



Bill Atkinson
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Electrical Installation Designs

Fourth Edition

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Fourth Edition

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Deceased

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Electrical Contractors' Association, UK

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About the Authors

Roger Lovegrove's extensive experience in the electrical contracting industry spans over 50 years. He served an apprenticeship, worked as an electrician and contracts engineer and then managed his own business for 18 years. Having left electrical contracting, he became a consultant specialising in inspecting, testing and surveying electrical installations. For a number of years he delivered lectures for ECA and IIE on various topics associated with *BS 7671*, the IEE Wiring Regulations. He is a Fellow of the IET and serves on the joint IET/BSI Wiring Regulations Committee. For many years an ECA member, he has served on the association's technical committee. Also, he has represented UK electrical contracting interests on International and European electrical installation standards working groups.

Gary Gundry is one of the UK's leading electrical safety trainers and presenters. Working at the Electrical Safety Council (ESC), he primarily produces technical guidance material for the electrical industry and safety literature for consumers. He also serves on one of the four committees responsible for the technical content of the Wiring Regulations (*BS 7671*); accordingly, he is able to speak authoritatively (to audiences of any number) on the requirements of the Seventeenth Edition of the Wiring Regulations.

Prior to working at the ESC, Gary was a Senior Engineer at NICEIC Training delivering bespoke training courses all over the United Kingdom, and before that he worked in the Standards division on, among other things, the NICEIC's Technical Manual.

Before joining the NICEIC in 1999, he was a Director and Qualified Supervisor of an electrical contracting business enrolled as an NICEIC Approved Contractor.

Gary began his career as an apprentice with SEEBBoard, and later joined Eastern Electricity.

Preface to the Fourth Edition

There are many books on electrical installation practice where the focus is on calculations and regulations. *Electrical Installation Designs* has been written from a different viewpoint. Typical projects are examined to produce designs that will fit current standards.

Most electrical contractors have an understanding of requirements related to their own regular everyday activities, where work is carried out using rule-of-thumb methods. Repetitive designs are used. Many installers claim that they are not designers and show concern that they are now required to certify the adequacy of an installation design.

In practice, problems only arise when an unusual project is undertaken or there is a change in regulations.

There is no harm in using a standardised design, rather in the way that an experienced cook uses a published recipe for a cake. *Electrical Installation Designs* is a book of recipes. The installer may select a design that corresponds as near as possible to the contract in hand and take up such technical and regulatory advice as is required. This will reduce the need for lengthy calculations and detailed study of *BS 7671, Requirements for Electrical Installations* (IET Wiring Regulations).

Most basic electrical installations may be completed by a competent person, with appropriate guidance to avoid serious problems and hazards.

Project chapters illustrate methods that could be used for particular types of installation ranging from a house to an industrial workshop. The ideas are by no means exclusive. Alternative solutions are always possible. In many instances carrying out detailed calculations and utilising different circuitry will be more profitable. By their very nature, simplified examples of fictional projects can only produce generalised results.

The book contains special chapters on earthing, isolation and switching and overcurrent protection, which give a down to earth interpretation of the regulations.

Electrical installation students and non-electrical associates in the construction industry will appreciate the user-friendly approach. Nevertheless, this is not a do-it-yourself book for the untrained person. Warnings are therefore given where more specialised study is necessary. For example, readers are advised not to embark on installations in hazardous areas (such as petrol filling stations) without further training. Apart from moral implications and contractual risks, statutory requirements are such that incompetent work may carry criminal penalties.

Although the emphasis is on tried and tested methods, some new techniques are introduced. The most significant is the option for tree circuitry as an alternative to the ring final circuit. This is the first book to give designers the opportunity to compare the advantages of the tree system for both domestic and commercial installations. In recent years, consumer requirements have changed. It is essential that the industry keeps an open mind on changes in traditional wiring practice. Introduced in this fourth edition are new chapters on Residual Current Devices and, for those readers who require a basic understanding of circuit design, a chapter explaining the process for carrying out simple cable design calculations.

Amendments

The Institution of Electrical Engineers (IEE) joint wiring regulations committee amended *BS 7671: 1992* (16th edition) in 1994, 1997 and 1999. In 2001, the standard was renamed *BS 7671: 2001* with further amendments, and minor amendments were made again in 2002.

In 2008, a complete review of the 16th edition saw the publication of the 17th edition: *BS 7671: 2008*. The first amendment to the 17th edition was published in 2011 and came fully into force on 1 January 2012. This latest amendment also introduced the rebranded name of the IEE, namely the IET (Institution of Engineering and Technology). The most recent edition of *BS 7671* incorporates all alterations and additions to the European HD 384 series of standards.

As is often the case, many of the changes are of a minor nature in order to harmonise with other standards. However, significant changes were introduced in *BS 7671: 2008* (17th edition) with several other significant changes being introduced in its first amendment, in 2011. These are summarised in the following tables – Table A.1 summarises the changes introduced by *BS 7671: 2008* (17th edition) and Table A.2 summarises the significant changes introduced by Amendment 1 to *BS 7671: 2008*:

This book takes account of all amendments published since the 17th edition of the Wiring Regulations was first issued in 2008, including those introduced by Amendment 1, which was first issued in 2011 and which came into effect on 1 January 2012.

Roger Lovegrove and Gary Gundry

Table A.1 Summary of changes introduced by *BS 7671: 2008* (17th edition).

BS 7671 reference	Subject	Summary of notable change/new content
General	Regulation numbering system	The 17th edition introduced the adoption of the IEC numbering system, in which the Regulation numbers are separated by a decimal point, rather than a hyphen as was previously the case.
Chapter 41	Protection against electric shock	Chapter was rewritten. Protection against direct contact – was replaced by basic protection. Protection against indirect contact – was replaced by fault protection. Introduction of term 'Additional protection'. Socket-outlets with a rated current not exceeding 20 A and intended for general use by ordinary persons must be protected by 30 mA RCDs. Mobile equipment having a current rating of 32 A or less for use outdoors must also have 30 mA RCD protection.
Chapter 52	Selection and erection of wiring systems	For installations not under the supervision of a skilled or instructed person, such as domestic or similar installations, cables that are buried in a wall or partition at a depth of 50 mm or less and are not enclosed in earthed metallic covering (metallic armouring), earthed conduit, earthed trunking or have mechanical protection capable of resisting nails, screws or the like, are required to be protected by a 30 mA RCD as well as being installed in the so-called 'safe zones'. Similarly cables that are installed in metal framed walls require 30 mA RCD protection if not otherwise protected by earthed metallic covering, earthed conduit, earthed trunking or have mechanical protection capable of resisting nails, screws or the like, to be protected by a 30 mA RCD, unless the installation is under the control of skilled or instructed persons, such as office buildings and industrial premises.
Section 559	Luminaires and lighting	A new section applicable to all general lighting installations as appropriate to particular locations and structures. Requirements for fixed outdoor lighting, highway power supplies and street furniture are also included, which were previously in Part 6.
Part 6	Inspection and testing	Was previously Part 7.
Part 7	Special installations or locations	Was previously Part 6. 701 – Locations containing a bath or a shower. Zones 0, 1 and 2 as defined in the 16th edition were retained. Zone 3 was removed. All circuits supplying equipment in bathrooms and shower rooms are required to be protected by 30 mA RCDs. Supplementary bonding is no longer required, provided all of the following three conditions are met: <ul style="list-style-type: none"> • all final circuits of the location are protected by a 30 mA RCD; • all final circuits of the location meet the required disconnection times; • main bonding of services within the property is correctly installed.

(Continued)

Table A.1 *Continued.*

BS 7671 reference	Subject	Summary of notable change/new content
		<p>SELV (separated extra-low voltage) socket-outlets and shaver socket-outlets are permitted outside Zone 1</p> <p>230 V socket-outlets are permitted, provided they are more than 3 metres horizontally from the boundary of zone 1.</p> <p>708 – Electrical installations in caravan/camping parks and similar locations. Formerly caravans, motor caravans and caravan parks in the 16th edition.</p>
		<p>New Sections were added as follows:</p> <ul style="list-style-type: none"> 709 – Marinas and similar locations; 711 – Exhibitions, shows and stands; 712 – Solar photovoltaic (PV) power supply systems; 717 – Mobile or transportable units; 721 – Electrical installations in caravans and motor caravans; 740 – Temporary electrical installations for structures, amusement devices and booths at fairgrounds, amusement parks and circuses.

Table A.2 Summary of changes introduced by Amendment 1 to BS 7671: 2008.

BS 7671 reference	Subject	Summary of notable change/new content
General	Regulation numbering system	In order to further implement changes to the requirements given in the International (IEC) and European (CENELEC) base documents, a number of the requirements contained in BS 7671 are particular to the United Kingdom. Those Regulations are identified via a '10X' suffix. For example, <i>Regulation 522.6.100</i> .
General	References to ESQCR 2002	Amendments have been made throughout BS 7671 to clarify the requirements of the <i>Electricity Safety, Quality and Continuity Regulations 2002</i> with regard to the suitability for use of Protective Multiple Earthing (PME).
Tables 41.2; 41.4; and 41.6	BS 88 fuses	Amended to reflect changes in product standards for cartridge fuses.
Table 41.5	Simplification of table	Scope of the table revised to cover only circuits at a nominal a.c. rms line-to-earth voltage (U_0) of 230 V.
Section 444	Measures against electromagnetic disturbances	New section added, <i>Measures against electromagnetic disturbances</i> .

(Continued)

Table A.2 *Continued.*

BS 7671 reference	Subject	Summary of notable change/new content
514.10.1	Nominal voltages	Simplification of wording regarding enclosures within which nominal voltages exceeding 230 V to earth are present but may not be expected. Requirement relating to nominal voltage exceeding 230 V between simultaneously accessible enclosures has been deleted.
522.6.100	Cables in floor or ceiling voids	Clarification provided by adding indent relating to SELV and PELV circuits.
522.6.101	Cables in walls or partitions	Clarification provided by adding indent relating to SELV and PELV circuits.
522.6.103	Cables in partitions having metallic parts	Clarification provided by adding indent relating to SELV and PELV circuits.
526.3	Connections	Maintenance-free accessories complying with <i>BS 5733</i> recognised as an option for not needing to be accessible for inspection and maintenance.
Section 534	Surge protection devices	New section added, <i>Devices for protection against overvoltage</i> .
Section 710	Medical locations	New section added, <i>Medical locations</i> .
Section 729	Operating and maintenance gangways	New section added, <i>Operating and maintenance gangways</i> .
Appendix 4	Current-carrying capacity and voltage drop for cables	New clauses added: 5.5, <i>Rating factors for triple harmonic currents in four-core and five-core cables with four cores carrying current</i> and 5.6 <i>Harmonic currents in line conductors</i> . (New clauses based on text that was previously in Appendix 11).
		New clause added: 6.4, <i>Voltage drop in consumers' installations</i> . (Text was previously in Appendix 12).
Appendix 6	Model forms for certification and reporting	Introduction of Electrical Installation Condition Report to replace Periodic Inspection Report. New Schedule added: <i>Condition report inspection schedule for domestic and similar premises with up to 100 A supply</i> . New item added for other types of installation: <i>Examples of items requiring inspection for an electrical installation condition report</i> .
Appendix 16	Protection against overvoltage	New Appendix added: <i>Devices for protection against overvoltage</i> .

Acknowledgements

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Special thanks goes to Peter, Liz, Laura and their colleagues at Wiley for the book design concept and typesetting, and to the Institution of Engineering and Technology for its permission to reproduce some of the model certificates and associated forms shown in Appendix 6 of the Seventeenth Edition of the IET Wiring Regulations.

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Finally, any views expressed within this publication are those of the authors' so they should not be associated with their employers, where applicable.

Introduction

This book contains designs for electrical installations that have been prepared with reference to the Wiring Regulations and includes interpretations of particular technicalities.

This is not a do-it-yourself book for the amateur or untrained person. It is a guidance manual for competent electrical designers and students of installation practice.

As far as possible, all information accords with the requirements of *BS 7671: 2008*, incorporating Amendment 1, 2011 *Requirements for Electrical Installations*, the IET Wiring Regulations (17th edition), which is issued jointly by the British Standards Institution (BSI) and the Institution of Engineering and Technology (IET) as *BS 7671*. Relevant Regulation numbers and other references are shown in the margins. (Because of the space restrictions, the following abbreviations have been used: Ch. – Chapter; Sec. – Section; Defs – Definitions; App. – Appendix.) Reference is also made to various other British and European Standards and related Health and Safety documentation.

1.1 Layout of chapters

Interspersed throughout the book are two types of chapters, giving information in different formats.

1. *Project chapters*: These may be compared with a selection of recipes for an experienced chef. The recipes give ideas for the design of typical electrical installations. Each project is dealt with on a stand-alone basis. Cross-references between these chapters are avoided, wherever possible, and similar information may be found for more than one scheme.

2. *Topic chapters:* These supplement the project chapters with in-depth discussion of generalised technicalities. They also provide study information on regulatory subjects. It may be necessary to refer to these details to finalise a design with particular problems.

1.2 Wiring regulations

Throughout this book the terms Wiring Regulations (or Regulations) refer to *BS 7671:2008 Requirements for Electrical Installations*, the IET Wiring Regulations, issued jointly by the BSI and the IET. The Standard therefore represents a code of acceptable safety for electrical installations to protect:

- persons;
- 131.1 ● property; and
- livestock.

against electrical hazards, which are described as:

- electric shock;
 - fire;
 - burns;
 - ignition of a potentially explosive atmosphere;
 - undervoltages, overvoltages and electromagnetic effects;
 - injury from mechanical movement of electrically actuated machinery;
 - power supply interruptions or interruptions of safety services; and
 - arcing or burning, excessive pressure or toxic gases.
- 114.1 The Regulations are not a statutory document, but are quoted as a means of compliance with certain statutory instruments. Criminal charges could not be brought for failure to comply with the Wiring Regulations, and such non-compliance could be used in evidence if there were a charge for breach of the forthcoming *Electrical Safety Quality and Continuity Regulations (ESQCR)* or the *Electricity at Work Regulations*.

It would be most unwise to ignore any of the requirements of the Regulations. They must be considered in their entirety and are a pass or fail test. An installation cannot partially comply.

1.3 Terminology

In order to understand technicalities, the importance of correct terminology is stressed throughout this book. In general, however, the use of overcomplicated expressions and trade jargon has been avoided.

The Wiring Regulations contain a list of definitions for words and expressions, which may not accord with standard dictionary definitions. Wherever there is any doubt, the Wiring Regulations definition should be applied.

1.4 Competence and responsibility

Any person involved with the installation of wiring in buildings takes on both legal and moral responsibilities for safety. A high level of technical and practical competence is essential. This can only be achieved with appropriate study.

There are always three components to an electrical installation project:

1. Design;
2. Installation;
3. Inspection and testing.

Often one person or company takes on all three responsibilities, especially for simple repetitive jobs such as house wiring. On larger schemes, specialist companies may be contractually involved for each aspect and in turn use a team of operators. As the work progresses from planning to completion, there must always be one or more supervising individuals, who will eventually certify that the three aspects of the contract have been carried out in accordance with the Wiring Regulations and any other statutory or specification requirements.

1.5 Procedures

1.5.1 Design

It is sometimes thought that the use of tried and tested methods removes the design aspect from a scheme. This is not the case. Every project involves electrotechnical design decisions, which should not to be confused with architectural or customer instructions for the physical location of electrical equipment. Thus, a self-employed electrical contractor, who makes a decision on the selection and connection of an electrical accessory, is a designer. The same applies to an electrician who makes a similar decision on behalf of an employer.

All technical design information must be recorded. This is a requirement of the Wiring Regulations 514.9. IET guidance stresses that it is essential to prepare a full specification prior to commencement or alteration of an electrical installation. The size and content of the specification will correspond with the complexity of the work. For simple installations, a schedule of circuit details and test results may suffice.

The designs shown in the following chapters are for guidance only and each one includes a suggestion for a suitable design specification. A person selecting this guidance makes a design decision and therefore becomes the person responsible.

- 632.3 Upon completion of a contract, the person or persons responsible for the design, construction, and inspection and testing of the installation must, as appropriate, provide the person who ordered the work with an Electrical Installation Certificate, stating the works that were carried out, together with schedules for inspection and for test results.

1.5.2 Installation

Where a technical design is drawn up by an electrical engineer or other competent person, it should not be the installer's job to check design details, unless this is one of the contract requirements. The installer is always under obligation to point out to the designer any obvious conflict with regulations or standards and the installer should always refuse to carry out substandard work. There would be no defence in law against creating an unsafe installation on the basis of inherently bad instructions.

The installer will use the designer's specification document as required by the Wiring Regulations. This may only cover performance requirements or may give full technical details for the selection and erection of equipment. Once again it must be emphasised that a non-technical instruction to take an electrical supply to a particular appliance or location does not constitute design information.

The installer has the responsibility to ensure that equipment is installed correctly and in accordance with the specification, supplemented by manufacturers' information. The installer is often delegated other tasks, such as that of negotiating with the electricity supply company and verifying local licensing requirements.

Upon completion of the project, the installer certifies that the installation work has been carried out in accordance with the Wiring Regulations.

1.6 Inspection and test

- 610.1 No matter how simple or straightforward a job is, the work should always be inspected, both during the course of the work, and upon completion, and tested before the installation is put into service. This applies equally to work carried out by a self-employed operator. Self-certification is normally acceptable, provided that the contractor has the competence and equipment to test correctly. The customer or an insurer may require specialist certification. This particularly applies in the case of safety alarm systems or work in hazardous areas.

Whether an in-house or independent specialist, the inspector must be given the full design documentation, with amendments showing any relevant on-site modifications. On larger projects, this will include 'as fitted' drawings.

Certain parts of the installation may be hidden from view upon completion. In such cases the inspector must arrange for inspection during the course of erection or receive certified confirmation that the work is satisfactory.

Upon completion of the project, the inspector certifies that the inspection and test have been carried out in accordance with the Wiring Regulations. 631.1

1.7 Completion

The signatures of the designer, installer and inspector are required for the Electrical Installation Certificate. This cannot be issued until the work has been completed in accordance with the Wiring Regulations. Where there are acceptable departures from the Regulations, these must be shown on the certificate. See Chapter 15 for inspection and test procedures. 632.3

1.8 Working methods and materials

The Wiring Regulations require good workmanship by competent persons and that proper materials are used. 134.1.1

1.9 Operatives

Any person carrying out electrical work must be competent, trained and skilled in the type of installation work being carried out. Where trainees or unskilled operatives are employed for electrical work, they must be appropriately supervised.

Workmanship must be of a quality appropriate to the location. A working knowledge of the building structure is necessary where holes and fixings are made to carry cables. Decor should be disturbed as little as possible, with prearranged responsibility for making good.

1.10 Materials

The Regulations require that every item of equipment complies with a British or harmonised Standard. Alternatively, equipment complying with a relevant foreign standard may be used, provided that the designer confirms that the equipment provides a degree of safety acceptable to the Regulations. This may mean product certification by an approvals organisation. 511.1

1.11 Amendments to BS 7671: 2008

There is one amendment to *BS 7671: 2008*, published in 2011. Many of the changes are minor, resulting from European harmonisation, and the numbering of product standards where these have also been harmonised. Where changes have been made that affect the technical or practical aspects of this book, the text has been changed accordingly. If an amendment noticeably alters conventional procedures, details of the change have been included. This particularly applies in the case of voltage harmonisation.

1.12 Voltages

On 1 January 1995, the *Electricity Supply Regulations 1988* were changed to take into account a change in the standard UK supply voltage (Table 1.1). All specifications, designs and calculations should now use the 230/400 V figures. The change in voltage is minimal, therefore load assessments given in this book have not been recalculated, but there are other consequences to be considered.

Taking all of the above factors and tolerances into account, it will be seen that under the most extreme circumstances, equipment rated at 230 V may be supplied at anything between 216 and 253 V.

1.13 Voltage drop

The Regulations require the voltage at the terminals of fixed current-using equipment under normal service conditions to be greater than the lower limit corresponding to the product standard for that equipment.

Table 1.1 Changes in nominal voltage.

	Nominal voltage	Tolerance % +	Tolerance % –	Range volts max.	Range volts min.
Up to 1.1.95					
U_o	240	6	6	254	226
U	415	6	6	440	390
From 1.1.95					
U_o	230	10	6	253	216
U	400	10	6	440	376

For an installation supplied from a public supply, a voltage drop of 3% for lighting and 5% for other uses is deemed to satisfy this requirement. At 230 V, this is 6.9 V and 11.5 V, respectively. Care therefore needs to be taken in the selection of cables, particularly where equipment is voltage-dependent:

- Motor starting currents may be such that machines may stall before achieving full speed running conditions.
- Inductive lighting loads take high current on start up and luminaires could fail to strike, especially in cold weather.

All of the designs shown in this book use cables that are capable of handling the prospective loadings with a reasonable margin of safety.

Three Bedroom House

At one time, domestic electrical installations were simple and only basic design planning was necessary. A good electrician could be sent on site with a van load of wiring materials, and with no written instructions or drawings. The installation arrangements were rule-of-thumb and the quality of the job depended on the craftsmanship of the operative.

Any special requirements or missing information could be negotiated on site. Costing was repetitive and easy. The contract price was a simple multiple of the number of lights and sockets.

Times have changed. There is probably no such thing as an average householder. Most occupiers have specialist requirements based upon the choice of room utilisation, decor, hobbies and the activities of the various residents.

It is not easy for an architect to forecast the furniture layout in a room. A modern speculative electrical installation cannot make universal provision for every conceivable arrangement. Most publications offering guidance on the requirements of *BS 7671* (the Wiring Regulations) will often recommend that a project should be discussed with the client. This is essential for a custom-built house. As an alternative, the installation could incorporate some design flexibility, so that the new family is not restricted to bed positions or where kitchen equipment may be plugged in.

Standards for the house industry are determined by the National House Building Council (NHBC). Most building societies and other mortgage lenders require compliance with NHBC requirements.

This chapter starts by illustrating a basic, cost-conscious electrical installation. A scheme may be lifted straight from the pages for such a contract. For more advanced schemes, it is hoped that developers will be enticed into better electrical facilities with a 'modern living' theme. A good quotation will include optional extras for improved lighting and socket-outlet facilities. Not all house purchasers want the cheapest possible electrical installation.

2.1 The bare minimum

The following is an outline of basic requirements for a three-bedroom house with 120 m² floor area. This would be a typical speculative estate development (Figure 2.1):

- *Rooms*: small kitchen; dining room; lounge; downstairs cloakroom; main bedroom with en-suite bathroom; second double bedroom; small single bedroom; landing bathroom or shower room;
- *Heating*: central heating by gas or oil;
- *Garden*: small garden at both front and rear.

2.2 Standards

2.2.1 National House Building Council (NHBC)

The NHBC give minimum standards for living accommodation and services, which are shown in Table 2.1. It should be noted that houses vary in size and use, so the values given should be considered as a minimum.

2.2.2 Relevant wiring regulations

13 A socket-outlets

- Building Regulations now require socket-outlets, wall switches and other similar accessories to be sited in habitable rooms at appropriate heights of between 450 and 1200 mm from the finished floor levels.
- Any socket-outlet with a rated current not exceeding 20 A, which is used by ordinary persons' equipment for use outdoors must be provided with additional protection by means of a 30 mA RCD. 411.3.3
- No 230 V sockets, except shaver sockets complying with *BS EN 61558-2* are permissible in bathrooms and shower rooms. 701.5
- 230 V socket-outlets must be located at least 3 m outside the boundary of zone 1 and provided with 30 mA RCD protection. 701.512.3

Lighting

- To avoid danger and inconvenience, there should be more than one lighting circuit. 314.1
- In a bathroom, all equipment must be suitable for the zone in which it is installed. 701.5
- Wall switches and other accessories must not be installed in zones 0, 1 and 2. 701.512.3
- Cord switches must be installed outside of zones 0, 1 and 2, but the cord may hang within zones 1 and 2. 701.512.3
- There are restrictions on the current-using equipment in zones 0, 1 and 2. 701.55
- Equipment that is installed in zones 1 and 2 must have water penetration protection of at least IPX4. 701.512.2
- A careful study of *BS 7671: 2008* Section 701 is recommended.

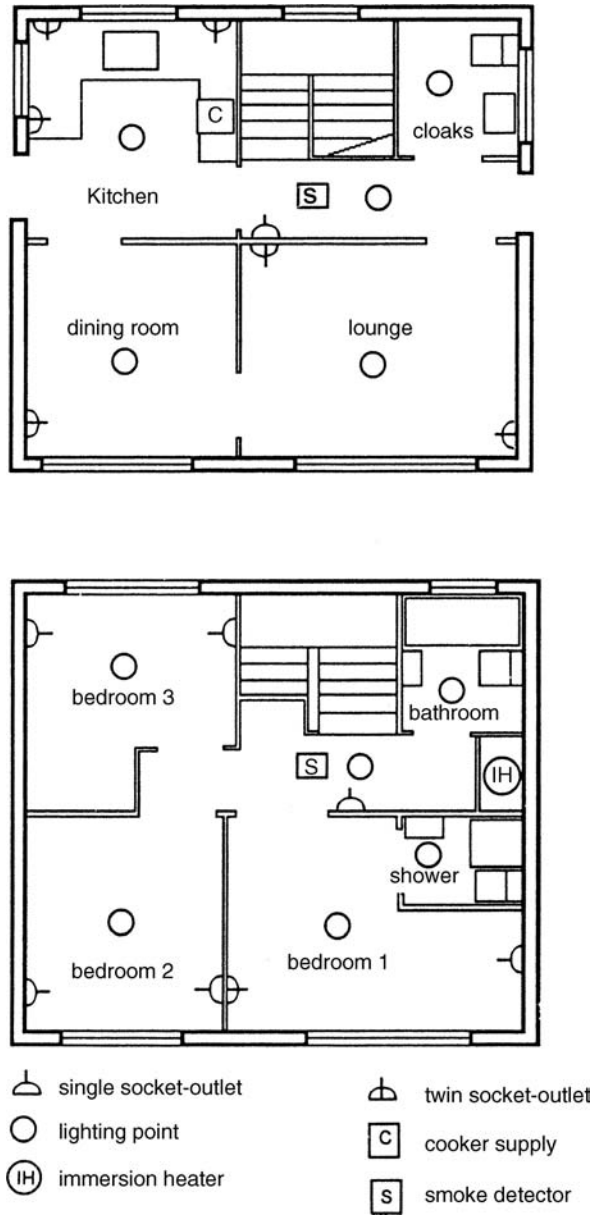


Figure 2.1 Typical three bedroom house.

Table 2.1 NHBC electrical recommendations for a house.

13 A socket-outlets (twin sockets count as two outlets)		
Room	Outlets	Notes
Kitchen/ Utility	6	Where homes have separate areas, the kitchen should have a minimum of four outlets and the utility room two.
Utility	3	Where appliances are provided, at least three outlets should be for general use.
Dining room	3	
Living room	4	At least one double outlet family room should be near the TV aerial outlet.
Bedroom	3 (2)	Three for main bedroom.
		Two for other bedrooms.
Landing	1	
Hall	1	
Combined rooms should have sockets equal to the sum of the number for individual rooms, with a minimum of seven in the case of kitchen/utility and another room.		
<i>Lighting</i> Every room should have at least one lighting point. Two-way switching should be provided to staircases.		
<i>Smoke detectors</i> For this two-storey house, two mains operated, interconnected alarms are required.		

2.3 Building regulations

2.3.1 Smoke detectors

All new domestic dwellings, including conversions, must either have:

- A fire detection and fire alarm system in accordance with the relevant recommendations of British Standard *BS 5839-6* system; or
- mains operated smoke alarms, with at least one on each floor and interconnected.

2.4 Load assessment

The Regulations require that the characteristics of the supply, including an assessment of the maximum demand, should be determined by calculation, measurement, enquiry or inspection. 311.1

It is assumed that this house will be connected to an underground PME 230 V a.c. supply and that the maximum demand load will be less than 100 A. The other characteristics may be

determined by enquiry to the electricity company (Distributor). Some of the Distributors publish guidance on the electricity supply characteristics and requirements for PME systems.

2.5 A typical domestic supply

Except in unusual circumstances, supply characteristics are:

- *Prospective short-circuit current at the origin:*
313.1 Never more than 16 kA and more likely to be less than 2 kA;
- *External earth fault loop impedance Z_e :*
Not exceeding 0.35 Ω (for TN-C-S) and more likely to be less than 0.2 Ω ;
- *Main fuse:*
This will be to the usual Distributor standard, *BS 88-3* (previously *BS 1361*, Part 2) 100 A.
Provided that these figures apply, there should be no problems in applying a standardised electrical design.

2.6 Project specification

It is necessary to produce a Project Specification, as in Figure 2.2. This will be used initially for pricing purposes. It will eventually be updated to form the basis of a user manual.

2.7 Wiring systems and cable sizes

Circuits are covered in Chapter 9 and circuit design in Chapter 19. Traditionally, domestic installations have been wired using the ‘three plate rose’ lighting system and ring circuits for the socket-outlets.

The specification illustrated for this three bedroom house uses *conventional circuits*, as described in the IETs *On-Site Guide*. The Guide explains that this system will comply with the Regulations and, provided that the circuit cable lengths are not exceeded, no calculations are necessary.

2.8 Lighting

Section 444 Various arrangements for lighting circuits have become standardised in different localities. Two methods are shown in Figure 2.3 and these utilise twin and earth cables for all runs, except two-way switch linkages. It is important to run conductors in pairs to reduce the effects of electromagnetic interference, which may be a particular nuisance with fluorescent lighting or where dimmer-switches are used, and to avoid conductors overheating caused by eddy-currents.

Wiring should be arranged with line/neutral or feed/return cables twinned to minimise interference. Separate single-core cable runs should be avoided. For the same reason, the most suitable two-way switching arrangement is as shown in Figure 2.4.

Project Specification BS 7671			
Name		Location	
Reference		Date	
230 V 50 Hz. TN-C-S. Supply fuse 100 A BS 88 3 PFC less than 16 kA. Earth loop impedance less than 0.35 Ω			
Consumer unit BS EN 60439-2 or BS EN 61439-1 100 A main switch 63 A 30 mA rcd type B cbs			
Circuits	Rating (A)	Cable size (mm ²)	Lights/points g = gang
1. Cooker	32	6.0/2.5	1
2. Ring 1 upstairs	32	2.5/1.5	... 1g ... 2g
3. Ring 2 downstairs	32	2.5/1.5	... 1g ... 2g
4. Tree kitchen	32	4.0/2.5	
5. Tree kitchen	32	4.0/2.5	... 1g ... 2g
6. Immersion Heater	16	2.5/1.5	1
7. Lights upstairs } Bathroom fans }	6	1.0/1.0	
8. Lights downstairs	6	1.0/1.0	
9. Boiler & Freezer	6	1.0/1.0	
10. Smoke detectors	6	1.0/1.0	

Figure 2.2 Project specification for standard three bedroom house.

It is a matter of choice whether the connection onto the next lighting point is made at the wall switch or ceiling rose. However, as far as possible, the systems should not be mixed, as this will only cause confusion when alterations and/or periodic inspection and testing are undertaken.

2.9 13 A socket-outlets

There are several reasons (see Chapter 9) why a ring final circuit is not always the best way to supply socket-outlets. This design shows traditional arrangements with two ring circuits and two 'tree' circuits, which may be considered more appropriate and save wiring.

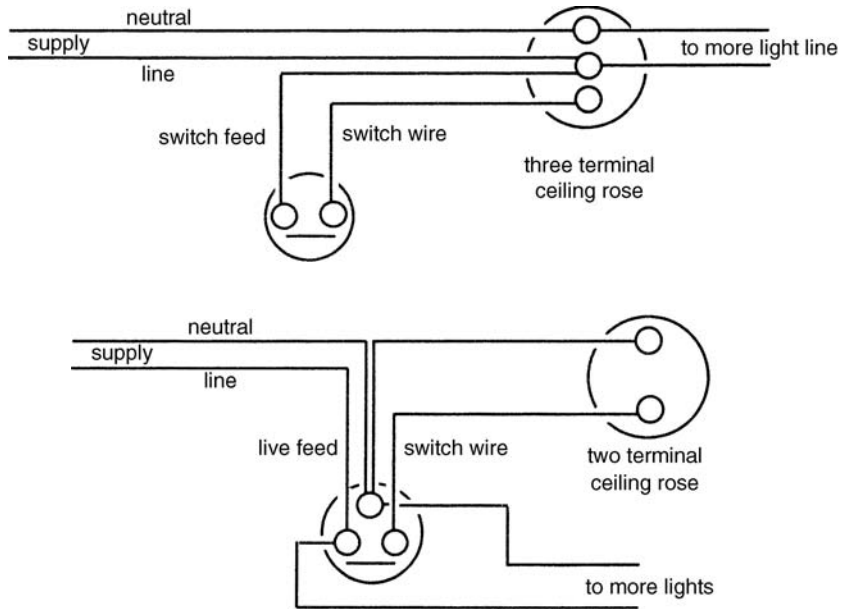


Figure 2.3 Alternative lighting circuitry using twin and earth cable (cpcs omitted for clarity).

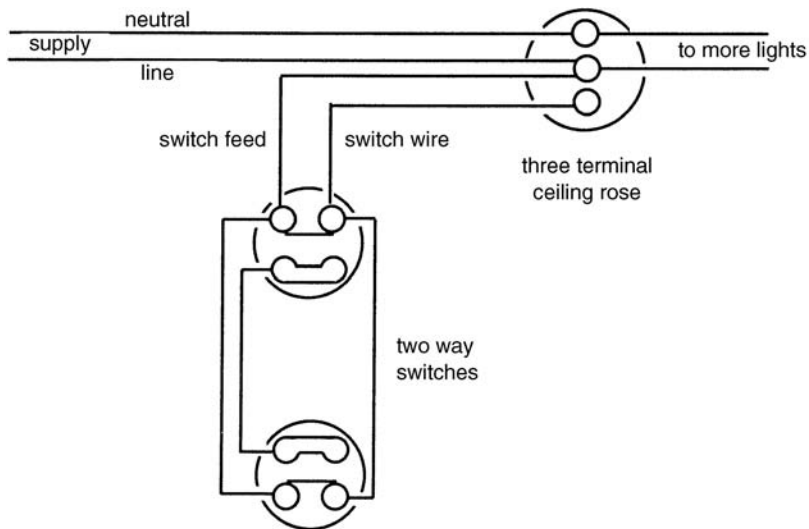


Figure 2.4 Two-way switching avoiding inductive problems.

2.10 Cable sizes

Conventions on sizing have developed in the industry. These are the sizes shown on the Project Specification. For very large houses, it is generally more economic to run one or more distribution circuit(s) (sub-mains) to remote areas, rather than increasing final circuit cable sizes. Information on determining maximum cable lengths is given in Chapter 19 of this book.

2.11 Circuit protection

2.11.1 Rewireable fuses

While the Wiring Regulations still permit the use of rewireable fuses, most, if not all, manufacturers no longer manufacture consumer units that are compatible for their use. Consequently, rewireable fuses are not considered as an option for this project or for any other project in this book.

2.11.2 Cartridge fuses

- Nobody ever has a spare cartridge fuse, and makeshift repairs can be more hazardous than on a rewireable fuse. 341.1

2.11.3 Circuit-breakers (cb)

- A cb is expensive for such infrequent use, but it is the most user-friendly device when a fault occurs.

2.12 Additional protection for socket-outlets

The introduction of the 17th edition of the Wiring Regulations saw a change to the requirements for providing additional protection for socket-outlets to what was required in the 16th edition. The change is that any socket-outlet rated at 20 A or less for general use by ordinary persons and mobile equipment rated at 32 A or less for use outdoors is required to be provided with additional protection, by means of a 30 mA RCD. An exception is permitted where the socket-outlet is for use under the supervision of a skilled or instructed person or where the socket-outlet is labelled or suitably identified for connection of a particular item of equipment, for example a freezer. 411.3.3

For this particular design project, as would probably be the case for the majority of domestic installations, it is unlikely that the socket-outlets would be used under the supervision of a skilled or instructed person. It has also been assumed that there will be no requirement for supplying a particular item of equipment that would not require additional protection by an RCD. In the interests of standardisation, a decision has to be taken. Therefore, it is recommended that the norm for all domestic installations should be for each socket-outlet to be RCD protected.

2.13 Arrangement of circuits

2.13.1 Residual current protection

As mentioned earlier all socket-outlets in domestic premises are usually required to have 30 mA protection. Therefore, all sockets on this particular design will be protected by an RCD.

522.6.102,
522.6.103
and
701.411.3.3

Additional protection by means of an RCD is also required in certain cases where cables are concealed in walls or partitions, and for all circuits located within a bathroom or shower room, with the exception of extra-low voltage circuits.

- 314.1 It would be inconvenient and cause unwanted tripping if the whole house was supplied through one very sensitive 30 mA RCD. Therefore, this design will specify a consumer unit having two or more 30 mA RCDs, RCBOs or a combination of both.

2.13.2 Circuit-breakers (cb)

This standard specification will be restricted to circuit-breakers.

The selection of cb types is covered in Chapter 4. For this domestic installation, Type B cbs would be appropriate, within a 16 kA conditionally rated enclosure.

2.14 Arrangement of consumer unit

There are many ways of arranging circuits within a consumer unit to minimise inconvenience from unwanted tripping:

- *Circuits protected by RCD 1:*
upstairs 13 A socket-outlets;
half of upstairs lights;
half of downstairs lights;
garage.
- *Circuits protected by RCD 2:*
downstairs socket-outlets;
half of upstairs lighting;
half of downstairs lighting;
immersion heater;
cooker.
- *Circuit protected by RCD 3(RCBO):*
smoke detectors.

In this case, probably the most cost-effective consumer unit arrangement is to install a board with provision for ten outgoing circuits, plus room for two RCDs. The number of outgoing ways on the specification will depend upon the size of the RCD modules (Figure 2.5).

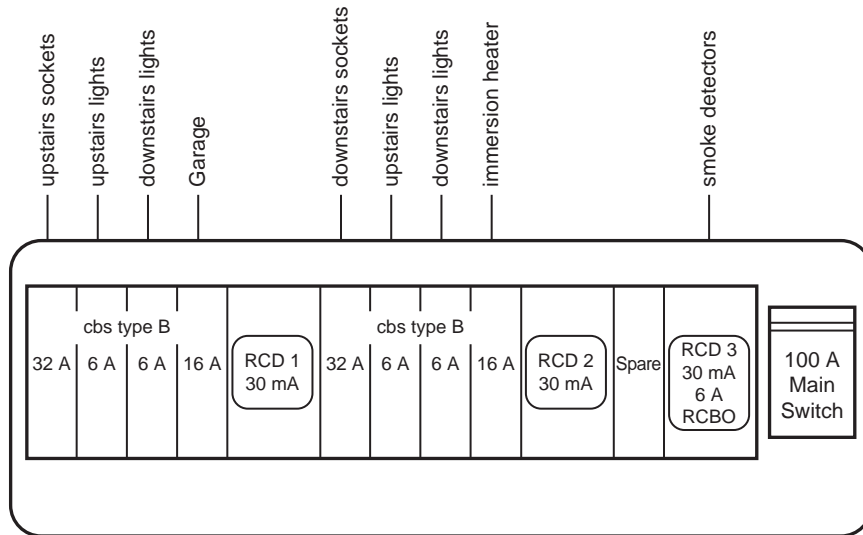


Figure 2.5 Main switch controls all circuits.

2.15 Main switch

The purchaser of a single consumer unit has little choice in the selection of the main switch, as this is usually specified/supplied by the manufacturer. Most units will accommodate a 100 A double-pole isolator. A switch with a lower current rating is inappropriate for a whole-house load.

A main switch for operation by unskilled persons, for example householder or similar, must interrupt both live (line and neutral) conductors of a single-phase supply. 537.1.4

2.16 Earthing and bonding

A main earthing terminal (MET) must be provided. This connects: 542.4.1

- the 16 mm² supply earthing conductor;
- 10 mm² main protective bonding conductors to the water, gas or oil installation pipework;
- 16 mm² circuit protective conductor to the consumer unit.

All cable sizes are the minimum required for compliance with PME requirements. It should be possible to remove any of the conductors for testing without disturbing others. 544.1.1

The MET should preferably be external to the consumer unit; it must be easily accessible for disconnecting the supply earth for testing purposes.

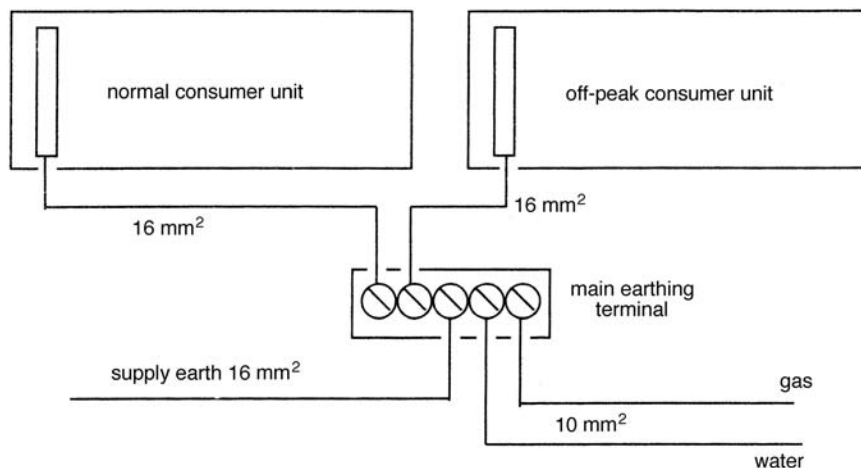


Figure 2.6 Earthing connections to two services.

If there is more than one consumer unit or distribution board, the MET must carry all bonding conductors and should be externally accessible. Separate circuit protective conductors should then be taken to the earthing bar within each consumer unit (Figure 2.6).

2.17 Gas services bonding and external meters

The Wiring Regulations require that bonding to the gas installation pipework should be made as near as practicable (within 600 mm) to the point where the service enters the house and before any branch pipework. This has often proved to be difficult where the gas pipe is buried in the floor. The only solution is to make the connection at the earliest point where the gas pipe surfaces.

Meters for new gas supplies are now generally located within what are known as semi-concealed meter boxes. Where the gas installation pipework enters the premises at low level, such as below floor boards, or buried in concrete flooring or screen, it may be impractical to make the bonding connection within the premises. Where this is the case, it is advisable to make the connection to the gas installation pipe within the gas meter box.

The 10 mm² bonding conductor should be taken through the pre-drilled hole and connected using an appropriate clamp to BS 951, and the appropriate label fitted. The cable should be as short as practicable, with no spare length curled up. The bonding conductor should be run through a separate hole in the external wall above the damp proof course and the hole should be effectively sealed on both sides. Alternatively, the bonding conductor may pass through the sleeve with the gas installation pipe, but it is essential that the sleeve is

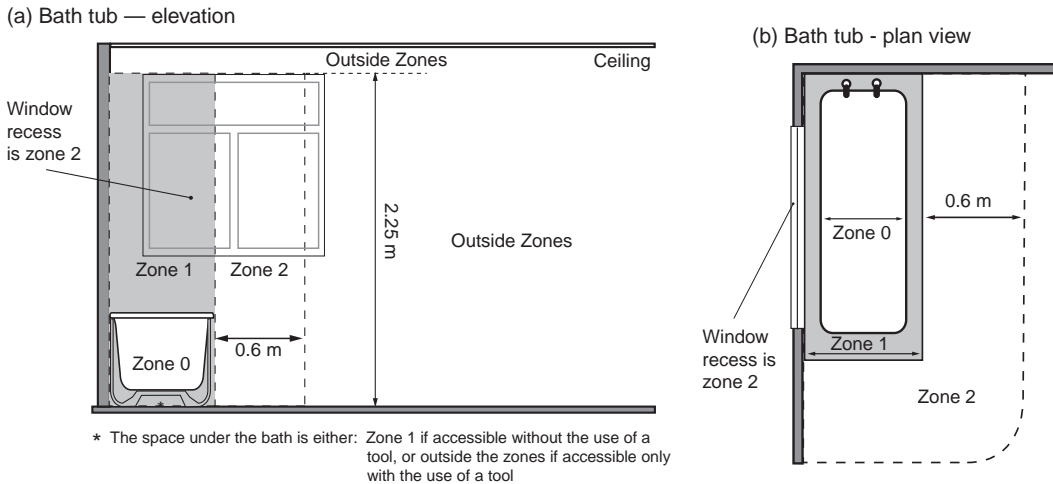


Figure 2.7 Bathroom zones: (a) elevation. (b) plan.

appropriately sealed with a non-setting, fire resistant compound, around both the installation pipework and the cable.

2.18 Supplementary bonding

The requirements for supplementary bonding within a room containing a bath or shower were changed significantly by *BS 7671: 2008*. There is still a general requirement for local supplementary bonding to be provided for these locations; however, such bonding may be omitted if all of the following three conditions are met: 701.415.2

1. All final circuits of the bathroom or shower room comply with the requirements for automatic disconnection according to Regulation 411.3.2
2. All final circuits of the location have additional protection by means of an RCD in accordance with Regulation 701.411.3.3
3. The bathroom or shower room is in a building where main protective equipotential bonding is provided in accordance with Regulation 411.3.1.2 and all extraneous-conductive-parts within these areas are connected to the main bonding, via the MET.

In a new installation, it is likely that all three of the above conditions will be met simply because the whole installation has to comply with the requirements of *BS 7671*. However, condition 3

should be checked, where there is doubt. This can be checked, for an a.c. system, using the following equation:

$$R \geq 50/I_a \quad (2.1)$$

where R is the resistance between exposed-conductive-parts and extraneous-conductive-parts, and between exposed-conductive-parts and exposed-conductive-parts. I_a is the value of current that causes operation of the fault current protective device, which for an RCD is $I_{\Delta n}$, typically 30 mA.

A Block of Retirement Flatlets

Flats and maisonettes are built as large and small complexes with a range of floor levels (high rise and low rise). The pattern of electrical distribution varies in accordance with the developer's arrangements for metering and the electricity supplier's distribution system.

An example is given for a block of 11 retirement flatlets, with some common facilities provided by the landlord. This may be local authority rented accommodation or a private housing association scheme for sheltered housing.

The basic electrical installation specification could be adapted for student accommodation or self-catering holiday flats.

3.1 Two schemes

There are two components to the electrical design; which will be treated separately:

- *Part 1:* Tenants' installations and wiring within flats;
- *Part 2:* Landlord's installation and services in common areas.

3.2 Early considerations

3.2.1 Metering and distribution

This subject requires early discussion with the Distributor and the client. The whole electrical distribution system depends upon who pays the electricity bills and where meters are to be sited.

Metering alternatives include:

- one landlord's metered supply, with either unmetered services to tenants or landlord's metering within flatlets;
- individual electricity distributor services to tenants with meters in flats;
- individual electricity distributor services to tenants with central metering.

The last arrangement is usually preferred by the Distributor.

There are advantages with centralised meter reading and the landlord taking responsibility for the electrical distribution in the building. A disadvantage may be the possibility of vandalism at the central meter position.

This exercise uses the central metering system. The plan provides the opportunity to design the distribution to the flats and to answer common problems with earthing arrangements for multiple dwellings.

3.3 Other interested parties

- *Fire authority:*
Fire alarms and emergency lighting;
- *Environmental health authority:*
Landlord's kitchen and common rooms;
- *Lift installer:*
Special requirements;
- *Aerial specialist:*
Amplifier for TV distribution system;
- *Telecom companies*
- *Building Insurers.*

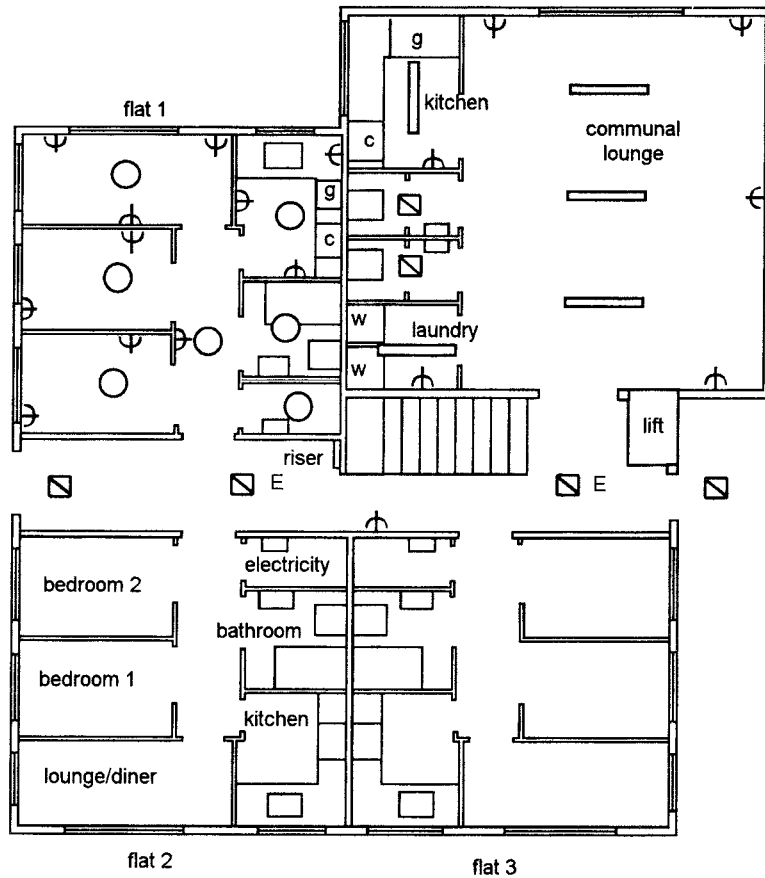
3.4 Building details

3.4.1 Construction

This is a new development, but the electrical scheme could be adapted for a refurbishment or conversion contract.

- *Design* (Figure 3.1):
Three-storey, four flats per floor on the upper two levels, three flats plus common rooms on the ground floor;
- *Walls:*
Externally and between flats, brick or other masonry. Partition walls within flats, plasterboard on timber studding or metallic frames;

- **Floors:**
Ground floor, heavy concrete base, upper floors concrete beams all with 50 mm levelling screed;
- **Ceilings:**
Ground and first floor, plasterboard on battens.
Second floor, plasterboard on timber joists under a pitched roof;



- | | | | |
|-----|---|-----|-----------------------|
| ○ | light in flat | ⚡ | 13 A twin socket |
| ◻ | 24 W fluorescent | ◻ c | cooker |
| ◻ E | 24 W fluorescent with 8 W non-maintained emergency tube | ◻ g | gas boiler |
| ▬ | 58 W fluorescent | ◻ w | washing machine point |

Figure 3.1 Layout of ground floor flats.

- *Lift:*
Hydraulic mechanism;
- *Heating:*
Gas or oil boiler in each flat and one in the landlord's common room area.

3.5 Part 1 – Flats

3.5.1 Mains distribution

Main switch fuse

For convenience, the mains distribution system and wiring is dealt with in item 3.2 of this chapter, which covers the landlord's areas.

The distributor's supply tails will connect from the meter into a 63 A switch fuse at the central metering position (Figure 3.2). Each consumer's supply will be taken through the building to a consumer unit within each flat.

3.5.2 Electrical requirements in flats

All flats are similar, with a conventional installation. The number of outlets is typical and broadly based upon NHBC standards. The fact that retirement dwellings are being considered may encourage the developer to be more generous with outlets than indicated in Table 3.1.

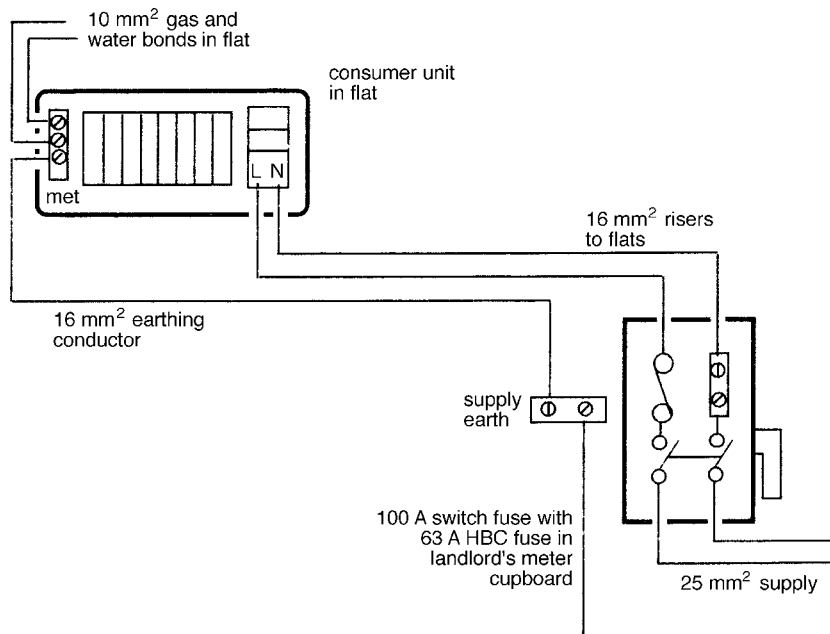


Figure 3.2 Distribution to flats.

Table 3.1 Basic electrical requirements for flats.

Rooms	Lights	13 A sockets (g = gang)		Other
		1 g	2 g	
Kitchen	1		3	Cooker
Lounge/diner	1	—	3	
Bedroom 1	1	—	2	
Bedroom 2	1	—	2	
Bathroom	1	—	—	
Hallway	1		1	Doorbell
				Smoke detector

The format for a Project Specification for a development of this type is shown in Figure 3.3. This layout could be used for various schemes, with full details completed to suit the work in hand.

3.5.3 Load assessment and maximum demand

There is no need to make any detailed assessment. The distributor will provide a standard 100 A domestic supply. 311.1

3.5.4 Wiring system

Cables will be contained within the concrete floor and lightweight walls. There are no requirements in the Wiring Regulations for rewireability, but if this were to be specified, a rigid plastic conduit system containing unsheathed single core thermoplastic (PVC) or thermosetting low smoke and fume (LSF) cables, would be the preferred method.

Alternatively, a proprietary flexible conduit system could be used. A typical system, which can be buried in floor screeds, utilises single core PVC cable with special outlet boxes and jointing arrangements.

Probably the best 'off the shelf' solution, without rewireability, would be to use standard flat twin-and-earth cable. For wiring convenience, and to protect the twin and earth cable from damage, a plastic conduit will be cast into the floor screed.

3.5.5 Wiring hints

- Light gauge, a rigid PVC conduit is suitable and may be used for casting into concrete screeds, but care must be taken to prevent damage to the conduit before the concrete is poured. Heavy gauge conduit is more robust and therefore more suitable.

Project Specification BS 7671			
Name		Flat No. Location	
Reference		Date	
230 V 50 Hz. TN-C-S. Supply fuse 100 A or BS 88-3 PFC less than 16 kA. Earth loop impedance less than 0,35Ω			
Main switch-fuse in meter cupboard 63 A BS 88-3 fuse Sub main to flat 16 mm ² swa 3-core			
Consumer unit in flat BS EN 60439-2 and BS EN 61439-1 100 A main switch 6 way type B cbs (6 kA)			
Circuits	Rating (A)	Cable size (mm ²)	Lights/points g = gang
1. Cooker	32	6.0/4.0	1
2. Sockets kitchen } Boiler }	32	2.5/2.5	3 × 2g
3. Sockets	32	2.5/2.5	7 × 2g
4. Lights 1 } Bathroom fan }	6	1.0/1.0	3
5. Lights 2	6	1.0	4
6. Smoke detector	6	1.0	

Figure 3.3 Project specification for a typical flat.

- It is essential to have at least 16 mm of concrete cover over the plastic conduit. This may be difficult if there are crossovers in the conduit runs, so careful planning of the conduit system layout is necessary to reduce crossovers to a minimum.

3.5.6 Wiring in false ceilings

522.6.100 On the ground and first floors, the ceilings are plasterboard fixed to the underside of timber battens. The use of sheathed cable is acceptable in this space, but subject to the same protective requirements as those for cables under floorboards. The Wiring Regulations require that unprotected cables, which do not incorporate an earthed metallic sheath when installed above a plasterboard false ceiling, must be at least 50 mm from the underside of the batten.

A convenient arrangement to comply with this requirement is to cross-batten the ceiling to give a 75 mm space above the plasterboard. This has the added advantage that cables may be easily routed in any direction with minimal drilling or notching.

Cross-battening arrangements should be negotiated early in the contract. Where there are on-site objections from the builder, cables must either be MICS, PVC/thermosetting installed in an earthed conduit, or given equivalent mechanical protection against penetration by nails and the like. This is obviously an expensive alternative to the cross-battening or a notched 75 mm batten.

The use of thin metallic or plastic cable capping as mechanical protection is not adequate in these locations.

3.5.7 Wiring in roof space

This may be conventional twin-and-earth cable fixed to the timber joists. The roof space will get hot in summer months and it is advisable to keep cables clear of thermal insulation. The lighting load for flats is minimal and no cable derating is necessary. 523.9

3.5.8 Cable sizes

All cable loads are relatively low and distances are short. No special factors apply (Table 3.2). App. 4

3.5.9 Arrangement of circuits

Lighting

Even though these are small flats, there must be more than one lighting circuit per dwelling, to ensure that the operation of a single device does not plunge the flat into darkness. This applies to all types of dwelling with more than about four lights and is especially important for sheltered accommodation. 314.1

Table 3.2 Cable sizes and circuitry for flats.

Circuits	Rating of Type B Circuit-breakers (Amps)	Minimum Cable CSA (mm ²)
Lighting 1	6 A	1.0
Lighting 2	6 A	1.0
Smoke detector	6 A	1.0
Sockets 1	20 A tree	2.5
	Or	
	32 A ring	2.5
Sockets 2	32 A tree	4.0
	Or	
	32 A ring	2.5
Cooker	32 A	6.0

Smoke detector

The British Standard for fire detection and fire alarm systems, *BS 5839*, permits the supply to smoke detectors and heat detectors in a Grade D system to be taken from either:

1. a separate independent circuit, for example via a separate 6 A circuit-breaker; or
2. a locally used lighting circuit. This arrangement prevents the user from turning off the circuit-breaker to the smoke detectors for several days or, worse still, permanently.

Socket-outlets

The kitchen should be considered separately. Either a 32 A ring final circuit or 32 A tree system is appropriate for heavy loading. For the rest of the flat, a 20 A tree system or a 32 A ring final circuit would be acceptable. See Chapter 9 for ideas on circuitry.

Boiler supply

The electrical loading for the gas/oil central heating system is negligible and may be fed through a fused spur on the local socket-outlet circuit. British Standards require a switch adjacent to the boiler or programmer to isolate the complete system.

3.5.10 Consumer unit

Circuit protection

- 411.3.3 The requirements for circuit protection and RCD protection are similar to those required in a house, therefore the details given in Chapter 2 should be followed. For more information on the application of RCDs, reference should be made to Chapter 17 of this book.

Accessibility

Although the mounting height of consumer units and accessories are not specifically covered by Building Regulations or *BS 7671*, they must be suitably located to provide access by the intended occupier.

Practicable consumer units should be mounted 1200 mm to 1400 mm from the floor, so that switches can be viewed by a person standing or sitting.

- 537.4.1 A similar judgement should be made on the location of the cooker control switch, which may be required in an emergency. If a sink waste disposal unit is installed, an accessible means of disconnection should be provided.

3.5.11 Earthing and bonding

Each flat has a separate electrical installation with a metered supply and therefore requires main equipotential bonding of water and gas services within the flat.

- 542.4.1 Bonding a landlord's water and gas mains to the MET in the remote meter cupboard would be appropriate for the communal areas and landlord areas, but would not give reliable protection to the installation in each flat.

It is necessary to take a 16 mm² earthing conductor to the main earthing terminal in the flat. This is shown in Figure 3.2.

It is permissible to use the armouring and the third conductor in a 16 mm² three-core steel wire armoured cable (swa) as an earthing conductor on a PME supply, but only if it has been determined by the electrical installation designer that heat produced in the armouring and core due to such use will not cause overheating of the live conductors of the cable. If a two-core cable is used, a separate 16 mm² earthing conductor will be required.

3.5.12 Earthing terminal

A consumer's earthing terminal will be located within the consumer unit. This is the point where the supply earthing conductor joins the main protective bonding conductors within each flat.

3.5.13 Bonding

Standard main bonding requirements apply for 10 mm² connections to incoming water, gas or oil piping. This bonding is to be applied within 600 mm of the point of entry into the flat. 544.1.1

Supplementary bonding is not required in the bathroom, as all three conditions permitting its omission, as described in Chapter 2, are intended to be satisfied. 701.415.2

3.6 Part 2 – Landlord's areas

3.6.1 Meter cupboard

This cupboard is used to enclose:

- the Distributor's intake and metering equipment;
- eleven meters and main switches for tenants' supplies; and
- the landlord's meter and distribution board.

It is preferable for the meter cupboard to be used exclusively for electrical equipment and it must not be used for the storage of cleaning materials. A suitable notice to this effect should be provided in this cupboard. There should be clear space in front of equipment for routine meter reading and clear access for emergency attention, for example fire-fighting. 513.1

3.6.2 Supplies to flats

The loading for each flat will be served by a 100 A switch fuse with a 63 A BS 88 fuse link. This will protect the 16 mm² sub-main. Cables should not be bunched and routes should avoid thermal insulation, otherwise the application of the rating factors may result in the need for a 25 mm² cable. The maximum circuit length for a 16 mm² two-core armoured cable having 90 °C thermosetting insulation (clipped direct and not grouped with other cables, not passing through 523.1

thermal insulation, based on a design current of 50 A) is 93 m. Further information on determining maximum cable length is given in Chapter 19.

Cables should be routed in protected ducts, when passing through public areas. It is not normally acceptable to run one consumer's cable through another consumer's property. Steel-wire-armoured or split concentric cable is generally used but non-armoured sheathed cable would be acceptable provided that it is adequately protected against physical (or mechanical) damage.

3.6.3 Landlord's electrical requirements

The full schedule is given in Table 3.3. Fire alarms, smoke detectors and emergency lighting are not included, and these must be discussed with the relevant statutory authorities.

3.6.4 Diversity

311.1 The IETs *Guidance Note 1* does not show a situation that exactly fits these landlord's premises. The nearest type of accommodation listed in *Guidance Note 1* is for a small hotel. Estimation of

Table 3.3 Landlord's services, cable sizes and circuitry.

Circuits	Rating of Type B Circuit-breakers (Amps)	Minimum Cable CSA (mm ²)
Lighting 1 lounge	6 A	1.0
Lighting 2 stairs	6 A	1.0
Lighting 3 stairs	6 A	1.0
Smoke detector	6 A	1.0
Sockets		
Kitchen	32 A tree	4.0
	Or	
	32 A ring	2.5
Lounge	20 A tree	2.5
	Or	
	32 A ring	2.5
Washing machines	32 A tree	4.0
Dryer	16 A radial	2.5
Cooker	32 A	6.0
Lift	10 A	2.5

diversity is not an exact science and some judgements must be made based upon experience and consultation with the client.

It is possible that the kitchen facilities in the communal area may be used fully on during winter evenings, but at such times it is unlikely that the laundry equipment will be in use.

For current loading calculations, fluorescent lamp ratings must be multiplied by 1.8 to take into account control gear losses.

3.6.5 Lighting

Stairs, etc.	$12 \times 24 \text{ W} \times 1.8 = 518 \text{ W}$
Toilets	$2 \times 24 \text{ W} \times 1.8 = 86 \text{ W}$
Lounge, kitchen and laundry	$5 \times 58 \text{ W} \times 1.8 = 522 \text{ W}$
	Current = $1126/230$
	= 4.9 A

The use of the '1.8' factor may not apply to some types of fluorescent luminaires. If in doubt, always consult with the manufacturer of the equipment.

3.6.6 Socket-outlets

There is central heating. Kitchen equipment and a laundry iron will be used.

Assume 100% load of one circuit = 32 A

3.6.7 Other equipment

cooker at 80% = 32 A;
washing machine and dryer at 75% = 18 A;
boiler and lift – ignore.

3.6.8 Total load

estimated maximum demand = approx. 87 A;
a single-phase 100 A service will be appropriate.

3.6.9 Cable sizes and circuitry

This is a conventional building structure. PVC twin and earth type cables (complying with BS 6008) are acceptable (Table 3.3). Low smoke and fume (LSF) cables to BS 6724 should also be considered. Refer to the notes for wiring in flats for installation details, including cables in false ceiling cavities. The Project Specification for the Landlord's area is shown in Figure 3.4.

Project Specification BS 7671			
Name		Landlord's services in block of flats	
Reference		Date	
230 V 50 Hz. TN-C-S. Supply fuse A or BS 88-3 PFC less than 16 kA. Earth loop impedance less than 0.35Ω			
Consumer unit in landlord's cupboard BS EN 60439-2 and BS EN 61439-1 100 A main switch 12 way Type B cbs (6 kA)			
Circuits	Rating (A)	Cable size (mm ²)	Lights/points g = gang
1. Cooker	32	6.0/2.5	1
2. Sockets (tree) kitchen & boiler }	32	4.0/2.5	3 × 2g
3. Sockets (ring) lounge & stairs	32	2.5/1.5	6 × 2g
4. Washing machines	32	4.0/2.5	2
5. Dryer	16	2.5/1.5	
6. Lights lounge } Toilet fans	6	1.0/1.0	7
7. Lights stairs	6	1.0/1.0	6
8. Lights stairs	6	1.0/1.0	4
9. Smoke detectors	6	1.0/1.0	
10. Lift	10	2.5/1.5	1

Figure 3.4 Project specification for landlord's services.

3.6.10 Lighting

The total lighting load is minimal. However, to avoid inconvenience in the event of a fault, two circuits are suggested using 1.0 mm² cables.

3.6.11 Socket-outlets

Socket-outlets will carry heavy loads in the kitchen and in the laundry. In other rooms, only small appliances will be plugged in. It is suggested that three circuits will be appropriate. Table 3.3 provides for the use of both 2.5 mm² ring or 4.0 mm² tree circuitry.

3.6.12 Other equipment

Separate circuits will be necessary for the cooker and the lift. Spare ways will need to be provided for possible extra circuits, such as fire alarms and door entry system. The minimal boiler supply requirement can be taken from a local socket-outlet circuit.

3.6.13 Distribution board

A conventional domestic type is appropriate. This should be easily accessible.

If the unit is locked for security purposes, the location of the key should be clearly indicated. 513.1
However, it is important that such keys remain under the control a responsible person.

3.6.14 Residual current protection

The Wiring Regulations require any socket-outlet rated at 20 A or less for general use by ordinary persons, and for mobile equipment rated at 32 A or less for use outdoors to be provided with additional protection by means of an RCD having an operating current not less than 30 mA. An exception is permitted where the socket-outlet is for use under the supervision of a skilled or instructed person (although this would not be permitted in a domestic installation) or where the socket-outlet is labelled or suitably identified for connection of a particular item of equipment, for example a freezer.

The installation has been designed using a split bus-bar circuit-breaker consumer unit, 411.3.3
although the use of RCBOs to provide protection for each final circuit would also be a suitable arrangement. Circuit arrangements are shown in Figure 3.5. The lift supply should not be RCD protected, nor should the lighting final circuits, where the installation is intended to be under the supervision of a skilled or instructed person.

3.6.15 Switchgear

Labelling

All equipment in the meter cupboard must be carefully labelled, giving flat numbers corresponding 514.9
to switchgear. It is probable that a 400 V label will be required to indicate the presence of three- 514.10
phase voltages between different consumers' equipment.

A detailed circuit schedule providing all appropriate circuit information is required to be fixed 514.9
adjacent to the landlord's distribution board:

- the numbers of points served;
- area locations;
- circuit loadings;
- type and rating of protective devices;
- cable types and conductor sizes;
- earth loop impedance values; and
- details of circuits or equipment vulnerable to any particular test (usually insulation resistance).

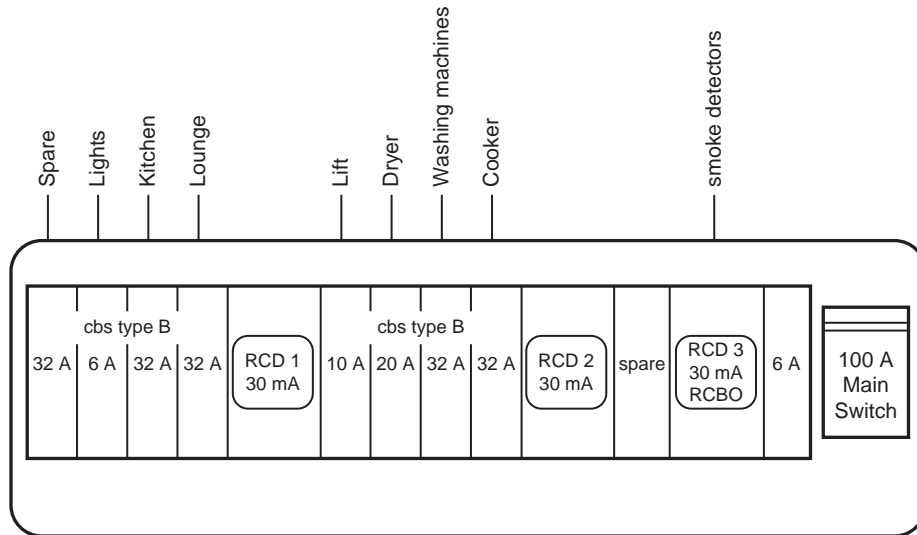


Figure 3.5 Landlord's distribution board.

3.6.16 Switching

Standard requirements apply as in flats.

3.6.17 Wiring

- 514.1 As far as is reasonably practicable, wiring should be arranged and marked so amended that it can be identified for testing, repair or alteration.

3.6.18 Earthing

- 542.4 The installation of the landlord's supply may be treated in a similar manner to that of the supply to the flats. Main protective bonding is required between the landlord's distribution board, main earthing terminal and other landlord's service entries, in the same way as that shown in Figure 3.2 for flats.

3.6.19 Emergency systems

Details of fire alarm and emergency lighting provision should be added to the specification.

Overcurrent Protection

There are two reasons for overcurrent.

- *Overload:*

This is overcurrent occurring in a circuit, which is electrically sound. Examples of this are where a user connects too many heavy-loading appliances to a single circuit or applies excessive mechanical load to a machine.

- *Fault:*

This is overcurrent occurring as a result of a faulty installation. Examples usually involve the failure of insulation, causing a short-circuit between live conductors or between a live conductor and earth.

The two conditions differ by way of cause and effect. Action to lessen safety hazards is either with practical measures to detect and remedy fault conditions or to apply regulations intended to prevent the occurrence of overcurrent. In most circumstances, overload and fault current protection will be given by one common device.

4.1 Overload

There are many reasons for the overloading of healthy wiring, including:

- an electric motor undertaking mechanical duty in excess of design parameters;
- faulty running of machinery caused by bearing failure or uneven loading;
- a motor starting current;

433.1

- loss of a phase from a three-phase load;
- excess loading added to a socket-outlet circuit;
- an underestimate of the maximum demand of an installation.

Overloads often arise gradually and at the early stages may not be apparent when testing is carried out. The transition from excess loading to overloading on a main service may result as a combination of unplanned extra sub-circuit demand.

The purpose of overload protection is to detect and clear an overloaded circuit before it becomes dangerous or damages the installation. A small overload may not cause an immediate hazard and may be tolerated by a protective device for a long time. A simple example of this is with a 13 A fuse to BS 1363. This will not rupture if the load current creeps up to 13 A. It should operate indefinitely at this nominal load without producing dangerous temperatures and/or overheat. The consequence is that it will continue to operate with a load of approximately 20 A for several minutes.

4.2 Overload protection

A protective device must be used to break overload current before any thermal damage is done to cable insulation or other load-carrying parts of the installation.

- 433.1.1 ● The *nominal rating* of the device must be:
greater than the design current (I_b) for the circuit and less than the operational rating of any conductor being protected;
- The *operating current* must not exceed:
 $1.45 \times$ the current rating of any conductor being protected after correction for grouping, and so on.

There are some conditions where the above overload protection need not be applied to a conductor:

- 433.3.1 ● where there is a reduction in conductor size, but the upstream protection gives effective protection to the smaller conductor; or
- where the load is such that it is unlikely to be overloaded, for example a fixed lighting circuit, fixed heating, immersion heater and shower circuit;
- at the intake position where the supply authority agrees that their equipment gives appropriate protection.

- 433.3 The above relaxations may not be applied where there is an abnormal fire risk or risk of explosion and where special requirements apply.

4.3 Overload protective devices

4.3.1 Rewirable fuses

Although permitted by the Wiring Regulations, preference is given to other devices. Nevertheless, provided that they are correctly selected and installed, rewirable fuses are fail-safe and for simple situations are trouble-free until abused. 533.1.1.3

One major technical disadvantage is that a cable down-rating factor of 0.725 has to be applied to a circuit protected by a rewirable fuse. Fault current breaking capacity is limited. This will be covered later in this chapter. A practical drawback of rewirable fuses is that consumer units manufactured for the UK market no longer accommodate such protective devices, as they favour integrated RCD protection alongside circuit-breakers.

To avoid the above complications, rewirable fuses are not specified for any of the projects in this book.

4.3.2 High Breaking Capacity (HBC) fuses

These are fail-safe devices with excellent characteristics, but liable to abuse when no spares are available. The installations covered by this book usually do not have skilled electrical maintenance personnel. So, for this reason, HBC fuses are also not specified in any of the projects in this book. 341.1

HBC fuse protection will be fitted by the supply authority in sealed meter heads and HBC type g(G) fuses may be used for large main distribution fuse gear as an alternative to moulded-case circuit-breakers. Motor circuit protection fuses have a g(M) characteristic. This gives a continuous operating rating and a motor starting rating. The subject is beyond the scope of this book, but is an essential study for motor installers. Suppliers' technical literature usually provides the best source of information. 435.2

4.3.3 Circuit-breakers

It is often said that these devices may not fail to safety. Nevertheless, their reliability is beyond question for most installations. Yet, if there is no choice but to install switchgear in a damp arduous situation, HBC fuses may give better long-term operational reliability.

In all normal locations, the use of circuit-breakers in distribution boards is recommended to give the most user-friendly protection.

4.3.4 The 'type' of circuit-breaker

It has already been mentioned that overload protective devices will be able to withstand moderate overloads for a short amount of time. By their nature, fuses run warm on full load and have a 'fusing factor' set by their operating characteristics. It is possible to design a circuit-breaker with an exact operational cut-off point.

Circuit-breakers conforming to *BS EN 60898-1: 2003* are classified into three distinct ‘Types’, known as Type B, Type C and Type D, according to their ‘instantaneous’ tripping current for a.c. installations. Instantaneous tripping current is the minimum value of current causing a circuit-breaker to operate automatically without an intentional time delay (i.e. <0.1 s or 100 ms).

Table 2 of *BS EN 60898-1: 2003* and Table 2 of *BS EN 60898-2: 2006* permits instantaneous tripping to begin to occur at a value of fault current, expressed as a multiple of the rated current (I_n), within a range of values for each type of circuit-breaker. The standard ranges are shown in Table 4.1 below, although it is possible for manufacturers to design circuit-breakers to operate instantaneously within tighter ranges of current, falling within the standard ranges.

This example indicates the selection method:

Consider a 32 A Type B circuit-breaker used in an office socket-outlet circuit. Table 4.1 shows that this could carry a maximum of 160 A for a few seconds before disconnection. *BS EN 60898* requires instantaneous disconnection (<0.1 s) for a Type B cb to occur between 96 A and 160 A (or between 3 to 5 I_n). The actual instantaneous tripping current depends upon manufacturers’ tolerances and the way that the overcurrent builds up. A Type B cb is usually a suitable standard choice for most domestic and commercial installations but, as will be seen later, this depends on the earth loop impedance.

4.4 Fault current

Section 4.34 Fault current is invariably caused by failure in the wiring system or equipment connected to it. This may be because:

- cable insulation has been damaged by heat or abrasion;
- water has entered into a badly protected connection;
- a motor has burnt out;
- a metal tool has fallen across bus-bars.

The consequences of a fault may be a fire or explosion, resulting in serious burn injuries or even death.

Table 4.1 Type characteristics of circuit-breakers.

cb type	Tripping current range (factor to be multiplied by nominal rating)	Typical application
B	3–5	General purpose and commercial.
C	5–10	Motors and highly inductive discharge lighting.
D	10–20	Only for special conditions, e.g. some welding plant.

A fault may occur between any conductors of the supply system, or to earth, or between both simultaneously. Speedy disconnection of the supply is therefore essential.

The initial surge of fault current is usually measured in thousands of amps (kA) and is limited by the impedance of the supply up to the fault position. This is known as the (Prospective Fault Current (pfc)). There will be a very short period of time before any protective device reacts to this overcurrent.

4.5 Fault Current Protection

The purpose of fault current protection is to disconnect the supply speedily and to restrict damage and danger as far as possible.

All parts of an installation must be protected against the highest pfc that can be anticipated at any particular point in the system. The pfc is at its highest at the intake position and will decrease (or attenuate) through the installation as the resistance of cables is added to the fault path.

4.6 Omission of fault current protection

In some conditions, fault current protection may be applied downstream, on the load side of part of the system. The conditions are: 434.2.1

- if the unprotected conductor up to the protection device is less than 3 m in length;
- this conductor is so located that it is unlikely to experience a short-circuit or earth fault; and
- has superior physical protection against risks of fire and electric shock.

This arrangement usually applies where short and relatively small cables are connected to heavy current bus-bars to take a supply to lightly loaded fuse switches.

Enclosure in conduit or trunking is regarded as superior physical protection and the cables in question should be separated from other circuitry. Consideration must be given to the consequences of 'flash-over' between live parts.

The above relaxations may not be applied where there is an abnormal fire risk or risk of explosion and where special requirements apply. 434.3

4.7 Short-circuit rating

Under short-circuit conditions there will be a considerable current surge. This is the pfc referred to previously. For a standard 100 A supply, the pfc often quoted by Distribution Network

Operators is 16 000 A (16 kA). However, in practice, the value is never as high as that, as much depends upon the arrangement of the supply network and the distance from the substation.

The rated short-circuit capacity (I_{cn}) of a circuit-breaker conforming to *BS EN 60898* is the value of the ultimate short-circuit breaking capacity assigned by the manufacturer.

A circuit-breaker also has a corresponding ‘in-service’ short-circuit breaking capacity (I_{cs}), which is either equal to, or lower than, the rated short-circuit capacity (I_{cn}).

The difference between the two short-circuit capacities relates to the condition of the device after it has been subjected to a short-circuit type-test. Conveniently, I_{cn} and I_{cs} are the same value for circuit-breakers conforming to *BS EN 60898* having an ultimate short-circuit capacity of 6 kA or less. Where an ultimate short-circuit capacity exceeds 6 kA, a rating factor of 0.75 or 0.5 applies (refer to Table 4.2).

So when selecting an overcurrent device, it is important to ascertain the pfc at the point of installation, so that an appropriately rated device can be selected.

Table 4.2 Breaking capacity of devices.

Device	Breaking Capacity (kA)	
BS 88-3 fuse, (previously BS 1361 Type I)	16.5	
Rewireable fuses (see marking on fuse carrier)	S1 = 1	
	S2 = 2	
	S4 = 4	
cbs to <i>BS EN 60898</i>	Standard values of I_{cn} and corresponding values of I_{cs}	
	Rated short-circuit capacity (I_{cn}) (A)	Service short-circuit capacity (I_{cs}) (A)
(see marking)	1500	1500
	3000	3000
	4500	4500
	6000	6000
	10 000	7500
	15 000	7500
	20 000	10 000
	25 000	12 500

As strange as it might seem, it is only the rated short-circuit capacity (I_{cn}) that is required to be marked on a circuit-breaker, usually within a rectangle, as follows:

6000

The example indicates a rated short-circuit capacity of 6000 A (6 kA).

Short-circuit current will flow until a fuse ruptures or a circuit-breaker's contacts separate. During this period, before the separation arc is extinguished, the overcurrent protective device must be able to withstand the heat and physical stress that are likely to occur within the device – this is known as the breaking capacity of the device. 432

Typical ratings are shown in Table 4.2.

Most domestic consumer units complying to a Harmonized Standard will be certified to have a conditional rating of 16 kA. This means that they may be used for conventional housing applications, where it is known that the pfc will not exceed 16 kA. The conditions rely upon the ability of the consumer unit to withstand the stresses involved and the back-up provided by the distributor's cut-out fuse.

4.8 Disconnection times

The Wiring Regulations specify various maximum disconnection times for different types and rating of circuits for TN systems and for TT systems which are reproduced in Table 4.3 for ease of reference. 411.3.2.2

As mentioned earlier, a circuit-breaker to *BS EN 60898* has the characteristics such that it will disconnect the supply in less than 0.1 s, provided that the maximum earth fault loop impedance permitted by *BS 7671* for the circuit being protected is not exceeded.

Table 4.3 Maximum disconnection times, as stated in *BS 7671: 2008*.

	TN systems	TT system
Final circuits not exceeding 32 A	0.4s	0.2s
Final circuits exceeding 32 A and for distribution circuits	5s	1s

Note: the above values are applicable for a nominal voltage $120\text{ V} < U_o \leq 230\text{ V}$ only.

4.9 Earth loop impedance

The pfc of an earth fault depends on the maximum earth fault loop impedance at the point of the fault. If that impedance is lower than the maximum permitted value given in Table 41.3 of Chapter 41 of *BS 7671*, disconnection of the supply will occur in less than 0.1 seconds, where the circuit-breaker conforms to *BS EN 60898*.

411.4.6 to
411.4.8

BS 7671 indicates that the use of circuit-breakers conforming to *BS EN 60898* is deemed to comply, but there is a need to take account of the increase in temperature and resistance of circuit conductors as a result of overcurrents. Circuit loop impedances given in the Wiring Regulations cover this condition and should not be exceeded where the conductors are at their normal operating temperature. However, if the conductors are at a different temperature when tested, which is usually around 20 °C, the reading should be adjusted accordingly.

This requirement often presents a problem for the person carrying out tests, who is unlikely to be certain of the normal operating temperature. Where this is the case, it is safe to assume the maximum permissible operating temperature of the cable which, in the case of (thermoplastic (PVC)) insulated cables, is 70 °C. Table 4.4 has been derived for typical test conditions on projects in this book. For other situations, refer to the Wiring Regulations and IET Guidance Notes.

4.10 Summary of cb specification

411.3.2 Projects covered in other chapters have selections made for each cb to be used in the standard circumstances described.

Table 4.4 Typical maximum earth loop impedance for test readings.

cb <i>BS EN 60898</i> type	Nominal rating (A)	Max. test earth loop impedance at 20 °C (Ω)
B	6	6.13
C	6	3.06
D	6	1.54
B	16	2.30
C	16	1.15
D	16	0.58
B	32	1.15
C	32	0.58
D	32	0.29
C	63	0.29

For non-standard projects or conditions, the following data must be assessed in order to specify a circuit-breaker for overload and short-circuit protection. Similar rules apply for fuses:

- Establish the pfc in order to select a circuit-breaker that has the ability to withstand that pfc as a minimum.
- Select a circuit-breaker Type to suit the application.
- Calculate the nominal current rating I_n of the cb as follows:
 - the normal load current of the circuit = I_b ;
 - use I_b to find the next highest suitable cb = I_n ;
 - I_n must be adjusted for cable grouping;
 - thermal insulation, ambient temperature, and so on = I_t ;
 - I_t will be used to select a cable with a rating = I_z ;
- Establish the maximum earth-loop impedance = Z_s .
- Check Z_s against I_n in the appropriate tables for disconnection times.

4.11 Conclusion

The choice of a cable size (csa of conductors) always follows the selection of a suitable overcurrent protective device.

Detailed information on the process of designing electrical circuits is described in Chapter 19 of this book, Circuit design calculations.

Once a firm choice of cable has been made, it is not acceptable to change the circuit-breaker or fuse specification without a complete circuit redesign.

An Architect's Office

This could be a local branch of a national organisation or the operational headquarters of a small business. It could be the premises of an estate agent or an insurance broker.

For the purposes of this exercise, the project is an architectural practice, with two or three partners and a small number of staff. Electrical requirements are modest but include storage heaters and mains services for computers. Some ideas are given for clean lines and uninterruptible power supplies (UPSs).

The lighting design will be specialised and so is beyond the scope of this book. However, basic lighting circuitry is given and there are general suggestions for extra-low voltage (elv) spotlights in two areas. The layout, as illustrated, shows lighting and heating in order to establish loads and circuitry only. This is not a lighting or heating design scheme. Where an installer is not experienced in this type of design, it is suggested that reference is made to product suppliers who usually provide a design service.

5.1 Other interested parties

Before settling the full electrical schedule, a check must be made upon special or additional requirements.

- *Fire authority:*
Fire alarms, emergency lighting and other safety features, especially if this office is part of a multi-occupancy building;
- *Client's insurers:*
There may be special requirements for the security of an office, which contains valuable computers and documentation;

- *Computer specialist:*
Requirements for clean earth and UPS;
- *Landlord:*
The subject of common alarm or security systems may be of interest;
- *Health and safety:*
Lighting may be important where operators view computer screens for long periods.
- *Distributor:*
Check availability of a supply to suit the potential load and confirm the location of the intake position.

5.2 Building structure and finishes

This is a part of a new building yet to be completed. Figure 5.1 shows the intended layout:

Total office floor area: 180 m²;

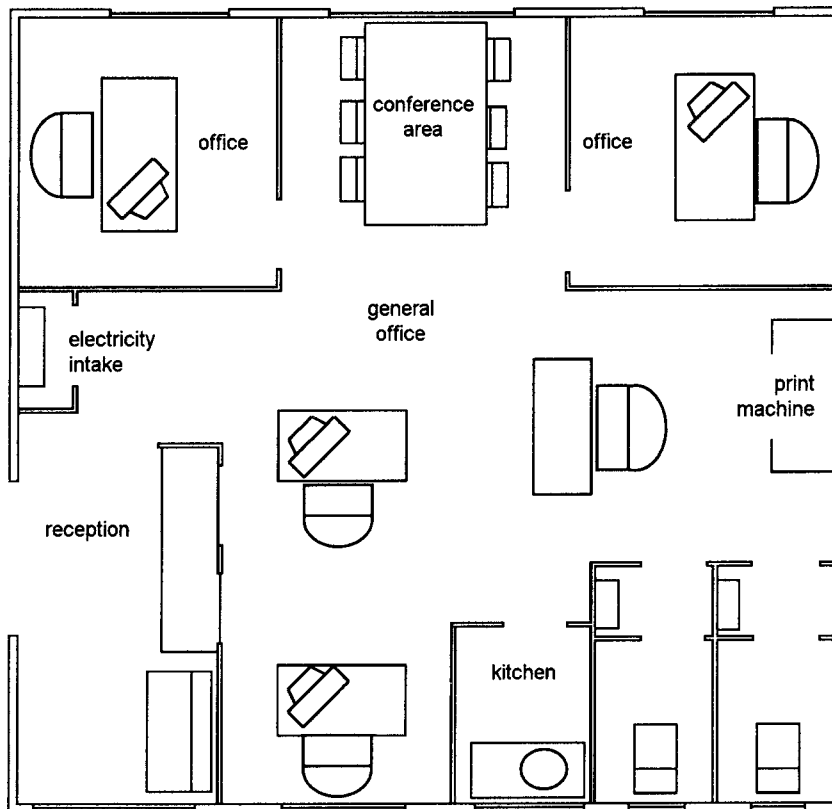


Figure 5.1 Layout of offices and furniture.

Floor below and above: concrete beams, as yet unscreeded;

Ceiling: suspended false ceiling, with 300 mm void;

Walls – external: masonry, with plaster finish; *internal:* lightweight partitions, plasterboard on steel framework.

5.3 Electrical requirements

A full schedule of requirements is shown in Table 5.1. Layout arrangements for lighting and power are complex. Two diagrams have been produced to supplement the schedule. Figure 5.2 shows the preliminary lighting arrangements and Figure 5.3 shows provisional heating and power arrangements. The requirement for off-peak storage heaters is noted and appropriate arrangements should be made for the amount of IT equipment that will be used in the office. It is the responsibility of the occupier or developer to consult with the Distributor to be certain that an appropriate electricity supply will be available. This task is normally delegated to the electrical contractor, who will need to establish supply requirements including the anticipated

Table 5.1 Electrical requirements.

Provisional electrical schedule	
Lighting	
General office lighting	9 × 1.8 m 70 W twin fluorescents
Two executive offices	2 × 1.8 m 70 W twin fluorescents
Conference area	9 × 50 W elv spotlights
Reception area	8 × 50 W elv spotlights
Toilets and kitchen	6 × 24 W low energy fluorescents
Direct acting heaters	
Three wall panel heaters in the kitchen and toilets, with individual Storage heaters on off-peak supply	4 × 1 kW thermostatic control
Nine block storage units	9 × 3 kW
Print Machine	
A single-phase 20A supply has been requested	
Socket-outlets	
Some discussion and decision is required at this early stage. Two systems are suggested:	
Conventional general purpose 13 A sockets.	
Special clean lines for computers. One dedicated socket per desk place. Consideration may be given eventually to a UPS service.	

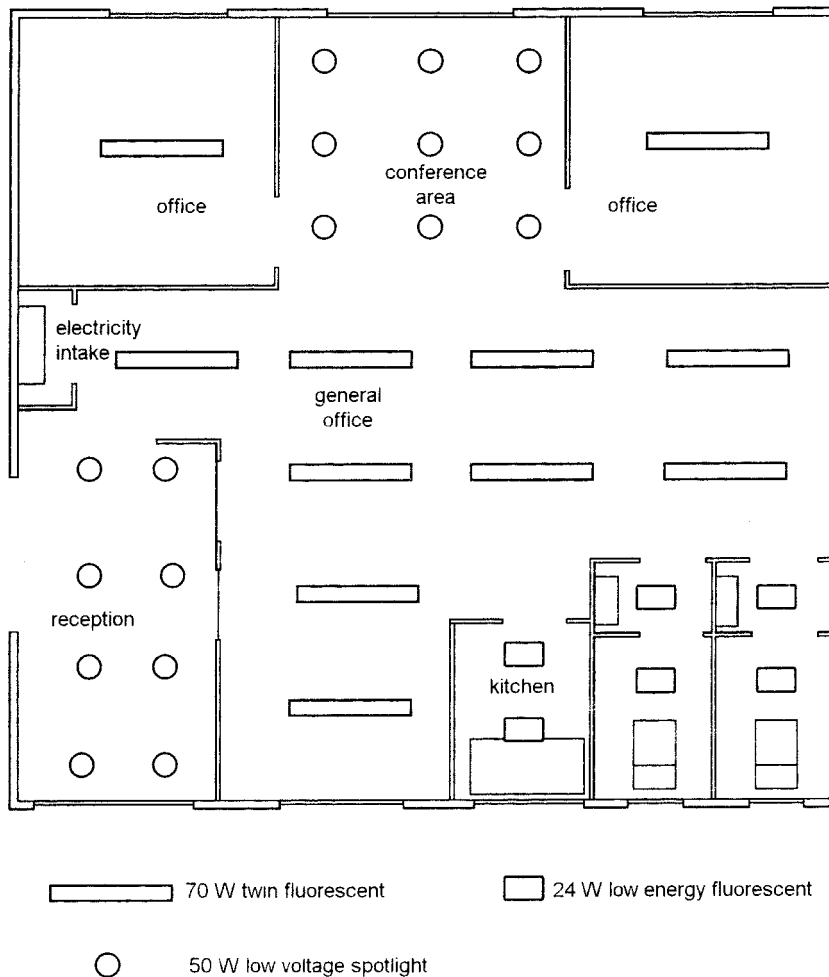


Figure 5.2 Provisional lighting layout for electrical design purposes.

maximum demand. A Project Specification format is shown in Figure 5.4. This, together with layout drawings, becomes part of the contract document.

5.3.1 Loading and diversity

This is not an exact science and calculations may be rounded off. Every project must be considered, taking into account working conditions. A small office situation illustrates the condition where lighting and heating loads are likely to be used simultaneously at maximum capacity on certain occasions. The off-peak heaters may also be brought on line at a time when the office is working. No diversity can be allowed on these loads. However, it is probably acceptable to ignore the lighting and thermostatically controlled heaters in toilets.

311.1

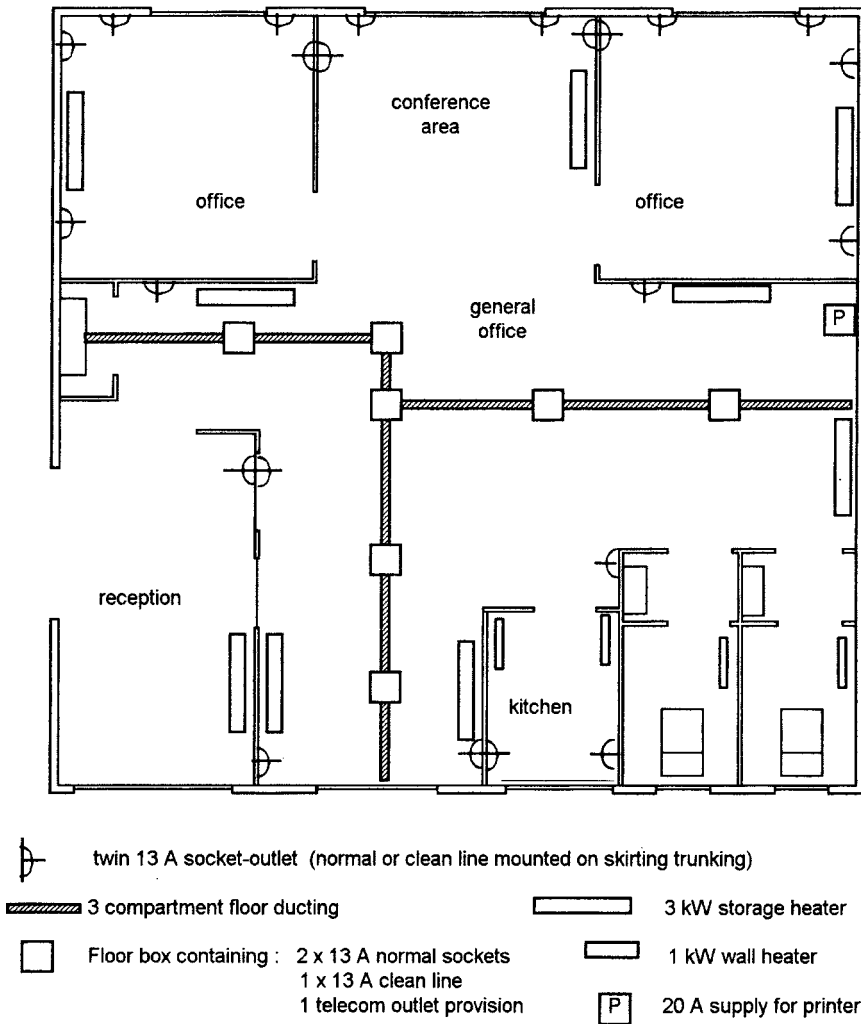


Figure 5.3 Provisional power and heating design layout.

Lighting

For current loading calculations, fluorescent lamp ratings must be multiplied by 1.8 to take into account control gear losses.

$$\text{Fluorescents} \quad \frac{22 \text{ lamps} \times 70 \text{ W} \times 1.8}{230} = 12.0 \text{ A} \tag{5.1}$$

$$\text{ELV spotlights} \quad \frac{17 \times 50 \text{ W}}{230} = 3.7 \text{ A}$$

Project Specification BS 7671 Office Unit				
Name		Location		
Reference		Date		
Three phase 240 V 50 Hz. TN-C-S. Supply fuse 100 A BS 88-3				
PFC less than 16 kA. Earth loop impedance less than 0.35 Ω 100 A TP main switch Two Type B distribution boards Normal and off-peak supplies Type B cbs (6 kA)				
Normal supply				
Circuits	Rating (A)	Cable size (mm ²)	Lights/points g = gang	
1. Sockets 1	32	2.5/2.5	10 × 2g	
2. Sockets 2	32	2.5/2.5	8 × 2g	
3. Sockets floor	32	2.5/2.5	7 × 2g	
4. Sockets clean line	32	2.5/2.5	5 × 2g	
5. Lights 1	10	1.5/1.5	11	
6. Lights 2	10	1.5/1.5	13	
7. Lights 3	10	1.5/1.5	10	
8. Print machine	20	2.5/2.5		
9. Heaters in toilets	20	2.5/2.5	4	
Off-peak service				
1–9 Storage heaters	20 A	2.5	25	9

Figure 5.4 Project specification for office.

5.3.2 Storage heaters

$$\frac{9 \times 3000 \text{ W}}{230} = 117.4 \text{ A} \tag{5.2}$$

5.3.3 Print machine

20 A supply = 20 A

5.3.4 Socket-outlets

These will be used for desktop equipment only. Any reference to floor area or number of outlets is meaningless. A suitable estimate of desktop loading is between 1 A and 3 A per station. Some diversity can be written in.

Assume 2 A per desk, with room for eight desks = 16 A

5.3.5 Total load

Total current (approx.) = 164 A

This will be distributed across three phases, so a three-phase 100 A supply will be appropriate. It is understood that the electricity company will provide a TN-C-S (PME) supply.

5.3.6 Wiring system

Discussions with the client indicate that the best method of socket-outlet distribution would be with electrical skirting and underfloor ducting with outlet boxes. To a large extent, the building construction has determined the wiring systems to be used.

Discussions with the client should also be held to determine whether the installation is likely to be under the control of a skilled or instructed person and, if not, whether the client wants additional protection by RCDs to be omitted for socket-outlets intended for general use.

The decision as to which socket-outlets or circuits do not require additional protection by RCD should be taken only after consultation with a person who has responsibility for health and safety for the premises. That person should be able to ensure that the socket-outlets or circuits in question are, and will remain, under the supervision of skilled or instructed persons.

When a decision has been made to omit RCD protection, traceable confirmation must be obtained from the client to identify the reason for the omission and such confirmation must be included within the documentation provided to the client upon completion of the work.

Where no such confirmation can be obtained, RCD protection should not be omitted.

For this installation, the client has provided written confirmation that the installation will be under the control of a skilled or instructed person and therefore RCD protection will be omitted for the general purpose socket-outlets.

5.4 Skirting system

This will be a proprietary steel or non-metallic system. A rigid PVC skirting may be most attractive for a prestigious office. *Three* compartments are necessary throughout, with suitable segregated door-crossing adaptations. Compartments will be used for: 528.1

1. general power circuitry and storage heaters;
2. the computer clean line;
3. telecommunication and data cables.

Provided that the skirting is installed to give a completely fire-resistant enclosure, ordinary unsheathed 6491X PVC-insulated cables may be used. Special care is needed at the internal and external corners and at junctions, to ensure that the cable enclosure is complete. Socket-outlets will be mounted directly on the skirting at positions related to user requirements. The skirting design should be suitable for future outlet additions.

5.5 Underfloor system

This will be a three-compartment system with segregated floor access boxes. These floor boxes have been planned on a 3 m module. Office users will either find socket-outlets specially located for desk positions or within 1.5 m. 521.8

The mains cables will be fully protected and enclosed within floor trunking. Standard unsheathed 6491X, PVC-insulated cables may be used.

5.6 Socket-outlets

Two systems will be in use:

1. the general-purpose 13 A standard *BS 1363* type; and
2. a special 13 A plug with non-standard pin orientation for the dedicated 'clean' service to computers.

It is recommended that the wiring for this clean line should, wherever possible, take a different route or be contained in a segregated trunking compartment. A dedicated circuit protective conductor will be taken to isolated earthing pins on the special sockets. This conductor will be insulated green-and-yellow throughout its length and finally connected to the main earthing terminal for the installation (see Regulation Group 543.7 of *BS 7671: 2008*).

5.7 Lighting circuits

There are various wiring possibilities, but two are considered as follows. In both cases, the use of luminaire support connectors (LSCs) is recommended. These provide a good accessible plug-in facility for maintenance work. Section 559

1. *Conduit and trunking system:*

Outlet positions will be fixed to the underside of the soffit and interconnected with plastic trunking or plastic conduit fixed to the ceiling. A flex connection is then made from these ceiling outlets to luminaires or extra low-voltage transformers.

Plastic conduit drops will be used for services to wall switches.

2. *Sheathed twin and earth cables:*

522.8 Flat twin and earth cable can be used, concealed in the ceiling void. It must be fixed to the ceiling either directly or on a timber batten and not draped across a metallic ceiling grid.

526.4 The cable can be taken straight into the luminaire connector or transformer terminals, provided that there is no excessive heat and the cable is protected against abrasion at the entry point. This tends to be an untidy installation and notice must be taken of the Wiring Regulations requirement for good workmanship.

134.1 A much tidier job can be achieved with the use of ceiling roses or luminaire supporting couplers with flex connections to luminaires and transformers.

5.8 Battened out ceilings

522.6 Where headroom is at a premium, or for reasons of economy, false ceilings are often constructed of plasterboard fitted to timber battens. Wiring installed in this space is subject to restrictions similar to those imposed on wiring installed beneath floor boarding:

1. cables that have a soft sheath, such as flat twin and earth, must run at least 50 mm from the underside of the batten; or
2. cables must incorporate an earthed sheath (MICS or SWA); or
3. cables must be enclosed in earthed steel conduit or given equivalent mechanical protection.

Options 2 and 3 are likely to be more expensive and time-consuming to install, so may therefore be not viable. In order to use unprotected twin and earth cable, a convenient method for lowering the ceiling to comply with the 50 mm requirement is to cross-batten the ceiling. If battens are orientated in the right direction, this has the added advantage that cables may be easily routed without the need to drill or notch-out wiring channels.

5.9 Extra-Low Voltage lighting (elv)

Two office areas have been planned to have decorative elv lighting.

This scheme is intended to give guidance upon wiring practice. The actual number and selection of luminaires will be a special design detail and is not included here. References should be made to suppliers regarding SELV lighting systems.

There is a choice of elv transformer systems.

5.10 Group transformers

This involves the use of relatively large transformers, each of which will supply a group of luminaires. This may have cost advantages but rating is important:

- Elv lamps are voltage critical. Only the designated number of luminaires may be connected to the transformer and with some designs the output voltage will rise upon failure of one lamp. This will shorten the life of other lamps connected to the same transformer.
- The transformer may run hot and good ventilation will be essential. There must be adequate clearance above and around the unit. Manufacturers' instructions should give this information. 422.1
- There must be access to transformer terminations. The length of cable runs is critical and this may cause problems in locating a good accessible mounting position. 526.3
- Wiring between the transformer and a luminaire must be completely segregated from other cables. The connection to the fitting must be contained in a fire-resistant enclosure and the final tails to the lampholder will need to be heat resistant. 414.4
528.1 526.2
- The wiring system may, depending on the equipment used and the system employed, be subject to the requirements for SELV, which include no provision for earthing. Where a SELV system is installed, care must be taken to ensure that all live parts, including the transformer secondary and the enclosure, are completely separated from earthed metalwork. Section 414

5.11 Individual transformers

These are matched to single luminaires; they usually run cool and have protective thermal cut-outs. Probably the most convenient is the type that fits through the luminaire mounting aperture and stands alongside within the ceiling cavity.

5.12 Fire prevention

All flush-mounted luminaires, which project to the rear of ceiling linings, must be enclosed and have adequate ventilation. Care must be taken to ensure that no combustible materials can come into contact with hot surfaces and that thermal insulation does not restrict ventilation.

ELV lamps that cause a focusing or concentration of heat must be of sufficient distance from other objects to prevent dangerous temperatures arising. Materials used for the construction of enclosures must comply with heat resistant standards. 422.1

5.13 Arrangement of circuits

Table 5.2 indicates a possible spread of circuits across three phases. There is flexibility in the arrangement, but it is sufficiently accurate for general applications. Actual conditions will vary with inevitable load diversification.

Table 5.2 Arrangement of circuits across three phases.

Phase	Circuits	Amps (approx.)
Brown	<i>Lights</i>	
	Executive offices and conference area	4.0
	Storage heaters	37.5
	Print machine	20
	Possible total	62
Black	<i>Lights</i>	
	Centre office and toilets	8.4
	Storage heaters	37.5
	Window wall sockets	10
	Inside wall sockets	10
	Possible total	66
Grey	<i>Lights</i>	
	Inside office and reception	3.7
	Storage heaters	37.5
	Floor sockets	10
	Dedicated sockets (clean line)	10
	Heaters in toilets	12
	Possible total	71

5.14 Distribution boards

411.3.3 There will be two three-phase distribution boards to accommodate normal and off-peak services (Figure 5.5). These will be located at the meter position. The office layout is compact and no sub-mains are required. None of the equipment has any especially high starting loads, so Type B circuit-breakers will be appropriate. There is no requirement for RCD protection for socket-outlets intended for general use, as the client has specified that the installation is to be under the control of a skilled or instructed person. RCD protection is also to be omitted for the socket-outlets supplying the computer equipment, as the use of an RCD could be the subject of unwanted tripping.

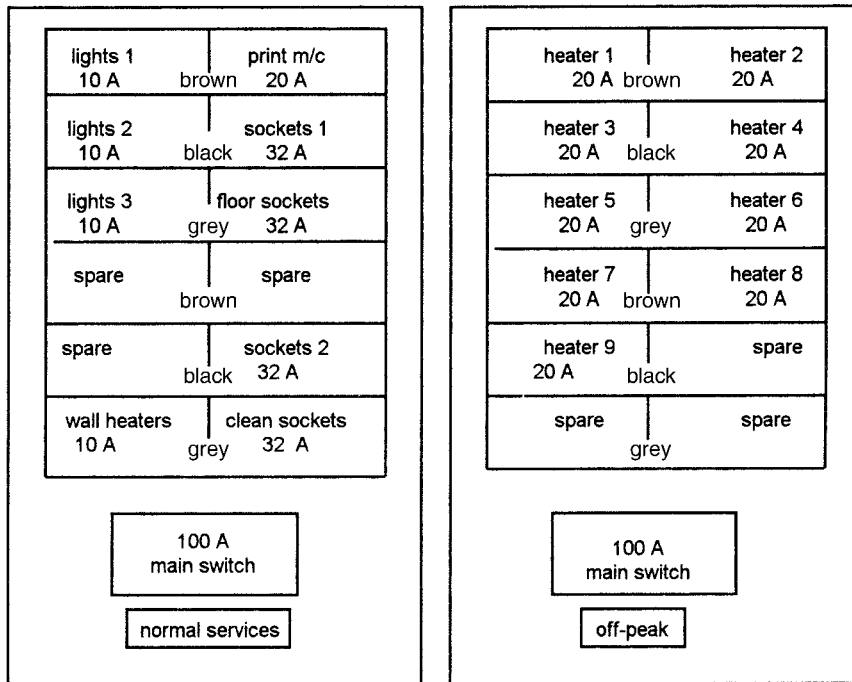


Figure 5.5 Two distribution boards for office.

5.15 Cable sizes

Cable sizes are given in Table 5.3. It will be seen that these relate to:

- the maximum design current for the circuit or appliance;
- the rating of the protective (circuit-breaker [cb]);
- installation methods and enclosures;
- grouping as shown;
- maximum length of run;
- maximum earth loop impedance of the pme supply at 0.35Ω ;
- voltage drop.

If any of these variables change or *exceed* the limits shown, sizes must be recalculated.

5.16 Switchgear

Standard requirements for isolation and switching apply.

Table 5.3 Cable sizes.

Circuit	Full load (A)	cb rating (A)	Cable type (ref.)	Size (mm²)
Lighting				
(Enclosed in conduit or trunking)				
1	4.0	10	singles 6491X	1.5
2	8.4	10	singles 6491X	1.5
3	3.7	10	singles 6491X	1.5
(Unenclosed)				
1	4.0	10	T&E 6242Y	1.5
2	8.4	10	T&E 6242Y	1.5
3	3.7	10	T&E 6242Y	1.5
Power sockets				
Floor and wall outlets				
Alternative possibilities with cables enclosed in skirting or underfloor trunking				
3 circuits each			Radial	
	20 A max.	20	singles 6491X	2.5
3 circuits each			Radial	
	32 A max.	32	singles 6491X	4.0
3 circuits each			Ring	
	32 A max.	32	singles 6491X	2.5
Dedicated power circuit for computers				
As above for power circuits with cables enclosed in skirting or under floor trunking				
Storage heaters				
All similar with a maximum of three circuits enclosed in skirting trunking				
9 × 3 kW	12.5	16	singles 6491X	2.5
Wall heaters				
One circuit, three heaters with cables enclosed in skirting trunking				
3 × 1 kW	12.5	16	singles 6491X	2.5

The storage heaters will be supplied via an off-peak tariff meter. This will involve either remote switching by the Distributor or time switch control at the meter position. Either method of control will require a contactor connected between the main heating isolator and the circuit-breaker distribution board busbars. This contactor coil should be supplied from the general purposes distribution board or from a separate fuse or circuit-breaker connected to the main switch and separate from the busbars. Regulations require that the contactor is labelled, indicating that it has more than one means of isolation and informing the user of the positions of relative isolators. 514.11

The switchgear will also require other labelling to identify, for example, any circuits that have requirements for 'high integrity earthing', and each distribution board will require a circuit schedule indicating, as a minimum, the: 514.9
543.7.1.105

- number of points;
- area location;
- circuit loadings;
- type and rating of protective devices;
- cable types and conductor sizes;
- earth fault loop impedance values;
- details of circuits vulnerable to any particular test (usually insulation resistance);
- circuits having high integrity earthing.

5.17 Print machine

A isolator makes provision for this machine at the point of connection.

A 20

5.18 Wall heaters in toilets

All three 1 kW heaters have individual thermostats, so they can be supplied from the same circuit, and fused locally. The most convenient arrangement will be to have a switched fused connection unit adjacent to each heater. 432.1

5.19 Storage heaters

There is a separate circuit for each storage heater. No local fusing is required and if the heater has user controls, no additional switching is required for functional switching, or for mechanical maintenance. Isolation for electrical work can be carried out by either switching off the 20 A double-pole switch installed adjacent to each heater (provided the competent person working on the heater can see the switch at all times) or by securing the circuit-breaker for the circuit concerned in the off position by some effective means, such as by using a locking-off kit. 537.2

5.20 Presence of 400 Volts

Although it is good practice to separate items of single-phase equipment and accessories that have been connected to different phases, such an arrangement is not prohibited by the Wiring Regulations.

- 514.10 There has also been some uncertainty over whether or not to warn others that 400 V is present within certain enclosures and between accessories that are simultaneously accessible. All of that has hopefully been resolved with the new wording of Regulation 514.10, which states that every item of equipment or enclosure within which a nominal voltage exceeding 230 volts to earth exists and where the presence of such a voltage would not normally be expected, the enclosure (or accessory), must be so arranged that before access can be gained to live parts, a warning of the maximum voltage present must be clearly visible.

This means that any item of three-phase switchgear does not normally need a warning label present, as the nominal voltage to earth within the enclosure will not exceed 230 V and the voltage would be expected.

5.21 Access to switchgear

- 513.1 In this instance, the main switchgear is located in a cupboard. Unless there is no possibility of confusion, the cupboard door should be labelled to indicate the presence of electrical equipment.
- 514.8 Normally the door should not be lockable, but where this is found to be necessary, a clear indication of where the key may be found should be given for emergency access. Wherever possible, the occupants should be advised of the need to keep clear access to switchgear and control gear.
- 132.12

5.22 Earthing and bonding

Even though this unit is part of a multi-occupancy building complex, this individual electrical installation must have the full earthing treatment. It may well be that water supplies are fed from a main riser, which is bonded to the landlord's electrical service elsewhere but, regardless of this, the water pipe must be bonded at the point of entry into the architect's office. This is considered to be good practice.

5.23 Main earthing terminal

- 542.4 A single main earthing terminal is required, which will be used to service both normal and off-peak installations. It should be possible to disconnect the earth from either installation without interfering with the other; therefore the terminal must be a separate item and be accessible for test purposes without exposing live parts (Figure 5.6).

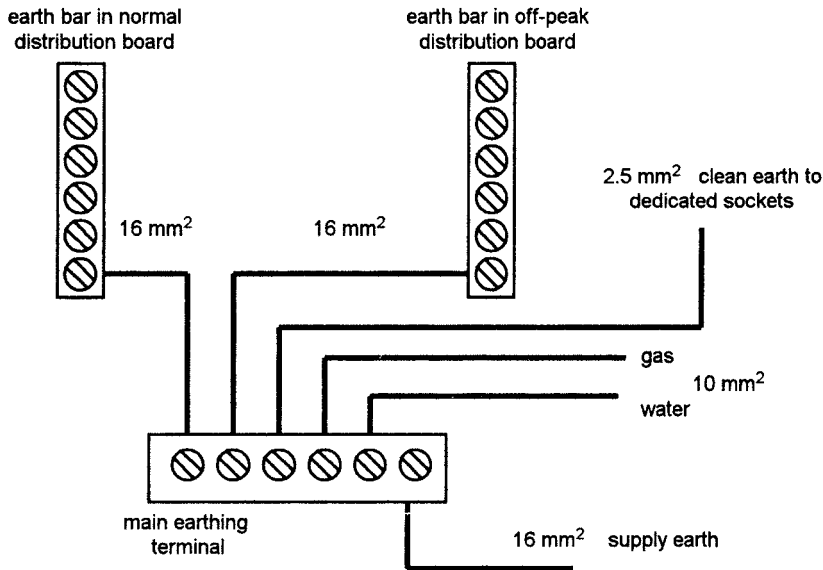


Figure 5.6 Earthing arrangements for office.

A 16 mm² earthing conductor connects the PME earthing terminal to the main earthing terminal. 544.1
The main protective bonding conductors are to be 10 mm² and connect the main earthing terminal to:

- water installation pipework;
- gas installation pipework (if applicable).

In addition:

- two 10 mm² (minimum) circuit protective conductors will connect to the earthing bars in the 543.1 distribution boards.

5.24 False ceiling grid

Previous mention has been made of the protection of wiring within a plasterboard false ceiling. Alternatively there may be a proprietary metallic ceiling grid with inset tiles. This raises the issue of bonding and the definition of an extraneous conductive part.

The definition of an extraneous-conductive part implies that it is liable to introduce a different earth potential into an otherwise equipotential zone. This would not apply to a metallic ceiling grid, which is entirely within the office equipotential zone. There is no requirement for the ceiling grid to be main or supplementary bonded.

If the ceiling grid is carrying lighting fittings, they will have circuit protective conductors, which may or may not make fortuitous contact with the grid. In either case, this is of no consequence as far as the equipotential bonding is concerned. If there are no lights in contact with the grid, it will be isolated metalwork within the zone and bonding is therefore not required.

- 544 If it is the case that a ceiling grid is continuous into the landlord's corridor or another equipotential zone, it will be necessary to bond the office grid to the main earthing terminal for the office, to ensure that it could not carry an imported potential into the office equipotential zone.

5.25 Computer installations

5.25.1 Computer supplies

- 542.4 A clean supply requires a separate *functional earth* to carry *protective conductor* current. This
543.7 conductor will be taken from the main earthing terminal, directly to the isolated special earth
411.3 terminal on dedicated non-standard socket-outlets (Figure 5.6). Any requirement for protective earthing on exposed-conductive-parts of equipment should be connected through the normal earthing facility. This will apply to the printer and photocopier.

The only point of interconnection between the protective earth and the functional clean earth should be at the main earthing terminal.

- 543.7 Apart from giving a clean earth connection, there are other implications to the use of Information Technology equipment in offices, which apply to a Regulation Group to a greater or lesser extent, according to whether a particular office computer is a basic word processor or if it is part of a 'networked' system involving data exchange with other equipment on or off the premises.

5.26 High protective conductor currents

In order to filter out mains spikes and surges, modern electronic equipment incorporates capacitor bridge circuitry connected to earth. This means that each item has an inbuilt and normally harmless protective conductor current, normally in the order of a few milliamps.

- 543.7 This subject is dealt with in depth in Chapter 7, which should be consulted for all large office installations. Many small offices will use sufficient IT equipment for the additional earthing requirements to be considered. On this small project, the few desktop computers will produce minimal protective conductor current, which will be handled by the specified earthing arrangements.

5.27 Mains filters

- 512.1.5 Special provision may be required for filtered mains supplies to desktop computers, especially where mains-borne interference is significant. Spikes and transients from external supply network loads can cause problems with both hardware and software.

Filtered, switched socket-outlets are available to deal with electronic noise, so these could be fitted at all points where computers may be plugged in. Alternatively, low-cost special plug adaptors are available.

5.28 Uninterruptible Power Supplies (UPS)

Unexpected power failure often causes loss of computer data. The installation of basic UPS equipment will supply power for a limited period of time to enable the operator to carry out regulated shut-down procedures. An operational period of five minutes may be adequate in most circumstances, but if a longer period of time is desirable, it should be appreciated that that the equipment would cost more. 313.2

The client may choose to have centralised UPS equipment, with all dedicated sockets connected to a system that can carry the full load. Alternatively, single desktop units may have a local individual UPS source.

The subject should be discussed at the design stage of the project, to ensure that mains switchgear and wiring takes account of UPS distribution requirements.

Earthing is also very important. A centralised UPS system is required to have an earth that is separate from the public supply earthing system, which will be maintained in the event of the supply cable being severed. This may take the form of an earth electrode (e.g. a rod, a plate, or the foundation steel of the building). It will be necessary to ascertain that the earth fault loop impedance values of the circuits supplied by the UPS will still provide automatic disconnection of the supply when the supply earth has been lost and the UPS is running in isolation. A careful study of the *BS 7671* requirements is necessary. 551.4

It is always preferable to segregate UPS cables from normal power cables and communications circuitry, as this topic is becoming increasingly important with new applications for Information Technology equipment. 331.1

A High Street Shop

A small shop with just a counter and storage areas is simple to design. The electrical system follows the layout for a house, but care must be taken on loading factors if direct-acting electric heaters are switched on all day.

These days, many shops have specialised equipment for cooking food or providing other services such as shoe repairs or photographic processing. It is this type of shop that sometimes causes problems for the electrical installer when it comes to estimating loads.

This exercise takes a high street bakery shop as a typical project. The design may be adapted for similar conditions.

6.1 Special considerations

The electrical contractor is often given a shop-fitter's layout plan with minimal electrical information. This is not sufficient to even offer a quotation.

For design purposes, it is essential that the electrical contractor has a full summary of services required. There may be specialised lighting and a mix of single-phase and three-phase machinery. The fact that food is processed on the premises implies strict hygiene rules, which may affect surface runs of conduit. The public have access to the shop, therefore equipment must be suitably located away from unauthorised interference.

Early consultation with the client is necessary. Sometimes equipment is brought from old premises and most clients should have some idea of their actual requirements.

6.2 Other interested parties

Before settling the full electrical schedule, a check must be made upon special or additional requirements:

- *Local authority:*
Food preparation hygiene facilities;
- *Fire authority:*
Fire alarms, emergency lighting and other safety features;
- *Client's insurers:*
Safety equipment in the shop and food preparation areas;
- *Landlord:*
Common alarm or security systems may be used in a shopping complex;
- *Health and safety:*
There may be safety restrictions regarding the use of machinery in some areas;
- *Distributor:*
Check availability of a supply to suit the potential load and confirm the location of the intake position.

6.3 Building structure and finishes

- total floor area, 100 m²;
- concrete floor, tiled throughout;
- concrete soffit, exposed in bakery; suspended false ceiling in shop area;
- walls, brick or building block. Fair-faced exposed in bakery; tiled or plastered in shop and toilets;
- space heating by gas.

6.4 Electrical requirements

Proposed electrical layouts are shown in Figures 6.1 and 6.2. A full schedule of requirements is shown in Table 6.1. It will be noted that space heating is by gas, although cooking is electric. This may not be realistic. In practice, a more likely situation would have gas cooking and heating. However, many catering establishments do have mixed services and in this case the electric cooking has been chosen in order to calculate diversity. A suitable Project Specification is shown in Figure 6.3.

6.5 Loading and diversity

It will be seen that the assessment of maximum demand is very much a matter of experience. There is a tendency to overestimate high fixed loads, which in practice only occur for short periods of time. Thermostats and energy regulators switch heater elements on and off at irregular intervals. 311.1

The largest load on this project is the oven in the kitchen and it is extremely unlikely that the fully loaded 10 kW condition will coincide with full loading on other appliances.

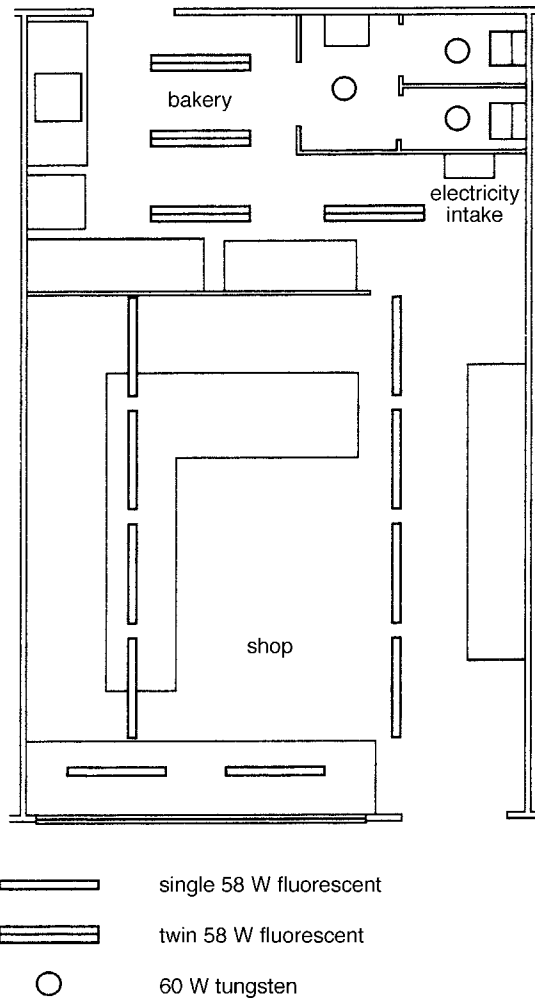


Figure 6.1 Lighting layout for wiring purposes only.

Information is required to determine the size of mains supply. If there is any doubt, it is worth showing diversity figures to the supply company.

IET Guidance Note 1, *Selection and Erection*, gives some advice about loading diversity. The figures used here have been taken from Guidance Note 1, but every project must be considered separately to take into account special factors. This is not an accurate exercise and all figures have been rounded off.

This installation will of necessity be a three-phase load, and maximum current per phase is the important calculation.

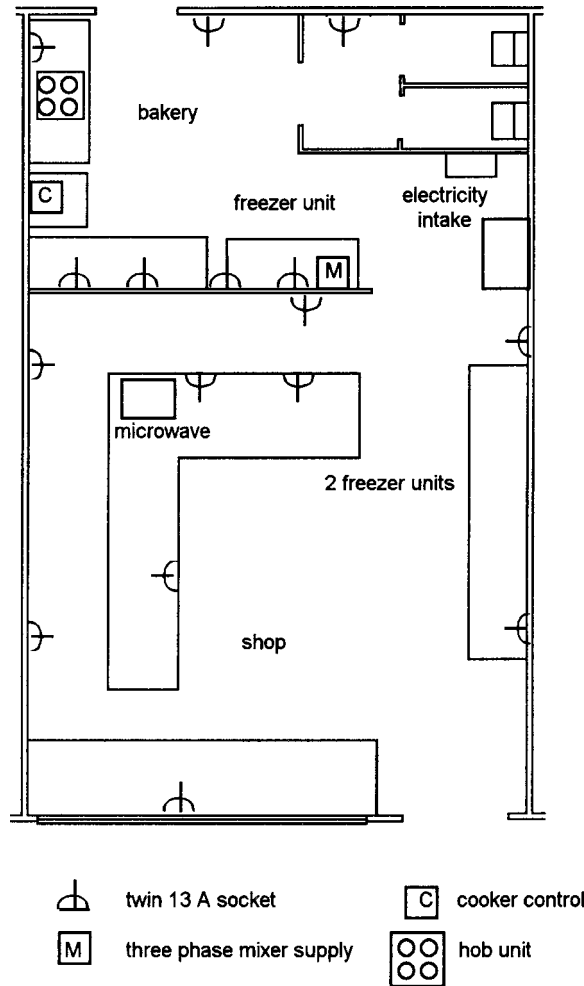


Figure 6.2 Power outlets in shop.

6.6 Lighting

An allowance of 90% diversity is acceptable. For current loading calculations, fluorescent lamp ratings must be multiplied by 1.8 to take into account control gear losses.

An assumption of 100 W per outlet is made for tungsten lamps, regardless of the specification lamp size. For convenience, the bakery shop lighting is spread over two circuits:

Shop lighting load:

$$= 10 \times 58 \text{ W} \times 1.8$$

$$= 1044 \text{ W}$$

$$\text{at 90\% diversity } \frac{1044 \times 90\%}{230} = 4.1 \text{ A}$$

(6.1)

Table 6.1 Provisional electrical schedule.

Shop	Bakery
<i>Lighting</i>	
10 × 58 W	8 × 58 W
	4 × 60 W
<i>Twin 13A sockets</i>	
Display units 2	Freezer 1
Microwave oven 1	Refrigerator 1
Freezers 2	Small mixers 2
General purpose 6	General purpose 4
<i>Other loads</i>	
	3-phase mixer, 750 W
	Oven, 10 kW
	Hob unit, 4 × 1.5 kW

Bakery lighting:

$$\begin{aligned}
 &= (8 \times 58 \text{ W} \times 1.8) + (3 \times 100) \\
 &= 1135 \text{ W} \\
 &\text{at 90\% diversity } \frac{1135 \times 90\%}{230} = 4.5 \text{ A}
 \end{aligned}
 \tag{6.2}$$

Note: 1.8 is a factor, which may or may not need to be applied to all types of fluorescent fittings. If in doubt, consult the manufacturer of the luminaire(s).

6.7 Socket-outlets

Three circuits would be appropriate. It has sometimes been taught that it is custom and practice to put all sockets on one phase, but there is no requirement for this in the Wiring Regulations. However, at this stage, phase balancing has yet to be considered. Diversity allowances are 100% of first circuit and 40% for all others:

$$\begin{aligned}
 &32 + 13 + 13 = 58 \text{ A} \\
 &= 19.3 \text{ A per circuit}
 \end{aligned}
 \tag{6.3}$$

Note that this figure is for total load calculations only, not circuit cable sizing.

Project Specification BS 7671			
High Street Shop			
Name.....		Location.....	
Reference.....		Date.....	
Three phase 230 V 50 Hz. TN-C-S. Supply fuse 100 A BS 88-3			
PFC less than 16 kA. Earth loop impedance less than 0.35Ω			
100 A TP main switch			
Type B distribution board			
Circuits	Rating (A)	Cable size (mm ²)	Lights/points g = gang
1. Sockets shop 1	32	2.5	4 x 2g
2. Sockets shop 2	32	2.5	5 x 2g
3. Sockets bakery	32	2.5	7 x 2g
4. Lights 1	10	1.5	11
5. Lights 2	6	1.0	13
6. Lights 3	6	1.0	10
7. Hob unit	32	6.0	
8. Oven	50	10.0	
9. Mixer 3-phase	6	1.0	

Figure 6.3 Project specification for shop.

6.8 Other appliances

Mixer, at 50% diversity:

$$\frac{750 \text{ W} \times 50\%}{230 \times 3} = 0.55 \text{ A per phase}; \quad (6.4)$$

Oven, at 100% diversity:

$$\frac{10 \times 1000 \text{ W}}{230} = 43.5 \text{ A}; \quad (6.5)$$

Hob unit, at 80% diversity:

$$\frac{6 \times 1000 \text{ W} \times 0.8}{230} = 21 \text{ A.} \quad (6.6)$$

6.9 Phase balance

It is essential to balance loads across three phases as far as possible. This exercise should consider the diversified current demands to obtain a balance under normal working conditions.

Table 6.2 gives an arrangement, which in the circumstances is reasonable but not a good balance. Note that at this stage, this does not necessarily indicate final distribution board particulars; although it may be better to put ring circuits on different phases.

6.10 Wiring systems

This project is interesting in that, at this early stage, some consideration must be given to the type of wiring systems appropriate to the two main areas, shop and bakery. This is one subject upon which the landlord or insurer may have an interest.

Table 6.2 Arrangement of loads taking diversity into account.

Phase	Circuit	Amps
Brown	Sockets	58
	Mixer	0.55
		58.55
Black	Lights	8.6
	Hob	21
	Mixer	0.55
		30.15
Grey	Oven	43.5
	Mixer	0.55
		44.05

6.11 Start by considering cost

From the financial viewpoint it is sensible to consider the most economical wiring system that the Wiring Regulations will permit. This is the starting point for design. Changes to more sophisticated methods may be introduced as the situation dictates.

Undoubtedly twin and earth cable is the easiest and cheapest system to install, but the outer sheathing gives only limited mechanical protection. In the case of the shop, a certain amount of physical maltreatment should be anticipated and considered during the design and specification stages. 522.6

6.12 Shop area

- The public have access and must not be put at risk by their own activities.
- Children will be present and inquisitive fingers can cause damage.
- The shop staff may be heavy-handed in cleaning or careless when handling trays of stock.
- This food shop is subject to hygiene standards, which may include frequent washing down.

Surface mounted twin and earth cable is unsuitable for this situation. It would be precluded by regulations, which specify that the electrical system must be appropriate to the situation and the method of installation must take into account the conditions likely to be encountered. Section 522

It is acceptable to install flat twin and earth cables under plaster or within building voids, provided the concealed cables are installed within prescribed zones. 522.6.101

522.6.02

522.6.103

6.13 Bakery area

Different parts of the bakery area are subject to differing conditions:

- Some general physical abuse can be expected.
- High temperatures will occur in close proximity to the oven and hob units.
- Wall surfaces may be frequently washed down.

In these circumstances, the choice of surface wiring systems should be one or more of:

- steel conduit and trunking;
- plastic conduit and trunking;
- mineral insulated, copper-sheathed cable (MICS) with thermoplastic (PVC) outer sheath;
- steel wire armoured PVC or thermosetting insulated cable.

6.14 Temperature limit of 70 °C

- 523.1 A point of interest is that wherever general purpose PVC cable is used, the recommended limiting temperature is 70 °C. This will apply to all the systems listed in item 6.13, including the MICS with PVC outer sheath. Therefore, none has any working temperature advantage.
- 423.1 A surface heated to 70 °C is very hot and is likely to exist only on the metallic casing of the oven when it is on. The Regulations show 70 °C as the limiting temperature for accessible parts of metallic enclosures for electrical equipment. An air temperature in excess of 70 °C will only be found in the oven or above a hob unit. There would appear to be no problem of cable selection on the basis of temperature alone.

6.15 Temperature limit of 90 °C

If a higher temperature rating is considered to be important, the use of 90 °C thermosetting (XLPE) cable may be possible. This insulation is available on single-core conduit cable. Care should be taken with armoured cable with XLPE insulation. Off-the-shelf supplies will probably have PVC sheathing.

In theory, rigid PVC conduit and trunking could also be used at 90 °C, but the fixing arrangements to accommodate expansion and prevent sagging would be impracticable.

- 512.1.5 It should be appreciated that conductors intended to operate at a temperature exceeding 70 °C in normal service must not be connected to switchgear, protective devices, accessories or other types of equipment, unless the manufacturer of the equipment has confirmed that the equipment is suitable for such conditions.

6.16 Final selection and cable sizes

Having taken all factors into account, the final selection of wiring systems on this project can be made, and are shown in Table 6.3. It should be noted that cable sizes are based upon the scheme as illustrated:

- 0.35 Ω maximum earth loop impedance;
 - maximum voltage drop of 3% for lighting circuits and 5% for other circuits;
 - Type B circuit-breakers.
- 525.101

Information on determining maximum cable length for final circuits is given in Chapter 19.

6.17 Bakery wiring

- *Cable:*
70 °C PVC-insulated Ref. 6491X, single-core cables;

Table 6.3 Proposed cable sizes.

Circuit	Full load (A)	cb (A)	Type ref	Size (mm ²)
Bakery lights in conduit and trunking	4.7	6	Singles to BS 6004: 2000 (2006)	1.0
				1.5
Shop lights, surface or embedded in plaster	4.3	6	T & E to BS 6004: 2000 (2006)	1.0
				1.5
Bakery sockets, ring in conduit and trunking	—	32	Singles BS 6004	2.5
Shop sockets, ring, surface or embedded in plaster	—	32	T & E BS 6004	2.5
Mixer 3-phase, in conduit and trunking	3.2	6	Singles BS 6004	1.0
Hob, in conduit and trunking	25	32	Singles BS 6004	6.0
Oven, in conduit and trunking	42	50	Singles BS 6004	10.0

- *Steel or PVC trunking:*

Main distribution from distribution board at high level to avoid any heat from appliances;

522.2

- *Heavy gauge PVC conduit:*

1. Drops to outlets at worktop mounting height;
2. Ceiling mounted exposed to luminaires.

As an alternative, and to make cleaning easier, PVC mini-trunking could be used for wall drops.

6.18 Shop wiring

- *Cable:*

Twin and earth PVC-insulated Ref. 6242Y:

1. Cables clipped to soffit within false ceiling;
2. Plaster depth down walls with PVC or steel capping.

6.19 Distribution board

This is a small layout and no sub-mains are required. Switchgear selection must take account of the total connected load and not take diversity into account. A suitable distribution board is shown in Figure 6.4.

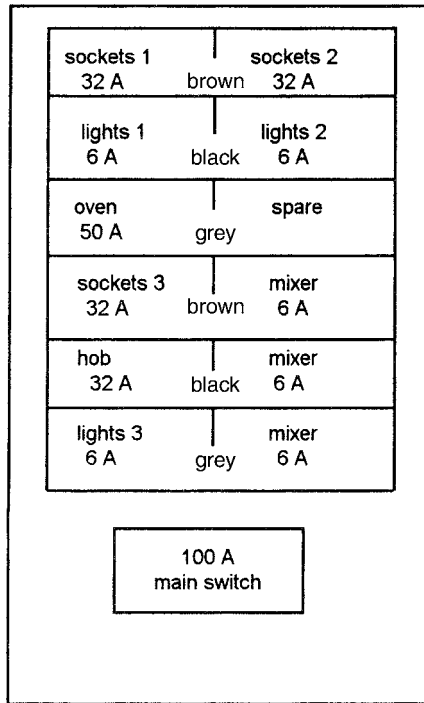


Figure 6.4 Arrangements at distribution board.

There is at least one three-phase appliance, but none of the equipment has especially high starting loads. Therefore a distribution board having a mixture of Type B circuit-breakers and Type B RCBOs is appropriate. A consumer unit incorporating three RCDs, Type B circuit-breakers and RCBOs will be used to supply final circuits supplying lighting and general purpose socket-outlets to *BS 1363*.

411.3.3 The installation will not be under the supervision of skilled or instructed persons, therefore the requirements for providing additional protection by RCD for socket-outlets rated at 20 A or less are almost identical to those for a domestic property. Refer to the requirements in Chapter 2. Consideration could be given to installing separate radial circuits to supply the freezer(s) and refrigerators(s), so that they are not protected by an RCD. If such an arrangement is desirable, a different wiring system would have to be employed or the cables will have to be surface-mounted.

6.20 Cable sizes

525.101 Sizing must take account of circuit-breaker rating, any applicable derating factors, earth loop impedance and voltage drop on full load. Information on how to design circuits can be found in App. 4 Chapter 19 of this book.

6.21 Switchgear

Care should be taken in the location of the metering and main distribution board, as conditions could often be dusty, with steam on occasions. The installer should recommend a cupboard to enclose the switchgear. 512.6

6.22 Isolation and switching

6.22.1 Main switch

This should be a three-pole device. Switching the neutral is not required. 537.1.2

6.22.2 Appliances

Cooker, hob unit and power mixer

All three appliances require individual treatment:

1. functional switching, each appliance will have its own integral controls; 537.5
2. switching for isolation; 537.2
3. switching for mechanical maintenance; 537.3
4. emergency switching. 537.4

All of these functions can be carried out with a suitably rated local isolator. For the emergency switching function, this isolator must be immediately accessible to the user of the appliance. It is possible that the mixer will be supplied through a three-phase *BS EN 60309* plug and socket. This connection would be acceptable as the means of disconnection for isolation and mechanical maintenance, but not for emergency switching. Sec. 537

The mixer has a rating in excess of 0.37 kW, so it is required to have no-volt provision. This may be incorporated in the machine or with an external starter. The starter stop button would then be acceptable as the emergency stop device.

Freezers, refrigerators and microwave ovens

Plug and socket disconnection is adequate for all of these appliances. To avoid accidental disconnection, it may be desirable to plug the freezer cabinets into unswitched socket-outlets, or use fused connection units (see earlier statement about providing separate radial circuits).

6.23 Earthing and bonding

Standard arrangements apply for a PME service. See also Chapter 7.

6.24 Main earthing terminal (MET)

The 16 mm² earthing conductor from the supply earth is taken to the main earthing terminal (MET) (Figure 6.5). 542.4

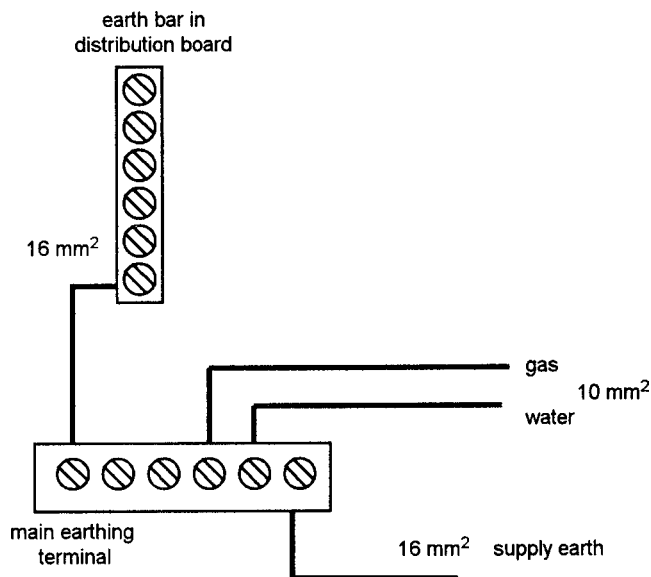


Figure 6.5 Earthing arrangements for shop. (The two bars may be combined if accessible.)

544.1 10 mm² Main bonding conductors are required from the MET to:

- main water installation pipework;
- main gas installation pipework;
- structural steelwork (if any).

6.25 False-ceiling grid

The Wiring Regulations' definition of an extraneous-conductive-part does not generally apply to a metallic false ceiling grid, so there is no requirement for main or supplementary bonding (this subject is explained in detail in Chapter 7).

6.26 Steel tables in the bakery

Using the same logic as for ceiling grids, free-standing stainless steel tables do not require bonding – even if electrical appliances are used. It is possible that a table bolted to a concrete floor could import an earth potential – this should be determined by assessment. In such a case, bonding may be necessary.

Earthing and Bonding

The subject of earthing and bonding is not straightforward, and often raises many controversial issues. This book therefore gives only one interpretation of the 17th edition of the IET Wiring Regulations, as amended, so it is offered in good faith as a starting point for specifications and contract negotiations.

IET Guidance Note No. 5, *Protection Against Electric Shock*, gives a general interpretation of the Regulations on this subject and is a good reference document, but there is no definitive interpretation for every situation. A competent person must be prepared to make a judgement, which ultimately may be tested in a court of law.

Customers and specifying engineers are entitled to state special requirements for contracts. In fact, their requirements are often in excess of the Wiring Regulations and there is no harm in this, provided that contract documents show what is actually required, and the customer is willing to pay for the work. If a project specification only calls for compliance with the Regulations, the contractor may make a judgement as to the minimum requirements. This does not imply a low standard. The IET Wiring Regulations is the Standard that designers and installers should follow, so that their electrical installations will be safe to put into service.

This chapter illustrates the use of these minimum requirements by explaining the reasoning behind earthing and bonding principles. These principles form the first line of electrical shock protection, so they should be studied carefully.

Take no chances. If in doubt upon earthing requirements, seek advice.

7.1 Terminology

Explanations in this chapter are based on the IET Wiring Regulations, so they stand alone, but they may refer to more than one Regulation number.

Electrical Installation Designs, Fourth Edition. Bill Atkinson, Roger Lovegrove and Gary Gundry.
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It is essential that the correct terminology is used when referring to electrical installations, especially if this is different from personally familiar words and phrases. This is because disputes are sometimes caused by a misunderstanding of the definitions given in *BS 7671*. Often the result is that participants talk at cross purposes. Confusion is even more significant where the wrong words are used in written documentation, especially when these are contract requirements.

Unfortunately, the definitions of many words have changed, in order to give internationally harmonised meanings. We must all therefore understand the new terms and definitions. We may be convinced that our own long-established usage is better than the official interpretation, but a court or tribunal will not settle a claim on personal interpretations.

7.2 Definitions

This is one occasion when it may help to give some actual definitions from the IET Wiring Regulations:

- *Exposed-conductive-part*:
A conductive part of equipment, which can be touched and is not normally live, but which can become live under fault conditions;
- *Extraneous-conductive-part*:
A conductive part liable to introduce a potential, general earth potential and not forming part of the electrical installation;
- *Earthing*:
The act of connecting exposed-conductive-parts of an installation to the main earthing terminal (MET) of that installation;
- *Equipotential bonding*:
Electrical connection maintaining various extraneous-conductive-parts and extraneous-conductive-parts at substantially the same potential;
- *Protective bonding conductor*:
Protective conductor provided for protective equipotential bonding.

7.3 Green-and-yellow conductors

514.4.2 The most important conclusion to be made from the definitions is that the words *earthing* and *bonding* are not synonymous or interchangeable, so the use of the phrase ‘Earth-bonding’ would be wrong and improper. The correct group term for green-and-yellow cables is *protective conductors*.

A protective conductor may be:

- The *earthing conductor*: connects the MET of an installation to an earth electrode or to other means of earthing;

- *A main protective bonding conductor*: connects the MET to extraneous-conductive-parts, for example water and gas installation pipework;
- *Supplementary bonding conductor*: is not normally required, except in special locations (such as swimming pools) where there is increased shock risk.
- *Circuit protective conductor(cpc)*: connects the exposed-conductive-parts of equipment to the MET.

7.4 Protective earthing and protective equipotential bonding

The most common protective measure in the UK for protection against electric shock is referred to as Automatic Disconnection of Supply (ADS). The principle is used to satisfy one or both of the basic international safety requirements to reduce the intensity or duration of an electric shock. 411.3.1.2

ADS is achieved by earthing, which is a separate part of the exercise that relies upon the use of cpcs, overcurrent protective devices and the installation connected to a reliable means of earthing.

The purpose of equipotential bonding is to maintain various exposed-conductive-parts and extraneous-conductive-parts within a zone, at substantially the same potential. Such components may not necessarily be simultaneously accessible. Bonding conductors are not intended to carry fault current, although they may well do so.

Bonding connections can sometimes carry substantial network current – even with the local supply isolated. Care should always be taken when disconnecting a protective bonding conductor for testing or service alterations.

7.5 Protective Multiple Earthing (PME)

7.5.1 Why earth at all?

A public electrical distribution system in the UK is required to be earthed at the source of supply (i.e. the local transformer). If the source is not earthed, it will inevitably acquire a connection to earth at some stage when an electrical fault occurs in a consumer's installation. This first fault would be harmless and may go undetected. However, the system would then be earthed.

Subsequently, a second fault to earth could arise in another location or installation. An electric current would then flow between the two independent earth connections, which may cause a fire at either or both places.

By making a positive earth connection at the transformer, the supplier ensures that all earth faults can be detected and made safe by the operation of protective devices, such as fuses, circuit-breakers or residual current devices.

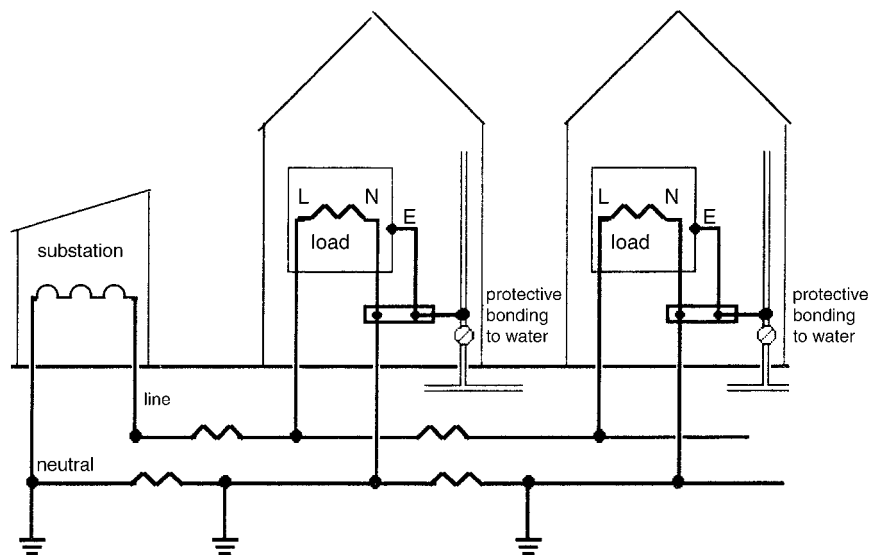


Figure 7.1 The principle of PME.

7.6 Reliability of the earth-neutral path

Over the years, distribution networks and installations have become more complex, and with complexity there are increased chances of faults and open circuits. It therefore became technically expedient to earth the neutral conductor at different places around the network. This is what is now called protective multiple earthing (PME):

The principle of PME is shown in Figure 7.1. For clarity, this is a simplified single-phase system. The IET Wiring Regulations designate an installation using an earth derived from a PME network as TN-C-S. It should be appreciated that a distributor has a general obligation under Regulation 24(4) of the ESQCR to make available for connection to the earthing conductor of the installation his PEN (combined neutral and protective) conductor or, if appropriate, the protective conductor of his network. However, there is an exception to this obligation where this would be inappropriate for safety reasons, such as may be the case for certain locations or installations (e.g. on farms and caravan supplies).

Note the multiple earthing, and the fact that this may only be carried out on the supply network. The consumer is provided with three terminals: line, neutral and earth. Within the installation, the neutral and earth should never be interconnected. This is dangerous, contrary to the *Electricity Safety, Quality and Continuity Regulations (ESQCR)*, and is therefore illegal in the UK. If neutral and earth are accidentally or deliberately joined, an indeterminate current will flow, which may be related to network conditions, not just the situation within the particular installation.

It will also be seen that all network conductors, including earth, have resistance. When current flows, resistance produces voltage drop. In the case of the soil, there will exist a potential gradient between earth electrodes. There could be a difference of a few volts between different ‘earths’ on the system. This is the reason why the introduction of ‘earthy’ extraneous-conductive parts into an existing equipotential zone may create hazardous, or inconvenient, touch voltages.

Equipotential bonding of all metallic services and extraneous-conductive-parts creates an electrical zone, where everything within reach is effectively at the same potential. Isolated metalwork, by definition, is insulated from earth and is not an extraneous-conductive-part. Isolated metalwork carries no potential and should not be bonded.

The equipotential zone may be extended to other related areas using main protective bonding conductors.

7.7 Main bonding

Metalwork entering the zone from another area is sometimes fortuitously connected to the earthing facility on a different system, which could bring in a different earth potential. This metalwork must therefore be bonded locally to maintain the equipotential characteristics of the zone. Metalwork or other conductive material entirely within the zone is no problem. The Wiring Regulations require installations that serve more than one building to have the main bonding applied in each building. This may not be practical or desirable, in which case an alternative to extending the equipotential zone is to provide each building with a separate TT earthing system by means of its own installation earth electrode. The requirements for a TT system would then apply to each building making use of an earth electrode.

544.1

Most of the following metallic items within the zone need not be bonded:

- door handles;
- window frames;
- stainless steel sinks with or without metallic drainpipes;
- suspended ceiling grids;
- free standing metallic tables or benches;
- metallic cupboards, shelving or racks.

Where electrical appliances or luminaires are in close proximity to one or more of the above excluded items, it may be decided to *earth* them. This is a subjective safety judgement and not considered to be an equipotential bonding issue.

Metallic water, gas and oil service pipes entering a building must have a main equipotential bonding connection made as near as practicable to the point of entry of that service into the premises. However, where there is an insulating section or insert at that point, or there is a meter, the connection must be made on the consumer’s hard metal pipework and before any

544.1.2

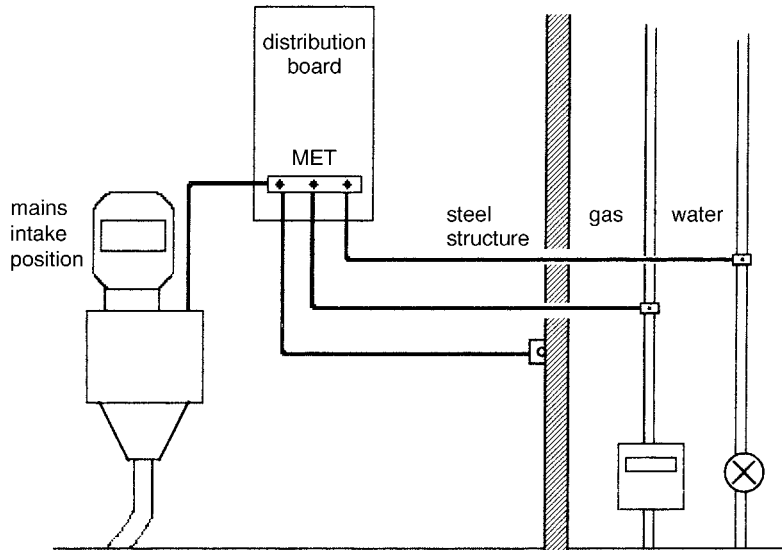


Figure 7.2 Connections at the MET must be accessible for testing.

branch pipework. Where practical, the connection must be made within 600 mm of the meter outlet union or at the point of entry to the building if the meter is installed outside (Figure 7.2). Depending on the location of such services, it may be convenient to run one main protective bonding conductor to more than one bonding connection. This is permitted, provided that it is possible to disconnect any single service without interfering with the bonding to other services (Figure 7.3).

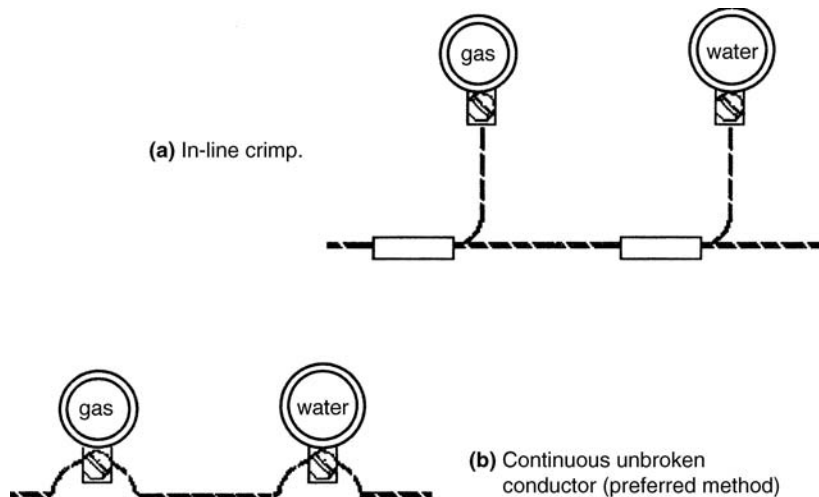


Figure 7.3 Three bonding methods using a single cable.

Table 7.1 Minimum size of PME main protective bonding conductors.

Copper equivalent cross-sectional area of the supply neutral conductor (mm ²)	Minimum copper equivalent, ^a cross-sectional area of the main protective bonding conductor (mm ²)
35 or less	10
>35 up to 50	16
>50 up to 95	25
>95 up to 150	35
>150	50

Note: Local distributor's network conditions may require a larger conductor.

^aThe minimum copper equivalent cross-sectional area is given by a copper bonding conductor of the tabulated cross-sectional area or a bonding conductor of another metal affording equivalent conductance.

Other items that may also need main equipotential bonding include structural steelwork and lightning protection conductors. A central heating system entering the building, or a rising main, would also need to be considered.

According to *BS 7671*, a protective bonding conductor need not always be a cable, or a conductor of a cable. For example, some extraneous-conductive-parts can be used, if considered to be appropriate, provided continuity is permanent and reliable and the conductivity is equivalent to that of the appropriate copper conductor. Suitable structural steelwork and pipework may be used, but not a gas pipe, oil pipe, flexible or pliable metal conduit, support wires or other flexible metallic parts.

The use of extraneous-conductive-parts for main bonding involves a careful examination of the on-site conditions. Only main bonding utilising cables is considered in the projects within this book.

Although the Wiring Regulations require minimum copper equivalent sizes of main bonding conductors for PME systems, as shown in Table 7.1, the local distributor's network may require a larger conductor. A conductor having a smaller csa may be acceptable for TT and TN-S systems, but as most installations may eventually be connected to a PME network, it is suggested that the values given in the table should be used for all situations. 544

7.8 Single fault condition

An important factor to be considered is that *BS 7671* only provides for a single fault condition. Bonding does not exist to clear faults on unrelated equipment, which should have their own protective measures. The risk of a live conductor coming into contact with an 410

extraneous-conductive-part elsewhere should be eliminated by protective and functional insulation or by placing it within a metallic enclosure, conduit or trunking or cable sheath, which is suitable for use as a cpc.

It is only when a fault on equipment is compounded by a failure of insulation, or a protective device will not operate, that an extraneous-conductive-part can become live. Main bonding can help to reduce the disconnection time when a fault occurs, but this is not its primary function.

7.9 Supplementary bonding

Supplementary bonding is normally required only in areas of increased shock risk, such as swimming pools, some agricultural premises and so on. Such applications are shown in projects in other chapters of this book.

As with main bonding, the prime purpose of supplementary bonding is to ensure that all simultaneously accessible metalwork that may already be earthed separately from electrical installation, for example water pipes, is at the same potential.

415.2 *BS 7671* permits the use of supplementary bonding for situations where the earth loop impedance is too high to affect automatic disconnection of the supply when an earth fault occurs. The condition rarely applies in small installations, and requires special consideration. Designers should therefore not consider this as their first choice for protection against electric shock and, therefore, it is not covered in detail within this publication. Nevertheless, it is sometimes a good idea to install supplementary bonding, for example by cross-connecting structural steel with metallic switchgear. This will generally help to lower the total earth loop impedance.

It is not a good idea to ‘cross-bond’ to isolated metalwork, such as windows or doors set in timber frames. This not only looks unsightly, but may transmit, under certain conditions, a potential to an otherwise safe component.

7.10 Circuit Protective Conductors (CPCs)

The subject changes now from bonding to earthing. This may be academic in that electric current will not take note of labels and differentiate between green-and-yellow cable routes, plumbing or structural metalwork. Fault current will be divided across all available paths in proportion to relative resistances in accordance with Ohm’s Law.

543.1 Circuit protective conductors (cpcs) are the green-and-yellow wires connected to appliances or taken through conduits to accessories. It is incorrect to call them ‘earth wires’. A cpc must be sized and installed to ensure that any earth fault current will operate the appropriate protective device safely and speedily.

The sizing of cpcs is related to:

- the cross-sectional area of the live circuit conductors (i.e. line and neutral);
- the rating of the protective device;
- rapid disconnection within a designated time;
- the prospective fault current.

Note that the above does not include the normal load current. This will have been taken into account when selecting the line and neutral conductors and the associated protective devices.

This book does not cover calculations for protective conductor sizes. However, the projects shown have been designed with suitable cpcs, which will conveniently fulfil the requirements of the Regulations. In some circumstances, this results in over-engineering and the designer may find it a commercial advantage in calculating the protective conductor sizes, rather than selecting the size from Table 54.7 of *BS 7671*. General information on the selection and calculation of protective conductors can be found in Pocket Guides 14 and 15, respectively, published by NICEIC.

7.11 Steel conduit and trunking

Undoubtedly, metallic conduit has sufficient conductivity to be an effective cpc. Unfortunately, a problem arises regarding continuity at joints, particularly where a coupler and bush is used at knock-out holes in sheet metal enclosures. It would be difficult to assert that every joint will give permanent and reliable continuity over the life of the installation. In addition, in the absence of definitive information, a full continuity calculation would need to be carried out for every joint in the installation. 543.2

For the purpose of the projects in this book, it is recommended that a green-and-yellow insulated copper conductor be installed in all conduits. The conductor should be the same size as the largest line conductor in the conduit.

It is important to remember that this does not reduce the responsibility to ensure the continuity of the conduit system. This is necessary to earth the conduit itself and constitutes a good reason to use insulated plastic conduit. 526.1

Steel trunking can be considered in the same light as conduit. Effective continuity is as good as the worst joint. If permanent and reliable continuity can be assured, there is no reason why the trunking should not be used as the sole cpc. However, the designer must be assured that the cross-sectional area at joints corresponds to the formula given in the Regulations.

An easier and possibly more reliable solution is to install a separate copper cpc.

Note that it is acceptable to use just one cpc and/or bonding conductor for a group of circuits. This conductor should be sized appropriately to the largest circuit or bonding requirement. 543.1

Tee-off connections should be made in a manner that allows modifications and disconnections to be carried out without breaking the continuity to other equipment. In-line crimped joints are recommended.

7.12 Steel wire armoured cable

Is the armouring of a particular cable adequate for 'earthing' purposes? This is a matter of terminology and, as will be seen, the armouring can sometimes be suitable as a main bonding conductor, but it will generally be satisfactory as a cpc but, where doubt exists, consult the manufacturer.

543.1 The cross-sectional area of every protective conductor, other than a protective bonding conductor, must be:

1. calculated (using the adiabatic equation) in accordance with Regulation 543.1.3; or
2. selected (using Table 54.7) in accordance with Regulation 543.1.4

Once again the issue of calculations is avoided in this book and only the second option is considered here. It must be emphasised that this method is probably unduly pessimistic and a more economical solution may result from detailed calculations.

7.13 Comparison of thermoplastic (PVC) and thermosetting (XLPE) armoured cable

The physical sizes of insulation around similar conductor size PVC and XLPE cable are different. XLPE cable has a smaller diameter. The quantity of steel armour is therefore different and these cable types must be considered separately. The Wiring Regulations also give different insulation factors. Table 7.2 shows differences for a selection of cables and clearly illustrates the problems associated with use of armouring as a cpc without making calculations. The subject is complicated by the different maximum operating temperatures of the two types of insulation. These are 70 °C for PVC and 90 °C for XLPE.

As a general rule, on the commonly-used smaller sizes of PVC SWA cable, armouring is nearly always acceptable as a cpc. It may also be acceptable for some sizes of XLPE SWA cable, but calculations need to be carried out. These involve a knowledge of the prospective earth fault current on the project.

7.14 Continuity of cable glands

526.1 Regardless of any of the above considerations, it is essential to ensure permanent and reliable continuity at terminations of armoured cable. This is necessary to carry fault current if the sheath is penetrated and there is a short-circuit between the armouring and a line conductor.

Table 7.2 Gross cross-sectional area of steel wire armour for use as a cpc. (Multicore armoured cables having copper conductors and thermosetting insulation complying with BS 5467 or BS 6724).

Nominal csa of conductor (mm ²)	Formula as given in Table 54.7 of BS 7671	Minimum required csa of armouring (mm ²)	Actual csa of armouring from BS 5467 or BS 6724 (mm ²)			
			Number of Cores			
			2	3	4	5
1.5	$\frac{k_1}{k_2} \times S$	4.66	15	16	17	19
2.5		7.77	17	19	20	22
4.0		12.43	19	20	22	25
6.0		18.65	22	23	36	40
10.0		31.09	26	30	42	46
16.0		49.74	42	45	50	72
25.0	$\frac{k_1}{k_2} \times 16$	49.74	42	62	70	80
35.0		49.74	60	68	78	100
50.0	$\frac{k_1}{k_2} \times \frac{S}{2}$	77.72	68	78	90	144
70.0		108.80	80	90	131	166
95.0		147.66	113	128	147	—
120.0		186.52	125	144	206	—
150.0		233.15	138	204	230	—

1. BS 5467 covers electric cables, thermosetting insulated, armoured cables for voltages of 600/1000 V and 1900/3300 V.

2. BS 6724 covers electric cables, thermosetting insulated, armoured cables for voltages of 600/1000 V and 1900/3300 V, having low emission of smoke and corrosive gases when affected by fire.

3. A crossed-out figure indicates that the csa of the armouring is not suitable for use as a protective conductor (i.e. it does not meet the requirements of Table 54.7 of BS 7671).

4. Where a value is close to the minimum required csa of armouring, or the cable has PVC insulation, consult with the manufacturer of the cable.

4. $k_1 = 143$, selected from Table 43.1 of BS 7671 (the value of k for copper conductor with 90 °C thermosetting insulation).

5. $k_1 = 46$, selected from Table 54.4 of BS 7671 (the value of k for a steel protective conductor with 90 °C thermosetting insulation).

Ensuring the continuity of SWA cable gland joints to steel switchgear enclosures can often present installers with a number of challenges, especially where the enclosure is powder coated. Furthermore, enclosure sections fabricated from separate panels increase the chances of a high resistance fault path to earth. To establish good continuity, it is considered good practice to fit an earth tag washer to the gland and link it with a suitably sized fly lead to the enclosure's earthing terminal.

7.15 Equipment having high protective conductor currents

543.7 The Regulations devote several regulations to earthing arrangements for equipment that have a continuous protective conductor current as part of the design.

The type of equipment that produces such a current includes:

- Information Technology equipment, which includes most computers, data processing devices and other specialised apparatus, such as life support systems in hospitals;
- luminaires operating at high frequency; and
- some types of heating element.

For the purposes of explaining how such currents are created, computer equipment is referred to from hereon as having inbuilt suppression filtering circuitry, which use capacitance bridge filters that (intentionally) pass unwanted components of the electricity supply to earth.

On small desktop computers, the individual protective conductor current is very small and of no great consequence. However, on large groups of personal computers or single items of mainframe and/or server equipment, the total protective conductor current can be substantial and introduces a potential hazard to personnel.

With good, reliable earthing on the consumer's installation, the protective conductor currents are adequately handled. However, if an open circuit occurs on the system earth, or a high resistance connection arises, everything connected to the faulty earthing system will acquire a potential from the filter circuitry. The fault may not occur suddenly; it may, for example, develop by way of corrosion at a joint.

Many computers have all-insulated enclosures; these would not cause a problem, but the fault potential will be transmitted to equipment with exposed metallic parts, such as photocopiers or heating appliances.

7.16 Protective conductor currents

The installer will not usually have any information on computer protective conductor currents (sometimes referred to as 'earth leakage current', for example in equipment product standards) and the supplier may be unhelpful. We can infer from the Wiring Regulations that a protective conductor current not exceeding 3.5 mA may be ignored. A single desktop computer will be below this figure, so a normal 13 A plug and socket connection is adequate for a single home computer.

Advice should be sought from the computer manufacturer for larger items of equipment or large office installations. The amount and sophistication of IT equipment is continually increasing, even in small offices. Almost every desk position has a computer screen. Equipment, such as photocopiers, are computerised and have leakage currents. If a circuit is likely to serve more than

four desk positions, then the special earthing requirements for high protective conductor currents need to be considered.

Highly sensitive milli-amp clampmeters are available for measuring protective conductor currents in IT equipment. In many offices and commercial premises, it will be necessary for the electrical contractor to measure the total protective conductor current in a circuit before adding socket-outlets for additional equipment. If necessary, the circuit earthing arrangements will need upgrading to accommodate additional equipment.

7.16.1 Items of stationary equipment

Where the protective conductor current is expected to be above 3.5 mA, but not exceeding 10 mA, the equipment should be either permanently connected to the fixed installation without the use of a plug and socket-outlet or connected by means of a plug and socket-outlet complying with *BS EN 60309-2* – such an arrangement is commonly known in the industry as a ‘Commando’ type plug and socket. 543.7.1.101

Where the item of stationary equipment has a protective conductor current in excess of 10 mA, the equipment should preferably have a permanent connection to the supply. Alternatively, a *BS EN 60309-2* plug may be used, provided the protective conductor of the associated flexible cable is of a cross-sectional area not less than 2.5 mm² for plugs rated at 16 A and not less than 4 mm² for plugs rated above 16 A.

7.17 ‘High integrity’ earthing

Where a final circuit or distribution circuit is intended to supply one or more items of equipment, such that the total protective conductor current is likely to exceed 10 mA, the Wiring Regulations requires them to have a ‘high integrity’ protective connection, by one or more of the following arrangements given in Regulation 543.7.103. This may be achieved by means of a single protective conductor having a cross-sectional area of not less than 10 mm², complying with the requirements of Regulations 543.2 and 543.3 (shown in Figure 7.4a).

An alternative arrangement is to supplement the normal cpc with an extra, dedicated, protective conductor (Regulation 543.7.1.103 refers).

Methods of supplementing the protective conductor are shown in Figures 7.4b and c. It can be seen that metallic conduit and cable armour or braid may be used, provided that connections are permanent and reliable. The same applies to metallic trunking.

7.18 Earth monitoring and isolated supplies

- An earth monitoring system (Figure 7.5) may be installed which, in the event of a continuity fault occurring in the protective conductor, automatically disconnects the supply to the equipment.

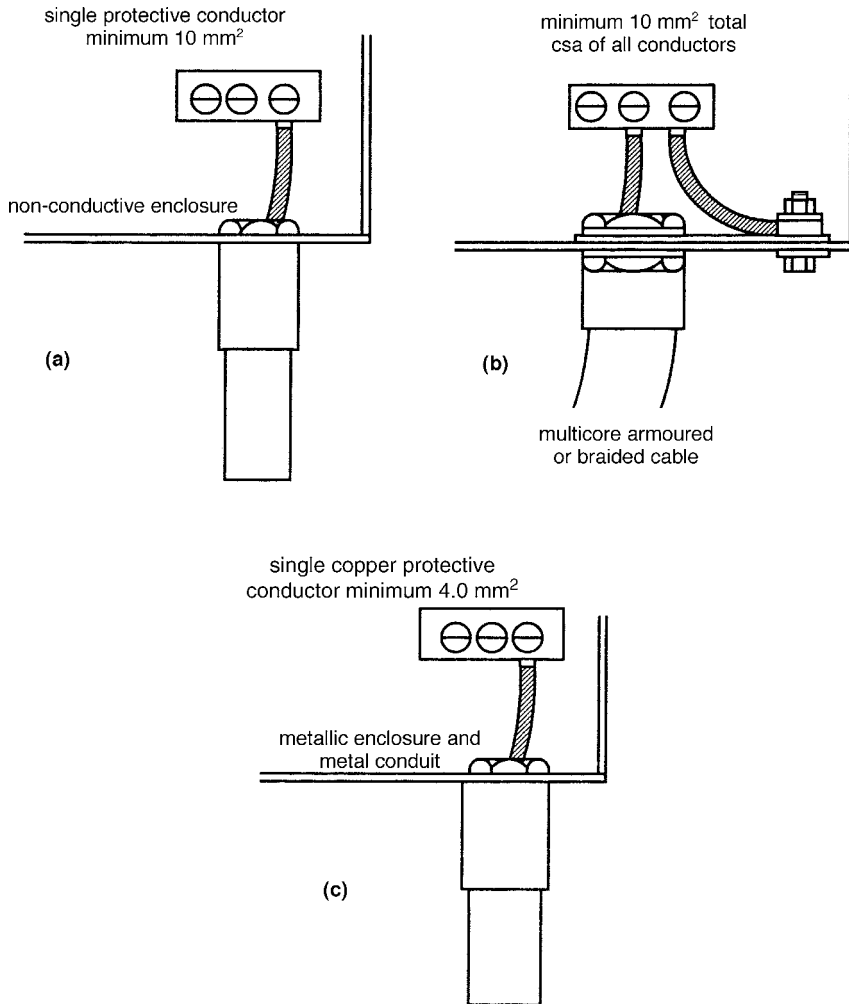


Figure 7.4 High integrity earthing for computerised systems. (Line and neutral conductors not shown for clarity.)

- Where the supply is fed from a double-wound transformer or equivalent unit, the protective conductor of the incoming supply must be connected to the exposed-conductive-parts of the equipment and to a point of the secondary winding of the transformer or equivalent device. This connection should be supplemented to the same standard as shown in Figure 7.4.

7.19 Socket-outlets for desktop computers

The Wiring Regulations covers the requirements for socket-outlet final circuits under their own heading. Where the final circuit is intended to supply several items of equipment where the total

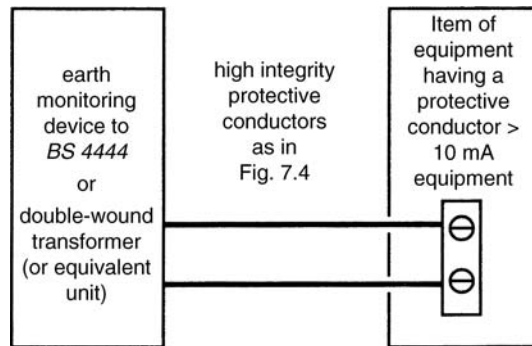


Figure 7.5 Similar earthing requirements apply to safety systems. (Line and neutral conductors are not shown.)

protective conductor current is known or reasonably expected to exceed 10 mA in normal service, a high integrity protective conductor connection must be made by one of the following:

1. One of the arrangements shown in Figures 7.4 or 7.5 should be applied; or
2. A ring circuit may be used, provided all of the protective conductors are connected to separate terminals at each socket-outlet and at the distribution board, and spur points have two protective conductors also separately connected at the socket-outlets.

7.20 Connections of protective conductors

Where more than one protective conductor on any of the systems described above is connected at a distribution board or equipment terminal block, separate terminals should be used.

7.21 Residual current devices

To avoid the loss of data from unwanted tripping, it may not be advisable to apply residual current devices to computer circuits. However, where such protection is specified for safety reasons, for example in schools, the total normal protective conductor current of the equipment, together with switch-on surges, must not cause the RCD to trip.

Electrical installations that form part of a TT system will, in almost all cases, require the means of an RCD to provide ADS. Therefore, careful design will have to be employed to avoid unwanted tripping of the RCD(s).

Car Service Workshop

There are limitations with this standard design. This is because some hazardous locations require special expertise and are beyond the scope of this book. The complexities of these situations cannot be ignored and note should be taken of the conditions.

This design for a car service workshop does not cover the forecourt area of petrol filling stations or for explosive atmospheres, covered by *BS EN 60079: 1997*.

8.1 Standards and recommendations

The Association for Petroleum and Explosives Administration (APEA) and the Institute of Petroleum (IP) have published an excellent book entitled *Guidance for the Design, Construction, Modification and Maintenance of Petrol Filling Stations*. This document is used as the standard for electrical installations in petrol filling station forecourts and replaces the previous standard Health and Safety Executive document *HS(G)41*. The Guide advises persons designing, installing, inspecting and testing, and certifying installations for petroleum dispensing equipment to be competent, and to be fully conversant with *BS 7671: 2008*, and *BS EN 60079-14: 1997 Electrical apparatus for explosive gas atmospheres, and electrical installations in hazardous areas (other than mines)*. *BS EN 60079-14* deals with what is generally known as flameproof installations. Similar restrictions upon competence apply to areas in a car repair workshop, which may be used for paint storage or spraying. For example, dust, and fine particles of paint powder, when ignited, even from a small spark, can explode. Therefore, anyone not experienced with such environments or familiar with the requirements set out in *BS EN 60079: 1997* must either undertake training or call in an expert to produce a suitable specification.

8.2 An adaptable design

Provided that the potentially hazardous areas are treated separately, the electrical installation in a vehicle repair workshop does not differ greatly from a typical industrial workshop. This design may be used as the basis for a small manufacturing unit or a warehouse with materials handling plant.

8.3 Motor vehicle repair premises

A suitable starting point for the design of an electrical installation in such areas is to refer to the Health and Safety Guidance Note HSG261, *Health and Safety in motor vehicle repair and associated industries*. This publication gives good advice on electrical installations in motor vehicle repair premises, so should be studied by the designer, installer and potential user of the installation.

Reference will be made to that publication and other HSE guidance documents wherever appropriate.

The use of electricity in such a workshop is also subject to the *Electricity at Work Regulations 1989*.

8.4 Other interested parties

- *Fire and rescue service:*
Emergency lighting and fire alarms, particularly if the building is associated with a petrol service station;
- *Client's insurers:*
Safety equipment and wiring systems;
- *Health and Safety:*
Consideration of HSG261 and other advice;
- *Electricity distributor:*
Check availability of a supply to suit the potential load and confirm the location of the intake position;
- *Dealer agency:*
In the motor industry, it is common for the vehicle manufacturer to specify systems and equipment to be used for approved dealer servicing;
- *Equipment supplier:*
Full details of equipment are required to ensure that the electrical requirements will be suitable. Some of this equipment may be imported and not to British Standards.

8.5 Building structure and finishes

The layout of the building can be seen in Figures 8.1 and 8.2, which also give details of the electrical installation:

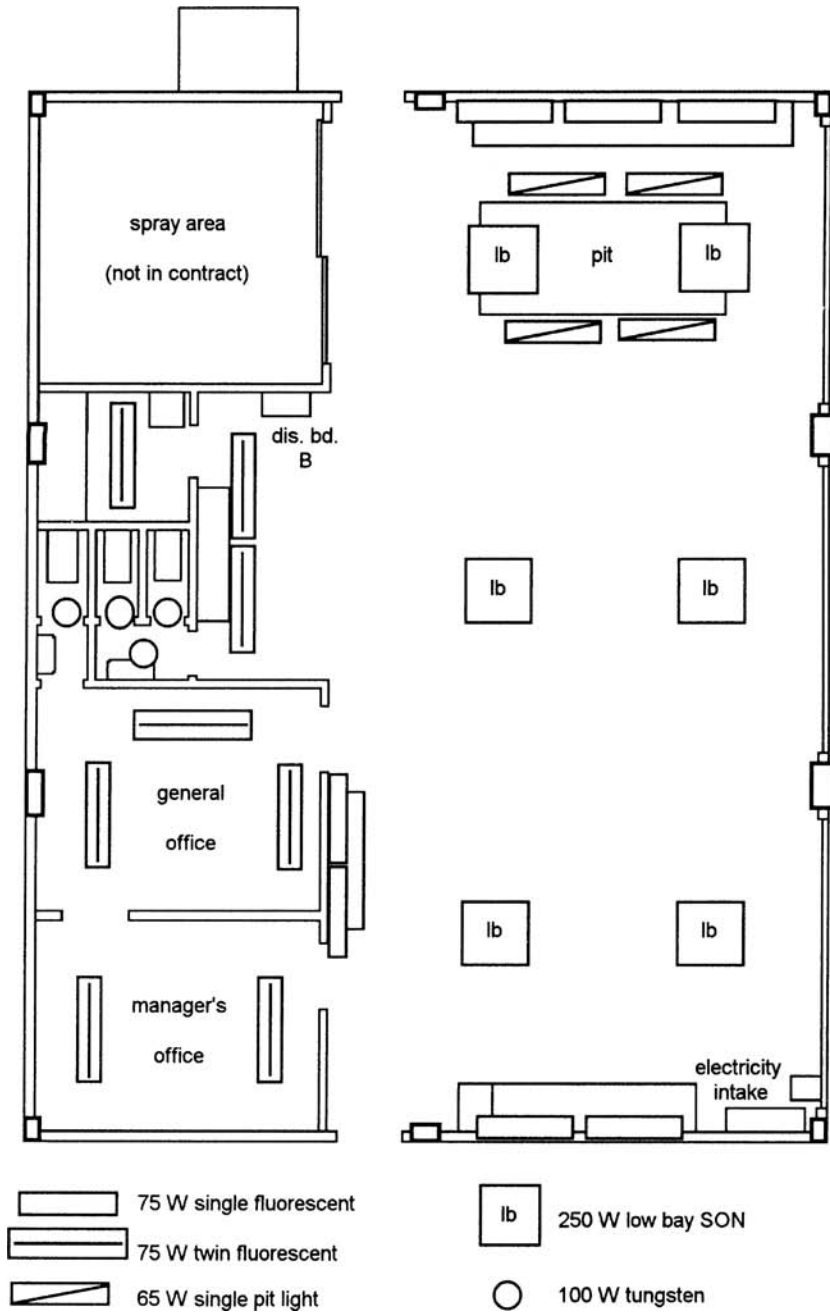


Figure 8.1 Car workshop lighting.

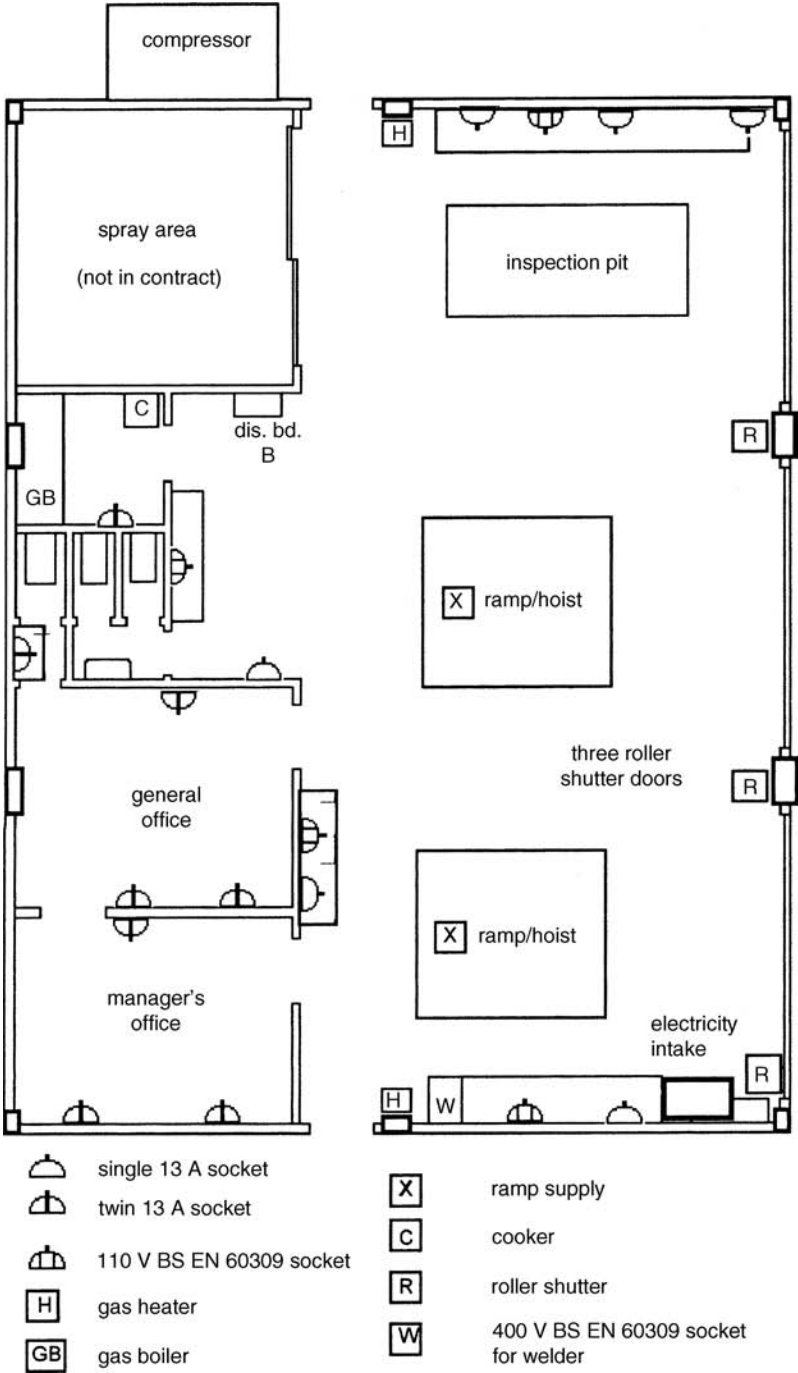


Figure 8.2 Car workshop power.

- *Floor areas (approx.):*
workshop 320 m²;
offices and so on, 100 m².
The 20 m² spray area is excluded from the contract, except that provision is required for an electrical supply to the area.

8.6 Construction

- *Workshop:*
steel frame with brick walls to 3 m and lightweight wall cladding above;
pitched roof, 5 m clear to underside of roof frame girders, 7 m to apex;
floor construction is concrete throughout;
vehicle inspection pit is concrete, with steps down and drainage.
- *Office:*
fair-faced building block walls;
ceiling height 2.5 m. Conventional plasterboard ceiling under timber beams;
space above the office ceiling has a blockboard floor and is used for storage.
- *Space heating and hot water: gas:*
workshop: two hot air blowers;
offices: central heating boiler.

8.7 Electrical requirements

A building layout plan is not sufficient to create an electrical design. Some specialist repair machinery requires dedicated supplies or special protection. A full schedule of equipment is required, listing:

- lighting;
- computerised equipment;
- heating;
- ventilation;
- small tools;
- large plant.

311.1 Early consultation with the client is necessary to establish, amongst other things, the maximum loading of the installation. In determining the maximum demand of an installation or part thereof, diversity may be taken into account.

8.8 Health and safety executive guidance and regulations

There are special hazards associated with this location where motor vehicles are repaired.

8.9 Health and safety guidance note HSG 261

- Steel conduit and/or trunking is recommended as a suitable wiring system. Alternatively, steel wire armoured (SWA) cables, with a PVC outer sheathing may be used. Plastic-covered, mineral-insulated cable may also be used.
- All parts of the electrical installation should be at least 1 m above the finished floor level, to reduce the risk of igniting spilt petrol or other flammable liquid.
- Switchgear must be accessible, but located where it will not suffer damage.
- Sufficient socket-outlets should be provided (above bench level), to reduce the number and length of trailing leads.
- Industrial 230 V plugs and sockets to *BS EN 60309-2* are more suitable than domestic *BS 1363* types.
- Extension leads should use flexible cable – not semi-rigid cable (e.g. ‘twin and earth’). Neoprene-covered cable resists damage from oil. Where an extension lead has a 13-amp socket-outlet, it must be wired in a three-core flexible cable
- Socket-outlets for equipment to operate in a wet or damp environment must have a rating of at least IP54. Ideally, a rating of IP57 would be preferred. Such socket-outlets must also have ‘additional protection’ by means of a residual current device (RCD) of 30 mA/40 ms specification; or an earth-monitoring device in the electrical supply to the device. The RCD must be trip-tested at appropriate intervals.
- Each item of electrical equipment that is supplied via a permanent cable should have its own switch, which is suitable for electrical disconnection and isolation from the electrical supply. This switch should always be used to disconnect the machine before cleaning and maintenance work.
- Lighting should be arranged to avoid stroboscopic effects from rotating equipment
- Fixed lighting beneath the vehicle inspection areas is preferable instead of portable hand lamps.
- There must be no provision for portable electric tools or hand lamps in inspection pits.
- Fixed luminaires in pits must be suitable for explosive atmospheres, Zone 2 (sealed) units fitted flush with the wall at least 1 m above the floor of the pit.
- The use of hand lamps should be discouraged. However, where they are needed, battery-operated LED or halogen hand/head lamps provide alternatives to traditional corded lamps, with the additional benefit of having no trailing cable.
- Where a mains-supplied hand lamp is to be used, it should be either:
 - ‘all insulated’/‘double insulated’, the bulb protected by a robust cage of insulating material or a transparent insulating enclosure; or
 - supplied by reduced low voltage 110 V (centre tapped to earth) or a separated extra-low voltage (SELV) system, which does not exceed 50 V a.c, supplied from an isolating transformer. SELV bulb filaments are heavier and it is understood that they are more robust than normal types, so are more suited to rough usage.
- Only totally enclosed hose-proof type hand lamps, operating at 24 V or less from a double wound transformer, should be used in the wet.
- Vehicle inspection pits, paint storage, preparation, mixing and spraying areas, and places where spilt petrol or LPG could accumulate (e.g. pits, drains or sumps) are all areas where

potentially explosive atmospheres could be present. Therefore, hand lamps suitable for use in these environments are available and are specifically constructed for this purpose. The use of extra-low voltage (even at 12 V) does not give protection against the risk of fires and explosions in potentially explosive atmospheres, unless the handlamp has been constructed in accordance with a suitable method of explosion protection.

- Other portable electric tools may operate on a 110 V centre tap earth system, but note that the use of reduced low voltage is no protection against fire and explosion from flammable vapours.
- Compressed air portable tools are preferable to electric tools.

The installer should advise the client of the HSE recommendation for the installation and use of 'industrial' type plugs and socket-outlets. But note, there can often be some user resistance to the use of industrial type plugs and sockets for 230 V equipment.

(This project is based on *BS 1363* 13 A plugs with the *BS EN 60309-2* alternative as an option.)

512.2.1 **8.10** Wiring regulations

- Every item of equipment must be of a design appropriate to the situation in which it is to be used or its mode of installation should take account of the conditions likely to be encountered. The electrical installation must be of an industrial nature and, where appropriate, suitable for wet conditions.

- 411.3.3 ● Additional protection by means on an RCD in accordance with Regulation 415.1 will be required for the:
 - socket-outlets in the offices or the workshop that have a rated current not exceeding 20 A, because they are intended for general use by ordinary persons.
 - mobile equipment with a current rating not exceeding 32 A.

- 522.6.101 and 522.6.102 ● Additional protection by means on an RCD in accordance with Regulation 415.1 will be required for twin and earth cables concealed in a wall or partition at a depth of less than 50 mm from the surface of that wall or partition, as the installation will not be under the supervision of a skilled or instructed person. (Regulation 522.6.102 refers).

8.11 Load assessment and maximum demand

After full consultations, a provisional list of electrical equipment has been drawn up in Table 8.1. A suitable format for a Project Specification is shown in Figure 8.3.

8.12 Maximum demand load and diversity

- 313.1 This project calls for special consideration in terms of total maximum demand. There is no relevant guidance. The designer must obtain manufacturer's data and rely upon experience.

Table 8.1 Schedule of equipment for garage workshop.

Offices	Workshop
<i>Lighting</i>	
Fluorescent	7 × 75 W single (benches)
8 × 75 W twin	4 × 65 W single pitlight
4 × 100 W tungsten	6 × 250 W low-bay SON light)
<i>13 A 230 V RCD protected socket-outlets</i>	6 × single
8 × twin socket-outlets	1 × single
<i>16 A 110 V sockets (yellow)</i>	4 × single
<i>400 V welder two phase, L1 and L2</i>	1 × 32 A two phases
<i>Roller shutters, gas blowers and ramps, 3-phase and neutral</i>	8 × 6 A
<i>Cooker and gas boiler supply, single phase</i>	1 × 6 A
	1 × 32 A
<i>Provision for spray area, three-phase and neutral</i>	1 × 20 A 3 Ø supply
<i>Compressor, three-phase and neutral</i>	1 × 16 A 3 Ø supply

Calculations and phase balancing figures for diversity will be approximate. Numbers have been rounded off.

8.13 Lighting

For current loading calculations, some types of discharge luminaires may have to be multiplied by 1.8 to take into account control gear losses. Most, if not all, manufacturers will provide such design data, on request.

An assumption of 100 W per outlet should be made for tungsten lamps, regardless of specification lamp size.

In the absence of more precise information, no diversity is being considered on discharge lighting and the tungsten load is discounted.

Project Specification BS 7671 Garage workshop			
Name.....		Location.....	
Reference.....		Date.....	
Three phase 230 V 50 Hz. TN-C-S. Supply fuse 100 A BS 83-3			
PFC less than 16 kA. Earth loop impedance less than 0.35 ohms 100 A TP main switch			
Circuits	Rating (A)	Cable size (mm ²)	Lights/points g = gang
Main distribution board A 125 A isolator 24 ways			
Lights wkshp 1	10	1.5	6
Lights wkshp 2	10	1.5	6
Lights wkshp 3	10	1.5	5
Ramps 3-phase	6	1.5	3
13 A sockets wkshp	32	2.5	3 x 1g
13 A sockets wkshp	32	2.5	4 x 1g
Roller shutters 3-phase	6	1.5	3
Welder socket 2-phase	32	6.0	1
110 V transformer	10	2.5	4 x 1
Gas heaters 3-phase	6	1.5	2
Supply to dis bd B	63	16	-
Sub distribution board B 125 A isolator 12 ways			
Lights office	10	1.5	12
13 A sockets office	32	2.5	8 x 2g
Cooker	32	6.0	1
Compressor 3 phase	16	4.0	1
Spray area provision	32	4.0	1
Gas boiler	6	1.5	1

Figure 8.3 Project specification for garage workshop.

8.13.1 Office lighting load

$$\begin{aligned} 8 \text{ twin fluorescent lamps} &= 8 \times 75 \text{ W} \times 2 \times 1.8 \\ &= 2160 \text{ W} \end{aligned} \quad (8.1)$$

$$\begin{aligned} \text{This will be on one phase} &= 9.4 \text{ A;} \\ 4 \times \text{tungsten filament lamps @100 W} &= 400 \text{ W;} \\ \text{This will be on one phase} &= 1.8 \text{ A.} \end{aligned} \quad (8.2)$$

8.13.2 Workshop lighting load

$$\begin{aligned} \text{Benches} &= 7 \times 75 \text{ W} \times 1.8 \\ &= 945 \text{ W} \\ \text{Plus pit lighting} &= 4 \times 65 \text{ W} \times 1.8 \\ &= 468 \text{ W} \\ \text{Plus low bay lighting} &= 6 \times 250 \text{ W} \times 1.8 \\ &= 2700 \text{ W} \\ \text{Total w/shop lighting load} &= 4113 \text{ W} \end{aligned} \quad (8.3)$$

Assuming that that this will be spread approximately equally across three phases:

$$\frac{4113}{230 \times 3} = 5.95 \text{ A/Phase} \quad (8.4)$$

8.14 Welder

400 V 10 kVA rating – full load must be anticipated across two phases. However, in practice, as this load is only likely to run for a few minutes at a time – every now and again – the loading on the installation can almost be ignored.

To convert kVA to KW, the kVA value and the power factor (pf) need to be multiplied together. In this case, the pf is assumed to be 0.9:

$$\begin{aligned} \text{therefore } 10\,000 \times 0.95 &= 9000 \text{ W;} \\ \text{this equates to a total load of : } &9000/230 = 39.1 \text{ A;} \\ 39.1/2 \text{ (over two phases)} &= 19.6 \text{ A per phase;} \\ \text{so, } 20 \text{ A per phase.} & \end{aligned} \quad (8.5)$$

8.15 Compressor

This runs on low load most of the time, so 50% diversity can be allowed:

$$\frac{15 \text{ kW} \times 50\%}{230 \times 3} = 10.87 \text{ A/Phase} \quad (8.6)$$

8.16 Gas blowers

2 × three-phase 0.75 kW fan motors. Full load must be anticipated:

$$I = \frac{750}{400 \times \sqrt{3}} \quad (8.7)$$

$$= 2 \text{ A/phase (rounded up).}$$

8.16.1 Provision for spray area

In the absence of other information, a maximum demand load has been assumed as:

$$= 20 \text{ A/phase.} \quad (8.8)$$

8.17 Phase balance

It is essential to balance loads across three phases as far as possible. This exercise should consider the diversified current demands to obtain a balance on normal working conditions.

Table 8.2 gives a suitable arrangement. Note that at this stage, this does not necessarily indicate distribution board particulars.

Table 8.2 Proposed balance across phases using diversified load figures.

Phase	Circuit	Amps
L1 (Brown)	Welder	19.6
	Workshop lights	6
	13 A sockets	20
	Gas blowers	2
	Spray area	20
	Compressor	10.9
	Ramp/hoists	–
	Roller shutters	–
L2 (Black)	Welder	19.6
	Workshop lights	6
	Office lights	11.2
	13 A sockets	20

Table 8.2 (Continued)

Phase	Circuit	Amps
	Gas blowers	2
	Spray area	20
	Compressor	10.9
	110V transformer	–
	Ramp/hoists	–
	Roller shutters	–
		89.3 (Total)
L3 (Grey)	Workshop lights	6
	13A sockets	20
	Gas blowers	2
	Spray area	20
	Compressor	10.9
	Gas boiler	–
	Ramp/hoists	–
	Roller shutters	–
	Cooker	25
		83.49 (Total)

8.18 Estimate of maximum demand

It will be seen that the estimate of maximum demand is very much a matter of experience. However, there is a tendency to overestimate high fixed loads, which in practice only occur for short periods of time. Compressor and fan motors run on low load most of the time and heaters have thermostatic regulation. The hoists run intermittently as well. The cooker is an unknown quantity, as are sundry items such as kettles and room heaters.

On this project it is unlikely that the estimated maximum demand figure will occur for more than a few minutes. Therefore, this information will be used to determine the size of the mains supply. If there is any doubt, it is worth showing the figures to the electricity distributor.

A 100 A three-phase supply will be suitable for this load.

8.19 What about a distribution circuit (sub-main)?

When all of the current loadings are studied, it can be seen that the major loads are located some distance from the mains intake position. Long runs of SWA cables will be necessary for the spray area and the compressor. The cooker could also create cable sizing problems using PVC insulated and sheathed cable.

There are at least three technical and commercial disadvantages in running long final circuits:

1. *Voltage drop:*
525.1 This is usually the deciding factor for cable sizing.
2. *Diversity:*
This cannot be applied to final circuit cables, which are selected with reference to the full load current and rating of the protective device.
3. *Earth fault loop impedance:*
The impedance along an extended small distribution circuit cable may exceed the limits for fault protection.

All three of the above factors apply to this project.

A convenient position for local sub-distribution is where it had been intended to locate a supply for the spray area requirements. A three-phase distribution board at this point will carry the circuits shown in Table 8.3.

8.20 Wiring systems

The workshop can be considered separately from the office situation.

8.21 Workshop

- 522.6 A layout such as this lends itself to a plastic conduit and/or trunking installation. Such systems are easy to install, but must be carefully located to avoid physical damage. If this was a light industrial application, such as a clothes manufacturing workshop, using non-metallic wiring systems would have advantages and would have been recommended. However, with this current project, electrical safety relies upon protection of cables in extreme circumstances. *HSG261* recommends the use of steel conduit and trunking or SWA cables for places where motor vehicles are serviced. It would be irresponsible to ignore this guidance.

8.21.1 Steel conduit and trunking

- 528.1 Trunking is suggested for major groups of cables for lighting and sockets around the building. A suitable clear route will usually be found on the walls at about 3–4 m above floor level; 400 V,

Table 8.3 Load distribution at sub-distribution board B.

Phase	Circuit	Amps
L1 (Brown)	Spray area	20
	Compressor	10.9
	13 A sockets	20
		50.4 (Total)
L2 (Black)	Spray area	20
	Compressor	10.9
	Office lights	11.2
	Gas boiler	5
		46.69 (Total)
L3 (Grey)	Spray area	20
	Compressor	10.9
	Cooker	25
		55.49 (Total)

Diversified loading figures have been taken from Table 8.2. The phase balance at the mains distribution would be unchanged.

230 V and 110 V single-core cables may be mixed, provided that standard 450/750 V minimum rated cables are used (refer to *BS 6004: 2000 (2006)*).

In the workshop location, ambient conditions will always be reasonable; therefore, if cable runs are surface mounted and never buried in any form of thermal insulation, there will be no temperature or insulation rating factors to be applied. 523.04

The sizes given in Table 8.4 have a good margin of tolerance in sizing, to the point that grouping factors may also be discounted.

Steel conduit will be taken from the perimeter trunking to lighting fittings and socket-outlets.

8.21.2 Steel Wire Armoured (SWA) cable

Undoubtedly, SWA cable is an economical method of taking an electricity supply to an isolated item of current-using equipment. The schedule therefore gives this as an option for door roller shutter mechanisms and the vehicle ramps.

Table 8.4 Cable sizes related to circuit-breaker ratings.

Circuit	Full load (A)	(A)	Circuit-breaker (type)	Cable type reference	Size (mm ²)
Distribution Board A					
Sub-main to Distribution Board B	Assume 60	63	C	XLPE-swa (4-core)	10 or 16
Ramps	2.8	6	C	PVC-swa (4-core)	1.5
Workshop lights (3 circuits)	6.0	10	C	singles 6491X	1.5
13 A sockets	20 A radial	20	B	singles 6491X	2.5
Roller shutters	1.0	6	C	PVC-swa (4-core) or	1.5
	24	32	C	singles 6491X	1.5
Welder				singles 6491X	6.0
Gas heaters	2.0	6	C	PVC-swa (4-core)	1.5
Distribution Board B					
Office lights	11.2	10	B	T&E 6242Y	1.5
Office sockets	20 A radial	20	B	T & E 6242Y	2.5
				T&E 6242Y	2.5
Cooker	30	32	B	T&E 6242Y	6.0
Gas boiler	2.0	6	B	T&E 6242Y	1.5
Compressor	10.4	16	C	-SWA	4.0

It must be remembered that the use of SWA cable is not a flexible cable for unsupported connections to machinery. Therefore, for vertical drops, the cable should be supported at maximum intervals of between 450 and 600 mm, depending on the cable's overall diameter, and ensure that no stress is put on the gland when it comes into contact with an enclosure.

522.8 Two methods are suggested for vertical supply drops from roof girders down to fixed equipment in workshops:

1. Clip to Dexion, cable tray, or other similar vertical supporting structure.
2. Terminate the SWA at high level and make the drop in flexible cable.

Horizontal runs of SWA along walls should be clipped at maximum intervals of between 350 mm and 450 mm, depending on the cable's overall diameter, or laid on a continuous support, such as a structural steel girder or cable tray.

8.22 Office

The office construction appears to be of an 'industrial' nature with plain building block walls. There is no cavity or plaster cover to hide PVC-sheathed cables, but the ceiling is conventional plasterboard fixed to joists with a floor above. This is a difficult location in which to install conduits.

The choice is either a complete surface-mounted conduit system throughout the office and toilet area, or sheathed cables concealed in the ceiling and enclosed in conduit for wall drops. In either case, plastic conduit is appropriate. An alternative solution would be to use mini-trunking for sheathed cable drops to lighting switches and sockets.

8.23 Arrangement of circuits

Using the schedules produced for balancing loads at two positions, distribution board circuitry can be planned. To size each distribution circuit (sub-main) and the final circuits, full load current must be used. This, in turn, will determine cable sizes.

8.24 Distribution boards

Three-phase distribution boards incorporating circuit-breakers complying with *BS EN 60898* would be suitable for both locations. Board A will carry the whole load and supply distribution board B (Figure 8.4):

Distribution Board A: 125 A main switch, 24 outgoing ways;

Distribution Board B: 125 A switch (optional), 12 outgoing ways.

8.25 Cable sizes

Sizing must take account of circuit-breaker rating, any applicable rating factors, earth fault loop impedance and voltage drop on full load. With the workshop layout shown, voltage drop is the most onerous. Suitable cable sizes are shown in Table 8.3. Maximum lengths of run should be noted if the design is used for a different layout. Information on circuit design calculations can be found in chapter 19 of this book.

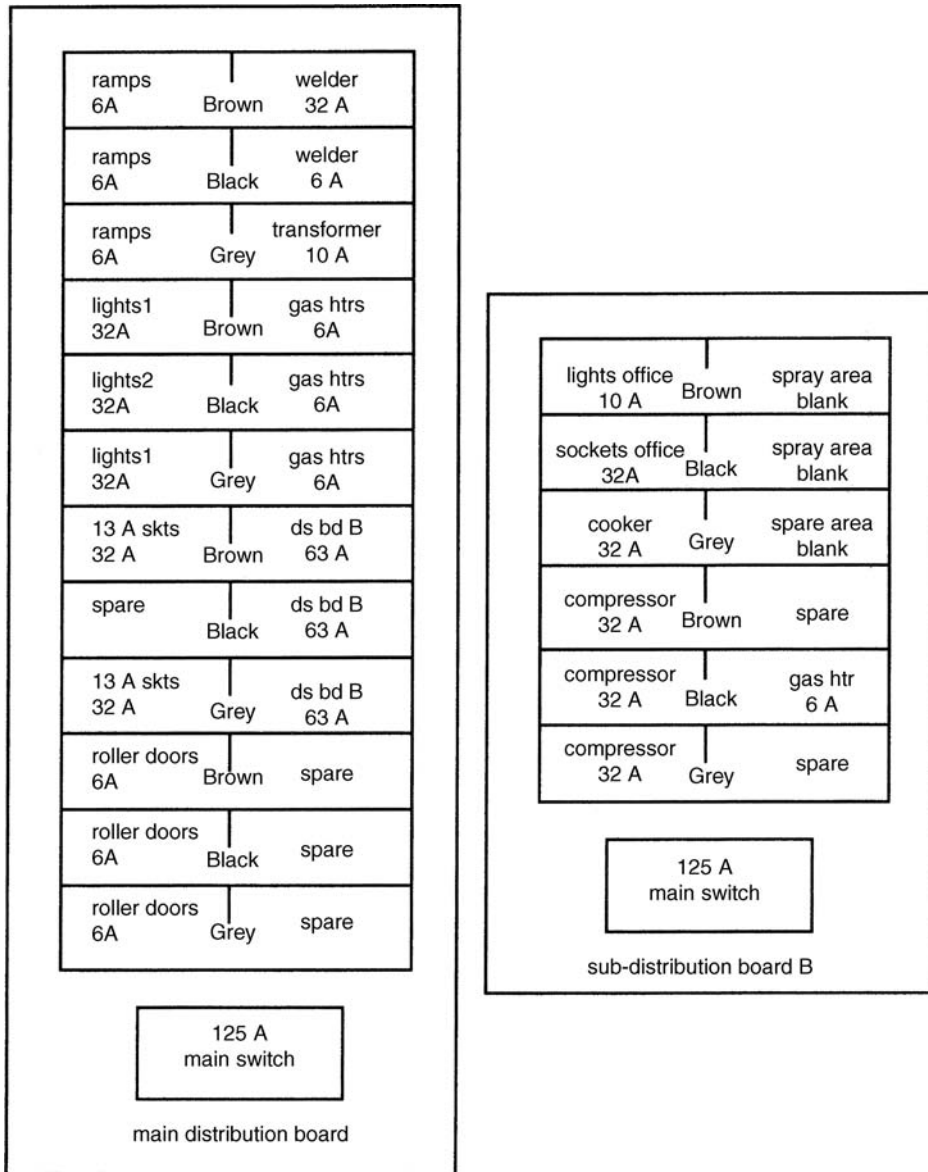


Figure 8.4 Distribution board circuits.

8.26 Isolation and switching

Sec. 537

Main switch, distribution board A

Provided the installation forms part of a TN system, the main switch disconnecter (or isolator) can be a three-pole device, as switching the neutral is not required.

Distribution board B

It is not essential to switch this board, unless there is a particular requirement to do so.

537.2.1.1

Isolation can be carried out by locking off the 63 A circuit-breaker at Board A.

8.27 Machinery

- compressor;
- gas heaters;
- ramps;
- roller shutters;
- welder.

All these items require:

- switching for isolation;
- switching for mechanical maintenance;
- emergency switching.

Isolation and switching for mechanical maintenance can be achieved by locking off the appropriate circuit-breaker at the distribution board. The requirement for emergency switching must be immediately accessible to the user of the equipment.

All three functions are best combined in an appropriate on-load isolating switch adjacent to each item.

8.28 Cooker

This item of equipment requires all three functions of isolation and switching. The most convenient method is with a conventional cooker control switch of the type without an integral socket-outlet.

8.29 Gas boiler

This requires a means of isolation adjacent to the boiler, which is often facilitated by means of a fused spur connection unit. Such a connection will supply the boiler system including its controls and valves.

8.30 110 V transformer

This item only requires switching for isolation purposes, which could simply be a lock-off arrangement on the circuit-breaker at the distribution board. A switch adjacent to the transformer may be more convenient and is recommended. It would also provide a functional facility to switch off the 110 V system at night, or at other times when it is not required.

8.31 Earthing and bonding

Standard earthing requirements apply, as shown in Figure 8.5, but there are some possible variations.

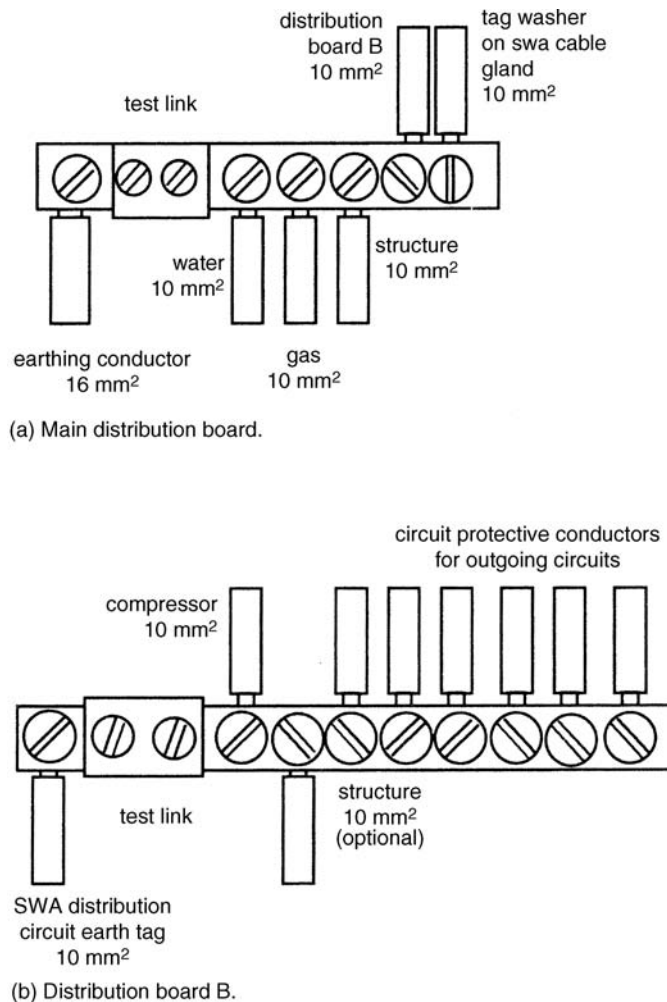


Figure 8.5 Earthing bar connections.

8.32 Main earthing terminal

The 16 mm² earthing conductor from the electricity distributor's PME earth connection is taken to the main earthing terminal (MET) at Distribution Board A.

Main bonding conductors having a csa of at least 10 mm² are required to connect the MET to the:

- water installation pipework;
- gas installation pipework;
- exposed metallic structural parts of the building, such as structural steelwork.

8.33 Protective conductors at distribution board B

Provided that all main bonding is carried out at Distribution Board A, there are no bonding requirements at Distribution Board B. Circuit protection is the requirement.

- The earthing terminal within Distribution Board B provides a marshalling terminal for the circuit protective conductors of the final circuits supplied from it.
- The armoring of some sizes of SWA cable are not suitable for use as a circuit protective conductor (Chapter 7), so it may be preferable to install a separate protective conductor, identified by the bi-colour green-and-yellow, alongside the SWA cable.
- To help improve the earth fault loop impedance value, Z_{db} , at the distribution circuit, it may prove worthwhile making an additional bonding connection to the structural steelwork at this distribution board. This could be achieved simply by bolting the metallic enclosure to a steel stanchion.

Provided certain conditions are complied with, it is acceptable to use an extraneous-conductive-part (i.e. steel stanchion) as a protective conductor. 543.2.6

8.34 Armoured cable glands

Where the continuity and integrity of the gland cannot always be assured, it is considered good practice to fit an earth fly-lead to the cable gland, whether or not the cable armoring is used as a protective conductor. Even if a separate cpc is installed, it is necessary to have the armoring permanently and reliably connected to the means of earthing.

The fly-lead should be linked to the earthing terminal in the distribution board or other enclosure. Unless the paintwork of the enclosure is thoroughly removed, it is generally not good enough to rely on continuity through the metal enclosure. 526.1

8.35 Steel conduit and trunking

In order to ensure permanent and reliable continuity through the conduit and trunking, consideration could be given to installing a separate insulated cpc throughout the system. However, this does not reduce the obligation to have good sound connections between the steel components of the system.

Regulation 543.2.5 permits the use metallic conduit and trunking to be used as a protective conductor for the associated circuit, provided the following two conditions are complied to:

1. Its electrical continuity can be assured, either by construction or by suitable connection, in such a way as to be protected against mechanical, chemical or electrochemical deterioration.
2. Its cross-sectional area is at least equal to that resulting from the application of Regulation 543.1, or verified by test in accordance with *BS EN 60439-1*.

Circuits

9.1 Terminology

It is essential that the correct terminology is used when describing electrical installation matters. This is of particular importance in this chapter when describing conductors and other items of electrical equipment.

The conductors on a single-phase supply are correctly known as:

- *Line*: This is coloured brown for both fixed wiring and flexible cables (e.g. one connected to a plug).
- *Neutral*: This is coloured blue for both fixed wiring and flexible cables (e.g. one connected to a plug).

Both of the above are known as live conductors.

- *Circuit protective conductor(cpc)*: This should always be identified by the bi-colour combination green-and-yellow.

A cpc should not be confused with an equipotential bonding conductor, which is also identified by the bi-colour combination green-and-yellow.

9.2 Colours of three phases

Three-phase supplies have three-line conductors, L1, L2 and L3, coloured brown, black and grey, respectively. The Wiring Regulations require the line conductor of all outgoing ways of Table 51

single-phase final distribution boards to be coloured brown. The colours black and grey may be used for three-phase final circuits and, where desired, for the supply conductors to three-phase distribution boards.

Strictly speaking, it is wrong to use black and grey conductors on two-way switching circuits. Regardless of this, in many areas, wiring with three-coloured multicore cable has become a convention that simplifies identification of wires at the switches of two-way switching arrangements. Care must be taken to ensure that this practice is never carried out on an installation with three-coloured cables for three-phase circuitry. A black or grey two-way switch connection could be taken as line colours. It is also contrary to Regulations to wire single-phase lighting and socket-outlet circuits in 'phase' colours. This is often a feature of large installations and there is logic in the identification of circuit phases.

To overcome this arrangement, it is excepted practice to over-sleeve the black and grey conductors at the terminations of two-way switches with brown sleeving – note, however, there is no minimum or maximum length the sleeving has to be, but most choose to sleeve the conductors back to the sheathing.

9.3 Conventional circuits

IET Guidance Notes for the Regulations describe 'conventional' circuits. These are based on previous ideas for standard circuits and generally apply to circuits supplying socket-outlets and other final circuits.

9.4 Lighting circuits

The industry has developed its own conventional circuitry for applications, such as lighting and motor control. Chapter 2 showed that there are alternative arrangements for wiring domestic lighting circuits. For example, systems that use flat twin and earth cable may be looped at the light position, or at the switch. The choice will be at the convenience of the electrician. Such elementary matters are not usually contained in specification documents.

Where conduit wiring and single-core cables are used, another convention is to loop line conductors from the switch and neutral conductors at the light.

It has also been known for a room light to be supplied from power circuits through fused connector units. This practice is often suited for hotel rooms. One 30 A circuit can supply all requirements in one or two rooms.

9.5 Induction

The incorrect installation of single-core lighting cables may introduce inductive nuisance for hearing-aid users or sensitive data processing activity. Chapter 2 showed a method of arranging two-way switch wiring to ensure that inductive effects are cancelled out. With the increase in use of electronic equipment and building management systems, this subject is becoming increasingly important.

331.1

9.6 Socket-outlet circuits

The circuit conventions for socket-outlets have been a subject of much debate over the years, but it should be remembered that the standard 13 A arrangements, relating to floor area, were originally intended for domestic installations only. They therefore have little relevance to commercial, industrial or other larger buildings.

9.7 Changing methods

Electrical designers and electricians have become accustomed to standardised wiring methods, which work on rule-of-thumb principles. This is good because everyone in the business understands circuitry conventions, as one domestic installation can be very much like any other.

Whilst it makes sense to use tried and tested methods, we should not be so blinkered as to think that nothing will ever change. In recent years, there have been tremendous changes in the utilisation of electricity, and equipment manufacturers have introduced some very sophisticated products. Switchgear and control equipment designers have taken up advanced technology associated with new materials and computer processing.

At a very basic level, electrical installers may be in danger of letting the world pass them by. Electrical appliances and equipment have changed on both domestic and commercial premises. Loadings are not the same as they were a few years ago, yet circuitry remains unchanged.

9.8 Ring main obsolescence

The one circuit arrangement commonly seen in most types of installation in the UK is:

A 'ring main', or, using the correct terminology, the ring final circuit. Ring mains are circuits that operate at high voltage, used to supply many transformers around, say, a university or hospital.

Strangely enough, the ring final circuit is not used in Europe, America and Japan, or any country that is outside the old British colonial sphere of influence. It is something that is peculiarly but not exclusively British.

9.9 History of the ring final circuit

In the late 1940s, the government of the day set about raising standards for post-war housing. Electricity was becoming a basic necessity and old methods of wiring concentrated on lighting with, at best, one or two power appliances in the kitchen. Few homes had anything more than a radio and a domestic iron, both of which could be plugged into a lighting two-way adaptor.

Central heating was unknown in the average home and was not taken into account in the design of a revolutionary domestic electrical power distribution system: the ring final circuit (ring main).

The principle of the ring final circuit system was that a householder would have one, or even two, electric heaters that could be taken from room to room and plugged into a convenient socket-outlet. This facility for limited space heating, plus the loading of an electric kettle in the kitchen was expected to require a 30 A supply.

Rather than run a 30 A cable to every outlet, an idea was developed to use a 20 A cable in the form of a ring with 13 A fused plugs. This permitted the connection of a 3 kW load at any socket-outlet. It was assumed that the average small householder with less than 1000 ft² (or 100 m²) of floor area would not have a sufficient number of appliances to overload the ring final circuit.

9.10 Times have changed

This was all very good for homes in the 1940s and 1950s, but bears no relation to domestic requirements in the twenty-first century, as shown in Figures 9.1 and 9.2. Furthermore, the allocation of 30 A/32 A ring final circuit to floor areas was never intended to apply to commercial situations, even as they existed in 1950. In today's high-tech office, the use of the 100 m² formula is nonsense. It all depends on which particular 100 m² area is being serviced.

There are good reasons for considering alternative wiring systems:

- Domestic and commercial consumers have a multitude of low-current appliances. Many more socket-outlets are required in a new installation and flexibility is needed for future alterations and additions. Extending or breaking into a ring final circuit is not a straightforward exercise.
- A dedicated 30 A/32 A circuit or two 20 A circuits are recommended for the domestic kitchen/utility room, or two 30 A/32 A circuits where these are separate areas.

bedroom 1	bedroom 2	bedroom 3
2 bedside lamps clock radio electric blanket LCD television hair straighteners hair dryer	2 bedside lamps stereo unit DVD player television computer, VDU and printer games console	bedside light transistor radio LCD television games console
loungue	dining room	hallway and study
LCD/plasma TV DVD player cable TV AV amplifier music centre 3 table lamps	plate warmer computer, VDU and printer	telephone answer phone table lamp

Figure 9.1 Small diversified loads outside of the kitchen.

- Unless thorough testing is carried out on a new or modified ring final circuit, wiring faults may go undetected and invalidate the basic safety principles of the system (Figure 9.3).
- The ring final circuit does not lend itself to separate control of groups of outlets for consumer convenience.

It is possible to divide a ring final circuit into two 16 A or 20 A radial circuits, but there are better alternatives.

kitchen	utility		
dishwasher microwave radio coffee maker refrigerator	<table border="0"> <tr> <td style="vertical-align: top;"> mixer toaster television kettle freezer </td> <td style="vertical-align: top;"> washing machine tumble dryer iron </td> </tr> </table>	mixer toaster television kettle freezer	washing machine tumble dryer iron
mixer toaster television kettle freezer	washing machine tumble dryer iron		

Figure 9.2 Heavy loading requires a 30 A/32 A circuit.

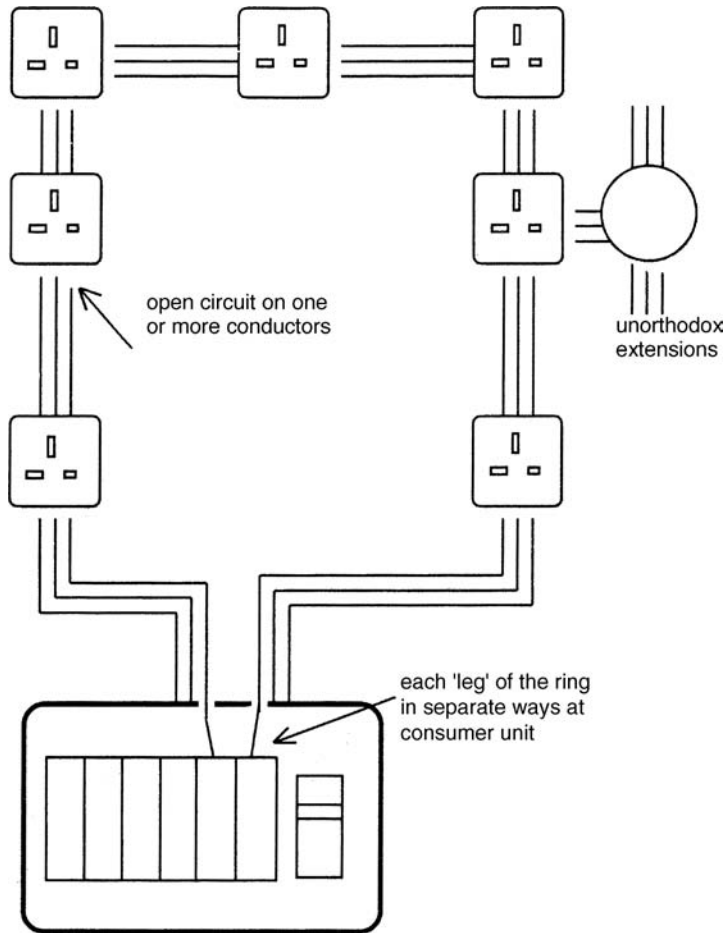


Figure 9.3 Common ring final circuit faults are undetected.

9.11 Alternative methods

9.11.1 Multiple plug sizes

The old round pin plug systems used three different sizes of plugs, each of which had to be used on their circuit. In theory, 5 A and 2 A plugs would have the capacity to handle lighting and low current appliances. 13 A or 15 A plugs would be needed for portable heaters and kitchen appliances.

This would contravene the most essential feature of any system, that of being able to use one type of plug and socket throughout an installation.

9.12 Radial circuits

IET Guidance Notes show radial circuits in the conventional circuit arrangements. There is no detail showing exactly what a socket-outlet radial circuit looks like, but most people seem to imagine that it is a single run of cable connected, in turn, to successive sockets in a long line. This arrangement has limited application, especially if the guidance restriction to 50 m² floor area is literally applied.

9.13 Introducing the tree

Designs for projects shown in other chapters are based on conventional ring circuitry, although the floor area limitations are not always applied. These arbitrary figures are not in the Wiring Regulations and, as shown in the Guidance Notes, only apply to domestic installations and similar.

The tree systems described here complies with the Wiring Regulations requirements with regard to current-carrying capacity in typical situations where no cable derating factors apply. They may be applied as appropriate to all types of installation.

As with any other type of circuit, the designer or installer of the circuit must make a judgement on the loading and diversity for each situation. It could be said that the tree is a variant on a conventional radial circuit but the name is more descriptive of the arrangement.

9.14 20 A tree

A 2.5 mm² cable is adequately protected by a 20 A fuse or circuit-breaker, and there is no reason why the system should not branch off in any direction from a socket or joint box terminals (Figure 9.4).

9.14.1 Domestic

Outside of the kitchen, domestic electrical loading is made up of many low current-using appliances, with perhaps one portable heater. When diversity is applied, a continuous load in excess of 5 kW is unlikely.

In the absence of any official guidance, the installer must decide upon areas to be covered by one tree. One tree circuit may be designated to two or more suitable rooms. Table 9.1 gives some ideas.

9.14.2 Commercial and similar

The 20 A tree circuit may be applied taking into account the following limiting factors:

- Diversified current loading must not exceed 4.5 kW in the area designated to one circuit.
- Earth fault loop impedance to the most remote socket-outlet on any branch must not exceed maximum permitted Z_s values specified in BS 7671. However, for practical reasons, such

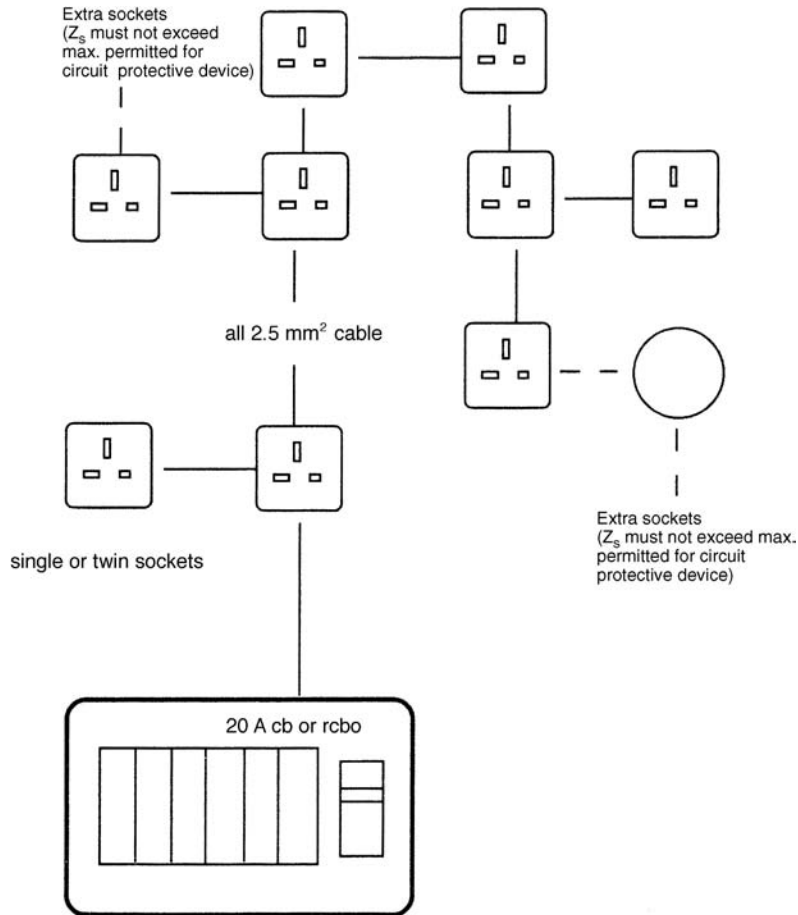


Figure 9.4 A versatile 20 A tree system.

values need not be achieved where earth fault protection is relied upon (e.g. on a TT system) by means of a 30 mA RCD.

- Voltage drop to the most remote socket-outlet on any branch should not exceed 5% on full load. On a typical PME supply, this requirement will be found to be more onerous than the earth loop impedance.

9.15 32 A tree

A 4.0 mm² cable will be adequately protected by a 32 A circuit-breaker or RCBO. Cables may branch off in any direction from a socket or accessible joint box.

Table 9.1 Suggestions for loading limits on domestic tree circuits.

Tree system	Typical application for one circuit
20 A fuse, circuit-breaker or RCBO 2.5 mm ² cable	Living room and dining room or three bedrooms or sheltered flat All the above exclude kitchens, but may include stairs and landings. A kitchen may have its own circuit provided there is a separate laundry or utility room.
30 A/32 A fuse, circuit-breaker or RCBO 4.00 mm ² cable	Kitchen and utility. 2.5 mm spurs as with a conventional 2.5 mm ² 30 A ring.

9.15.1 Domestic

One 32 A tree circuit may be applied in a kitchen, which encompasses domestic laundry equipment.

9.15.2 Commercial and similar

The 32 A tree may be applied taking into account the following limiting factors:

- Diversified current loading must not exceed 7.25 kW in the area designated to one circuit.
- The earth fault loop impedance at the most remote socket-outlet on any branch must not exceed the maximum permitted Z_s values specified in BS 7671. For practical purposes, this length of run is of no consequence if the circuit is protected by a 30 mA RCD.
- Volt drop to the most remote socket-outlet on any branch should not exceed 5% on full load. On a typical PME supply, this requirement will be found to be more onerous than the earth loop impedance.

9.16 Switching and control

An interesting aspect of a tree system is the ability to switch groups of sockets. It is often useful to have a switch by a door to operate table lamps. In other arrangements, time switches or security detectors could control a bank of socket-outlets. None of this is easy to arrange with a ring circuit.

As a final illustration of possibilities, Figure 9.5 illustrates some ideas for two rooms in a domestic situation.

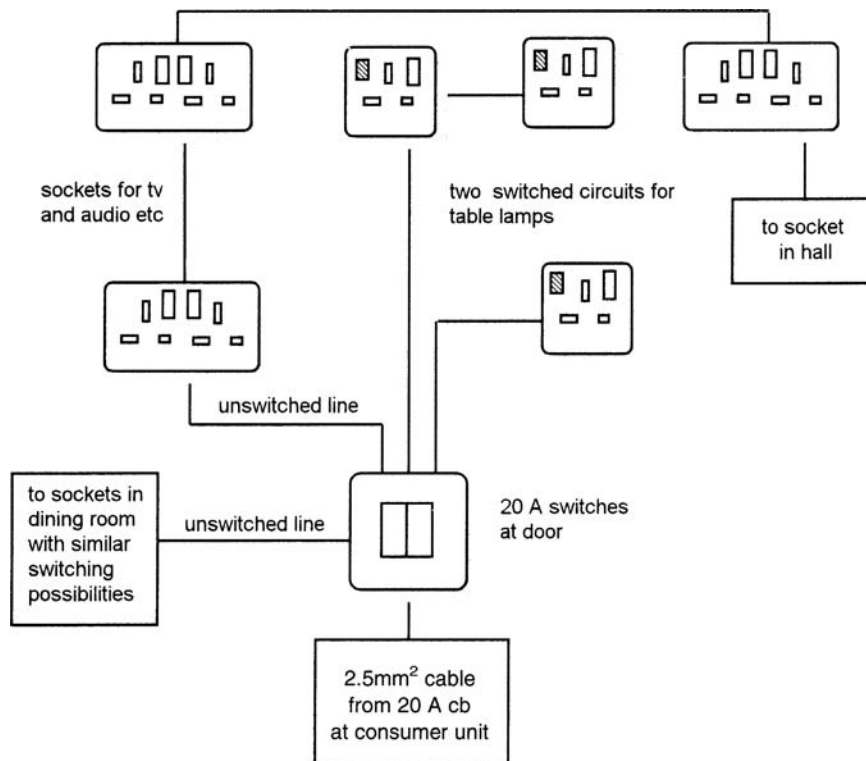


Figure 9.5 Tree system for downstairs rooms (note use of pilot light sockets).

9.17 Comparison of systems

There is no universal solution to every wiring situation but, in many cases, a 20 A tree system may be a suitable alternative to a 30 A/32 A ring final circuit.

9.18 32 A ring final circuit

9.18.1 Disadvantages

- untested installations or alterations may function with undetected faults;
- not necessarily suitable for modern load demands;
- inflexible for alterations and additions;
- in many cases, overrated for intended loading;
- will not easily convert to a future 16 A system.

9.18.2 Advantage

- 32 A capacity for large loads.

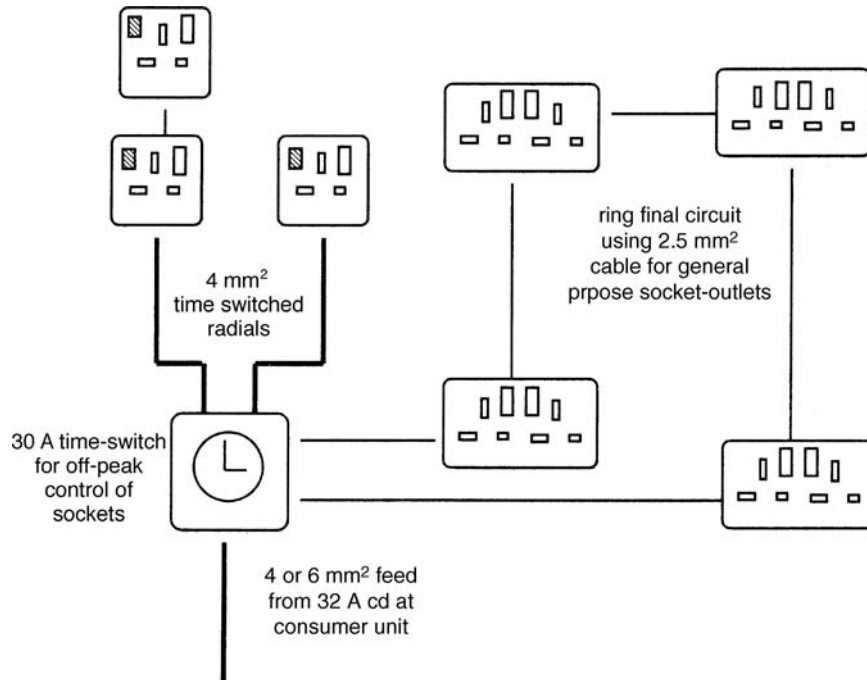


Figure 9.6 30 A radial-ring circuitry for kitchen.

9.19 20 A tree

9.19.1 Disadvantage

- limited to 20 A.

9.19.2 Advantages

- open circuits are easily discovered;
- crossed-connections in the circuitry are impossible;
- additional sockets-outlets can easily be added;
- simple conversion to a future 16 A system;
- possibly up to 20% saving in copper;
- switching or other controls can be built in to groups of sockets.

9.20 Composite circuits

There are some applications more suited to a 32 A ring circuit for large loads. A 32 A tree with 4 mm² cables may save on labour but not on material costs. Surprisingly, two 2.5 mm² cables can sometimes be cheaper than one 4.0 mm² cable.

It is acceptable to use a combination 32 A configuration combining the advantages of each system. One arrangement is shown in Figure 9.6, but ideas like this may have greater application for commercial installations.

433.1.103 It is a requirement of the Wiring Regulations for designers of ring final circuits to design such circuits so that the current-carrying capacity (I_z) of the cable is not less than 20 A and if, under the intended conditions of use, the load current in any part of the circuit is unlikely to exceed for long periods the current-carrying capacity (I_z) of the cable. This restriction could mean that, in some installations, it would not be practical to use a ring final circuit to supply standing loads such as a dishwasher, a washing machine and/or a tumble dryer from the same circuit, as conventionally done in kitchen/utility area.

In essence, two radial or tree circuits may therefore be the preferred method of wiring for this type of equipment.

Farming and Horticulture

Agricultural and horticultural premises are considered locations of increased electric shock risk, because people and livestock are in contact with the general mass of earth (i.e. the ground), in wet or damp conditions, and the electrical installation is generally exposed to all sorts of external influences such as dust, chemicals, and damage from animals and/or machinery.

Consequently, electric shock in such locations is more likely to cause serious injury or death than those where the conditions are dry and no contact is made directly with the general mass of the earth.

The particular requirements for agricultural and agricultural premises are given in Section 705 of *BS 7671*, and include fixed electrical installations indoors and outdoors in locations such as:

- animal husbandry units and zoos;
- barns, stables and intensive breeding units;
- commercial greenhouses, market gardens and garden centres;
- storage areas for hay, animal feed, grain, straw and fertilizers;
- garden centres and nurseries.

Locations that are not covered in this chapter include installations in farmhouses, offices and similar places for human accommodation, as these are covered by the general requirements of the Wiring Regulations.

The chapter is different from other chapters for two reasons:

1. Farming projects often involve installations that are not connected with a PME supply network.
2. It is difficult to devise a sample scheme that will take into account all the possible operations and conditions, as there is no such thing as a 'typical' farm.

A good approach to designing an electrical installation in an agriculture and horticulture premise is to consider each part of the installation in turn. Ideas will be given for design techniques, materials, safety and economy.

10.1 Why farms are different

10.1.1 Environment

By their very nature, agricultural and horticultural locations will be exposed to all sorts of external influences. The most obvious external influence is water, but others like mud, dust and agro-chemicals, together with the presence of animals and vegetation, should also be considered, especially when it comes to selecting switchgear and the wiring system(s). Potential risks include fire, explosion (from dusty atmospheres) and attack from vermin.

10.1.2 Livestock

Experience has shown that animals are more sensitive to an electric current passing through them than humans. For example, it is understood that a voltage of less than 50 volts a.c. has been known to kill a cow or a horse standing on a wet surface. Even if an animal were to survive an electric shock at such a voltage, the shock would cause the animal some distress that would inevitably lead to panic, which could be disastrous to both man and beast. Some animals also seem to remember the slightest shock ‘tingle’ and have been known to refuse to re-enter a pen or stable where it experienced an unpleasant sensation in the past.

In many intensive rearing situations, the continuation of heating and/or ventilation is critical to the survival of livestock. Therefore, the reliability of such equipment is very important. More information on this subject is covered later in this chapter.

10.1.3 Equipotential zones

Chapter 7, Earthing and Bonding, explains soil voltage gradients and voltage drop in cables. When these are considered, it can be seen that it is impossible to create a huge equipotential area across a farmyard or between separated horticultural buildings.

Where it is not possible to extend the equipotential bonding to each and every extraneous-conductive-part in such locations, then all extraneous-conductive-parts and exposed-conductive-parts that could be touched by livestock in that location should be equipotentially bonded and connected to an earth electrode, which is electrically separated from any other extraneous-conductive-parts and exposed-conductive-parts of any other earthing arrangement, such as those within an installation forming part of a TN-C-S system.

This chapter therefore offers only guidance and shortcuts to installers who fully understand the hazards of working in such environments.

10.1.4 Electrical systems

As farm installations can have earthing problems, we will briefly review conditions that are explained in more detail in Chapter 7.

An electrical installation that is connected to a distributor's PME network facility is described by the letters TN-C-S. Within the consumer's installation, the neutral is classed as a live conductor so it will be separate from earth, but the two conductors have a common termination at the origin of the installation.

It should be appreciated that a distributor has a general obligation under Regulation 24(4) of the ESQCR to make available for connection to the earthing conductor of the installation his PEN (combined neutral and protective) conductor or, if appropriate, the protective conductor of his network.

However, there is an exception to this obligation where this would be inappropriate for safety reasons, such as may be the case for certain locations or installations (e.g. on farms). To assist electrical installers, some distributors publish notes of guidance advising on situations where an earthing connection will not be made available.

So, as previously mentioned, it may not be advisable (or permissible) to use a PME earth. In other situations, it will be found to be impossible to use that earth and comply with earth fault loop impedance requirements for some or all of an installation. Where this is the case, the consumer must then provide his own means of earthing by using an installation earth electrode. The installation would then form part of a TT system (Figure 10.1).

Figure 10.1 shows that a consumer's installation can form part of a TN-C-S or a TT system.

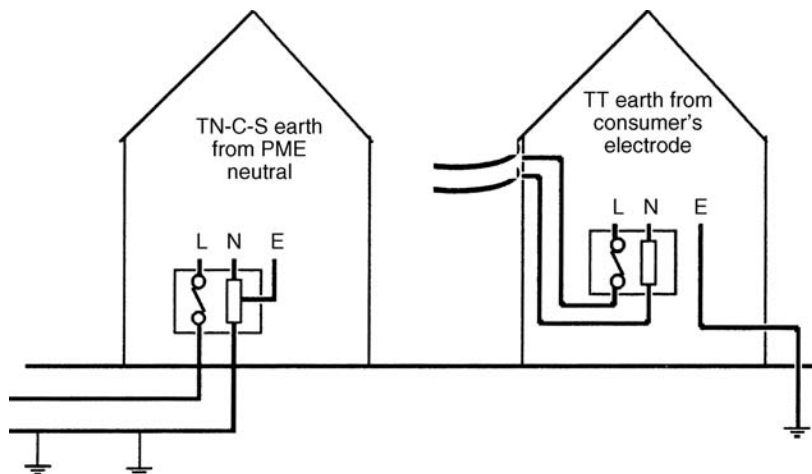


Figure 10.1 Usually TN-C-S is an underground service and TT is overhead, but not always.

It is not unusual for a farmhouse, or other such premise, to have a PME (TN-C-S) supply that utilises a distribution circuit (sub-mains) to supply an outbuilding or barn. Such an outbuilding will then have its own local installation earth electrode, so the installation will then form part of a TT system. The earthing between the two buildings (systems) should not be interconnected.

10.2 Special earthing requirements on farms with TT systems

Special earthing requirements apply to any installation where there is no connection to the distributor's earth:

- 542.4 ● Every protective conductor (green-and-yellow) must be connected to a common earth electrode via the main earthing terminal (MET).
- 411.5 ● If there are several protective devices in series (in separate buildings), each section of the installation may be connected to a separate earth electrode (Figure 10.2).
- A residual current device is the preferred protective device for protection against electric shock, and is the only device that will be considered for shock protection in this chapter. But, fuses and/or circuit-breakers must still be used for protection against overcurrents.

10.2.1 Warning

The resistance of an earth electrode should be as low as practicable. In fact, a note in Regulation 411.5.2 suggests that a value exceeding $200\ \Omega$ may not be stable. But what does this mean?

- 542.2.4 Whatever type of electrode is selected, electrical installers must take account of the effects of soil drying and freezing, as such conditions can affect an electrode's resistance by as much as eight times, especially in the latter case.

Other factors that affect the resistance of an earth electrode include the size and shape of the electrode, the soil resistivity, and the embedded depth of the electrode.

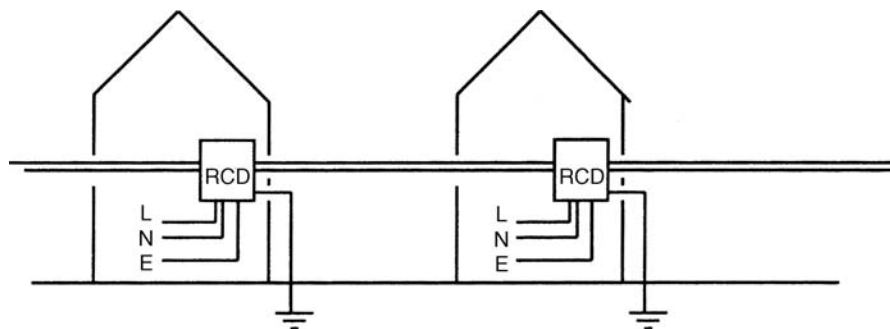


Figure 10.2 An installation earth electrode for each building.

Table 10.1 Characteristics of residual current devices.

RCD operating current	Maximum earth fault loop impedance (Z_s)
$I_{\Delta n}$ (mA)	$z_{pccs} + \text{electrode } (\Omega)$
30	1667
100	500
300	167
500	100

For detailed information on this subject, designers and installers should consult *BS 7430 Code of practice for earthing*, as it is an extremely useful document.

For the reasons already given, it is not possible to offer a typical value of resistance for an earth electrode, but experience has shown that earth electrode resistances of between 40 and 150 Ω are achievable. Maximum earth electrode resistance values for a range of RCD ratings are shown in Table 10.1.

10.3 Earth electrodes

It is conventional practice to drive a rod type earth electrode into the ground. Such electrodes (commonly referred to as an earth/earthing spike) must comply with the requirements of an applicable British Standard. So, a length of galvanised water piping (or similar) is therefore not satisfactory, and the exposed termination will be easily damaged. 542.2

The connection(s) to the electrode must be located in a position where it will not dry out, freeze or be subject to corrosion. This is especially important where chemical or slurry contamination may arise. It must be remembered that the shock protection features of the installation depend upon the effectiveness of this earth electrode current path. The installer carries full responsibility for future safety.

Provision must be made for disconnecting all earth electrodes for separately testing their earth resistance. 542.4.2

10.4 Alternative electrodes

BS 7671 recognises that the following may also be used as earth electrodes: 542.2.3

10.4.1 Earth tapes and wires

Earth tapes and wires are usually exposed, untinned copper, in strip or round cross-section and, in order to comply with Table 4 of *BS 7430*, an earth tape or wire must have a cross-sectional

area of not less than 50 mm^2 , and the thickness of a strip conductor or the strand diameter of a stranded conductor must be at least 3 mm.

10.4.2 Structural steelwork

The steel frame of a barn may create an excellent earth electrode. The relevant requirements are that a suitable resistance be achieved in a permanent and reliable manner.

10.4.3 Concrete reinforcement

Steel reinforcement in pre-stressed concrete columns or beams does not constitute a reliable earth electrode regardless of any initial test reading.

Welded metal reinforcement in poured concrete, such as in floor areas, may give good earthing, provided that connections are reliable and can be made accessible for future testing. Other suitable underground metalwork may also be used.

10.4.4 Earthing grids or plates

Where the nature of the soil gives a high or unreliable resistance, consideration should be given to the use of buried earthing mats. This is a specialist subject and depends upon local soil conditions. Consultation with a company that specialises in such work is recommended.

10.4.5 Pipework of other services

- 542.2.6 A metallic pipe for gases, flammable liquids and one belonging to a water utility should not be used as an earth electrode. However, other metallic water supply pipework (i.e. metallic pipe from a private well) may be utilised as an earth electrode, provided precautions are taken against its removal and it has been considered for such use.

10.5 Bonding

10.5.1 Main bonding

Standard arrangements apply whether the installation forms part of a TT or a TN system.

- 542.4A The MET must be established at the mains position, which connects the circuit protective conductors and the main protective bonding conductors to the earthing conductor.
- 544.1 All incoming services must be electrically connected together and connected to the MET of the installation. Where they fall under the definition of an extraneous-conductive-part, conductive pipework, such as that for compressed air, fuel oil or water from a well, will also have to be main bonded. Where plastic pipework is used for water, a main bonding connection should

be made on a metallic insert on the consumer's side of the stop cock. After this, no further main bonding will be necessary within the equipotential zone, as this is covered by the earthing facility. If the water service is taken into another equipotential zone, main bonding will need to be repeated at each point of entry of each building.

Milk pipes usually consist of sections of stainless steel with plastic connections. These should therefore not be connected to any bonding or earthing system, unless they are extraneous-conductive-parts in their own right.

10.6 Supplementary bonding

In locations intended for livestock, supplementary bonding must connect all exposed-conductive-parts and extraneous-conductive-parts that can be touched by livestock. 544.2

Protective bonding conductors must be protected against mechanical damage and corrosion, and be selected to avoid electrolytic effects. For examples of materials that can be used for supplementary bonding conductors (and sizes), refer to Regulation 705.544.2 of *BS 7671*.

Generally, 'earthy' metalwork does not normally constitute a major electrical hazard but, on a farm, slightly different potentials can sometimes arise as a result of soil and conductor resistances. As suggested earlier in this chapter, animals can sense these potential differences (voltages), which can be apparent on a PME network. 705.415.2.1

On a farm, the extraneous-conductive-parts that are in, or on, the floor (i.e. concrete reinforcement in general or reinforcement of cellars for liquid manure) are also required to be connected to the supplementary bonding.

The Wiring Regulations recommend that spaced floors made of prefabricated concrete elements should also be connected to the supplementary equipotential bonding. It is worth pointing out that the note in Regulation 705.415.2.1 recommends that where a metal grid is not laid in the floor, a TN-C-S supply should not be used. Milking parlours and pig-rearing pens are typical locations of where grids may be necessary.

Early consultation is therefore essential on all new farming developments, to ensure that metallic grids are provided, where necessary, in concrete floors.

10.7 Residual current devices

10.7.1 Discrimination

Before considering the various requirements for the use of RCDs on farms, the factors related to discrimination/co-ordination should be re-examined, as unwanted tripping may occur when there is more than one RCD in series with the supply to equipment or a socket-outlet. 531.2

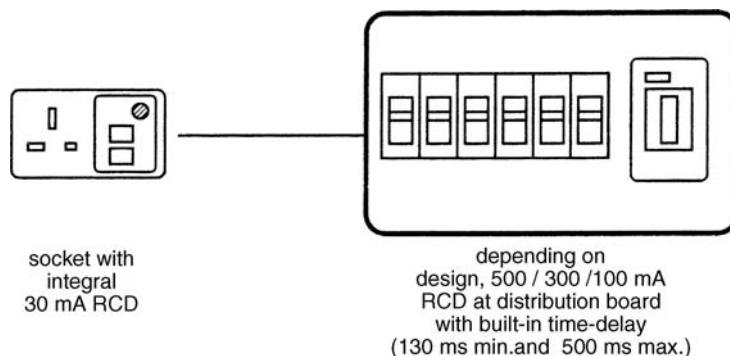


Figure 10.3 Time discrimination with series RCD protection.

Discrimination requires that the protective device nearest in line to a fault should operate before any upstream device(s). Thus, if there is a 30 mA protected socket-outlet in a workshop, this should trip before, say, a 300 mA RCD at the mains position. A lack of discrimination may mean that essential services for milking or ventilation are disconnected from the supply for trivial faults (Figure 10.3).

It is easy to understand that a local fuse with a small size wire (low rating) will react more quickly to any fault than a fuse having a higher rating. Circuit-breakers have a similar characteristic built into them. An RCD is different. The essential characteristic of an RCD for shock-protection purposes is that it reacts *instantaneously* under fault conditions. For practical purposes, instantaneous means in a time not exceeding 40 ms.

Therefore, reverting back to the example of a 30 mA protected socket in series with a 300 mA RCD, any fault in excess of 300 mA would cause both devices to operate instantaneously. This is because both are equally sensitive to this fault. However, in practice, age, working conditions and manufacturing tolerances may bring out one or other device first. But there is no designed discrimination.

The solution to the above is therefore to use an RCD that incorporates a time delay, upstream of the 30 mA RCD. Such devices are known as ‘selective’ (i.e. have an in-built time-delay). The time-delay is in terms of milliseconds but it should be sufficient to ensure that the local device (i.e. 30 mA RCD) normally operates first. Where doubt exists, manufacturers of RCDs should be consulted.

10.8 Shock protection

The requirements for protection against electric shock by Automatic Disconnection of Supply (ADS) have been brought together under one heading in the 17th edition of the Wiring Regulations for agricultural and horticultural premises.

10.9 General requirements for automatic disconnection of supply (ADS)

For both TN and TT systems, the following disconnection devices must be provided:

1. in final circuits supplying socket-outlets with a rated current not exceeding 32 A, an RCD having the characteristics specified in Regulation 415.1.1;
2. in final circuits supplying socket-outlets with a rated current of more than 32 A, an RCD with a rated residual operating current not exceeding 100 mA;
3. in all other circuits, RCDs with a rated residual operating current not exceeding 300 mA.

Regulation 415.1.1 refers to ‘Additional protection’, by means of an RCD having a residual operating current of 30 mA or less. Such devices must disconnect a 150 mA fault or greater within 40 ms. 415.1.1

The use of such devices is recognised in a.c. systems as additional protection in the event of failure of the provision for basic protection (e.g. insulation) and/or the provision for fault protection (i.e. a fuse or circuit-breaker), and/or carelessness by users of the installation.

It is wise to limit the number of socket-outlets that will be protected by a single RCD. So, rather than protecting the whole board with one 30 mA device, it is preferable to use two or more RCDs to protect a few circuits or use RCBOs to protect each outgoing way on a distribution board. Such an arrangement may help out in locations that are continually damp, where unavoidable leakage from many appliances will increase limit the sensitivity of the RCD and cause unwanted tripping (Figure 10.4). 531-02

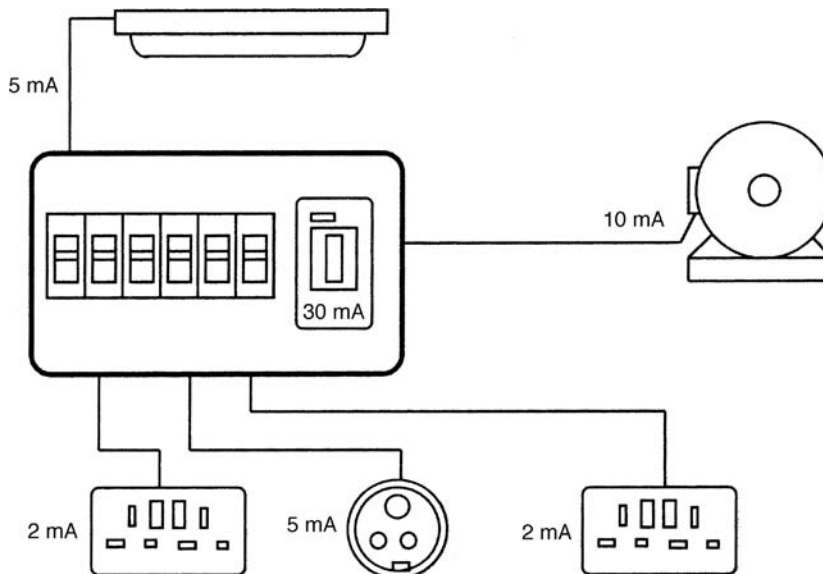


Figure 10.4 Cumulative effect of normal leakages may trip a 30 mA RCD.

The regulations for agricultural premises require all circuits in all farm buildings to have RCD protection rated at not greater than 300 mA. Such a rating is sufficient to provide an element of fire protection and, as they are not over-sensitive, unwanted tripping should not normally be a problem. A good electrical design will provide for separate RCDs for each section and each separate building, and designers may consider it to be prudent to standardise on using either 300 mA or 100 mA devices, where circumstances permit.

10.10 Fire protection

Regulation Group 422.3 states specific requirements for installations in locations where flammable materials are stored or processed.

Hay barns and store rooms on agricultural premises, for example, can contain a great deal of flammable materials, and grain processing operations produce large quantities of dust, which can be ignited, even from a minor electrical fault or earth leakage.

In these types of buildings, electrical equipment, such as switchgear and control gear, should be installed outside the location, unless the equipment:

- is suitable for the location; or
- is installed in an enclosure providing a degree of protection of at least IP4X or, where dust is likely to be present, IP5X, or in the presence of electrically conductive dust, IPX6, except where Regulation 422.3.11 applies.

As a minimum, a cable not completely embedded in non-combustible material, such as plaster, concrete or otherwise, suitably protected from fire, must meet the flame propagation characteristics as specified in *BS EN 60332-1-2*.

Where other types of wiring system (i.e. conduit or trunking) are to be installed in such locations, refer to Regulation 422.3.4.

Where improved continuity of service is required, RCDs not protecting socket-outlets must be of the 'S' Type or incorporate a time-delay.

10.11 Automatic life support for high density livestock rearing

705.560.6 Mention was made earlier of the importance of maintaining an electrical service to certain animal husbandry situations. Milking parlours, for instance, may require a continuous electricity supply, but such a case is not as important as keeping the electricity on to supply food, water, air and/or lighting for life support of animals in (say) chicken and pig units.

Unnecessary electrical supply failures must be avoided. Therefore, a secure source of supply may be required, from either an alternative or back-up supply. The supply to the ventilation and

lighting units are required to be via their own final circuits, with the appropriate discrimination in place, in case of any overcurrent and/or short-circuit to earth.

For further information on temperature and supply voltage monitoring, refer to Regulation 705.560.6.

10.12 Switchgear

Distribution boards and switchgear should be suitable for the location of the environment they will be used in. Therefore, where necessary, equipment must be specified to suit the expected conditions. This is a requirement of the Wiring Regulations and of the Electricity at Work Regulations. Standard industrial equipment may not be adequate and domestic type consumer units are usually unsuitable. 512.2

Electrical equipment should therefore have a degree of protection of at least IP44, when used under normal conditions. However, where a particular item of equipment is not available with that degree of protection, it can be installed in an enclosure that meets the requirements of IP44. 705.512

Socket-outlets must comply with either *BS EN 60309-1* or *BS EN 60309-2*, where interchangeability is required, or *BS 1363* or *BS 546*, provided the rated current does not exceed 20 A. They should also be installed in a position where they are unlikely to come into contact with combustible material.

Where there are conditions of external influences >AD4 (jets), >AE3 (very small foreign bodies) and/or >AG1 (low impact), socket-outlets must be provided with the appropriate protection.

Protection may also be provided by the use of additional enclosures or by installation in building recesses.

Note: the above requirements do not apply to residential locations, offices, shops and locations with similar external influences belonging to agricultural and horticultural premises where, for socket-outlets, *BS 1363-2* or *BS 546* apply.

In situations where corrosive substances are present, such as in dairies or cattle sheds, the electrical equipment must be adequately protected, such as mounting them at a reasonable height above floor level.

The electrical equipment should also have a degree of protection of IP44 or higher, to suit the environmental conditions. Here are some examples of other external influences that should be taken into consideration when selecting a particular item of equipment:

- *Dust Resistant:*

Grain, chemicals, animal foodstuffs and woodcutting all produce vast quantities of dust.

522.4

- *Water resistant:*
522.3 Rain, driving wind, condensation and hosing. The degree of protection must be specified. Non-metallic enclosures are always preferable.
- *Vermin resistant:*
522.10 Rats, mice, birds and insects will all produce problems, unless appropriate equipment is selected. Switchgear tends to be warm and inviting for nest building. Even when the gear is completely sealed, nests may be constructed behind enclosures.
- *Maintainable and user friendly:*
341.1 Farm operatives may not be electrically qualified, but speedy attention is often required to restore power.

Fuses are prone to abuse, which can create hazardous fire conditions. Circuit-breakers are preferably for unskilled operation, but care must be taken to ensure that their enclosure satisfies protective requirements for dust and vermin, and so on. An ordinary circuit-breaker or RCD is not dustproof and future efficiency could be restricted by a jammed mechanism. Frequent testing and operation will help to keep the mechanism free, but adequate dust protection is essential.

10.13 Wiring systems

In locations that are accessible to, and enclose, livestock, all wiring systems should be erected so that they are inaccessible to livestock or the wiring should be suitably protected against mechanical damage.

10.14 Overhead or underground wiring

- 522.8 It is often debatable whether a cable should be installed underground or routed overhead, so a lot will depend upon working conditions of the farm, and any future plans that it may have.
- 705.522 If a cable is to be installed overhead to span buildings, it must be insulated, and be installed at a height of at least 6 m.

Where a cable is to be concealed in the ground, it should be buried at a depth of at least 0.6 m, or where the cable is in arable or cultivated ground, at a depth of at least 1.0 m.

10.14.1 *Metallic conduit*

- 705.522.16 Metal conduit and trunking systems tend to give the highest physical protection but the primary concern on farms, and the like, is corrosion, as even galvanised conduit can rust, especially at unprotected joints. This can be overcome by applying paint at such joints, but to ensure the right conduit is selected for the environment, conduit that has protection against corrosion of at least

Class 2 (medium protection) should be selected for indoor use and Class 4 (high protection) for outdoor use (see *BS EN 61386-21*).

Should there be any chance that the wiring system will be exposed to impact and/or mechanical shock – from vehicles and/or mobile agricultural machines, and so on – the external influences must be classified as AG3 and:

1. conduits (complying with *BS EN 61386-21*) should be selected so that they are capable of resisting an impact of 5 J; and
2. cable trunking and ducting systems (complying with *BS EN 50085-2-1*) should be selected so that they are capable of resisting an impact of 5 J.

10.15 Non-metallic wiring systems

Plastic conduit and trunking will resist all the usual agro-chemical materials and water. Fears about attack by vermin are usually unfounded, unless conduit or trunking blocks holes that have previously been used as traffic routes by rodents. Rats and mice may sometimes eat soft polythene or plasticised PVC cable insulation, but they are not normally interested in unplasticised PVC conduit and trunking.

The installation of plastic conduit and trunking is quick and simple, but care and attention must be given to good workmanship:

- *Physical protection:*

Conduit must not be run in places where it is susceptible to impact or otherwise abused.

As far as possible, keep all circuit runs up high.

Adequate fixings are essential to eliminate sag.

- *Temperature:*

Standard PVC conduit and trunking is suitable for most ambient conditions. It is extensively used in both cold stores and tropical climates, where non-corrosive features are paramount.

Expansion and contraction of the plastic conduit system is inevitable. Therefore, special expansion couplers should be installed at strategic points throughout the system. In the absence of more precise information, PVC plastic conduit has been known to expand by approximately 1 mm per metre of run. This movement might be taken up at bends but, along straight runs, the conduit will cause sagging (i.e. wavy conduit syndrome). To overcome this, at least one expansion coupler should be fitted every 10 m. This, plus an adequate number of fixing saddles, will virtually eliminate sagging problems on exposed walls or under glass in hothouses. Saddles should permit longitudinal movement of conduit.

- *Water:*

Generally speaking, neither plastic cable nor conduit suffers from the occasional wetting.

Complete sealing of an electrical system is virtually impossible. Therefore drainage is more important than sealing. Conduit and trunking should have drainage holes at appropriate places and conduit entries should be taken into the bottom of fittings. It is worth mentioning

522.3

that some manufacturers of weather-resistant plastic accessories usually provide a small break-out drainage facility in the base of the mounting box for this purpose.

- *Solar radiation:*

522.11

Ultraviolet radiation from direct sunlight will biodegrade many unprotected plastics. White conduit and trunkings should be avoided in sunny positions. The colouring additive in black PVC compound inhibits the penetration of ultraviolet light beyond a surface layer, which may discolour.

10.16 Steel Wire Armoured (SWA) cable

Steel wire armoured (SWA) cables with PVC sheathing are suitable for most farming applications, provided certain precautionary measures are taken.

- *Corrosion:*

Special care is required to prevent corrosion of exposed armouring at joints.

- *Continuity:*

It is doubtful whether permanent and reliable continuity can be obtained where the armouring of SWA is connected to metallic enclosures. It is always therefore advisable to use a separate cpc within the cable, or externally if a spare core is not available within the cable.

- *Water immersion:*

The outer PVC sheathing of SWA cable should be good for most weather-resistant applications, but may not be suitable for continuous immersion in water.

Where a cable is required to be immersed in water, the application should be discussed with the cable manufacturer, who will be able to supply an armoured cable with an outer sheathing suitable for such purposes. An alternative solution would be to install the PVC-sheathed SWA cable in a continuous polythene pipe or waterproof duct.

10.17 Twin and earth cable

522.10

PVC insulated twin and earth cables are suitable for many farming applications, where there is no need for further mechanical protection. However, care should be taken in locations where vermin is likely to exist, as experience has shown that the insulation has been known to be chewed. Farm animals, horses and dogs have also been known to chew through insulation. Consideration should also be given to the possibility of barns being used as temporary storage areas, especially in bad weather.

10.18 General rules regarding farm electrical installations

This section summarises some of the important regulations for agricultural, horticultural and similar installations.

- Protection against electric shock and fire is provided by the use of a suitable wiring system and enclosures (having the appropriate IP rating) installed in safe positions.
- Shock protection against faults is achieved with good earthing and bonding practices, co-ordinated with fuses, circuit-breakers and/or RCDs.
- Additional protection is achieved by means of a 30 mA RCD, having the characteristics specified in Regulation 415.1.1
- Wherever possible, the use of all-insulated wiring systems and enclosures is recommended. Class II all-insulated switchgear is available, but this may be more expensive than industrial steel enclosures, but maintenance costs should be reduced.
- Wiring and switchgear must always be inaccessible to livestock. This applies to lighting switches in stable blocks in locations where horses may be temporarily tied up or in piggeries where barriers are moved about to suit farrowing requirements.
- The positioning of emergency switching devices should take into account animal movement and behaviour.
- In grain and hay/straw storage areas, additional fire protection can be achieved by the use of a 300 mA RCD.
- Heating appliances must be installed at a distance of 0.5 m or such other distance as specified 422.3 by the manufacturer. This is to minimise any risk of burns to animals and fire. The consequences of fire must be considered in buildings where fodder and bedding are stored. This especially applies in farrowing pens, kennels and catteries. Refer to Regulation Group 422.3 for further details.
- The regulations in Part 7 of *BS 7671* supplement or modify the general requirements 700 contained in other parts of the standard. The absence of reference to the exclusion of a part, a chapter, a section or a regulation means that the corresponding general regulations are applicable.

Isolation and Switching

This chapter deals extensively with safety requirements covered by the Wiring Regulations. Unless otherwise indicated, the reader must assume that statements are regulatory, that is there is no designer or installer choice.

If there is an element of judgement or choice in a design, this will be made clear. Where such a decision has been made, the person signing the Electrical Installation Certificate, as the designer, carries full responsibility. A design decision is acceptable, provided that a competent judgement has been made in good faith, with safety the prime consideration.

Terminology

It must be emphasised that the use of correct terminology is essential for the understanding of technicalities. Words such as switching or local isolation are meaningless, unless everyone is using them in the same way. So, if there is any doubt about the interpretation of a word, it is always worth checking the exact definition given in the Wiring Regulations.

Remember that both line and neutral conductors are defined as live conductors.

11.1 Isolation and switching

There are four categories of isolation and switching, which should not be confused:

1. *Functional switching (control):*

- 537.5 This is the control for the user of equipment (i.e. the on-off facility). This may be the switch on a socket or the light switch on the wall. It can even be a switch on an appliance or a piece of machinery that also provides for variable speeds or reversing control.

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For some items of equipment where continuous operation is essential, for example a refrigerator, there may be no functional switch, or the functional switching is achieved by pulling out the plug.

2. *Isolation:*

This means disconnecting the equipment or installation (or part of) from every source of electrical energy. The fundamental purpose of isolation is to enable work to be carried out safely by a skilled person on what would otherwise be live parts. Simply pulling out the plug may be sufficient to isolate an appliance. As a general rule, every installation must have means of isolation at the mains position. 537.2

3. *Switching off for mechanical maintenance:*

This is intended for a non-technical operative or a cleaner to maintain the non-electrical parts of a machine, such as changing a belt or cleaning a fan blade, or for a householder to change a lamp. 537.3

4. *Emergency switching:*

This means disconnection of the supply to remove an unexpected hazard. Not every installation or item of equipment requires this particular type of switching. 537.4

It can be seen that two or more of these switching applications can be combined in one item of switchgear, or even a plug and socket. In other cases, equipment may not need switching for every purpose. Take, for example, an immersion heater, which does not require mechanical maintenance or emergency switching.

Functional switching (control)

A functional switch need not necessarily control all live conductors and a single switch may control several items of equipment that operate simultaneously. A functional switch, enabling change-over from other supply sources, must switch all live conductors (line and neutral) and not be capable of connecting the sources in parallel, unless the installation is specifically designed for this condition. 537.5

11.2 Isolation

11.2.1 Main switch

Every installation must have a main linked switch or linked circuit-breaker installed as near as practicable to the origin of the supply intake. On very rare occasions, this provision may be given by the supply company, but permission must be obtained before omitting the customer's switch. 537.1.4

In most cases for TN systems, isolation is achieved by disconnection of all line conductors with a suitable switching device. The one common exception is at the main switch on a single-phase installation, which must be a double-pole device, in order to switch both the line and neutral conductors.

For an installation connected to a three-phase supply on a TT or IT system, the neutral need not be isolated. However, where a solid linkage is provided within a three-phase isolator, it must be accessible only to a skilled person who must need the use of a tool to remove the link.

537.2.1.1 The main switch for a TT or IT installation must isolate all live conductors. This means four-pole switching on a three-phase system.

Occasionally, a building will have more than one electrical installation, such as a building having normal and off-peak services. In such cases, the installations may be considered separately, each requiring its own main switch.

Security and lockability

Where an item of equipment contains live parts, which may need attention by a skilled person, adequate means of isolation must be provided.

537.2.1.1 One isolator can be used for several circuits or several items of equipment, unless safety or convenience demands that separate isolation is essential.

Isolators must be installed in such a way as to prevent unintentional reclosure. Furthermore, an isolator being used for a particular function must be under the control of the person carrying out the electrical work. This may be achieved by having an isolator next to the motor or equipment being examined, or by having a secure lock-off facility at a remote position:

537.2.1.5 ● Isolating switches usually have the facility to be secured (for padlock attachment) in the open position.

537.2 ● It is not sufficient to push a piece of wire through the padlock hole or hang up a notice.
● Special locking attachments are available for a standard circuit-breaker. Alternatively, a complete distribution board may be locked shut to prevent unauthorised resetting of a circuit-breaker. Care must be taken where there is more than one key that will open the distribution board.

Table 53.4 ● A local plug and socket-outlet arrangement provides adequate isolation, provided that it is under the control of the operative requiring protection.
● Isolation by the removal of fuses is not normally acceptable unless there is no possibility of replacement or substitution by another person or a lockable security barrier is used.

11.3 Mechanical maintenance

Often the device used for isolation doubles up as the switch for mechanical maintenance. Similar security rules apply.

537.3 ● In some circumstances, the mechanical maintenance switch may be in the control circuit of equipment but, where this is the case, it must not then double as an isolator. Where an isolator does double as a switch for mechanical maintenance, care must be taken to prevent automatic

restarting or inadvertent operation by another person. For example, push button control is not appropriate without a lock-off facility.

- The switch must be capable of breaking full load current. Therefore the removal of fuses is unacceptable.
- There is the possibility that the person carrying out mechanical maintenance may not be electrically skilled.
- The location of the correct switch must be made obvious, either by its proximity to the task in hand or by labelling.
- The ON or OFF condition must be clearly indicated.
- A suitable plug and socket of rating not exceeding 16 A may be used.

537.3.2.6

11.4 Emergency switching

The isolation device or switch for mechanical maintenance often also fulfils the function of an emergency switch. By its very nature, an emergency stopping device must be able to operate on full load current and act as directly as possible on the supply.

BS 7671: 2008 defines emergency switching as an operation intended to remove, as quickly as possible, danger, which may have occurred unexpectedly. There is also a definition for emergency stopping, which is emergency switching intended to stop an operation:

- An emergency switch must be provided for any part of an installation, where it may be necessary to control the supply to remove an unexpected danger.
- Where a risk of electric shock is involved, the rules for isolation of live conductors apply.
- A means of emergency stopping must be provided wherever electrically-driven machinery may give rise to danger from mechanical movement.
- The means of emergency switching or stopping must be durably marked, readily accessible and easily operated.
- An emergency stopping device may be incorporated into an appliance or as a part of the electrical installation. If separate from an appliance, one device may control more than one appliance, provided that it is readily accessible.
- Care must be taken to prevent unexpected restarting where the *emergency* stopping device is a push-button or if there is more than one means of restarting.
- A plug and socket-outlet or similar device is *not* permitted to be selected as a device for emergency switching.

537.4

Additional special regulations apply to the fireman's emergency switch for high voltage lighting installations and hazardous areas.

Examples of emergency switching

Emergency switching is necessary to protect people from danger, which at the time of an incident may have been unexpected, but should have been seen as a possibility at the time of design.

11.4.1 Domestic

Two domestic situations illustrate the point. Both require clearly identifiable and accessible emergency switching:

1. A kitchen cooker fire is not usually anticipated by the user, but it is not an uncommon occurrence.
2. A sink waste disposal unit can cause sudden physical injury, due to careless use or interference with the works.

Other domestic appliances either have built-in emergency switching or do not have any foreseeable emergency condition. Examples of such appliances include:

- hand-held motorised appliances, which usually have fingertip controls;
- portable electric heaters, which have built-in switches or can be readily disconnected at the socket-outlet;
- an immersion heater, which does not have a foreseeable emergency condition.

11.4.2 Industrial

In industrial and commercial type locations, consideration should be given to the use of the equipment and possible hazards likely to be encountered.

- Machine tools require positive emergency stopping. This is usually incorporated into a no-volt starter circuit.
- Continuous push-button pressure may be required for the operation of lifting equipment, or a 'dead-man's handle' principle applied.
- Electro-mechanical fail-safe braking may be essential to bring machinery to a speedy halt if a person becomes caught in rotating parts. Automatic braking may also be required if the mains power fails to prevent uncontrolled movement of lifting machinery.
- Multiple emergency stopping facilities may be essential in training workshops, laboratories and kitchens.

11.4.3 Emergency stopping decisions

The above examples indicate that this is a wide and specialised subject. There is no single answer to every condition.

Wherever there is a non-standard need for the speedy disconnection of electrical power to equipment or a complete installation, the condition should be discussed with all interested parties and Health and Safety Executive (HSE) advisers.

Accessibility of switchgear

Two significant regulations relate to fundamental requirements for safety:

1. Effective means, suitably placed ready for operation, shall be provided so that all voltage may be cut off from every installation, from every circuit thereof and from all equipment, as may be necessary to prevent or remove danger. 132.15.1
2. Every piece of equipment, which requires operation or attention by a person, shall be so installed that adequate and safe means of access and working space are afforded for such operation or attention. Such a facility shall not be significantly impaired by mounting equipment in an enclosure or a compartment. 513.1

Both of these regulations support similar statements in the *Electricity at Work Regulations 1989*. Therefore, in any working situation, they may be considered to be mandatory and may also apply to work in progress on domestic projects.

Switches for any purpose should always remain accessible. In some situations, it may be decided to lock switch room doors to prevent interference by children or unauthorised persons. In these circumstances, the door should carry a notice indicating the presence of electrical switchgear and giving advice upon access. The key may be provided behind a break-glass facility or on a caretaker's keyboard. Naming an individual is useless and retaining the key within a locked drawer or room invalidates the requirement for ready operation.

The installation of domestic switchgear in kitchen cupboards should always be avoided, as the cupboards inevitably become overcrowded with cooking utensils, shopping and cleaning materials.

11.5 Labelling and notices

Except where there is no possibility of confusion, every item of switchgear and controlgear should be labelled (or be provided with some other suitable means of identification) as to its function. Where an operator cannot observe the operation of switchgear and controlgear and where this might lead to danger, a suitable indicator complying, where applicable, with *BS EN 60073* and *BS EN 60447*, shall be fixed in a position visible to the operator. 514.1.1

Where there are two or more main switches in a building, each switch should be clearly marked to show which part of the system is being controlled. This may apply to normal and off-peak services or separate controls for dedicated computer supplies. 537.1.6

In an emergency, it will be equally important for the fire brigade or an unskilled occupant to know what is being switched off and what is not being switched off. Sometimes there are two supplies into a building, with isolation in different places. Details should be shown at all locations.

Notices and labelling must be permanent and clearly legible, and last for the lifetime of the installation.

514.9 A legible diagram, chart or table or an equivalent form of information is required to be provided indicating, in particular:

1. the type and composition of each circuit (points of utilisation served, number and size of conductors, type of wiring);
2. the method used for compliance with Regulation 410.3.2;
3. the information necessary for the identification of each device performing the functions of protection, isolation and switching, and its location; and
4. any circuit or equipment vulnerable to a typical test.

However, for simple installations, such information may be given in the form of a schedule, and a durable copy of the schedule relating to a distribution board (i.e. a copy of the '*Circuit Details Schedule*') should always be provided within or adjacent to each distribution board.

Notices must be displayed on or near the switchgear, as 'installation manuals' located in the manager's office are of no value in an emergency.

A Village Sports Centre

This building is located on the edge of a sports playing field, remote from other buildings and on a rural electricity supply. The building could be a football pavilion, a golf club-house, or a health centre.

The design for this project could be combined with that for a small swimming pool to broaden the scope, or the plans could be adapted for a school sports hall with a supply taken from the main building. Similar regulations and conditions apply to any isolated building equipped with changing and shower facilities.

12.1 Special conditions

As the building is some distance from the network supply cables, there may be a potential difference between the supply PME earth/neutral and true Earth. In normal circumstances, this is not a problem. However, for some individuals standing under running water in a shower, they may notice a potential difference of perhaps a few volts (e.g. 3–8 V) between the shower head and the ground. This is discomforting and often causes concern to those using the shower.

Such an anomaly can occur in electrical installations that have relatively heavy three-phase loads that are unbalanced. For this reason, some off-peak heating has been added to this design, with all-electric hot water.

It should be appreciated that the lighting and heating scheme shown in this project is generalised, so is intended to illustrate electrical installation aspects only.

12.2 Codes of practice

- *BS 9999: 2008*: Code of practice for fire safety in the design, management and use of buildings.

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Although this is a small sports hall, the design has taken into account the fact that it will be used for social functions, such as dance events, shows and pop gigs. The Code of practice referred to above deals with all sizes of building and will probably be used by the architect or developer for the design and construction.

This electrical design will mention recommendations from the Code of practice, which are advisory and not mandatory. However, it would be most unwise to ignore the recommendations that are likely to be applied by the Local Authority for licensing purposes. So, it would be in the best interests of the installer to obtain a reference copy of the document.

12.3 Other interested parties

Most consultations will be through the builder, the client or the developer. Often schemes, such as this, are commissioned by a local charity, with volunteer committee members directing the operations on an ad hoc basis. The importance of a full specification cannot be overstated.

The installation subcontractor must be certain that appropriate advice has been taken from all relevant authorities.

- *Electricity distributor:*

It is the developer's responsibility to negotiate for a supply. This job is usually delegated to the electrical installer. Make sure that a suitable electricity service can be taken to this remote building and establish the cost. On occasions, depending on location and distance from the nearest transformer, the cost to provide the electricity supply has been known to be prohibitive.

- *Local licensing authority:*

This building will be used for social functions, so safety and environmental factors will be important. Perhaps a children's play group will use the premises.

- *Fire authority:*

Emergency lighting and fire alarms will be arranged in conjunction with door exits and fire-fighting facilities.

- *Client's insurers:*

Fire and personal safety requirements and the possibility of vandalism.

- *Beer supplier:*

For details of chilling and dispensing equipment.

- *Future users:*

If possible, meet up with clubs and groups who will be using the facilities. There may, for example, be implications on the lighting design for badminton or volleyball activity.

12.4 Building details

An early study of the building's construction is essential before commencing the electrical design (Figure 12.1, which also shows lighting and socket-outlet provision).

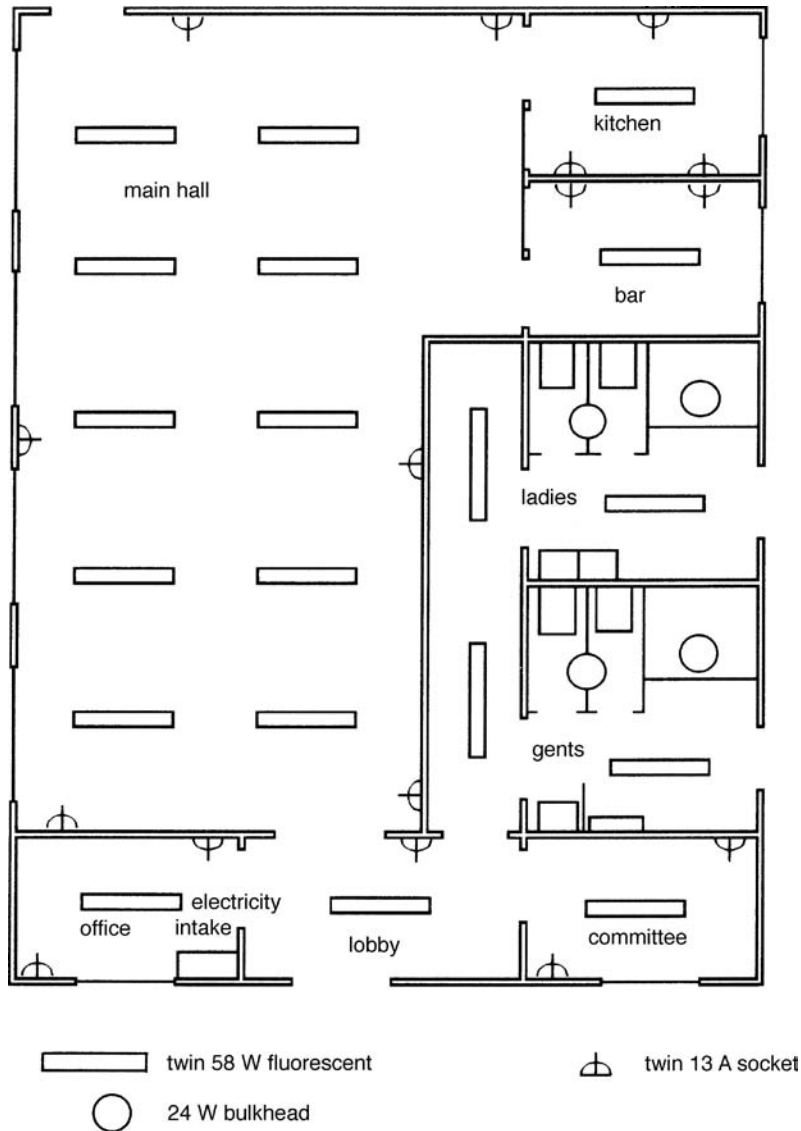


Figure 12.1 Lighting and 13A sockets in sports hall.

12.5 Structure and finishes

This is a new project. The general construction is lightweight, economy being the top priority. The building is 300 m from the nearest electricity supply:

- single storey, on flat ground;
- total floor area: approximately 550 m².
- *Walls:*
 - external:* cavity brick or building block;
 - internal:* single building block.
 - Wall finishes:* decorated fair faced in hall and side rooms; not plastered; tiled in shower/toilet areas.
- *Roof:*
 - pitched roof with timber trusses.
- *Ceilings:*
 - plasterboard with good access to a roof space; glass fibre insulation above the ceiling.
- *Floor:*
 - concrete base throughout with plastic floor tiles or ceramic tiles, as appropriate.

12.6 Electricity supply and requirements

An assumption is made that the electricity distributor has agreed to provide an overhead service from the local PME network, which will enter the building in the entrance lobby, as shown on the layout. A dual tariff meter will be installed, so that the storage heating can utilise a cheaper rate of electricity overnight:

- Space heating will be a mix of storage heaters and direct-acting heaters.
- Water heating will be with direct-acting showers and local sink water heaters. There is no stored hot water.

See Figure 12.2 for details of the heating system.

12.7 Off-peak tariff

Block storage heaters (15 × 3 kW) will be installed in the main hall and side rooms.

12.8 Normal tariff

- *Changing rooms:*
 - 4 × 7 kW electric showers;
 - 2 × 3 kW quartz radiant heaters;
 - 2 × 2.5 kW sink heaters;
 - 20 × 0.18 kW tubular heaters.
- *Kitchen and bar:*
 - 2 × 2.5 kW sink heaters;

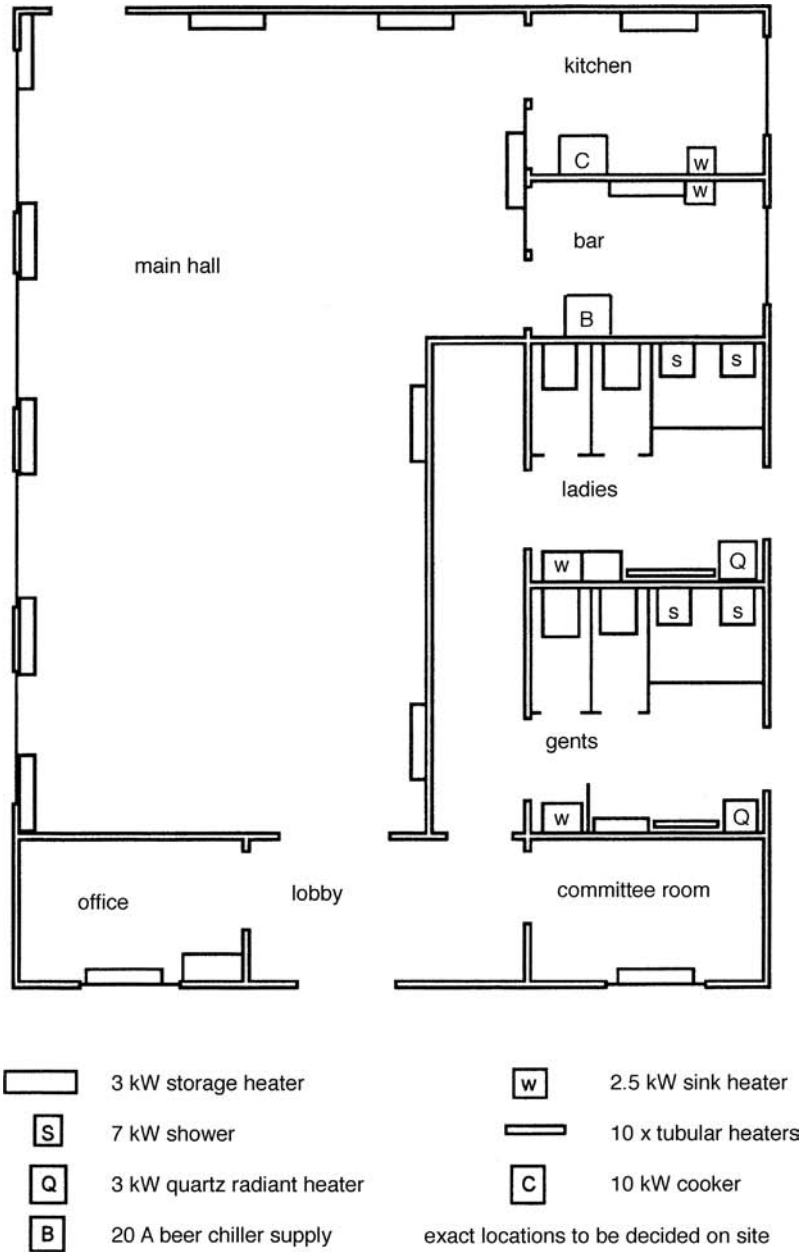


Figure 12.2 Heating loads in sports hall.

- 10 kW domestic type cooker;
- 20 A single-phase supply for beer chiller, and so on.
- **Socket-outlets:**
16 × twin 13 A sockets.
- **Lighting:**
(see Figure 12.1 for details of the lighting scheme);
19 × twin 58 W fluorescent fittings;
4 × 24 W fluorescent bulkheads.

12.9 Load assessment and diversity

311.1 It is important to calculate maximum demand characteristics at an early stage. This will affect much of the electrical design and will be required to confirm that the electricity company can make a supply available.

As there is little published guidance on this type of building with regard to maximum demand and diversity, or a comparison with a similar building, the designer must consult the client and make judgements about the usage of equipment. Conclusions reached by the application of diversity figures only apply to the estimated total maximum demand and not to the sizing of final circuits and cables. This is not an accurate study and many figures have been rounded off.

12.10 Off-peak heating

There is no diversity over the storage heaters, which will all operate simultaneously:

$$15 \times 3 \text{ kW heaters} = 45 \text{ kW} \quad (12.1)$$

This will be spread across three phases = 65.2 A per phase.

12.11 Normal tariff

12.11.1 Showers

Strictly speaking, a shower is an instantaneous water heater so when on, it is on at full load – so no diversity can be applied. However, as all four shower units may operate simultaneously for relatively short periods of time, usually when off-peak heating is off, an allowance of 75% has been given:

$$4 \times 7 \text{ kW} \times 75\% ((4 \times 7000 \times 0.75)/230) = 91.3 \text{ A} \quad (12.2)$$

12.11.2 Changing room

All quartz heaters and tubular heaters will be used for extended periods of time and, even though the tubular heaters will be thermostatically controlled, the heating will inevitably be required at

full load at crucial times. Therefore, no diversity can be allowed:

$$\begin{aligned} 2 \times 3 \text{ kW quartz heaters } (2 \times 3000)/230 &= 26 \text{ A} \\ 20 \times 0.18 \text{ kW tubular heaters } &= ((20 \times 180)/230) = 15.65 \text{ A} \end{aligned} \quad (12.3)$$

12.11.3 Sink water heaters

These will only be used for short periods of time. Allow for 25% diversity.

$$4 \times 2.5 \text{ kW} \times 25\% = 10.87 \text{ A} \quad (12.4)$$

12.11.4 Cooker

Only occasional use at normal times for short periods of time. For diversity, allow first 10 A, and then 30% of the remaining load:

$$\begin{aligned} 10 \text{ kW}/230 &= 43.48 \text{ A} \\ 1\text{st } 10 \text{ A} &= 10 \text{ A} \\ 30\% \text{ of } 33.48 &= 10.04 \text{ A} \\ \text{Total} &= 10 + 10.04 = \text{Approx. } 20 \text{ A} \end{aligned} \quad (12.5)$$

12.11.5 Socket-outlets

These will probably be divided across three circuits, with the greatest load on the kitchen circuit. In other locations, there may be occasional 'emergency' use of portable heaters. Otherwise loads will be small.

$$\text{Assume } 20 \text{ A max connected load} = 20 \text{ A}$$

12.11.6 Beer chiller

This will be an intermittent load. Allow 50% diversity.

$$20 \text{ A} \times 50\% = 10 \text{ A} \quad (12.6)$$

12.11.7 Lighting

All lighting is via fluorescent tubes. Therefore a 1.8 factor is applied to lamp ratings to allow for control gear losses, unless manufacturer's instructions state otherwise. On occasions, lighting will be fully used for extended periods. An 85% allowance is given:

$$\begin{aligned} 19 \times 2 \times 58 \times 1.8 \times 85\% &= \text{Approx. } 3.4 \text{ kW plus} \\ 4 \times 24 \times 1.8 \times 85\% &= \text{Approx. } 0.2 \text{ kW} \\ &= \text{Approx. } 16.0 \text{ A} \end{aligned} \quad (12.7)$$

12.12 Total estimated maximum current demand

$$\begin{aligned}
 \text{Off peak} &= 195.6 \text{ A or} \\
 &\quad 65.2 \text{ A per phase} \\
 \text{Normal} &= 210 \text{ A or} \\
 &\quad 70 \text{ A per phase}
 \end{aligned}
 \tag{12.8}$$

The electricity distributor should be given a figure of approximately 135 A per phase, on the assumption that load balancing is reasonable. Ultimately, the Distributor will use its own experience to determine the service provision. Experience will probably dictate that the off peak load would be drawn between the hours of midnight and 7 a.m. So, realistically, only a 100 A three-phase supply is needed for this building, which will leave some 'spare' capacity.

The designer must consider these loads for switchgear capacity and circuitry, making due allowance for unbalanced phases. Figure 12.3 shows a suggested project specification.

12.13 Wiring systems

As the installation has a variety of uses, all wiring should be enclosed to protect it from mechanical damage. Acceptable systems for mains wiring are steel wire armoured or mineral insulated cables and steel or heavy duty PVC conduit.

522.6 On this project, the obvious main wiring route is through the ceiling/roof space. Cables in this location could be thought of as not subject to physical mistreatment and there is therefore a choice of systems.

12.13.1 Insulated and sheathed cables

With economy in mind, some installation designers may consider using twin and earth cables for this project. However, there are practical reasons why thermoplastic (PVC) sheathed cables are unsuitable for this type of building.

Taking into account the Wiring Regulations' requirement for good workmanship, the use of unenclosed wiring is not recommended anywhere where there are large groups of cables. Consider initially the number of circuits. Unenclosed cables would need to be untangled before extensive clipping can be applied. One solution to the problem of cable fixing is to carry groups of sheathed cables through trunking, which has to be very large to handle the bulk without overcrowding.

Surface run cable drops downwall to heaters and sockets must be enclosed in conduit or mini-trunking for both protective and appearance reasons. The scheme eventually becomes a mixture of trunking, conduit and mini-trunking – with potential gaps between the systems where sheathed cables are exposed.

Project Specification BS 7671			
Sports Centre			
Name.....		Location.....	
Reference.....		Date.....	
3 - phase 230 V 50 Hz. TN-C-S. Supply fuse 3x100 A BS 88-3			
PFC less than 16 kA. Earth loop impedance less than 0.35 Ω Normal supply 125 A TP Main switch Off peak supply 125 A Main switch 2 Type B Distribution boards M6 Type B cbs			
Circuits	Rating (A)	Cable size mm ²	Lights/points g = gang
Normal supply distribution board 125 A isolator 18 ways			
lights 3 circuits	10	1.5/1.0	23
13 A sockets 3 circuits	32	2.5/1.5	16 x 2g
showers 4 circuits	32	6.0/2.5	4
quartz heaters 2 circuits	16	2.5/1.5	2
tubular heaters 2 circuits	10	1.5/1.0	20
sink heaters 4 circuits	16	2.5/1.5	4
cooker	32	6.0/2.5	1
beer chiller	20	2.5/1.5	1
Off peak distribution board 125 A isolator 18 ways			
Storage heaters 15 circuits	16	2.5/1.5	15

Figure 12.3 Project specification for village sports centre.

12.13.2 Steel conduit and trunking

It is generally best not to mix steel and PVC systems, as complications can arise with earthing and jointing. Steel conduit and trunking, for example, would undoubtedly make a good job, but the installation costs may be prohibitive.

If the large room will be used as a school gymnasium, some damage to wiring could be anticipated; therefore steel conduit would be desirable. However, it is a golden rule that the best method of protecting electrical cables is to install them in location where they will not be in harm's way.

12.13.3 Emergency systems

Details of fire alarm and emergency lighting provision should be added to the specification.

12.13.4 Plastic conduit and trunking

This is the preferred system for appearance, convenience and economy. Material costs may be higher than with sheathed cables but the use of single-core cables, smaller trunking, and speed of installation will compensate for this.

A recommendation here is that conduit and trunking should be obtained from the same manufacturer, as this will ensure compatibility with appearance and fit.

App. 4 At first sight, the most practical idea seems to be to run a large trunking above the ceiling, through the centre of the hall, and tee-off with conduits to outlet positions. However, such an arrangement may be problematic when cable sizing is considered after applying derating factors for grouping. Note that the storage heater cables will be fully loaded simultaneously. Note that excessive grouping may require larger than normal cables.

A better approach will be to take two or three smaller lateral trunking runs in the roof space along the length of the hall, where each runs would contain a mix of lighting, power and heating cables to local outlet positions. This reduces the need for derating-grouped, heavily-loaded cables. Single-core insulated cables will be installed with complete trunking enclosure and conduit drops down the walls. Common circuit protective conductors may be used as described in the section on earthing.

521.1 For aesthetic reasons, an alternative approach would be to enclose wall cable drops in mini-trunking. However, a problem then arises with bends in the roof space at the top of the wall and connections into the main trunking, as even the best mini-trunking systems do not have the same easy bending and jointing facility as with PVC conduit.

One solution to the above situation could be to come away from the trunking horizontally with plastic conduit and convert at the wall/ceiling junction with a blanked-off switchbox having conduit entry on one side and mini-trunking on the other.

12.14 Circuitry and cable sizing

App. 4 Grouping factors must be considered to determine cable sizes, but first it is worth looking at the circuits to establish 'ungrouped' sizes (Table 12.1).

Table 12.1 Circuits showing full load requirements.

Circuit	Full load (A)	cb (A)	Cable size, ungrouped (mm ²)
Lights (3 circuits)	6	10	1.0
or	6	10	1.5
Sockets (3 circuits)	Ring	32	2.5
Storage heaters			
(15 circuits)	13.05	16	2.5
Showers (4 circuits)	30.45	32	6.0
Quartz heaters			
(2 circuits)	13.05	16	2.5
Tubular heaters			
(2 circuits)	7.85	10	1.5
Sink water heaters			
(4 circuits)	10.87	16	2.5
Cooker	20	32	6.0
Beer chiller	20	20	2.5

12.15 Cable grouping factors

The Regulations give derating factors for groups of cables of all one size and apply the factors to fully loaded conditions. This situation rarely applies, so some sort of judgement must be made.

In this project, the only group of similar-sized, equally-loaded cables are the storage heater circuits. These are actually loaded at less than half the tabulated current-carrying capacity for the conductors. So, provided the cables do not come into contact with thermal insulation, the application of any [de]rating factors to the heating cables may be ignored.

Using similar logic, it will be seen that all other circuit cables are sized conservatively in terms of current-carrying capacity. This is because voltage drop considerations are more significant, which can often be a common situation. Therefore, it is suggested that the sequence of cable-sizing calculations should always start with voltage drop. Information on how to design circuits can be found in Chapter 19 (Cable design calculations) of this book.

As there is glass fibre insulation above the plasterboard ceiling, a sensible idea is to span trunking and conduit across the top of ceiling rafters, clear of thermal insulation. However, care must be

523.9

taken to ensure that adequate support is given to plastic conduit. It may be advisable to use timber bearers across spans in excess of about 2 m.

12.16 Arrangement of circuits

514-10 There is no regulation that requires 400 V circuits or equipment to be segregated. The only obligation is for suitable labelling. However, it is good practice to try to keep phases separate whenever possible. This consideration may be overruled when phase balancing is worked out (Table 12.2). This schedule uses approximate, diversified current demands and produces a good balance.

Table 12.2 Phase balancing using diversified loads.

Phase	Circuits	Amps
Brown	5 storage heaters	65.2
	No. 1 sockets	10
	No. 2 sockets	10
	No. 3 sockets	10
	2 showers	60
	Total (10 circuits)	155.2
Black	5 storage heaters	65.2
	No. 1 lights	6
	2 showers	60
	4 sink water heaters	12
	Cooker	10
	Total (13 circuits)	153.2
Grey	5 storage heaters	65.2
	No. 2 lights	6
	No. 3 lights	6
	2 quartz heaters	26
	2 tubular heater circuits	15.6
	Beer chiller	20
	Total (12 circuits)	138.8

Table 12.3 Two three-phase distribution boards, populated with Type B circuit-breakers.

• <i>Off peak</i>	
18 ways (15 used)	125 A main switch (four pole for TT)
• <i>Normal supply</i>	
24 ways (20 used)	125 A main switch (four pole for TT)

12.17 Switchgear

There will be two three-phase distribution boards installed in this installation. Refer to Figure 12.3 for details. Spare ways may be used for emergency systems (where appropriate), and/or future additions.

12.18 Shock protection

All socket-outlets, whether used for entertainment purposes or not, will need to have additional protection by means of a 30 mA RCD. This will satisfy licensing requirements and the requirements in the Wiring Regulations. For ease of installation, it will be wise to protect all socket-outlet circuits at the distribution board, by dividing the ways up so that two or more RCDs protect a percentage of the circuits within the installation.

An alternative arrangement would be to use RCBOs to protect each circuit supplying the socket-outlets, but this may add an extra cost onto the job. 411.3.3

There is no requirement for RCD protection elsewhere in the installation on the system with a PME supply, provided no sheathed cables are concealed in a wall or partition at a depth of less than 50 mm from the surface. The requirements on a TT installation will be shown later in this chapter.

12.19 Earthing

A main earthing terminal (MET) must be established adjacent to the distribution boards. It needs to be in an accessible position, so that the earthing conductor can be disconnected for testing purposes. An accessible and independent bar will be required to terminate the electricity distributor's PME earthing conductor or the earthing conductor from a TT electrode. A main protective bonding conductor to the water supply will connect at this position, along with the circuit protective conductors to each distribution board. 542.4

12.20 Bonding

Standard bonding requirements apply for a 10 mm² connection to the main water intake position, but this size should be confirmed with the electricity distributor. 544

12.21 An occasional problem

At the start of this chapter, it was indicated that a problem is often encountered with PME systems supplying a remote building of this type. The condition is illustrated with reference to Figure 12.4.

The supply company uses a combined earth/neutral conductor, which in this case is shown as an overhead line. This conductor is connected to an installation earth electrode at the foot of the

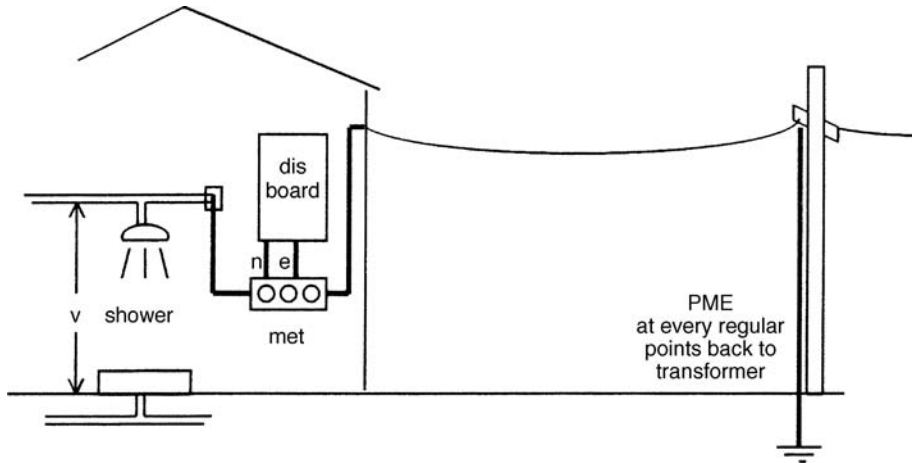


Figure 12.4 Problem caused by volt drop through PME neutral.

pole. The service divides at the meter cut-out, giving a neutral connection to the distribution board and an earth to the MET. Within the installation, a main protective bonding conductor has been taken to the consumer's side of the water stopcock, as the property is served via a mains water plastic service pipework.

All the plumbing in the building is connected to the equipotential bonding, with the supply earth/neutral and all exposed-conductive-parts on storage heaters, and so on. This creates standard PME conditions, but with two significant features:

1. Unless the load is perfectly balanced, the overhead neutral conductor will be carrying some load current. This results in voltage drop and the 'earth' at the cut-out is at a slightly different potential to the local ground earth (true earth).
2. Showers have a common tray with a direct water outflow into the ground. A person standing in the shower may notice a potential difference of perhaps a few volts (e.g. 6–8 V) between the shower head and the ground. This is discomforting and causes concern.

12.22 Solutions

1. At the time of building construction, a metallic grid should be installed into the concrete base beneath the shower trays and be connected to other exposed- and extraneous-conductive-parts within the location via supplementary bonding conductors – thus creating an equipotential zone in that location.
2. If the problem is noticeable on an existing installation, and it is not practicable to install a metallic grid below the shower tray(s), one solution would be to disconnect the PME earthing facility, provided by the electricity distributor, and establish a new earth via an installation earth electrode. Once that conversion has been made, the installation will then form part of a

TT system. In practice, wherever an earth electrode is used, an RCD will be needed to provide the necessary shock protection, as the maximum earth fault loop impedance (Z_s) will almost always be exceeded where a fuse or circuit-breaker is relied upon to provide that function.

12.23 Requirements for a TT installation

There are special requirements for a TT installation, and guidance on this subject is given in Chapter 7, Earthing and Bonding. The following factors should also be noted:

- All socket-outlets must be protected by an RCD having a rated residual current of 30 mA or less. This condition has already been achieved in the design. 411.3.3
- The installation earth facility for shock protection will be via an installation earth electrode associated with an RCD at the mains position. This RCD should not be over-sensitive, so a 300 mA or 500 mA rating is suggested. It should be of a type that has a built in time-delay or, as they are referred to these days, an S type.
- The resistance of an earth electrode should be as low as practicable. In fact, a note in Regulation 411.5.2 suggests that a value exceeding 200 Ω may not be stable. But what does this mean?

Whatever type of electrode is selected, electrical installers must take account of the effects of soil drying and freezing, as these conditions can affect the electrode's resistance by as much as eight times, especially the latter. Other factors that affect the resistance of an earth electrode include the size and shape of the electrode, the soil resistivity, and the embedded depth of the electrode.

For detailed information on this subject, designers and installers should consult *BS 7430 Code of practice for earthing*, as it is an extremely useful document.

Depending on the composition of the soil, type of electrode used, and the depth that it is embedded in the ground, earth electrode resistances of between 40 Ω and 150 Ω are common.

- To ensure discrimination in the event of a fault on a circuit with 30 mA protection, the main RCD should have time-delay characteristics, as mentioned above. For more information on time-delayed RCDs and what can be used for an earth electrode, refer to item 10.2 of Chapter 10 of this book. 531.2.9

An Indoor Swimming Pool

This project is based on a domestic swimming pool attached to a house, but it could easily be coupled with a sports centre (Chapter 12) and provision made for the pool's public use.

This project does not include designs for the electrical control and installation of certain types of equipment, such as water treatment, filtration systems and jet stream pumps, as they are likely to be installed by a specialist pool installer. For further information on the special requirements for the installation of these items of equipment, refer to Regulation 702.55.4 of BS 7671.

Although not required in this project, provision of emergency lighting and fire detection and alarm systems should be considered for similar projects, especially where the public would use the swimming pool.

13.1 Special conditions

Sec. 702 Swimming pools and their surroundings are considered locations of increased electric shock risk, because of the reduction in body resistance and the increased contact between the body and earth potential due to wet and/or bare skin. So, care must be taken with arrangements for electrical supplies to pool equipment and the electrical installation in and around the pool area. This chapter provides an overview of the requirements given in Section 702 of BS 7671, which deals with the subjects of swimming pools and other basins. Potential installers should be familiar with those requirements.

Section 522 Each item of equipment destined to be used in or around the pool must take account of all the external influences that exist or are likely to exist at the point of installation. Particular areas of concern include:

- 522.3 ● the presence of water (AD) and high humidity (AB); and
- 522.5 ● the presence of corrosive or polluting substances (AF) such as chlorine.

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This part of the design is important, because it helps to ensure the equipment will function properly and to ensure reliability of the measures of protection for safety.

13.2 Other interested parties

Most consultations will be through the client, an architect or the builder. It is important that a full specification is prepared in advance of tendering. Some aspects of electrical design affect the pool construction and should be considered before construction starts. Layout and decorative treatments need to take account of permissible lighting arrangements.

The electrical installer must be certain that appropriate advice has been taken from all relevant authorities.

- *Specialist pool installer:*
Electrical requirements for all pool equipment and servicing facilities.
- *Electricity distributor:*
It is the consumer's responsibility to ensure that an adequate supply is available. However, in practice, it is the electrical installer, acting on behalf of the consumer, who ensures that the electrical installation is correctly earthed. The local electricity company may have restrictions regarding the provision of a PME service.
- *Local authority:*
If there is any possibility that the pool will be used for public events, such as a garden party or fete, the local authority's environmental health department should be approached to ascertain any requirement(s) for safety services to be provided.
- *Client's insurers:*
Are there any special fire and personal safety requirements?

13.3 Building details

13.3.1 Construction

- *Design:*
A new single-storey purpose-built structure to be constructed on private land adjoining a large house. Total floor area: approximately 110 m².
- *Floor:*
Concrete, tiled throughout.
- *Walls:*
Brick, fair-faced externally and internally. Large glazed areas.
- *Roof:*
Timber frame, lined underside with pinewood ceiling. The ceiling over the pool area is 3 m above floor level. The ceiling over the projecting leisure veranda is 2.25 m above floor level.
- *Changing area:*
Walls: building block, tiled throughout.
- *Space and pool water heating:*
Gas.

Table 13.1 Schedule of equipment.

All single-phase equipment	
Location	Single-phase equipment
<i>Lighting</i>	
Pool area	5 × 150 W SON
Veranda	5 × 100 W recessed downlighters
Plant room	1 × 58 W fluorescent
Changing room	4 × 24 W bulkhead fluorescent
<i>De-humidifiers</i>	2 × 20 A supplies
<i>Plant Room Power</i>	1 × 30 A supply
<i>Socket-outlets</i>	1 × twin 13 A
Veranda	2 × 16 A BS EN 60309-2
Pool services	1 × twin 13 A
Plant room	1 × 16 A BS EN 60309-2
<i>Provision for dryer</i>	1 × 2 kW outlet
Changing room	

13.3.2 Electrical requirements

522.5 Full details of electrical loads are given in Table 13.1 and the electrical layout is shown in Figure 13.1. The lighting system as shown is for load assessment only. Manufacturers should be consulted regarding the suitability of products for this corrosive situation.

A suggested project specification is given in Figure 13.2.

13.4 Application of zoning to this project

702.32 The basins of pools and their surroundings are required to be divided into three zones, for the purposes of selecting suitable equipment and shock protection measures (Figure 13.3).

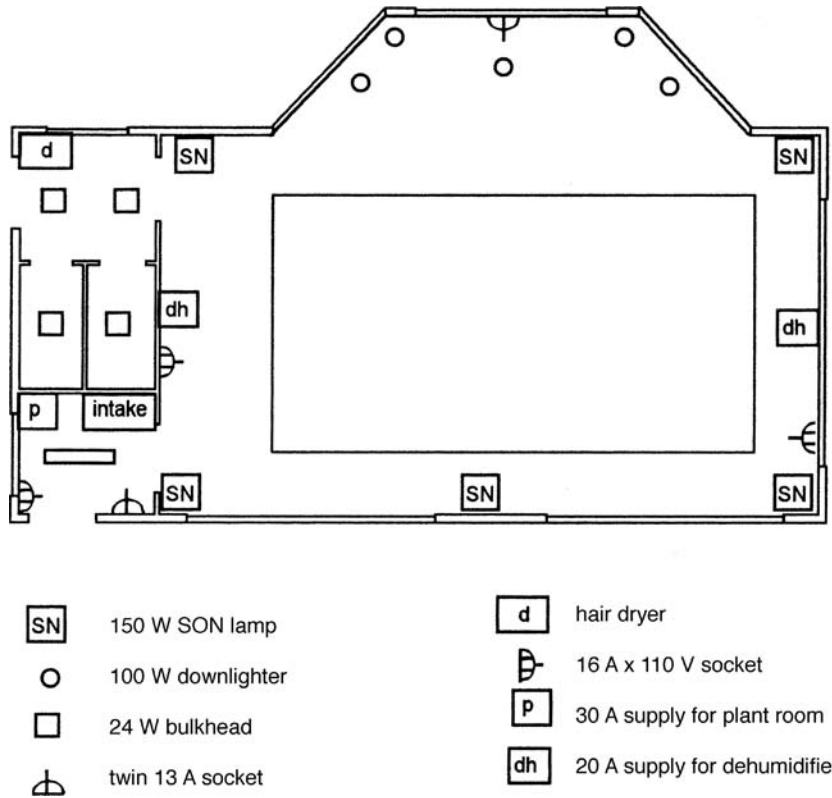


Figure 13.1 Electricity provision in swimming pool.

13.4.1 Zone 0

This zone is the interior of the pool basin and includes any recesses in its walls or floors, basin for foot cleaning and water jets or waterfalls and the space below them. 702.32

- Only protection by separated extra-low voltage (SELV at a nominal voltage not exceeding 12 V a.c. rms or 30 V ripple-free d.c. is permitted. The source for SELV must be installed outside of zones 0, 1 and 2.
- Electrical equipment for this zone (i.e. (submersible) purpose-made underwater floodlighting) is required to have a degree of protection of at least IPX8.
- A luminaire for use in the water (or one that comes into contact with the water) must be fixed and must comply with *BS EN 60598-2-18*. 702.55.2
- The wiring system should be limited to that necessary to supply equipment situated in this zone.
- No accessible junction boxes may be installed in this zone. 702.522.24
- No switchgear, controlgear or socket-outlet may be installed in zone 0. 702.53

Project Specification BS 7671				
Domestic Swimming Pool				
Name.....		Location.....		
Reference.....		Date.....		
Single phase 230 V 50 Hz. TN-C-S fed from adjacent house Supply fuse 63 A BS 88-3				
PFC less than 16 kA. Earth loop impedance less than 0.35 Consumer unit to <i>BS EN 60439-2</i> or <i>BS EN 61439-1</i> Four type B cbs circuits One type C cbs circuit Two 30 mA rcbo circuits				
Circuits	cb type	Rating (A)	Cable size (mm ²)	Lights/points g = gang
1. Lights -SON	C	10	1.5	5
2. Lights	B	10	1.5	10
3. Sockets 13 A	rcbo	20	2.5	2 x 2 g
4. Sockets 16 A	rcbo	20	2.5	3
5. Dehumidifier 1	B	20	2.5	1
6. Dehumidifier 2	B	20	2.5	1
7. Plant room	B	32	6.0	1

Figure 13.2 Project specification for the swimming pool.

13.4.2 Zone 1

702.32 This is the area above zone 0, extending vertically to a height of 2.5 m and 2 m horizontally from the edge of the water.

Where the swimming pool contains diving boards, springboards, starting blocks, chutes or other apparatus expected to be used/occupied by persons, the zone is limited by the horizontal plane 2.5 m above the highest surface expected to be occupied by persons, and a vertical plane 1.5 m from the periphery of the diving boards, and so on:

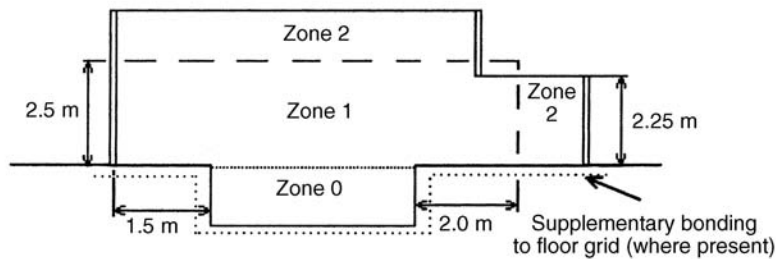
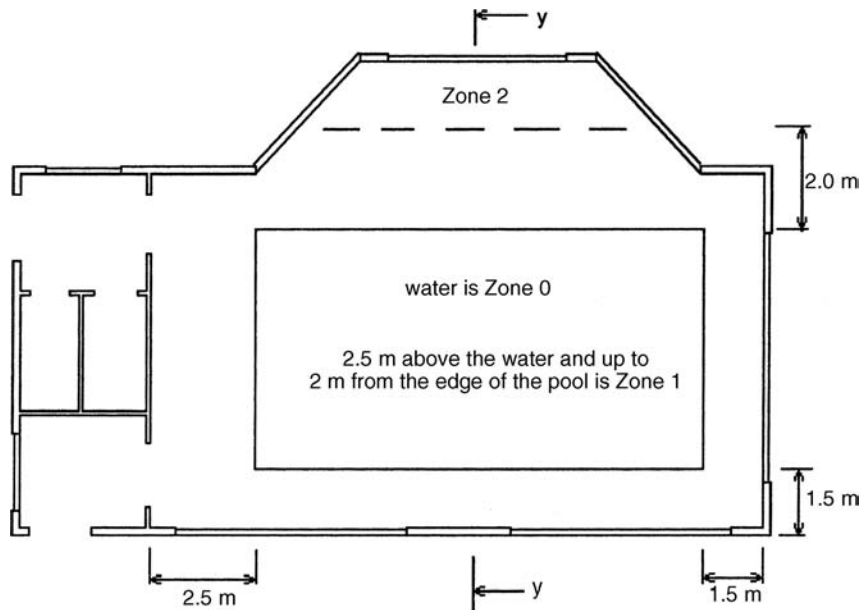


Figure 13.3 Assessment of zones.

- Only protection by SELV at a nominal voltage not exceeding 25 V a.c. rms or 60 V ripple-free d.c. is permitted. The source for SELV must be installed outside of zones 0, 1 and 2.
- Electrical equipment installed in this zone must have a degree of protection of at least IPX4, or IPX5 where water jets are likely to be used for cleaning purposes.
- The only wiring permitted within zone 1 is for equipment situated within the zone.

- Switchgear and accessories are not permitted in this zone. However, a socket-outlet or switch may be installed in this zone, if it is installed at least 1.25 m horizontally from the border of zone 0 and is located at least 0.3 m above the floor and the socket-outlet or switch has, preferably, a non-conductive cover or cover plate. The socket-outlet must be protected by either:
 - SELV at a nominal voltage not exceeding 25 V a.c. rms or 60 V ripple-free d.c., the source for SELV being installed outside of zones 0 and 1; or
 - automatic disconnection of supply by means of an RCD having the characteristics specified in Regulation 415.1.1 (e.g. 30 mA RCD); or
 - electrical separation for a supply to only one item of current-using equipment, the source for electrical separation being installed outside zones 0 and 1;
- 702.522.24 ● No accessible junction boxes may be installed in this zone, with the exception of those of SELV circuits.

13.4.3 Zone 2

702.32 This zone extends 1.5 m beyond the boundary of zone 1, and is limited by the horizontal plane 2.5 m above the floor or surface expected to be occupied by persons.

- Any equipment installed in this zone must have a degree of protection of at least IPX2 for indoor pools, IPX4 for outdoor pools, and IPX5 where water jets are likely to be used for cleaning purposes.
- A socket-outlet or switch is permitted to be installed in this zone, provided the supply circuit is protected by one of the following protective measures:
 - SELV, the source being installed outside of zones 0, 1 and 2. However, if the supply to the SELV source is protected by means of a 30 mA RCD, the source of SELV can be located in zone 2;
 - automatic disconnection of supply by means of an RCD having the characteristics specified in Regulation 415.1.1 (e.g. 30 mA RCD);
 - electrical separation, provided the source supplies only one item of current-using equipment (or one socket-outlet), and is outside zones 0, 1 and 2. However, if the supply to source is protected by means of a 30 mA RCD, the source can be located in zone 2.

13.4.4 Other current-using equipment of swimming pools

702.55.1 In zones 0 and 1, only fixed current-using equipment specifically designed for use in a swimming pool should be installed, in accordance with the requirements of Regulations 702.55.2 and 702.55.4.

702.410.3.4 Electrical equipment, which is intended to be in operation only when people are outside zone 0, may be used in all zones provided that the equipment is supplied by either SELV, automatic disconnection of supply by means of an RCD having the characteristics specified in Regulation 415.1.1 (e.g. 30 mA RCD), or is protected by electrical separation.

An electric heating unit embedded in the floor is permitted, provided that it:

1. is protected by SELV, and the source is installed outside zones 0, 1 and 2. However, the source of SELV can be installed in zone 2 if its supply circuit is protected by an RCD having the characteristics specified in Regulation 415.1.1; or
2. incorporates an earthed metallic sheath connected to the supplementary equipotential bonding and its supply circuit is additionally protected by an RCD that has a residual operating current of 30 mA or less; or
3. is covered by an embedded earthed metallic grid connected to the supplementary equipotential bonding and its supply circuit is additionally protected by an RCD that has a residual operating current of 30 mA or less.

Sometimes, a swimming pool does not have a zone 2. Where this is the case, lighting equipment supplied by other than SELV at 12 V a.c. rms or 30 V ripple-free d.c. may be installed in zone 1 on either a wall or on the ceiling (but avoid above the water, as maintenance may be an issue), provided the following two requirements are fulfilled:

1. The circuit is protected by automatic disconnection of supply and additional protection is provided by an RCD that has a residual operating current of 30 mA or less; and
2. The luminaire is installed at a height of at least 2 m from the lower limit of zone 1 (which is generally the floor).

13.5 Dehumidifiers

These may be mounted as fixed appliances in zone 2 areas, provided that they are of a type specifically intended for use in swimming pool areas. The equipment must be supplied by a 30 mA RCD protected circuit via a hard wired connection, not a plug and socket.

13.6 Changing room/shower area

Swimming pool zoning does not apply in these locations. However, the requirements applicable to locations that contain a bath or shower, as given in Section 701 of *BS 7671*, do apply. Some of the main requirements include:

- All low voltage circuits of the location (containing a bath or a shower) must be provided with additional protection by means of an RCD having a rated residual current of 30 mA or less.
- Except for SELV socket-outlets complying with Section 414 of *BS 7671* and shaver supply units complying with *BS EN 61558-2-5*, socket-outlets are prohibited within a distance of 3 m horizontally from the boundary of zone 1.
- Installed electrical equipment must have a degree of protection of at least IPX7 in zone 1, and IPX4 in zones 1 and 2.

There is also the question of where switchgear, controlgear, accessories and current-using equipment can be installed.

13.6.1 Switchgear, controlgear and accessories

The following information does not apply to switches and controls that are integral to fixed current-using equipment suitable for use in that zone, or insulating pull cords or cord operated switches:

Zone 0: Switchgear and accessories must not be installed in this zone.

Zone 1: Only switches of SELV circuits supplied at a nominal voltage not exceeding 12 V a.c. rms or 30 V ripple-free d.c. are permitted to be installed in this zone, provided the safety source is installed outside zones 0, 1 and 2.

Zone 2: Switchgear, socket-outlets or accessories that incorporate switches must not be installed in this zone, except:

- switches and socket-outlets are part of a SELV circuit, and the safety source is installed outside zones 0, 1 and 2; and
- shaver supply units that comply with *BS EN 61558-2-5*.

13.6.2 Current-using equipment

In zone 0, current-using equipment may be installed, provided all of the following conditions are met:

- The manufacturer's instructions confirm that the equipment is suitable for mounting and use within this zone, and the equipment complies with the relevant product standard.
- The equipment is securely fixed and permanently connected.
- The equipment is supplied by SELV at a nominal voltage that does not exceed 12 V a.c. rms or 30 V ripple-free d.c., and the safety source is installed outside zones 0, 1 and 2.

In zone 1, only the following fixed and permanently connected items of current-using equipment may be installed in this zone, according to the manufacturer's instructions:

- electric showers, shower pumps, and whirlpool units;
- ventilation equipment;
- towel rails and water heating appliances;
- luminaires, and equipment protected by SELV or PELV, provided the nominal voltage does not exceed 25 V a.c. rms or 60 V ripple-free d.c., and the safety source is installed outside zones 0, 1 and 2.

13.7 Loading and diversity for the swimming pool project

To help work out the loadings, it is sometimes best to group certain types of loads together, as follows:

13.7.1 Lighting

It is likely that all of the lights will be on at the same time, so no diversity will be taken into account. For current loading calculations, discharge lamp ratings should be multiplied

by 1.8 to take into account control gear losses, unless the manufacturer of the equipment states otherwise:

$$\text{Pool SON lighting } \frac{5 \times 150 \times 1.8}{230} = 5.9 \text{ A} \quad (13.1)$$

$$\text{Veranda spotlights } \frac{5 \times 100}{230} = 2.2 \text{ A} \quad (13.2)$$

$$\text{Changing room lights } \frac{4 \times 24 \times 1.8}{230} = 0.8 \text{ A} \quad (13.3)$$

$$\text{Plant room light } \frac{1 \times 58 \times 1.8}{230} = 0.5 \text{ A} \quad (13.4)$$

Total lighting load = 9.4 A

13.7.2 Dehumidifiers

These items of equipment do not work continuously, so the 20 A requirement is probably generous. Therefore diversity of 75% has been assumed:

$$2 \times 20 \times 75\% = 30 \text{ A} \quad (13.5)$$

13.7.3 Socket-outlets and hair dryer

There is no heating load, and all socket-outlets are provided for occasional use.

$$\begin{aligned} \text{Assume 30 A maximum load at 66\% diversity} &= 20 \text{ A} \\ \text{Total maximum demand} &= 59.5 \text{ A} \end{aligned} \quad (13.6)$$

A 60 A single-phase supply should therefore be adequate.

13.8 Wiring systems

As corrosion is probably one of the major external influences that need to be considered, 702.522.21 appropriate materials must be selected.

A wiring system can be installed on the surface, and if it has a metallic sheath or metallic covering, it must be connected to the supplementary bonding. However, the preferred wiring

system is to use non-metallic conduit, as this is better suited for the conditions likely to be encountered in a swimming pool environment.

Severe corrosion may be encountered where MICS enters steel enclosures, so for this reason it has been ruled out for this project.

- Steel wire armoured (SWA), thermoplastic (PVC)-sheathed cable would be acceptable, provided that terminations can be protected against corrosion. In this instance, the only large load that would warrant the use of this cable is the short run in the plant room for pool equipment.
- Flat twin and earth cables would be appropriate, but in some areas surface wiring would require additional non-metallic covering for protection as well as for appearance. If sheathed cables are buried beneath plaster-work in these damp conditions, plastic capping should be used. It should be remembered that where PVC-sheathed cable is concealed in a wall or partition, at a depth of less than 50 mm from the surface of the wall or partition, the requirements of Regulation 522.6.101 must be met.

13.9 Cable sizes

Provided that thermal insulation can be avoided, there are no special limitations requiring derating factors to be applied. Cables installed in plastic conduit or trunking will not be heavily loaded.

There may be a large group of mixed size cables in trunking near the distribution board. The 32 A supply for the plant room should be kept separate, which will be the case as an SWA cable is used for this short run.

Cable sizes are shown in Figure 13.4.

13.10 Distribution board

314.1 A single-phase eight-way distribution board is adequate and this should have a non-metallic enclosure. Two lighting circuits are shown to avoid inconvenience in the event of the failure of one circuit. SON discharge lamps do take a surge on start-up, so Type C circuit-breakers are recommended.

The 13 A sockets and the outlet for a hair dryer may be run from one single module 20 A RCBO. Similar RCD protection is required for the *BS EN 60309-2* socket-outlets, and a 16 A RCBO will give adequate protection. Although perhaps not strictly essential, RCD protection could also be provided for the dehumidifiers that are located in potentially wet areas.

It should be noted that a single-module RCBO is a single pole device, so the neutral remains connected, even after the device has operated as a result of a fault. It may therefore be desirable

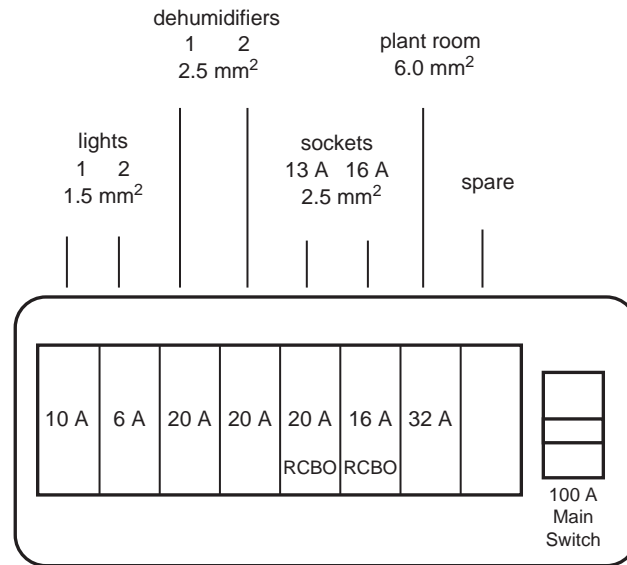


Figure 13.4 Distribution board and cable sizes.

to have double-pole RCD protection, but the trade-off is that each device is a double module unit, so two circuit ways will be taken up with each device used.

Apart from on the SON lighting circuit, all other circuit-breakers should be Type B, and unless the electricity distributor insists on a TT supply, no other RCD protection will be necessary. It is not advisable to install a 30 mA RCD as the main switch (front end protection), as this could be inconvenient when a fault on one circuit disconnects the supply to the whole installation, which could be hazardous to pool users. 314.1

13.11 Isolation

The facility for isolation of all circuits will be at the distribution board. The main switch must have a lock-off facility. 537.1.3

13.12 110 V system

A 1 kVA 230/110 V transformer will be located in the plant room adjacent to the distribution board. It is important to check that the 110 V winding has a mid-point earth connection. There is no requirement for switching at BS EN 60309-2 sockets. This subject should be discussed with the client. It may be considered that switched sockets would provide speedy disconnection in an

emergency situation. However, it may not always be safer to have a switch, which may encourage a user of cleaning equipment or a motorized pool cover to leave a plug permanently inserted. It is obviously safer to remove the plug for equipment not in use.

13.13 Earthing

543.3 This subject must be carefully considered. All conventional earthing and main bonding should be carried out in accessible locations where connections may be separated for periodic testing. Earthing clamps to pipework should comply with *BS 951*, and be of the non-corrosive type, usually colour coded blue. Those coded red are not suitable for damp environments. Cable terminations at earth clamps should be crimped to ensure reliability throughout the life of the installation.

13.14 Local supplementary bonding

702.415.2 This is one location where the Wiring Regulations require local supplementary bonding. There is no requirement for a special supplementary bonding cable to be taken back to the distribution board, only that extraneous-conductive-parts in zones 0, 1 and 2 must be connected by supplementary bonding conductors to the protective conductors of exposed-conductive-parts of equipment in those zones, in accordance with the requirements set out in Regulation 415.2.

The connection with the protective conductor may be provided in the proximity of the location, such as in an accessory or in a local distribution board.

The definition of an extraneous-conductive-part is covered in Chapter 7 of this book. Such a part is one that is liable to introduce a potential (usually earth potential) into an otherwise equipotential zone. Items such as wall, floor mounted or removable handrails are likely to have a local potential and therefore should not need bonding. However, metalwork entering the location from outside the building will need to be main bonded and supplementary bonded, where applicable.

544.4.5 In this project, the supplementary bonding will also have to be taken to the dehumidifiers, as they are of Class I construction (metallic). Other 'earthy' metalwork, such as exposed structural steel, will also have to be connected to the supplementary bonding.

13.15 Floor grid

There is no requirement in *BS 7671* for a metallic grid to be provided, but the need for such a provision should be considered early in the design stage, particularly where a solid floor may be

an extraneous-conductive-part (e.g. where the floor is not electrically well insulated from earth potential). Where a grid is installed, two or more bonding connections should be made to the grid, preferably at opposite corners of the grid, and it should be ensured that all parts of the grid are reliably electrically connected together.

This grid must be connected to the supplementary equipotential bonding system by means of accessible and reliable connections. Where there is more than one earthing grid, the subject of interconnection should be carefully planned with access covers over sunken inspection traps.

Cables and Wiring Systems

The choice of wiring systems for specific projects is increasing with developments in materials. There is also great interest nowadays in the performance of cables in fires.

An electrical installation designer must take account of the range of conditions under which a cable will be used. These conditions are listed under the heading of external influences in the Wiring Regulations.

14.1 External influences

App. 5 ● *Environmental:*

This relates to climatic influences, whether caused naturally by weather and geographical features, or by man-made conditions. Different considerations would apply, for example, in a refrigerated cold store and an abattoir on the same premises.

● *Utilisation:*

The occupancy of a building is important. A general hospital, for example, will have completely different utilisation features to, say, a factory workshop.

The actual electrical energy requirement at the point of use often dictates the wiring system.

Safety features, such as smoke production in a fire, will also need to be considered.

● *Building:*

The construction and shape of a building will affect the routing and protection required by the wiring system. The subject of fire resistance may also be significant.

14.2 Cost considerations

An installer should aim to select a wiring system that will give adequate technical features, at the best price. There is often no merit in over-specification. For example, there are cheaper alternatives, which would be more aesthetically pleasing to the eye and would be no less safe than, say, using heavy gauge steel conduit or trunking.

Labour costs are often one of the most important factors in the economy of any project. By its nature, the installation of a wiring system is labour intensive.

The cost per metre of a cable is not the sole criterion when designing an installation.

14.3 Choosing suitable cable routes

A wiring system can be physically protected, either by enclosure within a robust outer covering or by selecting a suitable route that avoids the possibility of damage. The latter choice is always the most sensible and may provide the opportunity to use a lower cost system with less complex mechanical protection. It is therefore important to have details of the building construction before deciding upon the type of cable to use.

Wherever possible, a cable route should be chosen that avoids hot, damp or dusty atmospheres. Many of these detrimental conditions require rating factors to be used for cable sizing with consequential financial penalties. App. 4

14.4 Is armouring always necessary?

A typical example of over-engineering is with the prolific use of steel wire armoured (SWA) cables for sub-main distribution circuits in commercial and public buildings. Usually, these heavy cables are routed on cable tray through vertical or horizontal service ducts. There is no conceivable reason for armouring, which is usually supplemented by a green-and-yellow circuit protective conductor (cpc), either as an additional core or with a separate conductor. The result is that complicated continuity arrangements are required at glands for the sole purpose of earthing the superfluous armouring. Non-armoured cables are available that are lighter and easier to install.

14.5 Fire barriers

In order to prevent the spread of fire and smoke, buildings are usually divided into zones, or compartments with appropriate fire resistant elements such as walls or floors. The effectiveness of this compartmentalisation may become a matter of life and death during emergency evacuation of a building. 527.1

14.6 Holes through fire barriers

527.2 Any wiring system that passes through elements of a building such as floors, walls, ceilings, partitions or cavity that have the openings remaining, may invalidate fire prevention measures. Open vertical cable ducts are notorious for producing a chimney effect that not only transmit smoke and fumes, but may also provide sufficient oxygen to fuel a cable fire.

The Wiring Regulations require that where a wiring system passes through any element of a building, the openings remaining around the wiring system must be made good to the appropriate standard of fire resistance before penetration.

This seal must:

- be compatible with the wiring system with which it is in contact;
- permit thermal movement without reducing the quality of the seal;
- provide the same degree of protection from water penetration as that required for the building construction which has been penetrated; and
- resist external influences to the same *degree* as the wiring system.

As far as possible, making good should involve reconstruction using the original barrier material. This may be bricks and mortar or a concrete filling. Alternatively, purpose-made removable 'intumescent' barrier materials are available in the form of bags, which may be packed into a hole or cavity.

14.7 Sealing the wiring system

Where a trunking or conduit penetrates a wall or other structural fire barrier, the wiring system will generally need to be sealed internally to prevent the spread of fire and fumes.

Trunking manufacturers provide fire-block components, which fit into the enclosure but permit the addition of further cables at a later date.

527.2.3 Provided certain conditions are complied with, smaller conduit and trunking systems need not be sealed, provided that the wiring system is classified as non-flame propagating and has a maximum internal cross-sectional area of 710 mm^2 , which approximates to a 32 mm diameter conduit.

14.8 Work in progress

527.1.1 It is important that sealing of fire barriers should be carried out as work progresses and before there is construction of false ceilings or decorative panelling. These may obscure sealing

deficiencies. On a larger project, the actual making good may be contracted to the builder, but the electrical installer cannot escape the responsibility of certifying satisfactory completion.

In many instances, electrical installation work is undertaken in an existing and occupied building. It is important not to put occupants at risk unnecessarily by leaving incomplete fire barriers. This would especially apply in hospitals, hotels and other residential buildings. The Wiring Regulations require that temporary sealing arrangements should be made.

14.9 Records

Although no longer a requirement of *BS 7671*, it is a good idea to keep a record of work involving fire barriers for the information of the person carrying out the final verification. Entries in a working diary may be the best method of compliance. This system would also constitute valuable evidence at a later date, should a dispute or disaster occur.

14.10 Hidden cables

Cables concealed within a wall, partition, beneath a floor or above a ceiling can be particularly vulnerable to damage (e.g. by penetration from a nail, screw or the like), which can lead to risk of electric shock or fire, unless suitable measures are taken.

Designers should therefore consider each wiring system for its properties and ability to work within a particular environment.

14.11 Cables within a floor

A cable installed under a floor or above a ceiling is required to be run in such a position that it is not liable to be damaged by contact with the floor or ceiling, or their fixings. A cable passing through a joist within a floor or ceiling construction or through a ceiling support (e.g. under floorboards), must be at least 50 mm measured vertically from the top or bottom, as appropriate, of the joist or batten.

522.6.100

In some older properties, it may be impossible to comply with the above restrictions. Therefore, where notches have been made on previous occasions, the cable may be routed near the surface, provided that some form of physical protection is placed above or below it, as appropriate, to prevent penetration by a nail, screw or the like. Proprietary steel cover plates at least 3 mm in thickness may be used to provide protection for electrical and plumbing services. Alternatively, purpose-made plates may be used, provided they are suitable for such protection.

14.12 Cables above false ceilings

This topic is mentioned in other chapters.

- Cables may not be run less than 50 mm above the plasterboard beneath a battened concrete soffit.
- Either notched battens at least 70 mm deep are required or a cross-batten technique must be used so that the cable(s) are installed at least 50 mm from the bottom of the batten. The latter gives clear routes for cables and is the preferable method of compliance. Alternatively proprietary steel cover plates are available for cable protection where they cross over timber battens.

14.13 Cables in walls

There is no practical alternative to the burying of cables within the plaster depth of walls in houses and commercial properties. It is usual to use metallic or plastic capping to retain cables in place and to avoid damage by a plasterer's float. This capping provides no physical protection against future penetration by a nail or masonry drill. There is no requirement for the capping to be connected to the MET.

Unless a cable is enclosed in steel conduit or it incorporates an earthed metallic covering or sheath (i.e. an SWA, MICS or it has an aluminium sheath that complies with *BS 8436*), it must be installed:

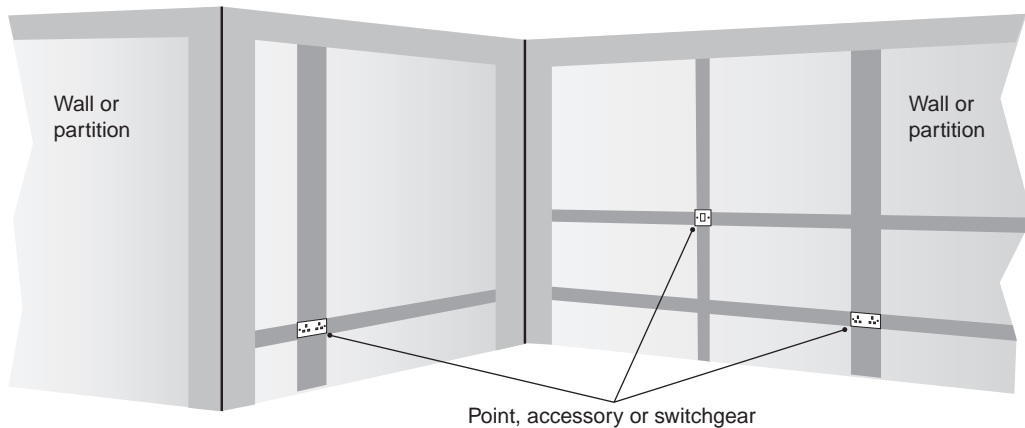
- in a zone within 150 mm from the top of the wall or partition or within 150 mm of an angle formed by two adjoining walls or partitions; or
- where a cable is connected to a point, accessory or switchgear on any surface of the wall or partition, the cable may be installed in a prescribed zone, either horizontally or vertically to that point, accessory or switchgear;
- where the location of the accessory, point or switchgear can be determined from the reverse side, a zone formed on one side of a wall or partition of 100 mm thickness or less extends to the reverse side

(Regulation 522.6.101 refers);

Diagonal runs of twin and earth cable, no matter how short, are inadmissible.

NOTE 1: Where Regulation 522.6.101 applies and the installation is not intended to be under the supervision of a skilled or instructed person, a cable installed in a prescribed zone – which is not SWA, MICS, earthed steel conduit, trunking or ducting, or forms a PELV or SELV circuit – is required to be provided with 'additional' protection by means of an RCD having the characteristics specified in Regulation 415.1.1 (i.e. a 30 mA or less).

NOTE 2: Irrespective of the depth of the cable from a surface of the wall or partition, in an installation not intended to be under the supervision of a skilled or instructed person, a cable concealed in a wall or partition the internal construction of which includes metallic parts, other



Prescribed zone:

- within 150 mm from the top of the wall or partition; or
within 150 mm of an angle formed by two adjoining walls or partitions
- either horizontally or vertically to a point, accessory or switchgear to which a cable is connected

Figure 14.1 Wiring zones in walls.

than metallic fixings such as nails, screws and the like, similar installation requirements must be met.

Figure 14.1 illustrates the prescribed zones. It should be remembered that walls have two sides.

14.14 Mechanically protected cables

Wiring systems, such as SWA, MICS and steel conduit, trunking and ducting, are considered to have adequate physical protection. In addition, the purpose of the metallic covering of a wiring system as a cpc is intended to ensure that it will not be possible for a nail, screw or the like to make contact with a line conductor of a cable without first coming into good electrical contact (with the earthed metallic covering), thus providing a direct path for earth fault current to flow, which should cause automatic disconnection of the supply to that circuit.

14.15 Fire and smoke

It is probably true that no standard wiring system has any advantage(s) over any other when it comes to prevention of a fire. A cable selected and installed in accordance with the Wiring Regulations is safe until subjected to fire. To ensure a cable does not initiate a fire, the cable

App. 4

should be suitably protected against overcurrent, such that disconnection of the supply occurs before danger arises.

The essential fire resistant characteristics of a wiring system are primarily concerned with insulation, rather than conductor material. Two significant factors are:

1. the contribution that combustible cable insulation and sheathing makes to fire, smoke and fumes; and
2. the continuity of supply given by the cable before disintegration.

The maximum operating temperature rating of a cable may be related to the above, but in most cases is of little consequence in an inferno.

14.16 Thermoplastic (PVC) insulation

523.1 At normal working temperatures thermoplastic (PVC) cables have excellent electrical characteristics that can resist chemical deterioration in most wet and dry conditions. If an unexpected rise in temperature occurs, where the insulation and/or sheathing overheats to the point of chemical decomposition, serious problems occur, as thick black clouds of choking acid smoke develop. This must be avoided at all costs. Apart from the suffocation consequences of burning and deprivation of oxygen, a major hazard to the victim is the emission of halogens of gaseous hydrochloric acid. At the very least, this will cause a sore throat, and is quite likely to kill.

Where a fire involving PVC cables develops, acidic fumes combine with water vapour and condense on surrounding surfaces. This will result in severe corrosion to both copper and steel. This will occur even with moderate overheating of cables, and the results are often seen after a fault on copper conductors and terminals. Any printed circuit boards in the vicinity of an overheated cable may suffer irreparable damage. For this reason, halogen-free cables are often specified for mainframe computer suites. It must be remembered that, in the course of combustion, non-electrical PVC products will add to the fire, as will other flammable plastic materials, such as paint and furnishings, which are all used in buildings. The contribution from electrical products may be relatively small. In the case of plastic conduit and trunking, the qualities of plasticised PVC introduce a favourable element of resistance to burning.

Polythene is more correctly known as polyethylene. This is not a suitable alternative or substitute for PVC. The material has excellent electrical characteristics, but as an extruded PVC material it has physical disadvantages:

- It is relatively soft, melts at low temperatures and has little 'scuff resistance'.
- Unless specially treated it will support combustion, and when burning produces flaming droplets.

Wherever PVC polyethylene has been used for power wiring, it has had to be protected by PVC or a similar sheathing.

14.17 Thermosetting (XLPE)

In recent years, the cable industry has been able to extrude a thermosetting version of cross-linked polyethylene. Known as XLPE, it possesses useful characteristics:

- XLPE will operate at higher temperatures than PVC.
- Higher operating temperatures mean less copper in cables where volt-drop is not a limiting factor.
- Flame retardant qualities are good.
- Virtually no hydrogen chloride is given off in a fire.

523.1

SWA cables are now supplied as standard, with XLPE insulation for almost all sizes. If PVC insulated SWA were required, it would generally have to be specially ordered. This has introduced an interesting variation in connection with the possible use of steel armouring as a cpc. A thinner extruded XLPE insulation cover is applied to conductor cores than with a similarly rated PVC insulated cable. The subject should be noted, but is not relevant to this consideration of fire precautions.

XLPE compound is not as robust as PVC. So, for this reason, the outer sheathing of standard SWA XLPE insulated cable is usually PVC. A cable manufacturer should be consulted where a halogen-free sheathing is required.

14.18 Silicone rubber

Cables with this type of insulation are available in multi-core form and are most commonly used for fire alarm installations. Silicone rubber will disintegrate in a fire but the resultant ash is, to a certain extent, physically stable and remains a good insulator.

Unfortunately, silicone rubber does not have the same qualities for mechanical protection and therefore usually the outer sheathing is normally PVC. This limits the operating temperature to PVC levels and does not eliminate the emission of hydrogen chloride in a fire. This point should be noted in connection with computerised, addressable fire alarm controls, which could suffer the consequences of acidic vapour corrosion. To avoid this problem, special low smoke, zero halogen (LS0H) sheathing is available. A single core, conduit version of silicone rubber cable has a braided glass over-sheath to give the requisite mechanical protection. The absence of PVC reduces the problem of fumes.

14.19 Low smoke zero halogen (LS0H)

The days of simple single compound plastics are rapidly disappearing. Chemists are producing complex multi-polymers with engineered characteristics. LS0H comes in this classification.

There are various LSOH compounds, which may differ to suit the intended application. In other words, LSOH is a description of a characteristic, not a material. The common factor with all LSOH cables is compliance with appropriate emission standards. One manufacturer can provide conduit cable with inner and outer composite layers giving specific insulation and fire resistance, and another manufacturer may have managed to combine similar qualities into one layer.

The advantages of LSOH cable are higher operating temperatures and the virtual elimination of smoke and halogen fumes. The industry is moving towards identifying such cables, by manufacturing them white in colour.

14.20 Mineral insulated copper sheathed (MICS) cables

523.1 Undoubtedly these cables offer supreme fire resistant qualities and will continue to function throughout the early stages of a fire. Eventually, though, even copper will melt, as it has a melting point of 1083 °C. The limiting factor for fire resistance will probably be at the cable termination. For special risk areas, high temperature terminations are advisable. It is common practice to use PVC-sheathed MICS cable to give good protection against corrosion. This again introduces the problem of halogen release in a fire and advice should be sought from manufacturers regarding alternative sheathing.

14.21 Heat transference from cables

512.1.5 Where a cable normally operates at a temperature in excess of 70 °C, it should not be connected to switchgear, protective devices, accessories or other types of equipment, unless the equipment manufacturer has confirmed that it is suitable for such temperatures.

14.22 Wiring systems and cable management

One of the principal reasons for selecting a particular wiring system will have been covered by the above explanation of fire resistant characteristics. Other reasons relate to cost, appearance and functional performance. In larger building complexes, the selection of a wiring system will be designated as a cable management subject.

14.23 Emergency systems

In the following brief review of care with wiring systems, some of the cables mentioned will be used for fire alarm and emergency lighting circuits. Installers may therefore need to become familiar with the appropriate British Standards for such systems before undertaking that type of

work. A local fire or licensing authority may also have ideas upon cable selection, but the ultimate responsibility rests with the installation designer.

14.24 Care with wiring systems

In other chapters of this book, suggestions are given for the use of suitable cables for specific projects. Some explanation is given to the reasoning behind each recommendation. However, in practice, deciding factors will often take into account safety and economy plus the external influences of environment, utilisation and building construction.

A designer must make a final decision on the wiring system based upon the actual installation conditions. There is no perfect all-purpose wiring system.

The following series of checklists cover some of the on-site practical measures that need to be considered with the installation of standard wiring systems. Both the installing electrician and commissioning inspector must take note of correct procedures and workmanship, although on smaller projects, total responsibility often rests with one person only.

14.25 Thermoplastic (PVC) insulated and sheathed cables

- This cable is vulnerable to physical damage. Therefore, short lengths of protective PVC conduit or mini-trunking may have to enclose the cable if it is unavoidably routed at skirting level or similar positions. 522.8.1
- The entire outer cable sheathing should be taken into fire resistant accessory or junction boxes. 526.8
- A bare cpc must have the correct green-and-yellow sleeving applied. 543.3.100
- Cable runs must be correctly supported by suitable means at appropriate intervals. A clip spacing of 300 mm should be appropriate for most accessible locations. Note, however, that particular care must be taken and suitable arrangements employed where such cables are installed above metallic false ceiling grids. 522.8.4

Suitable and adequate support means that all wiring systems should be secured to the structure by some sort of metallic fixing, at regular intervals. This is because plastic clips and/or mini-trunking will melt in the event of a fire. Therefore, suitable measures should be employed to prevent those cables from hanging down and becoming an entanglement hazard for fire fighters.

14.26 Thermosetting (PVC) insulated conduit cables

- Non-sheathed cables (i.e. single core cables) must always be enclosed in conduit or a continuous trunking system. Care must be taken at junctions and terminations, to ensure that the protective enclosure is complete. 521.10.1

14.27 Steel conduit systems and trunking

- 543.3 ● Earth continuity along the conduit is an important factor, even if an internal green-and-yellow cpc is used. Continuity through couplers and brass bushes must be permanent and reliable, taking into account the proposed life of the installation. Completion documentation will virtually be certifying that continuity will still be adequate to handle fault currents in five or more years' time.
- Reliable continuity arrangements are essential with trunking or metallic skirting systems. The correct linkage should be used at joints and terminations.
- 522.5 ● Protection against corrosion is essential and must take into account the surrounding environment and conditions of use. Exposed threads or pipe-vice marks must be painted over to maintain the protective quality of the conduit. Cut ends of trunking may need protection.
- Conduits must be suitably supported. This especially applies to vertical drops to machinery in workshops. In these circumstances it may be preferable to convert to flexible cable for the ceiling to machine linkage.

14.28 Plastic conduit systems and trunking

The appearance of a plastic conduit or trunking system usually indicates whether sufficient care has been taken in the installation. There is no excuse for distorted or sagging conduits, which result from inadequate fixings and lack of expansion facilities.

- A good general purpose rule is that conduit and trunking support is required at about 1 m intervals. Where ambient temperatures are high, or the installation is subject to solar radiation, spacing should be adjusted accordingly.
- Rigid PVC will expand and contract by about 1 mm per metre along the length of run in the normal temperature range that can be expected in the UK. To avoid problems, expansion couplers should be used at about 4 m intervals and saddles must allow for lateral movement.
- There are limitations in the weight that can be suspended from a PVC conduit box. Much depends upon the fixing of the box. Where a hot lighting fitting is connected directly to the conduit system, steel support clips should be used or a special heat resistant box.

14.29 MICS cables

- It is usual to use the copper sheathing as the cpc. This often causes problems regarding the adequacy of continuity at joints. Unless the installer is prepared to certify long-term reliability at all joints, it is good practice to use pot seals with earthing tails.
- Voltage surges occur when inductive loads are switched. This sometimes causes a failure of the mineral insulation. It is advisable to fit surge protection devices on cables supplying induction motors and fluorescent lighting installations.

14.30 Steel wire armoured cables

- Earthing continuity through the armouring gland at terminations must be effective, even if a separate cpc is used. A gland earthing ring should always be used with a cable linkage to the earthing terminal within a distribution board.
- The PVC outer cable sheathing is water resistant under normal conditions, but may not be suitable for continuous immersion. The cable manufacturer should be consulted and a suitable sheathing specified.

14.31 Silicone insulated PVC sheathed cables

- Care must be taken when stripping insulation. Silicone rubber is much softer and has less mechanical strength than PVC. Protective ferrules should be applied when sheathing is removed.

Inspection, Testing and Certification

It is a requirement of *BS 7671* that every electrical installation is inspected and tested, in order to verify that it complies with the relevant requirements of the standard. Procedures for the verification of a project are as important as any of the construction activities. Electrical installation work is often not subject to inspection and testing by another person or third party. Self-certification is acceptable, but does carry great responsibility.

With self-certification, there is an absolute requirement for full inspection and testing procedures. Everyone makes mistakes, but when work is claimed to comply with safety regulations, the installer will be negligent if faults are not rectified before an installation is put into service.

This chapter explains the minimum verification procedures that are required by Health and Safety legislation and *BS 7671*.

One would not expect to buy a car or computer that had not been tested. These products usually arrive with inspection certificates or labels, which show that full procedures have been carried out. Every reputable wiring accessory used on an installation carries a mark, which indicates certification to acceptable standards. In the case of mass-produced items, these involve routine and random sampling.

A customer has the right to expect that the electrical installation is of the same standard as the quality components that are used. The finished product is only as good as the continuity of hidden connections, the use of correct cable sizes, and many of the other items that make up a complete installation.

Switching a light on to see that it works is not a good enough test. Inspection and testing alone is not acceptable, unless someone is prepared to put a signature to a document certifying safety. No occupier should be put at risk with an unverified or untested installation. This point should be clearly explained to a customer who wants the system to operate before verification procedures have been carried out. It would not be expected with a car or an aircraft.

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15.1 Labelling and documentation

The comparison with motoring continues. Where the purpose is not obvious, all the switches and controls on a car are marked to indicate their functions. A driver's manual is provided for the purchaser and a technical service manual is made available for future maintenance and repair.

Similar information and documentation is required for an electrical installation.

15.2 Specification and manual

IET Guidance Notes suggest that each project should start with a specification. Ideas for specifications are given with each of the projects in this book.

At the completion of a job, information from the specification will form the basis of a user manual. In the case of a commercial project, Health and Safety legislation is concerned with the supply of suitable documentation. This composite manual should contain:

- Electrical Installation Certificate (EIC), as required by the Wiring Regulations;
- detailed schedules of inspection and test results;
- advice regarding the use of equipment, such as circuit-breakers or RCDs; and
- manufacturers' information regarding equipment.

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The complexity of the manual will be related to the size and complexity of the project. A simple three bedroom house will probably result in a manual containing the EIC, plus some manufacturers' leaflets covering the protective devices at the consumer unit.

15.3 Regulations

The Wiring Regulations require that every installation must be inspected and tested, both during erection and before being put into service. This covers the common situation where some parts of the installation become hidden from view as the builders' work progresses. It could be argued that inspection of inaccessible parts is more important than places where defects are visually obvious. 610.1

The persons signing certification take responsibility for all work, hidden and obvious. On larger projects, a system of programmed inspections may be necessary. The subject is less complex where work is self-certified.

15.4 Electrical installation certificate (EIC)

The format for a certificate is given in *BS 7671*. Figures 15.1 and 15.2 illustrate the two parts of one version of the certificate produced for general use. Contractors approved by the following App. 6

ELECTRICAL INSTALLATION CERTIFICATE
 (REQUIREMENTS FOR ELECTRICAL INSTALLATIONS - BS 7671 [IET WIRING REGULATIONS])

DETAILS OF THE CLIENT	
INSTALLATION ADDRESS	
DESCRIPTION AND EXTENT OF THE INSTALLATION Tick boxes as appropriate	
Description of installation:	New installation <input type="checkbox"/>
Extent of installation covered by this Certificate:	Addition to an existing installation <input type="checkbox"/>
	Alteration to an existing installation <input type="checkbox"/>
(Use continuation sheet if necessary) see continuation sheet No:	
FOR DESIGN I/We being the person(s) responsible for the design of the electrical installation (as indicated by my/our signatures below), particulars of which are described above, having exercised reasonable skill and care when carrying out the design hereby CERTIFY that the design work for which I/we have been responsible is to the best of my/our knowledge and belief in accordance with BS 7671:2008, amended to (date) except for the departures, if any, detailed as follows:	
Details of departures from BS 7671 (Regulations 120.3 and 133.5):	
The extent of liability of the signatory or the signatories is limited to the work described above as the subject of this Certificate.	
For the DESIGN of the installation: *(Where there is mutual responsibility for the design)	
Signature:	Date: Name (IN BLOCK LETTERS): Designer No 1
Signature:	Date: Name (IN BLOCK LETTERS): Designer No 2**
FOR CONSTRUCTION I/We being the person(s) responsible for the construction of the electrical installation (as indicated by my/our signatures below), particulars of which are described above, having exercised reasonable skill and care when carrying out the construction hereby CERTIFY that the construction work for which I/we have been responsible is to the best of my/our knowledge and belief in accordance with BS 7671:2008, amended to (date) except for the departures, if any, detailed as follows:	
Details of departures from BS 7671 (Regulations 120.3 and 133.5):	
The extent of liability of the signatory is limited to the work described above as the subject of this Certificate.	
For CONSTRUCTION of the installation:	
Signature:	Date: Name (IN BLOCK LETTERS): Constructor
FOR INSPECTION & TESTING I/We being the person(s) responsible for the inspection & testing of the electrical installation (as indicated by my/our signatures below), particulars of which are described above, having exercised reasonable skill and care when carrying out the inspection & testing hereby CERTIFY that the work for which I/we have been responsible is to the best of my/our knowledge and belief in accordance with BS 7671:2008, amended to (date) except for the departures, if any, detailed as follows:	
Details of departures from BS 7671 (Regulations 120.3 and 133.5):	
The extent of liability of the signatory is limited to the work described above as the subject of this Certificate.	
For INSPECTION AND TESTING of the installation:	
Signature:	Date: Name (IN BLOCK LETTERS): Inspector
NEXT INSPECTION I/We the designer(s), recommend that this installation is further inspected and tested after an interval of not more than years/months.	

Figure 15.1 Electrical Installation Certificate requires three signatures.

PARTICULARS OF SIGNATORIES TO THE ELECTRICAL INSTALLATION CERTIFICATE			
Designer (No 1)			
Name:		Company:	
Address:		Postcode:	Tel No:
Designer (No 2) (if applicable)			
Name:		Company:	
Address:		Postcode:	Tel No:
Constructor			
Name:		Company:	
Address:		Postcode:	Tel No:
Inspector			
Name:		Company:	
Address:		Postcode:	Tel No:
SUPPLY CHARACTERISTICS AND EARTHING ARRANGEMENTS <small>Tick boxes and enter details, as appropriate</small>			
Earthing arrangements	Number and Type of Live Conductors	Nature of Supply Parameters	Supply Protective Device Characteristics
TN-C <input type="checkbox"/>	a.c. <input type="checkbox"/> d.c. <input type="checkbox"/>	Nominal voltage, $U/U_0^{(1)}$ V	Type:
TN-S <input type="checkbox"/>	1-phase, 2-wire <input type="checkbox"/> 2-wire <input type="checkbox"/>	Nominal frequency, $f^{(1)}$ Hz	Rated current.....A
TN-C-S <input type="checkbox"/>	2-phase, 3-wire <input type="checkbox"/> 3-wire <input type="checkbox"/>	Prospective fault current, $I_{pf}^{(2)}$ kA	
TT <input type="checkbox"/>	3-phase, 3-wire <input type="checkbox"/> other <input type="checkbox"/>	External loop impedance, $Z_e^{(2)}$ Ω	
IT <input type="checkbox"/>	3-phase, 4-wire <input type="checkbox"/>	<small>(Note: (1) by enquiry, (2) by enquiry or by measurement)</small>	
Other sources of supply (to be detailed on attached schedules) <input type="checkbox"/>			
PARTICULARS OF INSTALLATION REFERRED TO IN THE CERTIFICATE <small>Tick boxes and enter details, as appropriate</small>			
Means of Earthing	Maximum Demand		
Distributor's facility <input type="checkbox"/>	Maximum demand (load) kVA / Amps <small>Delete as appropriate</small>		
Installation earth electrode <input type="checkbox"/>	Details of Installation Earth Electrode (where applicable)		
	Type (e.g. rod(s), tape etc)	Location	Electrode resistance to Earth Ω
Main Protective Conductors			
Earthing conductor:	material	csamm ²	Continuity and connection verified <input type="checkbox"/>
Main protective bonding conductors	material	csamm ²	Continuity and connection verified <input type="checkbox"/>
To incoming water and/or gas service <input type="checkbox"/>	To other elements:		
Main Switch or Circuit-breaker			
BS, Type and No. of poles	Current rating	Voltage ratingV	
Location	Fuse rating or setting.....A		
Rated residual operating current $I_{\Delta n}$ = mA, and operating time of ms (at $I_{\Delta n}$) <small>(Applicable only where an RCD is suitable and is used as a main circuit-breaker)</small>			
COMMENTS ON EXISTING INSTALLATION (in the case of an addition or alteration see Section 633):			
.....			
.....			
.....			
SCHEDULES			
The attached Schedules are part of this document and this Certificate is valid only when they are attached to it.			
..... Schedules of Inspections and Schedules of Test Results are attached.			
<small>(Enter quantities of schedules attached)</small>			

Figure 15.2 Installation particulars shown on Electrical Installation Certificate.

organisations will use certificates issued by those organisations (some specifiers insist on particular forms; the form may be supplemented with inspection reports for special areas): Electrical Contractors' Association (ECA), ECA of Scotland (SELECT), NICEIC, and National Association of Professional Inspectors and Testers (NAPIT).

15.5 Signatories

BS 7671 provides for three types of EICs. These can be described as:

1. an Electrical Installation Certificate (EIC);
2. a Domestic Electrical Installation Certificate (DEIC);
3. a Minor Electrical Installation Works Certificate (MEIWC).

The 'full' EIC is for general use and applies to most of the installations described in this book. It has three declaration of conformity boxes for the signatures of the designer(s), the installer, and the inspector and tester, respectively. Larger installations are likely to have more than one designer. For example, a consulting engineer may do the original design and the electrical contractor's engineer may also be responsible for on-site designs.

The DEIC is a hybrid of the EIC, used for domestic single distribution board installations or single circuit installations where the contractor designs, installs, and inspects and tests the installation. It contains a single signature declaration, and is commercially available by most, if not all, Part P scheme operators. As it is not a model form shown in *BS 7671*, an image is not included in this book.

The MEIWC (Figure 15.3) is used for new work that does not extend to the provision of a new circuit. It contains a single signature declaration.

15.5.1 Designer

This person may be a consultant, a local authority engineer or the installer. The designer will have made electrotechnical judgements and perhaps calculations. Generally architects and builders do not design electrical installations. They may give instructions upon the type and location of equipment and cable runs, but this is building design, not electrical design as required by the certificate.

An installer who uses rule-of-thumb methods or adopts published designs, or copies other designers' work, must take responsibility for the project design. This implies that the installer must have the competence to design the work, although an acceptable short-cut has been taken.

In some cases, a consultant may pay an installer to verify the design and take responsibility for the certification.

MINOR ELECTRICAL INSTALLATION WORKS CERTIFICATE
 (REQUIREMENTS FOR ELECTRICAL INSTALLATIONS - BS 7671 [IET WIRING REGULATIONS])
To be used only for minor electrical work which does not include the provision of a new circuit

<p>PART 1:Description of minor works</p> <p>1. Description of the minor works</p> <p>2. Location/Address</p> <p>3. Date minor works completed</p> <p>4. Details of departures, if any, from BS 7671:2008</p>	
<p>PART 2:Installation details</p> <p>1. System earthing arrangement TN-C-S <input type="checkbox"/> TN-S <input type="checkbox"/> TT <input type="checkbox"/></p> <p>2. Method of fault protection</p> <p>3. Protective device for the modified circuit Type Rating A</p> <p>Comments on existing installation, including adequacy of earthing and bonding arrangements (see Regulation 132.16):</p>	
<p>PART 3:Essential Tests</p> <p>Earth continuity satisfactory <input type="checkbox"/></p> <p>Insulation resistance:</p> <p style="padding-left: 40px;">Line/neutral MΩ</p> <p style="padding-left: 40px;">Line/earth MΩ</p> <p style="padding-left: 40px;">Neutral/earth MΩ</p> <p>Earth fault loop impedance Ω</p> <p>Polarity satisfactory <input type="checkbox"/></p> <p>RCD operation (if applicable). Rated residual operating current $I_{\Delta n}$mA and operating time ofms (at $I_{\Delta n}$)</p>	
<p>PART 4:Declaration</p> <p>I/We CERTIFY that the said works do not impair the safety of the existing installation, that the said works have been designed, constructed, inspected and tested in accordance with BS 7671:2008 (IET Wiring Regulations), amended to (date) and that the said works, to the best of my/our knowledge and belief, at the time of my/our inspection, complied with BS 7671 except as detailed in Part 1 above.</p>	
<p>Name:</p> <p>For and on behalf of:</p> <p>Address:</p> <p>.....</p> <p>.....</p>	<p>Signature:</p> <p>Position:</p> <p>Date:.....</p>

Figure 15.3 Minor Electrical Installation Works Certificate.

15.5.2 Installer

The designer cannot be held responsible for the way in which an installer follows the specification. The installer therefore certifies that there is compliance with the Wiring Regulations as far as on-site installation work is concerned. This will include the selection of appropriate materials to match the specification or to comply with Regulations. For example, wherever appropriate, all materials should carry a British Standard mark or other acceptable product certification.

This subject is summed up in the fundamental requirements section in the Wiring Regulations, which states that good workmanship by competent persons or persons under their supervision and proper materials must be used.

It is in this part of the project that inspection and testing may be necessary as the work progresses. It may be that the installation is intended to be progressively energised and put into service on a phased basis. In this instance, interim certification may be necessary to confirm that the installation is safe and fit for use. The Regulations offer no relaxation in safety standards for temporary work. It may even be considered that a higher standard of safety is necessary for incomplete installations used by people who will be unfamiliar with the system.

15.5.3 Inspection and testing

611.1 This may be carried out by a specialised operator, or the installer, or perhaps the design consultant. The inspector must be in possession of design data and the specification. Testing is carried out to ensure that the completed project complies with *BS 7671* and the intentions of the designer. Some aspects of the inspection may have been carried out during the progress of the work. This particularly applies to making good holes made in fire barrier walls for cable routes.

Full testing must be carried out before the system or part of the system is energised and handed over to the client. Future users should not be put at risk by incomplete work.

15.6 Alterations and additions

All work is subject to the full test requirements. Small jobs and alterations must be certified in a similar manner, although in some cases a MEIWC may be acceptable to the client.

15.7 Limits of responsibility

A signatory on an EIC can only be responsible for work for which there is a contractual arrangement. If, for example, the client only requires a house extension to be wired, the installer cannot be held responsible for the existing installation in the older part of the building, unless this is part of the agreement. The situation is illustrated clearly if one considers the consequences of installing an additional socket-outlet in a large multi-storey office complex. There is no way that the installer is going to certify the quality of the electrical system in the rest of the building.

The installer carries the obligation to ensure that the new work complies with current regulations and that downstream equipment supplying the addition or extension is adequate for the additional load. 132.16

There is a further requirement, which may have significant consequences. That is to ensure that the earthing and bonding arrangements, if necessary for the safety of the protective measure for the addition, are satisfactory. The problem is that each socket-outlet and service connection relies upon main earthing and bonding for safety. It is suggested that this matter is investigated before the contract is accepted.

In the case of domestic additions or alterations, for example the installation of a shower, the importance of correct bonding cannot be over-stressed. If there is any doubt about the old installation, the best solution is to install a new consumer unit for the shower and to establish this as a separate installation with the relevant earthing and bonding. Refer to Regulation 701.415.2 to see where supplementary bonding may be omitted.

Regardless of the above, an installer, as an electrical expert, has a moral and statutory duty to bring to the attention of the occupier any obvious dangers in the old installation. In extreme cases, this might best be covered by a written recommendation stating that the installation should have a full inspection either straightaway or within a stated period of time.

15.8 Deviations and departures

There may be circumstances in which some aspects of the installation do not strictly accord with the Wiring Regulations. The fact that there is a space on the form to record such departures implies that some of these may be acceptable. A departure from *BS 7671*, for example, would be where an installer connects a circuit to a 'spare' way at the consumer unit, populated with a *BS 3871* (miniature) circuit-breaker – as such devices are no longer recognised by *BS 7671* (but thousands, if not millions, of them are still in service today). Where such a situation occurs, this must be recorded on the appropriate part of the EIC or, where appropriate, the MEIWC. 120.3

15.9 New materials and inventions

In order to accommodate new materials and inventions, one or more departures from the Regulations are acceptable, provided they do not result in lower safety standards. This does not encompass situations where a client insists upon features that are in conflict with the Wiring Regulations. An example may be a request for a bathroom socket-outlet for a hair dryer, which is located within 3 m from the boundary of zone 1. In these circumstances, the installer may not deviate from the Regulations and must refuse to carry out the work. In the case of the hair dryer, it would be diplomatic to suggest alternative ideas for a fixed appliance. 133.5

15.10 Particulars of the installation

One page of the EIC is intended to carry a summarised technical report on the installation (Figure 15.2). Most questions are easily answered and in some cases may be deleted where they are not relevant to the particular premises.

Some topics that raise queries are:

- *Prospective fault current or prospective short-circuit current:*

- 313.1 This is the maximum instantaneous current that will flow under short-circuit conditions, either line to neutral or line to earth. Instrumentation is available to measure this condition. On a single-phase 230 V PME system, where neutral and earth are interconnected at the distributor's terminals:

$$\text{pfc} = \frac{230}{Z_e \times 1000} \text{ kA} \quad (15.1)$$

where Z_e is the earth fault loop impedance in Ω at the consumer unit.

- *Overcurrent protective device:*

This is the electricity company's fuse. On a PME domestic installation, it will probably be BS 88, 100 A rating.

- *Main switch:*

Details are shown on the front of the consumer unit or main switch.

- *Rated RCD current:*

Where applicable, this may be 300 mA or 100 mA. S Type

- *Method of protection:*

- 411.3 On the public supply this will almost always be Automatic Disconnection of Supply (ADS). Alternatives would only apply to special unearthed systems, and so on.

15.11 Inspections and test schedules

- 631.1 It is a requirement of BS 7671 that an EIC is accompanied by completed schedules of inspection and schedule(s) of test results.

- 514.9 There is no laid down format and all items may be combined on one sheet, provided the certificate contains the minimum information detailed on the model form shown in Appendix 6 of BS 7671. Figures 15.4 and 15.5 illustrate two pages covering separately the schedule of inspections and test results. These relate to circuitry at one distribution board. For large schemes, multiple copies will be required or purpose-made documentation produced.

15.12 Inspection procedures

- Sec. 611 The Wiring Regulations detail at length the inspection checks that must be carried out before testing. The idea is that every aspect of an installation should be viewed with a critical eye, to ensure that both the detail and spirit of the Wiring Regulations, have been met.

SCHEDULE OF INSPECTIONS (for new installation work only)

<u>Methods of protection against electric shock</u>	<u>Prevention of mutual detrimental influence</u>
<p>Both basic and fault protection:</p> <p><input type="checkbox"/> (i) SELV</p> <p><input type="checkbox"/> (ii) PELV</p> <p><input type="checkbox"/> (iii) Double insulation</p> <p><input type="checkbox"/> (iv) Reinforced insulation</p> <p>Basic protection:</p> <p><input type="checkbox"/> (i) Insulation of live parts</p> <p><input type="checkbox"/> (ii) Barriers or enclosures</p> <p><input type="checkbox"/> (iii) Obstacles</p> <p><input type="checkbox"/> (iv) Placing out of reach</p> <p>Fault protection:</p> <p>(i) Automatic disconnection of supply:</p> <p><input type="checkbox"/> Presence of earthing conductor</p> <p><input type="checkbox"/> Presence of circuit protective conductors</p> <p><input type="checkbox"/> Presence of protective bonding conductors</p> <p><input type="checkbox"/> Presence of supplementary bonding conductors</p> <p><input type="checkbox"/> Presence of earthing arrangements for combined protective and functional purposes</p> <p><input type="checkbox"/> Presence of adequate arrangements for other sources, where applicable</p> <p><input type="checkbox"/> FELV</p> <p><input type="checkbox"/> Choice and setting of protective and monitoring devices (for fault and/or overcurrent protection)</p> <p>(ii) Non-conducting location:</p> <p><input type="checkbox"/> Absence of protective conductors</p> <p>(iii) Earth-free local equipotential bonding:</p> <p><input type="checkbox"/> Presence of earth-free local equipotential bonding</p> <p>(iv) Electrical separation:</p> <p><input type="checkbox"/> Provided for one item of current-using equipment</p> <p><input type="checkbox"/> Provided for more than one item of current-using equipment</p> <p>Additional protection:</p> <p><input type="checkbox"/> Presence of residual current device(s)</p> <p><input type="checkbox"/> Presence of supplementary bonding conductors</p>	<p><input type="checkbox"/> (a) Proximity to non-electrical services and other influences</p> <p><input type="checkbox"/> (b) Segregation of Band I and Band II circuits or use of Band II insulation</p> <p><input type="checkbox"/> (c) Segregation of safety circuits</p> <p>Identification</p> <p><input type="checkbox"/> (a) Presence of diagrams, instructions, circuit charts and similar information</p> <p><input type="checkbox"/> (b) Presence of danger notices and other warning notices</p> <p><input type="checkbox"/> (c) Labelling of protective devices, switches and terminals</p> <p><input type="checkbox"/> (d) Identification of conductors</p> <p>Cables and conductors</p> <p><input type="checkbox"/> Selection of conductors for current-carrying capacity and voltage drop</p> <p><input type="checkbox"/> Erection methods</p> <p><input type="checkbox"/> Routing of cables in prescribed zones</p> <p><input type="checkbox"/> Cables incorporating earthed armour or sheath, or run within an earthed wiring system, or otherwise adequately protected against nails, screws and the like</p> <p><input type="checkbox"/> Additional protection provided by 30 mA RCD for cables concealed in walls (where required in premises not under the supervision of a skilled or instructed person)</p> <p><input type="checkbox"/> Connection of conductors</p> <p><input type="checkbox"/> Presence of fire barriers, suitable seals and protection against thermal effects</p> <p>General</p> <p><input type="checkbox"/> Presence and correct location of appropriate devices for isolation and switching</p> <p><input type="checkbox"/> Adequacy of access to switchgear and other equipment</p> <p><input type="checkbox"/> Particular protective measures for special installations and locations</p> <p><input type="checkbox"/> Connection of single-pole devices for protection or switching in line conductors only</p> <p><input type="checkbox"/> Correct connection of accessories and equipment</p> <p><input type="checkbox"/> Presence of undervoltage protective devices</p> <p><input type="checkbox"/> Selection of equipment and protective measures appropriate to external influences</p> <p><input type="checkbox"/> Selection of appropriate functional switching devices</p>
<p>Inspected by</p>	<p>Date</p>

NOTES:

✓ to indicate an inspection has been carried out and the result is satisfactory

N/A to indicate that the inspection is not applicable to a particular item

An entry must be made in every box.

Figure 15.4 Schedule of inspections.

GENERIC SCHEDULE OF TEST RESULTS

DB reference no Location Zs at DB (Ω) I _n at DB (KA) Correct supply polarity confirmed <input type="checkbox"/> Phase sequence confirmed (where appropriate) <input type="checkbox"/>		Details of circuits and/or installed equipment vulnerable to damage when testing										Details of test instruments used (state serial and/or asset numbers) Continuity Insulation resistance Earth fault loop impedance RCD Earth electrode resistance																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
Tested by: Name (Capitals) Signature Date		<table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <thead> <tr> <th rowspan="2" style="width: 5%;">Circuit number</th> <th colspan="10">Circuit details</th> <th rowspan="2" style="width: 5%;">Ring final circuit continuity (Ω)</th> <th rowspan="2" style="width: 5%;">Continuity (Ω) (R₁ + R₂ or R_Z)</th> <th rowspan="2" style="width: 5%;">Insulation Resistance (MΩ)</th> <th rowspan="2" style="width: 1.5%;">Polarity</th> <th rowspan="2" style="width: 1.5%;">Z_s (Ω)</th> <th colspan="3">RCD</th> <th rowspan="2" style="width: 10%;">Remarks (continue on a separate sheet if necessary)</th> </tr> <tr> <th style="width: 15%;">Circuit Description</th> <th style="width: 3%;">BS (EN)</th> <th style="width: 2%;">type</th> <th style="width: 2%;">rating (A)</th> <th style="width: 3%;">breaking capacity (kA)</th> <th style="width: 2%;">Reference Method</th> <th style="width: 2%;">Live (mm²)</th> <th style="width: 2%;">cpc (mm²)</th> <th style="width: 2%;">r₁ (line)</th> <th style="width: 2%;">r_n (neutral)</th> <th style="width: 2%;">r₂ (cpc)</th> <th style="width: 2%;">(R₁ + R₂) *</th> <th style="width: 2%;">R_Z</th> <th style="width: 2%;">Live-Live</th> <th style="width: 2%;">Live-E</th> <th style="width: 1.5%;">Z_s</th> <th style="width: 1.5%;">@ I_{sn}</th> <th style="width: 1.5%;">@ 5I_{sn}</th> <th style="width: 2%;">Test button operation</th> </tr> </thead> <tbody> <tr><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> 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necessary)	Circuit Description	BS (EN)	type	rating (A)	breaking capacity (kA)	Reference Method	Live (mm ²)	cpc (mm ²)	r ₁ (line)	r _n (neutral)	r ₂ (cpc)	(R ₁ + R ₂) *	R _Z	Live-Live	Live-E	Z _s	@ I _{sn}	@ 5I _{sn}	Test button 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* Where there are no spurs connected to a ring final circuit this value is also the (R₁ + R₂) of the circuit.

Figure 15.5 Test results schedule.

15.13 Testing

Sec. 612

The Wiring Regulations include test requirements, but not test procedures. Suggestions for suitable test methods are given in an IET Guidance Note 3 *Inspection and Testing*, but alternative methods may be used, provided that the results are equally effective.

Testing ideas shown here summarise the very minimum routine that may be applied to a simple installation. For detailed information on testing procedures, refer to either IET's *Guidance Note 3* or NICEIC's *Inspection, Testing and Certification* book.

It is important that the tests are carried out in the correct sequence, using reputable and reliable equipment. Instrument manufacturers' instructions and full safety procedures should be followed. Test instruments should be selected according to the relevant parts of *BS EN 61557*, which in turn calls for compliance with the safety requirements of *BS EN 61010*.

- Where testing requires the exposure of live parts, for example, when carrying out a measurement of Z_e , great care must be taken to avoid danger from both electric shock and burns caused by arcing.
- The requirements and guidance of the *Memorandum of Guidance on the Electricity at Work Regulations 1989*, published by the HSE, should be strictly observed.
- Low cost, uncertified multi-meters are not suitable for any of the tests required by the Wiring Regulations.
- The use of home-made test lamps or test leads would probably be a breach of the *Electricity at Work Regulations 1989*.
- Where tests are made on the supply, fused probes should always be used. HSE publication *GS 38* gives guidance on the safe use of test instruments and correct leads to use.
- Instruments must be regularly calibrated. Where re-calibration indicates that faulty readings have previously been given, all earlier tests are suspect and will need to be repeated.

It is a good idea to keep some local test reference arrangements that can be applied regularly on site by a testing electrician. A 'standard' coil of cable can be used to check the accuracy of a continuity scale and a particular convenient socket-outlet used to confirm the integrity of the earth loop impedance test instrument.

Results of testing should always be recorded, otherwise when disaster strikes there is no proof that testing was ever carried out. Remember that all documentation may be required for inspection by a court of law.

To help installers and those responsible for issuing and maintaining test equipment, the Electrical Safety Council has made available a Best Practice Guide (BPG) on this very subject. BPG No. 7 *Test instruments for electrical installations: Accuracy and consistency* can be viewed or downloaded for free from www.esc.org.uk.

15.14 Continuity testing

These tests are all carried out before the supply is connected and the system energised. If at any time there is found to be a test failure, all previous tests involving the particular conductors must be repeated.

15.15 Polarity

The opportunity should be taken to check polarity when conducting the following continuity tests. The polarity requirement may be ticked off on the testing schedule after the relevant check(s).

15.16 Continuity of protective conductors

Figure 15.6 illustrates a suitable method using a low current continuity tester. Each circuit protective conductor (cpc) is connected in series with the corresponding line conductor. The result gives the resistance of the fault path from an outlet or appliance to the consumer unit/distribution board. Readings must be supplemented by visual checks on terminations. Ideally, this test can be carried out before final connection to the consumer unit.

The test does not necessarily show the quality and long-term reliability of a joint, especially where corrosion may occur. Where a circuit relies upon continuity through steel conduit or the connections of conduit-type fittings to steel switchgear, testing with a loop impedance tester should also be carried out after the installation has been energised.

15.17 Continuity of ring circuit conductors

612.2.2 Figures 15.7 and 15.8 show suitable arrangements. It may be convenient to carry out this test at the same time as each ring circuit is connected into the distribution board. This will ensure that there is no subsequent cross-connection of circuits. Two sets of readings are taken.

15.17.1 Test no. 1

The first set of readings will give a comparative resistance of cable loops, where the cross-sectional area of each conductor is the same (refer to Figure 15.7). The values obtained will indicate whether or not the conductors are continuous. If one loop shows a noticeable difference from the other two loops, a check should be made of connections around the circuit. If the cpc has a smaller cross-sectional area than the line and neutral conductors, its resistance will be higher. For example, a 1.5 mm^2 cpc will have 1.67 times the resistance of a 2.5 mm^2 line or neutral conductor.

15.17.2 Test no. 2

This part of the test involves inter-connecting two loops – the outgoing line to the returning neutral, and vice versa. A test is then made between line and neutral at each socket-outlet on the ring final circuit. If the ring is correctly wired, there are no spurs, and the connections are correct, the test values should all be approximately the same, and the value will be 50% (half) of the resistance obtained for a single loop of the line (r_1) or neutral (r_n) conductor (Figure 15.8.)

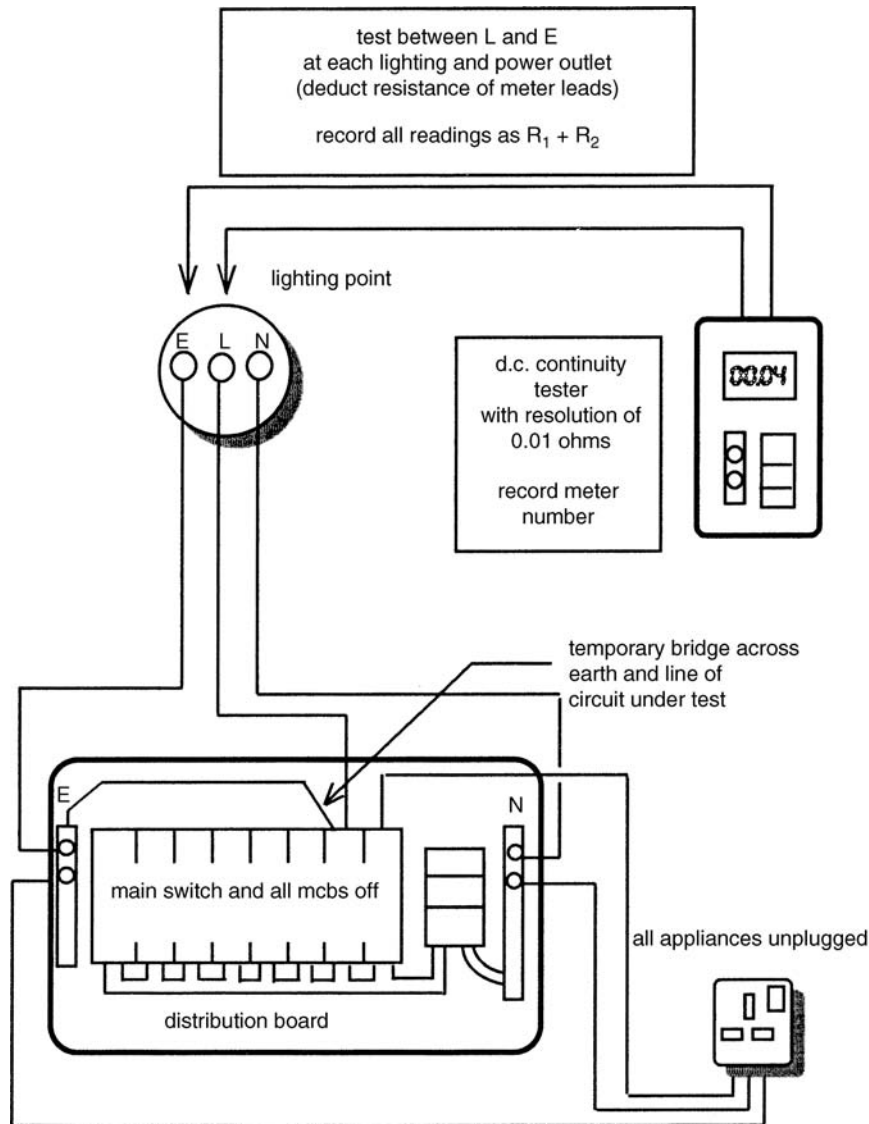


Figure 15.6 Testing continuity of protective conductors.

Step 3: The process is then repeated with the line and cpc conductors cross-connected, and then the test is repeated at each socket-outlet (this time between r_1 and r_2) – refer to Figure 15.9. Where the cross-sectional area of the cpc is the same as the live conductors, the results should be similar, but this time will equate with line loop plus cpc loop resistances.

The highest obtained will represent the maximum $R_1 + R_2$ value for the circuit, and should be recorded so on the Schedule of Test Results. This value will be equal to $(r_1 + r_2)/4$, where r_1 and

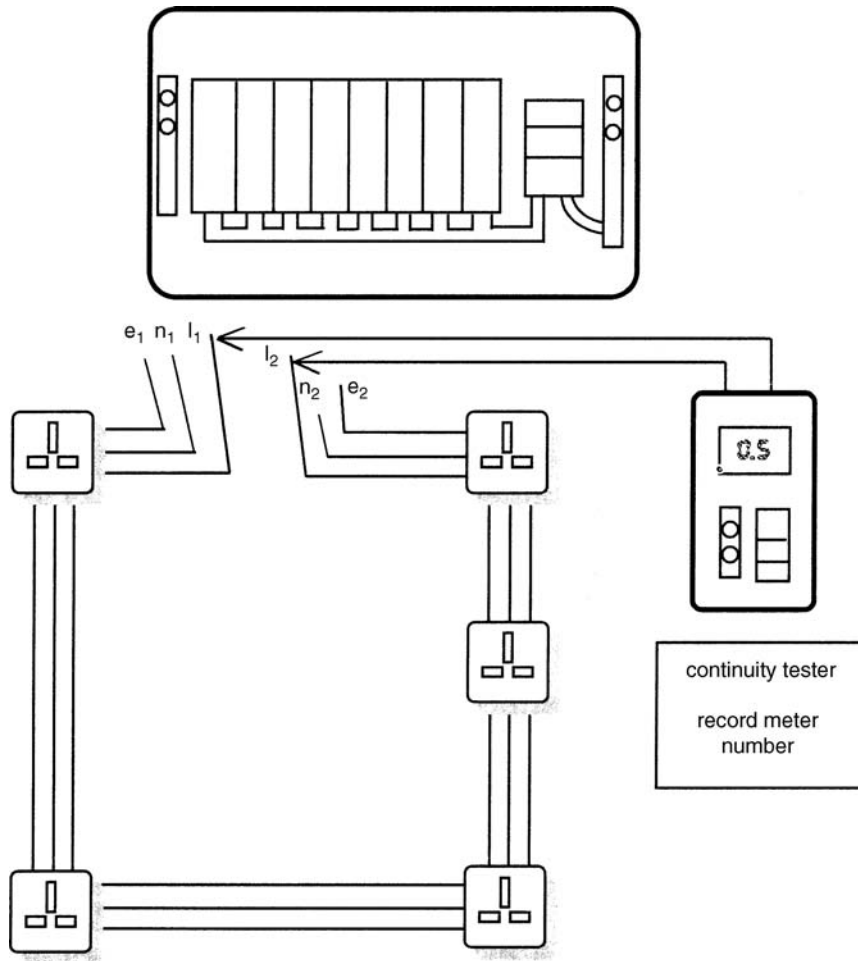


Figure 15.7 Testing continuity of ring circuit conductors. Test no. 1: Disconnect and separate ring circuit conductors to test for end-to-end continuity of r_1 , r_n and r_2 . Record and compare readings.

r_2 are the end-to-end resistances of the line and circuit cpcs, respectively. This test also verifies polarity and 'earth' continuity at each socket-outlet.

Remember: where the cpc has a smaller cross-sectional area, the reading will be higher.

15.18 Insulation resistance

612.3 This test is carried out before the supply is connected. The test must be carried out with the cpcs connected to the general mass of earth (as denoted by the capitalised earth). Irrespective of whether an insulation resistance test has been carried out to check that a cable has not been damaged while being installed, it is essential that the test is repeated before the installation is energised, where there is a risk that the cable may have been damaged by other trades working on the project.

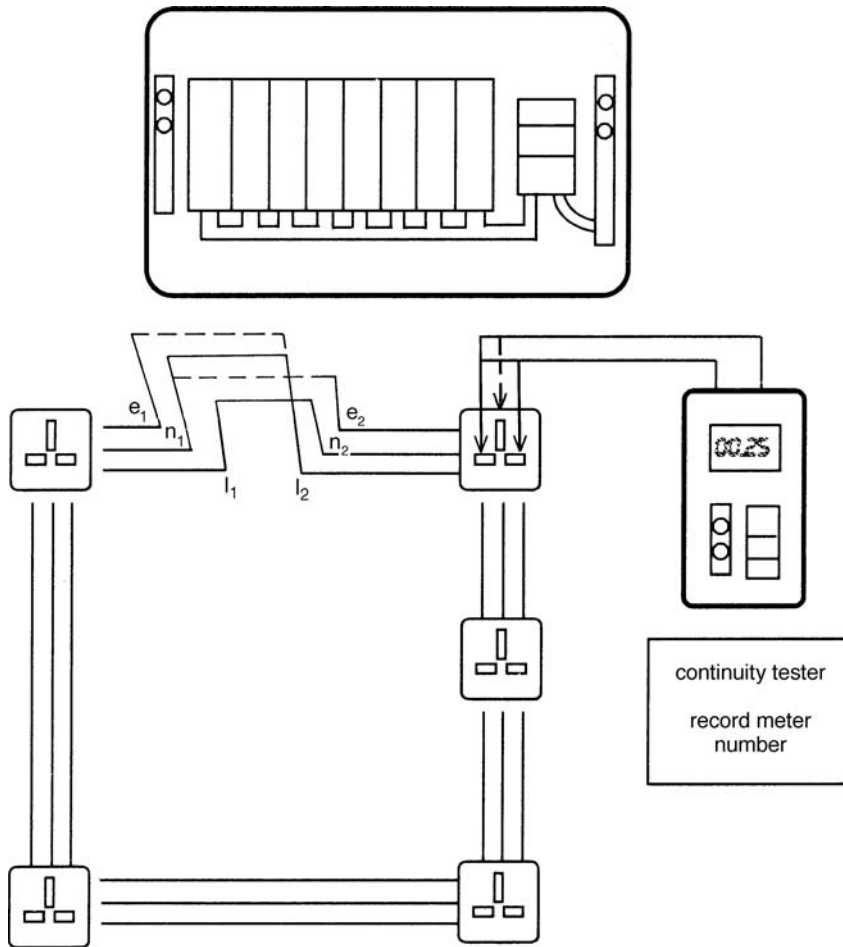


Figure 15.8 Testing continuity of ring final circuit live conductors. Test no. 2: Cross-connection of the live conductors. The readings need to be compared, but not recorded anywhere.

All lamps should be removed and control equipment disconnected. This is particularly important if delicate electronic devices are connected to the circuit/installation being tested. Tests, as shown in Figure 15.10, should be applied, using a 500 V insulation resistance test instrument. The reading across the whole installation must be greater than 1.0 M Ω , but it is more usual to achieve full-scale readings on each circuit. Inconsistent readings or results midway across the meter scale usually indicate localised dampness or cable damage, for example by a nail penetrating the sheath and/or putting pressure onto one of the live conductors. The cause of low readings must always be investigated.

Note: Whilst the minimum acceptable value for insulation resistance is 1.0 M Ω , a measured value that is less than 2.0 M Ω indicates that there is a faulty condition pending, which may cause a problem in the future. This condition requires further investigation and, if necessary, remedial action taken to correct the problem.

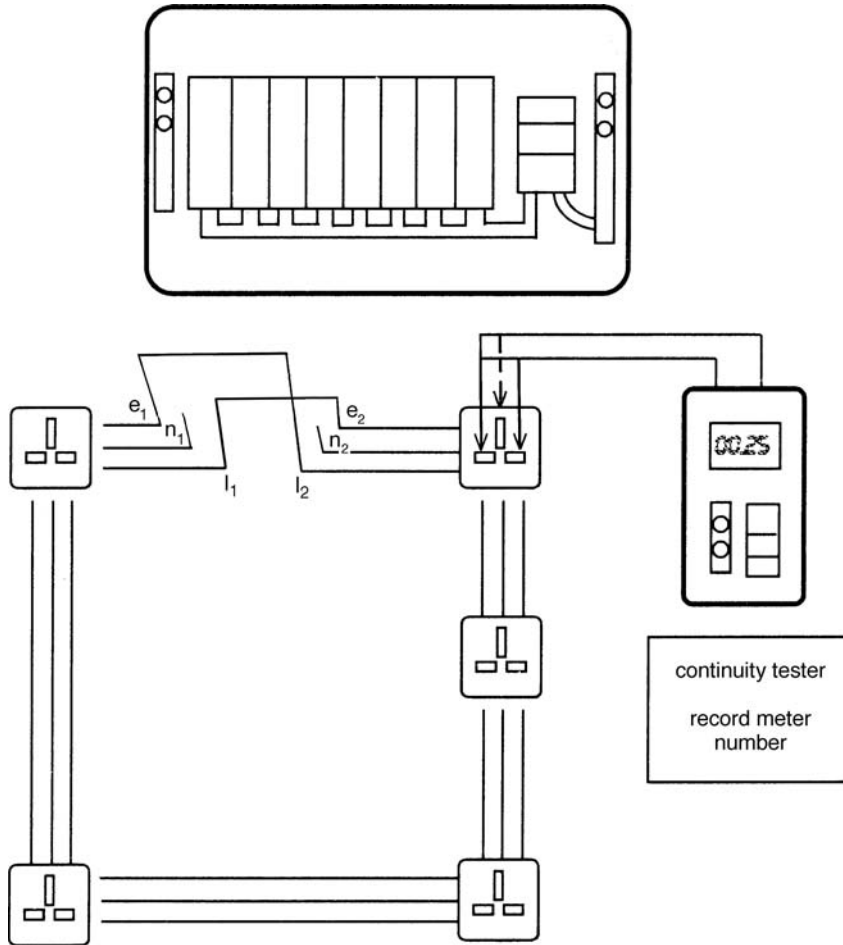


Figure 15.9 Cross-connection of line (r_1) and cpc (r_2) conductors.

15.19 Earth fault loop impedance

BS 7671 requires that wherever knowledge of earth fault loop impedance is required, it must be measured or determined. This generally means determining the values for every circuit (distribution circuit and final circuit) that is protected by an overcurrent or residual current device, because there are maximum values for each situation.

The impedances can be either measured/determined by adding the external impedance of the system (Z_e) to the resistances of the circuit cables ($R_1 + R_2$), or can be measured with an earth fault loop impedance test instrument after the system has been energised.

612.9 These tests are conducted after the system has been energised. They are possibly the most significant for ensuring the future safety of the installation. If carefully interpreted, results will show:

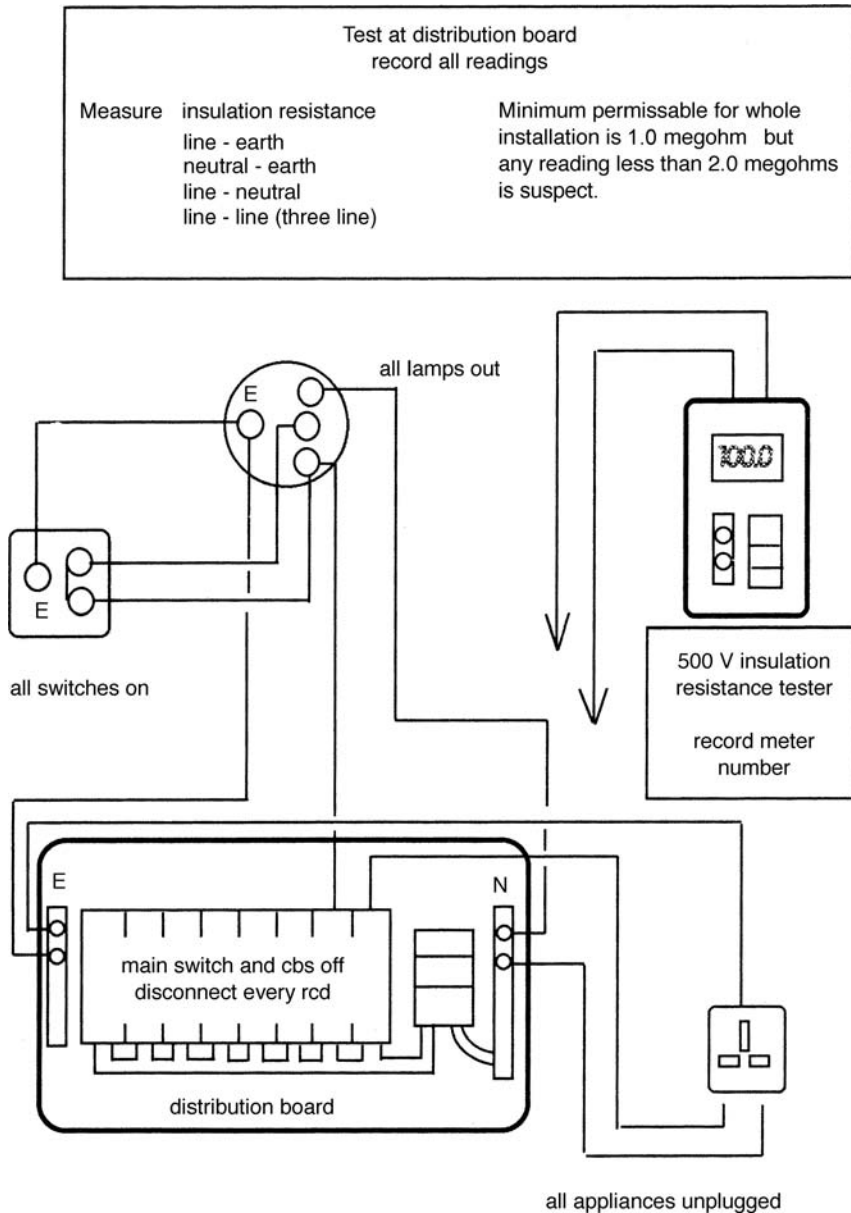


Figure 15.10 Testing for insulation resistance. Disconnect electronic circuitry before testing insulation resistance.

- the adequacy of earthing;
- poor connections;
- incorrect polarity at the supply or anywhere in the installation;
- continuity of ring circuit conductors; and
- correct positioning of switches.

The earth loop impedance test instrument injects a significant voltage onto the system. Care must be taken to ensure the safety of users of the installation or persons in contact with earthy metalwork whilst tests are in progress.

Any circuit found to be faulty should be immediately de-energised. After rectification, a repeat of all testing is necessary on the particular circuit and any related circuits.

15.20 Supply impedance Z_e

The main earth will be taken from the supply company's earthing terminal or an earth electrode.

Disconnect this main earth from all bonding and cpcs for the test. Note that this leaves the installation unearthed, therefore it is essential for safety reasons that all circuit-breakers are switched off for the test. Figure 15.11 shows the test method.

Table 15.1 indicates maximum readings for TN-S and TN-C-S installations. TT earth electrode resistances are covered in Chapter 10.

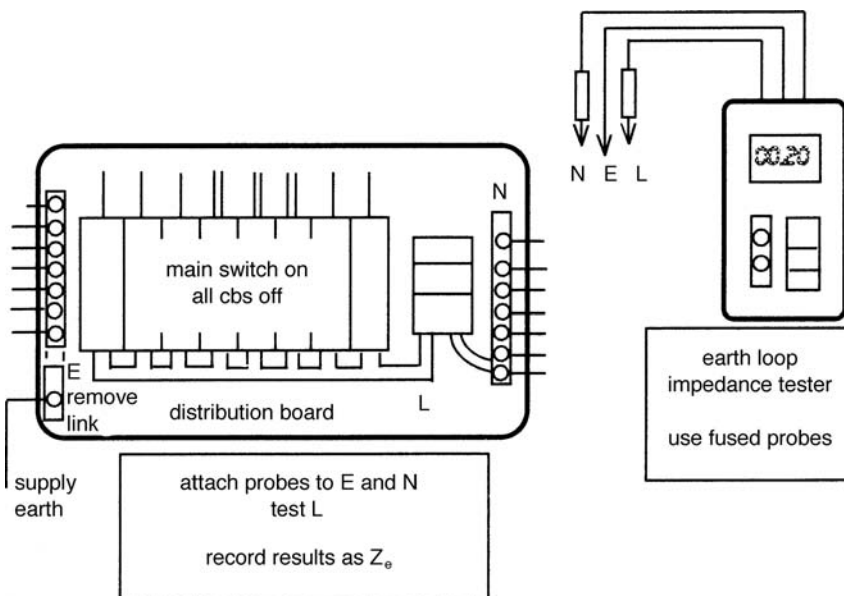


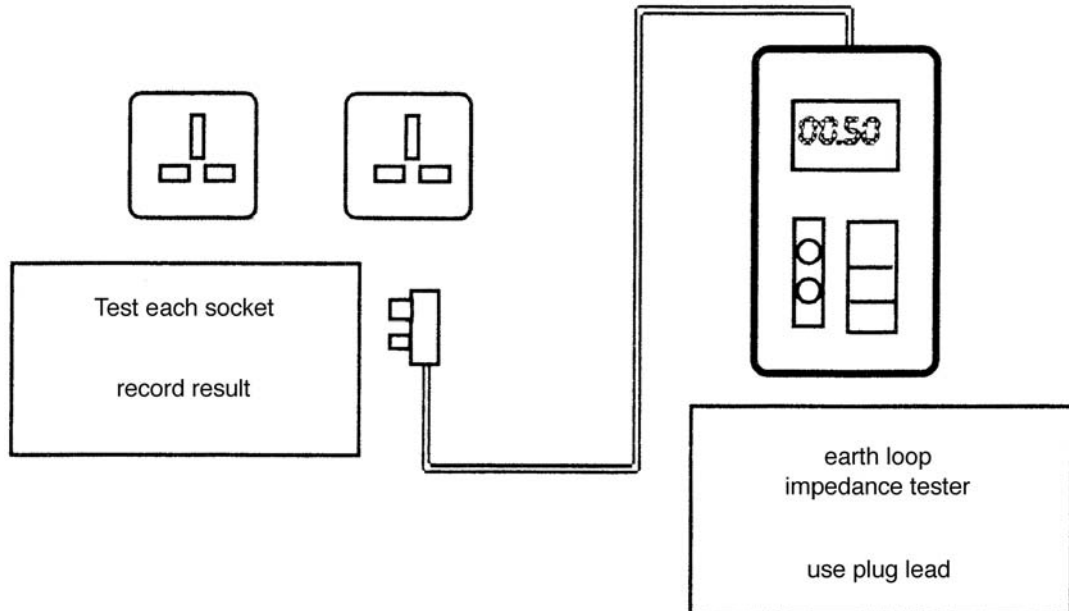
Figure 15.11 Testing the external earth loop impedance.

Table 15.1 Maximum acceptable earth loop impedances adjusted for test conditions.

Maximum measured earth loop impedance (Ω)								
Circuit-breaker	Current rating (A)							
	6	10	16	20	25	32	40	63
Type B	6.13	3.68	2.30	1.84	1.47	1.15	0.92	0.58
Type C	3.06	1.84	1.15	0.92	0.74	0.58	0.46	0.29
Type D	1.54	0.92	0.58	0.46	0.37	0.29	0.23	0.14

15.21 Earth loop impedance of circuits Z_s

Tests should be taken at every lighting position, socket-outlet and equipment connection. Figure 15.12 shows the method of measuring with a loop impedance tester. The maximum reading on each circuit should be recorded. Tables in *BS 7671* are based on maximum permissible cable operating temperatures. Table 15.1 has been adjusted to take account of the fact that tests are made cold.


Figure 15.12 Testing earth loop impedance at all outlets also checks polarity.

Note: Generic earth fault loop impedance values for related disconnection times for moulded-case circuit-breakers (MCCBs) are not published in *BS 7671*.

Where these values are required for verification of disconnection times, they should be obtained from the MCCB manufacturer's published technical data.

Note that erratic results indicate poor connections. A steadily increasing reading around a ring circuit usually indicates an open circuit condition.

15.22 Prospective fault current

612.11 *BS 7671: 2008* requires the prospective fault current to be measured, calculated or determined by another method at the origin and at other relevant points in the installation; relevant points being distribution boards, switchgear, and so on. The reason for this is to verify that the breaking capacity of fuses and circuit-breakers will not be exceeded when a fault occurs.

The prospective fault current may be either short-circuit or earth fault current. The preferred method of measurement is to use a prospective fault current instrument that indicates a direct reading. Alternatively, a measurement of earth loop impedance or line/neutral loop impedance can be used to calculate the approximate value of fault currents. A simple Ohm's Law calculation is all that is necessary.

Where an installation has a three-phase supply, the maximum fault current that can occur is when there is a simultaneous fault between all line conductors at the origin. In the absence of more precise information and/or a measurement, the prospective short-circuit current between line conductors will be approximately twice the single-phase value.

The maximum PSC between any two line conductors is $\sqrt{3}$ times the L-N value.

15.23 Operation of residual current devices

The simplest and safest way to check the operation of an RCD is to use an RCD test instrument connected to the line, neutral and earth on the load side of the RCD, with all loads disconnected. The connection can be made at any convenient point in the circuit such as at a socket-outlet, or using a proprietary split 3-lead connection with probes, at the outgoing terminals of the RCD.

Test procedures and sequences are as shown in Table 15.2. After carrying out these tests, each RCD should be operated by means of its integral test facility. This part of the test confirms that the device is responding to its manufactured level of sensitivity and that all internal mechanical parts are functioning, but it should be understood that this test alone cannot be accepted to verify

Table 15.2 Test procedures for standard residual current devices.

Test	Tester setting	Pass result	Conclusions
'Instantaneous' residual current device			
1	100% of rating	RCDs to BS 4293 should trip in less than 200 ms;	Correct fault operation
		RCDs to BS EN 61008 and RCBOs to BS EN 61009 should trip in less than 300 ms	
2	150 mA or $5I_{\Delta n}$	An RCD rated at 30 mA or less should trip in less than 40 ms	Correct additional protection
3	50% of rating	RCD should not trip	There is no excess standing leakage on the circuit and RCD is not over sensitive
Time-delay (selective) residual current device			
1	50% of rating	RCD should not trip	There is no excess standing leakage on the circuit and RCD is not over sensitive
2	100% of rating	RCD should trip in not less than 130 ms and not more than 500 ms	Correct fault operation and adequate time delay for discrimination

correct operation of the RCD to clear a fault. By means of a notice, at or near the origin of the installation, users of the installation are also advised to carry out this simple test at quarterly intervals – see Regulation 514.12.2.

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A Caravan Park

Caravan parks and camping parks are regarded by *BS 7671* as being locations of increased shock risk. This is because their electrical installations are exposed to arduous conditions, and persons using them are liable to be wet from poor weather conditions, and when outside the caravan they may be in contact directly with the general mass of earth.

Section 708 of *BS 7671* covers the installations of caravan parks providing facilities for the supply for leisure accommodation vehicles or tents at a nominal voltage not exceeding 230 V a.c. single-phase or 400 V a.c. three-phase.

Section 708 does not apply to the electrical installations in:

- mobile or transportable units (refer to Section 717 of *BS 7671*);
- leisure accommodation vehicles (Regulation 708.1 refers); or
- tents.

16.1 Measures for protection against electric shock

As is the case with many other types of special installation or location, *BS 7671* precludes the use of the following, seldom employed methods for protection against electric shock, such as:

Basic Protection

- obstacles;
- placing out of reach.

708.410.3.5

Fault Protection

- non-conducting location;
- earth-free local equipotential bonding.

708.410.3.6

The most common protective measure for providing shock protection is Automatic Disconnection of Supply (ADS).

16.2 Earthing arrangements

The three commonest earthing arrangements are TN-S, TN-C-S and TT. However, there is a limit on the use of the TN-C-S earthing arrangement within caravan/camping parks.

16.3 PME must not be used for caravans

The *Electricity Safety, Quality and Continuity Regulations (ESQCR) 2002* do not permit the use of protective multiple earthing (PME) for the supply to a leisure accommodation vehicle, including a caravan. 708.411.4

The ESQCR does not preclude the use of a PME earthing facility for permanent buildings on a caravan site, such as shops, recreation room or site reception, and it is recommended that PME is *not* employed for shower blocks having an uninsulated floor.

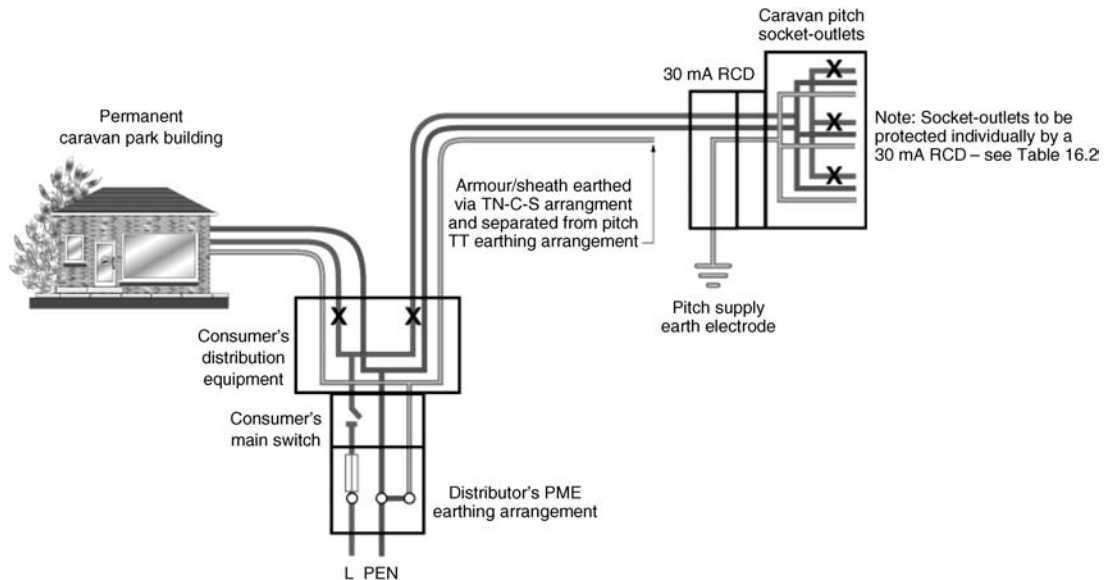


Figure 16.1 Separation of a caravan pitch TT earthing arrangement from a distributor's PME earthing facility.

16.4 Electrical equipment (external influences)

708.512.2 **Table 16.1** Outdoor electrical equipment installed on a caravan park should have the following minimum levels of ingress and mechanical protection.

Environmental Condition	Classification of External Influence	IP or IK Rating
Presence of water	AD4 (splashes)	IPX4 (BS EN 60529)
Presence of foreign solid bodies	AE2 (small objects)	IP3X (BS EN 60529)
Mechanical stress	AG3 (high severity)	IK08 (BS EN 62262)

16.5 Wiring systems

708.521.1 The preferred method of installation for the distribution circuits is to bury them in the ground, rather than to install overhead cabling.

Specific requirements for cables buried in the ground and overhead cables are as follows.

16.6 Cables buried in the ground

708.521.1.1 Cables should be buried at a depth of at least 0.6 m below the surface and should preferably be installed externally to a caravan pitch area and away from any location where the use of tent pegs or ground anchors is likely. Where this is not possible, appropriate means of protection must be provided, such as providing additional mechanical protection or installing the cables at a greater depth from the surface.

16.7 Overhead cables

708.521.1.2 Where overhead cables are installed, they must be insulated. Poles or other means of support must be suitably positioned or protected so that the supports themselves or the cables they support are unlikely to be damaged by the movement of vehicles. The minimum permitted heights above ground level are:

- 6 m where vehicle movement is likely; and
- 3.5 m in all other areas.

Distribution cables for supplying pitches in caravan parks and camping parks generally require the installation of long cable runs – runs of 50 m to 100 m are not unusual. As a consequence, careful consideration needs to be given when sizing of cables in order to comply with voltage drop requirements. For such long runs, the required cross-sectional area (csa) of distribution

cables is likely to be significantly greater than would otherwise be required to supply the actual load only for much shorter runs.

For example, for a load current of 50 A (four of 16 A socket-outlet supply points with approximately 80% diversity), Table 4E4A shows that for a three-core 90 °C thermosetting insulated armoured cable, the minimum conductor csa is 10 mm² (58 A). However, after applying the appropriate rating factors, including that for buried cables, and after accounting for complying with voltage drop requirements, the minimum acceptable conductor csa is likely to be at least 16 mm², if the run exceeds 50 m.

Chapter 19 provides more information on how to calculate the conductor csa for cables, including calculations associated with determining voltage drop.

16.8 Caravan pitch electrical supply equipment

Caravan pitch electricity supply equipment should ideally be located adjacent to the pitch but in any case, it must not be more than 20 m measured from the connection point on the leisure accommodation vehicle or tent on the pitch or pitches it is intended to serve. 708.530.3

16.9 Plugs and socket-outlets

Table 16.2 Summary of requirements for socket-outlets supplying electrical equipment in caravan pitches. 708.553.1

Regulation	Requirement
708.553.1.8	Pitch socket-outlets, including any associated enclosures, must comply with <i>BS EN 60309-2</i> , and have a minimum degree of protection of IP44. Be limited to groups of not more than four socket-outlets in one location
708.553.1.9	Must be installed at a height of between 0.5 and 1.5 m above the ground but, in special cases, may be installed higher than 1.5 m where there is a risk of local flooding or high snowfall
708.553.1.10	The rated current of each socket-outlet to be not less than 16 A, although a higher current rating may be provided where higher demand is necessary
708.553.1.11	At least one socket-outlet to be provided for each pitch
708.553.1.12	Each socket-outlet (and fixed connection point) to be provided with individual overcurrent protection
708.553.1.13	Each socket-outlet to be protected individually by an RCD having the characteristics specified in Regulation 415.1.1 ^a and which disconnects all live conductors, including the neutral
708.553.1.14	Protective conductor of each socket-outlet must not be connected to a PME earthing facility. Where PME conditions apply, the protective conductor of each socket-outlet should be connected to an earth electrode forming part of a TT system

^aRegulation 415.1.1 requires the use of an RCD having a rated residual operating current $I_{\Delta n}$ not exceeding 30 mA and able to disconnect within 40 ms at $5I_{\Delta n}$.

As each socket-outlet is required to be provided with individual overcurrent and RCD protection, a suitably rated double-pole RCBO could be used.

708.553.1.14 The final connection of a caravan pitch socket-outlet to the caravan, motor caravan or tent requires an assembly having the following:

- a plug complying with *BS EN 60309-2*;
- a flexible cable of type H05RN-F to *BS 7919* or equivalent, with a protective conductor having all of the following:
 - a length of 25 m (± 2 m);
 - a minimum csa of 2.5 mm^2 for a current rating of 16 A. For higher current rating, the csa must be such that under fault conditions the overcurrent protective device will operate at the lowest fault current, calculated at the end of the cord extension set;
 - conductors to be identified in accordance with Table 51 of *BS 7671*.
- a connector complying with *BS EN 60309-2*.

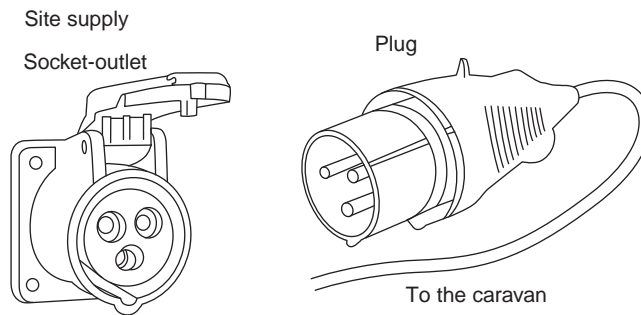


Figure 16.2 Example of a connector complying with *BS EN 60309-2*.

Residual Current Devices

A residual current device (RCD) is a life-saving electro-mechanical device designed to prevent people receiving a fatal electric shock if they touch something live, such as a bare conductor. They are also used to provide protection from fire, thermal effects and earth faults. So, for these reasons, RCDs offer a level of protection that ordinary fuses and circuit-breakers cannot provide.

This chapter provides basic information on how an RCD works, what level of protection such devices offer, and where they should be used. Where further or detailed information is required on any particular aspect of RCD protection, reference should be made to other authoritative guidance, such as the IET's Guidance Notes or the Electrical Safety Council's *Essential Guide*. The latter is available online, via subscription.

The RCD was invented in the 1950s by the Austrian scientist, Gottfried Biegelmeier. His research and experiments – on himself and on the corpses of dead animals – revealed that 95% of the population could survive an electric shock, provided that, amongst other things, the shock current and duration of the current that flowed through the body were below specific values; the very characteristics expected of modern-day 30 mA RCDs. His research went on to form the basis of a series of international standards (*IEC 60479*) relating to the effects of electric current passing through the bodies of humans and livestock (animals).

RCD is the generic name for a range of devices, which include:

- RCCB (residual current operated circuit-breaker without integral overcurrent protection);
- RCBO (residual current operated circuit-breaker with integral overcurrent protection);
- SRCD (socket-outlet incorporating an RCD).

RCDs are available as a stand-alone device and can be single, double or multi-pole devices. They can also be formed by an association of devices, including current transformers, a residual current sensor and a circuit-breaker.

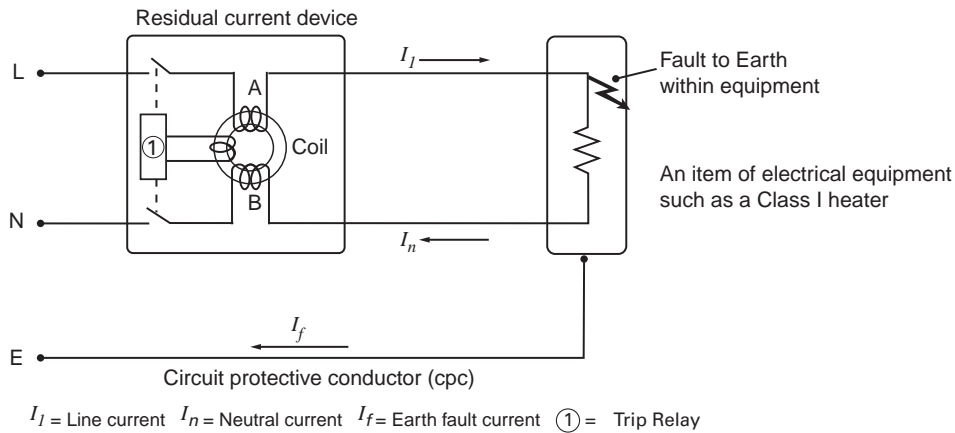


Figure 17.1 Line diagram of a simple circuit incorporating an RCD.

17.1 How does an RCD work?

An RCD monitors the difference in levels of current in the live (line and neutral) conductors (the residual current) at the point in the circuit where the device is installed, and mechanically interrupts the circuit when the levels go above a predetermined value, which is referred to as the rated residual operating current ($I_{\Delta n}$).

As can be seen from the Figure 17.1, coils A, B and the search coil (used for tripping the relay) are wound on a toroid (a common electromagnetic core). Coil A has the line conductor current passing through it and coil B has the neutral conductor current passing through it. When the live (line and neutral) conductor currents are equal, the net magnetic field in the toroid is zero. In effect, the current passing through coil A is cancelled out by the current passing through coil B, so the net magnetic field in the toroid is zero. Where any imbalance in the live (line and neutral) conductor currents exists, a magnetic field is created. This magnetic field is detected by the search coil, and the main contacts of the RCD open (or 'trip') when the strength of the magnetic field attains a value equivalent to the rated residual operating current of the RCD. From experience, though, that value is often known to be somewhere between 18 and 25 mA for a 30 mA device, although higher and lower values are possible.

A three-phase circuit arrangement would employ the same principle.

531.2.2 The toroid is required to enclose all live (line and neutral) conductors.

17.2 Fault protection

(411.5.1) An RCD is not a panacea for all aspects of electrical safety. It cannot, for example, protect against an overload or short-circuit current. However, it can help to protect against earth faults,

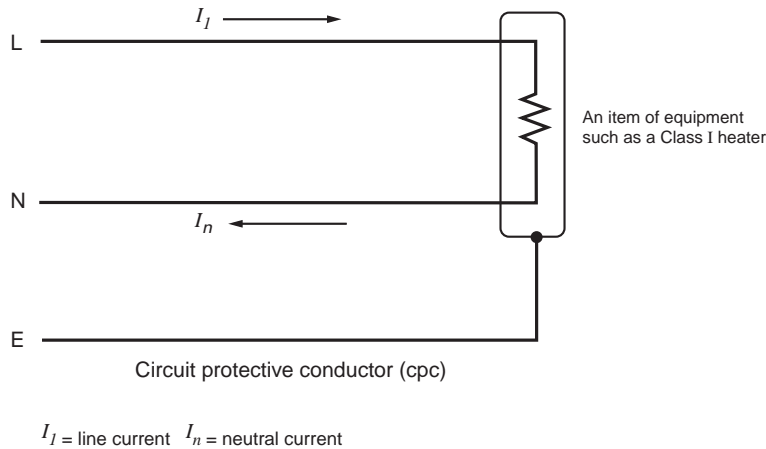


Figure 17.2 Line diagram of a healthy single phase circuit.

and this is why *BS 7671* prefers such devices to be used in a TT system. This is because the earth fault loop impedance at the furthest point in every circuit is likely to exceed the maximum value permitted for any overcurrent protective device, such as fuse or circuit-breaker. However, overcurrent protective devices must still be installed, as they are relied upon for overload and short-circuit protection.

In a healthy single-phase circuit, where there is no earth fault current or earth leakage current (Figure 17.2), the level of current in both the line and neutral conductors, I_l and I_n , respectively, are equal, because $I_l = I_n$.

So, should a line to earth fault occur (Figure 17.3), a portion of the current in the line conductor I_l will flow to earth, and not return via the neutral conductor. The current flowing to earth is indicated as I_f . Therefore, the current in the neutral conductor (I_n) will be equal to the current in the line conductor (I_l) minus the current (I_f) in the circuit protective conductor flowing to earth.

The difference in the currents I_l and I_n is referred to as a residual current, which is equal to the fault current (I_f). Thus, if an RCD were to be inserted in the circuit where the ellipse (XY) is shown in Figure 17.3, when the fault current I_f approaches a predetermined value, the RCD tripping mechanism would operate, and the load would be disconnected from the supply.

As an RCD has the ability to detect an imbalance in current to as low as a few thousandths of an amp, such a device is ideally suited to provide fault protection, particularly in a TT system. Relying on a circuit-breaker to provide fault protection is possible, but the earth fault loop impedance at the furthest point of any circuit in a TT system is often in the order of tens of ohms

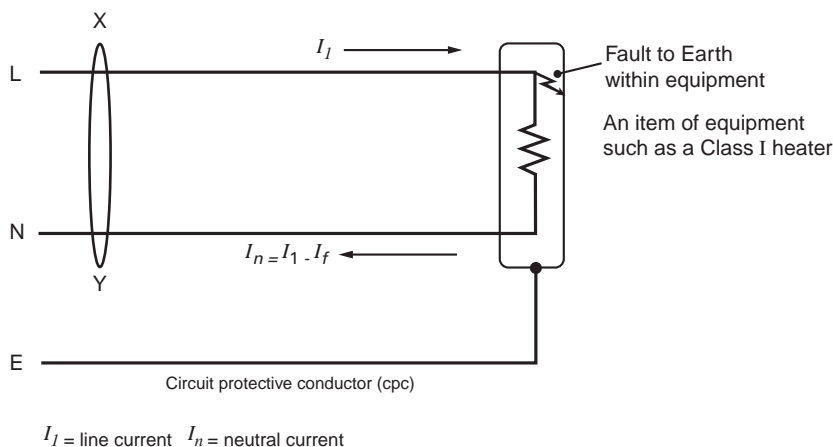


Figure 17.3 Simple circuit diagram showing an earth fault.

(or higher). So, the level of fault current generated, when an earth fault occurs, is generally below that required to trip the device. This is demonstrated in the following worked example:

TT System:

- earth fault loop impedance resistance of 57.5Ω , which includes the resistance of the installation earth electrode;
- lighting circuit, protected by a 6 A Type B circuit-breaker

Current generated under fault conditions would be:

$$I = \frac{V}{R} \quad (17.1)$$

$$I = \frac{230}{57.5} \quad (17.2)$$

$$I = 4 \text{ A} \quad (17.3)$$

Conclusion: Protection against fault current would not be achieved, because the 4 A of fault current is less than the level of current required to trip a 6 A Type B circuit-breaker.

Note: Type B circuit-breakers have an overcurrent tripping characteristic of between 3 and 5 five times I_n . Therefore, a current of between 18 A and 30 A must flow in order for the device to trip. To be absolutely sure that the device will trip under fault conditions, designers almost always work on the higher value, unless better information is available from, say, the device manufacturer.

Solution: Depending on connected load and the maximum value of earth electrode resistance likely to exist at any time of the year, an RCD that has a residual operating current of less than 300 mA (0.3 A) or 100 mA (0.1 A) should be selected to provide protection against fault current. Note that where ‘additional protection’ is required in, for example, dwellings, all final circuits are likely to require 30 mA RCD protection. One way to provide such protection would be to use a 30 mA RCBO on each circuit, as this will help minimise inconvenience when one device trips when a fault occurs.

17.3 Additional protection

When the 17th edition of the Wiring Regulations (*BS 7671: 2008*) came into effect, a new term, ‘additional protection’, was introduced. The term refers to a level of protection that is generally required where there is a possibility of increased risk of electric shock.

Two types of additional protection are outlined in Section 415 of *BS 7671*:

1. Residual current devices (RCDs);
2. Supplementary equipotential bonding, but this subject is outside the scope of this chapter.

The main areas in *BS 7671* that specify additional protection relate to special locations or installations, certain conditions of external influence, socket-outlets, and particular types of cables concealed in walls and so on, although these are not the only areas specified.

The introduction of ‘additional protection’ has resulted in most, if not all, final circuits in a new or rewired domestic property to be protected by the means of an RCD.

17.4 Requirements to provide additional protection by RCDs

The following situations listed in (Table 17.1) now require ‘additional protection’ by means of an RCD having a residual operating current of 30 mA or less: 415.1.1

Table 17.1 Main applications in domestic installations, where additional protection by means of an RCD is required*.

	Application	Regulation
Socket-outlets	Socket-outlets with a rated current not exceeding 20 A that are for use by ordinary persons and are intended for general use.	411.3.3 (j)
	Permitted exceptions:	
	<ul style="list-style-type: none"> • socket-outlets that are for use under the supervision of a skilled or instructed person. (NOTE: this is highly unlikely in a domestic electrical installation), and 	
	<ul style="list-style-type: none"> • a specific labelled or otherwise suitably identified socket-outlet provided for the connection of a particular item of equipment (i.e. a fridge freezer). 	

Mobile equipment	Mobile equipment that has a current rating of 32 A or less for use outdoors	411.3.3 (ii)
Cables concealed in a wall or partition	A cable concealed in a wall or partition at a depth of less than 50 mm from the surface of a wall or partition, unless the cable: <ul style="list-style-type: none"> incorporates and earthed metallic covering that complies with <i>BS 5467</i>, <i>BS 6724</i>, <i>BS 7846</i>, <i>BS EN 60702-1</i> or <i>BS 8436</i> is enclosed in earthed metallic conduit complying with <i>BS EN 61386-21</i>, or is enclosed in earthed metallic trunking or ducting complying with <i>BS EN 50085-2-1</i>, or is mechanically protected against damage sufficient to prevent penetration of the cable by nail, screws and the like, or forms part of a SELV or PELV circuit, or <ul style="list-style-type: none"> the installation is intended to be under the supervision of a skilled or instructed person (refer to Regulation 522.6.102). 	522.6.101
Cables concealed in a wall or partition of metallic construction	A cable concealed beneath the surface of a wall or partition that has metallic parts for its construction (other than metallic fixings such as nails, screws and the like). This requirement applies where the installation is not intended to be under the supervision of a skilled or instructed person, irrespective of how deep the cable is beneath the surface of the wall or partition, unless the cable: <ul style="list-style-type: none"> incorporates and earthed metallic covering that complies with <i>BS 5467</i>, <i>BS 6724</i>, <i>BS 7846</i>, <i>BS EN 60702-1</i> or <i>BS 8436</i> is enclosed in earthed metallic conduit complying with <i>BS EN 61386-21</i>, or is enclosed in earthed metallic trunking or ducting complying with <i>BS EN 50085-2-1</i>, or is mechanically protected sufficiently to avoid damage to the cable during construction of the wall or partition and during installation of the cable, or forms part of a SELV or PELV circuit. 	522.6.103
Locations containing a bath or shower	All low voltage circuits of a location that contain a bath or a shower.	701.411.3.3

(415.1.1) *NOTE: An RCD that is used to provide additional protection must have a rated residual operating current ($I_{\Delta n}$) of 30 mA or less, and an operating time not exceeding 40 ms at a residual current of $5 I_{\Delta n}$.

17.5 RCDs incorporated into a consumer unit, to meet the requirements for additional protection

In practice, RCD protection in a consumer unit is provided in one of two arrangements, to provide additional protection to most, if not all, outgoing circuits:

1. protecting each outgoing circuit by its own individual 30 mA RCD, such as by using RCBOs to *BS EN 61009-1* (instead of circuit-breakers complying with *BS EN 60898*); or

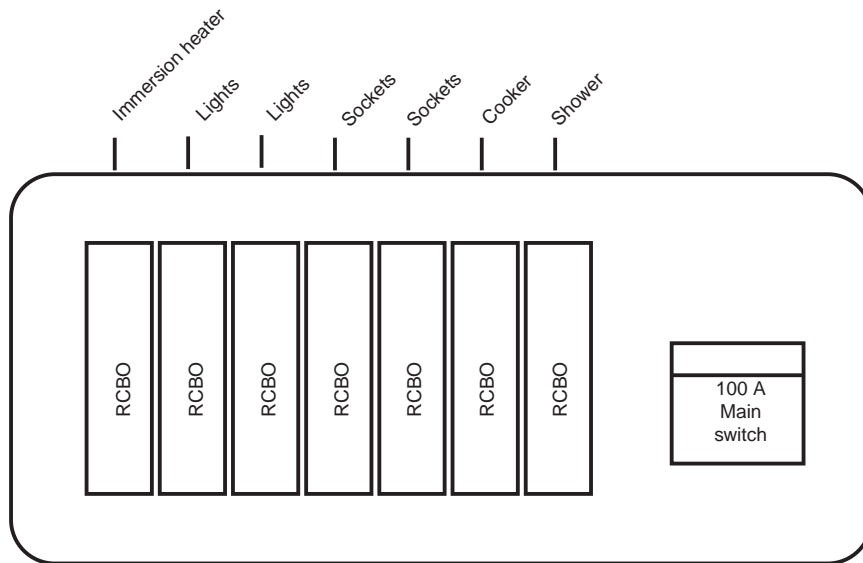


Figure 17.4 Typical arrangement of (1) – where each outgoing circuit is protected by its own individual 30 mA RCBO.

- using a split-load consumer unit that divides the outgoing circuits between two, or more, 30 mA RCDs (i.e. RCCBs to *BS EN 61008-1*), where each circuit is then protected against overcurrent by its own circuit-breaker complying with *BS EN 60898*.

Figures 17.4 and 17.5 show typical arrangements of (1) and (2), respectively.

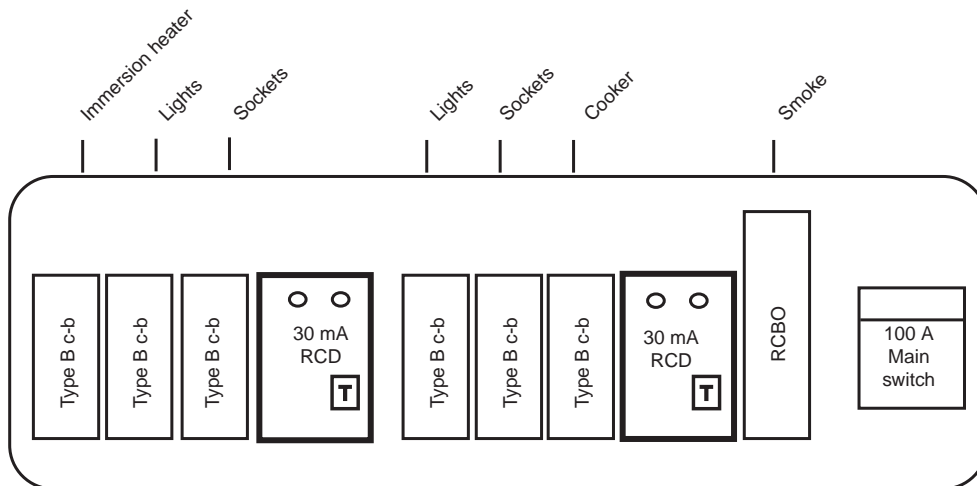


Figure 17.5 Typical arrangement of (2) – where a split-load consumer unit divides the outgoing circuits between two or more 30 mA RCDs (RCCBs, in this example).

Whichever arrangement is adopted, consideration should be given to the areas of the building covered by each lighting circuit. This is because the loss of supply to one lighting circuit should not cause a total loss of artificial light to any other area within the building that would otherwise cause a hazard or inconvenience. Areas of particular concern include a windowless bathroom, the top of a staircase and/or the landing.

In arrangement (2), it is recommended that lighting circuits are appropriately distributed between two, or possibly three, RCDs. In other words, in the case of a small dwelling, the downstairs lighting circuit should be protected by one RCD and the upstairs lighting circuit by the other RCD. The same approach should be adopted for mixing up the socket-outlet circuits.

17.6 Protection against fire

As mentioned in the introduction to this chapter, RCDs can help to protect against the risk of fire and other thermal effects.

705.422.7 An RCD having a rated residual current not exceeding 300 mA should be used in agricultural and horticultural installations. However, where improved continuity of service is necessary, all RCDs that protect circuits, other than those incorporating socket-outlets, should be of the S type, or have a time-delay. More on this subject can be found towards the end of this chapter, and in Chapter 10 of this book.

422.3.9 In other locations that have a risk of fire, due to the nature of processed or stored materials for example, any wiring system employed in those locations, except for mineral insulated cables, busbar trunking systems or powertrack system, must be protected against insulation faults:

- in a TN or TT system, by the means of an RCD having a rated residual operating current not exceeding 300 mA. Where a resistive fault may cause a fire, such as from heating film elements used in overhead heating, the rated residual operating current of the RCD must not exceed 30 mA.
- In an IT system, by an insulation monitoring device with an audible and visible signal. In the event of a second fault, the disconnection time of the overcurrent protective device is given in Chapter 41 of *BS 7671*. An RCD may be used, but it must have a rating not exceeding 300 mA, but in the event of a second fault, the circuit must be disconnected from the supply within the times specified in Chapter 41 of *BS 7671*.

532 Where, in order to comply with the requirements of Regulation 422.3.9, it is necessary to limit the consequence(s) of a fault current in a wiring system, with regards to the risk of fire, the circuit must be protected by an RCD:

- at the origin of the circuit to be protected;
- that can switch all live conductors; and
- that has a rated residual operating current not exceeding 300 mA.

Table 17.2 Requirements relating to minimising inconvenience and avoiding hazards, due to unwanted tripping of an RCD.

Aspect	Requirement	Regulation
Installation to be divided into circuits	Every installation must be divided into circuits, as necessary to:	314.1
	<ul style="list-style-type: none"> • avoid hazards and minimise inconvenience in the event of a fault 	
	<ul style="list-style-type: none"> • take account of hazards that may arise from the failure of a single circuit such as a lighting circuit 	
	<ul style="list-style-type: none"> • reduce the possibility of unwanted tripping of RCDs due to excessive protective conductor currents from equipment in normal operation (i.e. not due to a fault) 	
Separate circuits that need to be separately control	Separate circuits must be provided to parts of the installation that need to be separately controlled.	314.2
	This should be done in such a way that the circuits will not be affected by the failure of other circuits, with due account being taken of the consequences of the operation of a single protective device.	

17.7 Avoiding a hazard and/or minimising an inconvenience due to the tripping of an RCD

Electrical installation designers must consider and take steps, where appropriate, to reduce the possibility of unwanted tripping of an RCD. For ease of reference, these requirements are covered in Table 17.2.

In order to meet the two requirements in Table 17.2, it is good practice to use two, or more, RCDs to protect a large number of circuits, as the tripping of one RCD may cause inconvenience or a hazard due to the loss of supply to: (314)

- one or more lighting circuits within an installation, which would leave one or more areas in darkness;
- one or more socket-outlets supplying refrigeration equipment; or
- smoke alarms or fire alarm sounders, leaving the installation unprotected in the event of a fire.

17.8 Reducing the possibility of unwanted tripping of RCDs

It is unlikely these days that the protective conductor current produced by normal loads in domestic premises will be of sufficient magnitude to trip an RCD. However, it can be a real problem in other types of electrical installation. For this reason, the Wiring Regulations require designers and installers to consider the possibility of unwanted tripping of RCDs, and take steps, where appropriate, to avoid such tripping.

Typical causes of high protective conductor currents can originate from either:

- some types of high frequency fluorescent luminaires;
- some types of heating element (used in electric ovens and hobs); or
- radio frequency interference suppression filters (used in power supply of computer equipment).

531.2.4 *BS 7671* requires RCDs to be selected and circuits to be subdivided so that any protective conductor current expected to occur during normal operation of the connected load(s) will be unlikely to cause unnecessary tripping of the RCD. In other words, the number of circuits served by each RCD, and the number of protective conductor current-generating loads per circuit, should be kept to a minimum.

17.9 Use of a 'front-end' 30 mA RCD is generally considered unacceptable practice

Connection of a consumer unit to a 'front-end' RCD (i.e. a 30 mA RCCB main switch) to provide fault protection and/or additional protection will generally not meet the requirements of *BS 7671*.

This is because a fault from any circuit, or any connected item of current-using equipment, within the installation would trip the front-end RCD, and cause the loss of supply to the entire installation.

For similar reasons, a consumer unit controlled by a front-end RCD would not meet the recommendations given in *BS 5839-6* for where a Grade B or Grade E fire alarm and detection system is to be supplied.

17.10 Installations forming part of a TT system

The requirements for additional protection by RCDs covered in this chapter apply to TN-S, TN-C-S or TT electrical systems.

411.5 For an installation that forms part of a TT system, it should be appreciated that at least one RCD will almost always be required for fault protection.

Before the introduction of the 17th edition of the Wiring Regulations, fault protection (formerly referred to as protection against indirect contact) was often achieved by using a 300/100 mA time-delayed or 'S' type RCCB as the main switch in the consumer unit. However, for a domestic installation complying with the 17th edition, where all the final circuits are RCD-protected ($I_{\Delta n} \leq 30$ mA), an RCD main switch is no longer required, provided that the consumer unit is of all-insulated (non-metallic) construction. The omission of such a device is perfectly acceptable, because the RCDs (protecting all of the circuits) that provide additional protection can also be relied upon to provide fault protection.

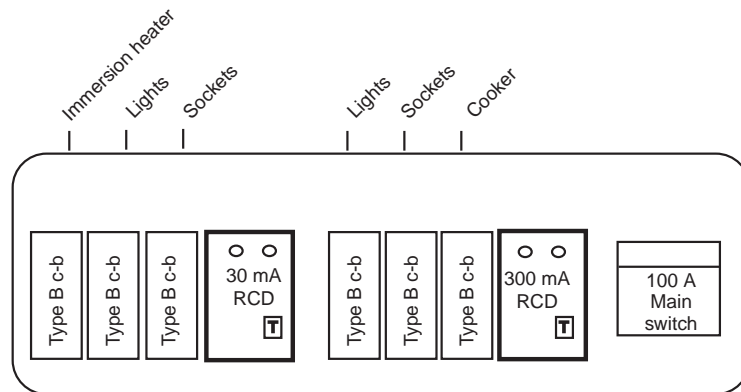


Figure 17.6 Two RCDs in series.

17.11 RCDs connected in series

There is sometimes a need for an electrical installation to have two, or more, RCDs connected in series, and to have discrimination in their operation to prevent danger and/or minimise inconvenience. Simply installing an RCD with a lower tripping current downstream of the first device is not the answer. This is because, in the event of an earth fault downstream of both devices, the fault current produced at that point will likely be of such magnitude that both RCDs, or all them if there are more in series, will ‘detect’ the imbalance – and trip! 531.2.9

The way to overcome this is to use an RCD that has an in-built time-delay, or be ‘selective’ (S), as they are called these days.

Figure 17.6 illustrates a typical configuration showing a split-load distribution board with two RCDs connected in series. Industrial installations and some commercial installations are good examples of where discrimination between two or more RCDs would be required, especially where (say) a 300 mA RCD is used to protect distribution circuit and socket-outlets are protected by a 30 mA RCD.

17.12 Labelling

Wherever an electrical installation incorporates an RCD, *BS 7671* requires a notice to be fixed in a prominent position at or near to the origin of the installation. The notice must have legible characters not smaller than those shown in Figure 17.7. 514.12.2

This installation, or part of it, is protected by a device which automatically switches off the if an earth fault develops. Test quarterly by pressing the button marked ‘T’ or ‘Test’. The device should switch off the supply and should then be switched on to restore the supply. If the device does not switch off the supply when the button is pressed, seek expert advice.

Figure 17.7 An RCD notice.

Flood Lighting (Outdoor Lighting) Project

This project is intended to be either stand alone or combined with one of the other projects included in this book. It could, for example, easily be used to provide illumination along a driveway, or be adapted for a car park or small caravan/camping park.

The requirements for luminaires (fixed lights) and lighting installations intended to be part of fixed installations and to highway power supplies and street furniture (i.e. bollards, street lamps, etc.) are given in Section 559 of BS 7671.

Section 559 also covers:

- fixed outdoor lighting installations;
- extra-low voltage lighting installations supplied from a source with a maximum rated voltage of 50 V a.c. or 120 V d.c.;
- lighting for display stands

For this lighting project, four 400 watt sodium flood lights will be mounted on top of 6 m high columns, to give a good spread of high intensity lighting.

18.1 Lighting arrangement

The layout of the flood lights is shown in Figure 18.1, which also gives the details of the project, but it should be appreciated that the arrangement of the columns may not necessarily always be in a straight line.

18.2 General requirements

App 4 Any luminaire selected must comply with the relevant product standard and should be selected and installed in accordance with the manufacturer's instructions. As the luminaires will be

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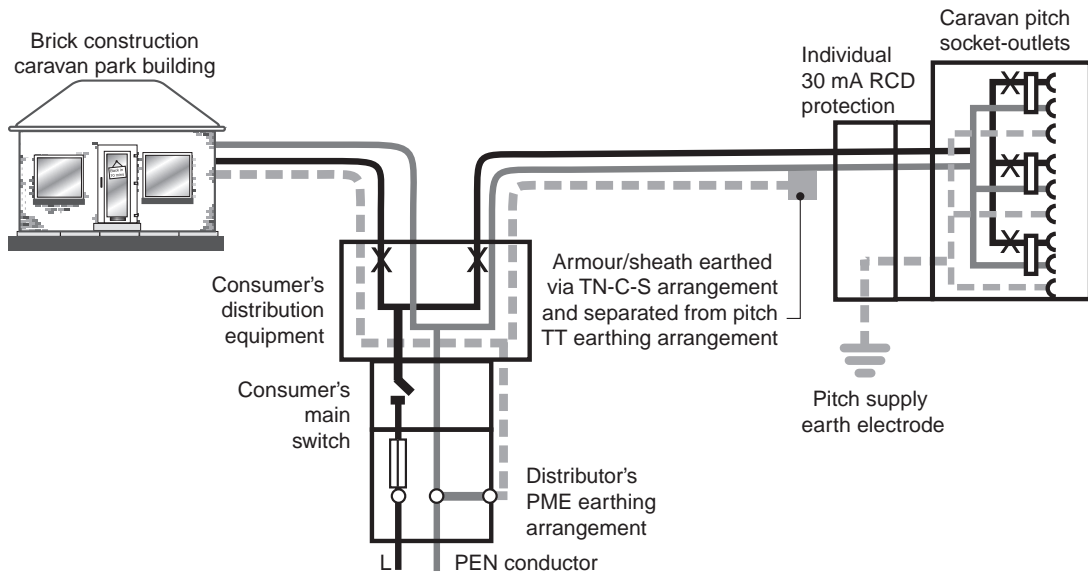


Figure 18.1 Schematic of flood lighting.

mounted 6 m above ground level, it should be assumed that they will be exposed to all sorts of weather, so they will need to have a degree of protection of at least IP65. The minimum degree of protection permitted for such equipment is IP 33.

Quartz halogen is probably the most popular choice of lamp for outdoor flood lighting, as the luminaires/lamps are relatively cheap to purchase and provide a good level of light. However, quartz halogen lamps are unfortunately expensive to run compared with other types of lamps. For that reason, 400 W high pressure sodium lamps (SONs) will be used on this project as they deliver a soft orange light similar to that of a street light, and have a good lumen per watt ratio, which makes them a more cost effective option when it comes to running costs. The SON lamps also have a longer lamp life (>20 000 hours), so this will also help minimise maintenance costs.

18.3 Wiring system

The wiring system for this project could easily be run overhead or installed underground. Whilst it might be quicker to run the cables above ground, consideration would have to be given to meeting minimum height requirements in places such as caravan parks and agricultural and horticultural premises, especially where vehicle movement is expected. There would also be the problem of supporting the cables from one column to another, as the distance between each column is excessive. For this reason, the preferred installation is 90 °C thermosetting insulated steel wired armoured (SWA) cable, buried in the ground in 100 mm ducting.

705.522
708.521.1.2

18.4 Protective measures

The protective measures of placing out of reach and obstacles are not permitted for this type of installation, and neither are the protective measures non-conducting location and earth-free equipotential bonding.

Therefore, like other projects in this book, the protective measure of choice is automatic disconnection of supply (ADS). Where ADS is used:

- all live parts must be protected by insulation or by barriers or enclosures that provide basic protection. The door of the lighting column, used for access to the electrical equipment, should not be used as a barrier or an enclosure.
- for every accessible enclosure, the live parts must be accessible only by means of a tool or a key, unless the enclosure is in a location where only skilled or instructed persons have access.
- a door giving access to electrical equipment, which is located less than 2.5 m above ground level, must be locked with a key, or require a tool for access. In addition, basic protection must be provided when the door is open by either the use of electrical equipment having a degree of protection of at least IPXXB or IP2X (by construction or by installation) or by installing a barrier or enclosure providing the same degree of protection.
- access to the light source of a luminaire that is located at a height of less than 2.8 m above ground must be possible, only after removing a barrier or an enclosure by the means of a tool.
- for an outdoor lighting installation, a metallic structure (i.e. a fence or railing), which is in close proximity of but is not part of the outdoor lighting installation, need not be connected to the main earthing terminal of the electrical installation.

559.10.3.3 The maximum disconnection time permitted for all circuits supplying fixed equipment in places such as parks, car parks, gardens, and those open to the public and so on, is 5 seconds.

18.5 Load assessment

This is referred to as the design current, (I_b), and is worked out as follows:

$$\text{Total Power} = 4 \times 400 \text{ W} = 1600 \text{ W} \quad (18.1)$$

To allow for control gear losses, a factor of 1.8 must be applied, unless the manufacturer of the luminaires state otherwise:

$$1600 \times 1.8 = 2880 \text{ W} \quad (18.2)$$

Now that the power has been determined, it is possible to calculate the current (I_b), by using the following formula:

$$\begin{aligned} (I_b) \text{ Amps} &= P (\text{Power})/V (\text{Volts}) \\ I_b &= 2880/230 \\ I_b &= 12.52 \text{ A} \end{aligned} \quad (18.3)$$

18.6 Rating of the overcurrent protective device

The rated current (or current setting) of the protective device, I_n , must be not less than the design current (I_b). 433.1

Therefore:

$$\begin{aligned} I_n &\geq I_b \\ I_n &\geq 12.52 \text{ A} \end{aligned} \quad (18.4)$$

From Table 41.3 of *BS 7671*, a 16 A Type C circuit-breaker will be selected for this project.

The reason why a Type C circuit-breaker is preferable to a Type B is because the characteristics of a Type C circuit-breaker are better-suited to the intended load, as the control gear within the luminaires is likely to produce high start-up currents. Chapter 4 provides further guidance on overcurrent protective devices.

18.7 Circuit design

After establishing the load current for the circuit, the next stage of the design process is to select a cable that has the current-carrying capacity equal to or greater than the load current, taking into account the rating of the overcurrent protective device, any applicable derating factors, earth fault loop impedance and voltage drop.

The information needed to work this out is provided in Chapter 19, Circuit Design Calculations, of this book, so the exact workings out have been omitted here. However, for illustrative purposes, the headline values have been used to show that voltage drop is often an overriding factor when it comes to determining cable cross-sectional area (csa) with circuits having very long runs.

In order to show how cables have to be sized to overcome voltage drop, an extract of Table 4E4A of *BS 7671* is reproduced in Table 18.1, below:

It can be seen that a 1.5 mm² multi-core armoured 90 °C thermosetting insulated cable has a current-carrying capacity of 25 A (column 6 of Table 4E4A of *BS 7671*), so this appears to be

Table 18.1 Extract of data from Table 4E4A of *BS 7671*.

Multi-core armoured 90 °C thermosetting cables (with copper conductors)		
Conductor cross-sectional area (mm ²)	Current-carrying capacity (A)	Voltage drop (mV/A/m)
1.5	25	31
2.5	33	19
4.0	43	12
6.0	53	7.9

more than sufficient to do the job, as $I_b = 12.52$ A. However, for the reason already given, this cable will prove to be unsuitable for this project.

18.8 Voltage drop consideration

When circuit conductors carry load current, a voltage drop is produced in the conductors due to their resistance (impedance), which means the voltage at the load is less than that at the supply end.

So, to ensure the safe and satisfactory operation of current-using equipment, it is necessary to limit the voltage drop in a circuit. Sometimes, in order to do this, it is often necessary to use circuit conductors larger than would otherwise be required, depending on the load and the circuit length.

525.101 The general requirement relating to this issue is that the voltage drop between the origin of the installation (usually, the supply terminals and the terminals of fixed current-using equipment, will be deemed to be satisfactory if it does not exceed that stated in Section 6.4 of Appendix 4 of BS 7671.

For low voltage installations supplied direct from a public low voltage distribution system, the *maximum* permitted value of voltage drop for a lighting circuit is 3% of the nominal supply, as follows:

$$3/100 \times 230 = 6.9 \text{ volts (maximum permitted)} \quad (18.5)$$

So, for a 1.5 mm^2 , having an mV/A/m value of 31, a load of 12.52 A, over a 100 m run equates to:

$$\text{Voltage drop} = \frac{\text{mV/A/m} \times I_b \times \text{length}}{1000} \quad (18.6)$$

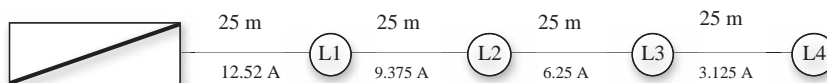
$$\text{Voltage drop} = \frac{31 \times 12.52 \times 100}{1000} \quad (18.7)$$

$$\text{Voltage drop} = 38.75 \text{ Volts} \quad (18.8)$$

Clearly, it can be seen that 38.75 V exceeds the maximum permitted value of voltage drop of 6.9 V, by more than six times so, as predicted, a 1.5 mm^2 is not suitable.

It would therefore seem natural to repeat the above process again, by selecting a cable (possibly, but not necessarily, the next size up) to achieve an acceptable outcome. However, this project needs to be looked at in another way, as the total load is assumed to be at the end of the cable (i.e. 100 m away, and the current is the same along the entire length of the circuit), which, in fact, it is not.

The circuit layout, including the loading at each point, is shown below:



Consideration could now be given to selecting a cable having a larger csa for the entire length of run or selecting a cable having a different csa for each part of the run. However, the latter would result in each part of the circuit having a different csa, which might present the installer with some difficulty when it comes to terminating the conductors at the first three columns along the circuit. The last lighting column will, of course, have only one cable to terminate.

Consequently, for ease of calculating, terminating the conductors at each column, and taking into account the voltage drop along the circuit, the circuit favours using a 6 mm² cable, which has a voltage drop of 7.9 mV/A/m:

$$\text{So, using : Voltage drop} = \frac{mV/A/m \times I_b \times length}{1000} \quad (18.9)$$

The voltage drop for each part of the circuit can be determined.

Origin to base of L1:

$$\text{Voltage drop} = \frac{7.9 \times 12.52 \times 25}{1000} = 2.47 \text{ V} \quad (18.10)$$

L1 to base of L2:

$$\text{Voltage drop} = \frac{7.9 \times 9.375 \times 25}{1000} = 1.85 \text{ V} \quad (18.11)$$

L2 to base of L3:

$$\text{Voltage drop} = \frac{7.9 \times 6.25 \times 25}{1000} = 1.23 \text{ V} \quad (18.12)$$

L3 to base of L4:

$$\text{Voltage drop} = \frac{7.9 \times 3.125 \times 25}{1000} = 0.62 \text{ V} \quad (18.13)$$

Total voltage drop from origin to base is L4 = 6.17 volts, which is lower than the maximum permitted value of 6.9 volts.

The last stage of the design process is to calculate the voltage drop produced by the 6 m length of cable within each column. There is not much room for manoeuvre, as 6.17 volts has already been lost to the base of column 4. So, provided the voltage drop on the twin and earth cable is less than 0.73 volts, everything will be satisfactory:

$$\text{Load current per luminaire} = \frac{400 \times 1.8}{230} = 3.125 \text{ Amps} \quad (18.14)$$

So, from Table 4D5 (a table dedicated to flat twin and earth cable) of *BS 7671*, a suitable cable size must be selected, so that the voltage drop does not exceed 0.73 volts. A 2.5 mm² cable should be suitable, as it has an mV/A/m value of 29:

$$\text{Voltage drop} = \frac{29 \times 3.125 \times 6}{1000} = 0.54 \text{ volts} \quad (18.15)$$

Therefore, a 2.5 mm² cable is suitable for supplying the lamp in each column.

18.9 Switchgear

Standard requirements for isolation and switching apply, information on which are given in Chapter 11.

As this project involves just one circuit, it can be fed from a spare way in a distribution board. At the base of each column, a cut-out should be provided that has the facility to 'loop' in and out with SWA cable. For further information, refer to *BS 7654: 2010 Specification for single-phase street lighting cut-out assemblies for low-voltage public electricity distribution systems. 25 A rating for highway power supplies and street furniture.*

Circuit Design Calculations

Nowadays, it is becoming increasingly popular to perform cable calculations using one of the widely available computer software packages, rather than to do it manually. Whilst using a software package almost certainly speeds up the design process, it is essential that a designer still has sufficient knowledge in order to spot when a result given by the software is not as expected, due to, for example, a data input error or a misplaced decimal point. Such investigations could result in checking all calculations manually to restore confidence in the software.

The aim of this chapter is to provide basic information for use when determining the cross-sectional area of a cable in an electrical installation design. For those who require more detailed information, guidance should be sought in other more specialised publications.

19.1 Design process

Every circuit has to be designed to meet the relevant requirements of *BS 7671*, relating to electric shock protection, overcurrent protection and voltage drop.

The steps that need to be taken as part of the cable design process are:

- Step 1:* Determine the characteristics of supply and the load;
- Step 2:* Select the cable and protective device;
- Step 3:* Check that the voltage drop is acceptable;
- Step 4:* Check that electrical shock protection is acceptable;
- Step 5:* Check that the conductors are protected against prospective fault current.

19.1.1 Step 1: Determine the characteristics of supply and the load

- 301.1 An installation design must start by determining the supply characteristics, including the particular earthing arrangements. The installation designs in this book have all been TN-C-S systems and have used the generally adopted value for Z_e of 0.35Ω . This is usually a good reference point for circuit design.

Note: the generally adopted value of Z_e for TN-S systems is 0.8Ω and 21Ω for TT systems.

- 311.1 The next thing to determine is the design current (I_b) of the circuit, taking into account any diversity, where permitted, and whether the circuit is likely to be subjected to overload current. Further information relating to diversity is given in IET Guidance Note 1 *Selection and Erection*.

19.1.2 Step 2: Select the cable and protective device

Once the design current (I_b) has been established, the circuit protective device can be selected. The nominal rating of the protective device (I_n) must be at least equal to the design current of the circuit, such that $I_n \geq I_b$. For example, a design current of 28 A would generally lead to selecting a protective device (fuse or circuit-breaker) having a nominal rating of 32 A.

The next step is to select a cable that is sufficient to carry the load(s) – this is done by first determining the tabulated current (I_t), which can then be used to select a cable from the sizes given in Appendix 4 of BS 7671.

- Appendix 4 The minimum acceptable tabulated current-carrying capacity (I_t) for the circuit cable is calculated by using the equation given below, which is based on the equations in clause 5 of Appendix 4 of BS 7671:

$$I_t \geq \frac{I_n}{C_g \times C_a \times C_i \times C_f} \text{ Amperes} \quad (19.1)$$

where:

I_t is the value of tabulated current given in the cable tables in Appendix 4 of BS 7671;
 I_n is the rated current or current setting of the protective device. If the circuit is not likely to carry overload current, I_n should be replaced with I_b ;

C_a is the rating factor for ambient temperature – refer to Table 4B1 of BS 7671;

C_g is the rating factor for grouping – refer to Table 4C1 of BS 7671;

C_i is the rating factor for conductors surrounded by thermal insulation – refer to Table 52.2 of BS 7671;

C_f is a rating factor applied for a semi-enclosed fuse to BS 3036, where $C_f = 0.725$.

Note: information relating to the above rating factors, and to others not listed above, is given in clause 5 of Appendix 4 of BS 7671.

19.1.3 Step 3: Check that the voltage drop is acceptable

Compliance with the voltage drop requirements is often the principal factor in determining the minimum cross-sectional area of conductors that can be used for a particular circuit.

The voltage drop may be calculated using the following equation:

$$V_D = \frac{I_b \times L \times mV/A/m}{1000} \text{ Volts} \quad (19.2)$$

where:

V_D is the voltage drop in volts;

L is the cable length in metres;

$mV/A/m$ is the value from the appropriate table in Appendix 4 of BS 7671.

This voltage drop should be equal to or lower than the appropriate 'deemed to comply' voltage drop percentages given in Table 4Ab of Appendix 4 of BS 7671 ($V_D/230 \times 100\%$ for a nominal voltage of 230 V).

Equation 19.2 errs on the safe side by not taking into account that the load current may be lower than the effective current-carrying capacity of the cable. Where the designer wishes to use the smallest possible cross-sectional area, a more accurate approach is required, which takes into account the conductor operating temperature. Equation 19.2 is modified as follows:

$$V_D = \frac{I_b \times L \times mV/A/m \times C_t}{1000} \quad (19.3)$$

where:

$$C_t = \frac{230 + t_p - \left[C_a^2 C_g^2 - \frac{I_b^2}{I_r^2} \right] (t_p - 30)}{230 + t_p} \quad (19.4)$$

where t_p : is the maximum permitted normal operating temperature ($^{\circ}\text{C}$).

19.1.4 Step 4: Check that electrical shock protection is acceptable

To check that fault protection requirements have been met, the earth fault loop impedance (Z_s) at the furthest point of the circuit must be determined by using the following equation:

$$Z_s = Z_e + ([R_1 + R_2] \times C_r) \quad (19.5)$$

where:

$(R_1 + R_2)$ is the resistance per metre of the line conductor and protective conductor, corrected for temperature rise under normal operating conditions;

C_r is the rating factor for operating temperature (see Table 19.1 for values);

Z_e is the value of external earth fault loop impedance.

Table 19.1 Values for temperature correction (C_r) to convert conductor resistance at 20°C to the resistance at maximum operating temperature.

	Maximum operating temperature and insulation type	
	70 °C thermoplastic	90 °C thermosetting
Protective conductor not incorporated in the cable and not bunched with the cable	1.04	1.04
Protective conductor is incorporated in the cable or bunched with the cable	1.20	1.28

Values for $(R_1 + R_2)$ per metre at 20°C are given in IETs *On-Site Guide*; however, if the protective conductor (R_2) is within the same cable as the live conductors and of the same cross-sectional area, then the values of $R_1 + R_2$ per metre can be found in the voltage drop tables in Appendix 4 of BS 7671.

The value of Z_s must be less than the maximum permitted value of Z_s given in Tables 41.2, 41.3 or 41.4 of BS 7671, as applicable.

19.1.5 Step 5: Check that the conductors are protected against prospective fault current

Live conductors

434.5.2 In order for the live conductors to be protected against short-circuit currents, their value of k^2S^2 must be greater than the value of let-through energy (I^2t) for the protective device; here:

S is the cross-sectional area of the conductors; and
 k is the value of k taken from Table 43.1 of BS 7671.

To obtain the let-through energy (I^2t), we need to know the short-circuit current (I_{sc}). This is determined by:

$$I_{sc} = \frac{U_o}{Z_{LN} + ([R_1 + R_n] \times C_r)} \quad (19.6)$$

where

Z_{L-N} is the line-to-neutral impedance at the origin of the installation;

$(R_1 + R_n)$ is the resistance per metre of the line conductor and neutral conductor, corrected for temperature rise under normal operating conditions (C_r);

t is the operating time of the protective device, corresponding to the fault current and can be determined from the time/current characteristics given in Appendix 3 of BS 7671. For an RCCB, t would be 0.04 s (40 ms).

The value of Z_{LN} can be determined by:

- direct measurement, using a loop impedance test instrument;
- enquiry via contacting the distributor; and
- calculation.

Using a loop impedance test instrument to measure short-circuit current is obviously only possible where a supply exists. Loop impedance test instruments are also generally limited to accurately measuring fault currents up to approximately 4.5 kA.

Electricity distributors will generally declare a maximum prospective short-circuit current at their cut-out of 16 kA; however, the fault level will only be that high if the installation is very close to the distribution transformer. Some attenuation of the fault level along the service cable to a consumer's intake point is expected, although this is outside the scope of this guidance.

Z_{LN} can be calculated by dividing the nominal voltage (U_o) by the value of short-circuit current (I_{sc}) at that point, where this is known.

19.2 Protective conductors

Applying a similar approach to that used for the live conductors, the cpc will be protected against earth fault current if its value of k^2S^2 is greater than the value of let-through energy (I^2t) for the protective device, where: 543.1.3

S is the cross-sectional area of the cpc;

k is the value of k taken from Table 54.2 to 54.5 of BS 7671;

t is the operating time of the protective device, corresponding to the fault current, as defined above; and

I is the earth fault current, which is equal to the nominal voltage (U_o) divided by the value of Z_s for the circuit, calculated at Step 4.

19.3 Worked example

A 230 V single phase distribution circuit is to be run in three-core 90 °C thermosetting insulated armoured cable having copper conductors clipped direct, not run with any other cables but passes through a wall having a thickness of 200 mm thermal insulation. A Type B circuit-breaker is to provide fault protection as well as overload and short-circuit protection. The installation forms part of a TN-C-S system, $Z_e = 0.35 \Omega$, and the short-circuit current at the point of installation of the protective device has been previously calculated to be 4000 A.

The circuit parameters are as follows:

$I_b = 45 \text{ A}$;
length = 35 m; and
ambient temperature $t_a = 30^\circ\text{C}$.

Determine the nominal rating of the protective device and the minimum conductor cross-sectional area that can be used.

19.4 Solution

As $I_n \geq I_b$, the circuit-breaker selected from the standard ratings $I_n = 50 \text{ A}$, having a short-circuit breaking capacity of 6000 A.

From Table 52.2 of BS 7671, $C_i = 0.63$:

As $C_a = 1$ and $C_g = 1$:

$$I_t \geq \frac{I_n}{C_g \times C_a \times C_i} = \frac{50}{0.63} = 79.4 \text{ A} \quad (19.7)$$

From Table 4E4A column 3, it can be seen that the minimum cross-sectional area of conductor that can be used is a 16 mm^2 , having an $I_t = 94 \text{ A}$.

To check that the voltage drop is acceptable:

$$C_t = \frac{230 + t_p - \left[C_a^2 C_g^2 - \frac{I_b^2}{I_t^2} \right] (t_p - 30)}{230 + t_p} = \frac{230 + 90 - \left[1 - \frac{45^2}{94^2} \right] (90 - 30)}{230 + 90} = 0.86 \quad (19.8)$$

$$V_D = \frac{I_b \times L \times \text{mV/A/m} \times C_t}{1000} = \frac{45 \times 35 \times 2.9 \times 0.86}{1000} = 3.92 \text{ V} = 1.71\% \text{ of } 230 \text{ V} \quad (19.9)$$

Table 4A b of App. 4 The circuit therefore satisfies the ‘deemed to comply’ voltage drop requirements of 5%.

To check that that electric shock protection is acceptable:

$$Z_s = Z_e + ([R_1 + R_2] \times C_r)$$

As the third core of the 16 mm^2 cable is to be used as the protective conductor, the value of $(R_1 + R_2)$ per metre is equal to $2.9 \text{ m}\Omega/\text{m}$, given in column 3 of Table 4E4B in BS 7671.

$$\text{Therefore, for a } 35 \text{ m run, } (R_1 + R_2) = 2.9/1000 \times 35 = 0.102 \Omega \quad (19.10)$$

As the protective conductor is incorporated in the cable, $C_r = 1.28$ (see Table 19.1).

$$\text{Therefore, } Z_s = 0.35 + ([0.102] \times 1.28) = 0.48 \Omega. \quad (19.11)$$

The circuit therefore complies with the maximum permitted earth fault loop impedance of 0.73Ω , given in Table 41.3 of BS 7671.

The last step is to check that the cable conductors are thermally protected against fault current, using the check formula of $k^2 S^2 \geq I^2 t$.

From Table 54.3 of BS 7671, $k = 143$ and the earth fault current $I_{ef} = 230/0.48 = 479 \text{ A}$.

The corresponding time (t), determined from the time/current characteristics given in Appendix 3 of BS 7671, is 0.1 s .

To check compliance with $k^2 S^2 \geq I^2 t$:

$$\begin{aligned} k^2 S^2 &= 1432 \times 16^2 = 5,234,944 \text{ A}^2 \text{ s} \\ I^2 t &= 479^2 \times 0.1^2 = 2,294 \text{ A}^2 \text{ s} \end{aligned} \quad (19.12)$$

The protective conductor is therefore thermally protected.

Having determined that the protective device has a breaking capacity greater than the prospective fault current at the point of installation (6000 against 4000 A), there is no need to check that the live conductors are thermally protected. 435.1

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