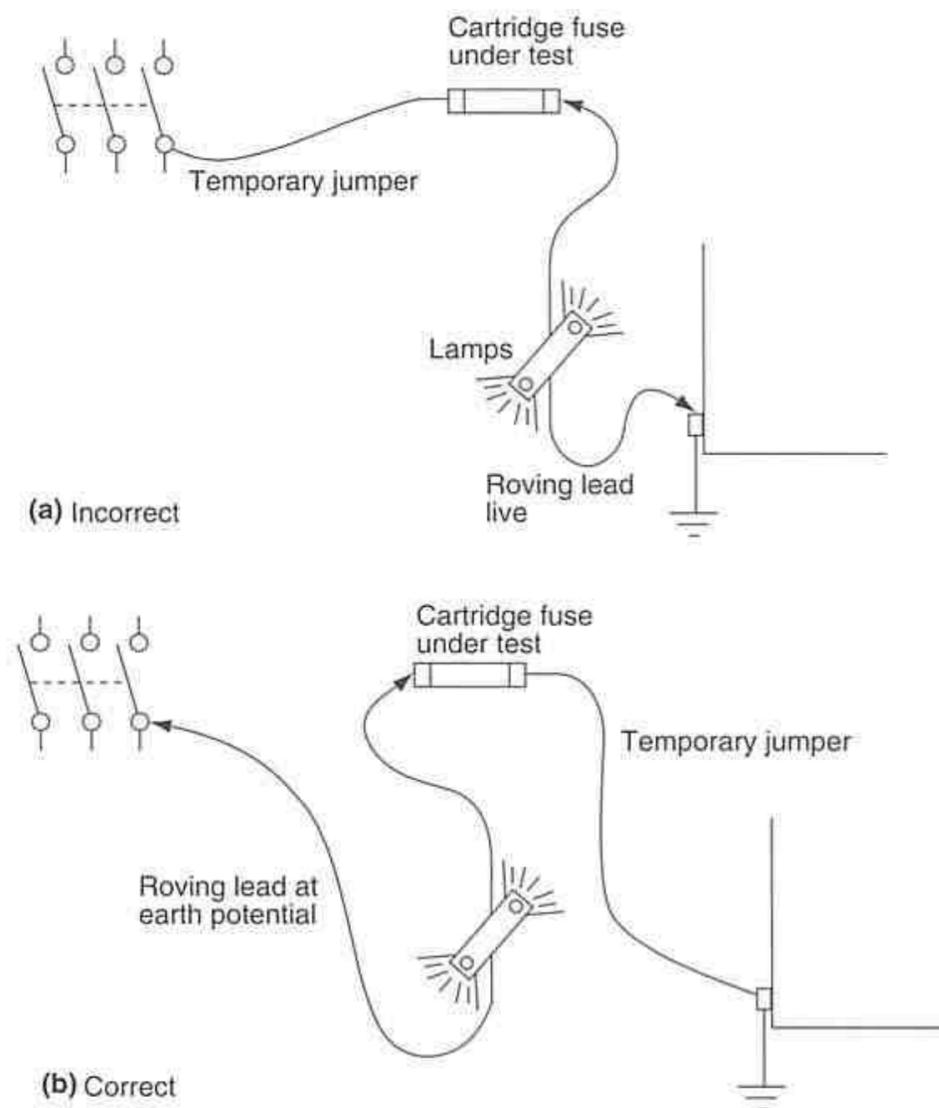


Fig. 11.20 Use of testing device with a roving lead

measured. On completion of the test, reset the range switch to the maximum range, ready for the next test.

Testing **safely** requires the adoption of thoughtful and methodical procedures. No person should be in danger of contact with live parts while the test is being carried out. At the completion of each test, 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 disconnected from the supply and tagged to notify that it is unsafe to use. No single test will prove that an installation is safe. It is the combination of necessary tests that will show the safety of an installation. If a polarity test reveals an incorrect connection then, after the connection is corrected, insulation and earth-resistance tests may need to be repeated.

11.5 Testing and checking the installation: general requirements and precautions

Any new installation or addition or major repairs to an existing installation must be tested and checked to

ensure that it is safe and complies with regulations. This must be done before the new work is connected to the supply. In the recent past, energy distributors' inspectors carried out installation testing and inspections and issued defect notices when the installation did not comply with regulations. Testing and checking the installation is now the responsibility of the electrical contractor or electrician carrying out the installation work, who must notify the energy distributor in writing when the installation is safe, complies with regulations and is ready for connection to the supply.

In some circumstances an electrical contractor may be given authority to connect the installation to the supply, provided it has been tested and proved safe. In most areas the energy distributor's inspectors have a responsibility under regulations to inspect consumers' mains, main switchboards, high-voltage installations and any wiring within a hazardous area, as defined by *Clause 9.0.1* of AS 3000. The responsibility also includes a schedule of random inspections to check that electrical installation standards are being maintained.

Electrical conditions such as the resistance of leakage paths and the value of conductor resistance cannot be seen, and to determine these conditions suitable tests with instruments must be carried out. Furthermore, a visual inspection of the whole installa-

tion must be made to ensure that it complies fully with all legal requirements, specifications, *SAA Wiring Rules* and any applicable codes. Thus testing and inspection are two separate procedures, but in practice are carried out concurrently.

The electrical tests include:

- tests for the effectiveness of the main earth
- tests of continuity and effectiveness of the earthing system and required equipotential bonding
- insulation-resistance tests of wiring, including consumers' mains, submains, busways, rising mains, final subcircuits and fixed wired appliances
- polarity testing of active and neutral connections of consumers' mains, submains, and final subcircuits
- tests for incorrect connections, such as interconnections between circuits, transposition of neutral and earthing conductors and short circuits
- operation of RCDs
- other testing required by local regulations.

The **visual check** must include inspection of the following:

- main earthing conductor and main earth connection, for correct rating, size and conductor type and for compliance with the Rules;
- all subcircuit and auxiliary earthing, earthing bonds and earthing of equipment frames, for general compliance with the regulations;
- main switchboard and distribution boards, for correct fuse and circuit-breaker ratings and correct labelling, including correct labelling of neutral conductors. Switches, fuses and circuit breakers should be checked as having adequate fault-current ratings (see Chapter 13, Volume 2), as well as for their working current rating. Fuse clearances and layout of equipment should be checked to ensure that layout is neat and logical to correspond with a neat and logical back-of-panel wiring. In addition, space at the front and sides of the switchboard, distance from the floor, clearance at the rear and correct panel thickness need to be inspected;
- wiring, for suitable cable types and for correct current ratings and voltage-drop conditions for the length of run. Derating factors (e.g. in cables affected by thermal insulation) may need to be applied;
- existing or potential, mechanical or chemical, hazards that may be present, such as dampness, high temperature, explosive gases, vapours or dust;
- all appliances, to ensure that their operation will not introduce a hazard or cause overcurrent or overvoltage conditions;
- equipment and accessories, for their suitability to be connected in the location in which they are installed (e.g. in a swimming pool area or in the restricted zone of a bathroom or laundry);
- fixing and support of electrical equipment, to check

their adequacy and that equipment is not subject to mechanical damage;

- number of 'points per circuit', to determine that the number is within the limits permitted by the Rules;
- provision for separate final subcircuits to appliances that require them;
- consumers' mains, point of attachment and metering facilities, for compliance with appropriate Rules.

The final testing and visual checks 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 and checking and testing while carrying out the installation work. 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 GPO come about from not checking or testing at the time they were connected. Rectifying defects after the event can be a time-consuming and costly exercise, quite apart from the poor impression given to the customer.

11.6 Testing techniques 1: earthing system

The maximum resistance of the earthing system of an installation is specified as 2Ω by *Clause 1.5.3*, which also states that its value must be low enough to permit sufficient fault current to operate the protection; so with high fuse or circuit-breaker ratings the value could be well below 2Ω . To ensure compliance with the Rule, the resistance of the earthing system of an installation must be tested. In New Zealand, the maximum value of resistance of the earthing system is 0.5Ω .

The object of the test is to determine the resistance value of the earthing system between the main earth connection and **any** part of the system: for example, to the earthing terminal of a three-pin plug socket, to the frame of a motor or to the metal enclosure of a fluorescent luminaire. If the multiple-earthed neutral (MEN) system is employed, this test is from any part of the earthing system to the main earth connection at the neutral link. This test must yield a resistance of 2Ω maximum. In addition, the resistance from the neutral link to the earth electrode must be within a 2Ω limit (see *Clause 1.5.3.3(b)*, also Figs 11.21(a) and (b)).

Where a water supply system is metallically continuous from inside the building in which wiring is installed to its point of contact with the ground, an equipotential bonding conductor must be installed. This is to maintain the water pipe system at earth potential. The bonding conductor may be connected at any point on the main earthing conductor or at the earth bar at the switchboard in a MEN system. Its resistance should

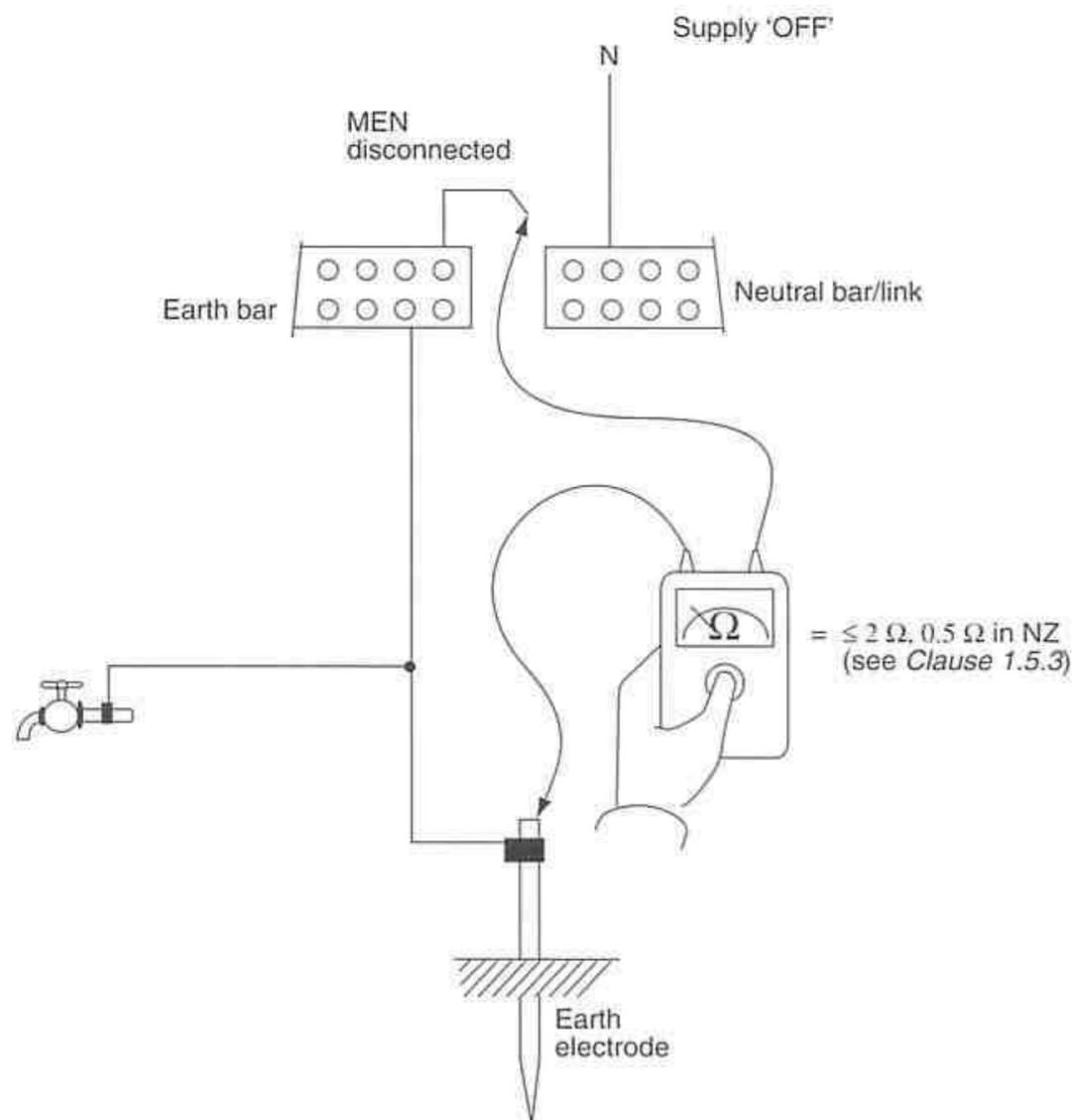


Fig. 11.21(a) Resistance test of main earthing conductor

not exceed 2Ω . Some appliances, such as a hot-water system, may be connected to earth by the metallic water supply, in which case the circuit earthing conductor to the appliance should be isolated and tested as having earth continuity resistance not exceeding 2Ω .

Figure 11.21(c) shows typical test results for a circuit protected by a 16 A circuit breaker. Using the test results shown:

$$\begin{aligned} \text{resistance of test leads} &= 0.378 \Omega \\ \text{resistance of return earthing system} &= 1.4 - 0.378 \\ &= 1.022 \Omega. \end{aligned}$$

This value of resistance complies with *Clause 1.5.3*, but in any case for the circuit shown the maximum resistance of 2Ω specified in *Clause 1.5.3* would permit sufficient fault current to flow and operate the fuse or circuit breaker:

$$\begin{aligned} I &= \frac{V}{R} \\ &= \frac{240}{2} \\ &= 120 \text{ A} \end{aligned}$$

which is sufficiently high to operate a 16 A circuit breaker quickly and which is approximately four times

the fusing current required to melt a 16 A rewirable fuse.

When carrying out earth-resistance tests, the metal frames of all appliances and luminaires should be checked, because:

- They are usually mass-produced in the factory; and, although manufacturers are required to keep the resistance between the earthing terminal and frame to 0.1Ω or less as specified in *Clause 5.3.4* of AS 3100, sometimes the internal earthing bonds of earthing terminal connections are defective when the appliance leaves the production line.
- The process of painting often affects the earth continuity between frame parts.
- Most appliances are handled while in operation; so effective earthing of the appliance is essential.

Visual inspection of the earthing system should also be made where it is accessible, both on new installations and when testing existing installations. As an example:

1. An earth-continuity test is made between the appliance frame and the main earth connection on the installation shown in Figure 11.22. Resistance value measured is 6Ω , which is obviously too high.
2. On making a check closer to the commencement of the conduit run, an acceptable resistance of 1Ω is measured from point A to main earth.

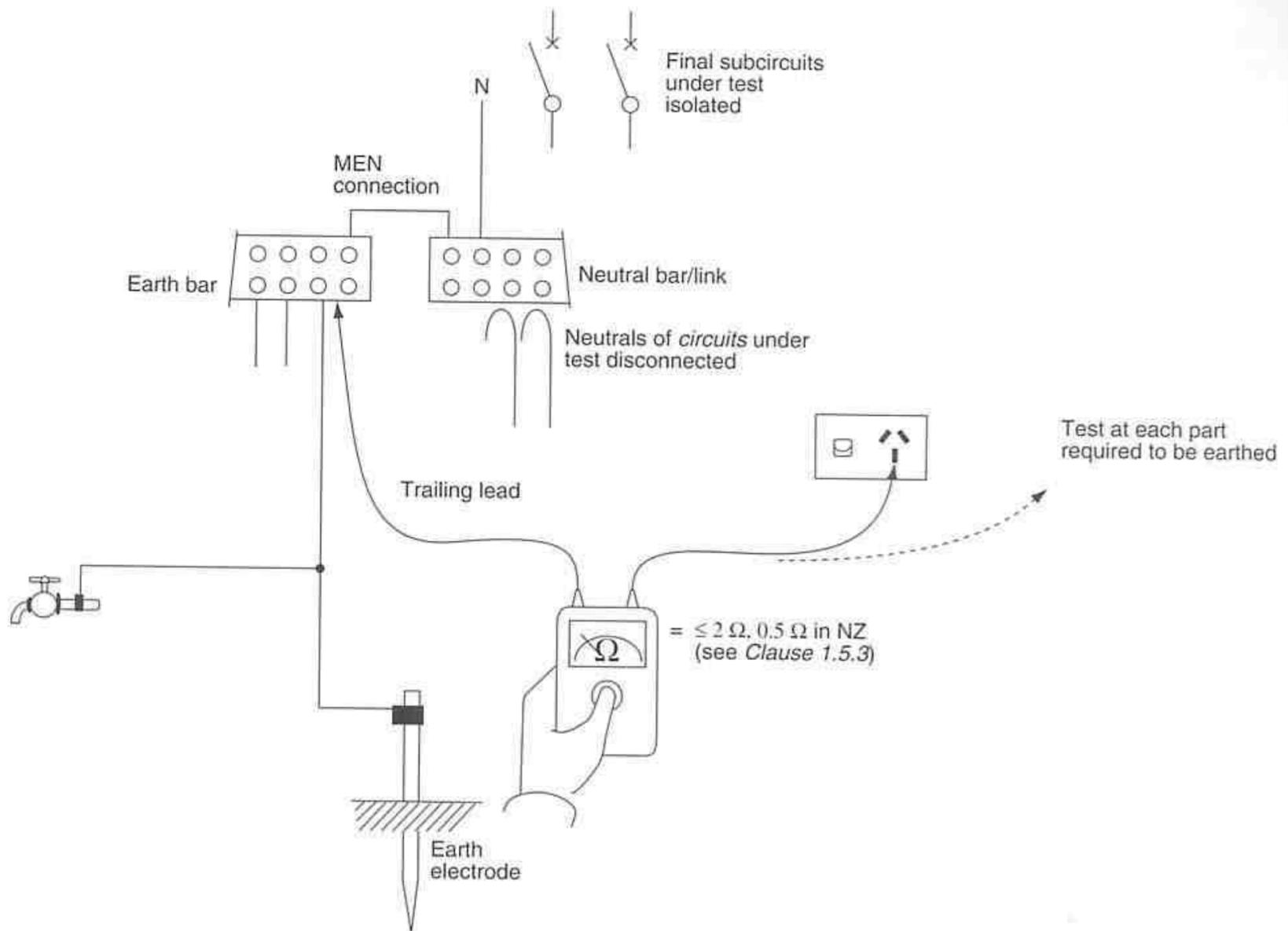


Fig. 11.21(b) Resistance tests of other earthing and equipotential bonding conductors

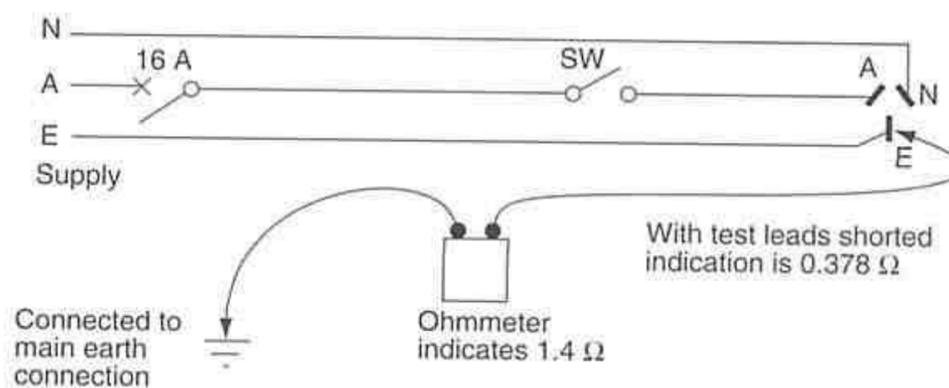


Fig. 11.21(c) Resistance of the earthing system must be low enough to permit sufficient current to operate the fuse or circuit breaker

3. A visual check is made for any apparent high resistance between point A and the appliance, as this is the high-resistance route, and it is noted that the galvanised metal conduit is painted with polyvinyl acrylic (PVA) paint as protection for the threaded entries to the tee fittings. As PVA paint is non-conductive, this could cause the high-resistance joint (see Clause 3.26.5.6).
4. To confirm the apparent cause of the high-resistance path to earth, a reading is taken across the tee between points A and B; it is found to be 4.95Ω (see Fig. 11.22(a)). This resistance must be reduced

by cleaning the conduit threads and repainting with a metallic paint, graphite jointing compound or a paint type that will not affect conductance, before screwing the conduit back into the tee.

As the Rules stand at present, the simple ohmmeter test is satisfactory to check for compliance with Clause 1.5.3 'Resistance of the earthing system'. Remember that these tests are applied for the purpose of testing the consumer's earthing system as a whole, or for determining the resistance of a particular section, and that the earthing system finishes at the main earth connection on the earthing electrode.

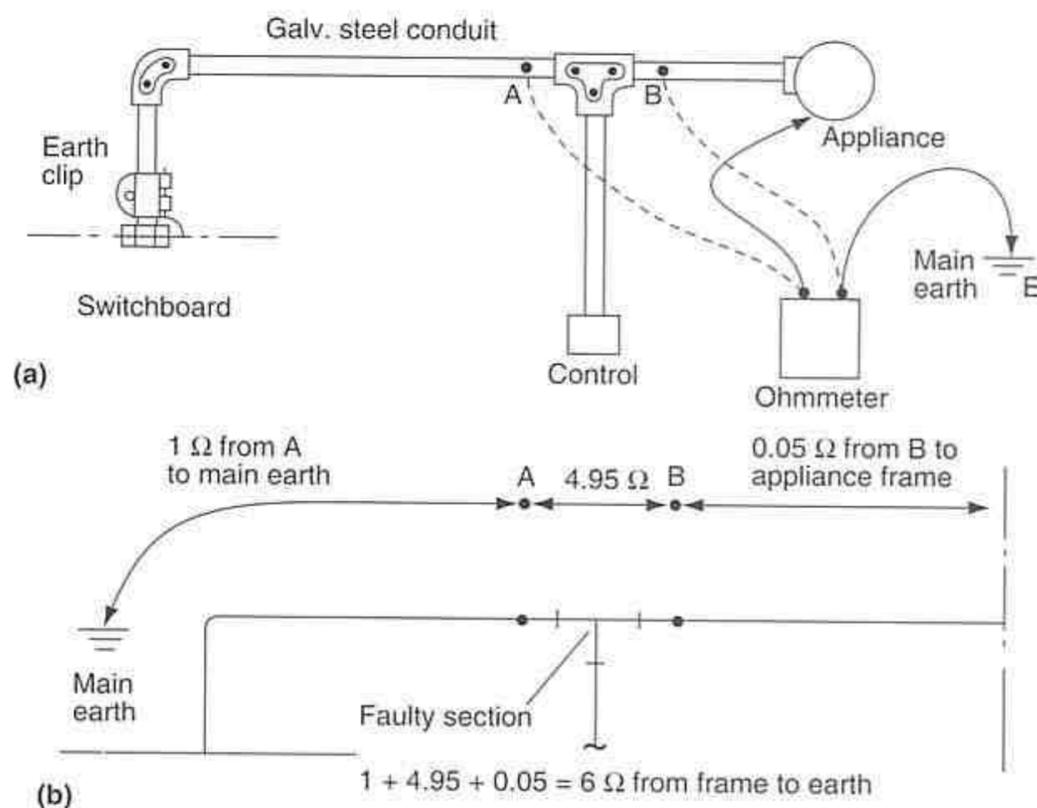


Fig. 11.22 Confirming a high-resistance fault observed in a visual check of the earth continuity

The testing of the earth electrode resistance, that is, the resistance between the electrode and the general mass of earth, usually requires one of the special types of earth resistance testers, such as that shown in Figure 11.10.

11.7 Testing techniques 2: insulation resistance

Clause 1.5.2 specifies the insulation resistance of either the whole or part of an installation as being a minimum of 1 MΩ. Note that only the **resistance to earth** is specified (refer to section 3.9 of Chapter 3 for a numerical example).

The installation must be tested for compliance with the above Rule, and, because it is only the wiring that is under test:

1. All lamps are removed and appliances disconnected. (Note that, although this is specified, if the value of insulation resistance is well above the minimum in practice the appliance will remain connected.)
2. All control switches are closed to the 'on' position. If the installation is incomplete, the necessary temporary connections should be made.
3. For large installations the testing proceeds in sectionalised groups, but for small installations the test for the whole installation is carried out as a single test.
4. Appliances and other equipment must be tested separately (see Clause 1.5.2.4) and in general must have a minimum insulation resistance as specified in

AS 3100, Clause 8.3.1. Despite this, Clause 1.5.2.4 of AS 3000 permits exceptions, with values down to 0.01 MΩ for an element-type heating appliance (e.g. a permanently connected electric range).

5. Busways also require separate testing (refer again to Clause 1.5.2.3 and to the reference in section 3.9 of Chapter 3).

To carry out an insulation resistance test, there must be available a source of dc with a minimum value of 500 V and an ohmmeter capable of indicating high values. Because scales of insulation-resistance testers are normally calibrated in megohms, a suitable instrument would be one of the insulation-resistance testers illustrated in Figures 11.13, 11.14 and 11.15. The source of dc may be a hand-driven or motor-driven generator, or the popular electric supply fed from an internal battery (see Fig. 11.15).

When conducting an insulation-resistance test, the following precautions should be observed:

1. Make certain that the section to be tested is isolated from the supply.
2. Check that **only** the section to be tested is included in the test. Make sure that there are no stray parallel leakage paths.
3. Ensure that the instrument is suitable for the test and that its operating voltage is safe to apply to the circuit, especially to an electronic circuit such as a lamp dimmer. Normally, dimmers are disconnected during the test.
4. Check the instrument for pointer index or any other preadjustment necessary.
5. Check the operation of the meter and test leads,

- indicated by an infinity sign on open circuit and zero indication with leads short-circuited.
6. When testing, avoid any large masses of iron or stray magnetic fields.
 7. Use well-insulated leads in good condition to avoid stray leakage paths.
 8. Operate the instrument as recommended by the manufacturer.
 9. If there are any capacitors in the circuit, ensure that they are discharged both before the test and after the test is completed. Also, be wary of false readings due to capacitance during the test.
 10. Before touching cable ends after testing, discharge any energy that may have been stored in the cables during the test. This is most likely to occur in long runs of larger cables due to their capacitance.

Figure 11.23 shows insulation-resistance test connections for a complete installation. Fuse links are in circuit or circuit breakers 'ON' and lamps have been removed, appliances disconnected and all switches left on. Because the earthing system is MEN, the main earth connection at the neutral link has been opened (see *Clause 1.5.2* 'Insulation resistance'). The scale indication on the insulation-resistance tester will be the value of the insulation resistance of the **complete** wiring between conductors and earth.

If the value indicated is below that permitted, a logical procedure for isolation of the faulty section would be:

1. Open the main switch to isolate the fault as being on either the active or neutral conductor.
2. If the fault appears to be on the neutral, isolate the faulty neutral by progressive disconnection of load neutrals at the neutral link.
3. Should the fault appear to be on the active, isolate the fault by the opening of circuit breakers or the withdrawal of circuit fuses in turn.
4. If a fault has been determined as being on the active of a particular subcircuit, the fault may be further isolated by progressively opening switches on the subcircuit, thus checking whether the low resistance to earth is on one of the 'switch lines'.

Once the low-reading section of wiring has been found, it is necessary to determine the exact point at which the circuit fault has occurred. Although modern insulation is of high quality and reliability, it is possible, but most unlikely, that the earth leak is via the insulation, especially on a new installation.

The most probable positions for earth leakage, however, are at the ends of runs, where the cable emerges and the end of the conductor has been stripped of its insulation to facilitate connection to an accessory. This leads to the possibility of surface leakage or mechanical failure. These positions should be checked for dampness, moisture, humid conditions or accumu-

lation of dirt or dust. The leak can also be due to mechanical damage, the action of heat or chemical action. A careful visual check for these possibilities should be made.

Assuming that these checks have not resulted in location of the actual leakage point, the faulty circuit conductor should be opened at a convenient connection as close to the centre of the run as possible, thus halving the extent of the faulty section. This process of sectionalisation should be repeated until the fault is located and any necessary repairs or replacements effected. Figure 11.24 shows insulation-resistance testing preparation for individual circuits.

11.8 Testing techniques 3: polarity tests

The importance of carrying out polarity tests on all parts of an installation cannot be overemphasised. In a survey of one Australian state a significant number of installations were found to have incorrect polarity connections; this could lead to a fatal electric shock.

For example, a most dangerous condition arises if the polarity of a consumer's mains is incorrect where a MEN system is employed. In this condition current will flow through the main earth to the earth electrode (see Fig. 11.25). The current is not likely to be sufficient to operate any circuit-protection device, placing any person in the vicinity of the installation at risk of electric shock. The same dangerous condition exists if the polarity of a submain is incorrect where it supplies a portion of an installation with a separate MEN connection.

Although testing the polarity of consumers' mains is usually carried out before the supply is available, a check must be made that they have been disconnected from the supply before tests are carried out. The test is a straightforward continuity test, preferably done with an ohmmeter, between the consumer's terminals and the line terminal of the main switch to identify the active conductors, and between the consumer's terminals and the main neutral connection at the neutral link to identify the neutral conductor, as shown in Figure 11.26. All main switches and circuit-protection devices must be open to avoid false readings from feedback that may occur through a final subcircuit.

Clause 2.20.1.2 of the *SAA Wiring Rules* stipulates that switches must be connected to operate in the active conductors, and *Clause 4.13.4.2* in effect restricts the polarity of a Goliath Edison screw lampholder to that of active for centre terminal and neutral for the outer or screw base.

In *Clause 4.14.8* the recommended polarity for all socket outlets is stated as being earth, active, neutral in a clockwise direction viewed from the front of the outlet,

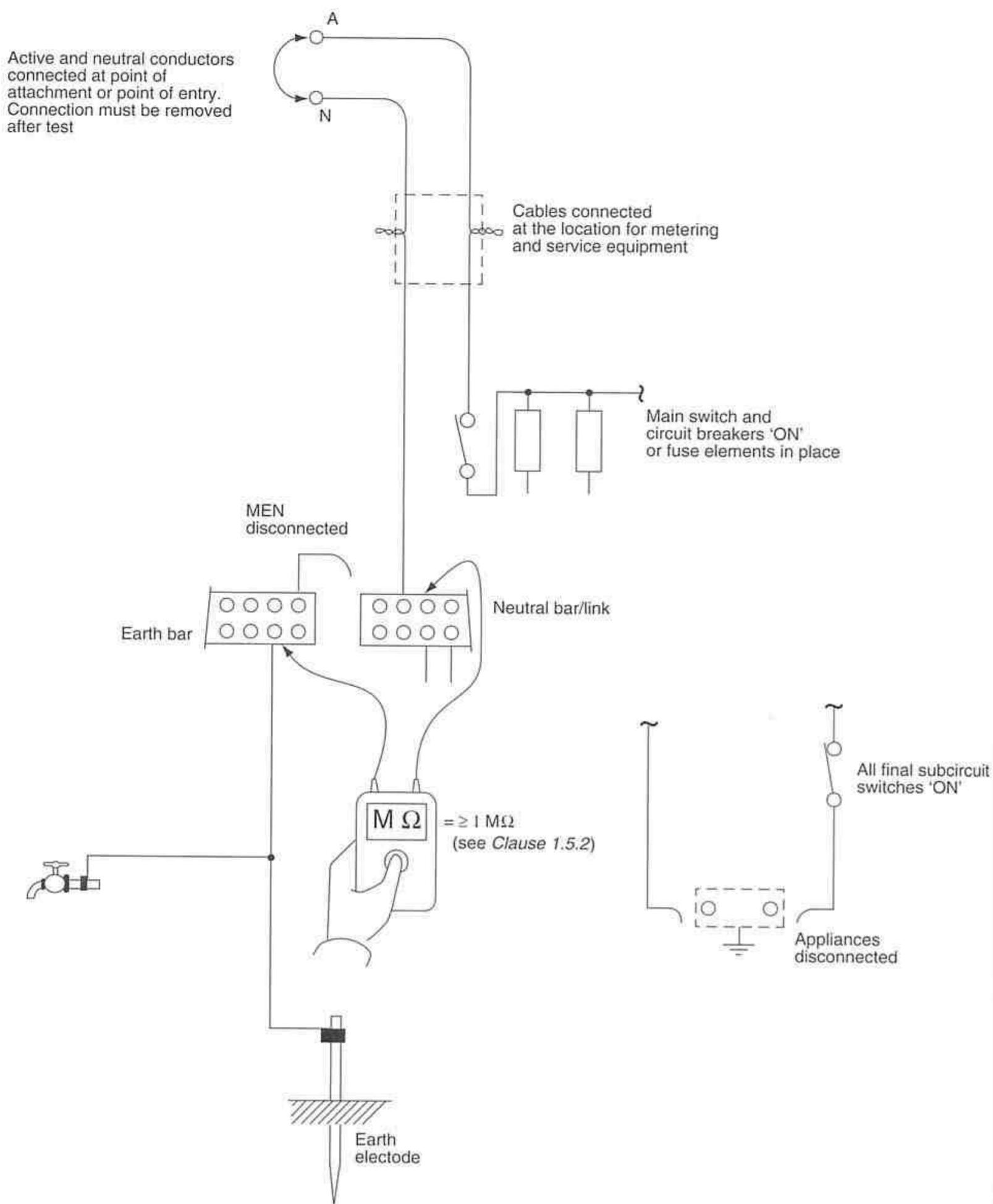


Fig. 11.23 Testing the insulation resistance for a complete installation

and this sequence of connection is mandatory for general-purpose outlets (GPOs) and for 15 A and 20 A socket outlets. It is obviously necessary to carry out 'polarity tests' to ensure compliance with these Rules. The tests should include a check of the supply active, earth and neutral, together with a check of the outgoing

circuit connections at the main switchboard.

A 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 11.27(a). Tracing out the test circuit shows that a correctly connected socket outlet will give the following test results:

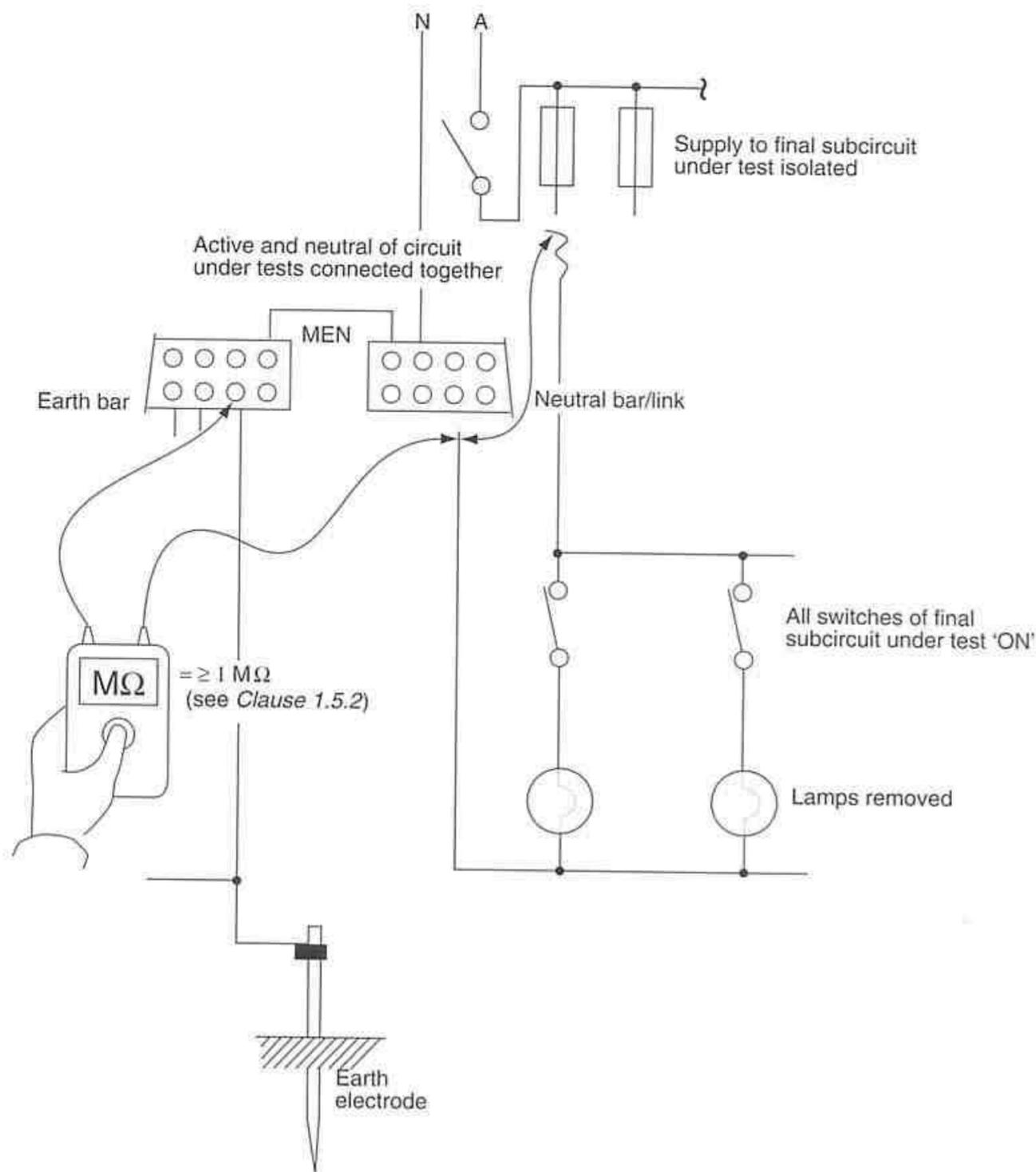


Fig. 11.24 Testing the insulation resistance of individual circuits

Test points	Switch position	
	Off	On
A  N	Infinity	20 Ω
A  E	Infinity	15 Ω
 N E	5 Ω	5 Ω

Any other results indicate an incorrect connection. For example, with active and neutral connections reversed, the A to N test results will be the same as above. However, the A to E test results will show 5 Ω with the switch 'on' and the N to E test will indicate 15 Ω with the switch 'on' or 'off'.

The simplest polarity tests on the outlets are made with the circuit energised at normal voltage, using a suitable 'voltage indicator' such as a test lamp, neon tester or voltmeter (see Fig. 11.27(b)).

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 carried out. If the RCD is incorporated within the circuit-protection circuit breaker, then bridging of the RCD should include a fuse or circuit breaker to maintain circuit protection while testing is being carried out.

Referring to Figure 11.27(b), the indications for correct polarity would be:

- test lamps connected between A and E, switch open (i.e. off)—no glow;

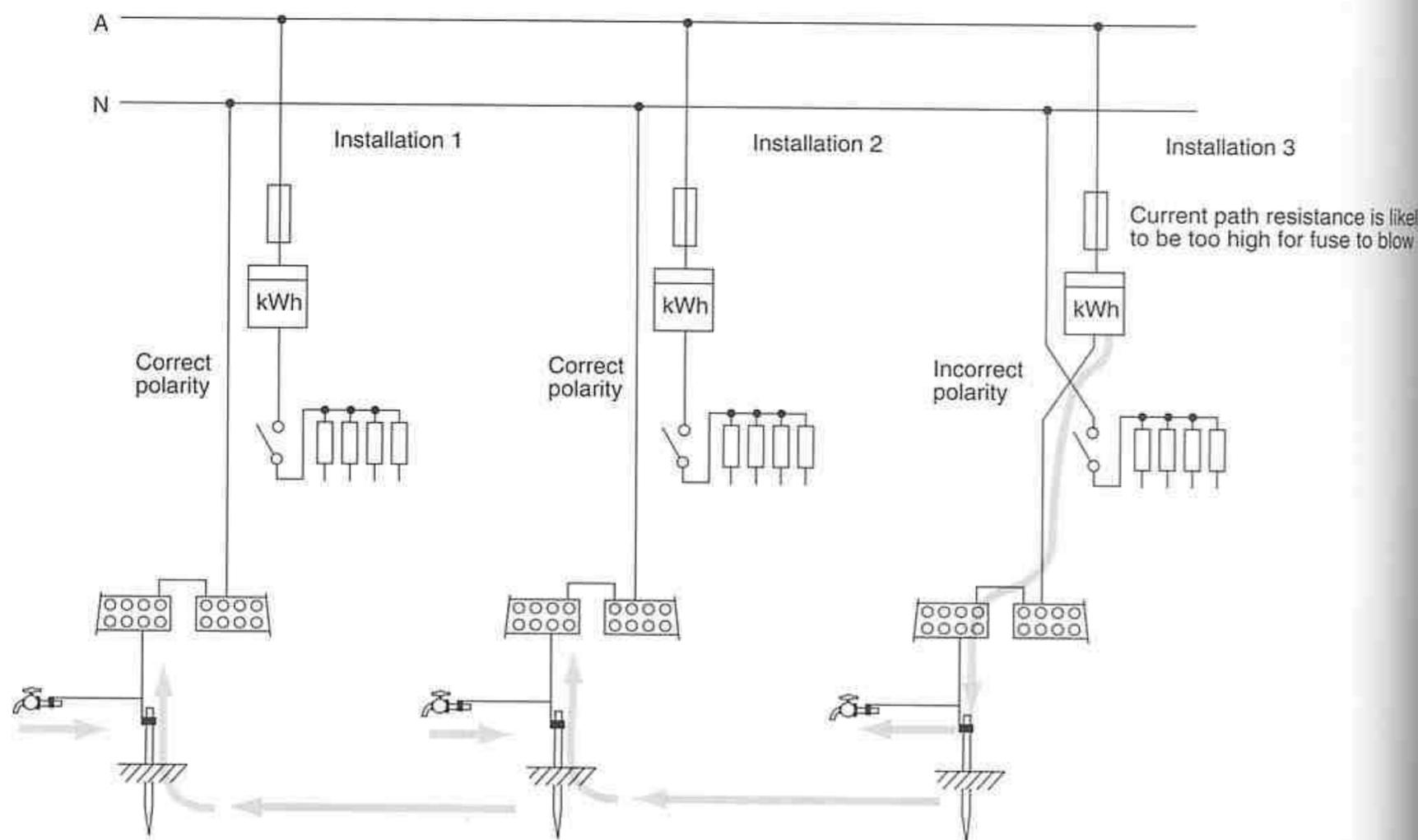


Fig. 11.25 Earthing system is carrying current due to incorrect polarity of a consumer's mains at installation 3. Any person in contact with earth or earthed metal in the installation or adjacent installations with separate MEN connection is in danger of electric shock. The shaded arrows indicate possible current paths

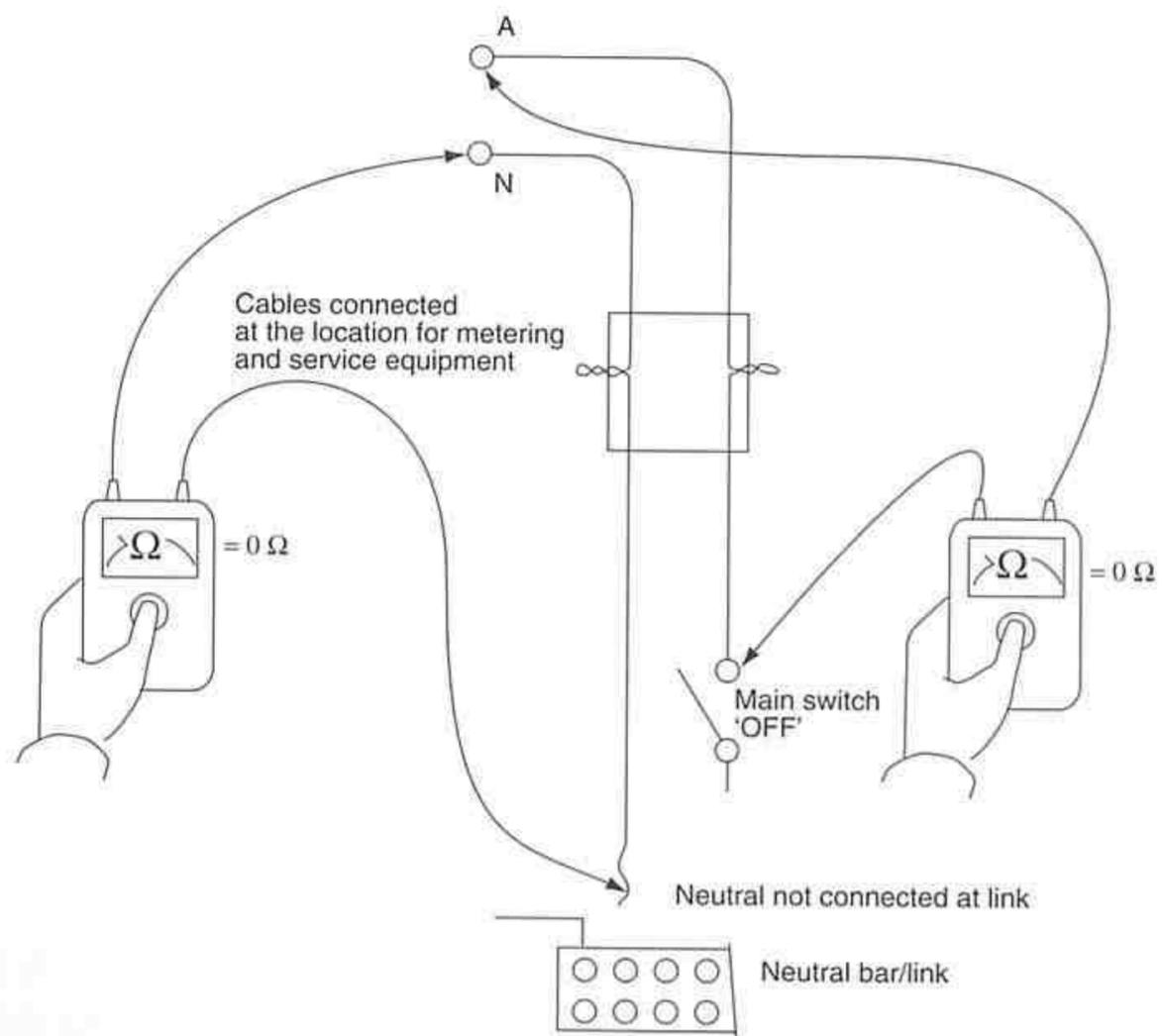


Fig. 11.26 Testing the polarity of a consumer's mains prior to connection. Similar procedures are used for testing the polarity of submains

is likely
to blow

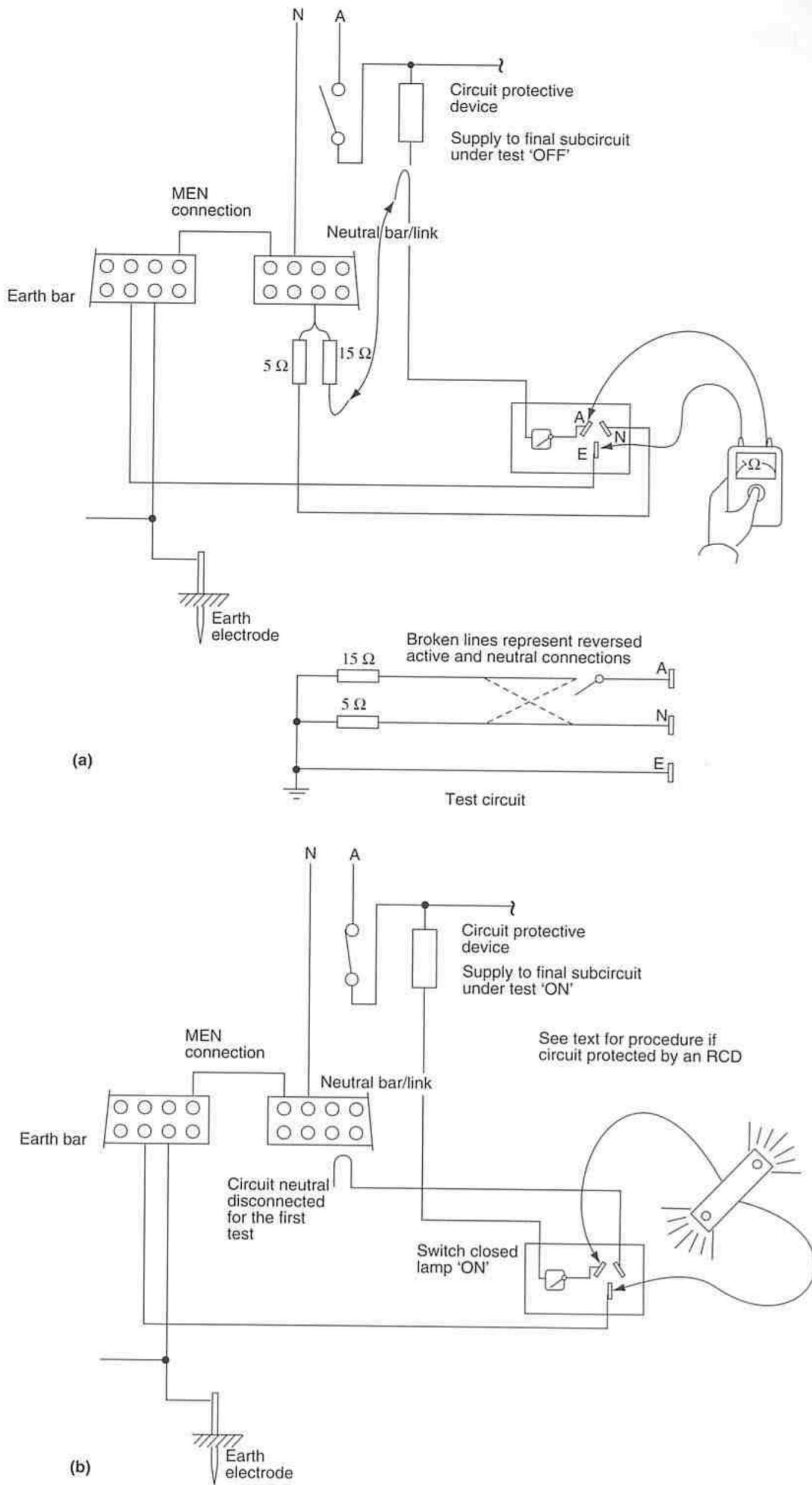


Fig. 11.27 Testing the polarity and correctness of connections at socket outlets: (a) dead testing; (b) testing with supply connected

- test lamps connected between A and E, switch closed (i.e. on)—lamps glow;
- test lamps reconnected between N and E, switch closed—no glow.

Check the test lamps by connecting between A and E with the switch closed. The polarity test should be made with the **circuit neutral disconnected at the neutral link**. Think about this, and check with the diagram. With the neutral disconnected, the test checks that the switch is connected in the active and also that the earth and neutral are in their correct relative positions. There is the possibility that the earth and neutral are reversed in the socket outlet connection, and the test would not detect this faulty connection if the neutral were not disconnected.

A testing method that checks both polarity of active and neutral and the earth and neutral connections of lighting circuits is shown in Figure 11.28. This test requires the same preparation as the 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 that for the socket outlet test.

A method for checking polarity in lighting circuits is illustrated in Figure 11.29. In this method of polarity testing, it does not matter whether lamps are left inserted or removed from the lampholders, provided that the switch at which the test is made is closed and all other switches are left open. Light to earth indicates correct polarity.

If the lamps in the circuit under test are removed, it does not matter whether the switch at which the test is being made is closed or open.

Now consider the case where the switch controlling one of the lights is in the neutral conductor, as shown in Figure 11.30. With the switch in the 'off' position and the test connection shown, the test lamp is in series with the light outlet, the lamp of which will probably be of much higher power rating (lower resistance) than the test lamp, thus causing test lamps to light and giving the false impression that the active is switched. If a volt-

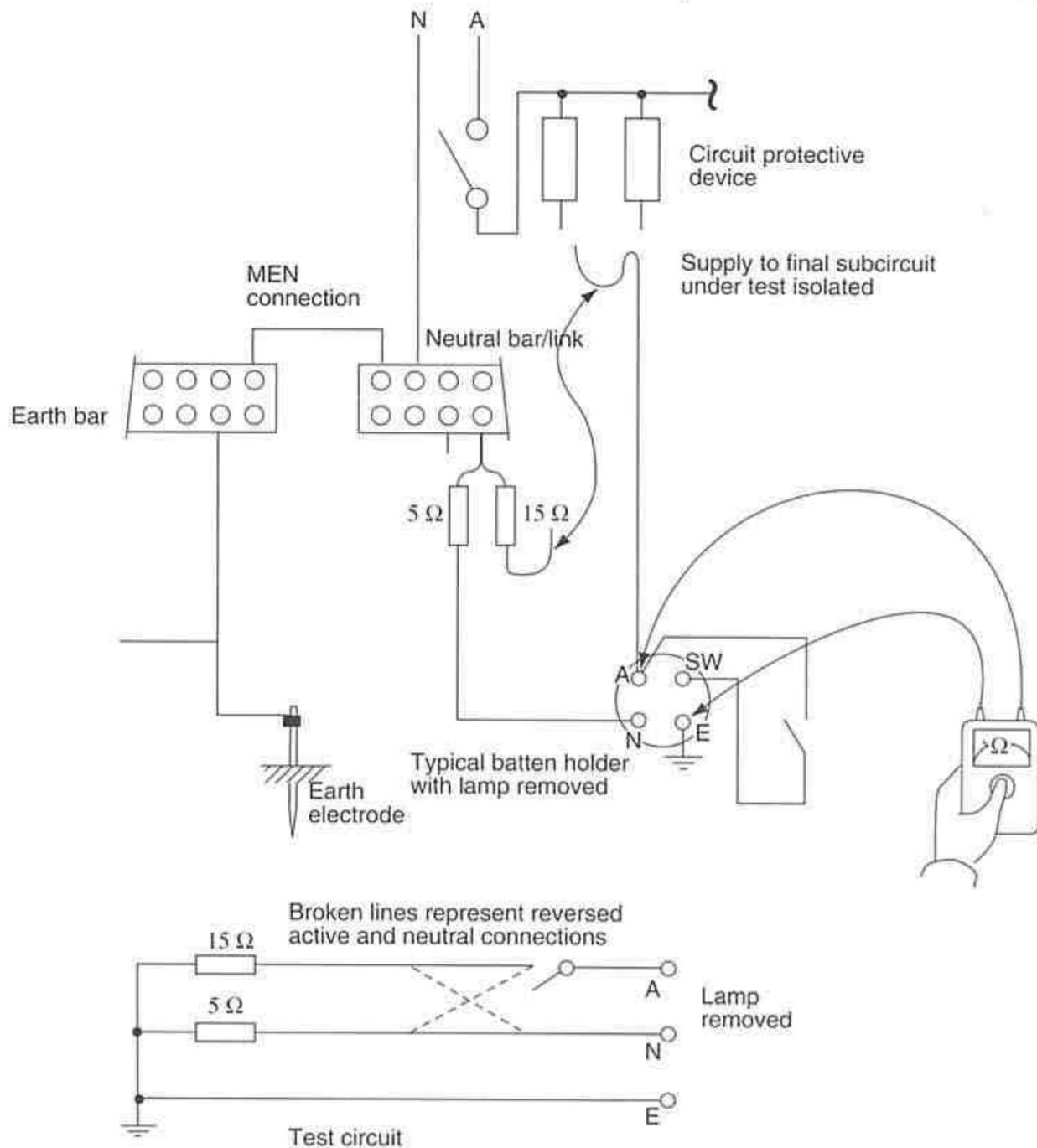


Fig. 11.28 Testing the polarity and correctness of connections at batten holders and switches of lighting circuits (dead testing)

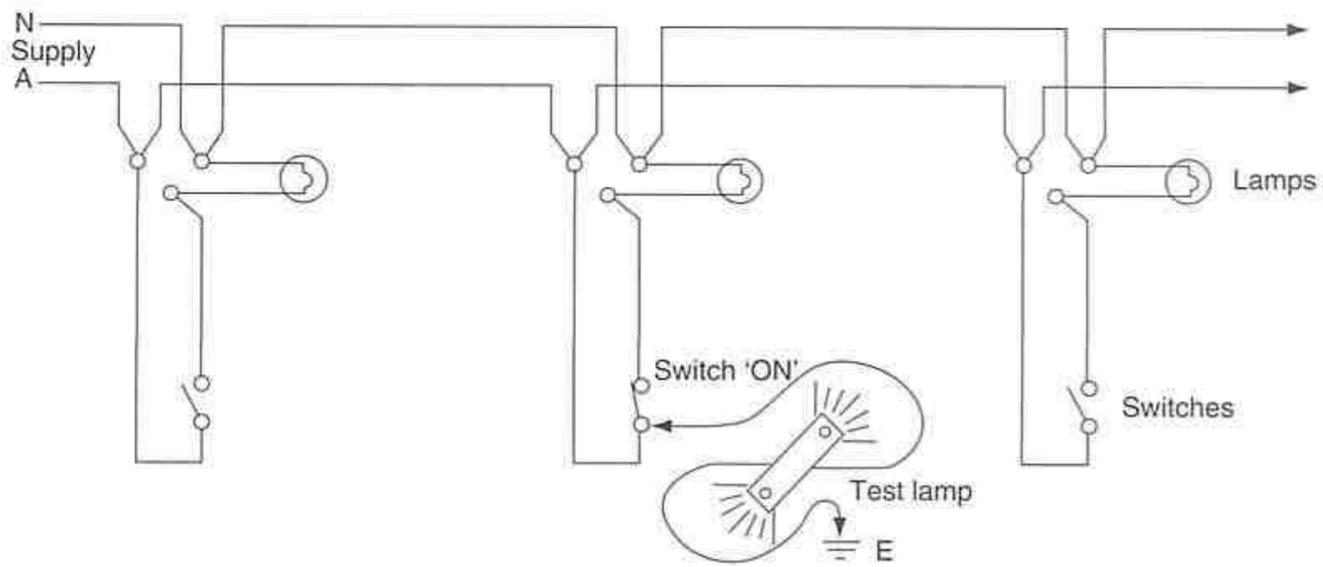


Fig. 11.29 Simple method of checking that light switches are in active conductors

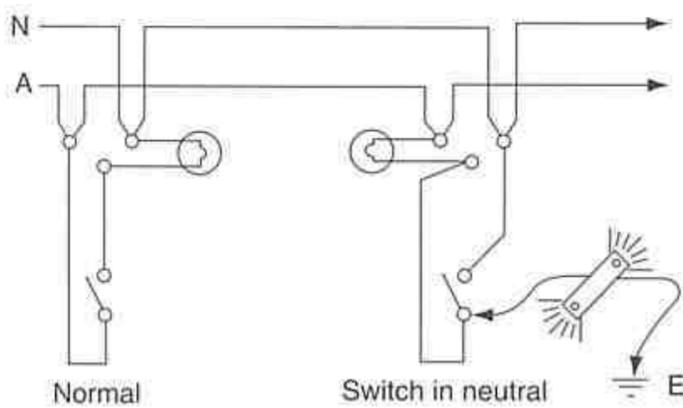


Fig. 11.30 Detecting a light switch in the neutral

meter were being used for the test it would indicate full-supply voltage (240 V) irrespective of the lamp rating, again leading to the false impression that connections were correct. Immediately the switch was closed, however, the lamps would cease to glow and a voltmeter would indicate zero, showing that there is a neutral at the switch instead of an active—an incorrect connection.

In this case, if the lamps are removed, no active will appear at the switch and the incorrect connection will be apparent without the switch being closed. However, in practice, it is usually easier to close a switch than to

climb up and down ladders removing and replacing lamps.

Referring again to the polarity test shown in Figure 11.29, it will be recalled that all switches are to be open **except** the one being tested. If this is not done, the polarity test will be valid, but by opening the other switches the wiring connections are in effect checked at the same time, ensuring that no switch is functioning as a 'master' control.

Study Figure 11.31. In this circuit all the polarities are correct and lamp L2 is correctly wired, but switch S2 is connected as a master switch so that there is no active supply to the rest of the circuit unless S2 is closed.

In the case of the multiway control, using two-way and intermediate switches, it is best to bridge temporarily all the switch terminals and test to earth as before. Study the circuit diagram of Figure 11.32(a), and imagine the polarity reversed.

Figure 11.32(b) shows the same testing principle, applied for polarity testing of a Goliath Edison screw lampholder. Provided that the test lamp is connected as in Figure 11.32(b) to the centre contact of the lampholder to which the circuit active should be connected, the lamp should glow when the control switch is turned

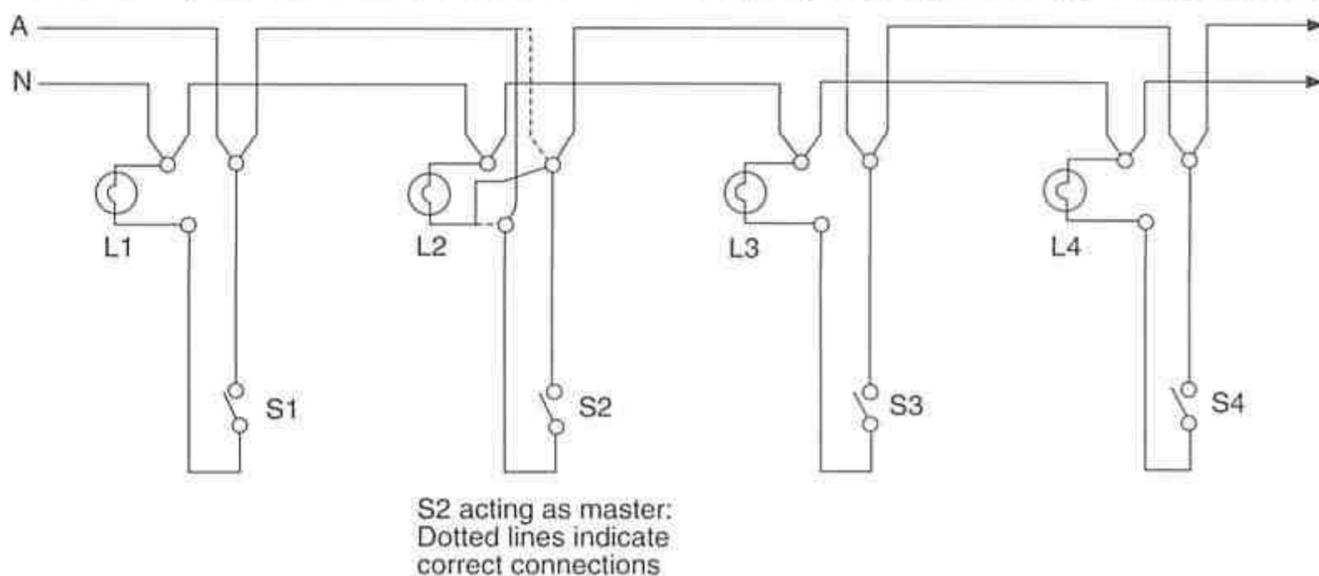


Fig. 11.31 Incorrect connections causing switch S2 to act as a master switch

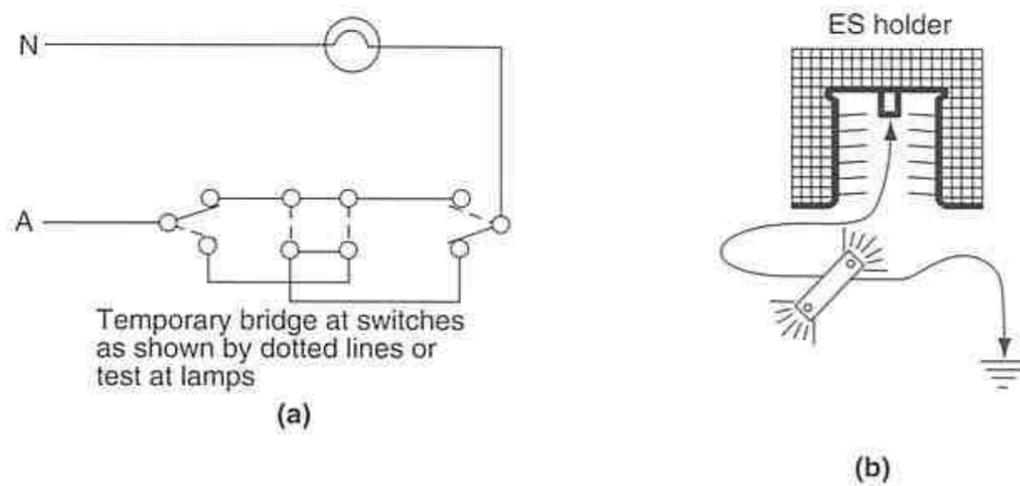


Fig. 11.32 Polarity testing multiposition controlled lighting and Edison screw (ES) lampholders

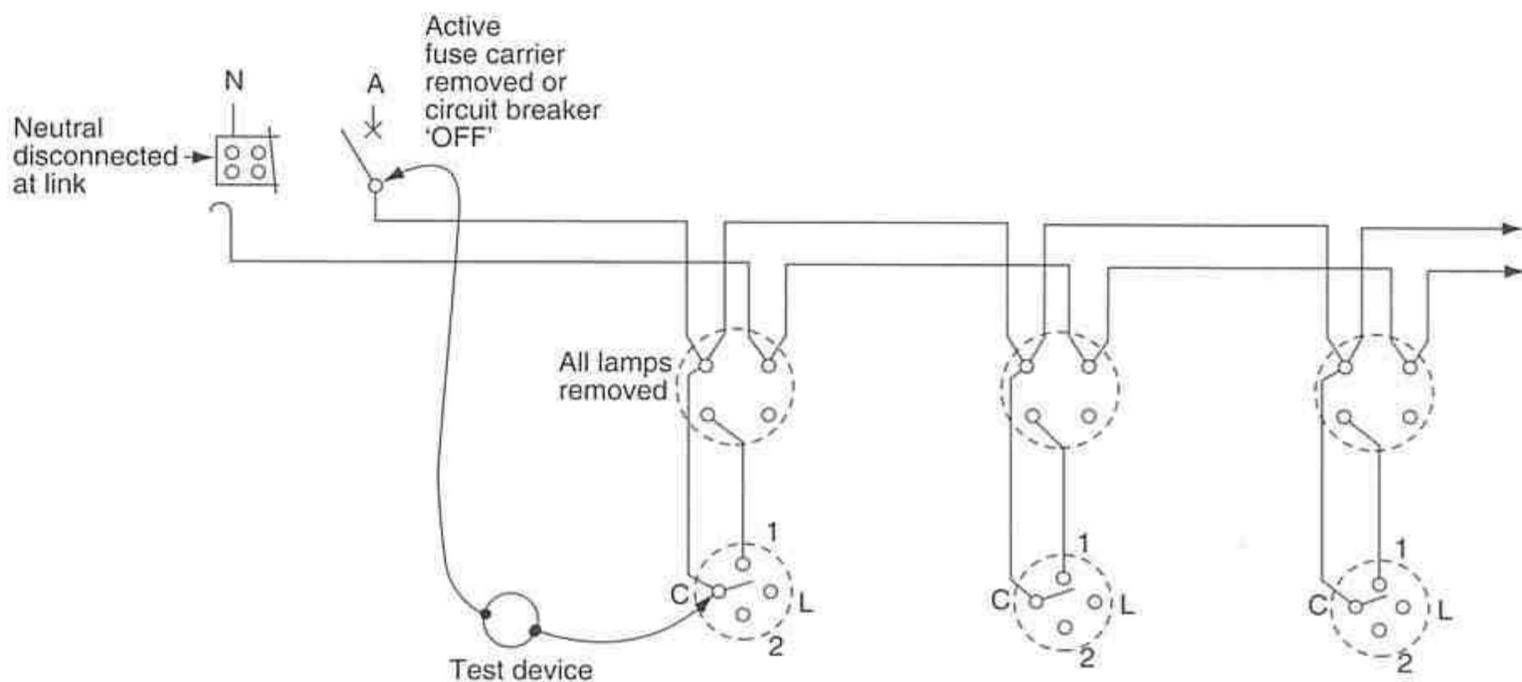


Fig. 11.33 Polarity testing a light circuit isolated from the supply

on. If the lamp is extinguished when the control switch is turned off, the polarity of connections to the terminals of the lampholder is correct.

Sometimes it is hard to gain access to switch contacts, in which case a special testing device that plugs into the circuit lampholder may be used, such as the 'Light Stix' shown in Figure 11.17, which is for live testing. For dead testing, the 'Light Stix' of Figure 11.16(b) is used. Both 'Light Stix' illustrated incorporate a switch that enables polarity checks to be made.

In the case of a new installation or an installation that has been isolated from the supply, any form of continuity test may be employed to achieve the object of polarity testing, which is to ensure that the active conductor is continuous from the load side of the circuit fuse or circuit breaker to each control position or switch. Always check that the circuit is de-energised first. All lamps should be removed, all switches in the 'off' position, the circuit fuse withdrawn or the circuit breaker opened, and the load neutral disconnected at the neutral link.

Virtually any type of ohmmeter, insulation-resis-

tance tester or ELV testing device may be used for this type of continuity test, provided always that the limitations of the testing device being used are realised. For example, if an ELV source is used to test a long circuit conductor for continuity, the overall length of the conductor and the test leads may be sufficient to increase the resistance to a point where current is reduced to a value below that required to operate the testing device. For the test illustrated in Figure 11.33, the return circuit to the testing device is completed through a roving lead as shown.

If the circuit is continuous, an insulation-resistance tester will indicate zero or very close to zero, as the usual minimum scale division is about 10 000 Ω . The average continuity tester, such as that shown in Figure 11.35, also will indicate a near-zero reading on the scale (usually less than 1 Ω on a meter having a full-scale deflection of 100 Ω).

The method described above requires long roving leads, but the lengths of the test leads may be reduced considerably by using sections of the circuit wiring

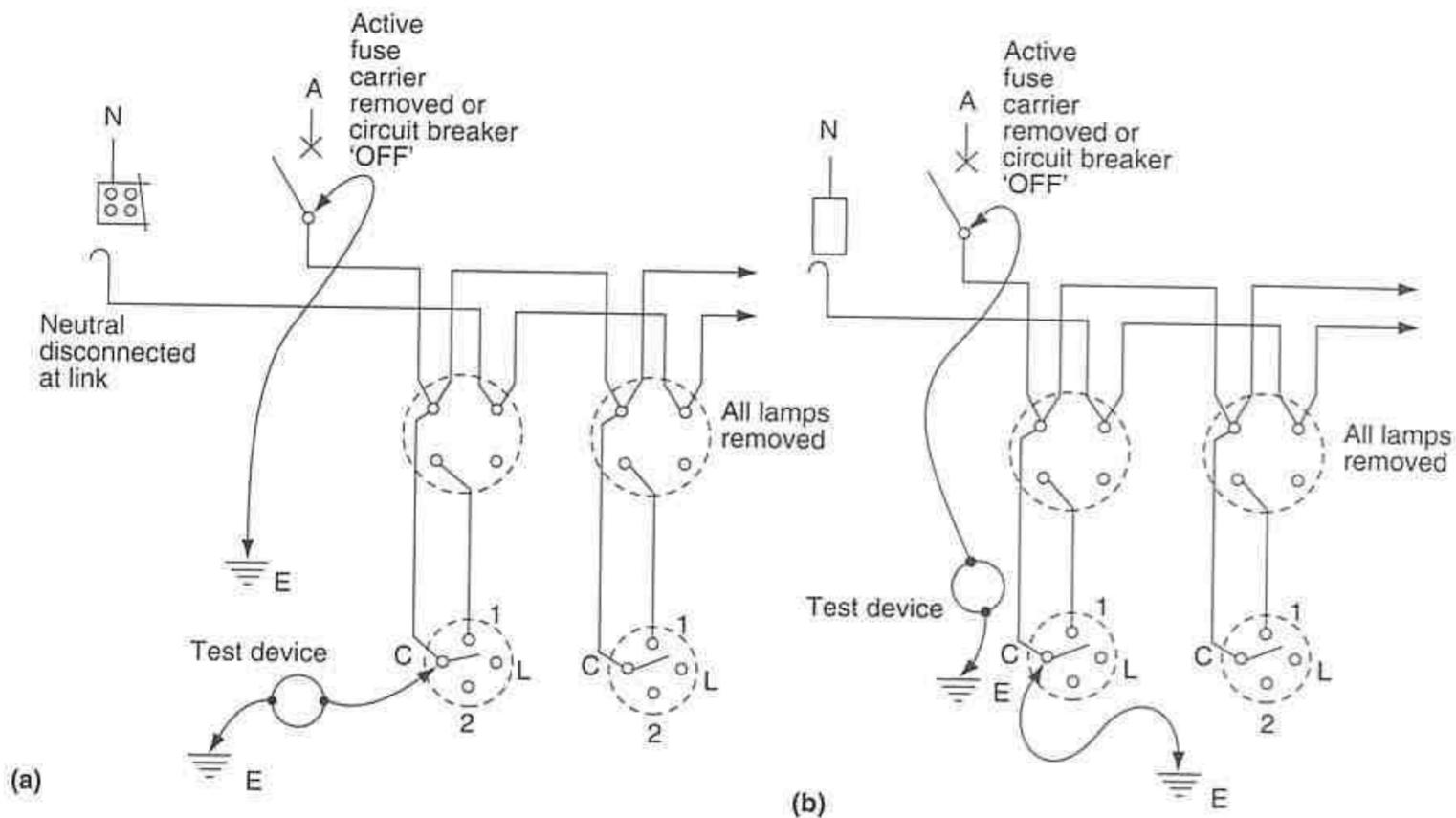


Fig. 11.34 Methods of reducing the effective length of test circuit

known to be electrically continuous, or by using the earthing system as the return test path as shown in Figure 11.34(a).

Figure 11.34(b) shows an alternative, where the switch terminals (or light outlets) are 'shorted to earth' in turn, giving the same indications as the previous two tests. Trace the test circuit out to check this.

It is important to note that the validity of the tests so far described depends on there being no short circuits to earth or between conductors in the circuit under test, so that **in practice insulation tests are carried out as a preliminary measure before continuity or polarity tests are applied.**

If a polarity test reveals an incorrect connection, then after the connection is corrected insulation- and earth-resistance tests may need to be repeated.



Fig. 11.35 Analogue/digital insulation and continuity tester
NILSEN INSTRUMENTS

11.9 Testing techniques 4: correctness of wiring circuits and connections

Some of the polarity checks described have utilised continuity testing to determine that the active feed is continuous, that it follows the correct circuit route, and that 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, that there are no interconnections between circuits, and that circuit loads, active conductors and corresponding neutral conductors are correctly identified at their switchboard of origin.

Interconnection of conductors between different circuits has been the cause of a number of electrical accidents. Anyone working on such an installation is exposed to the risk of electric shock even though it may 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, or the result of insulation breakdown. An 'incorrect' connection may result in the direct connection of conductors of separate circuits, as shown in Figure 11.36(a), or in a load supplied by active and neutral conductors of different circuits, as shown in Figure 11.36(b).

Testing between neutral conductors of all circuits and active conductors of the same circuits at the switchboard will show any direct interconnection faults. In

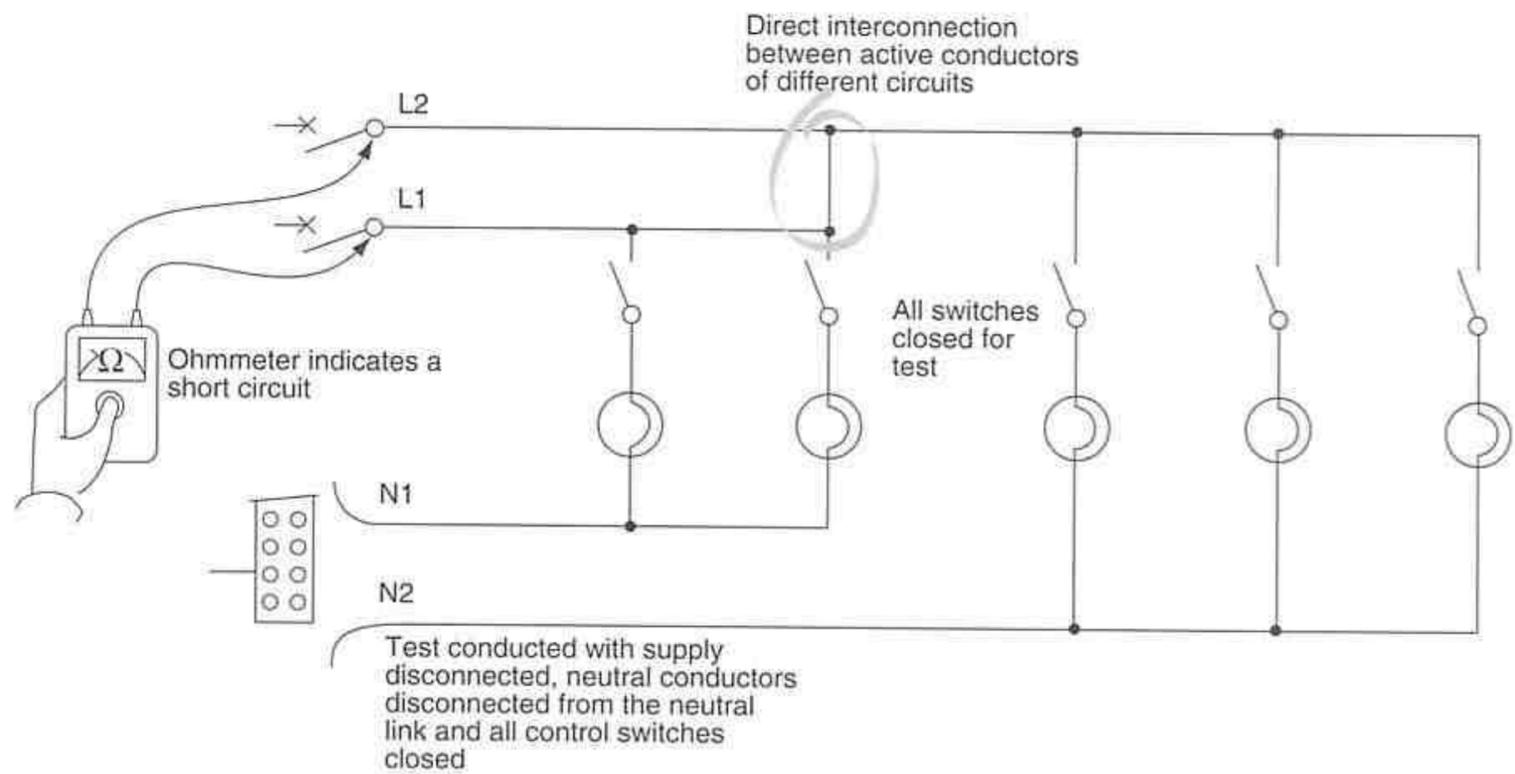


Fig. 11.36(a) Testing for a direct connection between conductors of different circuits, revealing an interconnection between active conductors of different lighting circuits

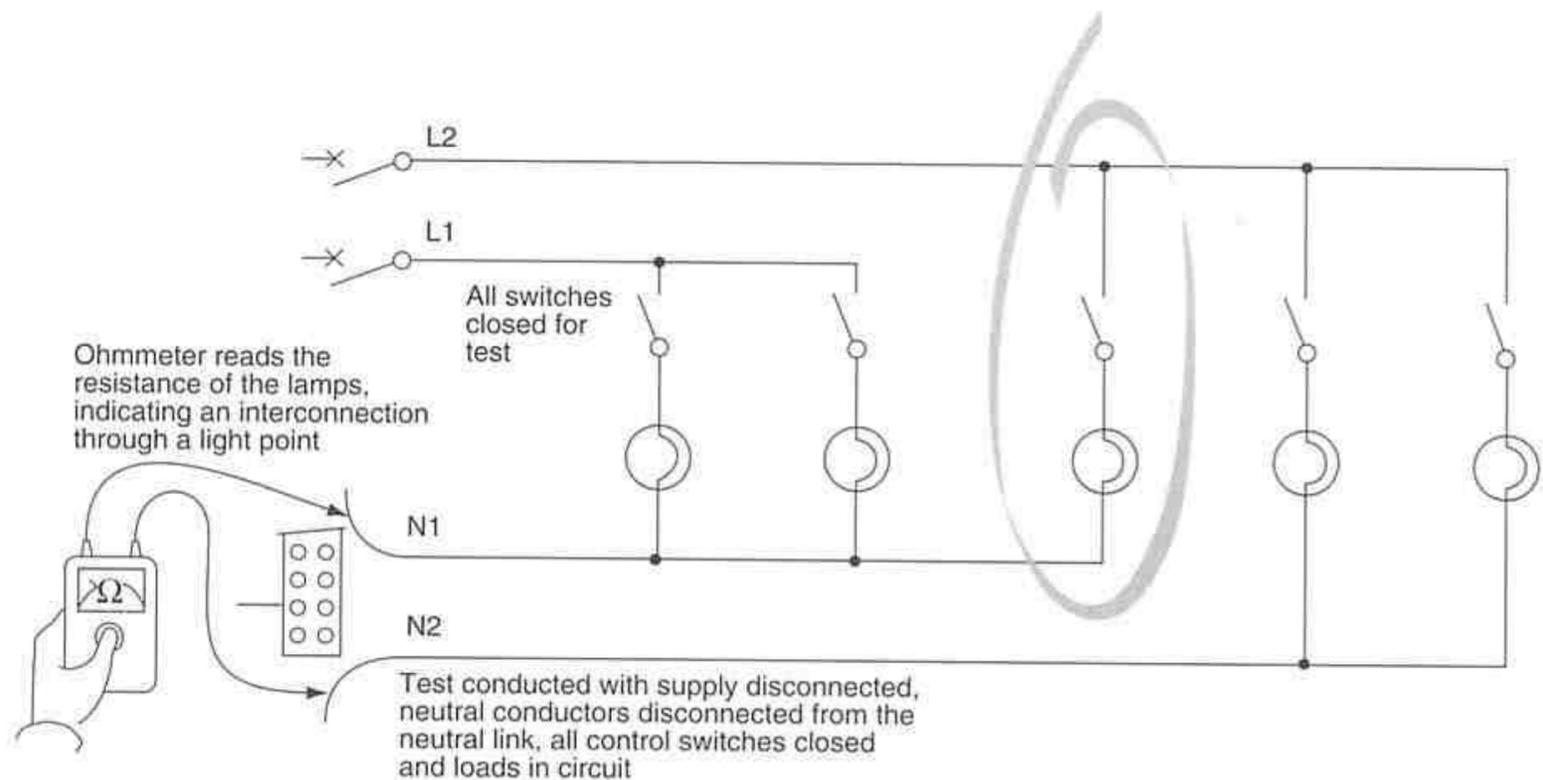


Fig. 11.36(b) Testing for an interconnection between circuits, revealing a light point connected to active and neutral conductors of different circuits

preparing for the test, the circuit protection devices must be opened, the circuit neutral disconnected from the neutral link, and all controlling switches or contactors closed. Testing with a low-reading ohmmeter will reveal any direct interconnections with the meter indicating a short circuit. If insulation breakdown is suspected, as may be the case in older installations, then an insulation-resistance tester should be used. Any reading below 1 M Ω indicates a problem with insulation either in the wiring or at the terminal of an accessory.

An interconnection where a load is supplied by an active and neutral of different circuits can only be

detected with the loads connected. The circuit protection devices must be opened, the circuit neutral disconnected from the neutral link, and all controlling switches or contactors closed. A low-reading ohmmeter is used to test between neutral conductors or between active conductors to show any interconnection between the circuits. For example, tracing out the path of the test circuit in Figure 11.36(b) shows an interconnection fault, with the ohmmeter reading the resistance of two lamps in parallel with one lamp in series. If the test were conducted between the active conductors, the fault would be shown by the same ohmmeter reading. This

test can be carried out at the same time as the following test.

Testing with an ohmmeter between the active and neutral conductors of each circuit at the switchboard can be done to check that circuits and corresponding neutrals are correctly identified. Preparation for the test is the same as for the previous test. The ohmmeter will read the resistance of each load. For example, light circuits have a cold resistance from a few ohms up to tens of ohms depending on the type of lamp and the number of points on the circuit. A 4.8 kW water heater will show an ohmmeter reading of 12 Ω , while the circuit supplying a 6.8 kW oven will read 8.5 Ω . In this way each circuit and neutral can be identified.

11.10 Testing techniques 5: general testing

Many other continuity tests are possible and will suggest themselves when electricians are confronted with a particular job situation requiring solution. Electricians should try to visualise the wiring layout and the wiring circuit under test and should remember that, to avoid long trailing leads, it is often possible to use the earthing system or circuit conductors as part of the test circuit. To illustrate this, consider the problem of identifying the ends of conductors in a long mineral-insulated metal-sheathed (MIMS) cable or in the long run of conduit illustrated in Figure 11.37.

Suppose that it is required to identify the load ends of cables L_1 , L_2 and L_3 and to label them accordingly. There are several solutions to this problem; one solution is given below.

1. Connect a continuity tester between earth and one outgoing conductor, say L_3 , at the supply end, as shown in Figure 11.37. The earth return can be the cable sheath itself (MIMS or metal conduit), in

which case connection to the main earthing conductor is not required.

2. Check that the conductor ends are physically separated, making certain that there are no short circuits between conductors.
3. Connect each conductor in turn to 'earth' at the load end. The one giving a test indication of a short circuit is L_3 .
4. Change the test lead from L_3 to L_2 at the supply end and repeat.
5. Having located L_3 and L_2 , the one remaining is obviously L_1 , but it is advisable to check it to ensure that it is not 'open-circuited'.

One variation of this method is to short-circuit successively the leads at the supply end and connect the test set at the load end. You should attempt to devise other solutions to this problem of conductor identification.

A cable tester that provides a quick method of tracing and identifying a large number of cables, say in a large industrial installation or multistorey building, is shown in Figure 11.38. It consists of a transmitter



Fig. 11.38 Cable tester for multicable runs GERARD INDUSTRIES

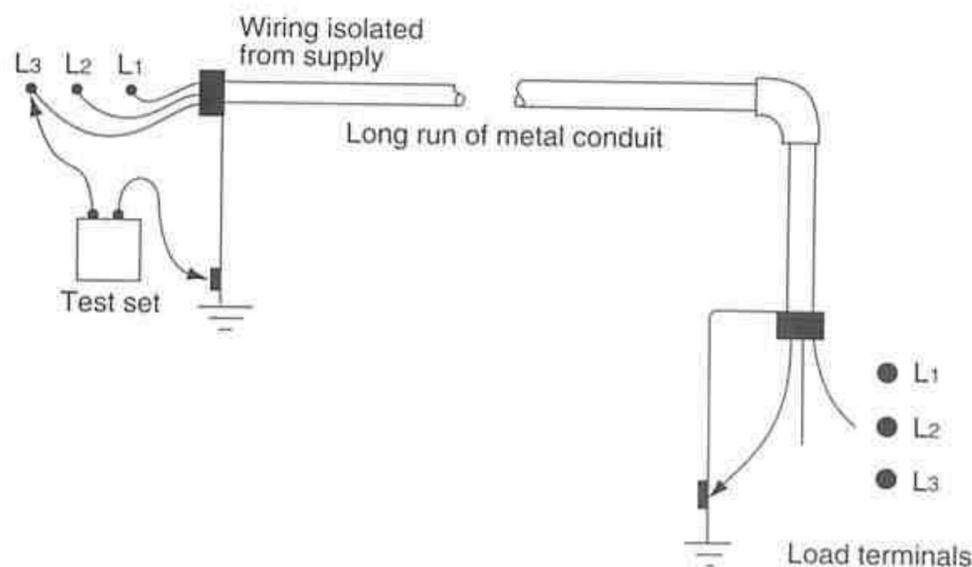


Fig. 11.37 Continuity testing on a long run of cable

having sixteen numbered leads, which are attached to unidentified conductors in an installation. A receiver having one contact is attached to one conductor at a time at the other end of the circuit. Pulses are sent to the receiver, which identifies the conductor as a number in the digital display window of the receiver. One wire, say the earth wire in the cable run being tested, must be used as a common (return) wire. The device is satisfactory for a route length up to 500 m and can identify crossed wires.

When testing an installation, you should always remember that any conductive path possesses resistance, and make allowance for this. For example, a 50 m run of 1 mm² conductor would have a resistance of approximately 0.89 Ω, and this would affect test results if using an extra-low test voltage as supply.

Resistance of wiring circuits and connections

If, for instance, the resistance of the current-carrying conductors of a circuit needs to be known for the purpose of connecting additional load, or if in the course of a routine inspection conductor resistance is required to be determined, a suitable ohmmeter on an appropriate scale will give a direct indication of the value of this resistance when its terminals are connected to the ends of the conductor. A suitable instrument for general work would be one similar to that shown in Figure 11.9. Instruments of higher sensitivity and special types are necessary for some work and are more expensive. The Bridge Megger and other adaptations of the Wheatstone Bridge also are used.

The resistance of a conductor is directly dependent on its length and the material of which it is made, but varies inversely with its cross-sectional area. Thus, for the resistance of an actual circuit conductor to change it would have to sustain violent mechanical or chemical damage to reduce its cross-sectional area, because both its length and its materials are fixed. This damage is possible, but in practice, when a continuity test reveals a higher than normal resistance value, it is usually due to poor connections at conductor joins in junction boxes or terminals of equipment (high-resistance joints).

A resistance test not only checks that there is a continuous circuit, as do the tests described earlier in this section, but ensures that the resistance of all joints and connections is sufficiently low. Sometimes high-resistance joints can be located by virtue of the fact that they often sustain an increase in temperature caused by the heating effect of the current.

To test for resistance between the two ends of a conductor (or circuit), the conductor or circuit must be isolated from all other wiring to avoid feedback or any parallel conductive paths. If the circuit is at all complex, it may be necessary to consult the circuit diagram to ensure that isolation is complete before testing.

When carrying out a test such as the one illustrated by Figure 11.39, keep in mind that measured resistance values are low, and so:

- All the test connections should be well made and of negligible resistance.
- Prior to any test, the resistance of the test leads should be determined by shorting them together. The value found must be deducted from the value read off the instrument; for example, using the method of Figure 11.39 the following test results were obtained:

resistance of test leads

$$= 0.01 \Omega$$

resistance of test circuit read off ohmmeter

$$= 1.13 \Omega$$

∴ resistance of circuit under test

$$= 1.13 - 0.01$$

$$= 1.12 \Omega.$$

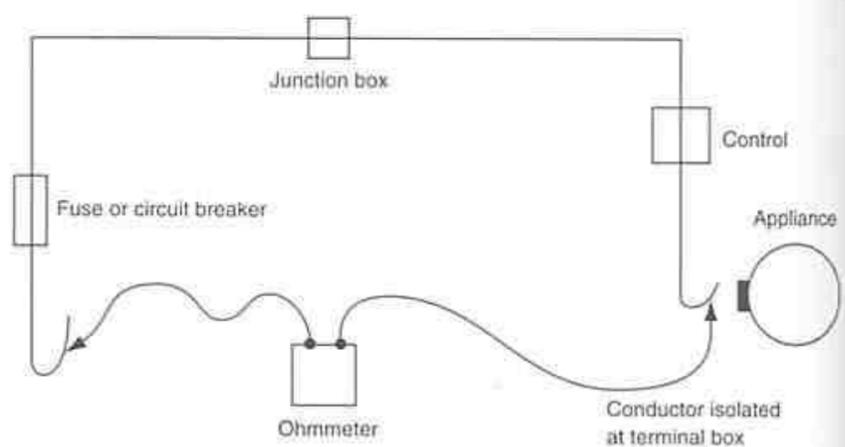


Fig. 11.39 Checking for suspected high resistance at a fuse, junction box or control device

Alternative testing methods

The testing and checking techniques for wiring installations outlined in this chapter cover only some suggested approaches to testing new and existing installations.

You should consult other references, such as AS/NZS 3017—1996 *Electrical Installations—Testing Guidelines*. There is also a need to be aware of local requirements and any other prescribed guidelines for carrying out electrical installation testing and checking.

11.11 Appliance testing

One of the most important safety assurance aspects in the use of electricity and requiring ongoing inspecting and testing is that related to portable appliances and extension cords. Occupational (workplace) health and safety legislation requires that all equipment 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.

The periodic tests include earthing resistance, which must not exceed 1Ω between exposed metal parts for non-double-insulated equipment. Also, insulation resistance must be greater than $1 M\Omega$ measured between live conductors and exposed metal parts. Portable residual current devices (RCDs) must be tested for operation within the maximum tripping time and tripping current for the particular type of RCD (see Chapter 14, Volume 2). Equipment and leads must be inspected for visually obvious damage or deterioration. Intervals between inspection and tests vary from 3 months to 5 years, depending on the activities of the environment in which they are used. For example, use of equipment on a construction site requires more frequent attention than equipment used in an office environment.

Testing equipment described in this chapter may be applied to testing portable equipment. However, purpose-built testing devices are available that help assure the accuracy and improve the efficiency of such testing.

The British version of an instrument specifically designed for testing portable appliances, and commonly

used in Australia, is illustrated in Figure 11.40. It will perform five tests on an appliance, which should be carried out in the following sequence:

1. *Earth bond test:* Continuity between the exposed metal of earthed equipment and the earthed terminal of the plug is checked. For double-insulated appliances, this test is omitted and the test sequence starts with test 2.
2. *Insulation test:* A test voltage of 600 V dc is applied to check insulation resistance between live conductors and the exposed metal of the appliance.
3. *Flash test:* A test voltage of 1.5 kV is applied to an earthed appliance in the same way as for the insulation test. A flash test voltage of 3 kV is applied to double-insulated appliances via a high-voltage test probe supplied with the instrument. For operator protection, short circuit current is limited to 6 mA in both cases.
4. *Load test:* Appliance is supplied with 6 V ac as a pretest of normal appliance operation without the problem of high currents damaging the appliance or testing instrument.
5. *Operation test:* Appliance is tested under normal operating conditions at mains supply voltage, and the power consumed is compared with the nameplate rating.

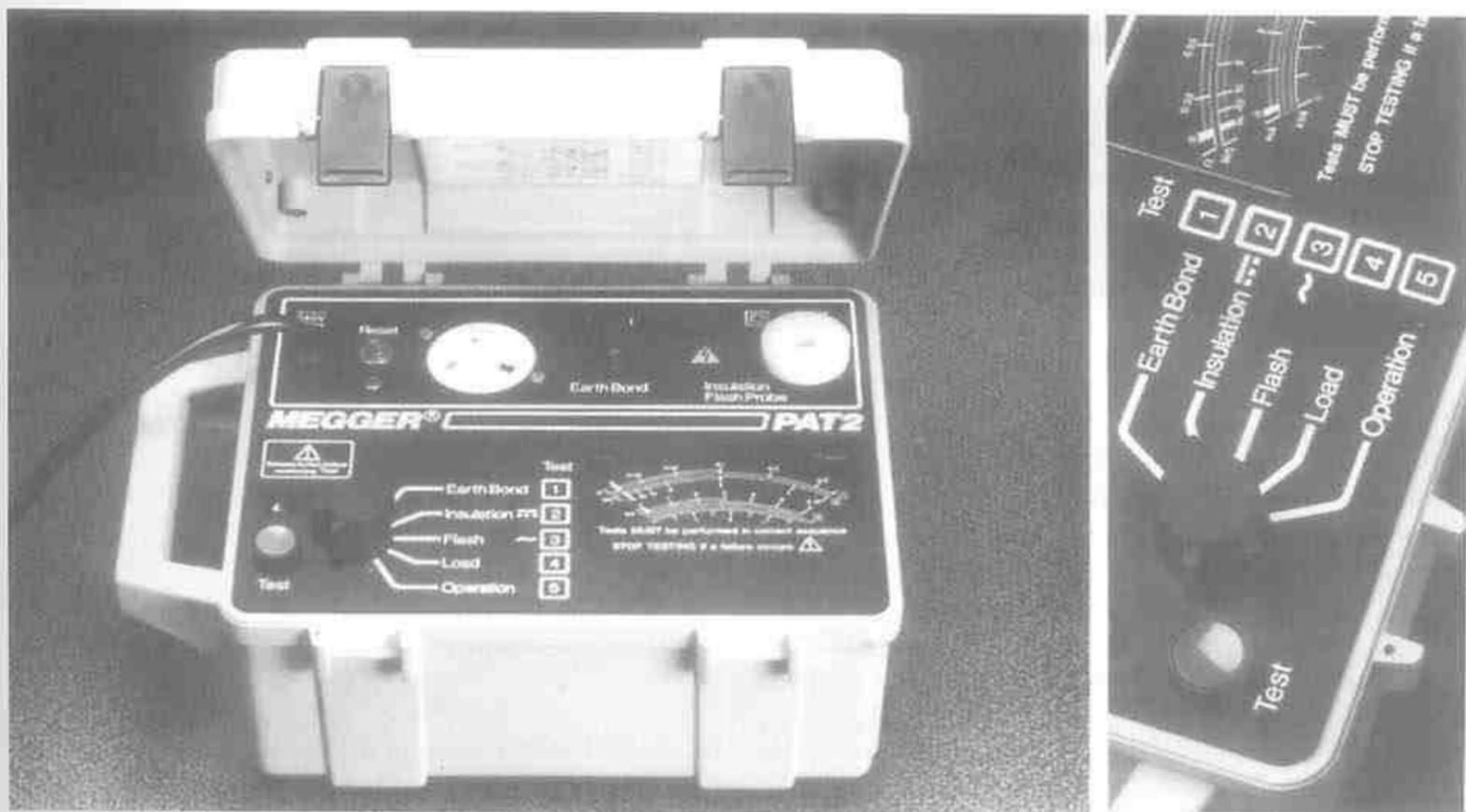


Fig. 11.40 Portable appliance tester NILSEN INSTRUMENTS

SUMMARY

- Testing of electrical circuits and wiring is carried out:
 - during the installation of wiring to avoid costly defects,
 - at the completion of an installation to ensure that it is safe and complies with the *SAA Wiring Rules*, service and installation rules and state wiring regulations, and
 - during routine maintenance and to locate faults when circuits and wiring malfunction.
- Regulations require that mandatory tests be conducted on all new and altered installations to ensure that the earth system is adequate, that the insulation is safe, that there are no incorrect polarity connections, and that the installation operates as intended.
- A sound knowledge of Ohm's Law and understanding of wiring arrangements is required if testing is to be carried out effectively.
- In electrical testing an energy source is connected to the circuit under test and indicators or meters are used to monitor the circuit's behaviour.
- Testing a conductor or circuit to determine whether it is electrically continuous using a testing device with an inbuilt energy source is referred to as 'continuity testing'.
- 'Dead testing' is carried out with the supply disconnected from the circuit under test, using testing devices with an inbuilt energy source.
- 'Live testing' is conducted with the supply connected to the circuit under test, the supply being used as the energy source.
- Visual indicators are the most widely used testing device; they include 480 V series test lamps, neon testers such as the neon test pencil, and high-impedance voltage testers with voltage level indicator.
- Analogue meters provide a visual indication through the movement of the pointer, and may be preferred to the digital-type meter where precise measurement is not required.
- Instruments must be suitable for the supply and set to the correct range to avoid damage to the instrument and creation of a safety hazard.
- The most commonly used meter for measuring current is the clip-on-type instrument, as no direct circuit connections are necessary, making it quicker and safer to use.
- Multimeters have incorporated in them the functions of several meters, including resistance measurement.
- The energy source in an insulation-resistance tester is a battery with an electronic circuit to boost the voltage to a test level of 500 V or 1000 V, as required by *Clause 1.5.2*.
- Purpose-built testing accessories are used to improve the efficiency and accuracy of testing new installations (see Figs 11.16, 11.17 and 11.18).
- When testing, control measures must be adopted to limit the risk of injury or death.
- Risk factors include:
 - using test probes with excessive bare metal at the tip
 - incorrectly setting meters
 - using devices with exposed terminals
 - leads coming adrift from meter terminals.
- Risks associated with testing can be reduced by selecting appropriately safe equipment, including:
 - fused test probes, particularly when testing systems having high energy levels
 - properly insulated and colour-coded leads
 - approved covered test lamps, marked with their maximum test voltage.
- All test equipment should be checked before, during and after testing to ensure that it works properly and is safe.
- Testing an installation to ensure that it is safe and complies with requirements is the responsibility of the electrical contractor or installing electrician.
- Earth-continuity testing is to check that sections of the earthing system do not exceed 2Ω or are sufficiently low to ensure the circuit protection device will operate quickly to cut off the supply in the event of a short circuit to earth fault. In New Zealand, earthing system resistance must not exceed 0.5Ω (see Figs 11.21 and 11.22).
- Insulation-resistance testing checks whether the insulation between live conductors and earth will break down under the stress of the supply voltage. The test is also used to check resistance between live conductors (see Figs 11.23 and 11.24).
- Polarity testing is to check that active and neutral conductors are connected to the correct terminals at socket outlets, that all switches are in the active conductor, and that there is no transposition of neutral and earthing conductors (see Figs 11.25 to 11.34).
- Testing the correctness of wiring circuits and connections includes checking that there are no short circuits, no interconnections between circuits, and that circuit loads, active conductors and corresponding neutral conductors are correctly identified (see Fig. 11.36).
- Other tests are required from time to time, as part of a routine inspection of an existing installation to identify cables prior to connection, or for the purpose of determining additional load capabilities of a circuit (see Figs 11.37 and 11.38).
- Appliance testing includes insulation resistance, continuity of earthing from the earth pin on the three-pin plug attached to the exposed metal of the appliance, and correct operation of switches.



REVIEW QUESTIONS

Where the answer to a review question is numerical or requires reference to the SAA Wiring Rules, the answer is given at the back of the book. These questions are marked *.

- * 1. Why is it necessary to give a completed installation a thorough visual inspection?
2. Could an electrical fault be present in a circuit without appearing to affect the normal operation of the circuit? Explain fully.
3. Why is it dangerous to use the single-lamp type of test lamp for tests on 415/250 V supply?
4. Suggest one disadvantage of the neon 'test pencil' that could lead to misinterpretation of a circuit condition.
5. How are:
 - (a) an ammeter
 - (b) a voltmeter
 connected into a testing circuit?
6. Is it possible to obtain an indication of the value of current in a circuit without making any electrical connection to the circuit? If so, why?
7. State some practical uses for a multimeter.
8. Could the inexpensive small type of multimeter be used for tests of insulation resistance?
9. Is there available any type of portable battery-powered instrument that is capable of insulation-resistance tests?
10. State common scale ranges for:
 - (a) an insulation-resistance tester
 - (b) a continuity tester.
11. What features would you look for in a probe intended for detecting the presence or absence of voltage?
12. When should a fused probe be used?
13. An apprentice is asked to test a circuit for values of insulation resistance and adopts the following procedure:
 - (a) connects insulation-resistance tester between active and earth and, with lamps removed, switches closed and appliances disconnected, takes and records a reading (infinity);
 - (b) repeats step (a) for a reading between neutral and earth (infinity);
 - (c) as an additional test, checks between active and neutral (infinity);
 - (d) checks recorded results and hands them to the person who requested the tests.
 Name three serious errors made.
- *14. A multimeter has voltage scale ranges of 0-10, 100, 200, 400, 800 and 1600. On what range should it be set before connection to a 240 V circuit?
15. When polarity testing between a switch terminal and earth, should the switch be open or closed?
- *16. What are the required polarity connections for a three-pin socket outlet?
17. What steps would you take before carrying out a polarity test on a circuit protected by an RCD?
18. Refer to the identification problem of Figure 11.37, and briefly list the testing steps for a solution other than the ones given.
19. At what positions in a circuit are high-resistance continuity faults most likely to occur?
20. When testing for the continuity of a conductor in a rather complex circuit, what steps must be taken to ensure that the instrument reading is due only to the resistance of the conductor?
21. How is allowance made for the resistance of the test leads in a continuity test on an earthing system?
- *22. What is the maximum permissible value for resistance measured between the main earth connection and any part of the earthing system?
- *23. Do the Rules require that an insulation-resistance test be made between conductors?
- *24. What would be the minimum value of insulation resistance to earth for any part of an electrical installation?
- *25. Why are appliances excluded from an insulation-resistance test of the wiring?
26. All switches must be closed for an insulation-resistance test. What is the reason for this?
- *27. What is the usual minimum value for insulation resistance of a heating appliance?
- *28. State the value of the minimum test voltage for an insulation-resistance test on a 240 V circuit.
29. Would an 'insulation-resistance tester' be suitable for indicating the resistance of the element in an appliance such as a hot-water urn?
30. An appliance cord is incorrectly connected as follows:
 - (a) neutral to the frame of the appliance
 - (b) active and earth to the motor of the appliance.
 What is the result when the appliance is plugged into the supply?
 Another appliance is connected as follows:
 - (a) active to appliance frame
 - (b) neutral and earth to the motor of the appliance.
 What are the possible results of this incorrect connection?

Answers

These answers are to problems with numerical answers or requiring reference to the *SAA Wiring Rules*.

Chapter 1

Q19. *Clause 0.2*

Chapter 2

- Q 9. *Clause 3.2.2*
- Q14. *Clause 0.5.41*
- Q16. *Clauses 0.5.57 and 0.5.58*
- Q18. *Clause 6.3*
- Q19. *Clause 6.3.6.3*

Chapter 3

- Q 2. *Foreword to SAA Wiring Rules and Clause 0.3*
- Q 3. *Foreword to SAA Wiring Rules*
- Q 4. *Clause 0.2*
- Q 5. *Clauses 0.5.3 and 0.5.7*
- Q 6. *Clauses 0.5.5, 3.14.1 and 3.15.1*
- Q 7. *Clauses 0.5.17 and 0.5.40*
- Q 8. *Clause 0.5.31*
- Q 9. *Clause 0.5.95*
- Q10. *Clauses 0.5.29 and 0.5.30*
- Q11. *Clauses 0.5.78 and 0.5.30*
- Q12. *Clause 0.5.2*
- Q13. *Section 5*
- Q14. *Clause 0.5.42*
- Q15. *Clause 0.5.64*
- Q16. *Clauses 0.5.18 and 0.5.27*
- Q17. *Clause 0.5.35*
- Q18. *Clause 0.5.54*
- Q19. *Clause 0.5.70*
- Q20. *Clause 3.24.2*
- Q24. *Clause 1.1.5*
- Q26. *Clause 1.2.3*
- Q27. *Clause 1.4.8.1*
- Q28. *Table 1.1, 0.6 m*
- Q29. *Clauses 1.1.6 and 2.4.3.2*
- Q30. *Clause 1.4.9.3, 50 mm*

- Q31. *Clause 1.4.9.3*
- Q32. *Clauses 1.4.9.1, 1.4.9.2 and 1.4.9.3*
- Q33. *Clause 1.5*
- Q34. *No, Clause 1.2.5.2*
- Q38. *Clause 1.5.2.4*

Chapter 4

- Q 1. *Clauses 0.5.18 and 0.5.27*
- Q 2. *Clause 0.5.21*
- Q 5. *Paragraph B3.1, Note 2 and text*
- Q 6. *Clause 3.4*
- Q 9. *Clause 3.2.4.2*
- Q19. *Table 2.1*
- Q20. *Clause 3.2.4.3*
- Q23. *Clause 0.5.31*
- Q24. *Clause 0.5.58*
- Q28. *Clauses 3.9.5.1 and 3.31.4.5*
- Q29. *Clause 3.24.2*

Chapter 5

- Q 1. *Clauses 0.5.3 and 0.5.7*
- Q 2. *Clause 5.5.4.2*
- Q10. *Clause 4.8.1*
- Q17. *Clause 3.15*
- Q23. *Clause 9.5.3*
- Q27. *Table 4.1*

Chapter 6

- Q 8. *Clauses 2.18(a), 6.11 and 6.14*

Chapter 7

- Q 1. *Clause 0.5.54*
- Q 8. *Clauses 0.5.40 and 0.5.94*
- Q 9. *Clauses 3.14 and 3.18*

- Q10. *Clause 6.8.2.1*
 Q11. *Clause 3.31.3.2*
 Q12. *Clauses 3.31.3.3 and 4.6.1*
 Q14. *Clauses 0.5.17 and 0.5.94*
 Q17. *Clauses 0.5.35 and 6.4*
 Q18. *Clause 6.6.2.2, Note 2*
 Q19. *Clause 6.6.4*
 Q21. (a) 0.5 m; (b) 0.3 m, *Table 3.7*
 Q23. *Clause 3.16.3.1(e)(iv)*
 Q24. *Clause 3.36*
 Q25. *Clause 3.36.2.2*

Chapter 8

- Q 1. *Clause 3.20.2.2*
 Q 2. 0.3 m or $20 \times$ minor cable diameter, *Clause 3.20.3.2(a)*
 Q 3. (a) *Clause 3.20.3.3(b)(ii)*; (b) *Clause 3.20.3.5(d)*
 Q 4. *Clause 3.20.3.2(b)(ii)*
 Q 5. *Clause 3.20.2.1(b)*
 Q 8. *Clause 3.20.2.2*

Chapter 9

- Q 4. 8
 Q 5. (a) 50 mm; (b) 63 mm
 Q 7. (a) 2.0 m, *Clause 3.26.4.4*; (b) 1.0 m, *Clause 3.28.4.3(a)*
 Q 8. *Clause 3.26.1(c)*
 Q12. *Clause 3.26.5.6*
 Q13. *Clause 3.26.1*
 Q14. *Clause 3.26.2*
 Q15. *Clause 3.26.1*
 Q16. *Clause 3.28.3*
 Q17. *Clause 5.4.4.3(b)*
 Q18. *Clause 3.26.5.3*
 Q19. *Clause 1.4.7.1*
 Q20. *Clause 3.26.4.8*
 Q21. *Clause 3.16.3 and Table 3.6*
 Q22. 4, *Clause 3.28.4.4(b)*
 Q23. *Clause 3.28.3(d)*
 Q27. *Clause 3.28.4.2*

- Q28. *Clause 1.4.7.1*
 Q30. *Clause 5.4.4.2(c)(v)*
 Q31. 7, *Table E7, column 5*
 Q32. 4, *Table E7, column 12*
 Q33. 10, *Table E7, column 8* (may have to be derated for current)
 Q34. No, 3 per cent over limit, *Table E7, column 8*
 Q35. No, derated to values shown in columns of *Table B3*
 Q36. *Clauses 3.16.3.2 and 3.16.4.2*
 Q37. *Clause 3.28.4.4*
 Q38. *Clauses 3.25.1(g) and 3.26.3 and Table 3.6*

Chapter 10

- Q 4. *Clause 2.19.7.2*
 Q 5. *Clause 1.2.3*
 Q 6. 2800°C
 Q 7. 32 A, *Table B4, AS 3000*; 40 A *Table 14, AS 3008.1*
 Q 8. (a) 90°C; higher temperature subject to conditions, *Note 5, Table 2.1*
 (b) 90°C, *Note 5, Table 2.1*, type V105 sheath
 Q16. *Clause 3.21.6*
 Q18. *Clause 2.2.5*
 Q19. *Clause 3.21.2.2*
 Q20. *Clause 5.4.4.3(c)*
 Q21. *Clause 3.21.2.3*
 Q22. *Clauses 6.3.3.1(a) and 6.3.3.4*

Chapter 11

- Q 1. *Clauses 1.1, 1.2, 1.3 and 1.4*
 Q14. 1600 V and step down
 Q16. *Clause 4.14.8*
 Q22. 2Ω, *Clause 1.5.3.3(a)* (0.5 Ω in NZ)
 Q23. *Clause 1.5.2.1*
 Q24. 1 MΩ, *Clause 1.5.2.2*
 Q25. *Clause 1.5.2.2*; text and *Clause 1.5.2.4*
 Q27. 0.01 MΩ, *Clause 1.5.2.4*
 Q28. 500 V dc, *Clause 1.5.2.1*

19

Special installations

This chapter deals with electrical installations in areas where additional precautions need to be taken due to the environmental conditions or the activities associated with the electrical installation, including:

- damp situations
- areas in which electromedical equipment is used
- outdoor living and recreational areas
- construction sites
- lifts and hoists.

19.1 Introduction

An electrical system must be installed so that its safe operation is ensured. This is achieved by the use of materials and techniques suitable for the conditions under which the electrical system is to operate. Many of these requirements are presented in other chapters. However, there are some areas in which the electrical system may become unsafe if special precautions are not taken. The intended use of an area may create the need for the electrical installation to meet special requirements, such as in a theatre. The *SAA Wiring Rules, Section 6*, refer to electrical installations in these areas as 'special situations'.

The electrical installation must comply with the requirements of special situations in areas where water or moisture is normally present, or likely to be present, due to the activities in the area. *Section 6* of AS 3000 also calls up a number of Australian and Australian/New Zealand Standards that specify the requirements for electrical installations in theatres and public halls, in film, video and television sites, in medical treatment areas, quarries and open mining, construction and demolition sites, caravan parks, shows and carnivals, boating marinas and tent areas.

Electrical work in many of these areas is not an everyday occurrence, and opportunities for you to gain installation experience in all of these areas may be limited. For this reason a basic knowledge of the methods used to meet the installation requirements of these special situations is essential.

19.2 Damp situations

The definition of a 'damp situation' (*Clause 0.5.35*) requires that moisture be present either permanently or intermittently to such an extent that the safety or effectiveness of the installation is impaired.

The specific areas in which electrical installations must comply with the additional requirements for damp situations are:

- swimming and spa pools;
- baths, showers, and other fixed water containers such as washbasins, sinks and laundry tubs;
- fountains and water features;
- controlled-atmosphere rooms such as coolrooms, freezerooms and sauna baths;
- general hosing areas (e.g. food-processing rooms, which may need to be hosed down regularly to meet health requirements).

Before looking more closely at installations in these areas, it is important that you have an understanding of the standard for various levels of protection against the

entry of solid materials or water into an equipment enclosure. The enclosures for electrical equipment must be appropriate for the environmental conditions under which the equipment is to operate. For example, a switch located outside in the weather must be enclosed to prevent the entry of rainwater, which could cause corrosion of the switch mechanism or a short circuit. AS 1939—1990 *Degrees of Protection Provided by Enclosures for Electrical Equipment* (IP Code) (IEC 529-1989) classifies the degree of protection to be provided by an enclosure.

The classifications are based on an international standard and are known as the International Protection Ratings or, more commonly, the **IP ratings**. The degree of protection for a given enclosure is signified by the letters 'IP' followed by two numbers. For example, a switch, supplied at low voltage, may be installed in the restricted zone near a bath or shower provided that it is protected by an enclosure with a degree of protection IP35.

The first number signifies the degree of protection against entry of solids. Referring to Table 19.1, degree of protection 3 is against the entry of solid objects larger than 2.5 mm. The second number signifies the degree of protection against entry of water. Again referring to the table, degree of protection 5 is against the entry of jets of water from all directions. You should study Table 19.1 to become familiar with the classifications of the degrees of protection under the IP rating system.

Figure 19.1 shows typical accessories in IP-rated enclosures.

Swimming and spa pools

A person immersed in the water of the pool itself is particularly susceptible to the effects of electric shock. It has been shown that very low potentials, which would usually be considered as safe (e.g. 10–15 V), if present as an electric field in the pool water are capable of causing muscular spasms and may lead to drowning.

Chapter 2, section 2.5 (Volume 1), covers electrical safety aspects in swimming pool and spa areas. The section also provides general safety rules for the benefit of pool owners and electricians concerning electrical wiring and equipment in a pool area.

For the purpose of *Clause 6.3*, part of the area surrounding a swimming or spa pool is defined as a 'swimming pool zone' or a 'spa pool zone' by *Clauses 6.3.2(a)* and *6.3.2(b)* respectively. The swimming pool zone includes the pool itself and the area measuring 3 m horizontally from the edge of the water and 1.2 m above maximum water level. It also includes the area 0.3 m below the lowest point of the inside of the water container of the pool. Study *Clause 6.3.2(a)(ii)* for variations where there is a solid barrier. A guide to the delineation of a swimming pool zone is given in Figure

Table 19.1 International protection (IP) rating assigned by manufacturers to their equipment enclosures to comply with international standards

First number	Degree of protection	Second number	Degree of protection of equipment against ingress of liquid
X	No specific protection.	X	No specific protection.
0	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	0 No protection.
1	1 Protection against accidental or inadvertent contact with live or moving parts inside the enclosure by a large surface of the human body, such as a hand, but no protection against deliberate access. Protection against ingress of large solid foreign bodies.	1	1 Protection against drops of condensed water. Drops of condensed water falling on the enclosure have no harmful effect.
2	2 Protection against contact with live or moving parts inside the enclosure by fingers. Protection against ingress of medium size solid foreign bodies.	2	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. (Drip-proof)
3	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	3 Protection against rain. Driving rain at an angle up to 60 degrees from the vertical shall have no harmful effect. (Rain-proof)
4	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	4 Protection against splashing. Liquid splashed from any direction shall have no harmful effect. (Splash-proof)
5	5 Complete protection against contact with live or moving parts inside the enclosure. Protection against harmful deposits of dust. Dust cannot enter in an amount sufficient to interfere with satisfactory operation of the equipment. (Dustproof)	5	5 Protection against water jets at low pressure. Water projected by a nozzle from any direction under stated conditions shall have no harmful effect. (Jet-proof)
6	6 Complete protection against contact with live or moving parts inside the enclosure and against the ingress of dust. (Dust-tight)	6	6 Protection against conditions on ships' decks, usually referred to as 'deck watertight' equipment. Water from heavy seas or high-pressure jets of water shall not enter the enclosures under prescribed conditions.
		7	7 Protection against immersion in water. It shall not be possible for water to enter the enclosure under stated conditions of pressure and time.
		8	8 Protection against indefinite immersion in water. Under specified pressure, it shall not be possible for water to enter the enclosure.

The second number in the classification indicates the degree of protection against ingress of liquids. There are 9 classes numbered from 0 to 8 and once again the higher the number the higher the degree of protection. A rain-proof luminaire, for example, with protection from finger contact within the enclosure would be IP 23, where the number 2 signifies the protection against finger contact and the number 3 signifies protection against rain. As a further example, a dust-tight luminaire which can be hosed down would carry the number IP65.



(a)



(b)



(c)



(d)

Fig. 19.1 A variety of accessories commonly available with the same degree of protection IP56: (a) metal-clad switched appliance inlet socket; (b) metal-clad DIN enclosure for residual current circuit breaker; (c) push-button emergency stop/start station; (d) light-operated 'sunset switch' GERARD INDUSTRIES

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Fig.

19.2, the pool zone being the area within the grey border.

The potential dangers associated with the electrical installation for swimming pools and spa pools are the same. The delineation of the pool zone is generally the same in both cases. However, for a spa pool, having a capacity of less than 5000 litres, the vertical plane for the pool zone is reduced from 3 m to 1 m from the inside edge of the water container of the pool.

Any wiring within the pool zone—supplying, for example, the filter pump motor or lighting—must be of the fixed type (see *Clause 0.5.98*). Copper- or aluminium-sheathed cables, served or unserved, are not permitted, nor is steel conduit. The wiring must be installed using elastomer-sheathed or thermoplastic-sheathed (TPS) copper cables or flexible cords enclosed in a sealed non-metallic enclosure (see *Clause 6.3.3.1*). For extra-low-voltage, insulated copper cable or flexible cords may be installed in the non-metallic enclosure.

Earthing and bonding conductors must be not less than seven-stranded, must be not less than 2.5 mm² for earthing conductors and 4 mm² for bonding conductors, and must be insulated (see *Clause 6.3.9.3*).

Access to a junction box or joints must be possible only by the use of tools. Unless the joint or junction box is within a structure prohibiting ingress of water or siphoning of water from the pool, then a minimum height of 0.45 m must be maintained above maximum water level or above any area where a person may stand (*Clause 6.3.3.1(b)*). The same 0.45 m clearance applies to a hoseproof socket (IP35), installed to permit the removal of equipment for servicing (see *Clause 6.3.6.2*, the requirements of which also apply to above-ground pools).

Where it is not considered necessary to remove equipment for servicing, all luminaires and fixed appliances,

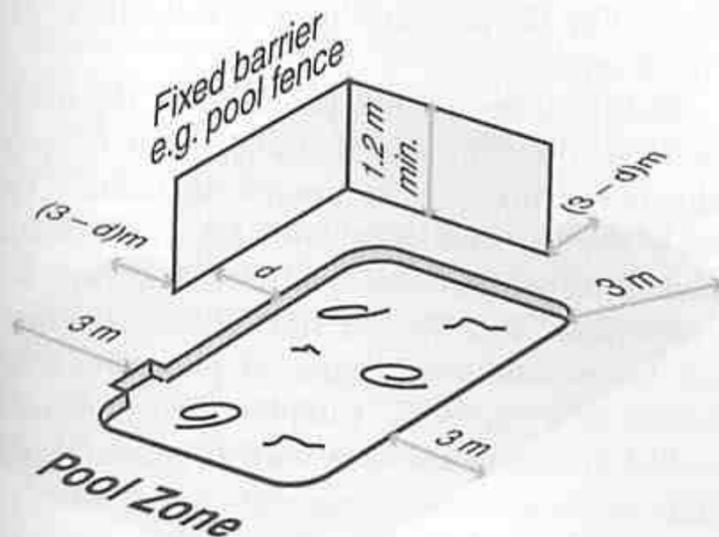


Fig. 19.2 Delineation of pool zone. Zone extends 1.2 m above maximum water level and 0.3 m below the lowest point inside the pool

such as filter pumps, must be permanently connected if they are located in the pool zone. Appliances such as filter pumps that are not immersed in the pool water but through which the pool water passes must be provided with degree of protection IP24. The supply to these appliances must be through a type I or II RCD or from an isolation transformer. All accessories used within the pool zone must provide degree of protection IP35, complying with AS 1939.

Switches, plug sockets and control equipment for a pool filter system are shown in Figure 19.3.

Table 3.3 of AS 3000 states the necessary clearances for aerial conductors and catenary-supported cables. Luminaires within the pool zone must be permanently fixed at not less than 2.5 m above maximum water level or a place where a person could stand.

Underwater lighting may be provided by the installation of the luminaires in adequately drained dry niches or by corrosion-resistant wet-niche luminaires (*Clause 6.3.8.1*). Supply to the lighting must be by one of the following methods:

- supply to **each** luminaire at low-voltage or extra-low-voltage (ELV) through its individual isolating transformer, with no conductors other than the secondary conductors of the transformer located in the wiring enclosure from transformer to luminaires, and no conductor of the secondary circuit earthed; or
- same system as above but using one transformer with the required number of separate secondary windings isolated from each other and from the primary windings, as specified by AS/NZS 3108: 1994 *Approval and Test Specification—Particular Requirements for Isolating Transformers and Safety Isolating Transformers* (see Fig. 19.4).

Where the multiple-earthed neutral (MEN) system of earthing is used, as it is in most supply areas, it is possible for a rise in the neutral potential to be

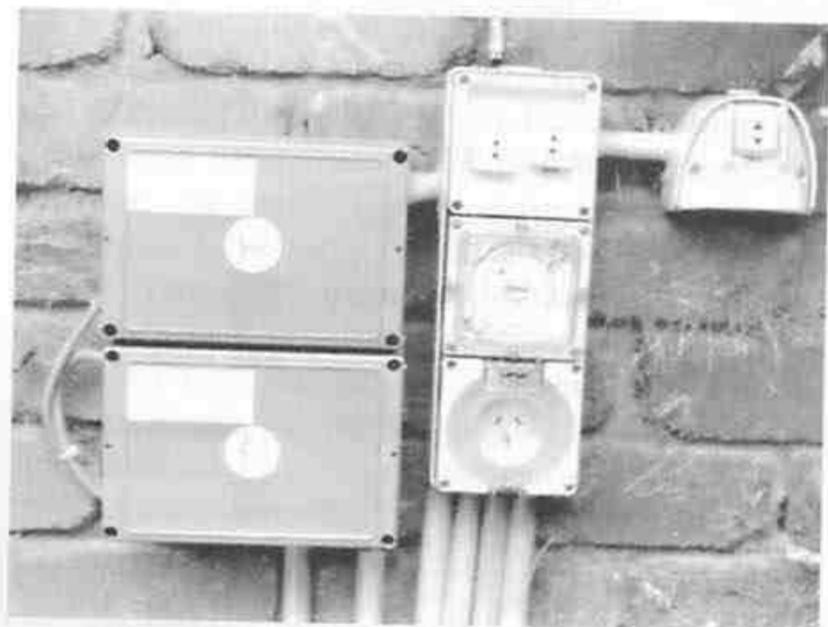
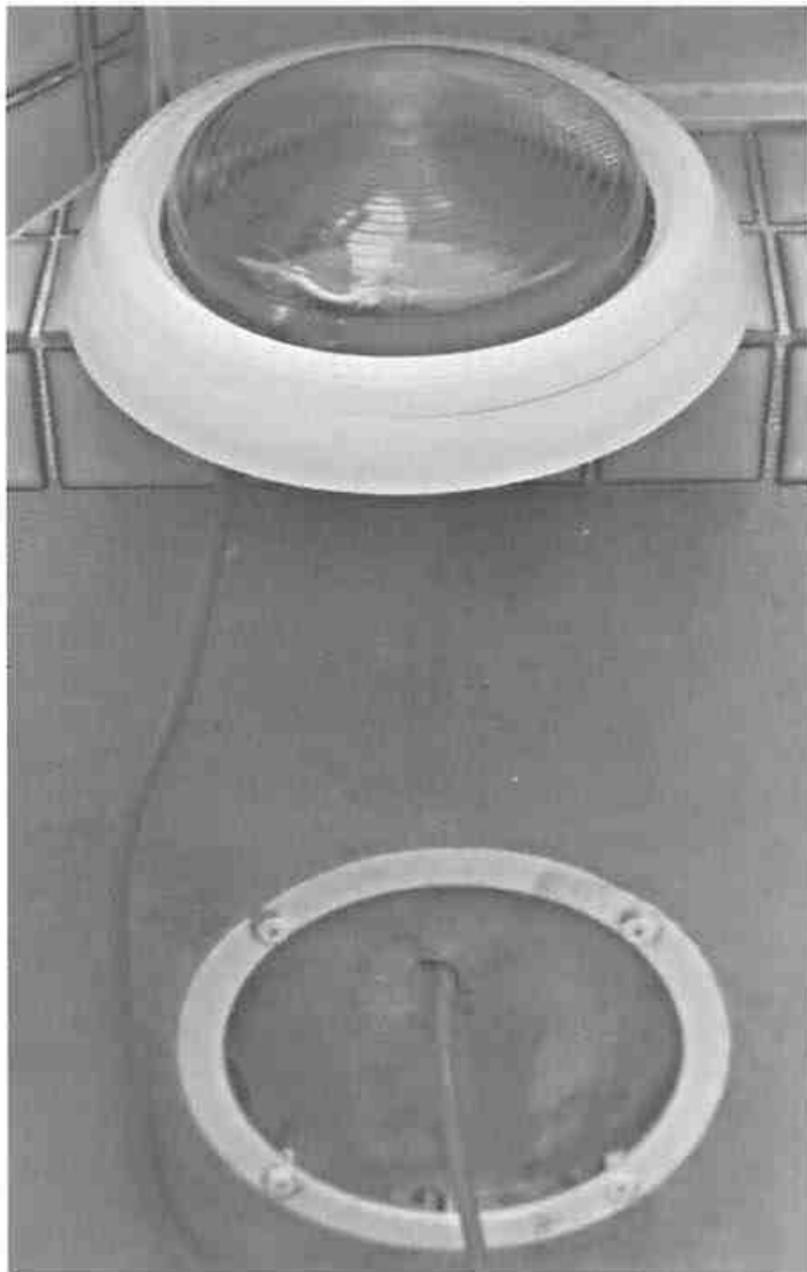


Fig. 19.3 Switchgear for a pool filter system installed outside the pool zone



(a)

Fig. 19.4 Wet-niche luminaire: (a) during installation—note that disconnecting the cable at the supply end will allow the replacement of a lamp without the need to drain the pool; (b) rear view—the nameplate details show that it is to operate at extra-low-voltage and is provided with degree of protection IPX8

impressed on the pool. This may occur with unbalanced loads, a fault, or even long neutral feeds. The problem could be overcome by effectively **bonding all metal parts** (e.g. concrete reinforcing, water pipes, ladders, metal drains, luminaire frames) to earth and to each other. A swimmer would then be within a cage (the so-called 'Faraday cage'), all parts of which would be at the same potential, and hence no voltage difference should be present within the pool. *Clause 6.3.9.2* specifies this as being an acceptable method. There are, however, practical difficulties, as the cooperation of contractors other than the electrical contractor is necessary.

The alternative offered by *Note 1* of the above clause is a method often used to isolate exposed metal parts, by using an ELV supply through a double-wound transformer. This method is mandatory for luminaires or appliances in contact with pool water.

Baths, showers and fixed water containers

Clause 6.4 sets out the restricted zones for switches, socket outlets and other accessories in damp situations



(b)

near baths, showers and water basins, and includes diagrams as a guide to the application of the zones delineated in the clause.

In the diagrams, which should be carefully studied, the restricted zones are shaded and include the volume contained by the projected areas of the surfaces shown in the diagrams.

Socket outlets are not permitted in the restricted zone unless they are installed in a cupboard. In confined bathrooms it may not be possible to locate a switch outside the restricted zone. Switches in the restricted zone near baths or showers must be enclosed with degree of protection IP35. Near a sink or washtub, switches must be enclosed with degree of protection IP34 or installed in a cupboard. Lampholders and luminaires installed in a restricted zone must comply with *Clause 6.4.5*.

Fountains and water features

In addition to the general requirements of *Clause 6.2*, fountains and water features with depth of water exceed-

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ing 0.5 m must comply with the requirements of *Clause 6.5*. Here the degree of protection for equipment installed underwater is IPX8 and IP34 is specified for enclosures up to 2.5 m above the feature. The supply can be an earthed system protected by a type II 30 mA RCD or unearthed through an isolation transformer.

Wiring systems for these installations must be unaffected by chemicals used to treat the water. Typically this will be a suitable thermoplastic- or elastomer-sheathed cable and where necessary installed in a wiring enclosure of similar properties. The wiring enclosure and joints in cables must be sealed to prevent the entry of moisture.

As with all damp situations, the general intention of the requirements is to reduce the risk of electric shock associated with water and prevent deterioration of the electrical installation due to corrosion.

Controlled-atmosphere rooms

In the case of a controlled-atmosphere room, only the wiring related to the equipment within the room is permitted in the area. Freezing chambers, coolrooms and chilling rooms are examples of atmosphere-controlled rooms. In these situations, damp is caused mainly by condensation. On the other hand, an air-conditioned area at below ambient temperature but controlled to prevent the condensation of water vapour is classified as a damp situation only at the points where the wiring enters or leaves the space.

The recommended approach to an electrical installation is to keep equipment out of damp situations. If this is not possible, the equipment within the area must be of a suitable type; some suitable devices are shown in section 5.4 of Chapter 5 (Volume 1). The installation in these areas must comply with *Clause 6.6*. Sealing, in the form of non-setting caulking compound, must be provided within a wiring enclosure where it enters the controlled space and at the entry to equipment. Enclosures that are not permanently sealed must be provided with drainage to prevent the accumulation of moisture. Bulkhead-type fittings are common for incandescent lamps, and special units are available for fluorescent luminaires, where:

- all components are within the fitting and at the top;
- sealing and provision for water drainage are provided;
- the points of entry of conductors to the fitting are sealed;
- clear covers with gaskets are fitted over the tubes to maintain tube temperature and light output.

Motors, such as fan motors, must be of the totally enclosed type. Splashproof types may be used where they are not subject to direct hosing; and, in common with all other equipment to be used in a damp situation, the wiring entry must be sealed and precautions taken with regard to water accumulation within the motor.

General hosing areas

The processing area of many industries must be cleaned at regular periods as a requirement of health and safety regulations. The cleaning may 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, to mention a few cases.

Electrical equipment installed within a general hosing area must be enclosed with degree of protection IP36, as specified in *Clause 6.7.2*. Conduits in the area must be of corrosion-resistant steel, such as galvanised or thermoplastic type. Inspection fittings need to be sealed to prevent the entry of water from the hosing-down activities.

19.3 Areas in which electromedical equipment is used

In locations where medical treatments using electrical equipment are administered, special precautions need to be taken with electrical installations to provide patients with additional protection against electric shock. Circuits carrying higher currents, such as submains, also can interfere with electrical equipment.

Many medical (and dental) procedures involve the use of electrically operated equipment for the purpose of diagnosis, therapy or monitoring patients. This equipment is generally known as 'electromedical equipment'.

Some medical procedures require a direct connection of low resistance between the patient and electromedical equipment, with probes attached to various parts of the body. Typical of these procedures is the determination of a patient's heart function by an electrocardiogram, as shown in Figure 19.5. 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.



Fig. 19.5 An electrocardiogram requires the direct connection of probes between the electromedical equipment and the patient

The specific areas in which the electrical installation requires consideration are those where:

- a patient is connected to electromedical equipment such that the impedance of the skin is reduced but there is no direct contact with the heart. This is known as **body-type procedure**;
- procedures involve contact with the heart by an electrically conductive medium. This is known as a **cardiac-type procedure**.

The requirements for electrical installations in the areas where these procedures are carried out is covered by the Australian Standard *Electrical Installations—Patient Treatment Areas of Hospitals, and Medical and Dental Practices* (AS 3003). This standard is not a requirement of the *SAA Wiring Rules*, but may be called up by a regulatory authority. At the time of writing (1997), the standard was under review.

The main components of an electrical installation in a medical treatment area that attract special attention are:

- protection of circuits supplying equipment and outlets in the treatment area;
- indication and monitoring of fault and hazard currents;
- location of protection and monitoring equipment;
- number of outlets (for connection of electromedical equipment) per circuit;
- earthing and equipotential bonding arrangements in cardiac treatment areas.

Protection of circuits supplying equipment and outlets

Generally, circuits supplying fixed electromedical equipment or socket outlets that may be used for electromedical appliances must be either supplied through an isolation transformer or protected by a type I residual current device (RCD; see Chapter 14). Permanently connected equipment must also be controlled by an isolator operating in all live conductors. This may apply also to circuits enclosed in metallic conduit that pass through a cardiac-type procedure area.

Indication and monitoring of fault and hazard currents

In areas where electromedical equipment is used, socket outlets supplied through an RCD must be fitted with an indicator to show that power is available.

The current that flows from any isolated supply to earth (known as 'hazard current') must not exceed a preset value. Isolation transformers must be provided with a line isolation monitor (LIM) that continually checks the hazard current. When the hazard current exceeds the preset value the LIM activates an alarm. A typical LIM is shown in Figure 19.6.

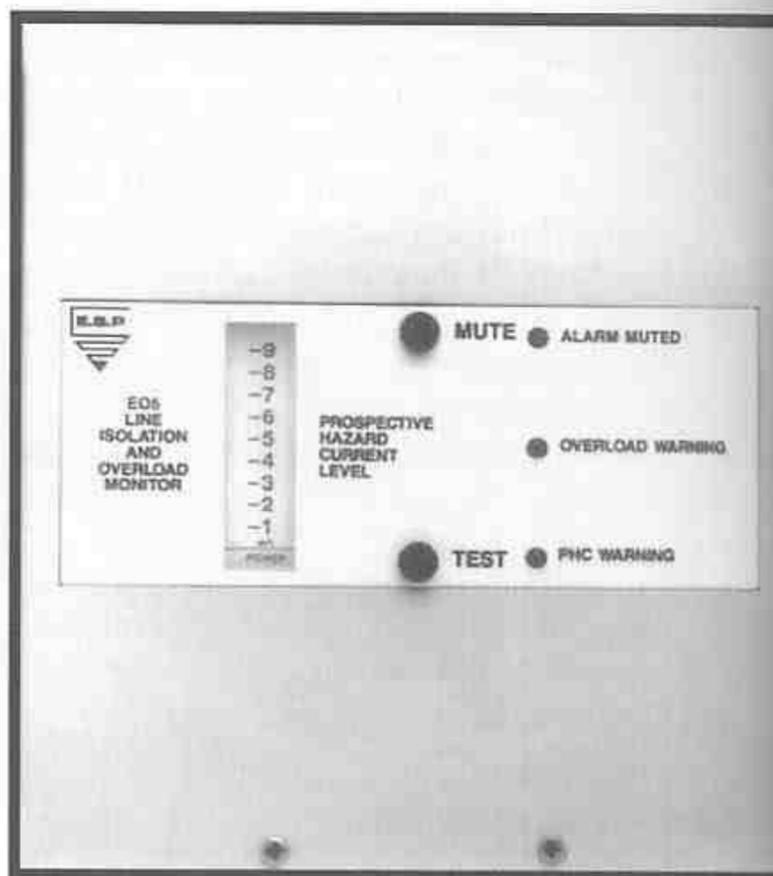


Fig. 19.6 Line isolation monitor (LIM) used to monitor hazard current from an isolated source supplying electromedical equipment GERARD INDUSTRIES

Location of protection and monitoring equipment

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 an isolation transformer indication and a LIM. Figure 19.7(a) shows such a panel, which is typically installed adjacent to a hospital bed.

Number of outlets per circuit

AS 3003 generally stipulates the minimum number of socket outlets for each patient location and the maximum number of socket outlets per circuit. The standard also limits the number of points supplied from an isolation transformer.

Earthing arrangements in cardiac treatment areas

In addition to the earthing requirements of AS 3000, equipotential earthing is required in a designated area (known as the 'patient equipotential area' or EP area; see Fig. 19.7(b)) where cardiac-type procedures are performed.

Equipotential earthing involves earthing equipment and the exposed metal of circuits supplied through an

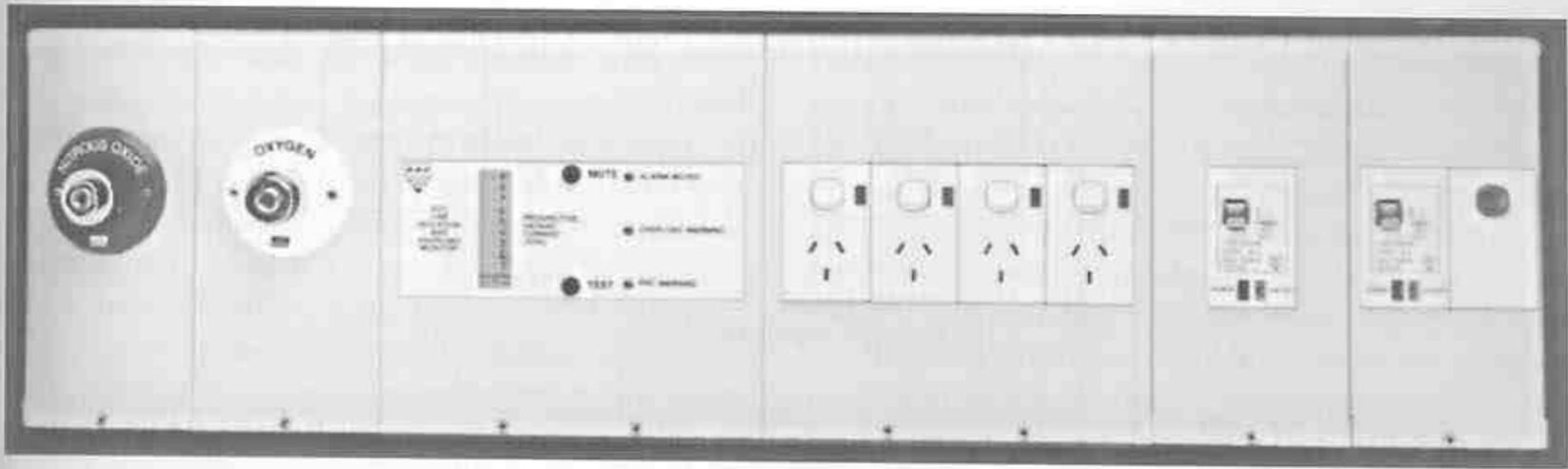


Fig. 19.7(a) A combination panel that includes socket outlets, supply-available indication, and line isolation and overload monitoring

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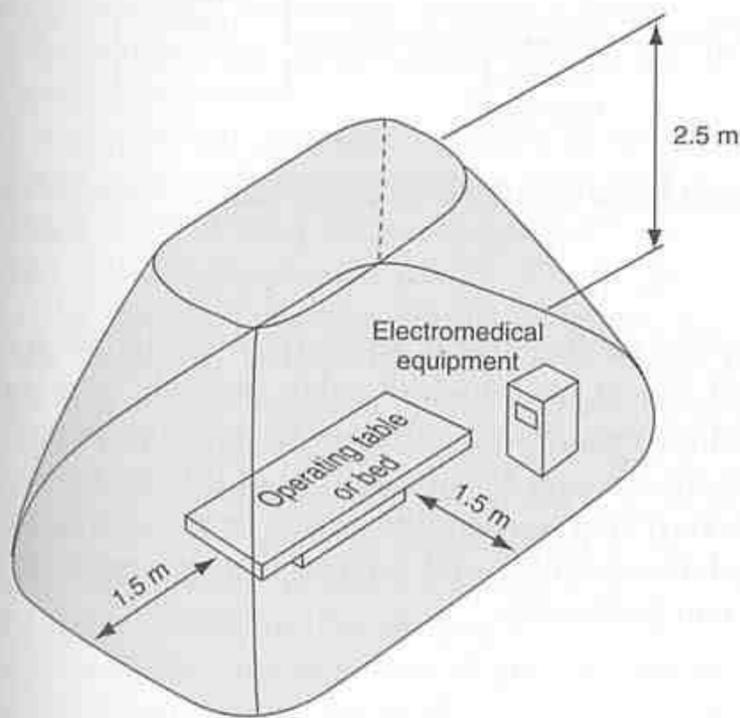


Fig. 19.7(b) Patient equipotential area

RCD or from an isolation transformer, by an earthing conductor with a resistance not exceeding 0.1Ω . This earthing conductor is known as the 'EP bus' (equipotential busbar). Equipment and exposed metal not protected by an RCD or supplied from an isolation transformer must be earthed separately, via earthing conductors connected to a single connection on the EP bus known as the 'EP junction'. The resistance of the earthing conductors must not exceed 0.01Ω . The return earthing conductor is connected from the EP junction to the normal MEN system (see Fig. 19.7(c)). Paragraph A2 of AS 3003 provides guidance in selecting earthing conductors that meet the low resistance requirements for the earthing system.

As mentioned earlier, circuits supplying electromedical equipment must be supplied through an isolation transformer or protected by a type I (10 mA) RCD (see Fig. 19.7(d)). The choice will depend on either the medical procedure or the type of equipment that will be used in the medical treatment area. With RCD protec-

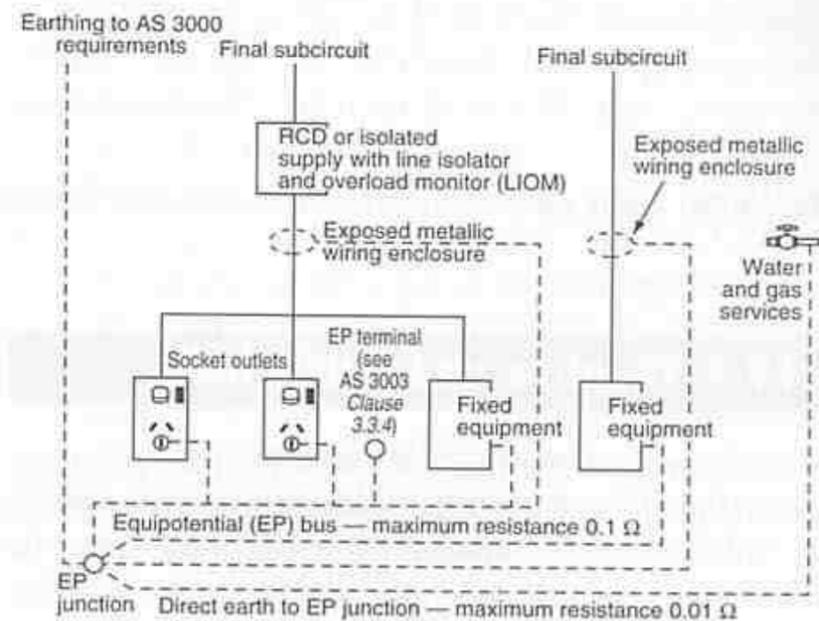


Fig. 19.7(c) Equipotential earthing in a cardiac-protected area

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tion, supply is interrupted when the RCD detects a fault, whereas an isolated supply is not. When a fault occurs on an isolated supply, an alarm indicates the potential risk of electrocution.

An isolation supply consists of an isolating transformer that provides a power source with electrical isolation from earth, plus a suitable monitor. Isolated supplies are normally used where open-heart procedures are carried out. They are also used where an uninterrupted supply is required even if an electrical fault should occur. This category of use is normally confined to areas where life-support equipment is in use. All other locations within cardiac-protected areas can be serviced by a type I RCD.

An electrician undertaking installation or maintenance work in medical treatment areas should consult AS 3003 for details of specific requirements. The appendixes of this standard provide information and methods for the implementation of the various sections and clauses. Manufacturers of equipment for use in medical treatment areas can also be a useful source of information.

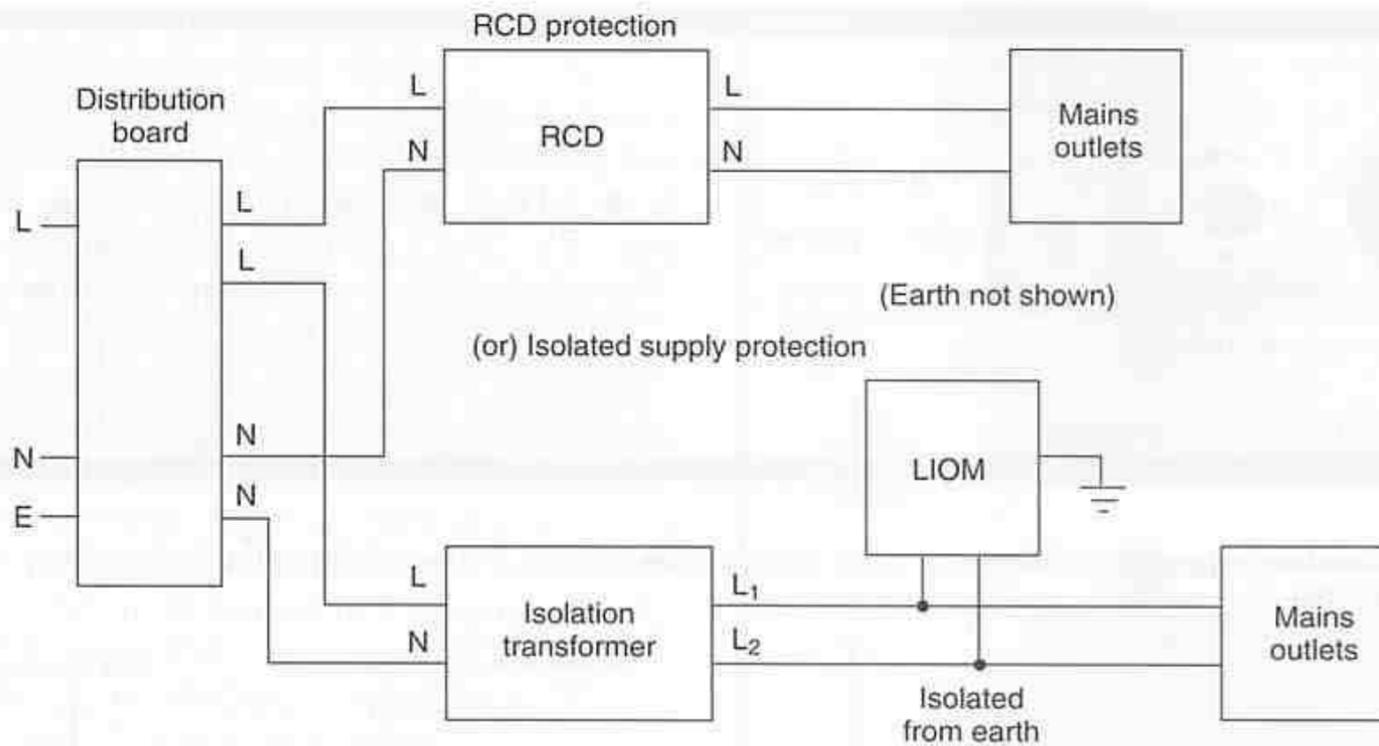


Fig. 19.7(d) Risk of electrocution may be minimised in medical treatment areas by the use of an RCD or an isolated supply GERARD INDUSTRIES

19.4 Theatres and public halls

Rules relating to theatres and public halls are given as a general guide, and any other codes or the requirements of the authorities administering the Acts must be observed. Note that, because of public access and fire risk, where there are surface-mounted cables within 2.5 m of the ground, floor or platform, then the wiring system to be employed is restricted to the following types:

- cables enclosed in steel conduit or other approved enclosure
- armoured cables
- MIMS cables.

However, other types that provide security against fire and damage equivalent to the above types may be used.

For wiring other than surface-mounted, the following are approved (note that any of the cables listed above may also be used):

- TPS cables
- thermoplastic-insulated cables in non-metallic conduit
- metallic-sheathed cables.

Reference should be made to Volume 1, Chapter 9 (on metallic and non-metallic conduit systems) and to Chapter 10, where a comprehensive description of metallic and non-metallic sheathed fire-performance cables is provided. The fire-performance characteristics of cable insulation are described, and some guidance is given for the installation of fire-retardant cables.

Note the rules restricting access to most switchboards and controls to authorised persons only. Note also the fireproofing requirements and provisions for the control of exit, entrance and auditorium lighting, to

prevent public panic in an emergency. Fire risk is the ever-present hazard where public assembly takes place, and the requirements of *Clause 6.8* are aimed at providing the safe and effective control of lighting and appliances, proper locations for switchboards and equipment, and the guarding and arrangement of equipment to minimise fire risk.

19.5 Outdoor living and recreation areas

Today, outdoor activities such as camping and boating involve the supply and use of electricity from the mains supply for the convenience of the consumer. Although the consumer may regard the supply of electricity under these circumstances as a temporary arrangement, the electrical system must be installed to maintain the highest standards of safety and effective operation.

The *SAA Wiring Rules* call up a number of separate standards that deal with installations related to recreational activities:

- *Caravan Parks* (AS 3001), called up by *Clause 6.11*;
- *Shows and Carnivals* (AS 3002), called up by *Clause 6.12*;
- *Boating and Marinas* (AS 3004), called up by *Clause 6.13*;
- *Tent Installation Areas* (AS 3005), called up by *Clause 6.14* of AS 3000.

Generally these standards cover two areas: the site installation; and the installation within, say, the caravan, boat or carnival ride itself.

The approved methods of supply to individual

camping and caravan sites are by underground or aerial wiring to comply with AS 3000, together with some additional requirements. For example, underground wiring can be category A or B installed at a depth of not less than 0.6 m, but must be covered with 100 mm of concrete. Alternatively, the wiring can be installed at a depth of not less than 1.5 m without additional protection. Similar installation requirements apply to supply to temporary sites for shows and carnivals.

In marinas, boats may be connected to the shore supply either directly or through an isolation transformer. It may be necessary to bond metallic parts of the boat to the system earthing or to one secondary lead of an isolation transformer, depending on the connection arrangement used. The various arrangements for obtaining low-voltage shore supply are detailed in AS 3004, *Appendix C*.

Acceptable wiring systems installed on the jetty or pontoon portion of a marina are those unaffected by the corrosive action of water, such as thermoplastic-insulated copper cables in non-metallic conduit. Overhead wiring or cables with aluminium conductors are not permitted. Where the wiring system is installed from shore or a fixed jetty to a pontoon, a flexible section must be included to allow for tidal movement (see Fig. 19.8).

The maximum demand of mains and submains for these installations is generally determined by one of the methods specified in AS 3000, in consultation with the local energy distributor. For the purpose of calculation, the standards for caravan parks and for marinas specify the contribution to the demand by socket outlets supplying caravan sites or boat connections.

When selecting cables for these types of installations, voltage drop will be a major factor in determining conductor size because of the long route lengths of the circuits (see Chapter 16). In caravan parks and marina installations, the voltage drop must not exceed 5 per cent measured from the consumer's terminals to any point or socket outlet in the installation. In show and carnival installations, the voltage drop must not exceed 4 per cent.

Figure 19.9 shows distribution posts for supplying camp sites on a recreational camping ground. Each post is equipped to supply four sites. The distribution board supplying each of the distribution posts is located at the left end of the amenities building seen in the background. In this example, although the maximum demands are the same, in order to satisfy voltage drop requirements the sizes of the submains supplying each distribution post vary from 16 mm² for the shortest run to 35 mm² for the longest run.

In caravan parks and tent areas where the MEN system of earthing is used, posts that support distribution boards may be regarded as outbuildings and separate MEN earthing may be employed, as specified in AS 3000, *Clause 5.9.4*. In marinas, separate MEN earthing is not permitted.

The approved method of connecting supply to a caravan, tent or boat is by socket outlet and cord extension set. Each socket outlet must be protected by a circuit breaker, and RCD protection is required by legislation in some areas. The socket outlet must be a three-flat-pin type rated at not less than 15 A. Requirements also specify the location, control and protection against damage of socket outlets for this purpose.



Fig. 19.8 The wiring system installed on this public marina is circular TPS cable. Note the additional section of cable, enclosed in black PVC flexible conduit, from the ramp to the pontoon section to allow for tidal movement



Fig. 19.9 Recreational camping ground showing distribution posts for supplying camp sites. Note the long distances from the distribution board at the left end of the amenities building to each distribution post

A typical arrangement is to provide centrally metered distribution posts, each supplying a number of sites as shown in Figures 19.10(a) and (b). An alternative arrangement, shown in Figure 19.10(c), is to provide a switchboard together with individual metering and distribution facilities, to service two caravan sites.

An approved method of providing socket outlets for the supply of electricity to pleasure craft at a modern marina is shown in Figures 19.11(a) and (b). The combined MCB (miniature circuit breaker)/RCD circuit protection devices and socket outlets at each distribution centre are protected from the weather and against mechanical damage by lockable moulded covers. The distribution centre has an outlet on each face, enabling it to supply four separate craft at the one time.

The cord extension set used to supply installations related to recreational activities must comply with the appropriate standards in regard to type, rating and length. The extension socket of the cord extension set is to be connected to an appliance inlet fitted to the caravan or boat. The appliance inlet must be of the specified type and protection rating and comply with installation requirements. In tent installations where more than one appliance is to be used, the extension cord set is to be connected to an approved outlet box.

The standards also set out requirements for the installation within a caravan or boat and for the arrangement of supply to an annexe or tent that is part of a single caravan site.



Fig. 19.10(a) Distribution post for servicing four camp sites



Fig. 19.10(b) The outlets and their circuit breakers are protected from the weather and against mechanical damage by being mounted on the underside of the overhanging cover. This equipment was installed before RCD protection became a requirement in some states

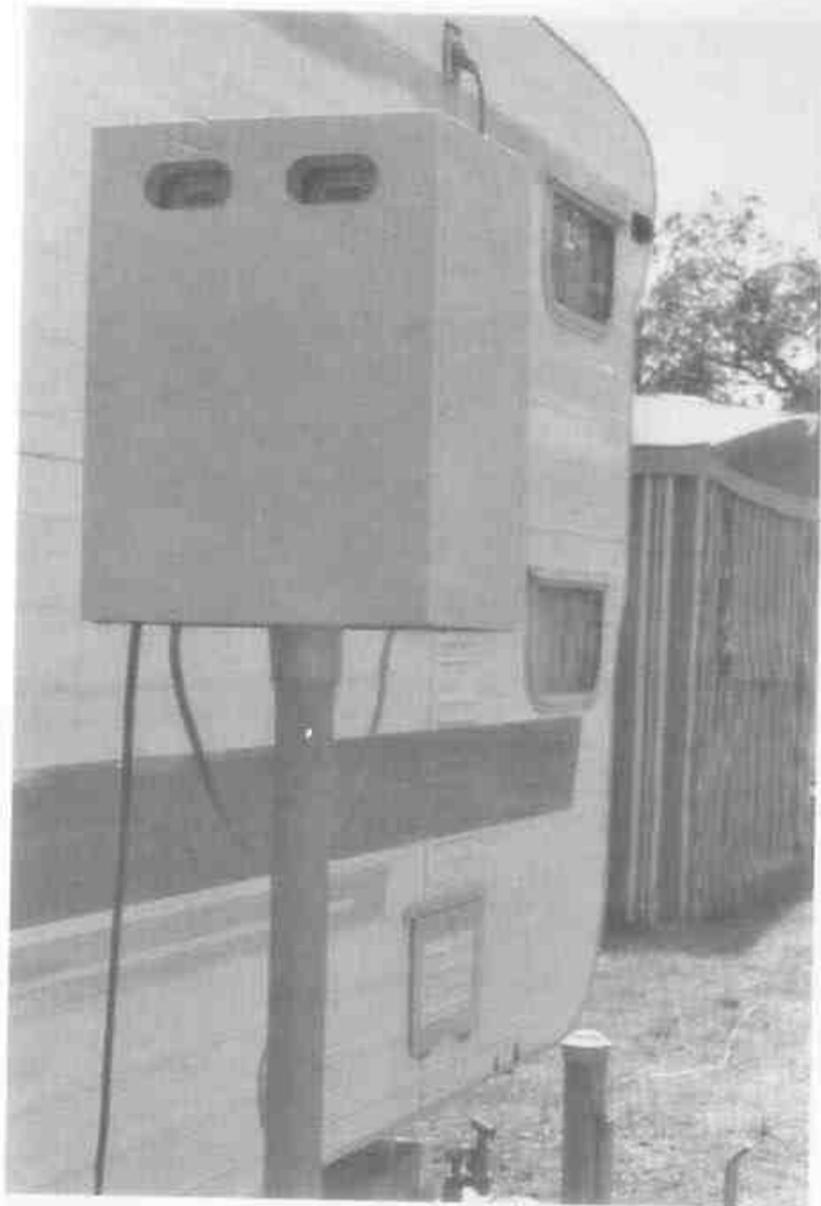


Fig. 19.10(c) Switchboard with metering and control facilities to service two caravan sites



Fig. 19.11(a) Modern marina with distribution centres for the supply of electricity and fresh water to moored pleasure craft



Fig. 19.11(b) Outlet protected by a combined RCD/MCB for connecting shore supply to a moored boat

An electrician, before working on these types of installations, must become completely familiar with the appropriate standard and with any other requirements under state legislation. The energy distributor should also be consulted to ensure that the installation will comply with relevant service rules.

19.6 Construction 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 *SAA Wiring Rules, Clause 6.15*, calls up AS/NZS 3012—1995 *Electrical Installations—Construction and Demolition Sites* as a guide. This standard gives a broad definition for construction sites to include excavation, civil work, new building work, building extensions, demolition and temporary buildings on these sites, such as site offices. In some areas this standard may be mandatory under local safety regulations, while in other areas a 'code of practice', similar to the Standards, is used. As with all electrical work, the electrical tradesperson should make sure he/she is familiar with the application of Standards and local requirements.

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 fixed 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 2.5* of AS 3000. However, AS/NZS 3012 assigns a rating to general-purpose outlets (GPOs) that is to be applied when the maximum demand is determined by calculation.

Every final subcircuit of fixed 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 type I or II 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.

The main switchboard for the construction site must be located at street level and protected from damage that may be caused by the construction activities. It is common for distribution boards to incorporate socket outlets for the connection of power tools and other portable appliances. Each distribution board must incorporate at least one 15 A socket outlet.

Careful consideration should be given to the placement of these distribution boards and socket outlets generally, as 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. The exception to this requirement is for work in stairwells, in lift shafts and on formwork and the like (see Fig. 19.12).

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's 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 the Australian Standard *In-Service Safety Inspection and Testing of Electrical Equipment* (AS/NZS 3760: 1996). All testing and corrective actions 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: 1996 *In-Service Safety Inspection and Testing of Electrical Equipment*.

19.7 Lifts and hoists

The regulatory authority responsible for the safe operation of lifts and escalators requires such installations to comply with the *SAA Lift Code* (AS 1735). An electrician installing lift equipment should endeavour to become familiar with the electrical requirements of this code. These requirements are in addition to compliance with the *SAA Wiring Rules*. The Rules give a limited cover of wiring systems supplying lifts and in lift shafts as well as the protection, control and arrangements of the lift supply.

The *SAA Lift Code* refers to the fire and mechanical performance classification of wiring systems given in AS/NZS 3013: 1995 *Electrical Installations—Classification of the Fire and Mechanical Performance of Wiring Systems* to specify wiring systems suitable for lift installations.

A modern control panel using programmable logic controllers (PLCs) for the multifunctional control of a low-cost, low-rise electrohydraulic lift installed in 1991 is illustrated in Figure 19.13(a). Any emergency stop device cannot depend on the operation of a PLC as the

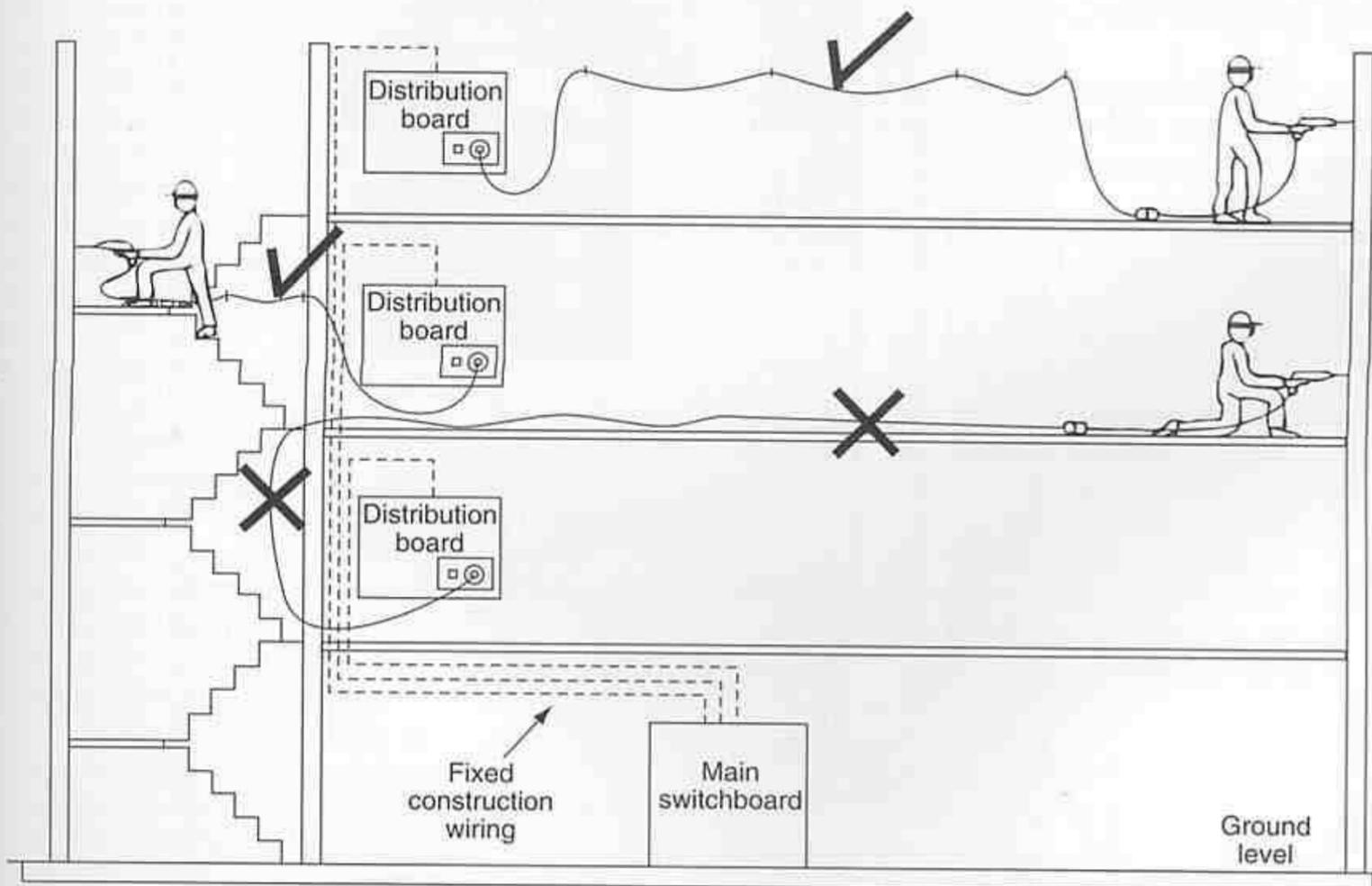
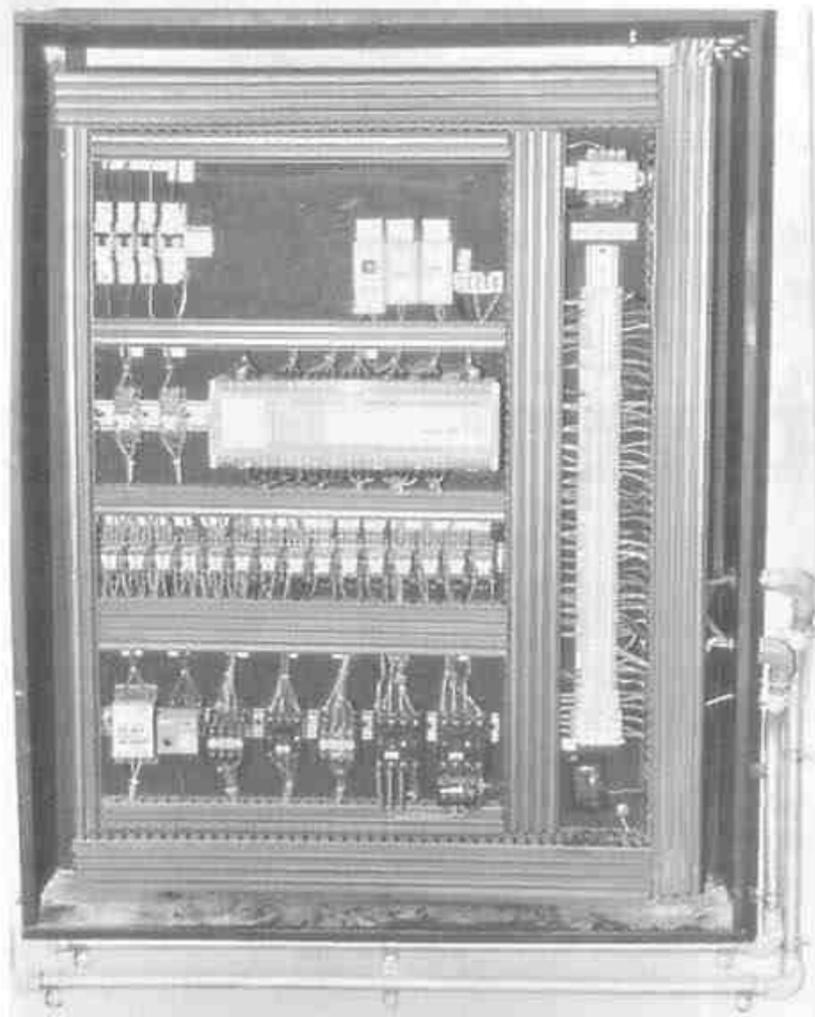
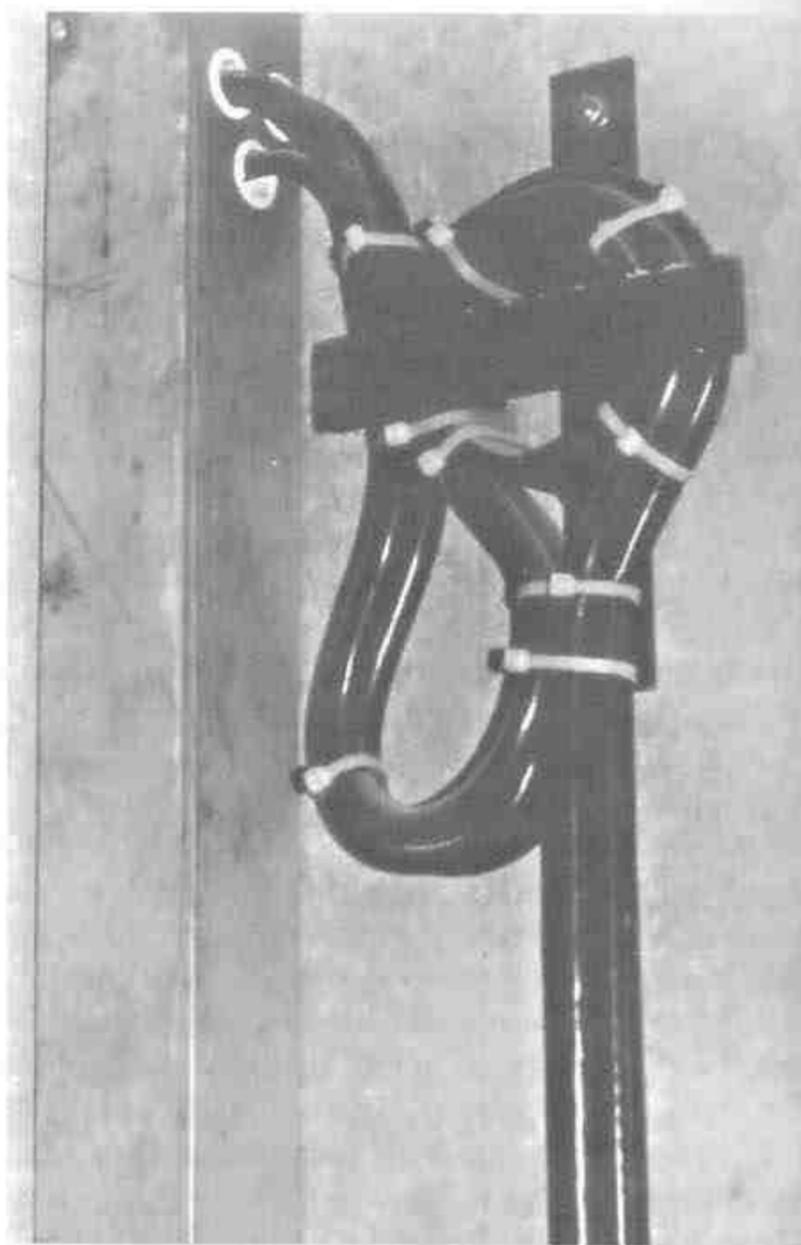


Fig. 19.12 Use of flexible cords on the construction of a multilevel building. AS/NZS 3012 requires flexible cords to be supported off the floor where they are more than 10 m from the appliance that they supply and where they are out of view or across passageways



(a)



(b)



(c)

Fig. 19.13 Electrohydraulic lift installation: (a) control panel using PLCs for multifunctional control of the lift; (b) flexible travelling cables emerging from steel trunking in the lift shaft; (c) distribution board installed in accordance with Clause 2.19.4.1

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only means of isolation, and this of course includes a lift installation. Refer to *Note 2 of Clause 4.1.6 of AS 3000*.

Under emergency conditions a lift may be required to operate for the evacuation of people from a building or to prevent people from being trapped in the lift between floors. Therefore, the wiring system supplying the lift and in the lift shaft must be able to operate under adverse conditions, such as in a fire. Refer to Chapter 10 in Volume 1, where a comprehensive description of metallic and non-metallic sheathed fire-performance cables is given. The fire-performance characteristics of cable insulation are described, and some guidance is given for the installation of fire-retardant cables.

Copper-sheathed MIMS cable and cable in metallic enclosures are typical of approved wiring systems. *Clause 2.19.7 of the SAA Wiring Rules* specifies the wiring systems suitable for supplying lifts. Supply wiring to the control panel of Figure 19.13(a) and for fixed wiring in the lift shaft is single-insulated PVC cable in steel

conduit, used in conjunction with steel trunking. The classifications of AS/NZS 3013 do not cover flexible travelling cables shown in Figure 19.13(b).

The supply to lifts is required to be controlled by a main switch, appropriately marked, and separate from the installation main switch. *Clause 2.19.4*, and in particular *Figure 2.1*, in the *SAA Wiring Rules* provides details of the supply arrangements and control for installations that include lifts.

The distribution board shown in Figure 19.13(c) is fed directly from the supply side of the general installation main switch, in accordance with *Clause 2.19.4.1*. The fan control panel mounted on the wall adjacent to that on which the distribution board is mounted controls the operation of a thermostatically controlled cooling fan for equipment housed in the lift control room. It incorporates a high-temperature alarm and an alarm mute button. An auto/manual button is installed to provide manual or automatic control of the fan as required.

SUMMARY

- In addition to the general requirements with which all electrical installations must comply, there are some areas where additional precautions need to be taken to ensure safety and the intended use of the area.
- Areas where moisture is likely to be present are known as 'damp situations', and include:
 - swimming and spa pools
 - baths, showers, and other fixed water containers
 - fountains and water features
 - controlled-atmosphere rooms
 - general hosing areas.
- Enclosures for electrical equipment must provide protection against the entry or ingress of solids and liquids. The various degrees of protection that are afforded by an enclosure are specified by the International Protection Ratings, known as the IP ratings, for an enclosure (see Table 19.1).
- Part of the area surrounding a swimming or spa pool is defined as the pool zone (see Fig. 19.2).
- Special requirements covering the electrical installation associated with swimming and spa pools, particularly within the pool zone, apply to:
 - wiring systems
 - earthing and equipotential bonding
 - IP rating of enclosures
 - luminaires
 - supply and protection arrangements.
- *Clause 6.4* sets out restricted zones for the installation of accessories near baths, showers and water basins.
- Electrical installations associated with fountains and water features must comply with special requirements applying to:
 - IP ratings of enclosures
 - wiring systems
 - supply and protection arrangements.
- Requirements related to electrical installations in controlled-atmosphere rooms deal with damp caused mainly by condensation.
- In 'hose-down' areas electrical systems must be protected against the entry of water and against the effects of corrosion.
- In areas where medical treatments are administered using electrical equipment, special precautions need to be taken with the electrical system to provide patients with additional protection against electric shock.
- The main components of an electrical installation in a medical treatment area that require special attention are:
 - protection of circuits supplying equipment and outlets in treatment areas
 - indication and monitoring of fault and hazard currents
 - location of protection and monitoring equipment
 - number of outlets per circuit
 - earthing and equipotential bonding arrangements in cardiac treatment areas.
- The special requirements for electrical installations in theatres and public halls are aimed at providing the safe and effective control of lighting and appliances, proper location for switchboards and equipment, and the guarding and arrangements of equipment to minimise fire risk.
- The electrical installations associated with outdoor activities such as camping and boating must maintain the highest standards of safety and effective operation. Standards dealing with such installations include:
 - *Caravan Parks* (AS 3001)
 - *Shows and Carnivals* (AS 3002)
 - *Boating and Marinas* (AS 3004)
 - *Tent Installation Areas* (AS 3005).
- Generally these standards cover two areas: the site installation; and the installation within the caravan, boat or carnival ride itself.

- The special requirements for these installations that apply are:
 - calculation of maximum demand for mains and submains
 - distribution and protection arrangements
 - wiring systems
 - socket outlets.
- In caravan parks and marinas, circuits supplying distribution points are likely to have long route lengths. This makes voltage drop a major consideration when selecting cables for these circuits.
- The special requirements for electrical installations on construction and demolition sites are specified in AS/NZS 3012, and cover:
 - wiring systems and methods
 - distribution and protection arrangements
 - socket outlets
 - location of equipment
 - testing in accordance with AS/NZS 3760—1996.
- The regulatory authority responsible for the safe operation of lifts and escalators requires such installations to comply with the *SAA Lift Code* (AS 1735).



REVIEW QUESTIONS

Where the answer to a review question is numerical or requires reference to the SAA Wiring Rules, the answer is given at the back of the book. These questions are marked ★.

1. Name the areas of electrical work covered by Section 6 of the *SAA Wiring Rules*.
 - ★ 2. What is meant by a 'damp situation'?
 3. What Australian Standard classifies the degree of protection provided by an enclosure?
 4. Under what environmental conditions can a switch marked IP56 operate?
 5. Why are there special requirements for the electrical installation in the vicinity of a swimming pool?
 - ★ 6. What is meant by the 'swimming pool zone'?
 - ★ 7. What is the minimum size of conductor permitted for equipotential bonding in a swimming pool zone?
 - ★ 8. What are the requirements for the installation of luminaires in a swimming pool zone?
 - ★ 9. What is meant by the 'restricted zone' in a bathroom?
 - ★ 10. Is it permissible to install a light switch in a restricted zone adjacent to a shower?
 - ★ 11. Name the wiring systems approved for installation in a coolroom.
 12. Describe an electromedical treatment area.
 13. Why is it necessary to apply special precautions to electrical installations in electromedical treatment areas?
 - ★ 14. Which Australian Standard covers the requirements for electrical installations in electromedical treatment areas?
 15. What is the purpose of a line isolation monitor?
 - ★ 16. List the additional requirements for electrical installations in theatres and public halls.
 - ★ 17. Name the standards that cover the additional requirements for electrical installations in caravan parks, boating marinas and tent areas.
 18. Why is a voltage drop likely to be a major factor in selecting cables for a camping area installation?
 - ★ 19. What Australian Standard covers electrical installations on construction sites?
- Note:* Answers to questions 20, 21 and 22 will require reference to AS/NZS 3012.
- ★ 20. On a construction site, what is meant by 'fixed construction wiring'?
 - ★ 21. Describe the restrictions to the use of extension cords on a construction site.
 - ★ 22. What are the testing inspection requirements for the electrical installation and equipment on a construction site?
 - ★ 23. Name the Australian Standards that apply to the installation of lifts.
 - ★ 24. Is it permissible to install a rigid non-metallic wiring system in a lift shaft?
 - ★ 25. Describe the permitted arrangement for the supply to a lift.