2365 Level 2

Electrotechnical Qualification

Unit 203: Electrical Installations Technology

Pre-attendance Workbook

v2.0

203: Electrical installations technology

Handout 1: Regulations

Learning outcome
The learner will:
1. know implications of electrical industry regulations.

Assessment criteria
The learner can:
1.1. identify **statutory regulations**
1.2. identify **non-statutory regulations**
1.3. state **implications** of **statutory regulations**
1.4. state **implications** of **non-statutory regulations.**

Range
Statutory regulations: HASAWA, EAWR, ESQCR, PUWER, COSHH, CDM, Manual Handling, PPE, Noise at Work, Environmental Act, DDA, Equal Opportunities.
Non-statutory regulations: BS 7671:2018, On-Site Guide, Unite Union Book, Guidance Notes, Codes of Practice.
Implications: Prosecution, fine, imprisonment, prohibition notices, improvement notices, dismissal, injury, death, loss of earnings, lost clients, loss of reputation.

Regulations

When working in the building services industry, it is necessary to comply with a number of Regulations. These Regulations can be classified as follows:

- statutory
- non-statutory.

Acts (of Parliament) are '**statutory**', ie they are legally binding and therefore enforceable by law. Certain **Regulations** are made under **Acts of Parliament** and, as a result, are also statutory.

Other Regulations have advisory/guidance purposes only and, as a result, they are '**non-statutory**', ie they cannot be enforced by law.

However, non-statutory Regulations are generally considered to reflect standards of good practice and may be cited in a court of law. Additionally, although certain Regulations have no legal status, they are based on Acts/Regulations that are statutory and, consequently, breaking the non-statutory Regulations will often result in breaking one or more statutory Acts or Regulations.

Statutory Regulations

A number of statutory Acts and Regulations were identified in Unit 201 under Health and Safety Executive (HSE) legislation. Some of these are repeated here, along with others of which you will need to be aware.

The Health and Safety at Work etc Act (HASAWA)

These are statutory and cover all places where work is carried out. The 'etc' was added to cover voluntary work, etc. All persons are responsible for their own and others' safety.

The Electricity at Work Regulations (EAWR)

There are currently 33 regulations, of which 1–16 and 29 are the most relevant to most electricians. This is a legal (statutory) document, whereas the wiring Regulations (BS 7671:2018) are not.

Electricity Safety, Quality and Continuity Regulations (ESQCR)

The opening up of the electricity markets resulted in there being many more ‘generators’ than the original CEGB, and many more ‘suppliers and ‘distributors’ of electricity and ‘meter operators’ than the original Regional Electricity Authorities. New regulations were necessary to unify engineering, safety and contractual standards for all generators, suppliers, distributors and meter operators. The Regulations seek to safeguard continuity and quality of electricity supplies to all consumers, from whoever they are obtained, and to ensure the safety of the public from the substation installations, as well as electrical distribution via overhead and underground distribution systems.

Provision and Use of Work Equipment Regulations (PUWER)

This covers the supply and use of equipment in the workplace. Equipment must be safe to use and used safely by the operatives.

Control of Substances Hazardous to Health Regulations (COSHH)

As the name suggests, these Regulations cover anything used in the workplace that could be considered hazardous to health. This would include chemicals, asbestos, cements, oils, sprays, etc.

Construction (Design and Management) Regulations (CDM)

The Regulations place specific duties on clients, designers and contractors to rethink their approach to health and safety so that it is taken into account throughout the life of a construction project, from its inception to its subsequent final demolition and removal.

Manual Handling Operations Regulations (MHOR)

These Regulations aim to reduce the very large incidence of injury and ill health caused by the manual handling of loads at work.

Personal Protective Equipment at Work Regulations (PPEWR)

Requires an assessment of PPE requirements to be carried out, the employer to supply the PPE and the employee to wear the protective equipment.

Control of Noise at Work Regulations

Everyone at work could be exposed to noise and suffer temporary or permanent hearing loss. These Regulations place a duty on employers within Great Britain to reduce the risk to their employees’ health by controlling the noise they are exposed to whilst at work.

Environmental Act

This is an Act of Parliament that defines the fundamental structure and authority for waste management and control of emissions into the environment.

Disability Discrimination Act (DDA)

This has now been repealed and replaced by the Equality Act 2010 (except in Northern Ireland where the Act still applies). Formerly, it made it unlawful to discriminate against people because of their disabilities in relation to employment, the provision of goods and services, education and transport.

Equality Act

This act requires equal treatment in access to employment, as well as private and public services, regardless of the protected characteristics of age, disability, gender reassignment, marriage and civil partnership, race, religion or belief, sex and sexual orientation.

Non-statutory Regulations

A number of non-statutory Acts and Regulations were identified in Unit 201 under Health and Safety Executive (HSE) legislation. Some of these are repeated here, along with others of which you will need to be aware.

Requirements for Electrical Installations (BS 7671:2018)

Published by the Institution of Engineering and Technology (IET), these are the national standard in the United Kingdom for low voltage electrical installations.

The IET (formerly IEE) has published wiring Regulations in the United Kingdom since 1882. Since their 15th edition (1981), these Regulations have closely followed the corresponding international standard IEC 60364. Today, they are largely based on the European Committee for Electrotechnical Standardization (CENELEC) harmonization documents and therefore are technically very similar to the current wiring regulations of other European countries.

In 1992, the IEE Wiring Regulations became British Standard BS 7671 and they are now treated similarly to other British Standards. Although the IET and BSI are non-governmental organisations and the Wiring Regulations are non-statutory, they are referenced in several UK statutory instruments.

On-Site Guide

The On-Site Guide published by the IET is a handbook that contains some information that is not found in BS 7671: 2018. It is meant as a handy notebook reference for electricians working on building sites.

Unite Union Book

This book has been published by the trade union **Unite** for over 20 years; *The Electrician's Guide To Good Electrical Practice* revised to BS 7671:2018 contains a wealth of information for the practising electrician. This information is based on BS 7671:2018 but contains much more and is, additionally, pocket-sized and therefore ideal to keep in the toolbox or van for reference purposes.

IET Guidance Notes

The IET issues a number of Guidance Notes based on different topics. They provide additional clarification on how to implement and comply with BS 7671:2018. Current titles are:

- *Guidance Note 1: Selection and Erection*, 8th Edition
- *Guidance Note 2: Isolation and Switching*, 8th Edition
- *Guidance Note 3: Inspection and Testing*, 8th Edition
- *Guidance Note 4: Protection Against Fire*, 8th Edition
- *Guidance Note 5: Protection Against Electric Shock*, 8th Edition
- *Guidance Note 6: Protection Against Overcurrent*, 8th Edition
- *Guidance Note 7: Special Locations*, 6th Edition
- *Guidance Note 8: Earthing and Bonding*, 4th Edition.

Although all are important, when designing and installing electrical installations, the most popular in the set is *Guidance Note 3: Inspection and Testing*.

Codes of Practice

These give practical guidance on compliance. Although failure to comply with an Approved Code of Practice is not an offence in itself, these Codes have special legal status. If an employer/individual faces criminal prosecution under health and safety law, and it is proved that the advice of the Approved Code of Practice has not been followed, a court can regard it as evidence of guilt unless it is satisfied that the employer/individual has complied with the law in some other way. Following Approved Codes of Practice is therefore regarded as best practice.

Implications of non-compliance with regulations

The direct implications of breaking statutory Regulations include the following:

- prosecution
- fine
- imprisonment
- prohibition notices (a work activity or premises must **not** be used until the non-compliant situation is rectified)
- improvement notices (a work activity or premises can continued to be used but shortcomings must be rectified within a specified time period).

In addition, the non-direct implications of breaking statutory Regulations include the following:

- dismissal
- injury
- death
- loss of earnings
- lost clients
- loss of reputation.

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Worksheet 1: Regulations
Answer guide

Using your notes and other sources, answer the following questions.

1. State five implications of not complying with regulations.

2. State whether the following are statutory or non-statutory.

BS 7671:2018 ____________________

CDM: ____________________

Codes of Practice: ____________________

COSHH: ____________________

DDA: ____________________

EAWR: ____________________

Environmental Act: ____________________

ESQCR: ____________________

Equal Opportunities: ____________________

Guidance Notes: ____________________

HASAWA: ____________________

Manual Handling: ____________________

Noise at Work: ____________________

On-Site Guide: ____________________

PPE: ____________________

PUWER: ____________________

Unite Union Book: ____________________

3. State the main requirements of the Electricity at Work Regulations.

4. Which regulations cover the requirements for electricity supply in the United Kingdom?

5. Which regulations may require site operators to specify the wearing of boots, high visibility clothing and hard hat, as well specifying safety procedures on particulars construction sites?

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Handout 2: Technical information

Learning outcome
The learner will:
2. know how to obtain technical information.

Assessment criteria
The learner can:
2.1 state purpose of different **sources** of technical information.

Range
Sources: Specifications (to select correct materials), drawings (provide technical information on wiring systems), BS 7671:2018, On-Site Guide, Unite Union Book, manufacturers' data, Guidance Notes (install in accordance with Regulations), client's needs.

Technical information

Technical information required to enable us to carry out electrical installations can come from many sources. These include the following:

- specifications (to select correct materials)
- drawings (provide technical information on wiring systems)
- BS 7671:2018
- On-Site Guide
- Unite Union Book
- manufacturers' data
- Guidance Notes (install in accordance with Regulations)
- client's needs.

Specifications, drawings and diagrams

In order to enable the various contractors to tender for the work, detailed specifications, drawings and diagrams have to be produced.

It is essential that, when pricing against other companies, everyone uses the same base for their final price. This ensures that everyone sets their prices similarly for the same equipment, cable sizes and runs, etc. Companies are free to apply their own wage rates, discounts and profit margins in determining the total cost.

Installation specifications give complete details of what is to be included in the installation, including plans. They will give details of the equipment to be installed, where it is to be installed, sizes, etc.

Requirements for Electrical Installations (BS 7671:2018)

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Manufacturers' information and data

Manufacturers provide a wide range of information about their products in general and specifically to individual equipment or components.

Catalogues are produced which illustrate the type and range produced by that manufacturer. It is usual for this to be quite general but some will include technical data as well.

The production costs of these catalogues, and so on is covered by the price charged by the manufacturer. The printing costs of these catalogues are relatively high.

Data sheets are normally provided with individual accessories or components where needed. These apply to wiring diagrams for heating controls, connections for lighting systems etc and give the load capacity amongst other information.

Paper based systems tend to get out of date relatively quickly. Widespread access to the internet means that most companies have started to place all their catalogues and data on their websites. This is a cheaper option, reducing component cost and allowing instant updates to be posted as and when required.

IET Guidance Notes

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Client's needs

The client or customer will produce a general statement as to what they require. They will normally appoint an architect or consultant to produce a more detailed plan for approval. Once approved by the client (and approving authority), the customer's agent will draw up detailed plans and specifications.

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Worksheet 2: Technical information
Answer guide

1. What type of information is the below an example of? And where could it be found?

Cylinder Thermostat £100 (inc VAT) Product code: Y747A652 Manufacturer: SmartElectro Surface mounting cylinder thermostat, range 40–80°C, SPDT, 12°C differential

2. ‘A set of documents, plans or diagrams which sets out requirements for materials, components and service.’ What is this sentence describing?

3. ‘The system is to consist of single core thermoplastic cables installed in galvanised trunking run at a height of 2.3m above ffl.’ This statement could form part of what type of document?

4. What set of documents can the design electrician use to determine how the Regulations can be applied to specific situations?

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Handout 3: Drawings

Learning outcome
The learner will:
2. know how to obtain technical information.

Assessment criteria
The learner can:
2.2 recognise different **drawing types.**

Range
Drawing types: As fitted drawings, circuit diagrams, block diagrams, schematics, wiring diagrams, bar charts.

Drawings

Various types of drawings can be used to convey information relating to all aspects of electrical installations. These include the following:

- as fitted drawings
- circuit diagrams
- block diagrams
- schematics
- wiring diagrams
- bar charts.

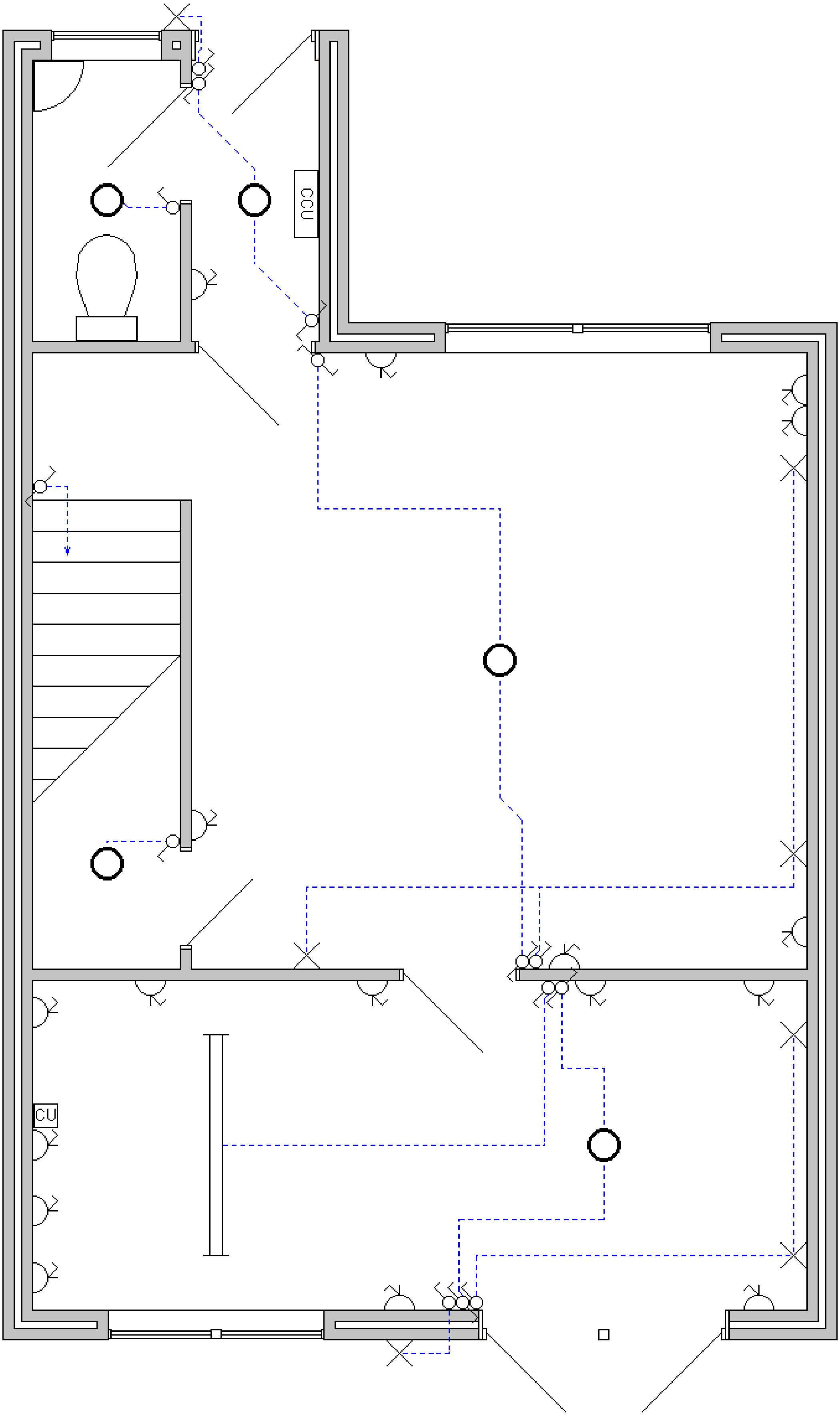
Architectural plans including as fitted drawings

These are the types of drawing most likely to be encountered by installation electricians. They show the layout of the building and the position of accessories and equipment, using standard symbols.

At the design stage, the electrical company will receive the plans along with the specification. A typical architectural plan can be found on the following page. This will show on a scale drawing the position of all accessories and equipment and will allow the designer to determine the material requirements for the job, and hence accurate pricing.

During the installation phase, the electrician will use the scale architectural plans to position accessories and equipment accurately. For example, when positioning a socket outlet, the distance to the socket outlet to a fixed point (eg a wall) will be measured on the plan. This will be scaled up to give the actual ‘real life’ measurement.

When the installation is complete, there may be some accessories and equipment that, by mutual consent with the customer, were positioned differently from the original plans. These changes will be marked on a set of plans referred to as the ‘**as fitted**’ drawings to reflect what was actually installed. These are handed over to the customer with the installation pack.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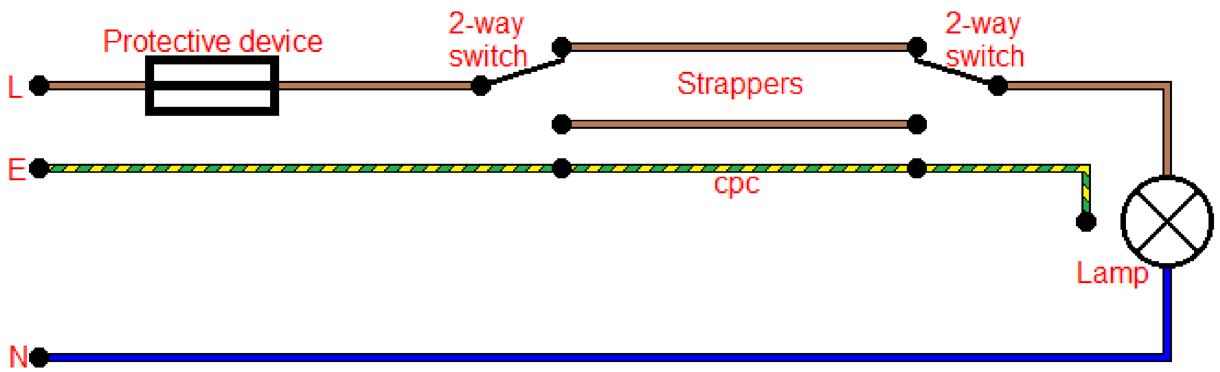
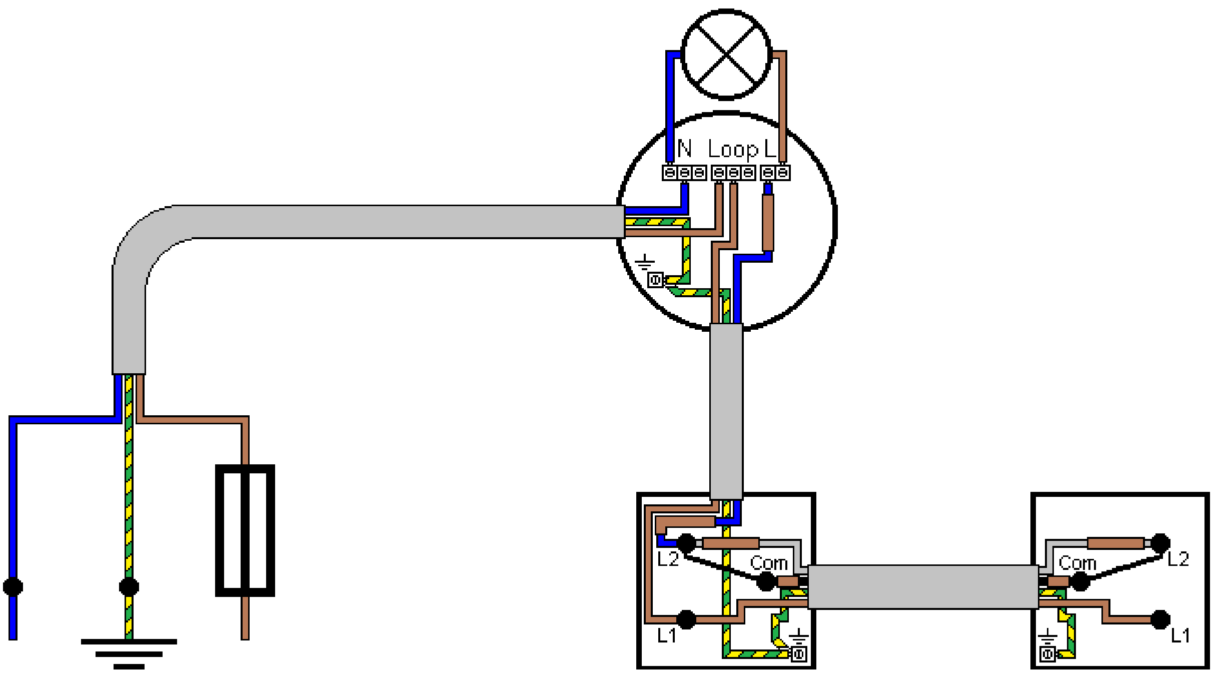
Circuit diagrams

A circuit diagram is the representation of a circuit arrangement that permits easier understanding of how the circuit works. In practice, the actual wiring may be different to the circuit diagram. An example of a circuit diagram is shown below:



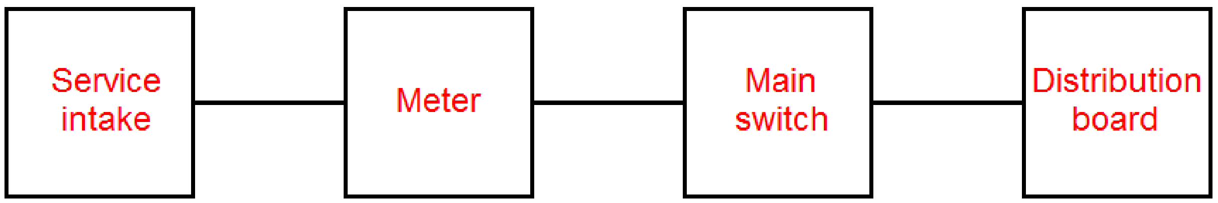
Wiring diagrams

A wiring diagram shows how a circuit is actually wired in practice. This may result in a diagram that makes it harder to understand how the circuit functions. An example wiring diagram is shown below:



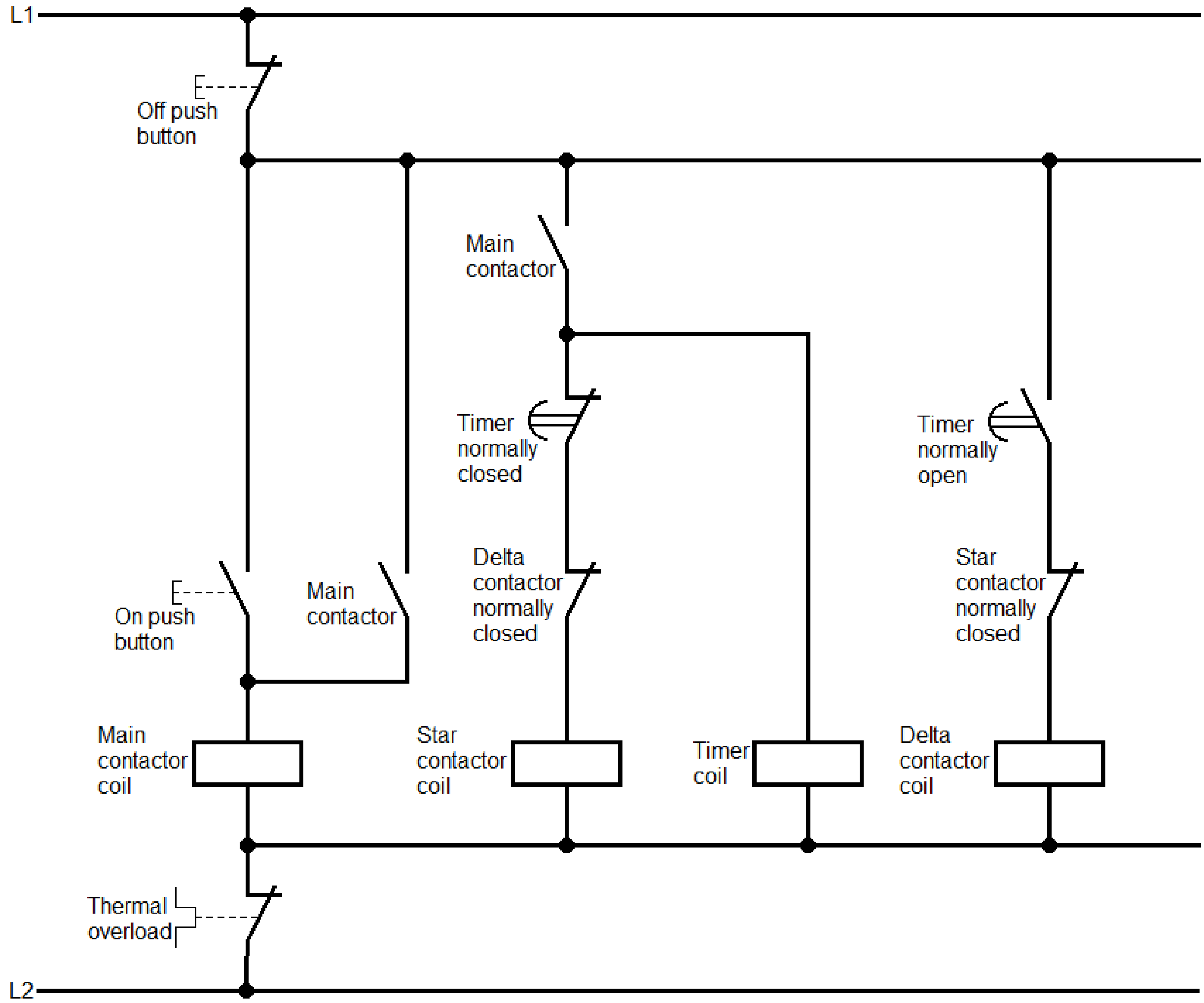
Block diagrams

A block diagram does not show individual conductors or cables but the sequence of equipment instead. For example, the diagram below shows the supply sequence to an installation:



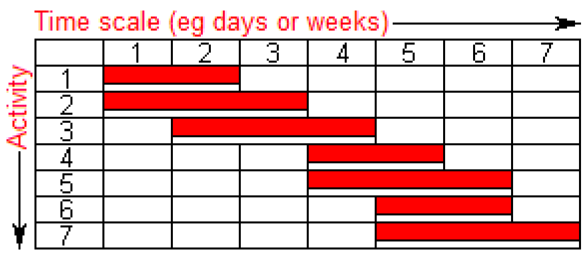
Schematic diagrams

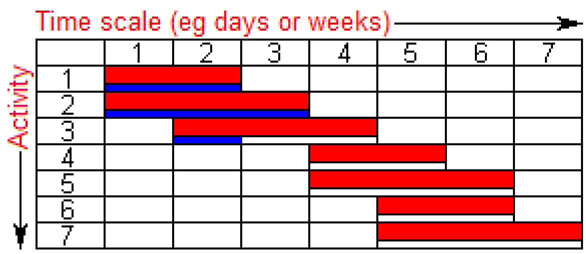
These are very similar to circuit diagrams in that they show how a system works rather than how it is wired. They are generally used on larger control systems, as they can make fault-finding much simpler. An example is shown below:



Bar charts

Bar charts can be used for many purposes but the most common are involved in planning the sequence of works; this can be represented graphically by bar charts, as shown below:





The chart on the left indicates when certain activities are due to start and finish. This will allow the allocation of labour and ordering of material to be carried out. The chart on the right indicates progress of the job. For example, if we have just completed week three, you can see that activities one and two have been completed on time but task three is one week behind. We can also indicate on the bar chart those activities that cannot start until others have been completed.

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Worksheet 3: Drawings
Answer guide

1. **What type of diagram shows how a circuit is wired in practice?**

2. **What type of diagram shows the position accessories in an installation?**

3. **What type of diagram allows a contractor to plan the sequence of work?**

4. **What type of diagram better shows how a circuit works rather than how it is wired?**

5. **What type of diagram better shows how a system works?**

6. **What type of diagram shows the sequence of equipment?**

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Handout 4: Symbols and scales

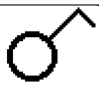
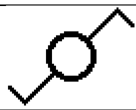
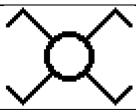
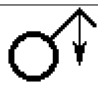
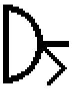
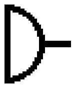
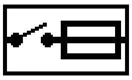
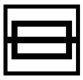
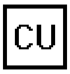
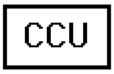
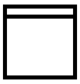
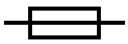
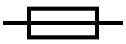
Learning outcome
The learner will:
2. know how to obtain technical information.

Assessment criteria
The learner can:
2.3 recognise **symbols** used in drawings
2.4 convert scale from drawings to actual dimensions.

Range
Symbols: Switching (one way, two way, intermediate, pull, switched socket outlets, unswitched socket outlets, fused connection units, switched fused connection units) lighting points (fluorescent, incandescent, wall), cooker control unit, consumer control unit, integrated meter, fuse, circuit breaker.

Symbols

Below is a selection of architectural symbols that you may find on a plan. These and others can be found on the inside rear cover of the IET On-Site Guide.

Switching			
one way		two way	
Intermediate		pull	
Socket outlets			
Switched		Unswitched	
fused connection units		switched fused connection units	
Lighting points			
Fluorescent		Incandescent	
Wall			
Various			
Cooker control unit		Consumer control unit	
Integrated meter		Fuse	
Circuit breaker			

Scales

There need to be plans or drawings of where everything should go if an installation is to be completed accurately.

Drawing on a piece of paper the size of a whole house or factory would clearly be impracticable so a plan is drawn to scale, ie it is first decided how much smaller everything needs to be drawn on the paper. In order to retain accuracy, everything obviously needs to be made smaller by the same amount.

The most common scales in electrical installation are: 1:20, 1:50, 1:100.

In each case, everything is a 20th, 50th or 100th of its normal size, respectively.

A scale drawing is a drawing that represents a real object. The scale of the drawing is the ratio of the size of the drawing to the actual size of the object.

Example 1

The length of a building is 60 metres, its width is 40 metres and it is drawn to a scale of 1:100. What are the length and breadth of the building on the drawing?

Solution:

Length	Width
$\text{Scale length} = \dfrac{\text{Actual length}}{\text{Scale}} = \dfrac{60}{100} = 0.6 \text{ metres} = \mathbf{60cm}$	$\text{Scale length} = \dfrac{\text{Actual length}}{\text{Scale}} = \dfrac{40}{100} = 0.4 \text{ metres} = \mathbf{40cm}$

Example 2

On a plan with a scale of 1:50, a socket is measured at 23mm from a wall. How far from the wall must the socket be installed in the finished installation?

Solution:

$$\text{Actual distance} = \text{Distance on plan} \times \text{scale}$$
$$= 23 \times 50$$
$$= 1{,}150\text{mm}$$

or $= \mathbf{1.15\ metres}$

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Worksheet 4: Symbols and scales
Answer guide

Try the following problems.

1. **The length of a motorway is 600 kilometres. If 0.5cm represents 50 kilometres, calculate the length of the motorway on the map.**

2. **The dimensions of a building are 250 metres by 120 metres. If 10mm represents 20 metres on a scale drawing, calculate the dimensions of the building on the drawing.**

3. **If one centimetre represents 10 metres, calculate the dimensions used to make a scale drawing of a room 20 metres by 40 metres.**

4. **If on a scale drawing a particular dimension is 120mm, using a scale of 1:10 how many metres does this represent?**

5. **If 1cm represents 75 kilometres on a map, calculate how many centimetres will represent 1,500 kilometres.**

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Handout 5: Lighting circuits

Learning outcome

The learner will:

3. know wiring systems of electrical installations.

Assessment criteria

The learner can:

3.1 describe principles of operation of different **circuit types.**

Range

Circuit types: Lighting, power and heating, alarm and emergency systems, data communications, control circuits, ring final, radial.

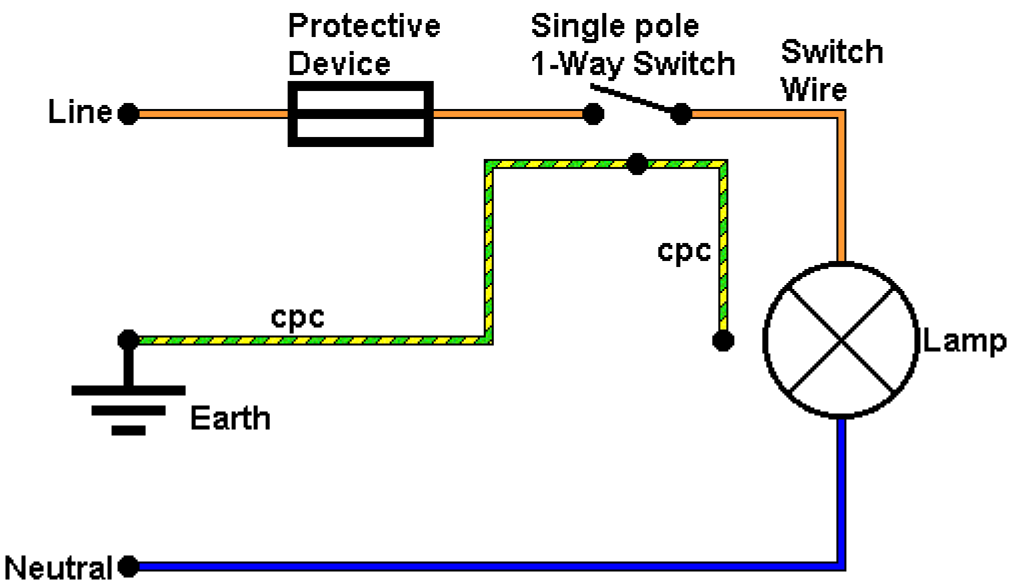
Lighting circuits

Here are some points to note.

- All lighting points, unless specific light sources with known power ratings are being used, are assumed to have a rating of 100 watts minimum.
- In order to ensure that there is not a complete blackout when a fault occurs, we should install at least two lighting circuits in the premises.
- Earthing terminal and cpc. must be provided at **all** lighting points, including switches and ceiling roses.
- 5/6 amp protective devices are normally used to protect domestic lighting circuits (5 amp if BS 3036 semi-enclosed rewireable fuse; 6 amp if a circuit breaker).
- Domestic lighting circuits are generally wired in 1.0mm^2 or 1.5mm^2 cables.
- Two types of wiring system are used for lighting circuits:
  - **two-plate system** – normally used where single-core cables are used, eg in conduit and trunking systems
  - **three-plate system** – normally used where multi-core cables are used, eg domestic installations using twin and earth.

Practical lighting circuits – two-plate

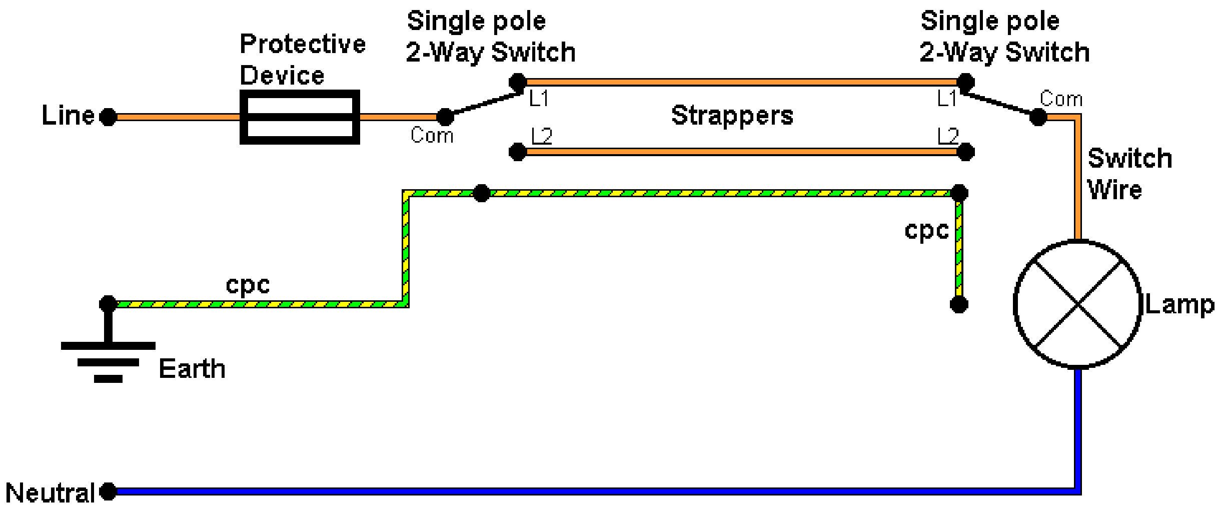
One-way switching



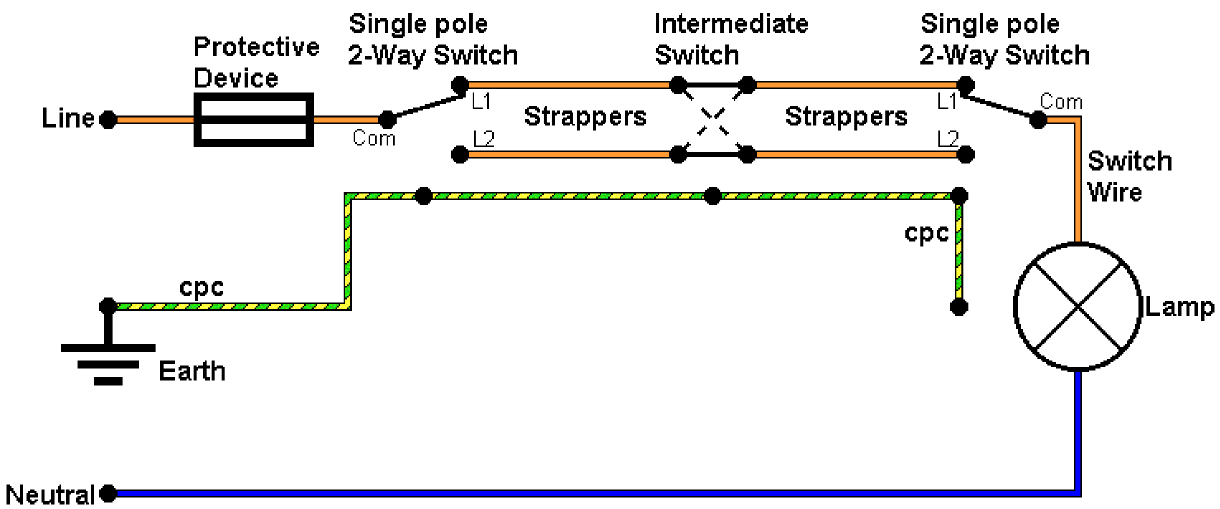
Here are some points to note.

- Single pole switches and protective devices **must** be installed in the line conductor **only**.
- For Edison Screw (ES) lamp holders the line conductor **must** be connected to the centre contact of the lamp holder.

Two-way switching

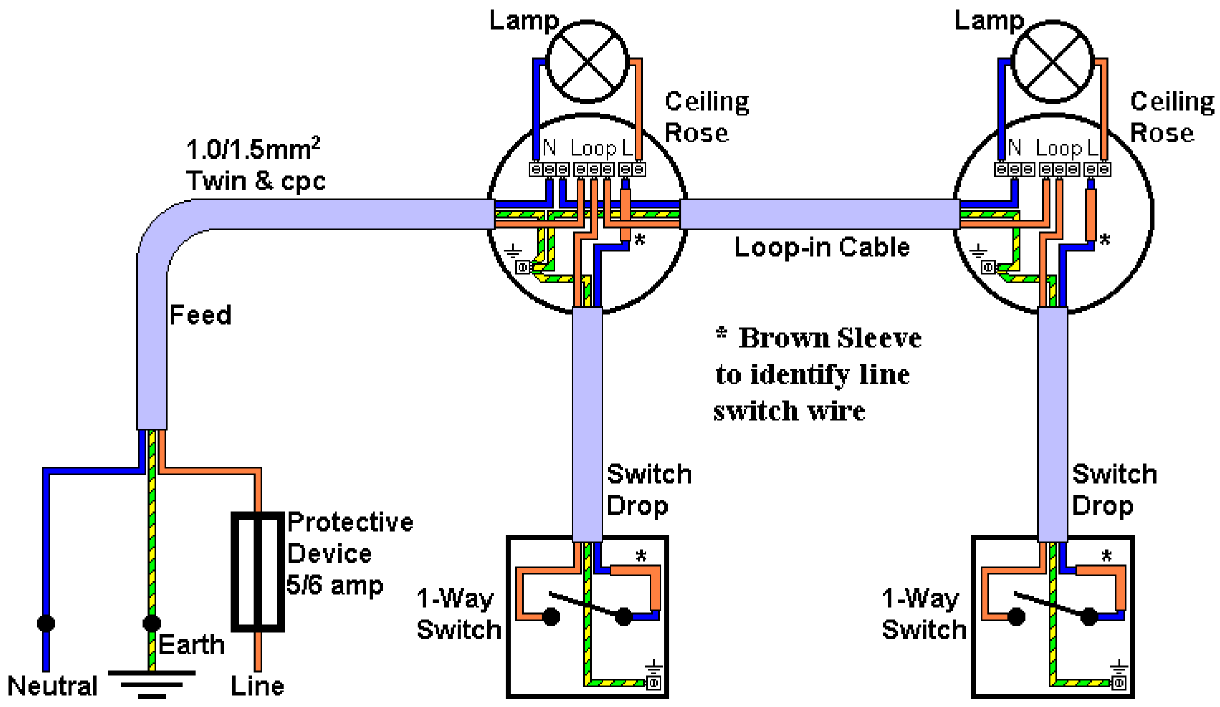


Two-way and intermediate switching

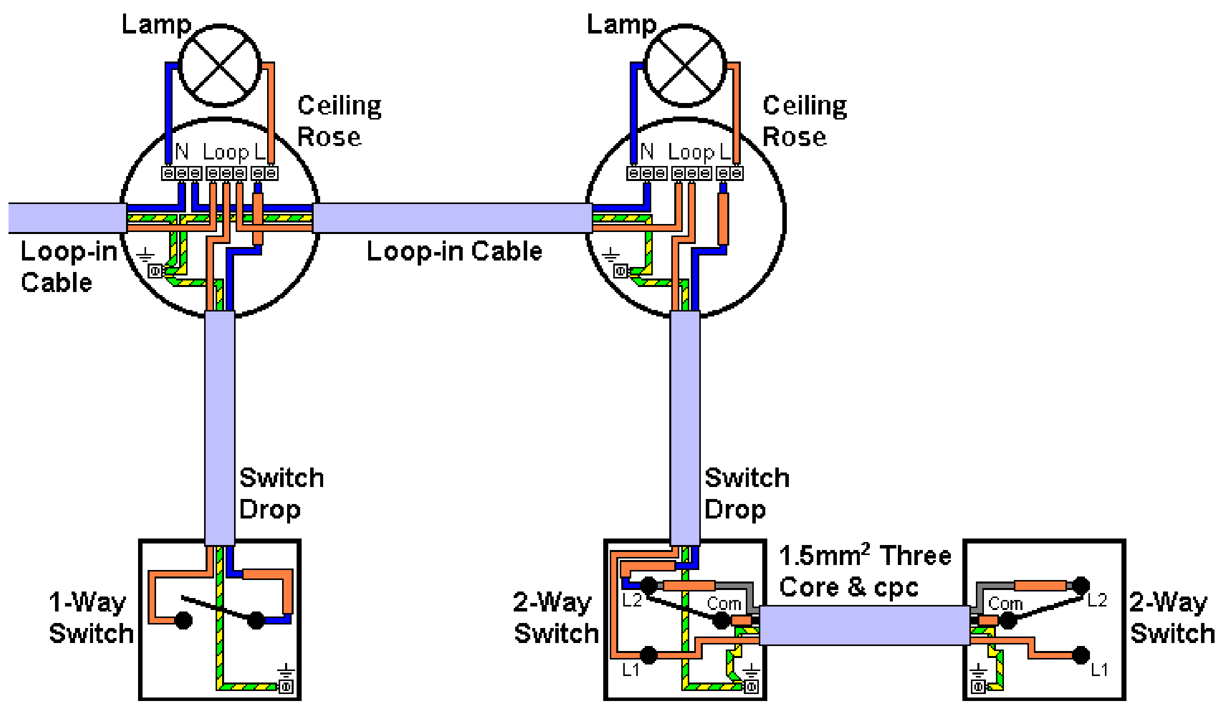


Practical lighting circuits – three-plate

One-way lighting circuit



Two-way conversion lighting circuit

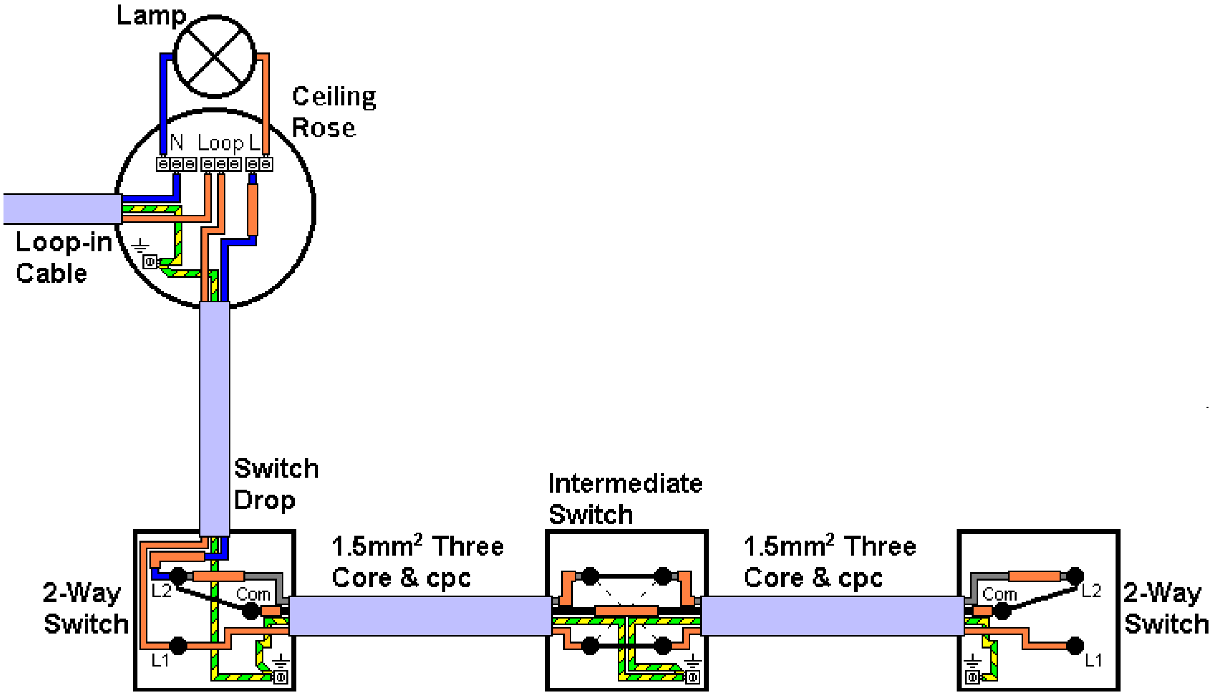


Here are some points to note.

- Although this is called a 'conversion' circuit, most electricians use this circuit as a matter of course in domestic installations. For example, the landing light in a house would be connected to the upstairs lighting circuit with the switch drop going to the switch on the landing. The three-core and cpc would be run from the landing switch downstairs to the switch at the bottom of the stairs.

Intermediate switches in the two-way conversion lighting circuit

Intermediate switches can be inserted in to the two-way conversion circuit, as shown below:



Looping at switches

Domestic lighting circuits have for many years been connected using the three-plate method where the loop terminal is at the ceiling rose.

Today it is increasingly likely to have a decorative light fitting or even down lighters fitted in place of a standard pendant. These fittings are rarely provided with a loop terminal.

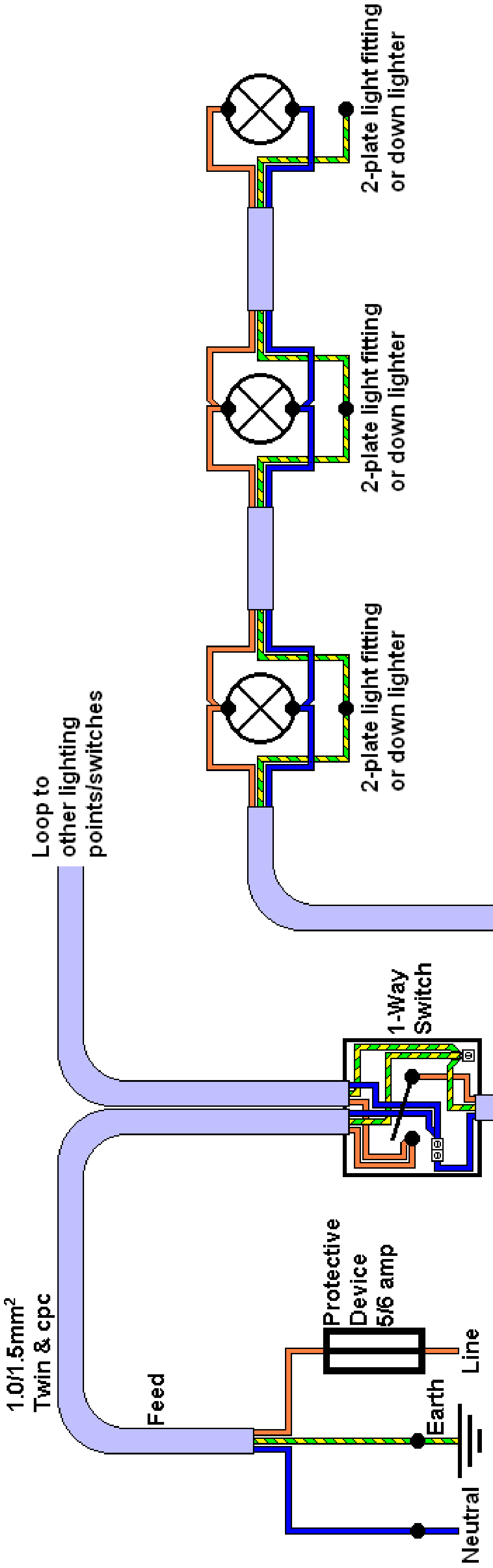
As a result, it has become more popular to make the loop connection at the switch.

This has the advantage of the connections being accessible and at a more convenient working height.

However, this leaves the problem of terminating the neutral conductor. One solution is to connect the neutral to a connector block inside the wall box, which takes up extra space.

Some accessory manufacturers now produce light switches with a built-in neutral loop terminal.

An example of looping at the switch is shown on the following page.

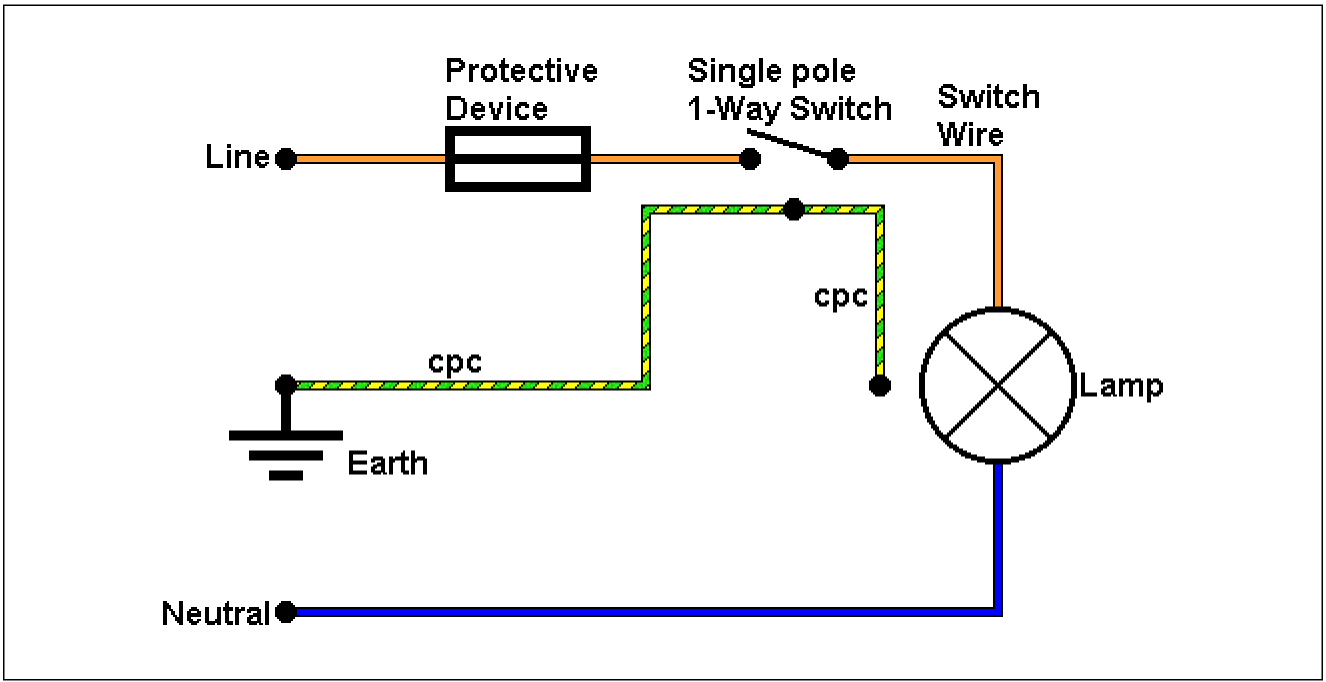

2-plate light fitting
or down lighter
2-plate light fitting
or down lighter
2-plate light fitting
or down lighter
Loop to
other lighting
points/switches
1-Way
Switch
Protective
Device
5/6 amp
Line
Earth
Neutral
Feed
1.0/1.5mm²
Twin & cpc

203: Electrical installations technology

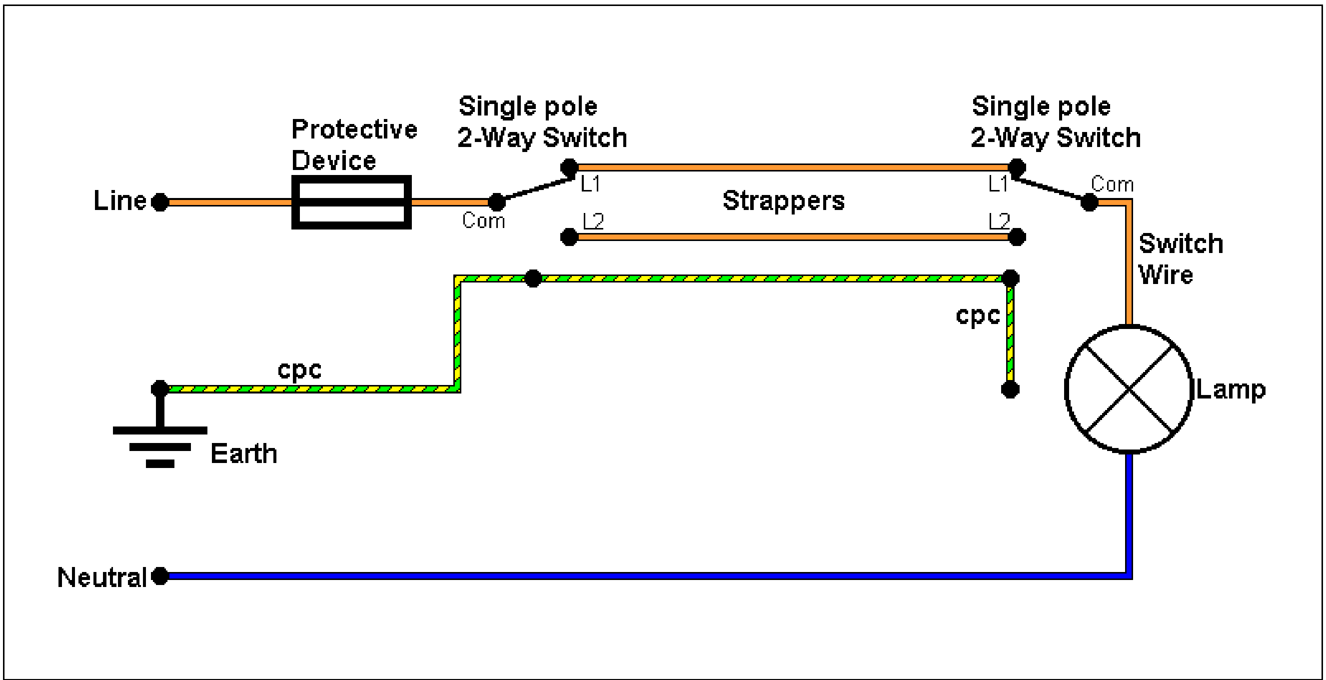
Worksheet 5: Lighting circuits
Answer guide

Try the following.

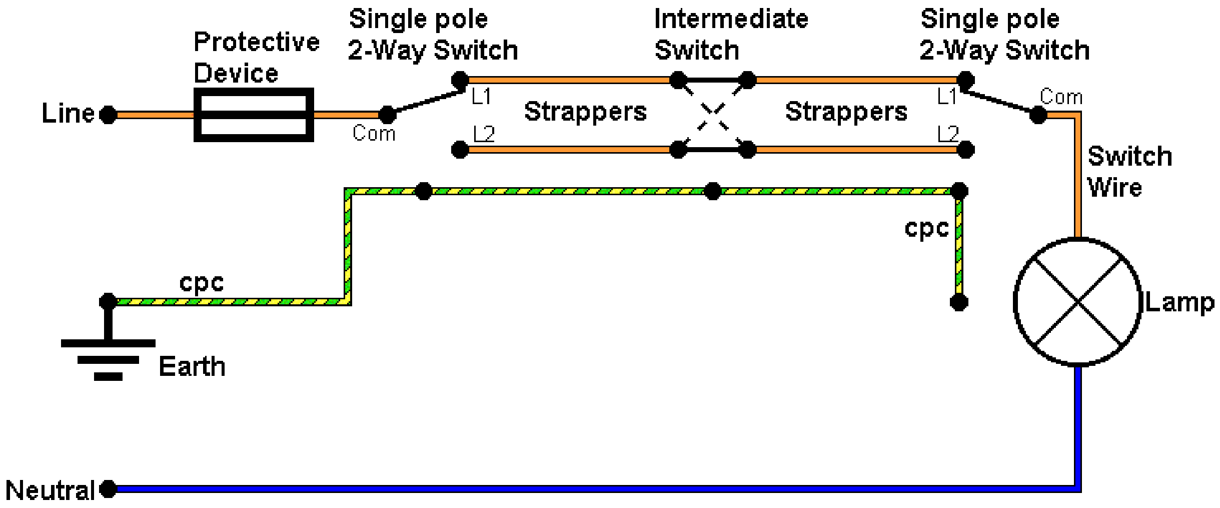
1. Using coloured pencils, produce a labelled diagram of a two-plate, one-way lighting circuit.



2. Using coloured pencils, produce a labelled diagram of a two-plate, two-way lighting circuit.



3. Using coloured pencils, produce a labelled diagram of a two-plate, two-way and intermediate lighting circuit.



203: Electrical installations technology

Handout 5: Socket circuits

Learning outcome
The learner will:
3. know wiring systems of electrical installations.

Assessment criteria
The learner can:
3.1 describe principles of operation of different **circuit types.**

Range
Circuit types: Lighting, power and heating, alarm and emergency systems, data communications, control circuits, ring final, radial.

Socket circuits

Socket circuits are used to easily connect the wide range of electrical and electronic appliances to the mains supply using a plug and socket arrangement.

A flexible cord, normally not longer than 2 metres, connects the appliance to the plug top, which is then inserted into a conveniently located socket outlet.

BS 7671:2018, Regulation 553.1.201 states that, *'Every socket-outlet for household and similar use shall be of the shuttered type and, for an AC installation, shall preferably be of a type complying with BS 1363'*.

Various current ratings are available but the 13-ampere flat pin type is the most commonly encountered in Great Britain, with each plug top fitted with a cartridge fuse to BS 1362 to protect the flexible cord.

In order to enable appliances to be wired from a convenient and adjacent socket outlet, the outlets are wired to a ring radial circuit or to a radial final circuit.

As long as the circuit complies with the requirements of Table H2.1 in Appendix.

Table H2.1 – Final circuits using BS 1363 socket-outlets and connection units

Type of Circuit		Overcurrent protective device rating (A)	Minimum live conductor cross-sectional area* (mm^2)		Maximum floor area served (m^2)
			Copper conductor thermoplastic or thermosetting insulated cables	Copper conductor mineral insulated cables	
1	2	3	4	5	6
A1	Ring	30 or 32	2.5	1.5	100
A2	Radial	30 or 32	4	2.5	75
A3	Radial	20	2.5	1.5	50

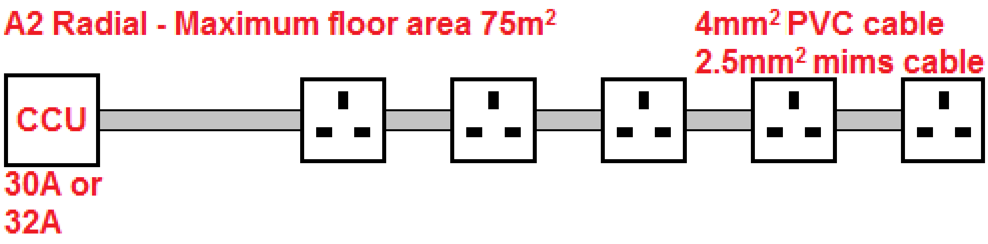
* See Section 7 and Table 7.1(i) for the minimum csa for particular installation reference methods. It is permitted to reduce the values of conductor cross-sectional area for fused spurs.

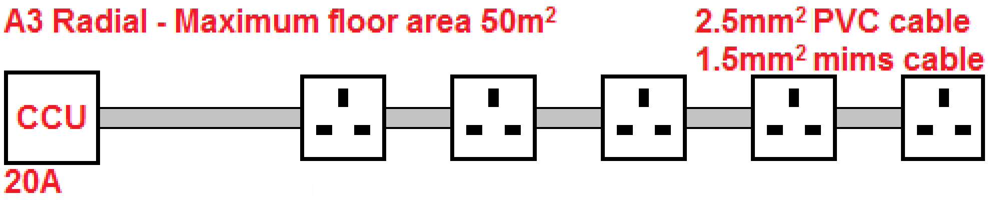
The above reproduced from the IET On-Site Guide

Additionally, sockets outlets with a rating not exceeding 32A and mobile equipment with a current rating not exceeding 32A for use outdoors, must be protected by an RCD with a rating ($I_{\Delta n}$) not exceeding 30mA (BS 7671:2018 Regulation 411.3.3).

Radial final circuits

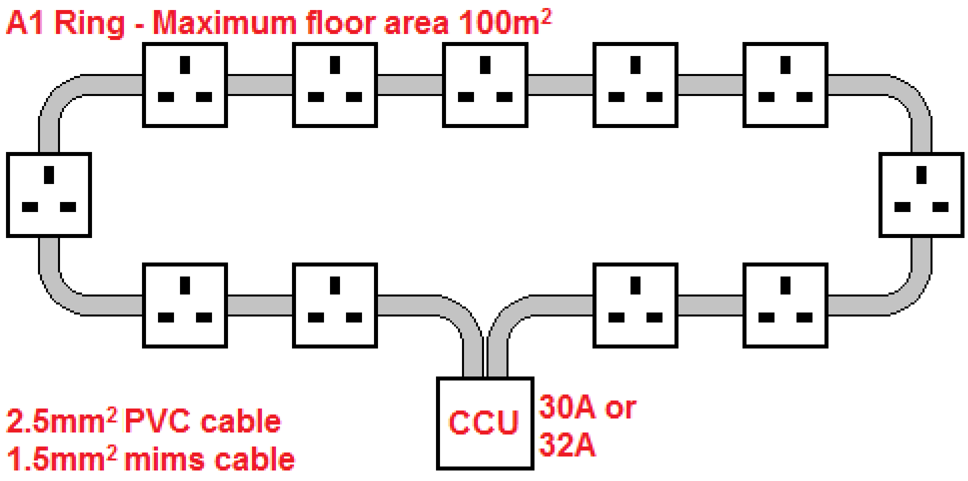
In a radial final circuit the cable comprising of a line, neutral and cpc 'radiates' from the consumer control unit (CCU) looping in and out of each socket outlet until the last outlet is reached and the circuit ends. The protective device and cable sizes can be found in Table H2.1 in Appendix H of the On-Site Guide but can be represented by the diagram below:





Ring final circuits

In a ring final circuit the cable comprising of a line, neutral and cpc starts at the consumer control unit (CCU) looping in and out of each socket outlet until the last outlet is reached and then a cable is brought back to the CCU where it is connected into the same terminals as the outgoing cable. The protective device and cable sizes can be found in Table H2.1 in Appendix H of the On-Site Guide but can be represented by the diagram below:



The standard ring final circuit utilises smaller conductors than the equivalent radial final circuit because the current going to each socket outlet comes from two directions, thus spreading the load. It is vitally important that the ring remains continuous; otherwise there is a risk of overloading one or more of the cables if the ring is broken. It is for this reason that a special test – the **continuity of ring final circuit conductors** test – must be carried out during the testing process to check that there are no breaks or interconnections to the ring.

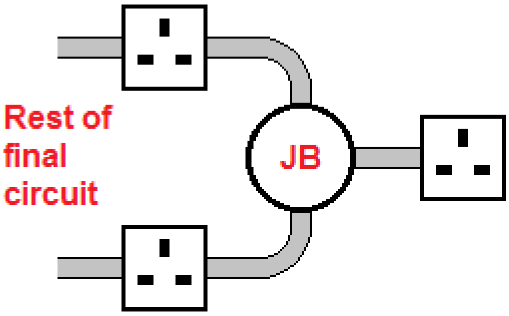
Spurs from socket circuits

A spur is defined in Part 2 of BS 7671:2018 as **'a branch from a ring or radial final circuit'**.

Further clarification on the arrangement of spurs for ring and radial final circuits can be found in Appendix 15 of BS 7671:2018.

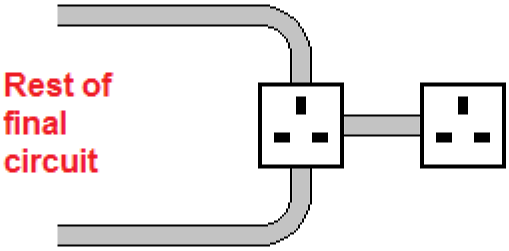
A spur can branch from the circuit by:

- using a joint box of the appropriate rating (must be accessible for inspection, testing and maintenance unless fitted with maintenance-free terminals)
- branching from an outlet connected directly into the final circuit.



The following points must be remembered when dealing with unfused spurs from ring final circuits.

- The number of unfused spurs must not exceed the number of outlets connected directly to the ring.
- Only one outlet is permitted on each unfused spur.
- An outlet is one single or one twin socket outlet or one piece of permanently connected equipment.



With fused spurs, that is, one fed from a fused connection unit, the number of outlets connected to the fused spur is not restricted.

General socket circuit considerations

- It is generally desirable to install at least two socket circuits in an installation so that if a fault occurs, there will still be some live outlets available in the premises. In a domestic house this usually means one circuit downstairs and one upstairs.
- Where multiple circuits are installed, the number of outlets connected to each circuit should be roughly the same so that no circuit is greatly loaded compared to others.
- Although socket outlet circuits allow an unlimited number of outlets to be installed, the total estimated current demand connected to the circuit should not exceed the rating of the protective device protecting that circuit.
- A separate circuit for the kitchen, where there is likely to be a large number of appliances used simultaneously, should be considered.

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Worksheet 6: Socket circuits

Answer guide

Try the following problems.

1. State the number of unfused spurs that can be installed on a standard A1 ring final circuit.

2. State the protective device rating for an A3 radial final circuit.

3. State the minimum sized conductor for use on an A2 radial final circuit if it is insulated with thermosetting plastic.

4. The number of outlets that can be connected to an A1 ring final circuit is unlimited provided that the floor area served does not exceed:

5. The number of outlets that can be connected to an A2 radial final circuit is unlimited provided that the floor area served does not exceed:

6. The number of outlets that can be connected to an A3 radial final circuit is unlimited provided that the floor area served does not exceed:

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Handout 7: Cooker circuits and diversity

Learning outcome

The learner will:

3. know wiring systems of electrical installations.

Assessment criteria

The learner can:

3.1 describe principles of operation of different **circuit types.**

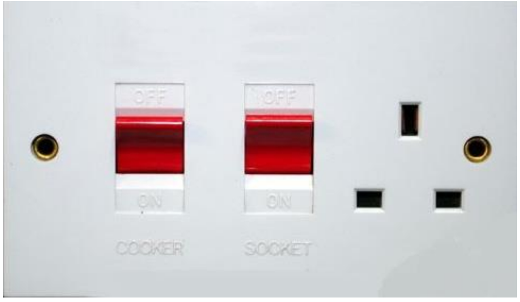
Range

Circuit types: Lighting, power and heating, alarm and emergency systems, data communications, control circuits, ring final, radial.

Cooker circuits and diversity

Traditional free-standing cookers are generally one of the largest current-using pieces of equipment in domestic premises. Therefore, they are fed by their own circuit directly from consumer control unit (CCU).

Adjacent to the cooker there will be a double pole switch to control the supply to the cooker. This switch may or may not incorporate a 13A socket outlet.



When determining the size of cable to be used for the cooker circuit, it is necessary to calculate the design current, I_b, of the cooker. Simply, all we need to do is to take the total power rating of the cooker and divide it by the voltage to give the current.

However, it is very unlikely that everything on the cooker will be turned full on simultaneously. Even if all the elements are on, built-in control gear, such as simmerstats and ovenstats, will mean that full current will probably not be drawn.

Therefore, we can make an allowance and reduce the design current when calculating protective device rating and cable size. This allowance is referred to as **diversity**.

Appendix A of the IET On-Site Guide covers maximum demand and diversity, and Table A2 (page 123) gives the allowances for diversity for various types of circuit and premises. For a cooking appliance in an individual household installation, the following allowance can be made:

- the first 10 amperes
- plus 30% full load (f.l.) of connected cooking appliances in excess of 10A
- plus 5A if a socket outlet is incorporated in the control unit.

Example 1

Calculate the assumed demand for a 230 volt cooker which contains:

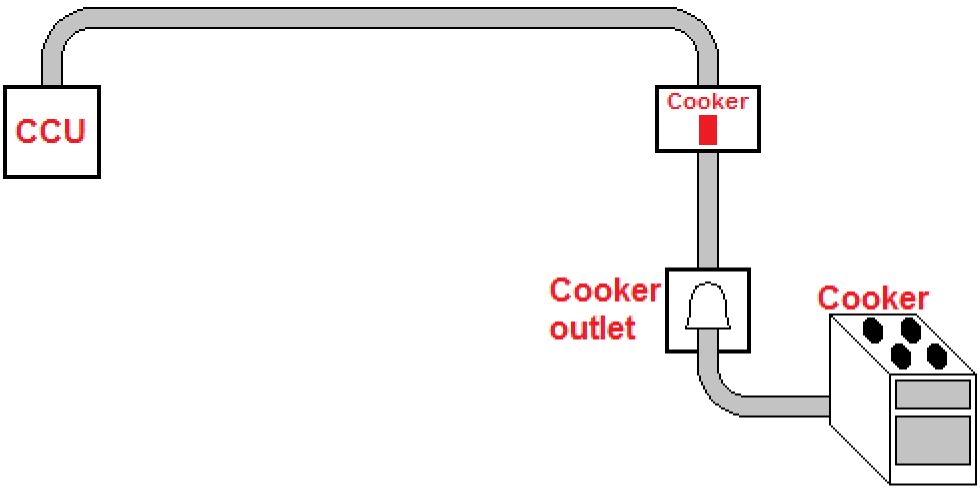
- 2 x 1.0kW hob plates
- 2 x 2.0kW hob plates
- 1 x 2.0kW oven/grill
- 1 x 3.0kW oven

$$\text{Maximum total power} = (2 \times 1) + (2 \times 2) + 2 + 3$$
$$= 11\text{kW}$$
$$\text{Maximum current} = \frac{P}{V}$$
$$= \frac{11 \times 1{,}000}{230}$$
$$= 47.83\text{A}$$

The assumed current demand, allowing for diversity, is:

$$\text{the first 10A at 100\%} = 10\text{A}$$
$$\text{leaving 37.83A at 30\%} = 11.35\text{A}$$
$$\text{Total} = \mathbf{21.35A}$$

This means that the cable supplying this cooker would have to have a rating of at least 21.35A. If the control unit contained a socket outlet then the rating would have to be at least 26.35A.



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Worksheet 7: Cooker circuits and diversity
Answer guide

Try the following problem.

1. The rating for a 230V electric cooker is:

- 4 x 2.75kW hob plates
- 1 x 2.5kW top oven
- 1 x 4.5kW main oven.

Calculate the maximum assumed current demand, allowing for diversity, if the cooker control is fitted with a 13A socket outlet.

The assumed current demand, allowing for diversity, is:

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Handout 8: Space heating

Learning outcome
The learner will:
3. know wiring systems of electrical installations.

Assessment criteria
The learner can:
3.1 describe principles of operation of different **circuit types.**

Range
Circuit types: Lighting, power and heating, alarm and emergency systems, data communications, control circuits, ring final, radial.

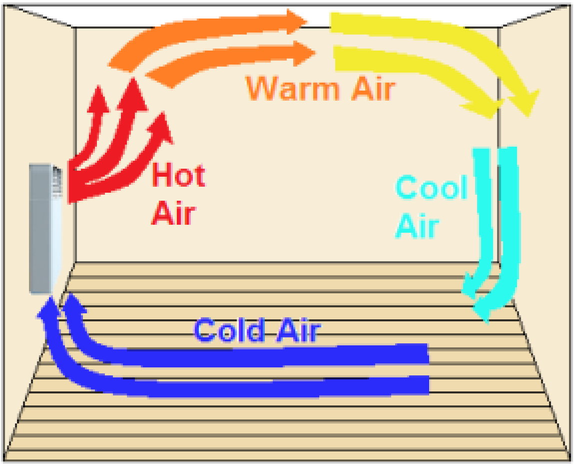
Space heating

Space heating is generally employed to warm an enclosed space in premises and is usually held in contrast with central heating, which warms many connected spaces at once from one heating source.

Space heaters can be divided into those that transfer their heat primarily by convection or by radiation.

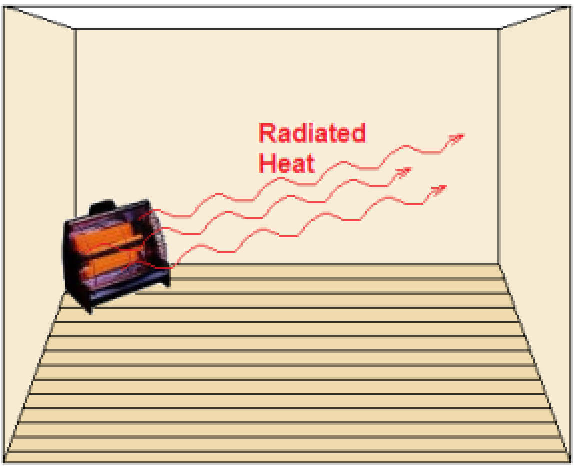
With **convection heaters**, heating elements either warm the air directly, or heat oil or another filler, which in turn transfers heat to the air. The air then warms the objects and people in the space.

Convective heaters are suitable for providing constant, diffuse heat in well-insulated rooms. Oil heaters warm up slowly but do not reach dangerous surface temperatures; wire-element heaters, which may be fan-assisted, reach operating temperature much more quickly but may pose a fire hazard.



Radiant heaters usually comprise tungsten filaments in heat-resistant quartz envelopes, mounted in front of a metal reflector in a plastic or metal case. They operate much like light bulbs but radiate their energy primarily in the infrared spectrum. They convert up to 86% of their input power to radiant energy, losing the remainder to conductive and convective heat.

The advantage of radiant heaters is that the radiation they produce is absorbed directly by clothing and skin, without first heating the air in the space. This makes them suitable for warming people in poorly-insulated rooms, or even outdoors.

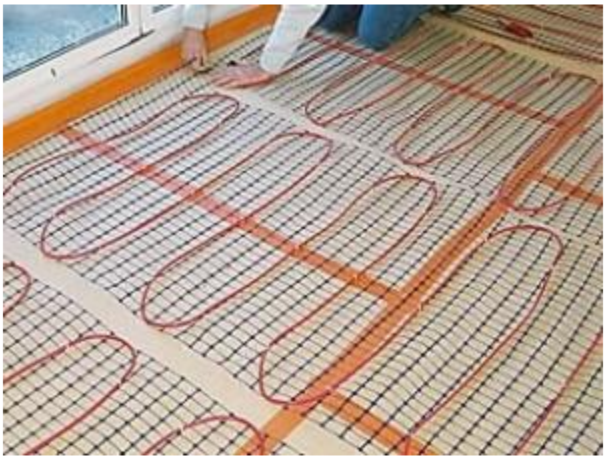


Most small electrical convector and radiant heaters can be connected via a flexible cord to a plug-top inserted into a convenient socket outlet. If the (small) heater is fixed to the wall it can be permanently connected into a socket outlet using a switched fused connection unit with a flex outlet (see right).

For larger heating appliances, eg electric storage heaters, a separate circuit for each heater wired back to its own protective device will be required. A flex outlet will be installed adjacent to the heater to make the final connections.

The type of flex required to make the final connection to the heater, whatever type it is, needs to be carefully considered and usually needs to be heat resistant flexible cable.

Underfloor heating



Underfloor heating systems, which can sit beneath stone, tile, wooden or even carpeted surfaces, will help to keep cold floors and rooms warm and can offer an alternative to using radiators to deliver central heating.

A series of electric wires are installed beneath or within the flooring as a means of heating an area or room such as a cold, tiled bathroom floor, for example.

The electric system installed will depend on the size of the room and the type of flooring it has; options include loose-fit wiring flexible enough to fit into small or awkward spaces, electric cable systems or heating mats you roll out to cover larger areas.

Underfloor heating is generally associated with stone or tiled floors but can be installed in a carpeted room – just ensure that the carpet and underlay aren't so dense that they stop the heat moving upwards.

The electric heating sheets or cables are fitted beneath the flooring and usually on top of a layer of screed (to ensure the surface is completely flat) and a layer of floor insulation (to keep the heating source travelling upwards rather than down).

In order to allow control of the temperature, a sensor is installed in the floor and connected to a thermostat. This often incorporates a time clock to allow the user to pre-set when the heating turns on and off.

Storage heaters

Heat-retaining clay bricks inside the storage heater are charged overnight by a heating element to store heat and release it during the day. Convection and radiation give out a comfortable balance of heat in the room. Storage heaters use Economy 7 electricity at night. The Economy 7 electric tariff is designed to save money on heating bills.

Storage heaters offer comfortable economical warmth throughout the day by taking advantage of low tariff, overnight electricity.

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Worksheet 8: Space heating
Answer guide

Try the following.

1. In an underfloor heating system, what is a cold tail?

2. State the two means of heat transference used in space heating.

3. Research what is meant by the term 'Economy 7' and describe the benefits for the consumer.

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Handout 9: Water heating

Learning outcome
The learner will:
3. know wiring systems of electrical installations.

Assessment criteria
The learner can:
3.1 describe principles of operation of different **circuit types.**

Range
Circuit types: Lighting, power and heating, alarm and emergency systems, data communications, control circuits, ring final, radial.

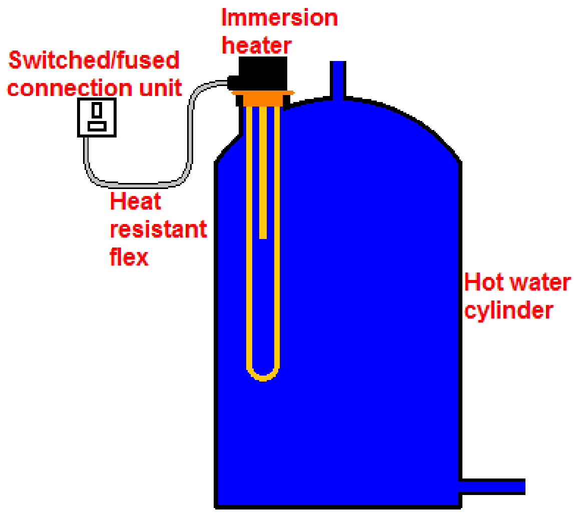
Water heating

There are various types of water heating but they can be classified into two groups:

- stored hot water
- instantaneous.

Stored hot water

The most common form of this group is the immersion heater that is installed into a hot water cylinder (see right).

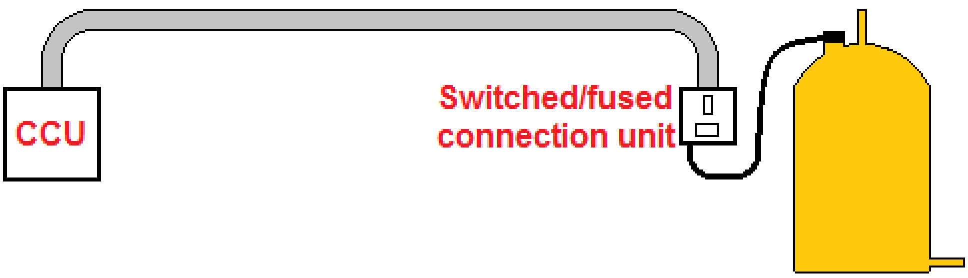


The element is constructed with resistance wire that will get hot when current flows through it and this heats the water.

A thermostat is fitted to disconnect the supply when the water reaches the required temperature; this is usually set at 55–60°, which is a compromise between low enough to reduce the risk of scalding and high enough to prevent the risk from Legionella.

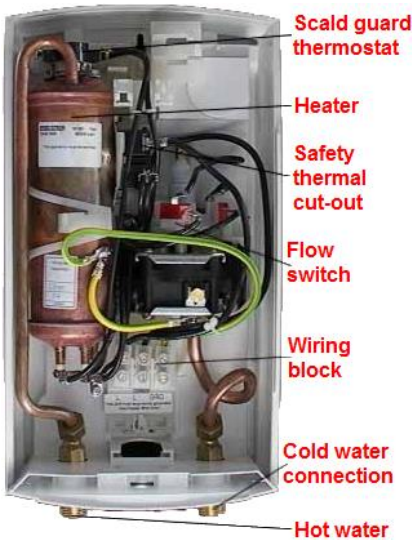
Also, Regulation 554.2.1 of BS 7671 requires a means to automatically prevent a dangerous rise in temperature.

Regulation 554.3.3 of BS 7671 requires that the immersion heater must be fed from its own circuit and connected into a switched/fused connection unit installed adjacent to the cylinder and connected by heat resistant flex as shown below:



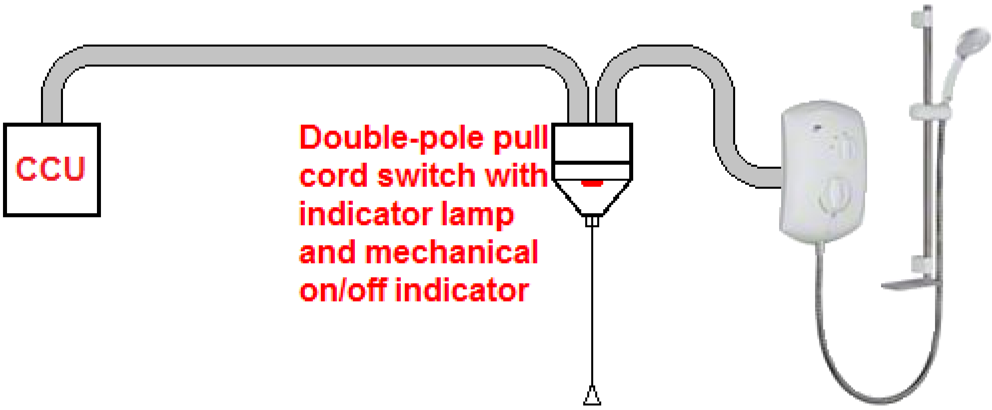
Instantaneous water heater

These high-power water heaters instantly heat water as it flows through the device and do not retain any water internally, except for what is in the heat exchanger coil. Common examples include instantaneous showers and point of use (POU) water heaters for supplying the hot tap of a sink or basin. The inside of an electric shower is shown right.



When the shower unit is turned on, water flows through the heater chamber and is heated quickly by the high-powered heating element. This then passes to the hot water outlet. The temperature of the water is regulated by the flow rate; a slow flow rate gives hot water and a fast flow rate gives cooler water.

The shower unit is fed from its own circuit in the consumer control unit and a double-pole switch is installed in the vicinity of the shower unit. See the circuit arrangement below:



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Handout 10: Alarm and emergency systems

Learning outcome
The learner will:
3. know wiring systems of electrical installations.

Assessment criteria
The learner can:
3.1 describe principles of operation of different **circuit types.**

Range
Circuit types: Lighting, power and heating, alarm and emergency systems, data communications, control circuits, ring final, radial.

Alarm and emergency systems

The alarm and emergency systems that electricians are most likely to encounter are the following:

- fire alarm systems
- intruder alarm systems
- emergency lighting.

Before looking at alarms systems, there is a need to understand basic circuit configurations, including the following:

- open circuit
- closed circuit.

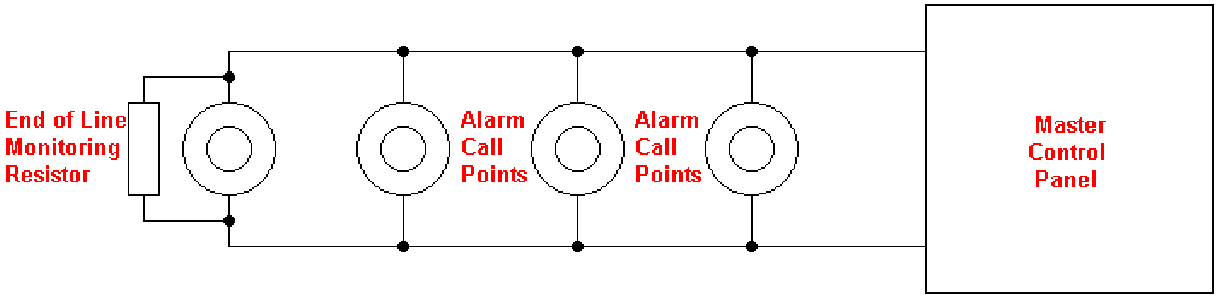
Open circuit

As the name would suggest, in the open circuit arrangement the circuit is incomplete or 'open' and detection devices close to initiate an alarm condition.

The advantage of this system is that, as detectors are connected in parallel with the circuit, it is easy to connect or disconnect sensors as required.

The drawback with this system is that if a circuit conductor or connection is broken, the alarm will not operate when required. However, by incorporating monitoring of the circuits, an alarm condition can be indicated when a conductor or connection is broken.

Monitoring is achieved by connecting an **end of line** (EOL) resistor across the circuit at the last detector (or call-point) and a monitoring voltage applied to the circuit; the resulting current will be relatively small. When a detector closes, the EOL resistor will be short-circuited and the current will increase greatly, which will be detected by the control panel that will initiate an alarm condition. This arrangement is shown simply below:

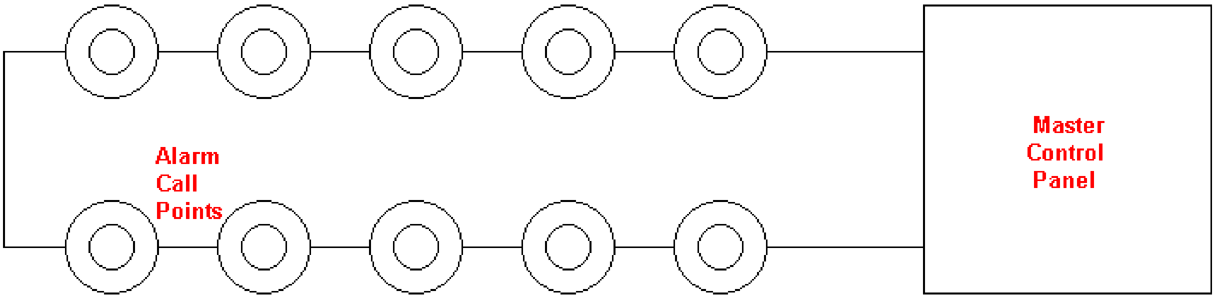


Closed circuit

As the name would suggest, in the closed circuit arrangement the circuit is complete or 'closed' and detection devices open to break the circuit to initiate an alarm condition.

The disadvantage of this system is that, as the detectors are connected in series, the circuit must be interrupted to insert additional sensors and this would prove difficult in practice.

The advantage of this system is that if a circuit conductor or connection is broken, the alarm will operate; this could be considered **fail safe** and therefore monitoring is not required.



Fire alarm systems

Fire alarm systems are designed to protect one or both of the following:

- life
- property.

When protecting life, the alarm will be initiated by a combination of manual call points and automatic detectors, and will generally be audible and possibly automatic to a remote alarm receiving centre who will then summon the emergency services.

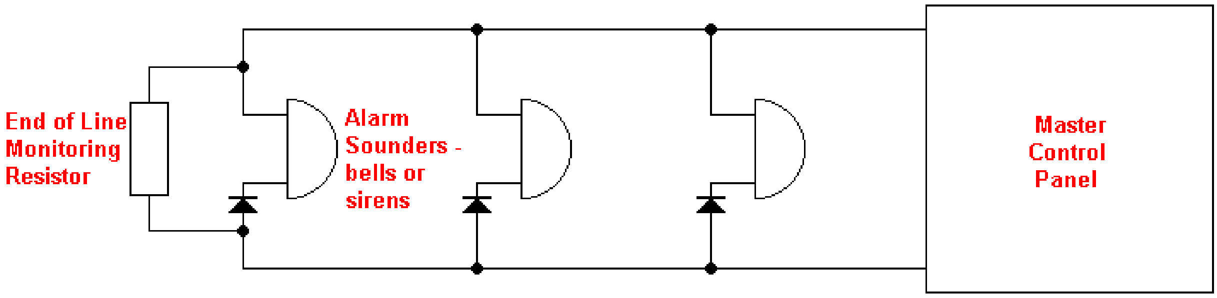
When protecting property, the alarm will generally be initiated by automatic detectors with emergency services being summoned by a remote alarm receiving centre; this is because these properties are generally unoccupied most of the time.

The range of automatic detectors includes:

- smoke detectors
- heat detectors
- flame detectors.

It is a requirement that firefighters do not have to search further than 30 metres into premises to determine the location of the fire. For this reason, a number of circuits are installed in zones.

Generally, there is more than one sounder circuit but not normally as many as there are detector circuits.
Fire alarm circuits are generally wired in the open circuit configuration so end of line monitoring is required. This monitoring is also applied to the sounder circuit but it is necessary for diodes to be installed so that the monitoring voltage does operate the sounder; the voltage is reversed in alarm condition to operate the sounder (see below):



When installing smoke detectors in domestic premises – apart from retrofit battery alarms – it is a requirement that the detectors are mains powered with battery backup and, if more than one is installed, they should be linked so that when one goes into alarm condition, they all go into alarm condition.

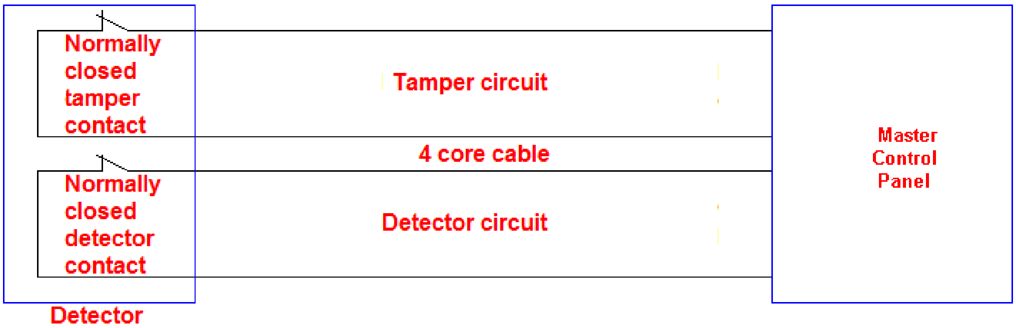
Intruder alarm systems

Intruder alarms are designed to detect an intrusion or attempted intrusion into premises. A range of detectors are available for this purpose, including:

- break glass detectors
- door and window contacts
- passive infrared movement detectors
- ultrasonic movement detectors
- microwave movement detector
- beam break detectors.

Most intruder alarm systems are wired closed circuit as a failsafe measure so that if the cable is cut the alarm is initiated anyway. Additional protection is provided by installing a tamper circuit that is run with the detector circuit. Enclosures of detectors (and sounder box and the panel itself) will be fitted with one or more micro-switches that will open the tamper circuit to give a tamper warning if the alarm is not set or a full alarm if it is set. Additionally, cutting the tamper circuit conductors will have the same effect.

Modern intruder alarm panels are multi-zone or addressable so detectors can be wired to their own circuits, thus making identification of the source of the alarm much easier. A typical detector zone arrangement is shown below:



Since the detector and tamper circuits have different polarities, if a would-be intruder tried to short out the detector contact, the probability is that they would short out the wrong pair of conductors and this would also trigger an alarm condition.

Emergency lighting

Emergency lighting must not be confused with standby lighting, whose purpose is to provide sufficient illumination for normal activities to continue. Emergency lighting provides sufficient illumination to allow occupants to safely evacuate premises in the event of an emergency. Similarly, emergency lighting will not provide long-term lighting but should last over a sufficient duration for the evacuation to take place; emergency lighting luminaires are rated at between one to three hours duration.

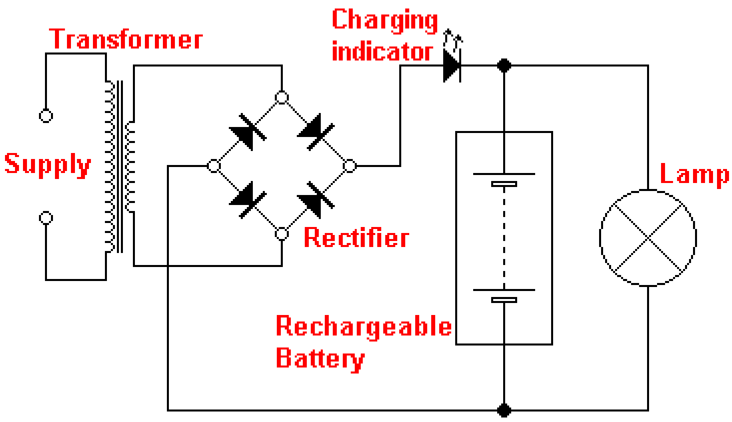
There are two classifications of emergency lighting:

- maintained
- non-maintained.

Maintained emergency lighting

These are emergency lighting luminaires that are illuminated at all materials times, ie all the time the premises are expected to be occupied. An example of this type is an illuminated exit sign in public entertainment premises, eg cinemas.

The luminaire is powered from the mains supply under normal conditions and this also keeps internal batteries charged. If the supply fails, the batteries keep the luminaire lit.

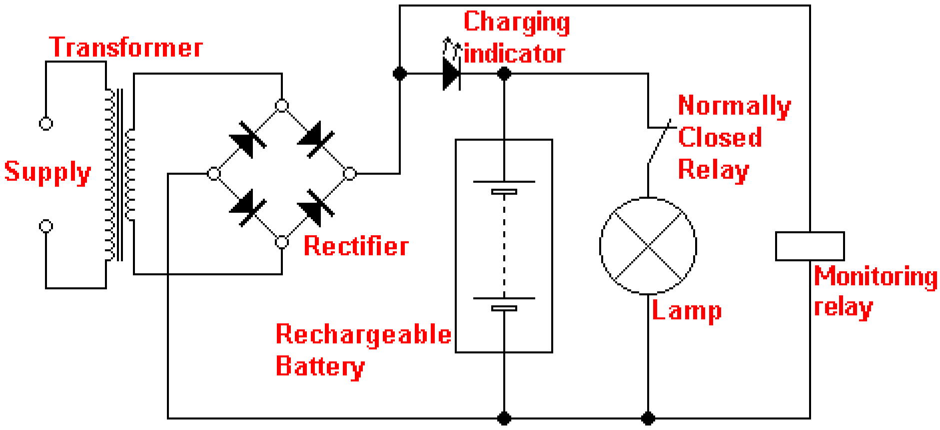


A circuit for this is shown above. Although a relay is shown, this is to make it easier to understand how it works; most luminaires achieve the switch-over by using electronics.

Non-maintained emergency lighting

These are emergency lighting luminaires that are only illuminated during a power failure. At other times the luminaire is off.

A circuit for this is shown on the right.



All emergency luminaires must be tested regularly to determine that they stay illuminated for the rated period of time, eg one or three hours. This is usually carried out by inserting a special 'fish-tail' key into a special witch to simulate a power interruption.

The period of time that the luminaire remains illuminated under battery power is then recorded on the luminaire testing sheet.

203: Electrical installations technology

Worksheet 9: Alarm and emergency systems
Answer guide

Try the following problems.

1. State the two circuit configurations for alarm circuits.

2. In an open circuit the detectors are connected in (delete as appropriate):

Series / Parallel

3. What device is connected to the end of an open circuit in order to check that the circuit has not been broken?

4. In closed circuit the detectors are connected in (delete as appropriate):

Series / Parallel

5. What two things are fire alarm circuits designed to protect?

6. Fire alarm systems are usually connected in:

Series / Parallel

7. Intruder alarm systems are usually connected in:

Series / Parallel

8. State the two classifications for emergency lighting.

203: Electrical installations technology

Handout 11: Data communications

Learning outcome
The learner will:
3. know wiring systems of electrical installations.

Assessment criteria
The learner can:
3.1 describe principles of operation of different **circuit types.**

Range
Circuit types: Lighting, power and heating, alarm and emergency systems, data communications, control circuits, ring final, radial.

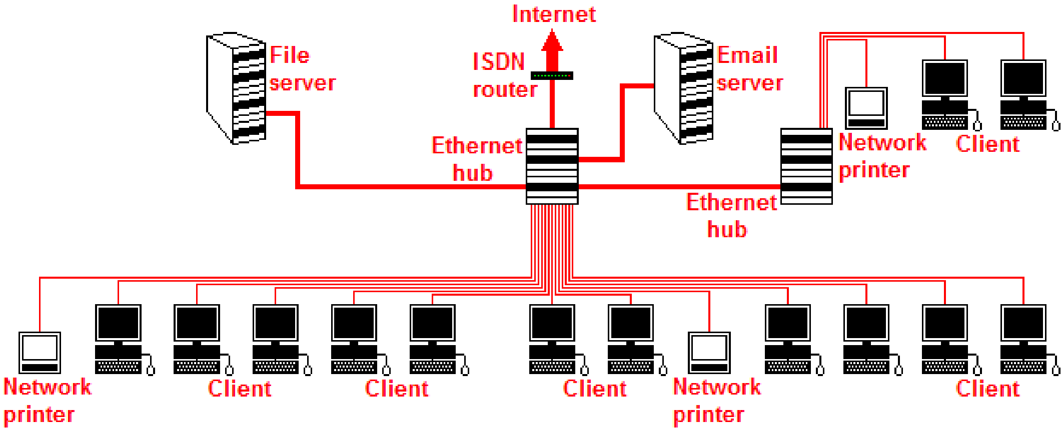
Data communications

In this day and age, the use of computers is widespread, with many businesses, hospitals and schools having their own data networks linking all of their computers together to allow them to share data internally and externally via the internet.

Whilst the role of the electrician will not generally involve installing the computer and associated equipment (servers, data switches, etc), the electrician may well need to install the data cabling connecting this network together.

Local Area Network (LAN)

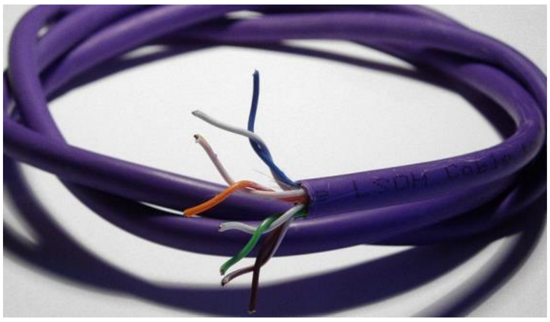
A LAN is installed within an organisation to link computers, servers and printers together, and to connect to other networks, including the internet. A basic arrangement is shown below:



Electricians are likely to be called on to install the cabling between the Ethernet hub and the users' equipment (client and printer in the above example). The cables from the hub to the equipment will generally be installed in some form of cable containment system, eg trunking or cable basket. The cable will generally be terminated at a suitable socket (eg RG45) adjacent to the equipment, with the final connection made by an Ethernet patch lead plugged into the socket at one end and the equipment at the other.
The cable used has to meet very stringent requirements if it is to transfer data quickly and without loss of data, and not be prone to interference and cross-talk.
Cables are categorised according to their maximum operating speeds, as detailed below.

- **Category 3**: supports frequencies up to 16MHz and was commonly used in the 1980s.
- **Category 4**: supports frequencies up to 20MHz but was quickly replaced by category 5.
- **Category 5**: supports frequencies up to 100MHz and is the most common type of cable in use today.
- **Category 6**: supports frequencies up to 250MHz; the augmented category 6 (Cat 6a) reaches speeds of 500MHz and is gaining increased usage.

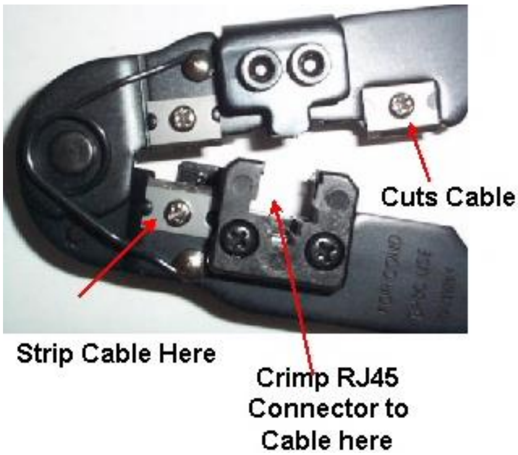
The most common category installed is still Cat 5. This cable consists of four pairs of insulated conductors. Each pair is twisted together to reduce interference and cross-talk, and the pitch of the twist is different for each pair. The diagram on the right shows a cable stripped and ready for termination.



The cables are either crimped or pressed into RJ45 plugs and sockets, as shown below:

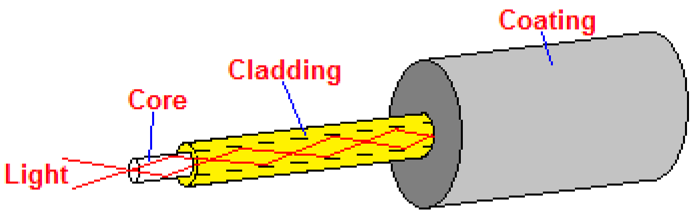
Here are a few installation points to note.

- Maximum length of cable should not exceed 100 metres. If longer runs are required, the use of active hardware, such as a repeater or a switch, is necessary.
- This allows for 90 metres of fixed cabling, two connectors and two patch leads of 5 metres – one at each end.
- Bending radius should be at least 4 times the overall diameter of the cable.



Fibre optic

This is being used more frequently for high volume data transmission. An optical fibre cable is a cable containing one or more optical fibres. The latter consist of a core and a cladding layer, selected for total internal reflection.



When a light source, usually a laser, is projected in one end, it is reflected off the borders between the core and the cladding, and will emerge from the other end with only a small level of reduction in the light strength. By rapidly switching on and off the light source, digital data in vast quantities can be transmitted over very long distances with minimal interference and data loss.

Advantages of fibre optic:

- very large data transfer rates
- no electromagnetic interference
- longer lengths of run without the need for repeaters
- better data security.

Disadvantages:

- high installation cost
- complicated installation procedure
- possible health risk during installation.

When stripping the cables, there is a possibility that a small shard of fibre optic cable could pierce the skin and enter the blood stream; it could then be carried around the body and possibly cause fatal damage within vital organs.

Care must be taken never to look down the end of the fibre optic cable. This is because if the laser is fired at one end of the cable, it could cause damage if it gets into the eyes when it comes out of the other end of the cable.

203: Electrical installations technology

Handout 12: Control circuits

Learning outcome
The learner will:
3. know wiring systems of electrical installations.

Assessment criteria
The learner can:
3.1 describe principles of operation of different **circuit types.**

Range
Circuit types: Lighting, power and heating, alarm and emergency systems, data communications, control circuits, ring final, radial.

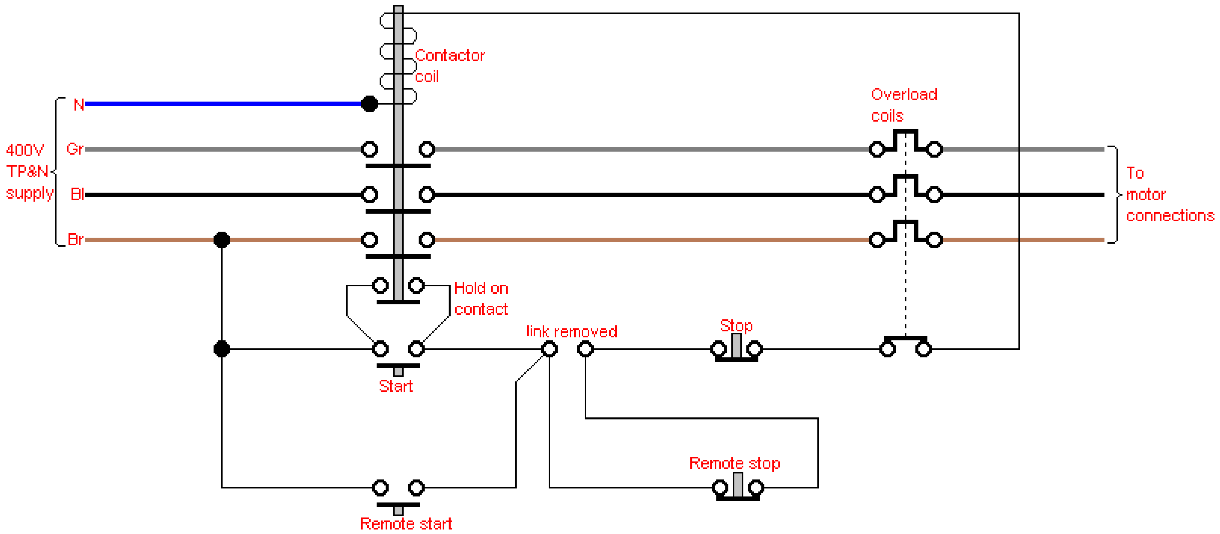
Control circuits

BS 7671:2018 define an '***Auxiliary circuit***' as a "*Circuit for transmission of signals intended for control, detection, supervision or measurement of the functional status of a main circuit*"; a control circuit is therefore classified as an auxiliary circuit. **Section 557** of BS 7671:2018 deals with the requirements of auxiliary circuits.

The principle of any control circuit is to turn a load on or off; this could be achieved by a simple switch. However, we may wish to control equipment automatically, depending on the situation of one or more sensors. An example of this is a thermostat and a time clock to control a heating system.

A control circuit could be defined as a circuit that uses control devices, eg stop buttons, start buttons, limit switches, temperature sensors, relays, etc, to turn loads on and off. Sometimes, control circuits operate at lower voltages than the power circuits that they control.

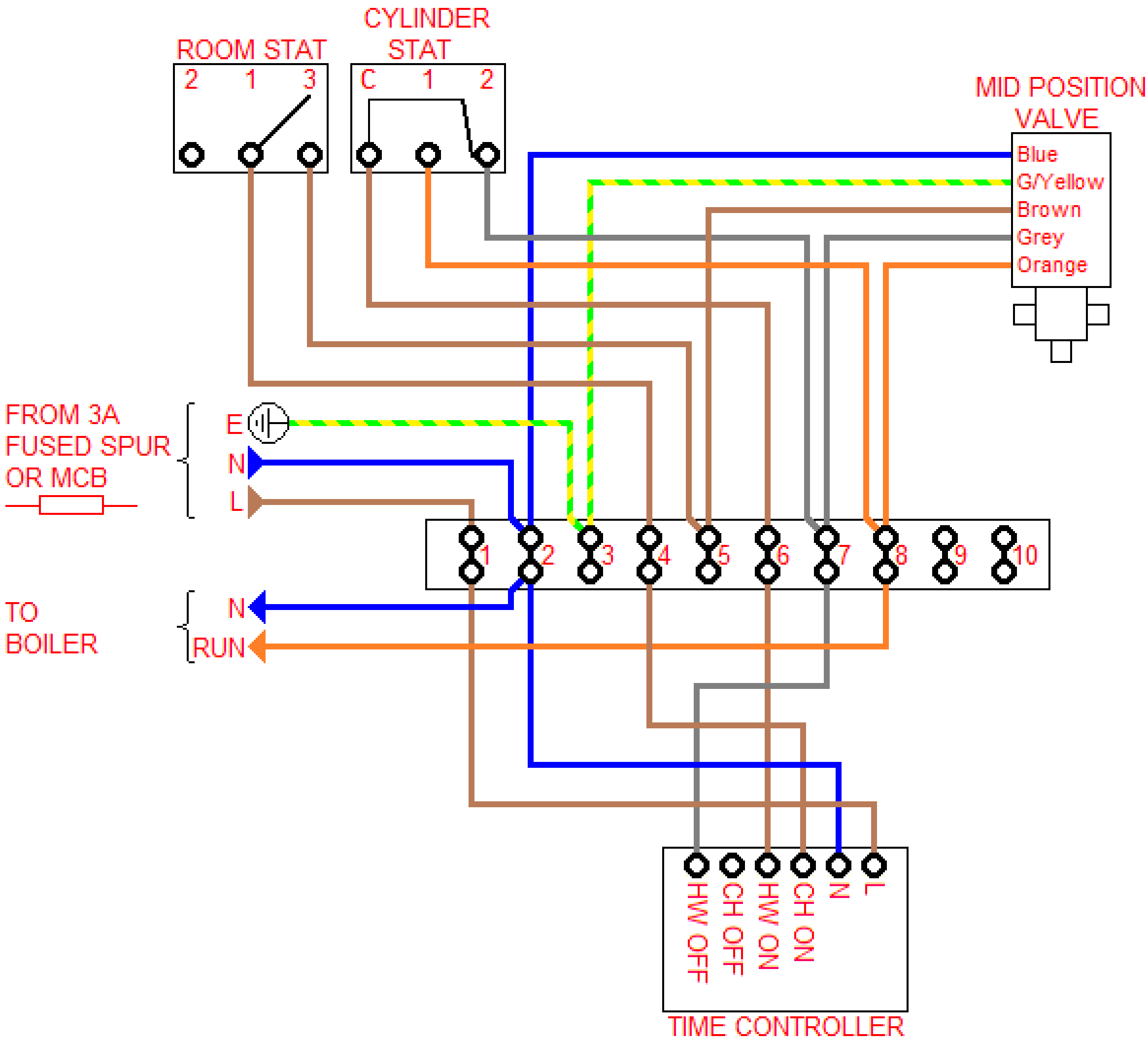
Apart from lighting circuits that are covered elsewhere, probably the simplest control circuit that an electrician needs to be familiar with is the direct on line (dol) starter for a motor. The circuit is shown below:



The control circuit above is indicated by the thinner wires, whereas the motor cables are the thicker ones.

Control circuits for industrial processes can be very complicated with large cabinets full of relays, contactors and timers with inputs from many different types of sensors. Wiring and fault-finding on these requires the provision of good wiring and schematic diagrams.

Another control circuit that the electrician may need to install in domestic premises is a central heating control system. There are different configurations, depending on the system arrangement, and these are generally identified by a single letter. Below is the arrangement for one of the common configurations: the **Y-Plan**.



203: Electrical installations technology

Handout 13: Wiring systems

Learning outcome
The learner will:
3. know wiring systems of electrical installations.

Assessment criteria
The learner can:
3.2 identify **wiring systems** for different **environments.**

Range
Wiring systems: Cable tray, cable trunking, cable conduit, ladder racking, thermoplastic multi-core, flat profile, SWA, MICC, FP200, thermoplastic single-core, support methods and requirements, component parts.
Environments: Domestic, commercial, hazardous, industrial installation, agricultural.

Wiring systems

Electricians will be called on to install electric systems in a wide range of environments with the more common being:

- domestic installations
- commercial installation
- hazardous installations
- industrial installations
- agricultural installations.

These will all have their own unique hazards, both to anyone using the installation and also to the installation itself, from activities within those premises or the environment within those premises.

The wiring system chosen for a particular environment will depend on the level of protection required by the cabling and the type of support needed.

In any electrical system, the means of delivery of electrical energy to a load will vary. Different types of cable are used, as well as different ways in which these cables are supported and protected. The name attached to these are called wiring systems and they fall into general areas.

- **Clipped direct**: We can clip mineral insulated (MICC), steel wired armoured (SWA), cross-linked polyethylene (XLPE), polyvinyl chloride/polyvinyl chloride (PVC/PVC) cables directly to a surface, using appropriate clips. The setting defines the nature of the clips and how the cables are run.
- **Steel conduit and trunking**: Generally used to deliver single core cables in industrial, commercial and health settings. They are strong and able to resist high mechanical stresses.
- **Plastic conduit and trunking**: As with steel conduit and trunking, single core cables are generally installed in schools and commercial premises. It is less robust than steel conduit but easier to install.
- **Cable tray**: Cable tray is commonly used to support a number of cables where individual clipping is difficult or not economical. Tray is used either above ceilings or in industrial or commercial settings. It has a range of sizes from 50mm to 1,000mm.
- **Ladder rack**: This is similar to cable tray but with greater strength and is used in industrial settings to deliver large numbers of sub-main cables.
- **Basket tray**: Again, this is similar to cable tray but is more likely to be used in commercial premises for large amounts of smaller cables.

203: Electrical installations technology

Handout 14: PVC cables

Learning outcome
The learner will:
3. know wiring systems of electrical installations.

Assessment criteria
The learner can:
3.2 identify **wiring systems** for different **environments.**

Range
Wiring systems: Cable tray, cable trunking, cable conduit, ladder racking, thermoplastic multi-core, flat profile, SWA, MICC, FP200, thermoplastic single-core, support methods and requirements, component parts.
Environments: Domestic, commercial, hazardous, industrial installation, agricultural.

PVC cables

The vast majority of cables encountered by electricians will have conductors made of copper. Some larger cables (16mm^2 and above) may have aluminium conductors.

Unless they are placed out of reach, eg overhead, these cables will need to be insulated to prevent short circuits and people and livestock coming into contact with the live conductors.

The most commonly utilised insulator currently used is **polyvinyl chloride**, referred to as **PVC**. This material is one of the many plastics that are generally used is industry for a wide range of purposes but is the most suitable for cable insulation.

Although it is very versatile, PVC cable is susceptible to damage when exposed to high temperatures and also becomes brittle at temperatures approaching freezing point. It also requires mechanical protection in many situations to prevent damage to the cable.

PVC comes in two main forms:

- thermoplastic
- thermosetting.

Thermoplastic

This is the standard type of PVC insulation used on most electrical cables. It has a maximum continuous operating temperature of 70 °C and will soften above this temperature, resulting in possible ‘conductor migration’.

Thermosetting

This type of cable is designated as XLPE (cross-linked polyethylene). It has a higher continuous operating temperature of 90 °C. It is often used for mains distribution because it can operate at higher temperatures, which can bring about a reduction in conductor size with larger cables.

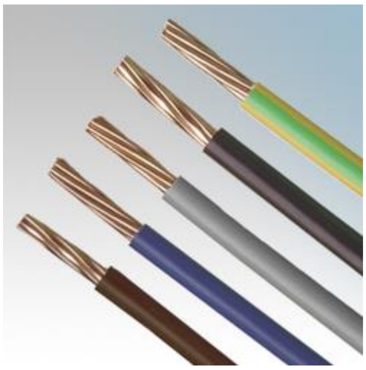
Low smoke and fume (LSF) cable

One major drawback of PVC is that when it is burnt, it can produce hydrogen chloride fumes that are toxic; these fumes can also produce hydrochloric acid on surfaces.

Many specifications for public buildings, such as schools and offices, will require the installation of LSF cable to reduce this risk in the event of a fire.

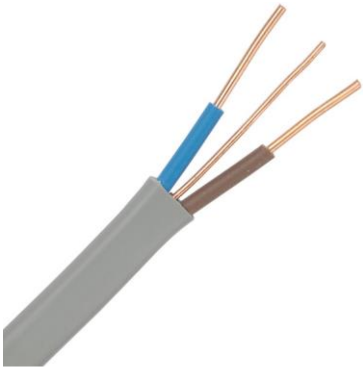
PVC cable types

PVC single core (6491X)



- This cable comes in sizes from 1.0mm^2 upwards and usually has stranded conductors, although single strand 'solid' conductor cable is still available.
- This type of cable requires additional mechanical protection and is generally installed in conduit and trunking.
- It is generally found in commercial, industrial and agricultural installations.
- A range of insulation colours are available to facilitate cable identification.

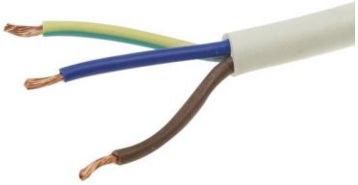
PVC insulated PVC sheathed flat twin and cpc (6242Y)



- This cable comes in sizes from 1.5mm^2 upwards; 1.5mm^2 and 2.5mm^2 have solid conductors, and larger sizes have stranded conductors.
- The sheathing provides some mechanical protection for the cable and it can be clipped directly to a surface without any other protection in less onerous conditions.
- It has PVC insulated conductors and an uninsulated cpc conductor.
- Flat three core and cpc (6243Y) is also available, as is single core and cpc.
- It is generally, but not exclusively, used for wiring domestic installations.

PVC insulated PVC sheathed flexible cable (3092Y and 3093Y)

- This cable comes in sizes from 0.5mm^2 upwards.
- Each conductor is made up of many fine strands which make the cable much more flexible.
- The sheathing provides some mechanical protection for the cable.
- Whilst two- and three-core cables are the most common, this type of cable is available with many cores.
- It is generally used for connecting portable appliances to the socket outlet and for connecting lighting points, eg pendant ceiling rose.
- In order to ensure that all the strands are clamped by the terminals and that to avoid inappropriate separation or spreading BS 7671:2018 requires the conductor ends to be suitably treated.



203: Electrical installations technology

Worksheet 10: PVC cables

Answer guide

Try the following problems.

1. State the main difference between PVC thermoplastic and PVC thermosetting cables.

2. State the cable manufacturers' code for the following cable types:

PVC insulated single core

PVC insulated PVC sheathed flat twin and cpc

PVC insulated PVC sheathed flat 3-core and cpc

PVC insulated PVC sheathed 2-core flexible cable

PVC insulated PVC sheathed 3-core flexible cable

3. State the type of cable that is often specified for public buildings.

203: Electrical installations technology

Handout 15: Steel wire armoured cable (SWA)

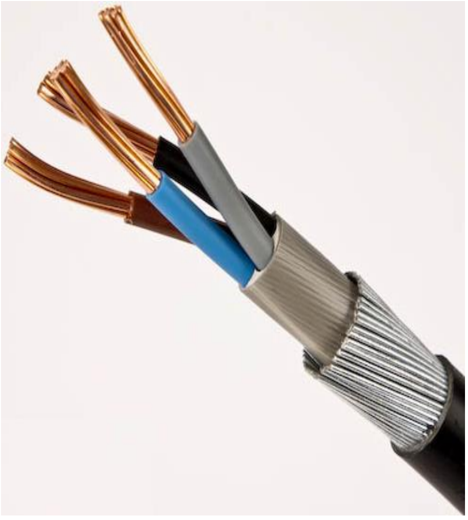
Learning outcome
The learner will:
3. know wiring systems of electrical installations.

Assessment criteria
The learner can:
3.2 identify **wiring systems** for different **environments.**

Range
Wiring systems: Cable tray, cable trunking, cable conduit, ladder racking, thermoplastic multi-core, flat profile, SWA, MICC, FP200, thermoplastic single-core, support methods and requirements, component parts.
Environments: Domestic, commercial, hazardous, industrial installation, agricultural.

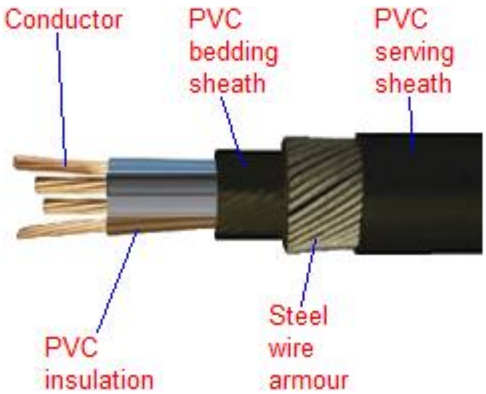
Steel wire armoured (SWA) cable

SWA cables are used extensively for main and sub-main cables, and for wiring circuits in industrial installations. They can also be buried directly in the ground and are therefore useful for connecting between buildings in domestic installations. The cable consists of single or multi-core PVC insulated conductors made of copper or aluminium with steel wire armour and PVC over sheath.



Typical sizes range from 50mm^2–1,000mm^2 for single core types and anything from 1.5mm^2 up to 400mm^2 for two, three and four core types.

The cable can be fixed directly on to walls, using cable cleats, or laid directly in the ground or in cable ducts. If several cables are to follow the same route, they may be best supported on cable tray, ladder or racks.



The steel wire armouring can be used as the circuit protective conductor (cpc) but it must be ascertained from manufacturers' information that it has at least the equivalent cross-sectional area as the corresponding copper cpc.

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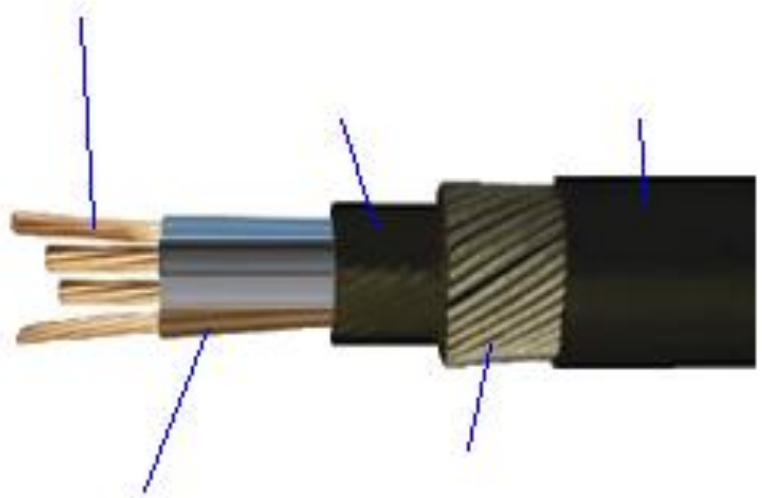
Worksheet 11: Steel wire armoured cable (SWA)
Answer guide

Try the following problems.

1. State four installation methods for steel wire armoured cable.

2. The steel wire armour can be used as the cpc, provided:

3. Label the following diagram:



203: Electrical installations technology

Handout 16: Fire resistant cables

Learning outcome

The learner will:

3. know wiring systems of electrical installations.

Assessment criteria

The learner can:

3.2 identify **wiring systems** for different **environments.**

Range

Wiring systems: Cable tray, cable trunking, cable conduit, ladder racking, thermoplastic multi-core, flat profile, SWA, MICC, FP200, thermoplastic single-core, support methods and requirements, component parts.

Environments: Domestic, commercial, hazardous, industrial installation, agricultural.

Fire resistant cables

There are industrial and commercial installations that need to continue working even when subjected to high temperatures and fire. Examples of these are fire alarm installations, centrally fed emergency lighting installations and petro-chemical installations. Two types of cable are available for this purpose:

- mineral insulated copper clad (MICC)
- FP200.

Mineral insulated copper clad (MICC) cable

This cable is made from copper conductors inside a copper sheath, insulated by inorganic **magnesium oxide** powder. The name is often abbreviated to **MICC** or **MI** cable, and it's known in the trade as **pyro** (because the original UK manufacturer is a company called Pyrotenax). A similar product sheathed with metals other than copper is called mineral insulated metal sheathed (**MIMS**) cable.

MI cables may be covered with a PVC sheath that is coloured for identification purposes: red for fire alarms, white for emergency lighting and orange for general purpose. The plastic sheath provides additional corrosion protection for the copper sheath, as well as reducing shock risk under fault conditions.

Advantages

- fireproof
- great mechanical strength
- waterproof
- non-ageing
- small overall diameter
- high current carrying capacity
- earth continuity
- high corrosion resistance
- high operating temperature.

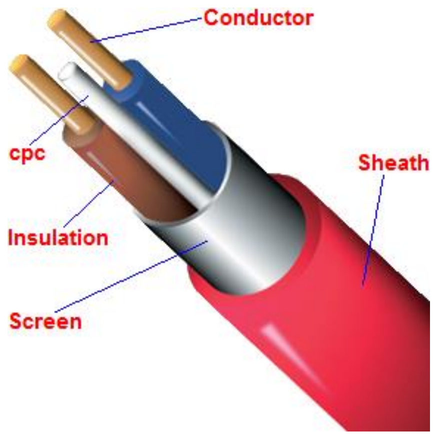
Disadvantages

- moisture absorption
- complicated termination process
- cost.

FP200

Key applications:

- fire detection and fire alarm systems for buildings
- voice alarm systems
- emergency lighting
- other essential service circuits.



The conductors are made from plain annealed copper solid (1.0–2.5mm^2) or stranded (4.0mm^2) circular.

The conductor insulation is high-performance damage resistant Insudite*. Insudite is a tough composite insulation that is resistant to impact, nicking and abrasion, ie all things that normally result in failure of silicone insulated cables. Consequently, protective ferrules are not required.

The screen is made from laminated aluminium tape screen bonded to sheath and in contact with full size tinned annealed copper circuit protective conductor, which provides automatic screen earthing.

The sheath is made from robust thermoplastic LSOH sheath (the colours are white or red; other colours to special order). For external exposure, the use of a white sheath is recommended.

The cable passes a set of tests specified in BS 6387:2013 (Test method for resistance to fire of cables required to maintain circuit integrity under fire conditions), referred to as the CWZ tests, which comprise of three separate fire, water and shock tests. In order to meet CWZ and comply with the standard, the cable must pass the following three separate tests:

- C: resistance to fire at 950ºC for three hours
- W: resistance to fire and water at 650ºC for 30 minutes
- Z: resistance to fire and mechanical shock at 950°C for 15 minutes.

Advantages

- Fire resistant
- Good mechanical strength
- waterproof
- easy to terminate
- relatively cheap compared to MICC.

Disadvantage

- Types with silicon insulation require ferrules to be fitted because this insulation is brittle and easily damaged.

203: Electrical installations technology

Worksheet 12: Fire resistant cables
Answer guide

Try the following problems.

1. State two types of fire resistant cables.

2. State the insulation used in mineral insulated cable.

3. State three advantages of mineral insulated cable.

4. State three disadvantages of mineral insulated cable.

5. State three advantages of FP200 cable.

6. State a disadvantage of FP200 cable.

203: Electrical installations technology

Handout 17: Conduit systems

Learning outcome
The learner will:
3. know wiring systems of electrical installations.

Assessment criteria
The learner can:
3.2 identify **wiring systems** for different **environments**
3.5 identify purpose of **specialised** equipment for installing **wiring systems**
3.6 calculate spacing factor of **wiring enclosures**.

Range
Wiring systems: Cable tray, cable trunking, cable conduit, ladder racking, thermoplastic multi-core, flat profile, SWA, MICC, FP200, thermoplastic single-core, support methods and requirements, component parts.
Environments: Domestic, commercial, hazardous, industrial installation, agricultural.
Specialised: Conduit and tray benders, stocks, dies, formers.
Wiring enclosures: Conduit, trunking.

Conduit systems

Conduit is used as a containment system for electrical cables. There are three main types:

- metal (steel)
- PVC
- flexible.

Metal (steel) conduit

The most common form of conduit used for electrical installation work is steel conduit. The screwed steel conduit system is undoubtedly the most popular for permanent wiring installations, particularly in modern commercial and industrial buildings.

Advantages of steel conduit:

- affords conductors good mechanical protection
- permits easy rewiring
- minimises fire risks
- can be utilised as the circuit protective conductor.

Disadvantages of steel conduit:

- under certain conditions, moisture is liable to form on the inside of the conduit
- expensive compared with some other systems
- liable to corrosion when subject to acid, alkali and other fumes.

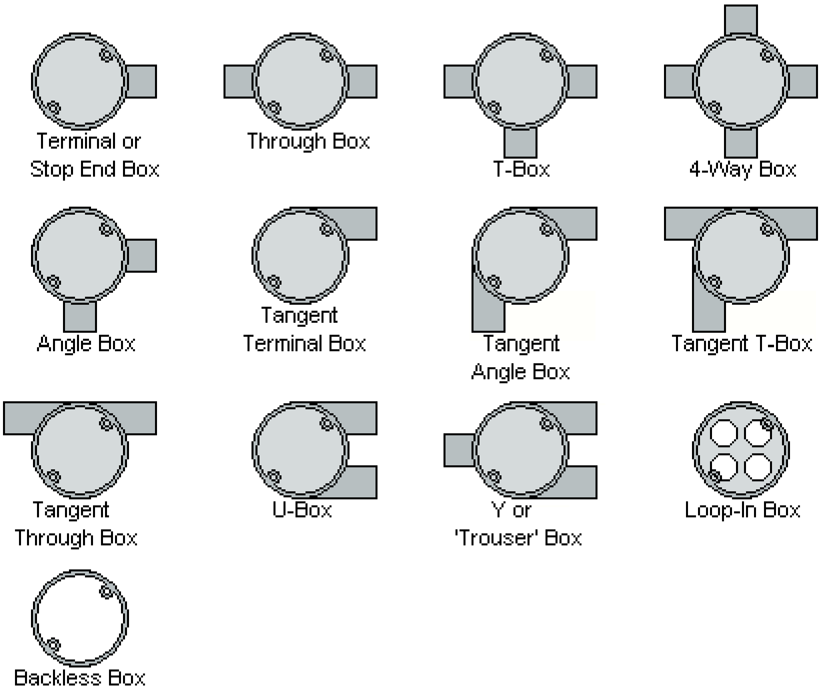
Types of steel conduit finish:

- galvanised for outdoors or situations where steam or dampness is present.
- black enamelled for general work in dry situations.

Typical sizes are 16, 20, 25 and 32mm diameters – available in 3.75 metre lengths.

The working of steel conduit, ie cutting, threading, bending, etc, will be covered in Unit 204.

Steel conduit accessories



Specialist steel conduit tools

PVC conduit

The basic material is polyvinyl chloride (PVC), which is produced in both flexible and rigid forms. It is impervious to acids, alkalis, oil, aggressive soils, fungi and bacteria, and is unaffected by sea, air and atmospheric conditions. It withstands all pests and does not attract rodents. PVC conduit may be buried in lime, concrete or plaster without harmful effects.

Advantages of PVC conduit:

- light in weight and easy to handle
- easy to saw, cut and clean
- simple to form and bend
- does not require painting
- minimal condensation, due to low thermal conductivity in walls
- speed of erection
- excellent electrical and fire resistant properties.

Disadvantages of PVC conduit:

- care must be taken when gluing joints to avoid forming a barrier across the inside of the conduit
- if insufficient adhesive is used the joints may not be waterproof
- PVC expands around five times as much as steel and this expansion must be allowed for.

Types of PVC conduit:

- **Heavy Gauge Super High Impact**: Designed to withstand arduous site conditions and extreme weather conditions. Major building contractors and government departments often specify this type of conduit for use.
- **Light Gauge Super High Impact**: Suitable for pre-cast and *in situ* concrete work.
- **Heavy Gauge Standard Impact**: Suitable for typical conduit installations.
- **Heavy Gauge High Temperature Material**: Suitable for installations where 80/85°C temperatures are expected.

Typical sizes

Rigid round PVC conduit is typically available in the following sizes: 16, 20, 25, 32, 38 and 50mm diameter in 3 metre lengths.

Flexible conduit

Flexible conduits are used to connect to motors or other devices where isolation from vibration is useful.

Flexible conduit can be obtained in PVC or metallic form. Whichever type is used, a separate cpc must be installed throughout the entire length of the conduit and terminated to an appropriate earth terminal at each end.

Sizing conduit

The size of conduit required is worked out using **Tables E1**, **E2**, **E3** and **E4** of the IET On-Site Guide; these are reproduced on the following pages of this Handout. For each of the cables that are going to be installed, a term for that particular size of cable is given in either **Table E1** or **E3**, depending on whether we are dealing with short straight runs or long runs or runs with bends. The terms for all the cables are added together and compared to the factors for conduit given in **Table E2** or **E4**. The size of conduit that is most suitable for use with these cables is the one whose factor is equal to or greater than the sum of the cable factors.

Table E1 – Cable factors for use in conduit in short straight runs

Type of conductor	Conductor cross-sectional area (mm^2)	Cable factor
Solid	1	22
	1.5	27
	2.5	39
Stranded	1.5	31
	2.5	43
	4	58
	6	88
	10	146
	16	202
	25	385

Table E2 – Conduit factors for use in short straight runs

Conduit diameter (mm)	Conduit factor
16	290
20	460
25	800
32	1400
38	1900
50	3500
63	5600

Table E3 – Cable factors for use in conduit in long straight runs over 3m or runs of any length incorporating bends

Type of conductor	Conductor cross-sectional area (mm^2)	Cable factor
Solid or Stranded	1	16
	1.5	22
	2.5	30
	4	43
	6	58
	10	105
	16	145
	25	217

The above tables reproduced from the IET On-Site Guide

Table E4 – Conduit factors for runs incorporating bends and long straight runs

Length of run (m)	Conduit diameter (mm)																			
	16	20	25	32	16	20	25	32	16	20	25	32	16	20	25	32	16	20	25	32
	Straight				One bend				Two bends				Three bends				Four bends			
1	Covered by Tables E1 and E2				188	303	543	947	177	286	514	900	158	256	463	818	130	213	388	692
1.5					182	294	528	923	167	270	487	857	143	233	422	750	111	182	333	600
2					177	286	514	900	158	256	463	818	130	213	388	692	97	159	292	529
2.5					171	278	500	878	150	244	442	783	120	196	358	643	86	141	260	474
3					167	270	487	857	143	233	422	750	111	182	333	600				
3.5	179	290	521	911	162	263	475	837	136	222	404	720	103	169	311	563				
4	177	286	514	900	158	256	463	818	130	213	388	692	97	159	292	529				
4.5	174	282	507	889	154	250	452	800	125	204	373	667	91	149	275	500				
5	171	278	500	878	150	244	442	783	120	196	358	643	86	141	260	474				
6	167	270	487	857	143	233	422	750	111	182	333	600								
7	162	263	475	837	136	222	404	720	103	169	311	563								
8	158	256	463	818	130	213	388	692	97	159	292	529								
9	154	250	452	800	125	204	373	667	91	149	275	500								
10	150	244	442	783	120	196	358	643	86	141	260	474								

Additional factors

- For 38mm diameter use 1.4 x (32mm factor)
- For 50mm diameter use 2.6 x (32mm factor)
- For 63mm diameter use 4.2 x (32mm factor)

The above table reproduced from the IET On-Site Guide

Example 1

The following cables are to be drawn into a straight 2m length of conduit:

- 2 off solid core 1.5mm^2
- 4 off solid core 2.5mm^2
- 4 off stranded 4mm^2.

Calculate the conduit size required to accommodate these cables.

Solution:

Factor for 2 off solid core 1.5mm^2 from On-Site Guide Table E1 $= 27 \times 2$

$= 54$

Factor for 4 off solid core 2.5mm^2 from On-Site Guide Table E1 $= 39 \times 4$

$= 156$

Factor for 4 off stranded 4mm^2 from On-Site Guide Table E1 $= 58 \times 4$

$= 232$

$54 + 156 + 232 = 442$

From On-Site Guide Table E2, size required $=$ **20mm**

Example 2

The following cables are to be drawn into a 2m length of conduit with 2 bends:

- 2 off solid core 1.5mm^2
- 4 off solid core 2.5mm^2
- 4 off stranded 4mm^2

Calculate the conduit size required to accommodate these cables.

Solution:

Factor for 2 off solid core 1.5mm^2 from On-Site Guide Table E3 $= 22 \times 2$

$= 44$

Factor for 4 off solid core 2.5mm^2 from On-Site Guide Table E3 $= 30 \times 4$

$= 120$

Factor for 4 off stranded 4mm^2 from On-Site Guide Table E3 $= 43 \times 4$

$= 172$

$44 + 120 + 172 = 336$

From On-Site Guide Table E4, size required $=$ **25mm**

203: Electrical installations technology

Worksheet 13: Conduit systems
Answer guide

Try the following problems.

1. State three advantages of steel conduit.

2. State three disadvantages of steel conduit.

3. List four sizes (diameters) of steel conduit.

4. List three specialist tools needed to work on steel conduit.

5. State three advantages of PVC conduit.

6. State three disadvantages of PVC conduit.

7. The following cables are to be drawn into a 4m length of conduit with 1 bend:

- **6 off solid core 1.5mm^2**
- **6 off solid core 2.5mm^2**
- **2 off stranded 4mm^2.**

Calculate the conduit size required to accommodate these cables.

203: Electrical installations technology

Handout 18: Trunking systems

Learning outcome
The learner will:
3. know wiring systems of electrical installations.

Assessment criteria
The learner can:
3.2 identify **wiring systems** for different **environments**
3.6 calculate spacing factor of **wiring enclosures**.

Range
Wiring systems: Cable tray, cable trunking, cable conduit, ladder racking, thermoplastic multi-core, flat profile, SWA, MICC, FP200, thermoplastic single-core, support methods and requirements, component parts.
Environments: Domestic, commercial, hazardous, industrial installation, agricultural.
Wiring enclosures: Conduit, trunking.

Trunking systems

Trunking is used as a large-scale containment system for electrical cables in industrial and commercial installations. There are three main types:

- metal (steel)
- PVC
- mini trunking.

Metal (steel) trunking

Cable trunking offers a highly versatile and adaptable system of cable installation. It provides good mechanical protection to cables so it is entirely suitable for installations in workshops or industrial premises.

The standard trunking, with its removable lid, means that circuits can be added or removed with relative ease and – provided the regulations on segregation of different types of circuit are complied with – the cables need only be of the single PVC insulated type.

Advantages of steel trunking:

- affords conductors good mechanical protection
- can accommodate many cables of different sizes
- permits easy rewiring
- minimises fire risks
- can be utilised as the circuit protective conductor.

Disadvantages of steel trunking:

- expensive compared with some other systems
- requires skill to fabricate and install
- difficult to make it gas- and water-proof
- liable to corrosion when subject to acid, alkali and other fumes.

Types of steel conduit finish:

- galvanised for outdoors or situations where steam or dampness is present.
- painted enamel for general work in dry situations.

Typical sizes are 50mm by 50mm section to 300mm by 300mm section and are generally supplied in 2.5m or 3m lengths.

Steel trunking accessories

A range of accessories are available and some are shown in the picture on the right.

The working of steel trunking, ie cutting, forming, etc, will be covered in Unit 204.

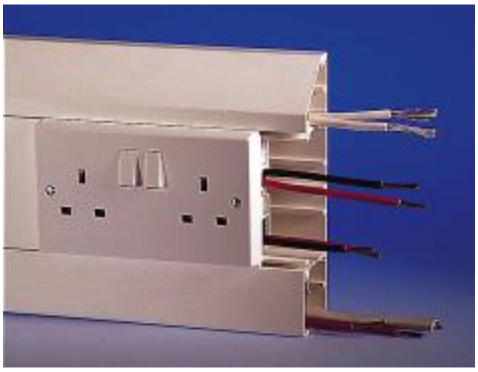
Lighting trunking

Without doubt, the biggest increase in recent times in the use of cable trunking is the widespread use in industrial and commercial premises of lighting trunking.

Easy to install with the use of specially designed hangers, it can span large distances between roof supports of the modern prefabricated premises.

Not only does it give mechanical protection for the cables, but it also provides a means of mounting the luminaires in neat straight rows and reduces the number of fixings required to the fabric of the building.

Skirting trunking



As its name implies, skirting trunking is fixed in place of the normal skirting board.

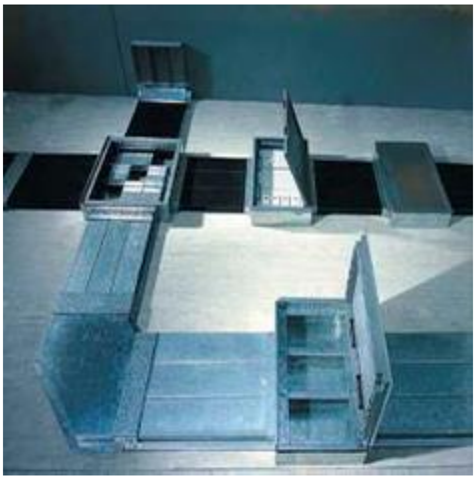
Its main use is confined to the outer perimeter of rooms, where there is a call for a large number of outlets for small power, telephone and computer outlets.

Dado trunking

Where there is a need for multiple electrical service outlet points at desk height, then this form of trunking can be considered.

It is ideal for use in offices where outlets for various voltages, telephones and computer networks are required.

It comes in multi-compartment types to provide segregation of the different services and can be obtained in a number of attractive finishes and styles.



Underfloor trunking

In some large buildings under construction, it is sometimes found practical and economical to provide a network of cable ducts or trunking in the concrete floor or under a suspended floor.

One advantage of this is that in large commercial buildings there are often changes of tenancy of individual office suites that may entail alterations of the layout of the areas.

These can be carried out more easily if there is a system of ducts or trunking, particularly in the large open plan offices favoured today.

Busbar trunking

The metal-clad overhead busbar system is often used for three phase distribution in factories to feed a number of machines.

The usual arrangement consists of zinc-coated sheet steel trunking finished in grey stove enamel, containing copper busbars mounted on insulators.

At intervals – for instance, every metre – tapping off points are provided, to which a fused unit can be fitted. The fused units consist of some means of making contact with the busbars – usually some type of socket or clamping arrangement.

Connection from the fused unit to the equipment is made by flexible connections, cable in conduit, mineral insulated cables, etc.

The initial cost of the overhead busbar trunking is high. However, once installed, it provides a highly flexible system to which additions and alterations can be carried out quickly and easily.

Rising main trunking

For electrical installations in large multi-floor buildings, busbar trunking is sometimes used for vertical rising mains.

It consists of a zinc-coated sheet steel case finished in grey stove enamel. The sections are joined by the use of connectors, complete with plated steel screws, copper earthing links and shake-proof washers in much the same way as standard cable trunking.

The trunking contains copper busbars, often extruded in PVC insulation and colour coded to help identification of the phases.

These are mounted on insulators made of laminated insulating material.

The sections of busbar are connected by solid copper links but, in extremely long runs, joints consisting of flexible braided tape are included at certain points to take up any variations in length due to temperature change.

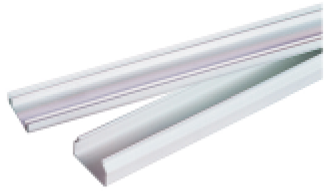
PVC trunking

Many of the trunking types mentioned above can be obtained in high impact PVC.

These are suitable for many different applications in domestic, commercial or industrial situations and have the added advantage of being light in weight, easy to cut and prefabricated.

The IET Regulation 521.6 requires that all trunking complies with BS EN 50085. Additionally, PVC trunking is acid- and corrosion-resistant, and can be obtained in more attractive colours than the metallic types.

PVC mini trunking



Mini trunking comes in various sizes, including 16 x 16mm and 16 x 25mm.

Using mini trunking and surface mounted switch and socket boxes, circuits can easily be extended and even complete rewires are carried out without disturbing the underlying decoration.

Consequently, it was favoured by councils and housing associations as a quick and easy method of carrying out domestic rewires without the need for expensive post-rewire decorating. It is for this reason that they became colloquially known in the trade as 'council rewires'.

Sizing trunking

The size of trunking required is worked out by using **Tables E5** and **E6** of the IET On-Site Guide; these are reproduced on the following pages of this Handout. For each of the cables that are going to be installed, a term for that particular size of cable is given in **Table E5**. The terms for all the cables are added together and compared to the factors for trunking given in **Table E6**. The size of trunking that is most suitable for use with these cables is the one whose factor is equal to or greater than the sum of the cable factors.

Table E5 – Cable factors for trunking

Type of conductor	Conductor cross-sectional area (mm^2)	PVC BS 6004 Cable factor	Thermosetting BS 7211 Cable factor
Solid	1.5	8.0	8.6
	2.5	11.9	11.9
Stranded	1.5	8.6	9.6
	2.5	12.6	13.9
	4	16.6	18.1
	6	21.2	22.9
	10	35.3	36.3
	16	47.8	50.3
	25	73.9	75.4

Notes:

1 These factors are for metal trunking and may be optimistic for plastic trunking, where the cross-sectional area available may be significantly reduced from the nominal by the thickness of the wall material.

2 The provision of spare space is advisable; however, any circuits added at a later date must take into account grouping, Regulation 523.5.

Table E6 – Factors for trunking

Dimensions of trunking (mm x mm)	Factor	Dimensions of trunking (mm x mm)	Factor
50 x 38	767	200 x 100	8572
50 x 50	1037	200 x 150	13001
75 x 25	738	200 x 200	17429
75 x 38	1146	225 x 38	3474
75 x 50	1555	225 x 50	4671
75 x 75	2371	225 x 75	7167
100 x 25	993	225 x 100	9662
100 x 38	1542	225 x 150	14652
100 x 50	2091	225 x 200	19643
100 x 75	3189	225 x 225	22138
100 x 100	4252	300 x 38	4648
150 x 38	2999	300 x 50	6251
150 x 50	3091	300 x 75	9590
150 x 75	4743	300 x 100	12929
150 x 100	6394	300 x 150	19607
150 x 150	9697	300 x 200	26285
200 x 38	3082	300 x 225	29624
200 x 50	4145	300 x 300	39428
200 x 75	6359		

Notes:
Space factor is 45% with trunking thickness taken into account.

Example

The following PVC insulated cables are to be installed in steel cable trunking:

- 10 off 4mm^2 cables
- 10 off 6mm^2 cables
- 10 off 10mm^2 cables.

Calculate the size of cable trunking that would be suitable for this application.

Factor for 10 off solid core 4mm^2 from On-Site Guide Table E5 $= 16.6 \times 10$

$= 166$

Factor for 10 off solid core 6mm^2 from On-Site Guide Table E5 $= 21.2 \times 10$

$= 212$

Factor for 10 off solid core 10mm^2 from On-Site Guide Table E5 $= 35.3 \times 10$

$= 353$

$166 + 212 + 353 = 731$

From **IET On-Site Guide, Table E6** a **75 x 25mm trunking** with a term of 738 would be suitable in this case.

However, in practice the electrician will use a larger size to allow for future extensions to the installation and it is more likely that a 50 x 50mm trunking would be installed in this case.

For sizes of cables and trunking not given in the tables, the number of cables installed should be such that the resulting spacing factor does not exceed 45%. The space factor in this case is the ratio of the sum of the overall cross-sectional area (CSA) of the cables (including cable and sheath) to the internal CSA of the trunking. This is calculated as follows:

$$\text{Space factor} = \frac{\text{Sum of overall CSA of cables}}{\text{Internal available CSA of trunking}} \times 100\%$$

203: Electrical installations technology

Worksheet 14: Trunking systems
Answer guide

Try the following problems.

1. State three advantages of steel trunking.

2. State three disadvantages of steel trunking.

3. The following PVC (BS6004) cables are to be installed into trunking:

- **15 off solid core 1.5mm^2**
- **12 off solid core 2.5mm^2**
- **18 off stranded 4mm^2**
- **10 off stranded 6mm^2**
- **9 off stranded 10mm^2**
- **3 off stranded 25mm^2**

Calculate the conduit size required to accommodate these cables.

203: Electrical installations technology

Handout 19: Cable tray and ladder systems

Learning outcome
The learner will:
3. know wiring systems of electrical installations.

Assessment criteria
The learner can:
3.2 identify **wiring systems** for different **environments**
3.5 identify purpose of **specialised** equipment for installing **wiring systems.**

Range
Wiring systems: Cable tray, cable trunking, cable conduit, ladder racking, thermoplastic multi-core, flat profile, SWA, MICC, FP200, thermoplastic single-core, support methods and requirements, component parts.
Environments: Domestic, commercial, hazardous, industrial installation, agricultural.
Specialised: Conduit and tray benders, stocks, dies, formers.

Cable tray and ladder systems

If it is required to run several sheathed cables, such as MIMC or SWA, along a common route then the time spent clipping and saddling the individual cables can be saved by the installation of cable tray.

Cable tray is usually installed in commercial and industrial installations.

Apart from carrying a large number of cables, cable tray can be used as a means of clearing obstructions such as pipework, etc.

It consists of a perforated metal channel which, once installed, can have cables fastened to it by means of cleats or cable ties.

Standard duty cable tray

Made from perforated sheet steel, the standard cable tray consists of a simple flat tray with a turned up edge.

It is available in widths varying from 50mm to 900mm and is most suitable for the installation of lightweight cables, such as MIMC cables or the smaller sizes of SWA.

Heavy-duty cable tray

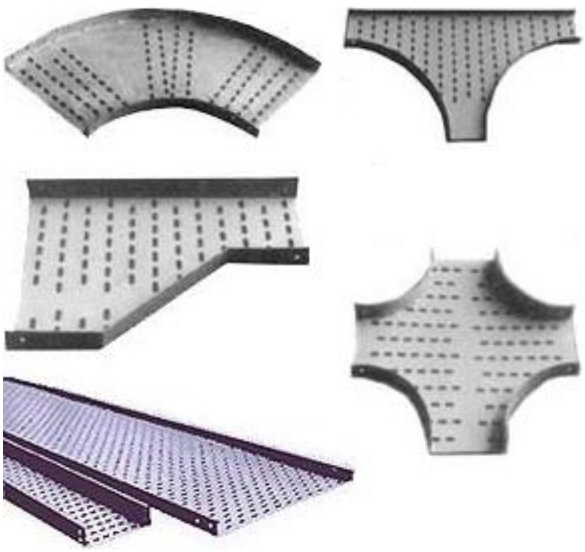
Like the standard cable tray, this is manufactured from perforated sheet steel. However, this is of heavier gauge and the flanged edge is deeper.

Heavy-duty trays, despite the name, are suitable for medium-duty installation work. There is a full range of accessories for this type of tray and it comes in widths ranging from 150mm to 600mm.

Return flange cable tray

There are a number of different patterns of this type of cable tray, varying from a simple returned flange to the heavy-duty types.

The returned flange gives the tray additional strength and therefore it can span greater distances without support, compared with the standard cable tray.



Types of tray finish:

- hot dipped galvanised
- unfinished sheet steel
- red oxide undercoat
- yellow chromate undercoat
- epoxy resin coated
- plastic coated.

Typical sizes available are 50mm to 900mm widths and it is generally supplied in 3m lengths.

Tray accessories

A range of accessories are available and some are shown in the picture on the right.

The working of cable tray, ie cutting, forming, etc, will be covered in Unit 204.

Cable tray specialist tools

Tray bending machine

Cable ladder

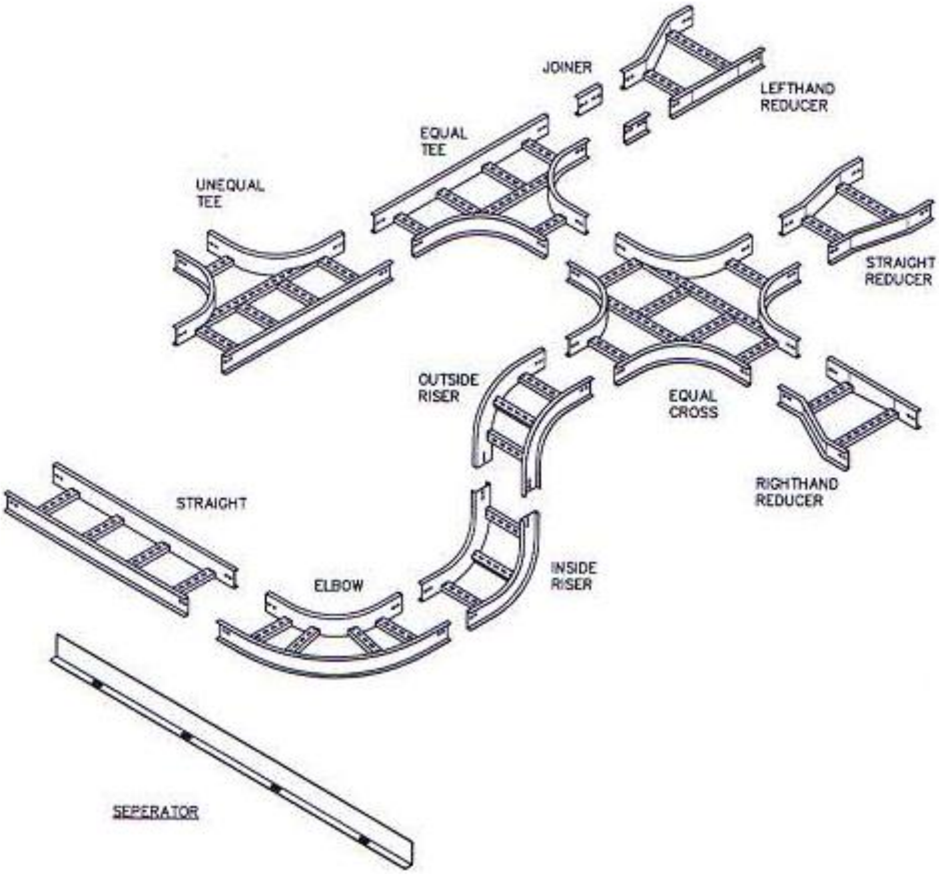
This is used when a number of larger cables need to be carried along the same route (generally in larger industrial premises).

It is so named because it resembles a ladder, where the 'rungs' provide the fixing points for the cable.

Since the cables installed on ladder rack are generally larger ones, the gap between the rungs will not present a problem, as the cable will self-support across the gaps.

Side wall heights available are generally between 50mm and 150mm, with various widths to suit a wide range of applications.

A range of accessories are available, including bends, reducers and tees, as shown below:



Cable basket

When running large numbers of small cables (eg data cable), cable basket can be used.

With this, the cables are simply laid into the basket and no cable fixing is required.

It is generally used in large commercial premises that have an extensive local area network (LAN) system to interconnect all computers and peripheral equipment.

203: Electrical installations technology

Handout 20: Protective devices

Learning outcome
The learner will:
3. know wiring systems of electrical installations.

Assessment criteria
The learner can:
3.4 state **applications** of different types of **protective devices.**

Range
Protective devices: Fuses (BS 88 (gM, gG), BS 3036, BS 1362), circuit breaker BS EN 60898 types b, c and d, RCD BS EN 61008, RCBO BS EN 61009 types b, c and d.

Protective devices

It is necessary to install protective devices in circuits for when faults occur, in order to provide protection against electric shock and also to ensure that the premises and wiring systems are not damaged as a result of, for example, fire.

Faults will generally cause one or both of the following to occur:

- overcurrent
- earth leakage.

Overcurrent

An overcurrent is defined in BS7671:2018 as '**a current exceeding the rated value. For conductors the rated value is the current-carrying capacity**'.

Protection against overcurrent can be provided by a fuse, circuit breaker or a residual current operated circuit breaker with integral overcurrent protection (RCBO).

Overcurrent can be further subdivided into two categories:

- overload current
- fault current.

BS 7671:2018 defines an overload current as '**an overcurrent occurring in a circuit which is electrically sound**'. This generally occurs when a circuit is abused, eg too many appliances plugged into socket outlets, or it was badly designed or modified, or a machine is trying to drive a mechanical load that is too much for it. An overload normally results in an overcurrent up to two to three times the rated value of the circuit.

BS 7671:2018 defines a fault current as '**a current resulting from a fault**'. A fault is further defined as '**a circuit condition in which current flows through an abnormal or unintended path. This may result from an insulation failure or a bridging of insulation. Conventionally, the impedance between live conductors or between live conductors and exposed- or extraneous-conductive-parts at the fault position is considered negligible**.' A fault current can be many hundreds of times the rated current of the circuit.

In either case, the purpose of circuit protection is to interrupt the circuit quickly, before damage is caused to the installation, as well as ensuring that the risk of electric shock is removed. In order to achieve this, protective devices are placed in the line conductor(s).

Earth leakage

In BS 7671:2018, earth leakage is referred to as 'protective conductor current', as it is defined as an '**electric current appearing in a protective conductor, such as leakage current or electric current resulting from an insulation fault**'.

Protection against earth leakage can be provided by a fuse, circuit breaker, a residual current operated circuit breaker with integral overcurrent protection (RCBO) or a residual current device (RCD).

Whilst the most common cause of earth leakage is as a result of an insulation fault, it must be remembered that some equipment, eg computer power supplies, are naturally 'leaky'. If a number of similar pieces of equipment are connected to the same circuit, the earth leakage current could reach dangerously high levels, as their effect will be cumulative.

Some typical current levels (a.c.) and their effect on the average human body are given below:

- 1mA: perception level (you would start to feel a slight 'tingle')
- 10–15mA: can cause powerful muscle contractions; the victim is unable to voluntarily control muscles and cannot release an electrified object.
- >30mA: can cause ventricular fibrillation which can lead to cardiac arrest.

Fuses

BS 3036 semi-enclosed fuse

Also referred to as a rewireable fuse, these were commonly used but, due to their inferior protection characteristics resulting in cables having to be de-rated, they are now very rarely installed. However, there will still be numerous installations that will be protected by these devices.

A fuse wire is connected between the two blades and provides a 'weak link' in the circuit. When a certain current flows through this wire, it will become hot, melt and break the circuit.

Available sizes are:

- 5A (white)
- 15A (blue)
- 20A (yellow)
- 30A (red)
- 45A (green).

Advantages of BS 3036 fuses:

- simple to check if blown
- low cost to replace fuse element
- no moving parts.

Disadvantages of BS 3036 fuses:

- danger of being repaired with wrong size wire
- deteriorate with age
- circuit cannot be quickly restored
- cannot break large fault currents
- danger if replaced on faulty circuit (melting wire)
- fusing factor of around 1.8–2.0 means that they cannot be guaranteed to operate up to twice the rated current that is flowing. As a result, cables protected by them must have a larger current-carrying capacity.

BS 88-3:2010 cartridge fuses (replacing BS 1361)

These cartridge fuses are for use by unskilled persons, mainly for household and similar applications.

The cartridge fuse breaks a faulty circuit in the same way as a semi-enclosed fuse, but its construction eliminates some of the disadvantages experienced with an open fuse element.

The cartridges are manufactured in such a way that higher rated fuses are physically larger in size; this is done to minimise the risk of replacing a blown fuse with an overrated cartridge.

Advantages of BS 88-3:2010 fuses:

- small physical size
- no mechanical moving parts
- accurate current rating
- not liable to deterioration with age
- fusing factor 1.6–1.9.

Disadvantages of BS 88-3:2010 fuses:

- more expensive than rewireable
- can be shorted by silver foil
- cannot safely break fault currents over 31.5kA

BS 88-2:2010 fuses (replacing BS 88-2 and BS 88-2.1)

These cartridge fuses are for use by authorised persons, mainly for industrial applications, and include bolted and clip type.

These generally have a high current breaking capacity and are often referred to as HBC fuses (high breaking capacity), formerly HRC (high rupturing capacity).

These fuses can be classified as either gG or gM, depending on their intended usage.

The difference between the two is that gG fuses are general purpose and gM are motor rated.

gG fuses have a single rating, eg 20A, which means it can carry 20 amperes indefinitely.

The gM fuses have a double rating, eg 20M32. The first figure indicates the continuous current rating, whilst the second figure is a short-term characteristic that allows the motor starting current to subside before the device operates.

Motor rated fuses are handy because you can use smaller rated cables/switchgear.

Advantages of BS 88-2:2010 fuses:

- no mechanical moving parts
- declared rating is very accurate
- operation is very quick
- with gM fuses you can distinguish between a persistent fault and a transient fault such as the large starting current taken by motors
- reliable – it can break large current safely
- fusing factor 1.25–1.70.

Disadvantages of BS 88-2:2010 fuses:

- expensive.

BS 1362 cartridge fuses

These cartridge fuses are especially for use in the standard UK BS 1363 13 ampere plug top.

This cartridge fuse breaks a faulty circuit in the same way as other fuses, ie by the internal fuse wire melting when current becomes excessive.

When the BS 1363 plug was first introduced, there were five fuses in the official BS1362 range (with their specified colour): 2 (blue), 5 (grey), 7 (black), 10 (yellow) and 13 (brown) amps.

The current version, BS 1362:1973, allows any fuse rating up to 13A, with 3 amp (coloured red) and 13 amp (coloured brown) as the preferred (but not mandated) values when used in a plug. All other ratings are to be coloured black (this is why 5 amp fuses are now black instead of grey).

The purpose of the plug mounted fuse is to protect the flexible cord, **not** the appliance itself.

Circuit breaker to BS EN 60898

With their continual reduction in cost, circuit breakers (CB) are for most electricians the most common type of protective device installed.

BS EN 60898 includes ratings up to 100A and maximum fault capacities of 9kA.

CBs provide much closer overcurrent protection compared to traditional fuses and it is much easier to reset the circuit when the fault is cleared.

Formerly referred to as 'miniature circuit breakers' (MCB), they are now simply referred to as 'circuit breakers' (CB).

Advantages of BS EN 60898 CBs:

- tripping characteristics, and therefore circuit protection, are set by the installer
- circuit protection difficult to interfere with
- the circuit provides discrimination
- a faulty circuit may be easily and quickly restored by an unskilled operator.

Disadvantages of BS EN 60898 CBs:

- they contain mechanical moving parts.

Circuit breakers' two means of tripping:

- thermal trip that operates relatively slowly and is ideal for detecting overload currents
- magnetic tripping device that operates very quickly and is ideal for detecting fault currents.

A typical circuit breaker is shown to the right:

1. Box terminal
2. Thermal element
3. Magnetic hammer action solenoid
4. Arc chamber
5. Trip bar
6. Moving contact
7. Fixed contact
8. DIN clip

Circuit breakers are graded according to their tolerance to overload and this is summarised in the table below, which is Table 7.2.7(ii) from the IET On-Site Guide (BS 7671:2018 – page 80):

Table 7.2.7(ii) Application of circuit breakers

Circuit-breaker type	Trip current (0.1 s to 5 s)	Application
1 **B**	**2.7 to 4 I_n** **3 to 5 I_n**	**Domestic and commercial installations having little or no switching surge**
2 **C** **3**	**4 to 7 I_n** **5 to 10 I_n** **7 to 10 I_n**	**General use in commercial/industrial installations where the use of fluorescent lighting, small motors, etc, can produce switching surges that would operate a Type 1 or B circuit breaker. Type C or 3 may be necessary in highly inductive circuits such as banks of fluorescent lighting.**
4 **D**	**10 to 50 I_n** **10 to 20 I_n**	**Not suitable for general use.** **Suitable for transformers, X-ray machines, industrial welding equipment, etc, where high inrush currents may occur.**

Note: I_n is the nominal rating of the circuit-breaker.

Whilst you will encounter types 1, 2, 3 and 4 already installed, these types are now not available. The recognised types readily available are types B, C and D.

Residual current device (RCD) BS EN 61008

All the devices mentioned so far will provide protection against both overcurrent and earth leakage. However, providing earth leakage protection with these devices requires a large current to flow to earth.

In order to detect much smaller leakage currents that could still be lethal to life, an RCD must be used.

An RCD compares the current flowing out through the line conductor with the current returning through the neutral; if the current exceeds a predetermined value, the device will trip and disconnect the circuit.

The rated value is referred to as the $I_{\Delta n}$ and is usually rated in mA.

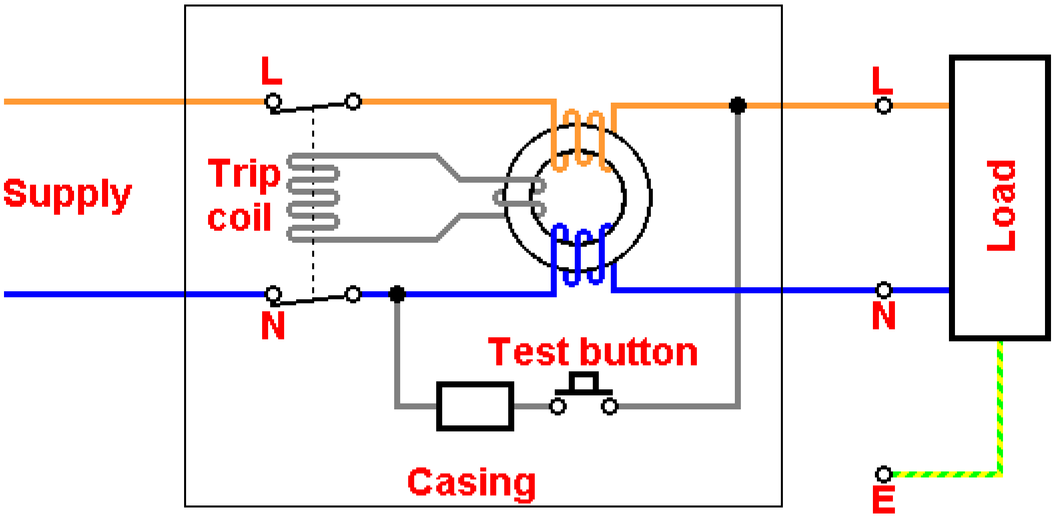
Until the introduction of the 17th Edition of BS 7671:2008, the use of RCDs was generally limited to protecting socket outlets feeding appliances used outside the premises.

However, it is now likely that most circuits will require RCD protection, including the following:

- locations containing a bath or shower (Regulation 701.411.3.3 – page 241)
- socket-outlets with a rated current not exceeding 32A (Regulation 411.3.3 –page 59)
- Final circuits supply luminaries within domestic (household) premises (Regulation 411.3.4 – page 59).
- mobile equipment with a current rating not exceeding 32A for use outdoors (Regulation 411.3.3 - page 59)
- where cables are concealed in walls at a depth of less than 50mm without mechanical protection (Regulation 522.6.202 – page 139).

This list shows examples of use and is not exhaustive.

The diagram below shows the internal circuit arrangement which has been drawn to best show the operation of the RCD.



IMPORTANT NOTE: An RCD does **not** provide overcurrent protection – it will only provide earth leakage protection.

Residual current operated circuit breaker with integral overcurrent protection (RCBO) BS EN 61009

An RCBO is a combination of a thermal-magnetic circuit breaker and an RCD that enable both overcurrent protection and earth fault protection to be provided in a single unit for individual circuits, usually but not exclusively in domestic installations.

The major advantage is that this allows earth fault protection to be restricted to a single circuit and therefore only the circuit with the fault is interrupted, thus providing better discrimination.

With most devices, two additional wires must be connected in order for this device to function. One wire connects to the neutral block, whilst the other connects to the earth block. However, there are RCBOs on the market that do not need an earth connection.

RCBOs are available in types B and C but not in type D.

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Worksheet 15: Protective devices
Answer guide

Try the following problems.

1. What is meant by the term 'overcurrent'?

2. Overcurrent can be subdivided into two categories, which are:

3. What is meant by the term 'overload current'?

4. What is meant by the term 'fault current'?

5. What is meant by the term 'protective conductor current?

6. List the five sizes of BS 3036 fuses including their colours.

7. State three advantages of BS 3036 fuses.

8. State three disadvantages of BS 3036 fuses.

9. State three advantages of BS 88-3:2010 fuses.

10. State three disadvantages of BS 88-3:2010 fuses.

11. State three advantages of BS88-2:2010 fuses.

12. State a disadvantage of BS 88-2:2010 fuses.

13. State three advantages of BS EN 60898 circuit breakers.

14. State a disadvantage of BS EN 60898 circuit breakers.

15. State the three type classifications of circuit breakers currently available.

16. State the general principle of operation of an RCD.

203: Electrical installations technology

Handout 21: Cable selection

Learning outcome
The learner will:
3. know wiring systems of electrical installations.

Assessment criteria
The learner can:
3.3 determine minimum current carrying capacity of live conductors for given **installation conditions.**

Range
Installation conditions: Ib In Iz It, Ca, Cc, Cf, Cg, Ci, voltage drop.

Cable selection

The size of a cable to be used for an installation depends upon:

- the current rating of a cable under defined installation conditions
- the maximum permitted drop in voltage, as defined by BS 7671:2018 Section 525 with specific values given in BS 7671:2018 Appendix 4, section 6.4
- satisfying earth fault loop impedance requirements specified in BS 7671:2018 Regulation Tables 41.2, 41.3 and 41.4.

The factors which influence the current rating are the:

- design current, I_b – the cable must carry the full load current
- type of cable – PVC, MIMS, copper conductors or aluminium conductors
- installed conditions – eg clipped to the surface or installed with other cables in trunking
- surrounding temperature – cable resistance increases as temperature increases and insulation may melt if the temperature is too high
- type and size of protection – for how long will the cable have to carry fault current?

Current carrying capacity

In order to comply with BS 7671:2018, the following relationship must be complied with:

$$I_b \leq I_n \leq I_z$$

where: I_b = design current of circuit

I_n = rated current or current setting of protective device

I_z = current carrying capacity of a cable for continuous service under the particular installation conditions concerned

and

$$I_t \geq I_z$$

where: I_t = tabulated current carrying capacity of a cable.

Based on these relationships, the following steps should be taken when determining the cable to be used for a particular situation with respect to current carrying capacity, which must comply with BS 7671:2018 Regulation 523.1.

- Determine the design current (I_b) of the circuit. This should be the value after applying any applicable factors for diversity.
- Select the type and current rating of the protective device, which must be equal to or larger than the design current (I_n).
- Determine the various correction factors applicable and apply them to the protective rating.
- Determine the installation method to be used.
- Select the cable from the current carrying capacity tables in Appendix 4 of BS 7671:2018.

A number of correction factors are available to take into account various installation conditions. These are as follows:

C_a ambient or surrounding temperature correction factor which is given in Tables 4B1 and 4B2 of BS 7671:2018, Appendix 4.

C_c for circuits buried directly in the ground or in a duct in the ground C_c = 0.9 (Appendix 4 section 5.1 – page 377). For cables installed above ground C_c = 1.

C_d for depth of burial correction factor, which is given in Table 4B4 of BS 7671:2018 Appendix 4.

C_f where the protective device is a semi-enclosed fuse to BS 3036, C_f = 0.725, otherwise C_f = 1 (Appendix 4 section 5.1).

C_g grouping correction factor given in Tables 4C1 to 4C6 of BS 7671:2018 Appendix 4.

C_i correction factor to be used when cables are enclosed in thermal insulation. BS 7671:2018 Regulation 523.9 gives three possible correction values:

- where a cable is installed in a thermally insulated wall or above a thermally insulated ceiling, the cable being in contact with a thermally conductive surface on one side, current carrying capacities are tabulated in Appendix 4
- where the cable is totally surrounded over a length greater than 0.5m, a factor of 0.5 must be applied
- where the cable is totally surrounded over a short length less than 0.5m, the appropriate factor given in Table 52.2 of BS 7671:2018 should be applied.

C_s for thermal resistivity of soil correction factor, which is given in Table 4B3 of BS 7671:2018 Appendix 4.

These factors are to be divided into the rated current or current setting of protective device (I_n).

If the factors occur at the same time, eg a certain number of cables grouped together in a certain ambient temperature, then all the relevant factors are divided into the value of I_n. However, if the factors occur at different points in the cable run, eg a certain number of cables grouped together that separate before passing through an area of elevated ambient temperature, then only the 'worst case' factor needs to be applied.

Dividing the value of I_n by all the appropriate factors will give use the current carrying capacity of the cable for continuous service under the particular installation conditions concerned (I_z).

Then the appropriate cable type table must be selected from those in Appendix 4 of BS 7671:2018, as well as the appropriate installation reference method column in that table. A cable with a tabulated current carrying capacity (I_t) greater than I_z is selected.

Example 1

A 6.5kW, 230V shower unit is to be wired in a domestic bathroom some 18m away from the mains consumer unit. A general purpose thermoplastic PVC insulated and sheathed flat twin with cpc cable will be clipped to the side of the 100mm ceiling joists over much of its length with one other similar cable in a roof space which, it is anticipated, will reach 35 °C in the summer and where thermal insulation is installed up to the top of the joists. Assuming a TN-S supply, calculate the minimum cable size to carry the current if the circuit is to be protected by:

a) a semi-enclosed fuse to BS 3036

b) a Type B CB to BS EN 60898.

Solution:

$$\text{Design current, } I_b = \frac{\text{Power}}{\text{Volts}} = \frac{6{,}500\text{W}}{230\text{V}} = 28.26 \text{ amperes}$$

a) $$\text{Current setting of protection, } I_n = 30\text{A (next size up from 28.26A)}$$

The correction factors to be included in this calculation are:

- **C_a** ambient temperature; the correction factor for 35 °C is 0.94 from Table 4B1 of Appendix 4
- **C_c** cable is installed above ground so C_c = 1
- **C_d** as the cable is installed above ground, this factor does not apply
- **C_f** the protection is by a semi-enclosed fuse and, therefore, a factor of 0.725 must be applied
- **C_g** the cable is grouped with one similar cable so we have a factor of 0.8 from Table 4C1 of Appendix 4
- **C_i** thermal insulation is in contact with one side of the cable and therefore current carrying capacities are tabulated in Appendix 4
- **C_s** as the cable is installed above ground, this factor does not apply.

$$\text{Cable rating, } I_z = \frac{I_n}{(C_a \times C_c \times C_f \times C_g)} = \frac{30}{(0.94 \times 1 \times 0.725 \times 0.8)} = 55\text{A}$$

The installation method is from Table 4A2 Reference Method 100.

From Column 2 of Table 4D5 a **16mm²** cable, having a rating (I_t) of 57 amperes, is required to carry this current.

We must now check that this cable complies with volt drop requirements. BS 7671:2018 Regulation 525.202 refers to Appendix 4 section 6.4, stating that the drop in voltage between the origin of an installation and any load point must not exceed 3% of the nominal supply voltage for lighting circuits and 5% of the nominal supply voltage for other circuits for low voltage installations supplied directly from a public low voltage distribution system.

The voltage drop for a particular cable may be found from:

$$\text{Voltage drop} = \text{factor} \times \text{design current} \times \text{length of run}$$

Now test for volt drop. The maximum permissible volt drop is 5% of the nominal supply voltage:

$$\begin{aligned}\text{Maximum voltage drop} &= 5\% \text{ of nominal supply voltage}\\ &= \frac{5 \times 230}{100}\\ &= 11.5\text{V}\end{aligned}$$

From Table 4D5 Column 8 the volt drop per ampere metre for a 16mm^2 cable is 2.8mV. Therefore, the volt drop for this cable length and load is equal to:

$$\begin{aligned}\text{Voltage drop} &= 2.8 \times 10^{-3} \times 28.26 \times 18\\ &= \mathbf{1.42V}\end{aligned}$$

Since this is less than the maximum permissible value of 11.5 volts, a 16mm^2 cable satisfies the current carrying capacity and voltage drop requirements, and is therefore the chosen cable when semi-enclosed fuse protection is used.

b) $$\text{Current setting of protection, } I_n = 32\text{A (next size up from 28.26A)}$$

The correction factors to be included in this calculation are:

- **C_a** ambient temperature; the correction factor for 35 °C is 0.94 from Table 4B1 of Appendix 4
- **C_c** cable is installed above ground so C_c = 1
- **C_d** as the cable is installed above ground, this factor does not apply
- **C_f** since protection is by a CB, the factor is 1
- **C_g** the cable is grouped with one similar cable so we have a factor of 0.8 from Table 4C1 of Appendix 4
- **C_i** thermal insulation is in contact with one side of the cable and therefore current carrying capacities are tabulated in Appendix 4
- **C_s** as the cable is installed above ground, this factor does not apply.

$$\begin{aligned}\text{Cable rating, } I_z &= \frac{I_n}{(C_a \times C_c \times C_f \times C_g)}\\ &= \frac{32}{(0.94 \times 1 \times 1 \times 0.8)}\\ &= 42.6\text{A}\end{aligned}$$

The installation method is from Table 4A2 Reference Method 100.

From Column 2 of Table 4D5 a **10mm^2** cable, having a rating (I_t) of 45 amperes, is required to carry this current.

Again, we test for volt drop. The maximum permissible volt drop is 5% of the nominal supply voltage, which we calculated earlier is 11.5 volts.

From Table 4D5 Column 8 the volt drop per ampere metre for a 10mm^2 cable is 4.4mV. Therefore, the volt drop for this cable length and load is equal to:

$$\text{Voltage drop} = 4.4 \times 10^{-3} \times 28.26 \times 18$$
$$= \mathbf{2.24V}$$

Since this is less than the maximum permissible value of 11.5 volts, a 10mm^2 cable satisfies the current carrying capacity and voltage drop requirements, and is therefore the chosen cable when circuit breaker type B protection is used.

NB: A further step is necessary in the cable selection process. This is to check that the chosen cable complies with the earth loop impedance requirements.

This will be covered later in your studies.

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Worksheet 16: Cable selection
Answer guide

1. **A 230V 4kW load is to be wired in non-armoured single-core 70 °C thermoplastic insulated copper conductors wired in steel conduit installed on the surface some 25 metres from the distribution board. Three other similar circuits are installed in the same conduit which passes through an area where the ambient temperature reaches 40 °C. Calculate the cross-sectional area of cable required if protection is by a BS 88-2 fuse. Show all working.**

203: Electrical installations technology

Handout 22: Earthing systems

Learning outcome

The learner will:

4. know requirements of earthing systems.

Assessment criteria

The learner can:

4.1 identify different types of **earthing systems.**

Range

Earthing systems: TT, TN-S, TN-C-S.

Earthing systems

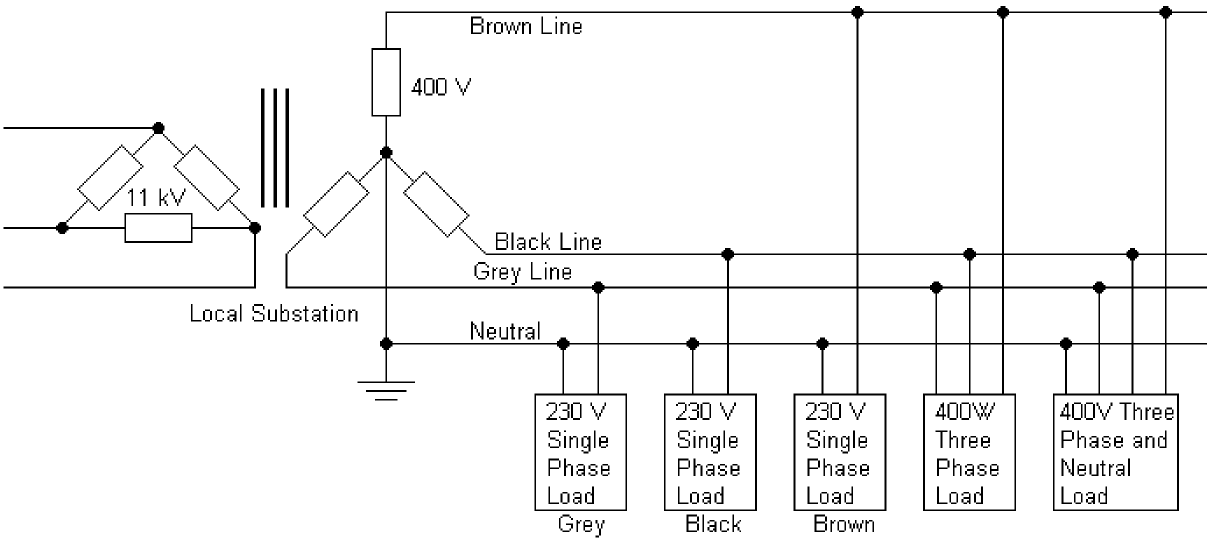
Purpose of earthing

The three main reasons for earthing electrical systems are as follows:

- to maintain the potential of any part of the system at a defined value with respect to earth
- to allow current to flow to earth in the event of a fault, so that the protective equipment will operate to isolate the faulty circuit
- to ensure that, in the event of a fault, apparatus normally '**dead**' cannot reach a dangerous potential with respect to earth (earth is normally taken as 0 volts, '**no volts**').

Supply system earthing

Local distribution is normally undertaken with a three-phase three-wire system at 11kV. This is then transformed down to 400V/230V four-wire system, as shown in the diagram below:



The primary is connected in delta, whilst the secondary is connected in star. The star point of the secondary provides the neutral. Connecting between any two line conductors will give us 400 volts, whilst connecting between any line and neutral will give us 230 volts.

It is a legal requirement that all electrical systems connected to the public supply system must be earthed. This is usually achieved by connecting the star point of the supply transformer to earth using an earth electrode.

Electrical installations connected to the public supply system will also be earthed in some way. The method of providing this earth will determine the earthing system used.

Earthing systems are distinguished by a series of letters that identify the nature of earthing as follows.

- **First letter – relationship of the power system to earth:**

T **=** direct connection of one point to Earth

I **=** all live parts are isolated from earth, or one point connected to earth through a high impedance.

- **Second letter – relationship of the exposed-conductive-parts of the installation earth:**

T **=** direct electrical connection of exposed-conductive-parts to earth, independently of the earthing of any point of the power system

N **=** direct electrical connection of the exposed-conductive-parts to the earthed point of the power system (in AC systems, the earthed point of the power system is normally the neutral point or, if a neutral point is not available, a line conductor).

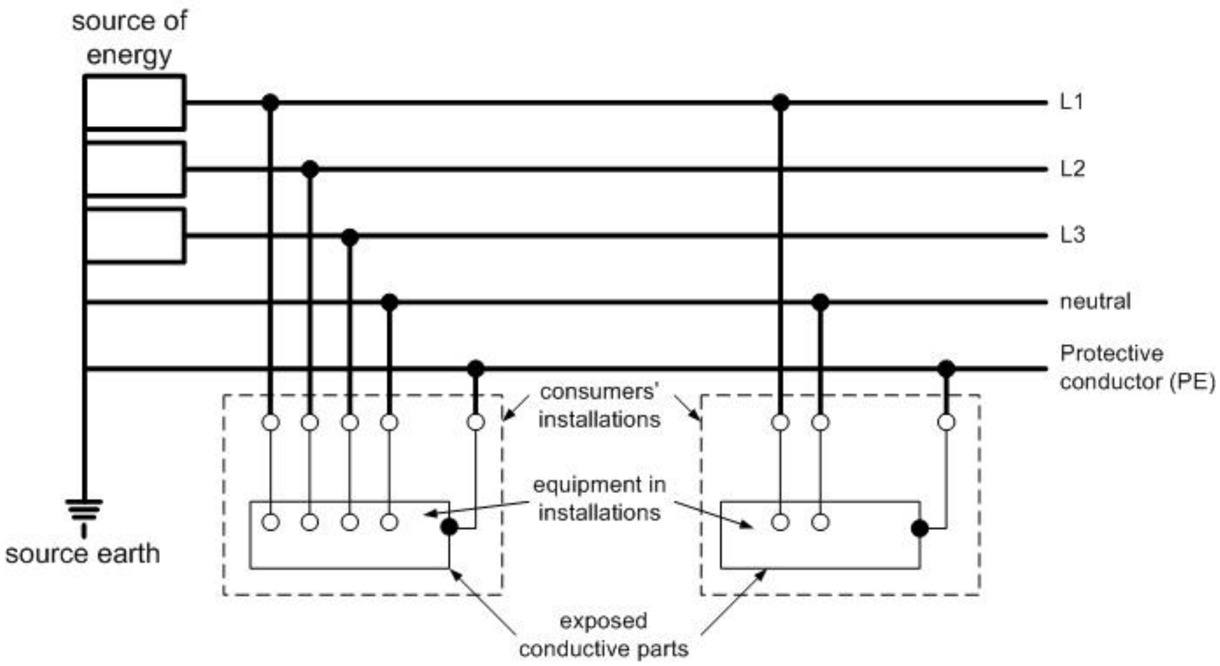
- **Subsequent letter(s) (if any) – arrangement of neutral and protective conductors:**

S **=** protective function provided by a conductor separate from the neutral conductor or from the earthed line (or, in AC systems, earthed phase) conductor

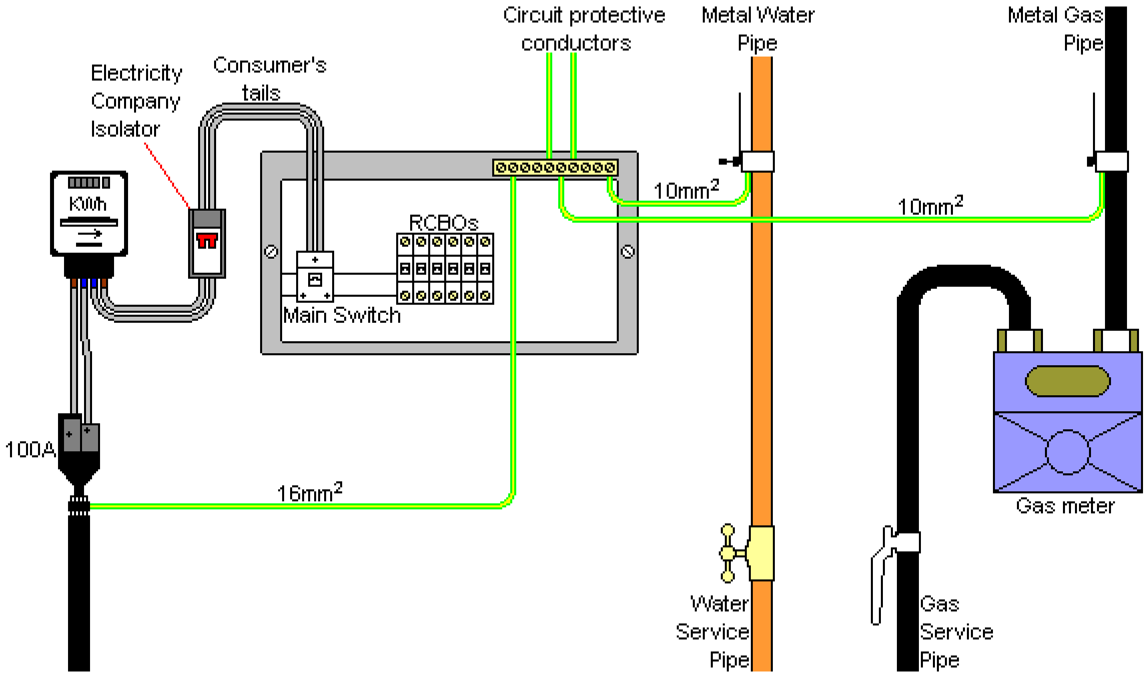
C **=** neutral and protective functions combined in a single conductor (PEN conductor).

TN-S system

Neutral and protective conductors are separate throughout the system. The protective earth conductor (PE) is generally the metal sheath and armour of the underground cable which this is connected to the consumer's main earthing terminal. All exposed and extraneous conductive parts of the installation, including gas pipes, water pipes and any lightning protective system are connected to the protective conductor via the main earthing terminal of the installation. The arrangement is shown in the diagram below:

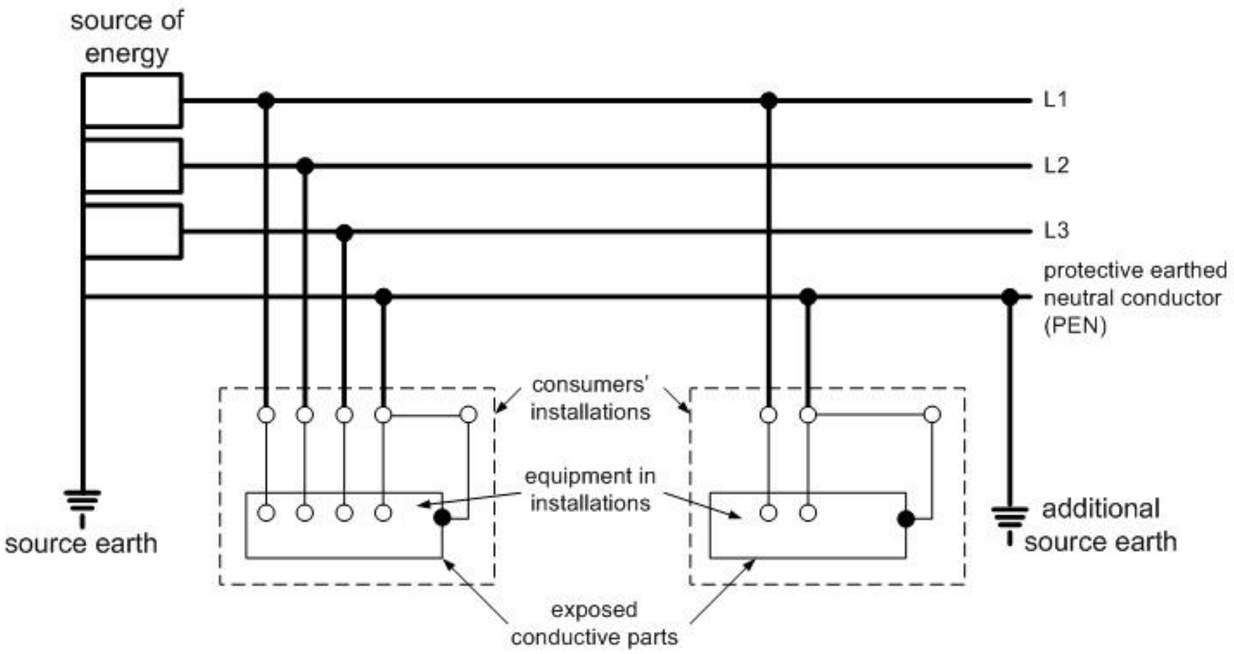


The layout of a typical TN-S domestic service position is shown in the following diagram:

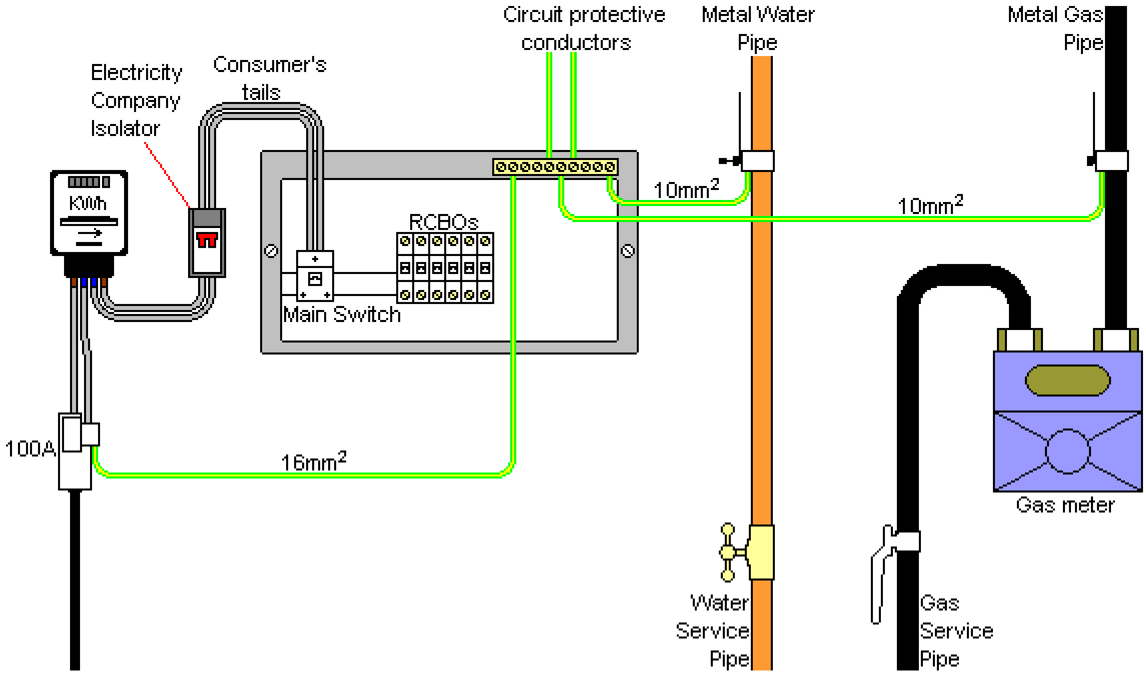


TN-C-S system

The supply cable uses a combined protective earth and neutral conductor (PEN conductor). At the supply intake point a consumer's main earthing terminal is formed by connecting the earthing terminal to the neutral conductor. All exposed and extraneous conductive parts of the installation, including gas pipes, water pipes and any lightning protective system, are connected to the main earthing terminal. Line to earth faults are effectively converted into line to neutral faults, which give a lower value of Z_e. This system is frequently referred to as protective multiple earthing (PME). The arrangement for a TN-C-S is shown in the diagram below:

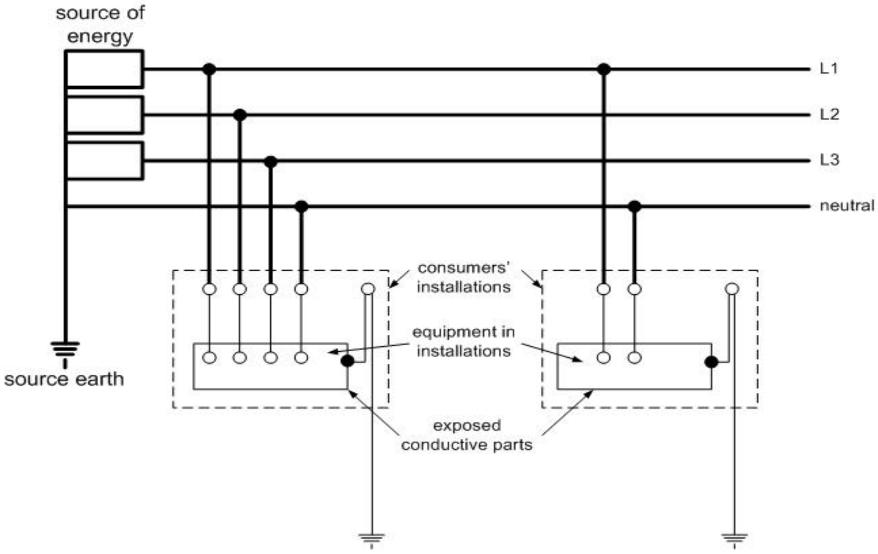


The layout of a typical TN-C-S domestic service position is shown in the following diagram:

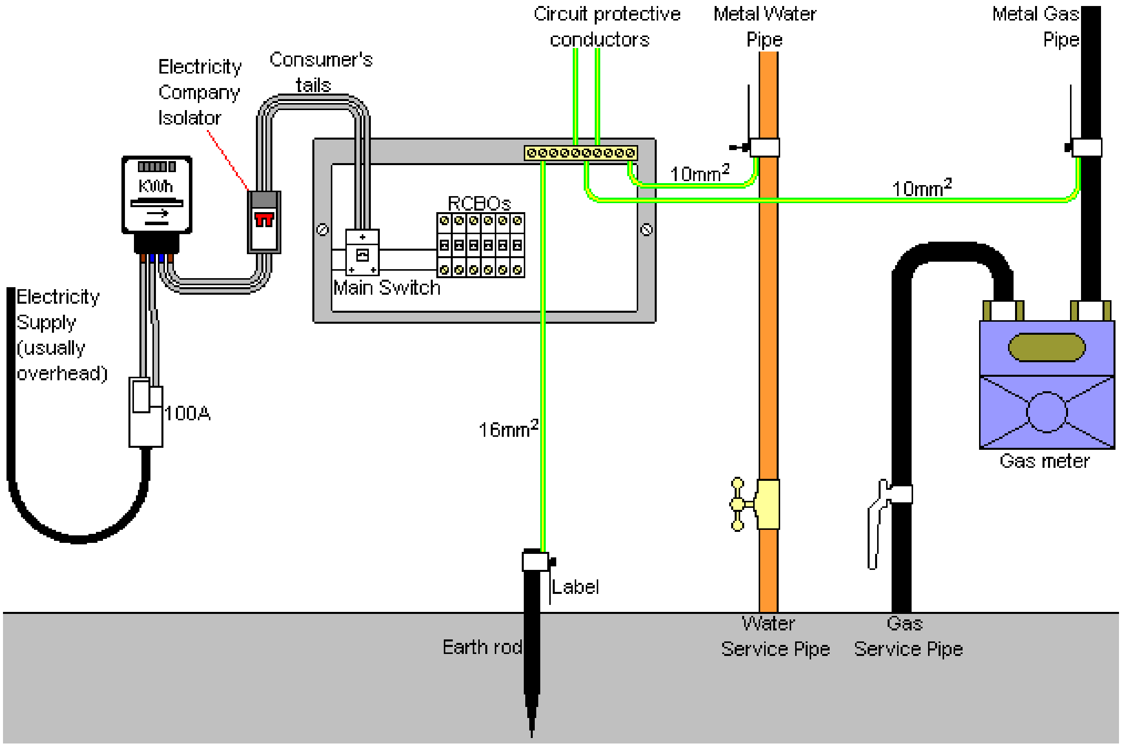


TT system

Often, TT systems are fed to the installation via overhead cables and the distribution network operators (DNO) do not provide an earth. The installation's circuit protective conductors must be connected to earth via an earth electrode provided by the consumer. An effective earth connection is sometimes difficult to obtain and in most cases a residual current device is provided when this type of supply is used. The arrangement for a TT is shown in the diagram below:



The layout of a typical TT domestic service position is shown in the following diagram:



203: Electrical installations technology

Handout 23: Equipotential bonding

Learning outcome
The learner will:
4. know requirements of earthing systems.

Assessment criteria
The learner can:
4.2 identify **component parts** of Automatic Disconnection of Supply (ADS)
4.3 identify **exposed conductive parts**
4.4 identify **extraneous conductive parts.**

Range
Component parts: CPC, main protective bonding conductor, supplementary equipotential bonding conductor, earthing conductor, protective devices, earth electrode.
Exposed conductive parts: Steel conduit, steel trunking, steel tray, steel enclosures of wiring systems, metal accessories, metallic equipment.
Extraneous conductive parts: Metallic service pipes (gas, oil, water), steel duct work, structural steel.

Equipotential bonding

BS 7671:2018 defines 'equipotential bonding' as:

> **Electrical connection maintaining various exposed-conductive-parts and extraneous-conductive-parts at substantially the same potential.**

When used (as it usually is) for the purpose of safety, it is referred to as **'Protective equipotential bonding'**, which is defined as **'equipotential bonding for the purpose of safety'**.

BS 7671:2018 further defines 'Exposed-conductive-parts' as:

> **Conductive part of equipment which can be touched and which is not normally live, but which can become live under fault conditions.**

This includes:

- steel conduit
- steel trunking
- steel tray
- steel enclosures of wiring systems
- metal accessories
- metallic equipment.

BS 7671:2018 defines 'Extraneous-conductive-parts' as:

> **A conductive part liable to introduce a potential, generally earth potential, and not forming part of the electrical installation.**

This will include:

- metallic service pipes (gas, oil, water)
- steel duct work
- structural steel.

If all conductive parts within an installation are electrically connected together then they will be at the same electrical potential. If two separate parts that are at the same potential are touched simultaneously then the potential difference between them will be 0 volts and no current will flow. This will apply even if the parts are at, say, 230 volts as a result of a fault.

Since the supply system is earthed, generally at the star point of the supply transformer, when a fault to the equipotential bonding occurs and its potential rises, then current will flow to earth and this current will cause the protective device(s) to operate and disconnect the supply.

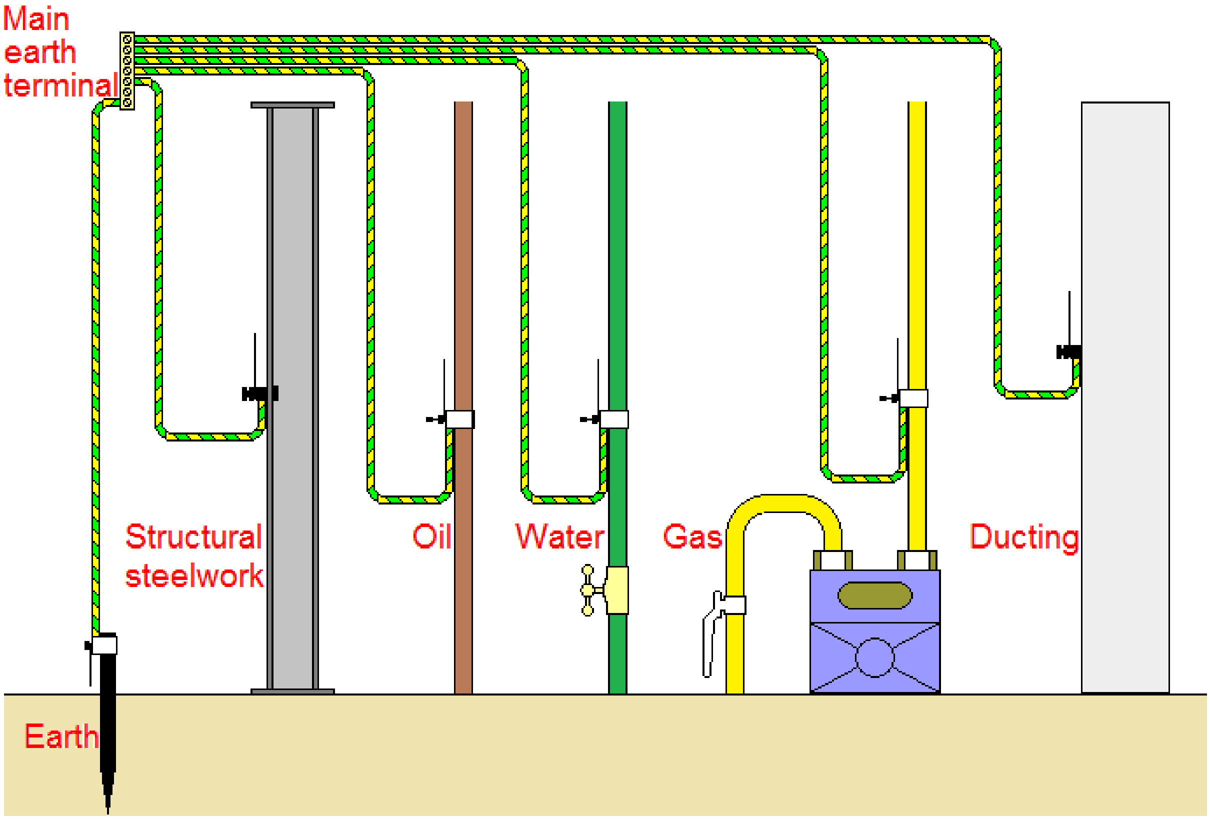
These are the principles of equipotential bonding and protective equipotential bonding.

Main protective bonding

BS 7671:2018 Regulation 411.3.1.2 states that, ‘in each installation, main protective bonding conductors complying with Chapter 54 shall connect to the main earthing terminal extraneous-conductive-parts, including the following:

(i) water installation pipes
(ii) gas installation pipes
(iii) other installation pipework and ducting
(iv) central heating and air conditioning systems
(v) exposed metallic structural parts of the building.

The diagram below shows how this is applied:



Supplementary equipotential bonding

The IET **ON-Site Guide** (Section 4.6, page 50) states that: ‘The purpose of supplementary bonding is to reduce the voltage between the various exposed-conductive-parts and extraneous-conductive-parts of a location during a fault to earth.’

If the required disconnection time cannot be achieved, supplementary bonding shall be applied (Regulation **419.2**) in accordance with Regulation **415.2**.

The sizing of supplementary bonding conductors is dealt with in Regulation **544.2.1 to 544.2.5, Table 4.6** of the IET **On-Site Guide** (page 50) gives clearer guidance on this.

There are many myths relating to where and when supplementary equipotential bonding should be used and **Section 4.7** (page 51) of the IET **ON-Site Guide** dispels some of these myths and is reproduced in full below.

Supplementary equipotential bonding is required in some of the locations and installations falling within the scope of **Part 7** of BS 7671:2018.

If the installation meets the requirements for BS 7671:2018 for earthing and bonding, there is no specific requirement for supplementary equipotential bonding of:

- kitchen pipes, sinks or draining boards
- metallic boiler pipework
- metal furniture in kitchens
- metallic pipes to wash hand basins and WCs
- locations containing a bath or shower, providing the requirements of **701.415.2** are met.

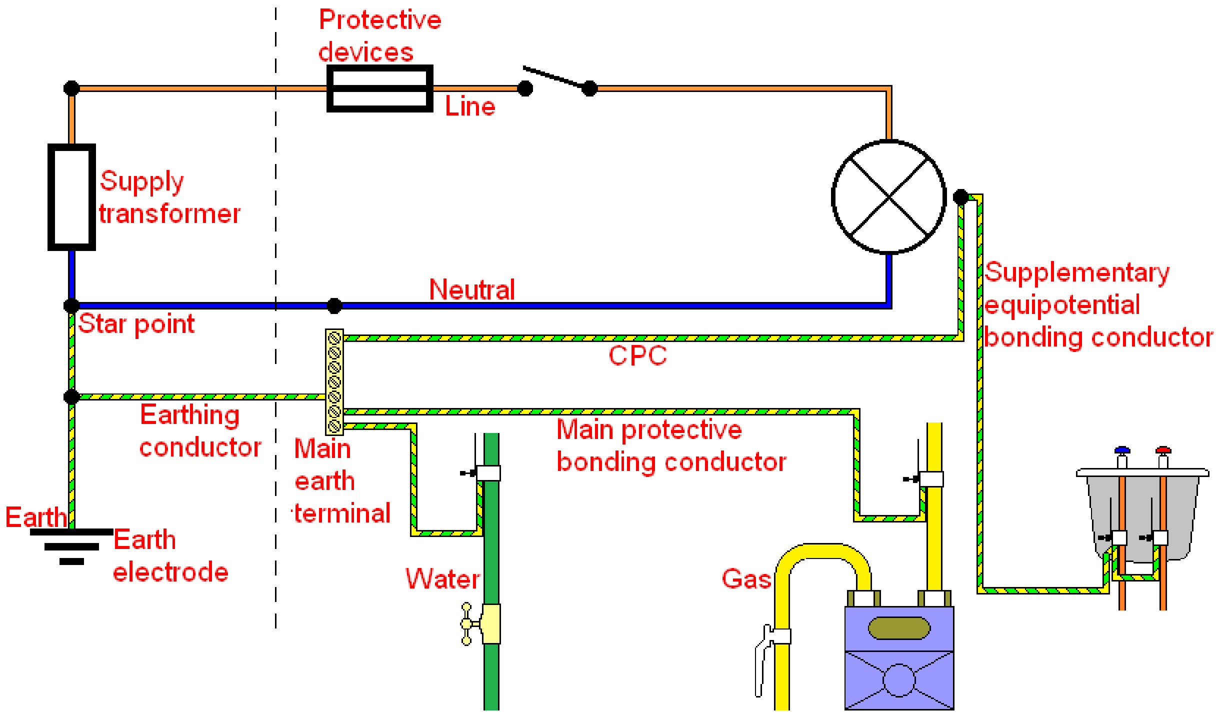
Note: Metallic waste pipes deemed to be extraneous-conductive-parts must be connected by main protective bonding conductors to the main earthing terminal; see also 4.3 (page 47-48).

Automatic disconnection of supply (ADS)

With all the main and supplementary bonding in place, in the event of a fault to earth occurring, current will flow to earth and bring about a rapid disconnection of the supply from the faulty circuit by operation of the protective device. This could be a fuse, circuit breaker or RCD.

Important component parts relating to the automatic disconnection of supply to be remembered include:

- CPC
- main protective bonding conductor
- supplementary equipotential bonding conductor
- earthing conductor
- protective devices
- earth electrode.



For further information refer to **Section 4** (Earthing and Bonding) of the IET On-Site Guide (page 47).

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Worksheet 17: Equipotential bonding
Answer guide

Try the following problems using your IET On-site Guide for reference.

1. **The line conductor tails feeding an installation connected to a TN-S system have a cross-sectional area of $25mm^2$.**

   What is the minimum size earthing conductor that must be used (assuming it is not buried)?

   What is the minimum size of the main protective bonding conductors that must be used?

2. **The neutral conductor tails feeding an installation connected to a TN-C-S system have a cross-sectional area of $6mm^2$.**

   What is the minimum size earthing conductor that must be used (assuming it is not buried)?

   What is the minimum size of the main protective bonding conductors that must be used?

3. **Supplementary equipotential bonding is to be installed in a room containing a bath. This will bond the cpc terminal of a lighting point to the extraneous-conductive-parts (water pipes, radiator, etc) within the room. The cpc feeding the lighting point has a cross-sectional area of $1.5mm^2$. Determine the size of supplementary bonding conductor if it has mechanical protections.**

203: Electrical installations technology

Handout 24: Earth loop impedance

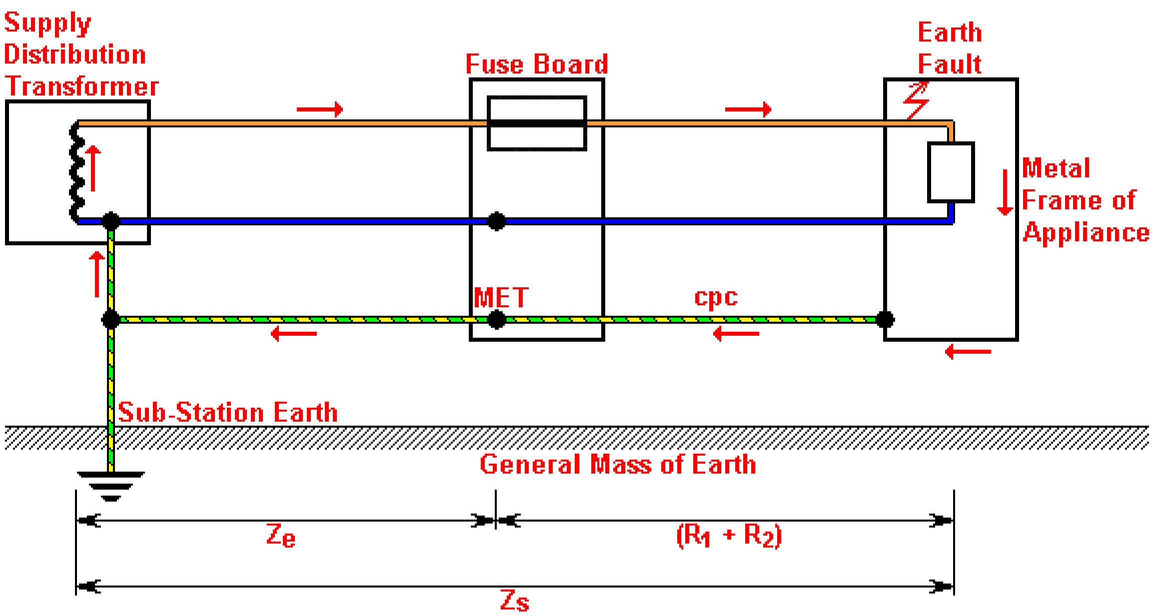
Learning outcome
The learner will:
4. know requirements of earthing systems.

Assessment criteria
The learner can:
4.5 identify **component parts** of an earth loop impedance path.

Range
Component parts: Zs, Ze, R1, R2, main earthing terminal (MET), supplier's earth return path.

Earth loop impedance

If a fault of negligible resistance occurs between line and earth then an earth fault current will flow. The magnitude of current that flows will depend upon the resistance or impedance of the earth fault path. This fault path is shown below for a TN-S system:



The loop comprises the following parts, starting at the point of the fault:

- circuit protective conductor
- the main earthing terminal (MET) and earthing conductor
- for TN-S systems, the supply earth
- the path through the earthed neutral point of the supply transformer
- the source line winding
- the line conductor from the source to the point of the fault.

The impedance of this fault path, ie the 'earth fault loop impedance', is denoted by the symbol Z_s and is measured in ohms (Ω).

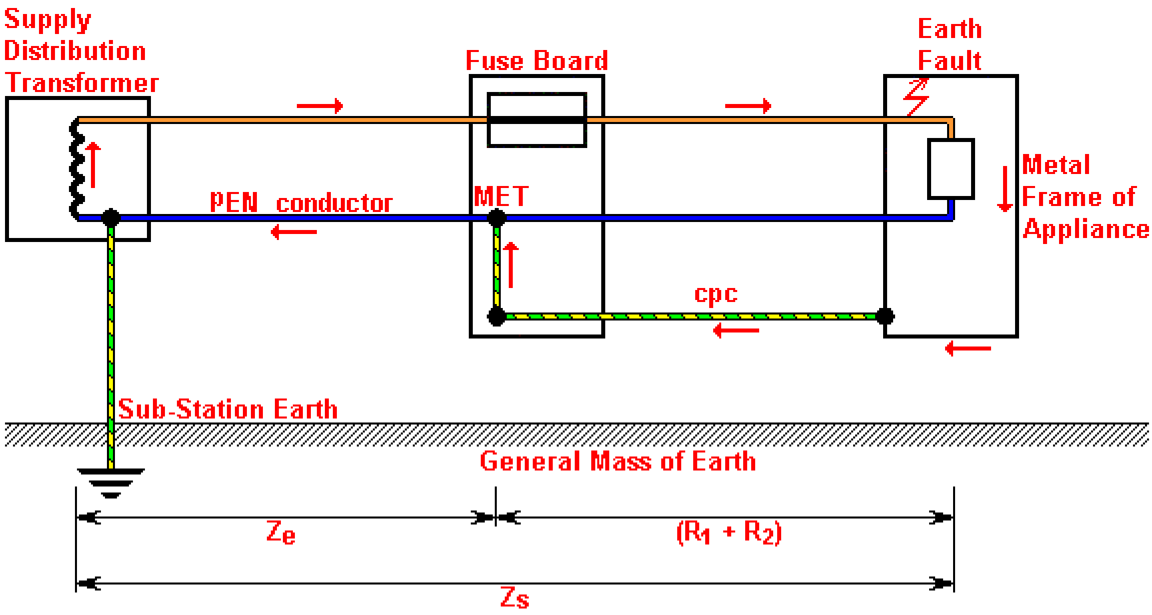
The fault path is broken into two parts:

- the external impedance (Z_e) comprises combined resistances/impedances of the fault path on distribution network operators (DNO) side of the supply intake
- the combined resistance of the consumers' line conductor (R_1) and the consumers' cpc conductor (R_2). This combined resistance is referred to as ($R_1 + R_2$).

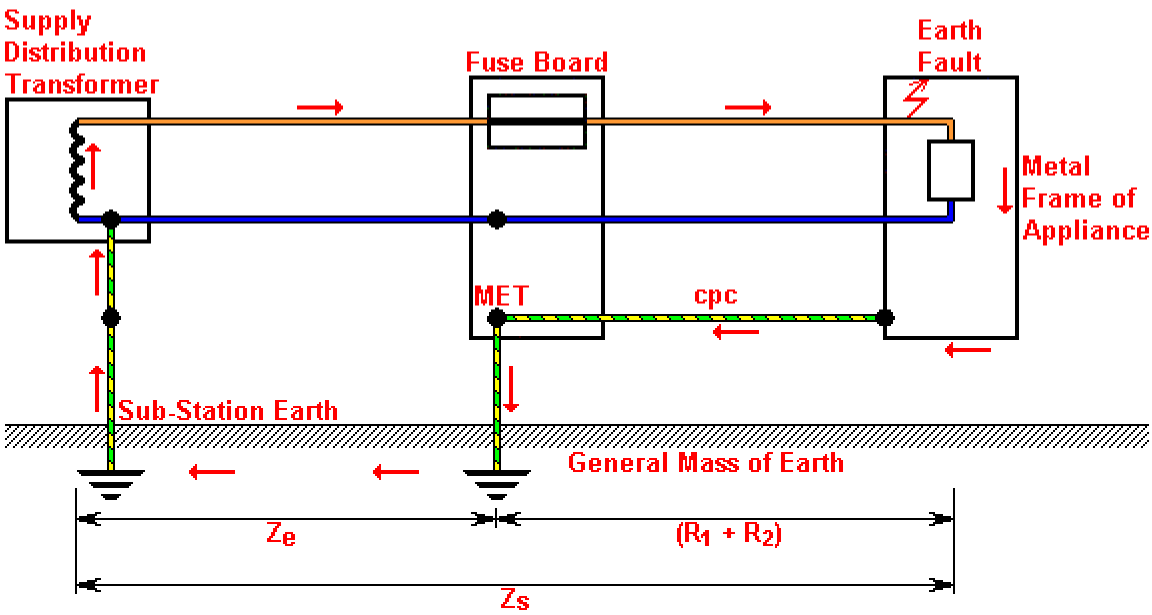
Both of these value combined is the earth loop impedance (Z_s) and is measured in ohms (Ω).

The previous diagram showed the earth loop impedance path for a TN-S system; the following two diagrams show the earth loop impedance path for a TN-C-S system and TT system, respectively:

TN-C-S system



TT system



203: Electrical installations technology

Worksheet 18: Earth loop impedance
Answer guide

Try the following problems.

1. List the typical components that make up the earth loop impedance path.

2. Draw a labelled circuit diagram showing the earth loop impedance path for a TN-C-S system.

203: Electrical installations technology

Handout 25: Electricity generation

Learning outcome
The learner will:
5. know how electricity is supplied.

Assessment criteria
The learner can:
5.1 identify **methods** of generating electricity for distribution.

Range
Methods: Coal, oil, biomass, wind, wave, hydro, nuclear, photo-voltaic, gas, micro-generation.

Electricity generation

Electricity is a vital part of our everyday lives in the United Kingdom and, compared with the rest of the world, we are large consumers. For example, although the UK accounts for less than 1% of the global population, in 2008 it used 2% of the total electrical energy generated in the world.

There are many means available to generate electricity, including the following:

- coal
- oil
- biomass
- wind
- wave
- hydro
- nuclear
- photo-voltaic
- gas
- micro-generation.

Each has its advantages and disadvantages. We generally cannot choose where the electricity that comes from the supply company is generated; this will be a combination of the methods listed above.

However, we need to be able to give advice to customers who may want to install their own small-scale generation systems in their premises, such as biomass, wind or photo-voltaic, which can all fall under the category of micro-generation.

Coal

During the 1940s some 90% of the UK generating capacity was fired by coal, with oil providing most of the remainder. By 2004 the use of coal-fired power stations had dropped to about 40% of the total generating capacity.

Coal-fired power stations burn coal that heats water and produces steam which powers turbines connected to generators.

The biggest problems with the use of coal are:

- it uses non-renewable fossil fuels
- it produces a lot of air pollution
- it requires large quantities of cooling water.

Oil

The use of oil to generate electricity has dropped considerably and by 2004 had dropped to just over 1% of the total generating capacity.

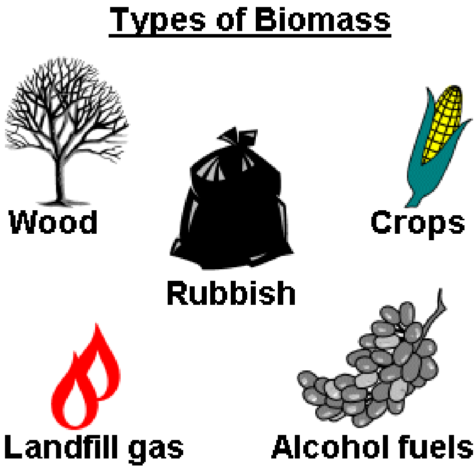
Larger oil-fired power stations produce electricity in a similar manner to coal but instead they burn oil to heat water that produces steam, which powers turbines connected to generators.

On a smaller scale, generators can be powered by internal combustion engines (petrol or diesel) and these are used frequently on-site. Alternatively, some power stations that can be run-up quickly to meet transient demand are powered by aero gas turbines driving generators.

The biggest problems with the use of oil are:

- it uses non-renewable fossil fuels
- it produces air pollution
- larger stations require large quantities of cooling water.

Biomass



Biomass is biological material derived from living or recently living organisms. In the context of biomass for energy this is often used to mean plant-based material, but biomass can equally apply to both animal- and vegetable-derived material.

It usually involves the burning of organic material to heat water for local hot water supplies (hot water and central heating) or to produce steam to power generators.

These can be either small scale ‘micro-generation’ or much larger plants feeding into the National Grid.

It is also possible to produce ‘bio-fuel’ for use in internal combustion engines to power generators.

Biomass is currently the largest source of renewable energy in the UK.

Wind

Wind power currently constitutes the second largest source of renewable energy in the UK with over 5 gigawatts capacity in 2010 and still increasing.

Whilst generating, the turbines produce no pollution. However, provision must be made for ‘windless’ days when the turbines will not be generating.

The installation and maintenance costs are quite high and the turbines will require replacing after 20–25 years.

There are aesthetic implications of land-based wind turbines, with a large number of the population objecting to them being built near their homes.

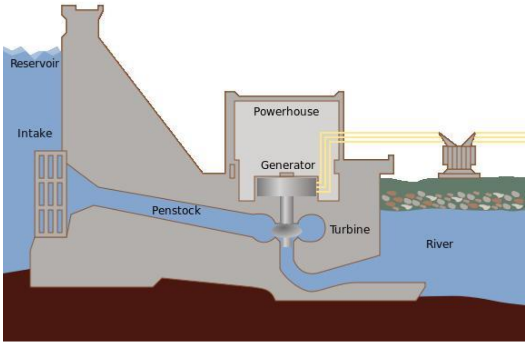
Individual consumers can supplement their electrical supply by installing small scale wind generators (C.1-2kW).

Wave

Wave power is the transport of energy by ocean surface waves, and the capture of that energy to do useful work, such as electricity generation, water desalination, or the pumping of water (into reservoirs). Machinery able to exploit wave power is generally known as a wave energy converter (WEC).

Wave-power generation is not currently a widely employed commercial technology, although there have been attempts to use it since at least 1890. In 2008, the first experimental wave farm was opened in Portugal, at the Aguçadoura Wave Park. The major competitor of wave power is off-shore wind power.

Hydro



Hydroelectricity is the term referring to electricity generated by hydropower: the production of electrical power through the use of the gravitational force of falling or flowing water.

It is the most widely used form of renewable energy, accounting for 16% of global electricity generation – 3,427 terawatt-hours of electricity production in 2010 – and is expected to increase about 3.1% each year for the next 25 years.

Despite being one of the cheapest forms of renewable energy, it has limited applications in England and Wales due to the limited locations that are suitable for this type of project.

However, pumped-storage systems have been used, eg Dinorwig, to store energy generated during off-peak periods, which can be utilised during periods of high electricity demand.

Nuclear

A nuclear power station is a thermal power station in which the heat source is a nuclear reactor.

As in a conventional thermal power station, the heat is used to generate steam that drives a steam turbine connected to a generator, which produces electricity.

Nuclear power plants are usually considered to be base-load stations, since large quantities of energy generation can be sustained to meet the regular demand of the nation.

In the UK approximately one sixth of electricity generation is from 16 operational nuclear reactors.

The biggest problems with the use of nuclear are:

- it uses non-renewable fuels
- radioactive material is highly dangerous
- safe disposal of spent radioactive fuel is very difficult.

Photo-voltaic

Solar panel electricity systems, also known as solar photo-voltaics (PV), capture the sun's energy using photo-voltaic cells. These cells don't need direct sunlight to work – they can still generate some electricity on a cloudy day.

The cells convert the sunlight into electricity, which can be used to run household appliances and lighting.

These are gaining widespread popularity in the UK thanks to incentive schemes for consumers to have them installed.

Apart from reducing the consumers' electricity bill by supplementing the electricity supply, the customer can 'sell back' surplus electricity to the electricity supplier via a 'smart meter', using a feed-in tariff.

Whilst the equipment is relatively expensive to install initially, the payback over a number of years will benefit the consumer. Additionally, as photo-voltaic is another example of a renewable energy source, the consumer's carbon footprint is greatly reduced.

Gas

A gas-powered station is a thermal power station in which the heat source is obtained by burning natural gas.

As in a conventional thermal power station, the heat is used to generate steam that drives a steam turbine connected to a generator, which produces electricity.

In 1990 only 0.05% of electricity in the UK was produced using gas but this had risen to 39.93% by 2004.

The biggest problems with the use of gas are:

- it uses non-renewable fossil fuels
- it produces air pollution
- larger stations require large quantities of cooling water.

Micro-generation

Micro-generation is the small-scale generation of heat and electric power by individuals, small businesses and communities to meet their own needs, as alternatives or supplements to traditional centralised grid-connected power.

Although this may be motivated by practical considerations, such as unreliable grid power or long distance from the electrical grid, the term is mainly used currently for environmentally conscious approaches that aspire to zero or low-carbon footprints.

Examples include:

- solar thermal (hot water)
- ground source heat pump
- air source heat pump
- biomass
- solar photo-voltaic
- micro-wind
- micro-hydro
- micro-combined heat and power (heat led)
- rainwater harvesting
- greywater re-use.

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Worksheet 19: Electricity generation
Answer guide

Try the following problems.

1. List three means of generating electricity using fossil fuels.

2. List six means of generating electricity using renewable sources.

3. Give three problems linked to using nuclear power stations.

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Handout 26: Electricity supply

Learning outcome
The learner will:
5. know how electricity is supplied.

Assessment criteria
The learner can:
5.2 identify **transmission voltages**
5.3 identify **distribution voltages**
5.4 state the **component parts** of the electrical distribution network.

Range
Transmission voltages: 400kV, 275kV, 132kV.
Distribution voltages: 33KV, 11KV, 400/230V.
Component parts: Sub-stations, pylons, power stations, cables, insulators, transformers.

Electricity supply

The electricity supply industry comprises:

- generation
- transmission
- distribution.

Generation

In the UK, power stations are often sited close to the fuel source and other important resources required for generation, eg a large source of cooling water. Most base-load power stations produce electricity at around 25,000 volts (25kV).

Transmission

This electricity needs to be transmitted around the country to the load centres. These transmission lines form the basis of the National Grid. The National Grid is the high-voltage electric power transmission network in Great Britain, connecting power stations and major sub-stations, and ensuring that electricity generated anywhere in England, Scotland and Wales can be used to satisfy demand elsewhere.

By connecting the power stations and load centres in the form of a grid, greater security of supplies can be ensured. Additionally, during periods of light loading, eg in the summer, individual power stations can be shut down to enable maintenance operations to be carried out, whilst maintaining supply to consumers.

Using a step-up transformer, the output from the power station is then stepped up to the transmission voltage. The reason why transmission is carried out at high voltages is to reduce the I^2R losses across the system.

Three transmission voltages are used:

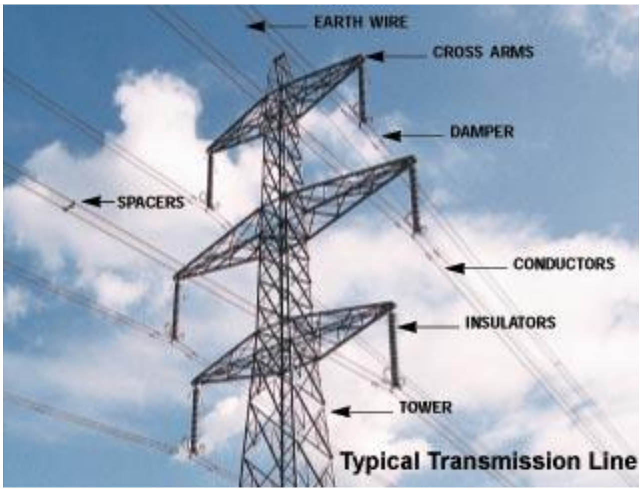
- 400kV
- 275kV
- 132kV.

The original Grid that came into operation in 1933 operated at 132kV. In 1949, the British Electricity Authority decided to upgrade the grid by adding 275kV links. From 1965, the Grid was partly upgraded to 400kV to become the supergrid, defined as referring to those parts of the British electricity transmission system that are connected at voltages in excess of 200kV.

Most of the grid is formed by overhead power lines, with cables suspended from insulators mounted on metal pylons or – to give them their proper name – transmission towers.

Normally, there are two off three phase circuits on each pylon. One or two earth wires, also called 'guard' wires, are placed on top to intercept lightning and harmlessly divert it to ground.

The conductors are generally made of a steel inner core for strength, surrounded by aluminium conductors around the outside; the cable has no insulation applied.



Distribution

When these transmission lines are in the vicinity of the load centres, using a step-down transformer, the voltage is stepped down for secondary transmission (132kV; 66kV). When the load centre is reached, it is stepped down again for local distribution at 33kV and 11kV. Supplies to individual users will see a further step-down to 400V for commercial and industrial users (heavy industry will be supplied at 33kV or 11kV, depending on demand) and 230V for domestic users.

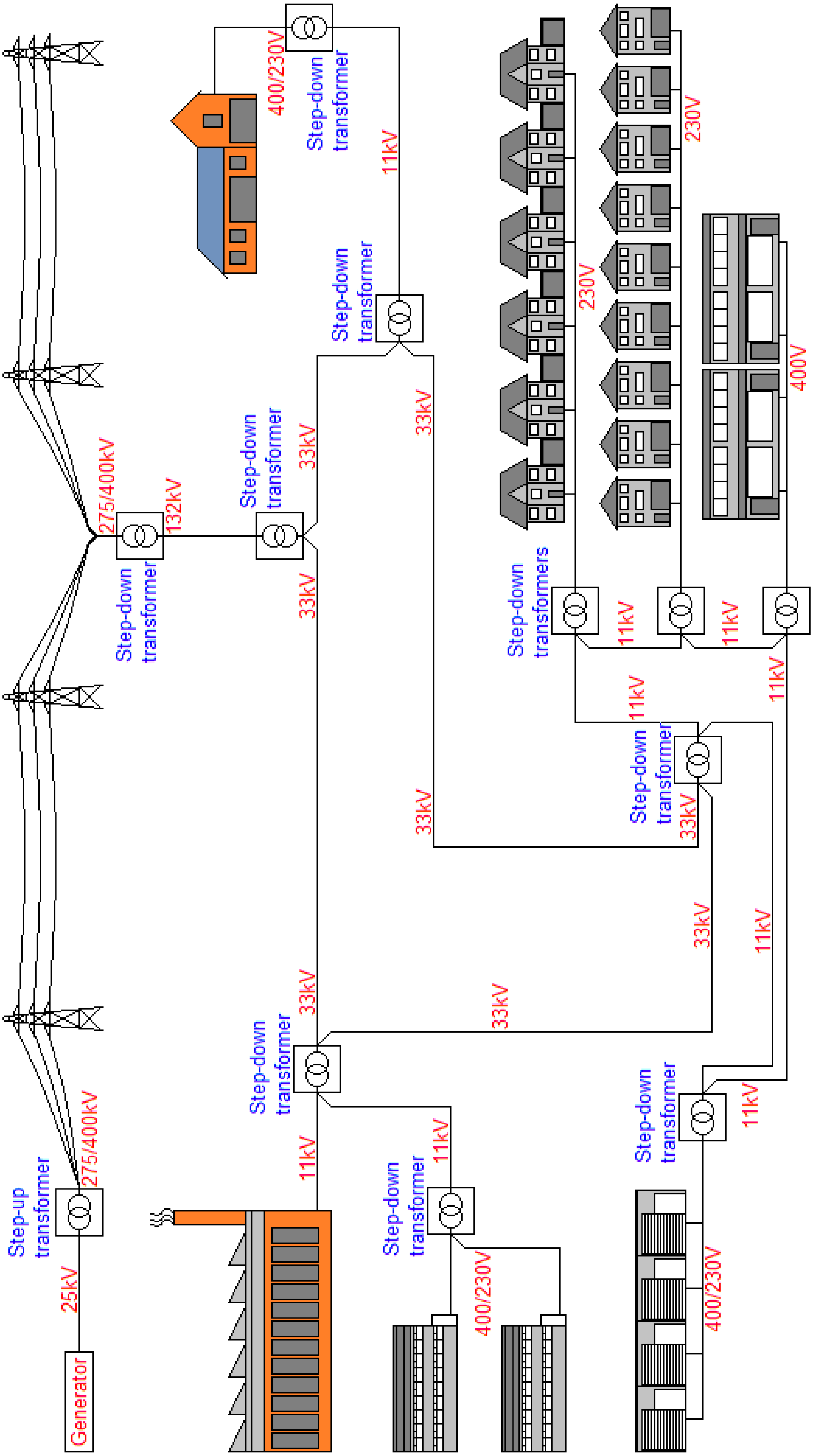
Three distribution voltages are used:

- 33kV
- 11kV
- 400/230V

Component parts of the electrical distribution network include:

- sub-stations
- pylons
- power stations
- cables
- insulators
- transformers.

See the diagram on the following page for the transmission and distribution supply system.


Generator
25kV
Step-up transformer
275/400kV
Step-down transformer
132kV
33kV
11kV
400/230V
Step-down transformers
230V
400V

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Worksheet 20: Electricity supply
Answer guide

Try the following problems.

1. List three transmission voltages.

2. List three distribution voltages.

3. List four component parts of the electrical distribution network.

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Handout 27: Micro-renewable energies

Learning outcome
The learner will:
6. know requirements for different types of micro-renewable energies.

Assessment criteria
The learner can:
6.1 describe types of **micro-renewable energies**
6.2 identify **requirements** for installation of **micro-renewable energies**
6.3 identify advantages and disadvantages of **micro-renewable energies**.

Range
Micro-renewable energies: Solar thermal (hot water), ground source heat pump, air source heat pump, biomass, solar photo-voltaic, micro-wind, micro-hydro, micro-combined heat and power (heat led), rainwater harvesting, greywater re-use.
Requirements: Legal, regulatory, building location, building fabric.

Micro-renewable energies

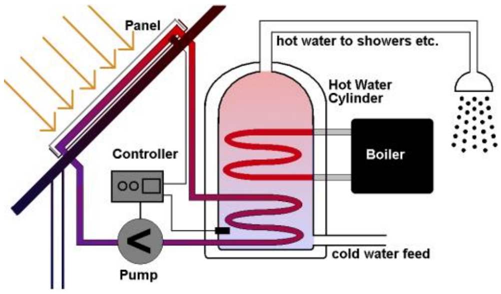
So far we have discussed large-scale electricity generation. However, there are many means of generating electricity and energy conservation for individual consumers. This is referred to as micro-generation or micro-renewable energies.

Most of these are relatively new technologies and it is important to determine the specific requirements for each one. These requirements include:

- legal
- regulatory
- building location
- building fabric.

Solar thermal (hot water)

Solar thermal (hot water) is a renewable energy system for generating domestic hot water by using solar panels (known as 'collectors') fitted at an optimal angle on a south-facing roof or other suitable surface.



Solar heat warms fluid, usually anti-freeze, in the collectors and this is then pumped to heat water stored in a hot water cylinder.

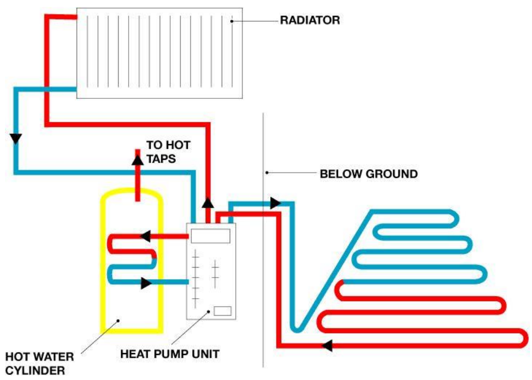
A boiler or immersion heater tops up the water to the temperature set by the cylinder's thermostat (>60 °C).

In England, Wales and Scotland, planning permission is not needed for most home solar water heating systems, as long as they are below a certain size, but you should check with your local planning officer, especially if the premise is a listed building, or in a conservation area or World Heritage Site.

Here are the benefits of solar thermal.

- It should work all year round during the day but consumers will probably need to heat the water further in winter months, using a boiler or immersion heater.
- It can save on fuel bills.
- It should be eligible for renewable heat incentives.
- It can cost a lot less to install than other micro-generation technologies.
- It does not cost more than £5,000.

Ground source heat pump (GSHP)



Ground source heat pumps use pipes which are buried in the garden to extract heat from the ground. This heat can then be used to heat radiators and underfloor or warm air heating systems and hot water in your home.

A ground source heat pump circulates a mixture of water and anti-freeze around a loop of pipe – called a ground loop – which is buried in the garden.

Heat from the ground is absorbed into the fluid and then passes through a heat exchanger into the heat pump.

The ground stays at a fairly constant temperature under the surface, so the heat pump can be used throughout the year – even in the middle of winter.

The length of the ground loop depends on the size of the premises and the amount of heat needed. Longer loops can draw more heat from the ground but need more space to be buried in. If space is limited, a vertical borehole can be drilled instead.

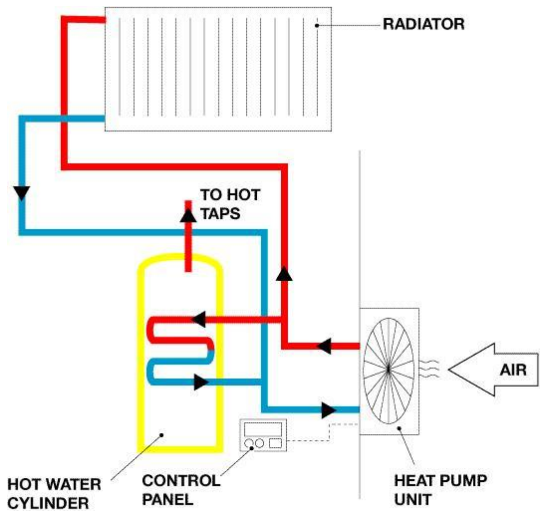
In England, Scotland and Wales, domestic ground source heat pumps are generally allowed as Permitted Developments but check with your local authority to find out whether you need planning permission or not.

In Northern Ireland you must consult with your local authority regarding planning permission for ground source heat pumps.

Here are the benefits of GSHP.

- It could lower fuel bills, especially if replacing conventional electric heating.
- It could provide an income through the government's Renewable Heat Incentive (RHI).
- It could lower the premises' carbon emissions, depending on which fuel is being replaced.
- It doesn't need fuel deliveries.
- It can heat the premises and provide hot water.
- It needs little maintenance – they are called 'fit and forget' technology.

Air source heat pump (ASHP)



Air source heat pumps absorb heat from the outside air. This heat can then be used to heat radiators, underfloor heating systems or warm air convectors and hot water in the home.

An air source heat pump extracts heat from the outside air in the same way that a fridge extracts heat from inside itself. It can get heat from the air even when the temperature is as low as –15 °C.

Heat pumps have some impact on the environment, as they need electricity to run, but the heat they extract from the ground, air or water is constantly being renewed naturally.

Air source heat pump installations in Wales and Northern Ireland require planning permission.

In England and Scotland they may be considered Permitted Developments, in which case planning permission is not required, but the criteria are complex so it is always a good idea to check with your local planning office.

Here are the benefits of ASHP.

- It could lower fuel bills, especially if replacing conventional electric heating.
- It could provide an income through the government's Renewable Heat Incentive (RHI).
- It could lower the premises' carbon emissions, depending on which fuel is being replaced.
- It doesn't need fuel deliveries.
- It can heat the home and provide hot water.
- It needs little maintenance – they are called 'fit and forget' technology.
- It can be easier to install than a ground source heat pump, though efficiencies may be lower.

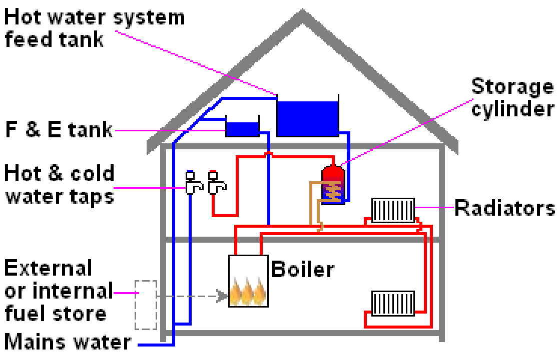
Unlike gas and oil boilers, heat pumps deliver heat at lower temperatures over much longer periods. During the winter it generally needs to be on constantly to heat the home efficiently. The radiators won't feel as hot to the touch as they might do when using a gas or oil boiler.

Wood-fuelled heating

Wood-fuelled heating systems – also called **biomass** systems – burn wood pellets, chips or logs to provide warmth in a single room or to power central heating and hot water boilers.

A stove burns logs or pellets to heat a single room and may be fitted with a back boiler to provide water heating as well.

A boiler burns logs, pellets or chips and is connected to a central heating and hot water system. A wood-fuelled boiler could save nearly £600 a year compared to electric heating.



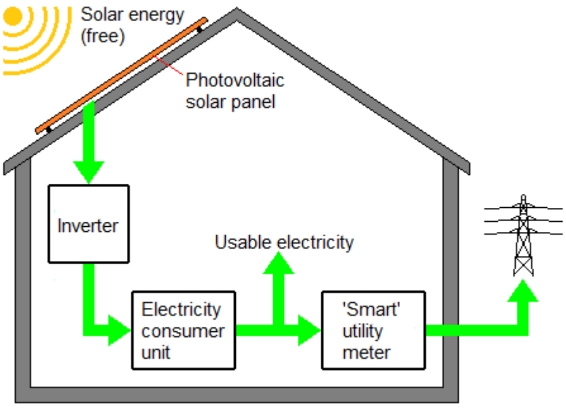
Here are the benefits of wood-fuelled heating.

- **Affordable heating fuel:** although the price of wood fuel varies considerably, it is often cheaper than other heating options.
- **Financial support:** wood-fuelled boiler systems could benefit from the Renewable Heat Premium Payment and the Renewable Heat Incentive (RHI).
- **A low-carbon option:** the carbon dioxide emitted when wood is burned is the same amount that was absorbed over the months and years during which the plant was growing. The process is sustainable, as long as new plants continue to grow in place of those used for fuel. There are some carbon emissions caused by the cultivation, manufacture and transportation of the fuel but, as long as the fuel is sourced locally, these are much lower than the emissions from fossil fuels.

A flue which meets the regulations for wood-burning appliances will be needed: a new insulated stainless steel flue pipe or an existing chimney – although chimneys normally need lining to make them safe and legal.

You may not need planning permission, but you should always check. All new wood heating systems have to comply with building regulations.

Photo-voltaic (PV)



These are gaining widespread popularity in the UK with incentive schemes for consumers to have them installed.

Solar panel electricity systems – also known as solar photo-voltaics (PV) – capture the sun's energy using photo-voltaic cells. These cells don't need direct sunlight to work – they can still generate some electricity on a cloudy day.

The cells convert the sunlight into electricity, which can be used to run household appliances and lighting.

Apart from reducing the consumer's electricity bill by supplementing the electricity supply, the customer can 'sell back' surplus electricity to the electricity supplier via a 'smart meter' using a feed-in tariff.

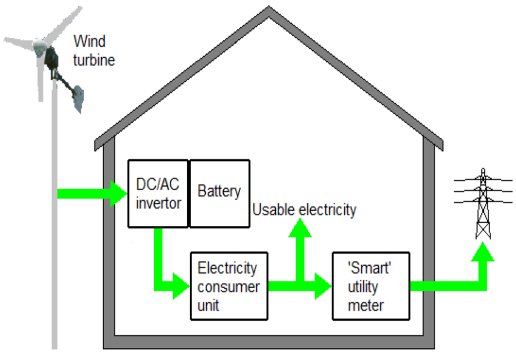
Whilst the equipment is relatively expensive to install initially, the payback over a number of years will benefit the consumer. Additionally, as photo-voltaic is another example of renewable energy source, the consumer's carbon footprint is greatly reduced.

In England, Wales and Scotland, planning permission is not required for most home photo-voltaic systems – as long as they are below a certain size – but you should check with your local planning officer, especially if the premises are a listed building, or in a conservation area or World Heritage Site.

Here are the benefits of photo-voltaic.

- Sunlight is free so, after the initial installation, electricity costs will be reduced.
- The government's feed-in tariffs pay the consumer for electricity generated, even if they use it.
- If the system is producing more electricity than needed by the consumer, or when they can't use it, the surplus can be sold back to the Grid.
- You will cut your carbon footprint. Solar electricity is green, renewable energy and doesn't release any harmful carbon dioxide or other pollutants. A typical home solar PV system could save over a tonne of carbon dioxide per year – that's more than 30 tonnes over its lifetime.

Micro-wind



Wind turbines harness the power of the wind and use it to generate electricity.

The UK is an ideal country for domestic turbines (known as 'micro-wind' or 'small-wind' turbines), as 40% of all the wind energy in Europe blows over it.

A typical system in an exposed site could easily generate more power than your lights and electrical appliances use.

Wind turbines use large blades to catch the wind. When the wind blows, the blades are forced round, driving a turbine which generates electricity. The stronger the wind, the more electricity produced.

There are two types of domestic-sized wind turbine.

- Pole mounted: these are free-standing and are erected in a suitably exposed position, Often these are around 5kW to 6kW in size.
- Building mounted: these are smaller than mast mounted systems and can be installed on the roof of a home where there is a suitable wind resource. Often these are around 1kW to 2kW in size.

Wind turbines are eligible for the UK government's feed-in-tariffs, which means that the consumer can earn money from the electricity generated by the turbine. Payments can also be received for the electricity not used by the consumer and exported to the local grid.

In order to be eligible, the installer and wind turbine product must be certified under the Microgeneration Certification Scheme (MCS).

If the turbine is not connected to the local electricity grid (known as off grid), unused electricity can be stored in a battery for use when there is no wind. **NB:** the feed-in tariffs scheme is not available in Northern Ireland.

Planning permission is required to install a wind turbine in Wales or Northern Ireland; contact your local authority for details.

In England and Scotland, a domestic wind turbine may be classified as Permitted Development, in which case planning permission will not be needed. However, the criteria are complex – and very different in England and Scotland – so we recommend that you contact your local planning office at an early stage to check whether planning is required.

For **building-mounted turbines**, the criteria include:

- the house is detached
- the top of the turbine blades is no more than three metres above the top of the house, or 15 metres above the ground
- all of the turbine is at least five metres from the edge of the householder's property.

For **pole-mounted turbines**, the criteria include:

- the top of the turbine is no more than 11.1 metres above ground
- all of the turbine is at least 1.1 times the height of the turbine away from the edge of the householder's property.

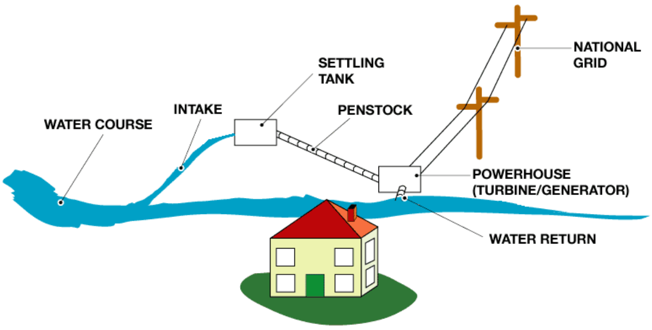
And for **both types of turbine**:

- there is no other wind turbine and no air source heat pump on the site
- the bottom of the blades is at least five metres above ground
- the turbine's swept area is no more than $3.8m^2$
- the site is not on land safeguarded for aviation or defence purpose.

Micro-hydro

Running water can be used to generate electricity, whether it's a small stream or a larger river.

Small or micro-hydroelectricity systems – also called hydropower systems or just hydro systems – can produce enough electricity for lighting and electrical appliances in an average home.



All streams and rivers flow downhill. Before the water flows down the hill, it has potential energy because of its height. Hydropower systems convert this potential energy into kinetic energy in a turbine, which drives a generator to produce electricity. The greater the height and the more water there is flowing through the turbine, the more electricity can be generated.

The amount of electricity that a system actually generates also depends on how efficiently it converts the power of the moving water into electrical power.

Here are the benefits of micro-hydro.

- A hydro system can generate 24 hours a day, often generating all the electricity the consumer needs and more.
- If eligible, the consumer will get payments from the feed-in tariff for all the electricity generated, as well as for any surplus electricity sold back to the Grid.
- A hydro system may generate more electricity than needed for lighting the home and powering the electrical appliances – so the excess electricity can be used to heat the home and hot water too.
- Installing a hydro system can be expensive but in many cases it's less than the cost of getting a connection to the National Grid if the premises do not already have one.
- Hydroelectricity is green, renewable energy and doesn't release any harmful carbon dioxide or other pollutants.

Hydropower is very site specific. Most homes will not have access to a suitable resource even if they have a water course running nearby. Assessing a hydro site properly is a job for a professional.

In order to be suitable for electricity generation, a river needs to have a combination of:

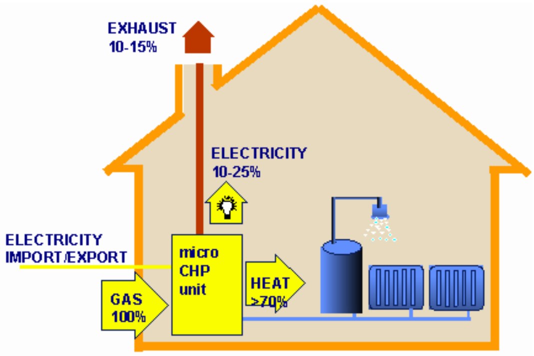
- **flow** – how much water is flowing down the river per second, and
- **head** – a difference in height over a reasonably short distance.

Developing a hydroelectric system can take a long time, mainly because of the need to obtain planning permission and an abstraction licence, and because of the number of organisations that may need to be involved in giving consent.

All new hydroelectric systems require planning permission and an abstraction licence.

Micro-combined heat and power (micro-CHP)

This technology generates heat and electricity simultaneously, from the same energy source, in individual homes or buildings. The main output of a micro-CHP system is heat, with some electricity generation, at a typical ratio of about 6:1 for domestic appliances.



A typical domestic system will generate up to 1kW of electricity once warmed up; the amount of electricity generated over a year depends on how long the system is able to run. Any electricity you generate and don't use can be sold back to the Grid.

Domestic micro-CHP systems are currently powered by mains gas or LPG; in the future there may be models powered by oil or bio-liquids. Although gas and LPG are fossil fuels rather than renewable energy sources, the technology is still considered to be a 'low carbon technology' because it can be more efficient than just burning a fossil fuel for heat and getting electricity from the National Grid.

Micro-CHP systems are similar in size and shape to ordinary, domestic boilers and like them can be wall-hung or floor standing. The only difference to a standard boiler is that they are able to generate electricity while they are heating water.

Here are the benefits of micro-CHP.

- When the micro-CHP is generating heat, the unit will also generate electricity to be used in the home (or exported).
- By generating electricity on-site, the consumer could be saving carbon dioxide compared with using Grid electricity and a standard heating boiler.
- Micro-CHP is eligible for feed-in tariffs. Please note that the feed-in tariff is not available in Northern Ireland.
- For the householder, there is very little difference between a micro-CHP installation and a standard boiler. If the consumer already has a conventional boiler then a micro-CHP unit should be able to replace it, as it's roughly the same size. However, the installer must be approved under the Microgeneration Certification Scheme (MCS).
- Servicing costs and maintenance are estimated to be similar to those of a standard boiler, although a specialist will be required.

Rainwater harvesting

Rainwater harvesting (RWH) is a practice of growing importance in the UK, particularly in the South-east of England where there is less water available per person than in many Mediterranean countries.

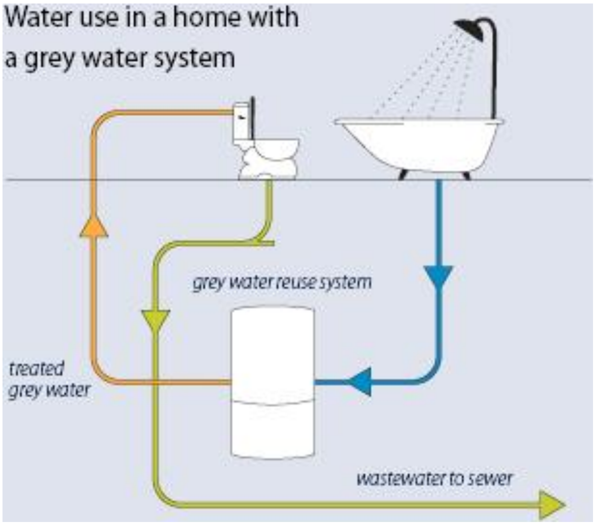
Rainwater harvesting in the UK is both a traditional and reviving technique for collecting water for domestic uses. This water is generally used for non-hygienic purposes, such as watering gardens, flushing toilets and washing clothes.

There is a growing demand for larger tank systems collecting between 1,000–7,500 litres of water. The two main uses for harvested rainwater are botanical uses (in gardening for plant irrigation) and domestic uses (flushing toilets and running washing machines).

Rainwater is almost always collected strictly from the roof and then heavily filtered by using either a filter attached to the down pipe, a fine basket filter or, for more expensive systems like self-cleaning ones, filters placed in an underground tank.

The velodrome of the London Olympic Park is designed to harvest rainwater.

Greywater re-use



Greywater, or sullage, is wastewater generated from domestic activities, such as laundry, dishwashing and bathing, which can be recycled on-site for uses such as landscape irrigation and constructed wetlands.

Greywater differs from water from the toilets, which is designated sewage or blackwater to indicate that it contains human waste.

Most greywater is easier to treat and recycle than blackwater, because of lower levels of contaminants.

If collected using a separate plumbing system from blackwater, domestic greywater can be recycled directly within the home, garden or company and used either immediately or processed and stored.

If stored, it must be used within a very short time or it will begin to putrefy, due to the organic solids in the water.

Recycled greywater of this kind is never safe to drink, but a number of stages of filtration and microbial digestion can be used to provide water for washing or flushing toilets.

203: Electrical installations technology

Worksheet 21: Micro-renewable energies
Answer guide

Try the following problems.

1. **List four requirements that must be taken into consideration when planning to install a micro-renewable system.**

2. **Is planning permission required to install a micro-hydro system?**

3. **What licence is required for a micro-hydro system?**

4. **List four benefits of a micro photo-voltaic system.**

5. **List five requirements for a building-mounted wind turbine.**

203: Electrical installations technology

Sample questions version A
Answer guide

There are 40 multiple choice questions. Answer them all, selecting the correct answer out of the four provided.

1. Which one of the following directly affects all persons working with electricity in a working environment? (L1.1)
   a) Electricity Safety, Quality and Continuity Regulations
   b) BS 7671:2018
   c) Electricity at Work Regulations
   d) Construction design and management Regulations

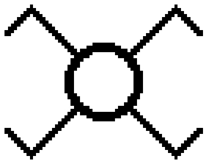
2. Which one of the following are non-statutory regulations? (L1.2)
   a) Electricity at Work Regulation
   b) Manual Handling Regulation
   c) BS 7671:2018
   d) Provision and Use of Work Equipment Regulations

3. Which one of the following is a direct implication of not complying with statutory regulations? (L1.3)
   a) Loss of earnings
   b) Lost clients
   c) Dismissal
   d) Prosecution

4. The document showing the location of electrical equipment in an electrical installation is a: (L2.1)
   a) specification
   b) drawing
   c) variation order
   d) Gannt chart

5. Which one of the following diagram types does not show individual conductors or cables but shows the sequence of equipment? (L2.2)
   a) Block
   b) Circuit
   c) Schematic
   d) Bar chart

6. The symbol shown represents: (L2.3)
   a) one-way switch
   b) two-way switch
   c) intermediate switch
   d) pull switch



7. Which one of the following is the correct drawing scale where a wall, 4m in length, measures 8cm on a drawing? (L2.4)
   a) 1:50
   b) 1:100
   c) 1:200
   d) 1:500

8. A drawing is produced to a scale of 1:50 showing a socket outlet installed 3.5cm from the corner of a room. Which one of the following is the actual distance from the corner in the room? (L2.4)
   a) 0.875m
   b) 1.75m
   c) 3.5m
   d) 7m

9. A circuit installed to supply a fire panel would be identified as: (L3.1)
   a) power and heating
   b) data communication
   c) control circuit
   d) alarm and emergency system

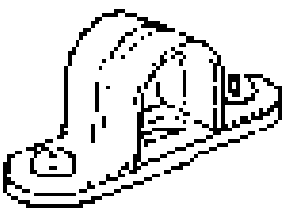
10. The type of trunking that can be used as a circuit protective conductor is: (L3.2)
    a) mini
    b) PVC dado
    c) steel
    d) plastic

11. The insulation material of mineral insulated metal sheathed cables is absorbent; therefore, the terminations must be: (L3.2)
    a) watertight
    b) correctly identified
    c) fitted with a gland
    d) fitted with a shroud

12. Additional cable supports should be provided in trunking where: (L3.2)
    a) segregation is required
    b) there are long vertical runs
    c) trunking is made of plastic
    d) the walls are made of lightweight block

13. Band I and Band II circuits can be enclosed in the same enclosure, provided that: (L3.2)
    a) the current rating of all circuits does not exceed 10A
    b) they are twisted around each other along the trunking length
    c) every cable or conductor is insulated for the highest voltage present
    d) there are the same number of Band I and Band II circuits

14. Which one of the following is the type of conduit fixing shown? (L3.2)
    a) Cleat
    b) Clip
    c) Crampet
    d) Saddle



15. Which one of the following symbols represents the rating factor for thermal insulation? (L3.3)
    a) Ci
    b) Ca
    c) Cf
    d) Cg

16. Which one of the following is the value of voltage drop, per ampere, per metre, for a 10mm^2 multi-core flat thermoplastic 70 °C cable, intended to supply a single-phase circuit? (L3.3)
a) 44 mV/A/m
b) 11 mV/A/m
c) 4.4 mV/A/m
d) 2.8 mV/A/m

17. Which one of the following is the maximum current carrying capacity for a single-core 6mm^2 70 °C thermoplastic insulated non-armoured cable, enclosed in conduit on a wall installed for a single-phase circuit? (L3.3)
a) 31A
b) 32A
c) 36A
d) 41A

18. Which one of the following is the value of voltage drop, in millivolts per ampere per metre, for a 4mm^2 multi-core thermosetting non-armoured cable, intended to supply a single-phase circuit? (L3.3)
a) 29 mV/A/m
b) 18 mV/A/m
c) 11 mV/A/m
d) 7.3 mV/A/m

19. Which one of the following devices is suitable for an installation supplying an X-ray machine in a hospital? (L3.4)
a) BS 3036 rewireable fuse
b) BS EN 60898 Type D
c) BS EN 60898 Type C
d) BS EN 60898 Type B

20. Which one of the following devices will disconnect in the fastest time if a short circuit current of approximately 300A occurred on a circuit? (L3.4)
a) 32A/30mA Type C RCBO
b) 32A Type B circuit breaker
c) 32A Type C circuit breaker
d) 32A Type D circuit breaker

21. Which one of the following is the minimum conduit size suitable for a short straight run containing the following stranded cables: (L3.6)
- 4 x 1.5mm^2
- 3 x 2.5mm^2?

a) 16mm
b) 20mm
c) 25mm
d) 32mm

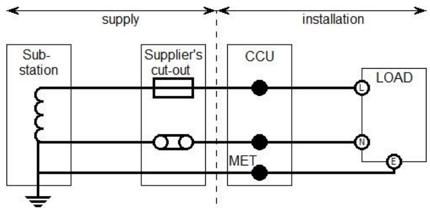
22. Which one of the following is the minimum conduit size suitable for a short straight run containing the following stranded cables: (L3.6)
- 8 x 1.5mm^2
- 2 x 2.5mm^2
- 2 x 4.0mm^2?

a) 16mm
b) 20mm
c) 25mm
d) 32mm

23. Which one of the following is the conduit capacity factor to be used where a 25mm conduit has 2 bend in a 6m run? (L3.6)
a) 111
b) 182
c) 333
d) 600

24. The electrical system in which the connection to earth is by an earth electrode is: (L4.1)
a) TT
b) TN-S
c) TN-C
d) TN-C-S

25. Which one of the following earthing arrangements is shown in the diagram? (L4.1)
a) TN-C-S
b) TT
c) TN-C
d) TN-S



26. Which one of the following is the correct name of the component which links the main earthing terminal of an installation to the means of earthing? (L4.2)
a) Main protective bonding conductor
b) Supplementary equipotential bond
c) Earthing conductor
d) Functional earth

27. What is represented by Z_s in the following formula: $Z_s=Z_e+(R_1+R_2)$? (L4.2)
a) Total earth fault loop impedance
b) External earth fault loop impedance
c) Final circuit earth fault loop impedance
d) Combined resistance of the earth path

28. Which one of the following defines the term ‘main protective bonding conductor’? (L4.2)
a) The conductor which links the MET to an earth electrode
b) The conductor which links the MET to extraneous conductive parts
c) The conductor which links the MET to exposed conductive parts
d) The conductor which links the MET to the means of earthing

29. Which one of the following is the purpose of the main protective bonding conductor? (L4.2)
a) To raise extraneous conductive parts to the same voltage as the supply under overload
b) To raise extraneous conductive parts to the same voltage as the supply under earth fault conditions
c) To raise extraneous conductive parts to the same voltage as the supply under normal conditions
d) To raise extraneous conductive parts to the same voltage as the supply under transient fault conditions

30. Which one of the following is an exposed conductive part? (L4.3)
a) Metal-clad switch
b) Structural steelwork
c) Air conditioning ducting
d) Metallic oil service pipe

31. Which one of the following is metal cable trunking? (L4.3)
 a) Earthed conductive part
 b) Extraneous conductive part
 c) Insulated part
 d) Exposed conductive part

32. Which one of the following is an extraneous conductive part? (L4.4)
 a) Metallic gas service pipe
 b) Metal-clad twin socket outlet
 c) Heavy duty steel conduit
 d) PVC mini-trunking

33. Which one of the following methods of generating electricity uses fossil fuels? (L5.1)
 a) Wave power
 b) Solar
 c) Gas
 d) Wind

34. Which one of the following uses sunlight to generate electricity? (L5.1)
 a) Photo-voltaic
 b) Biomass
 c) Wind
 d) Air source heat pump

35. Which one of the following is a transmission voltage? (L5.2)
 a) 400kV
 b) 33kV
 c) 11kV
 d) 400V

36. Which one of the following is a typical distribution voltage for a medium-sized factory where a private sub-station is located? (L5.3)
 a) 230V
 b) 400V
 c) 5kV
 d) 11kV

37. In which of the following parts of the electrical distribution network would a step-down transformer be located? (L5.4)
 a) Power station
 b) Pylon
 c) Local distribution sub-station
 d) Inverter

38. Which one of the following describes the process of a solar photo-voltaic system? (L6.1)
 a) Solar power is used to ignite a biomass which heats up water
 b) Solar power is collected by a solar panel which provides electricity
 c) Solar power is collected by a solar panel which provides hot water
 d) Solar power causes hot air to rise, rotating a generator that produces electricity

39. Which one of the following is a suitable use for rainwater harvesting? (L6.1)
 a) Baths/showers
 b) Toilet flushing
 c) Drinking water
 d) Cooking water

40. Which one of the following micro-generation systems requires the least maintenance once installed? (L6.3)

a) Micro-combined heat and power
b) Air source heat pump
c) Biomass
d) Solar thermal