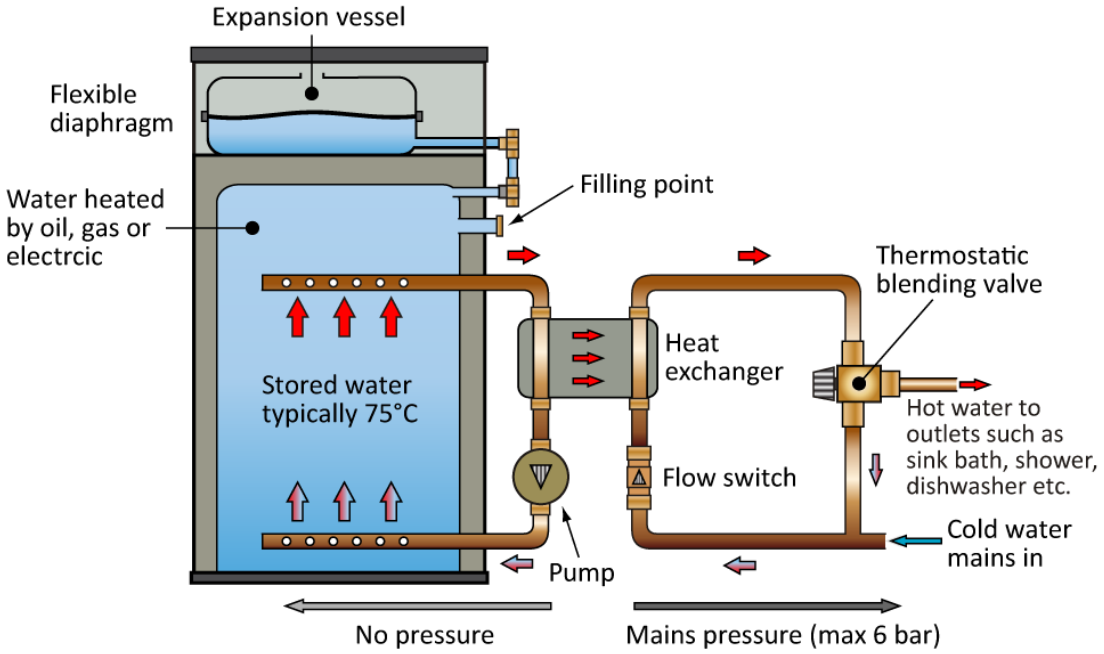
Level 3 Diploma in Installing Electrotechnical Systems & Equipment

C&G 2357

Unit 309-11 Understand the principles and applications of electrical heating systems



B&B Training Associates Ltd

Learning Materials for the Electrical Industry

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Aims and objectives

By the end of this study book you will have be able to:

- Explain the basic principles of electrical space heating and electrical water heating.
- Explain the operating principles, types, limitations and applications of electrical space and water heating appliances and components.

  Range of appliance

  - Immersion heaters.
  - Storage heaters.
  - Convector heaters.
  - Under floor heating.
  - Controls, timers and programmers for heating systems.

1: Heating systems

In this session the student will:

- Gain an understanding of the ways in which heat is transferred via conduction, radiation and convection.
- Gain an understanding of the different types of heating used within the electrical industry.

As with lighting arrangements, heating arrangements are wide ranging. We may need to heat up air, water or chemicals. We may have to arrange things so that temperatures are limited so that people don't get burned or installations catch fire or explode.

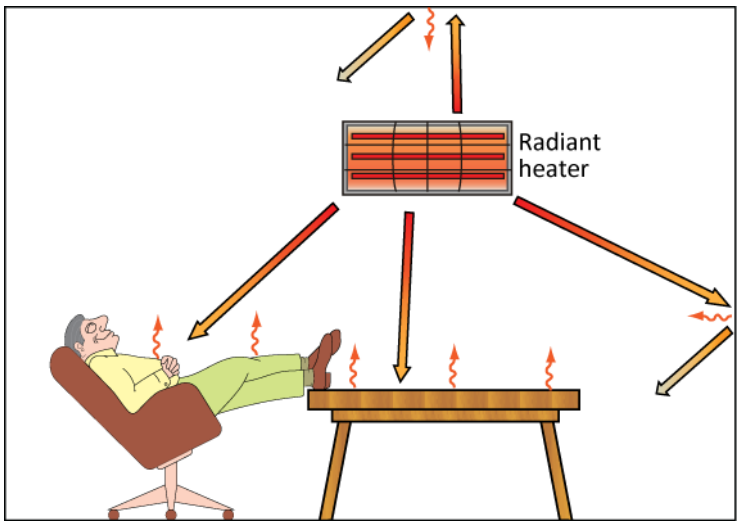
There are a wide variety of heaters and they all operate on slightly differing principles. Heat is transferred in one of three ways, convection, conduction and radiation.

All heaters operate on one of these three principles.

Space heating falls into two categories, direct heating and storage heating.
One of the common misconceptions about space heating is that different types of heaters are more expensive to run than other types. This is simply not accurate. All direct acting heaters such as radiant, convection etc are 100% efficient at the point of use and simply put, on a given tariff, 1kWh of energy used will cost the same whether it's a hairdryer, kettle, fan heater, panel heater or oil filled radiator using it.
However, the key to improving efficiency is to use products that have thermostatic control as these will ensure that the room is not overheated, thereby saving energy.
It has been found that the optimum mix for human comfort is a blend of 80% convected and 20% radiant from a heating appliance.

Radiant heaters

Radiant heaters are often found in bathrooms and other small rooms. With this type of heater, the air itself is not heated directly and the rays of energy travel in straight lines, only converting to heat when the rays strike and are absorbed by the receiving object.



This type of heater is used in those places where large areas do not require heating, but people do. You will find a variety of types in large warehouses, churches etc.

It is worth noting that where there is a location with a risk of fire due to the nature of the processed or stored material, such as sawmills, flour mills, gas-rich environments etc. then the requirements of Chapter 42 of BS 7671 apply.

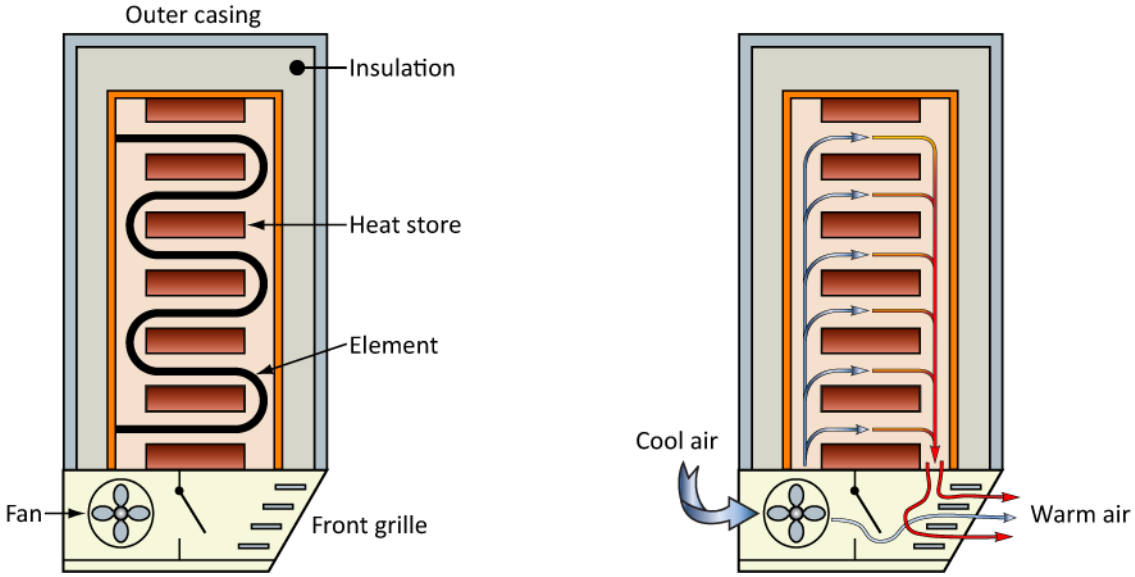
Convection heaters

Night storage heaters and fan-assisted heaters operate on the principle of convection. They heat up the air closest to it and this causes the air to rise which draws in colder air at the bottom.

These types of heaters fall within the overall group of space heaters. Space heaters can be classified as direct or indirect acting. Direct acting space heating responds immediately to temperature fluctuations and is costly. Indirect space heating operates on a storage principle and night store heaters and Electricaire systems fall into this category. It is generally cheaper as it operates on off-peak tariffs.

Night storage

With the night storage heater, heat is stored via bricks. The bricks are heated up using an element, a bit like an electric kettle. The bricks are excellent retainers of heat and so give out heat at a steady rate, even after the element has been switched off. Have a look below.



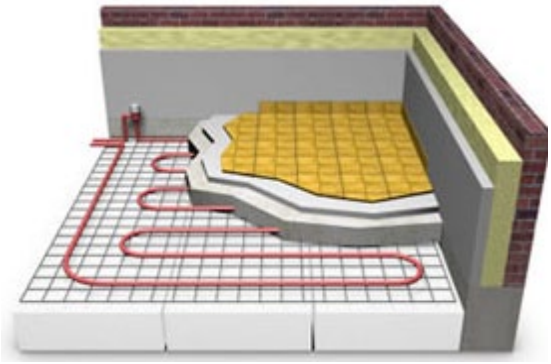
An Electricaire system consists of a central unit which can be a standalone unit or have a series of ducts attached to it which feeds each of the rooms with heated air. The units have a user control panel situated on the front so that the temperature can be manually controlled. These systems are usually complete and are supplied from off-peak electricity, such as economy7.

The core of the unit is made up of a number of 1 kW-coiled elements fitted within blocks. It is these blocks that hold the heat. Air is discharged from the unit to the insulated ducts by a fan.
The input rating of this type of systems ranges from 6 kW to 15 kW, and is less than flexible, which is why it is no longer in fashion with other forms of heating being used.

Floor warming

Floor warming is another form of space heating that is becoming more popular today and uses elements embedded in the floor. In effect the floor becomes the means of storage of heat and the energy is delivered to it via the off-peak tariffs.

A floor warming system comprises insulated heating elements that are usually embedded in screed



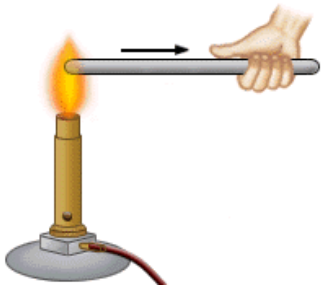
The above pictures show the installation of a wet system whilst the ones below show how a cable system might look.

The heating cables themselves are made from a range of substances. Chromium, aluminium, copper, silicon and manganese alloys have all been used. The insulators used include asbestos, mineral insulation, butyl, silicon rubber and nylon. All of these insulators are usually covered with a plastic sheet to protect them from damage.

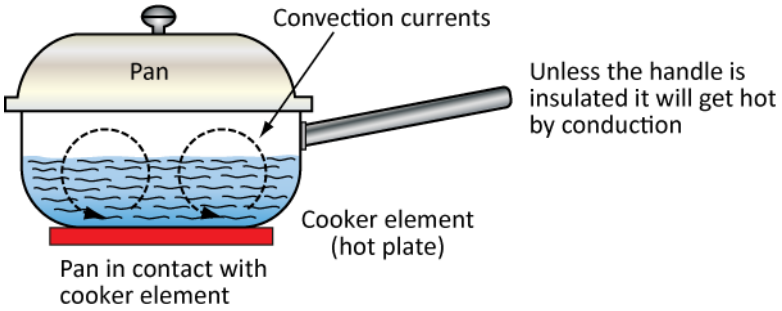
Under floor heating systems have their temperature generally limited to 26 ˚C. However, what this creates in a room is a comfortable temperature at low level with cooler, fresher air nearer the ceiling. People often find that this arrangement is very comfortable.

Conduction heating

Cookers and water heaters generally operate on the principle of conduction. The pan is in contact with the heating element and heat is passed from one to the other directly. The heater element is in contact with the water and the water heats up directly, although there is convection that takes place within the water.



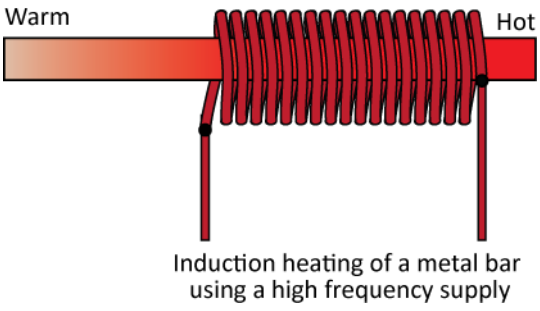
The end of the bar will get warm by the process of heat being conducted along its length.



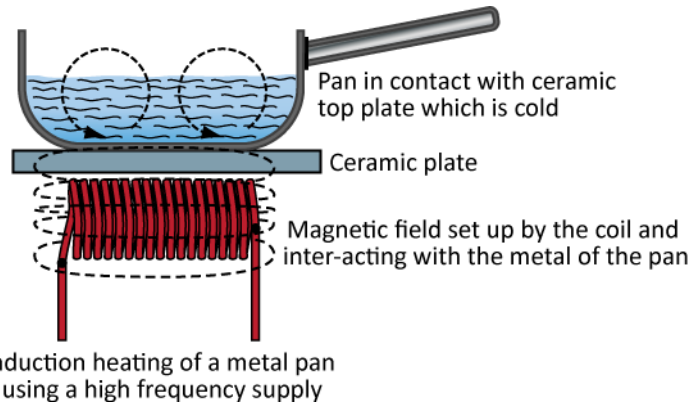
Induction heating

Induction heating is the process of heating an electrically conducting object which needs to be metal based by electromagnetic induction, where eddy currents are generated within the metal and the metals resistance leads to heating of the metal.

Think about how conduit becomes warm if only one conductor is run through it. Imagine the effect if a metal object was placed either inside a coil (industrial induction furnace) or above it (cooking by induction). The advantage of this process is that only the metal object gets hot and the level of control is very precise.



Induction heating



Cooking by induction

An induction heater for any process consists of an electromagnet, through which a high-frequency alternating current (a.c.) is passed.

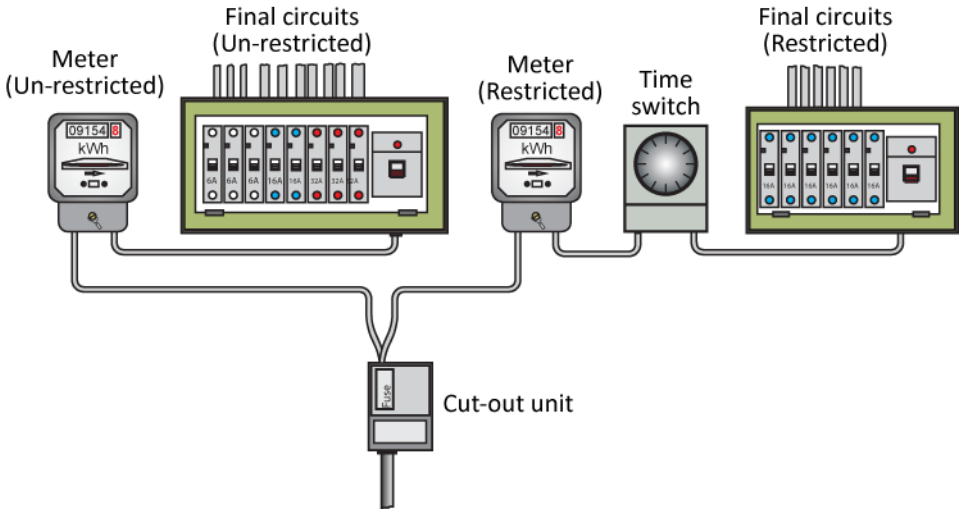
The frequency of a.c. used depends on the object size, material type, coupling (between the work coil and the object to be heated) and the penetration depth.

Tariffs

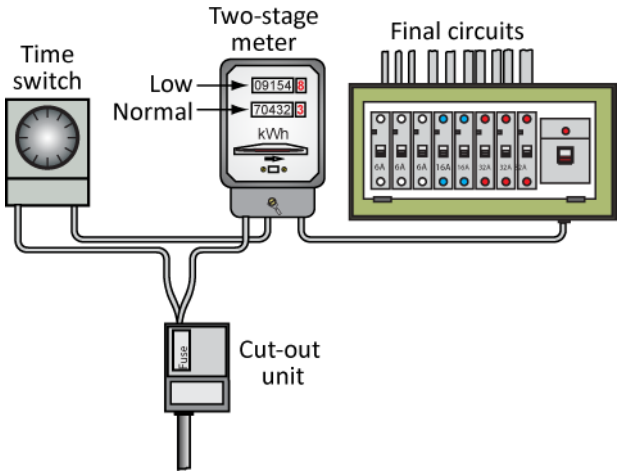
Most of the heating systems described above can be expensive to run. I refer particularly to the night stage heaters, the electricaire units and the under floor heating system. All of these require an off-peak tariff which is considerably less than the peak rate because it is used at quiet periods such as during the night.

There are two ways that the circuits and metering can be arranged.

One method uses two meters, one to record normal usage and the other to record off-peak usage. The diagram below could be such an arrangement.



The other method still uses a time switch but uses one meter which has dual means of recording energy usage. This is more popular as the time switch is normally radio controlled by the distributor. This is done so that the distributor can vary the 7 hours of cheaper energy.



The cheaper period is usually between;
2300 hrs and 0600 hrs, 2400 hrs and 0700 hrs or 0100 hrs and 0800 hrs.

Economy 7 will only be offered if the home owner has night storage heating or underfloor warming installed.

With E7 the tariff rate is approximately;
17 p/kWh for the single rate and 6 p/kWh for the off-peak rate.

Remember; $Cost = kW \times hours \times tariff$

Another tariff option is called Economy 10. This at present is only offered by Scottish Power. It gives the customer three time periods during a 24 hour period; midnight to 5:00 am (5 hours), a boost in the afternoon between 1:00 and 4:00 pm (3 hours), then another boost mid-evening between 8:00 and 10:00 pm (2 hours). This adds up to 10 hours in total.

Exercise 1

1. Briefly describe the three methods of heat transfer.

2. Describe the operation of a night storage heater

3. What is the difference between power and energy?

4. What are the advantages of economy 7 and economy 10 and who are they aimed at?

5. What is the cost of charging a night storage heater rated at 3 kW for a 7 hour period?

2: Water Heating

In this session the student will:

- Gain an understanding of the ways in which water can be heated, using electricity

As hot water rarely occurs naturally other than from hot springs, we need to use a different means to get our water hot.

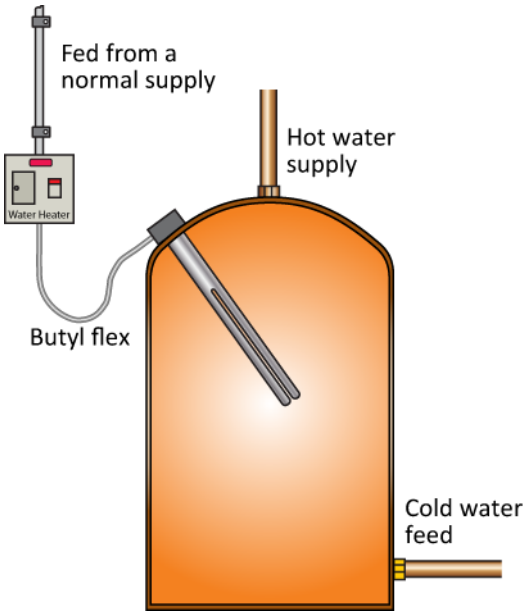
The options available include fossil fuels used either directly such as for oil and gas boilers to indirectly, which is to burn the fossil fuels to generate electricity for immersion heaters and electrode boilers.
There is also the option to use the energy of the sun to heat solar panels on the roof or to use ground source pumps to heat the water.

There are a number of types of electric water heaters on the market today:

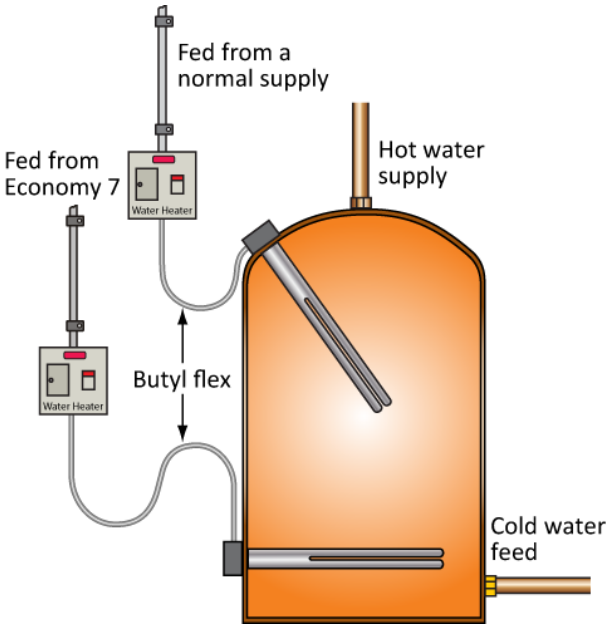
- immersion heater
- cistern-type water heater
- non-pressure water heater
- instantaneous water heater
- electrode boiler.

Immersion heater

This is the classic method of heating a large volume of water. Water is heated via the element placed within a protected jacket in the tank.



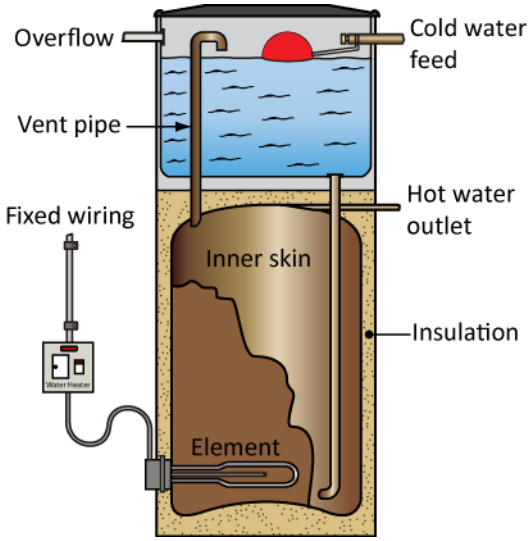
Single element



Dual element

With the dual heater, a small element is used for heating just the top of the tank, and a large one for when more hot water is needed such as when running a bath, is placed at the bottom. This provides some flexibility. In reality the ideal position for the element is the bottom of the tank.
With this arrangement it is more common that the larger element is controlled via an economy 7 tariff, whilst the smaller element is used for a daytime boost.

Cistern type water heater

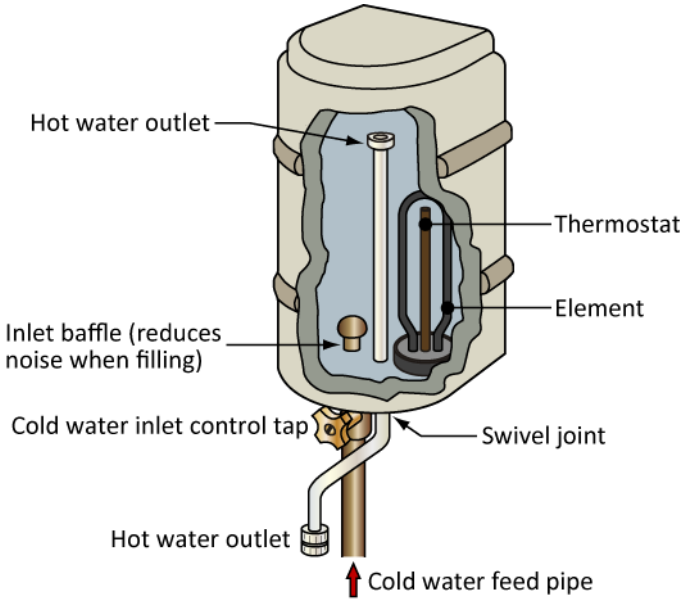


The immersion heater is usually placed in a large tank. This type of arrangement is a little smaller, although it is still capable of feeding a number of hand basins.

The principle is still very similar to the immersion heater, just on a smaller scale.

Non-pressure water heater

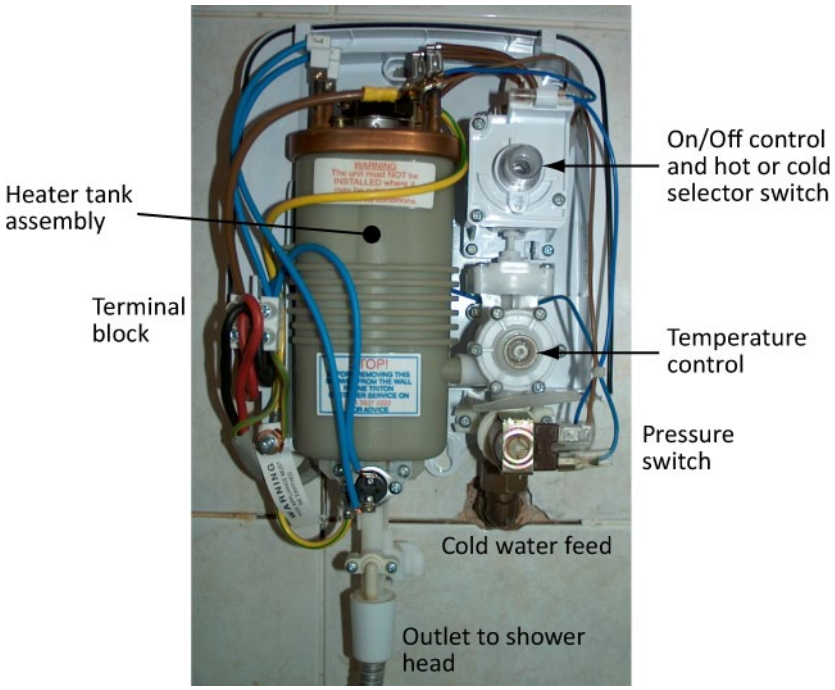
This type of arrangement is used for a single outlet. It has one inlet and only one outlet. It is usually placed over sinks, particularly in those places where it is not used very often, for example, garage forecourt toilets.



The water is heated via the element and controlled via the thermostat. The hot water, when required, will only flow when the cold-water tap is open. This quietly fills the heater because of the inlet baffle and pushes the heated water into the hot water outlet pipe.

Instantaneous water heater

This is very similar to the last type of heater. It is a single point outlet. Most people have this type of arrangement for their electric showers. The hot water flows when heat is correctly set. The water is heated as it flows over an element.

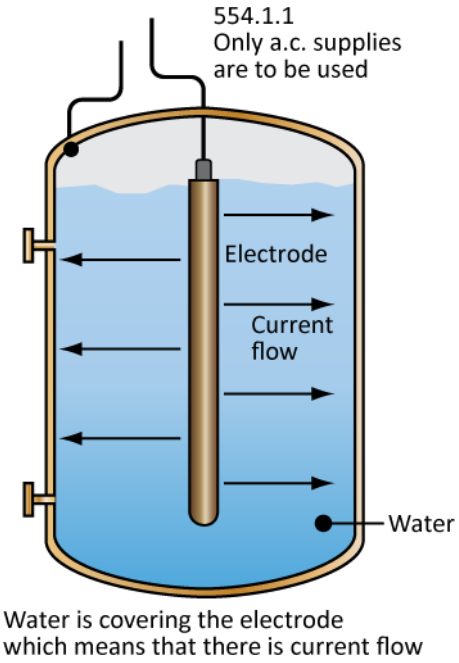


An electric shower is a classic instantaneous water heater.

Electrode boilers

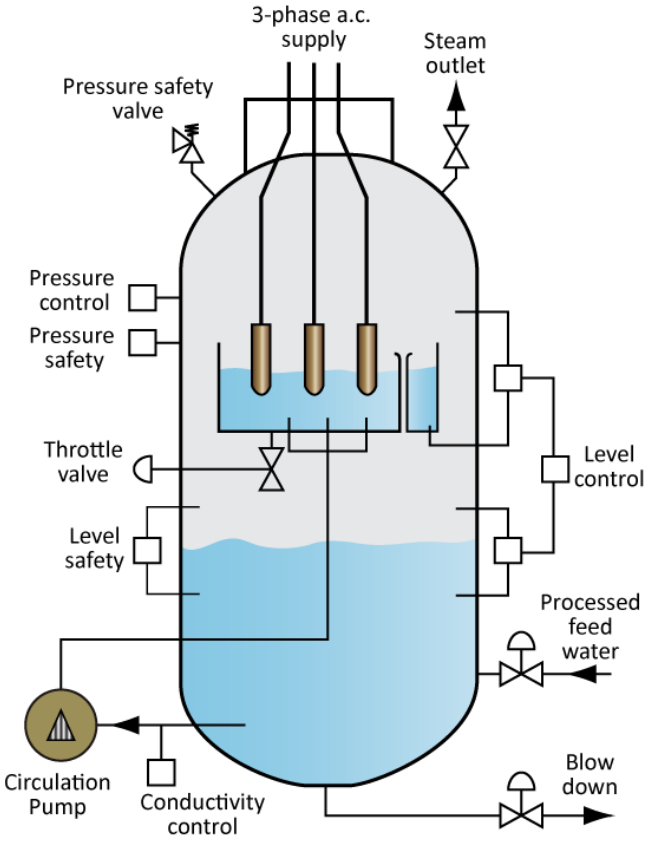
Whereas gas boilers rely on burning gas to generate heat, electric boilers rely on the electricity from the mains supply of the property to heat electodes within the boiler. Water gets hotter as it passes over these elements and once sufficiently heated the water is then pumped to where it is required.

Electric boilers remain popular because they are considered to be around 99% efficient to the end user. This is because electric boilers do not rely on the burning of fossil fuels such as gas or oil to produce heat and there is therefore no chance of losing valuable heat when releasing waste gases into the atmosphere



Water is covering the electrode which means that there is current flow

Very simple layout of an electrode boiler. It shows how current flows through the water.



A more detailed drawing showing the safety features.

Electrode Boiler Benefits

- No flue required
- No fumes
- Greater than 99% efficient
- Economic running costs
- Can provide central heating only or central heating and hot water
- Can be used for underfloor heating
- No annual safety certificate required
- Preferential electricity tariffs available
- Silent in operation

Disadvantages of an electric boiler:

- Not always suitable for larger properties
- Environmental benefits myth
- Cost of electricity
- Potential power cuts

Temperature control is gained by altering the depth of the electrodes in the water, or usually by altering a shield that covers the electrodes.
Section 554 of BS 7671 deals with specific requirements for electrode water heaters and boilers.

Exercise 2

1. How does an electrode boiler work and why might it be chosen over fossil fuels to heat water.

2. State the type of water heater most suited for the locations listed below. Give a reason for your choice.
   a) Church kitchen
   b) Garage workshop
   c) College
   d) Domestic dwelling

3: Control mechanisms

In this session the student will:

- Gain an understanding of the ways in which heating systems are controlled.

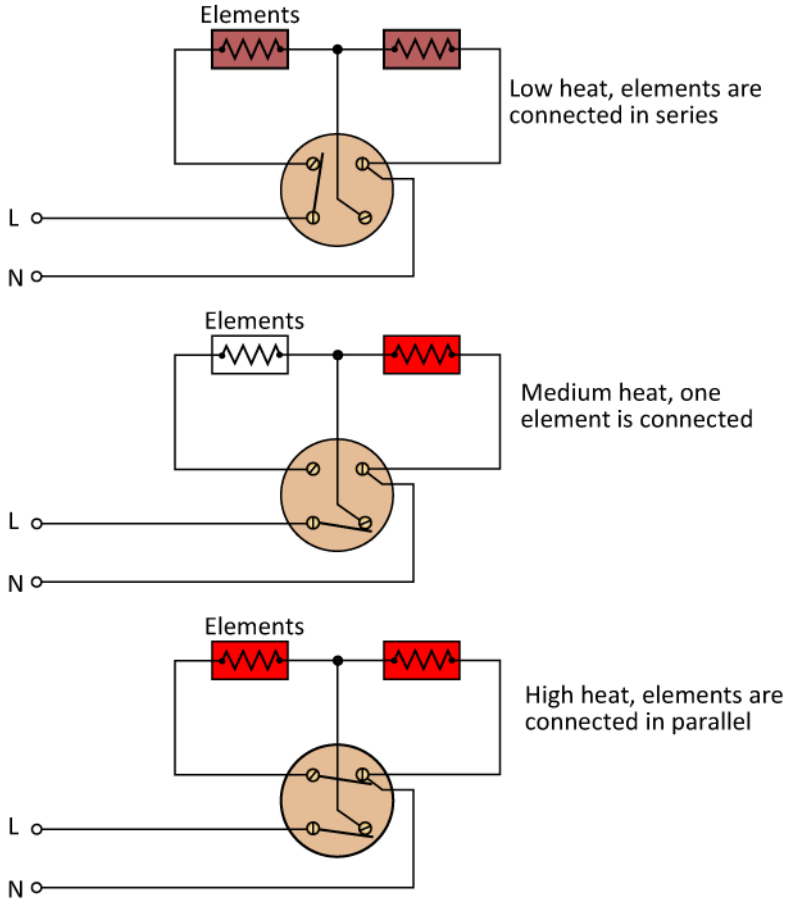
There are a whole raft of control mechanisms and circuits that are used to deal with heaters. This next section looks at some of the more common types of control mechanism, other than the double pole switch.

It is important that consideration be given to Part L of the Building Regulations which came into force in 2005 and updated in October 2010. The changes reflect how the CO2 emissions from dwellings (DER)[1] can be reduced through careful planning of heating controls and zoning of dwellings. The aim is to get a 25% reduction by 2016 and ultimately have zero-carbon houses.

1 DER – dwelling emission rate

Three-heat switch

Cooker elements sometimes have a three setting switch, low, medium and high. This commonly alters the settings to the double ring on a cooker. The cooker ring has two elements. These two elements have similar ratings.



The first of the three diagrams shown above shows the cooker with both of the elements connected in series. This is the lowest setting

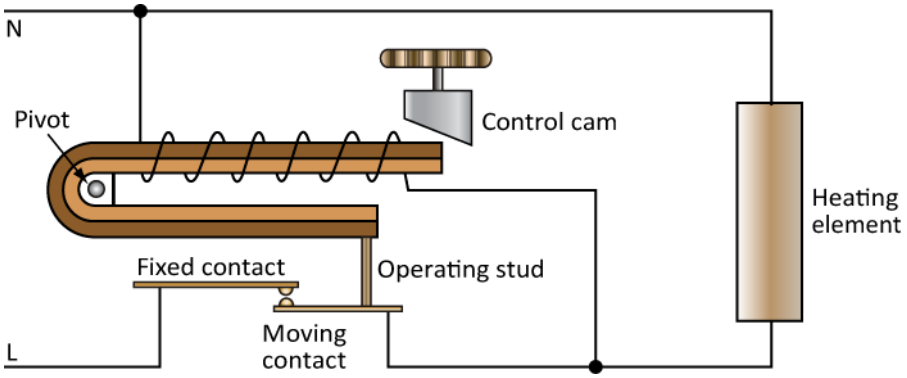
- If the resistance is increased (resistors in series) the current must fall; if the current falls then so will the power; $\left(P = I^2R\right)$.
- The second diagram shows the mid-heat position. In this only one of the elements is connected in the circuit. The current must have doubled from the previous value, and consequently, so must the power.
- The final diagram shows both elements connected in parallel. In parallel the resistance halves again and so the power must double again. This is the highest heat position.

Thermostats

There are three types of thermostat that are used to control the temperature of electrical heating devices.

Simmer stat

Have a look below.

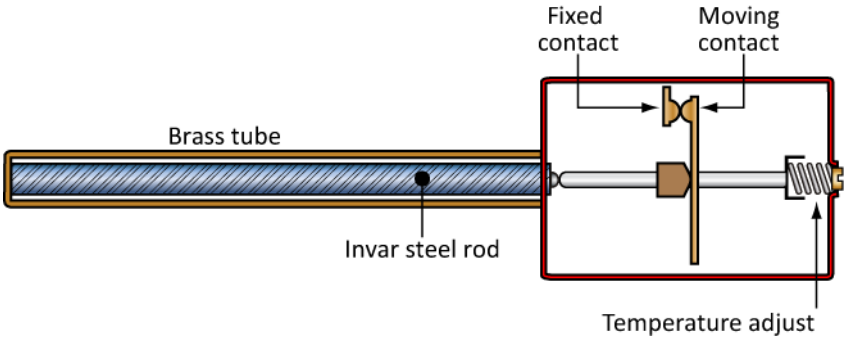


Here the simmer stat is a bimetallic strip wound with a coil. The coil around the bimetallic strip operates in tandem with the current passing through the cooker element.

Current flows through the heating element, also some current flows through the coil wrapped around the bimetallic strip. The bimetallic strip warms up and opens and closes the moving contact. Current to the heating element is then continually interrupted and reconnected as the bimetallic strip moves. At its simplest all we have is a bi-metallic strip – two dissimilar metals which bend at different rates.

Invar rod

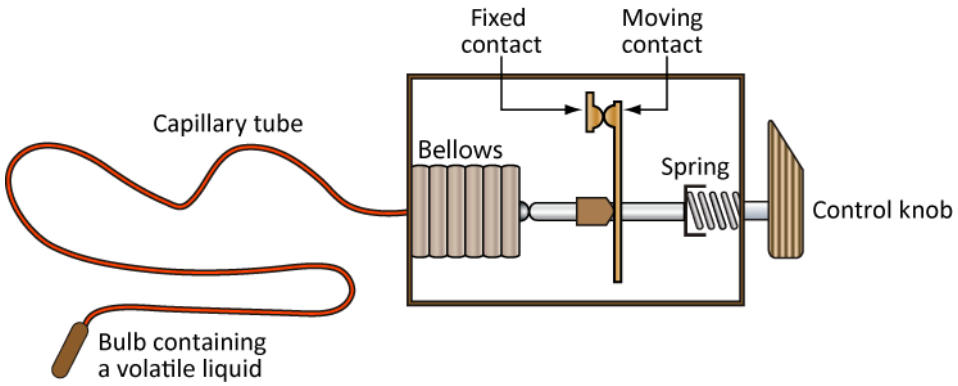
The invar rod in an immersion heater operates on the same principle, although this time the invar rod does not expand but everything else around it does.



This type of arrangement is slightly different to the normal bi-metallic strip, but the principle of expanding materials at temperature is the same.

Oven thermostat

The oven thermostat (oven stat) operates differently.



Here the tube is filled with a liquid that responds very readily to heat change. As the liquid expands then the bellows expand and break the contacts.

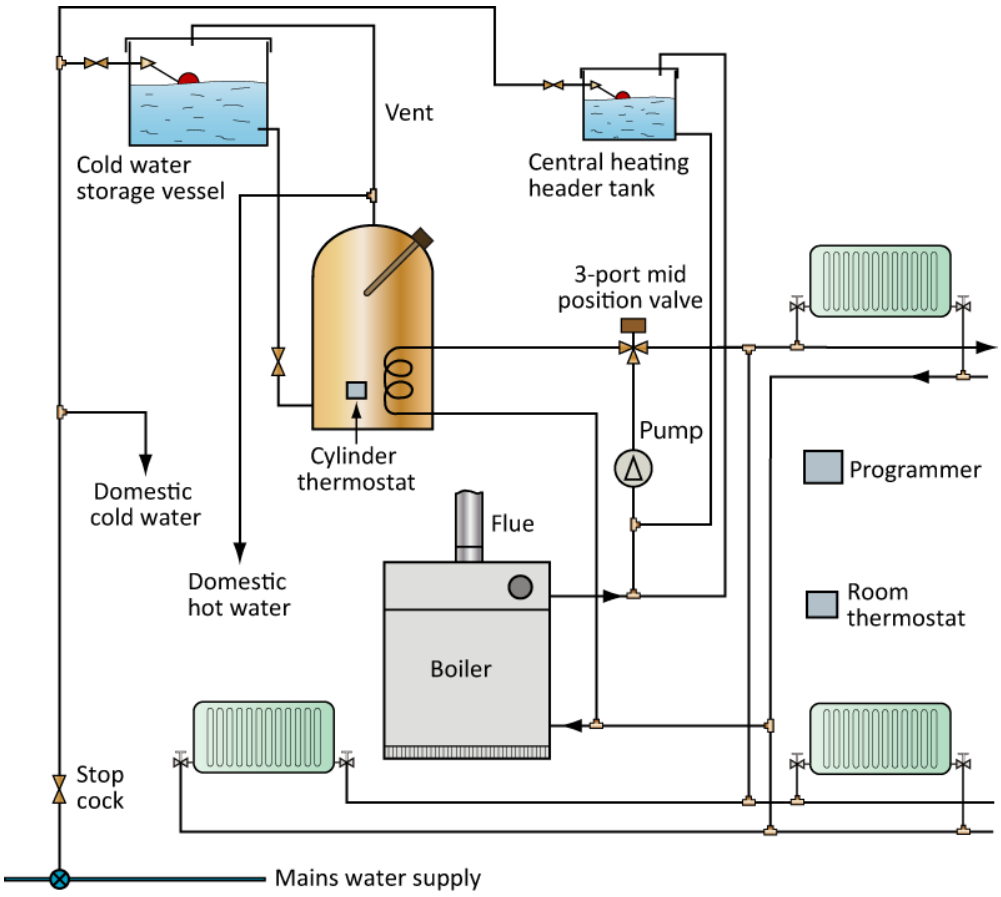
Liquids expand as they are heated; another very simple principle.

Bimetallic strips are commonly found in storage heaters and other appliances such as irons etc. They are not to be thought of as a switch in the same sense as the double-pole switch. They will reset after a period of time has elapsed and the strip has cooled down.

Central heating

It is worthwhile just taking a moment to consider typical central heating systems and their wiring requirements.

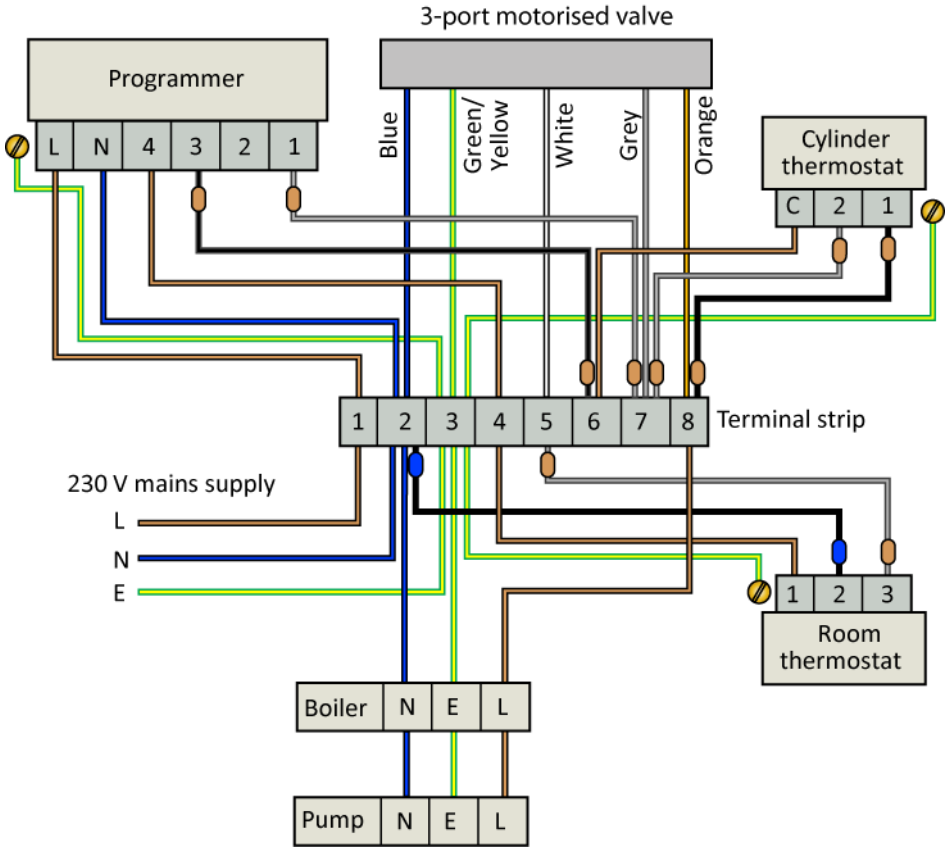
The system below is called a Y-Plan. It is an improvement on the older gravity hot water pumped heating system. It uses a 3-port mid position motorised valve. This allows for hot water only, central heating only or both together. To allow these configurations, a two channel timer/programmer is needed.



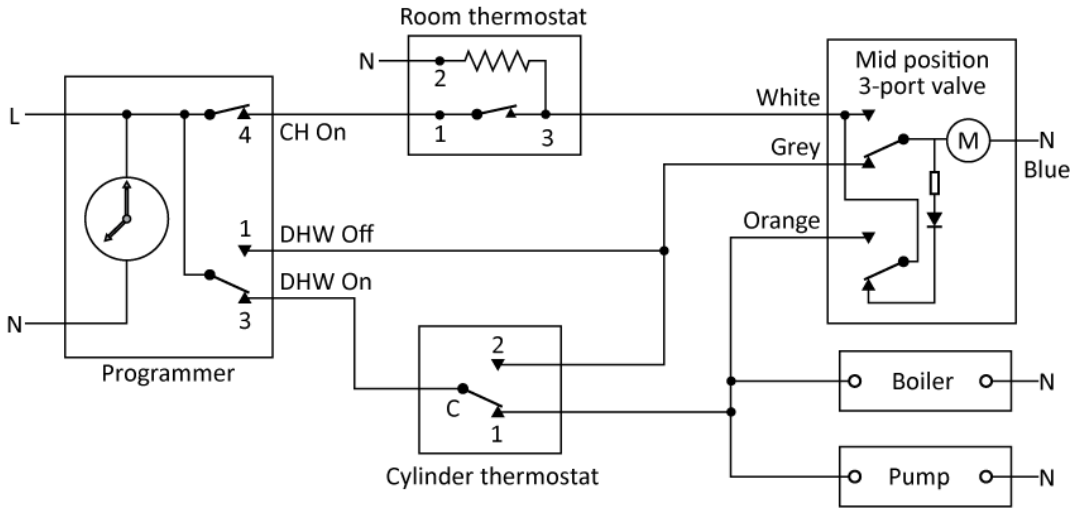
This is a fairly common type of arrangement and does satisfy the requirements of Part L of the Building Regulations if used with thermostatic radiator valves (TRV's). The disadvantages of this plan are that it doesn't allow for zoning of say the upstairs and downstairs rooms in larger houses, for this the S-Plan Plus must be used, and the flow rate through the mid-position valve is not as good as through a two port valve.

The diagram over the page shows the wiring diagram for the above system. Think carefully and you should be able to follow what is happening.

Y-Plan wiring diagram



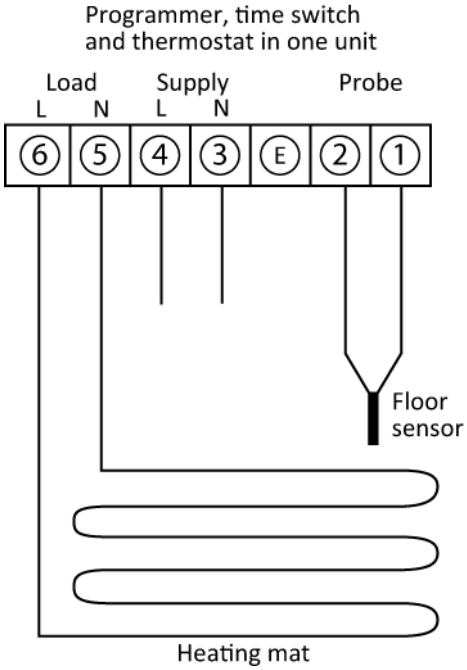
Circuit diagram



Voltage	Heating	Position of port
No power on the valve	DHW only	Port B open
230 V 0n the white	DHW and CH	Mid position
230 V on grey and white	CH only	Port A open
230 V on grey		Valve held in last position

Underfloor heating control

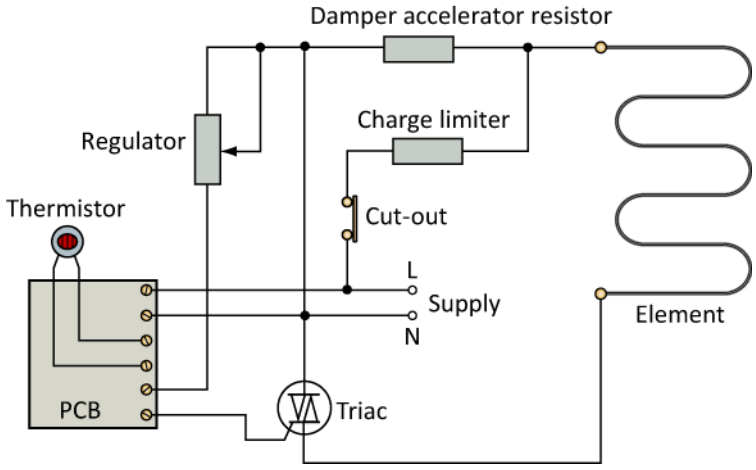
Underfloor heating systems have their temperature generally limited to 26 ˚C, although Regulation 753.423 limits the maximum exemplar value to 35 ˚C. The control of this type of heating is via a thermostat and time switch.



In terms of the heat loss from this type of heating, carpet will have a tendency to drive heat downwards into the ground and even when carpet is not used, it would be sensible to provide insulation near to walls where heat can escape sideways.

Section 753 Floor and Ceiling Heating Systems details the additional requirements of BS 7671 for such types of heating arrangement.

Night store control



The cutout is a short-term means of limiting the problems of overheating and will either automatically reset or be reset by the press of a button.

The triac is a bi directional controlled conducting device. Its operation will be dealt with in the next unit.

This is a straightforward means of control of a night storage heater. The printed circuit board (PCB) is used to control the current going to the element. This arrangement makes use of a timing circuit and a triac/diac arrangement.

Energy

There are a number of factors that affect the comfort of a room; air temperature, surface temperature, air movement, humidity, activity, clothing, age and sex (male or female!).

Most of these cannot be covered in this study book, and are parts of a wider study of building services engineering such as the design course.

However, it is worth as part of your studying to become an electrician, that we at least consider the energy used to raise the temperature of water and the energy used to heat a room.

So far in our electrical work, we have considered energy in terms of electrical energy and have used the formula, $W = IUt$.

This is no longer adequate. When we are dealing with substances, we need something that will take into account the ability of a substance to heat up.

Heat capacity is the quantity of heat required to raise a body by 1°C. It is measured in '***joule per kilogram***' $\left(\frac{J}{kg} \text{ or } Jkg^{-1} \right)$.

The specific heat capacity of a substance is material specific and is measured in '***joule per kilogram per kelvin***'. You can use '***joule per kilogram per degree C***'.

$$\left(\frac{J}{kg°K} \text{ or } Jkg^{-1}°K^{-1} \text{ or } Jkg^{-1}°C^{-1} \right).$$

The specific heat capacity of some common substances can be found in the table below.

Material	Specific heat capacity J/kgºC
Water	4190
Concrete and brickwork	3300
Ice	2100
Aluminium	910
Glass	700
Steel	450
Copper	390

There is, as you expect, an equation that is used when we are dealing with the increase in temperature of a substance such as water.

$$Q = mc\theta \quad \text{or} \quad Q = mc\left(\theta_1 - \theta_2\right)$$

Where $m = \text{mass}\ (\text{kg})$

$c = \text{specific heat capacity}\ (\text{Jkg}^{-1}\text{°C})$

$\theta = \text{temperature change}\ (\text{°C or °K})$

The mass must always be measured in kilograms. The specific heat capacity is always found in tables and the change in temperature is just that!

We'll look at some examples.

1. What is the total heat energy required to raise 5 litres of water from 2°C up to 85°C. Assume that the specific heat capacity of water is 4200 J/kg°C.

With this type of example, it is a case of filling in the numbers.

*Remember that 1 litre of water is assumed to have the same mass as 1kg of water.

$$Q = mc\left(\theta_1 - \theta_2\right)$$
$$Q = 5 \times 4200\left(85 - 2\right)$$
$$Q = 5 \times 4200 \times 83 = \underline{\underline{1743000\text{J}}} = \underline{\underline{1.743\text{MJ}}}$$

2. A storage heater contains concrete blocks measuring, in total, 2m×1m×0.3m. The blocks have a density of 2400 kg/m^3. The specific heat capacity is assumed to 3300 J/kg°C. What is the heat energy required, assuming there are no losses, to raise the temperature from 12°C to 45 °C.

With this example, you are expected to remember that there is a relationship between density, volume and mass. From the information given here, you should be able to determine the mass.

Density (ρ) is found from; $\rho = \dfrac{mass}{Volume} \quad \therefore mass(m) = \rho V$ *The density is given as 2400 kg/m^3*

First we need to find the volume. $V = lbh = 2 \times 1 \times 0.3 = 0.6\,m^3$

The mass becomes; $m = 2400 \times 0.6 = 400\,kg$

Energy required; $Q = mc\left(\theta_1 - \theta_2\right) = 400 \times 3300\left(45 - 12\right) = 43560000\,J = 43.56\,MJ$

So far, we have looked at systems that have no losses. We all know that there are losses. We cannot avoid them.

Let's look at an example that takes this into account.

3. A storage heater contains 250 kg of concrete blocks. The 230 V heating elements produce a temperature rise of 65 °C in 1.5 hours. The elements are 84% efficient. Determine the rating of the elements, assuming there are three of them, if the specific heat capacity of the concrete is 3300 J/kg°C.

Follow the working out carefully.

Energy required; $Q = mc\theta = 250 \times 3300 \times 65 = 53.625 MJ$

Actual heat input considering the efficiency; $Q \times \frac{100}{84} = 53.625 \times \frac{100}{84} = 63.84 MJ$

Power rating of the blocks; $P = \frac{Q}{t} = \frac{63.84 \times 10^6}{1.5 \times 60 \times 60} = 11.82 kW$

Power of individual blocks; $P = \frac{11.82}{3} = 3.94 kW$

Method

- Calculate the heat required without losses;
- Determine the losses;
- Determine the power required.

Remember that the time is always in seconds, so multiply the hours by 3600, which is sixty seconds in sixty minutes.

Exercise 3

1. Why is off-peak control better for managing night storage heaters?

2. State three types of thermal control and list where they might be found.

3. Is it a requirement of BS 7671 for underfloor heating systems to be protected by an RCD? (Justify your answer).

4. In addition to the general requirement to provide fault protection for a circuit, what additional protection must a water heater have?

B&B Training Associates

Engineering Learning Materials

Attempt all questions.

All marks are shown in the right-hand margin.

You should aim to pass with an 85% minimum mark.

Anything less than this mark should lead you to re-read the text.

1. Give examples of appliances that give off heat via radiation, conduction and convection. 3

2. Why is an invar rod used in an immersion heater? 2

3. Compare the advantages of an electrically heated instant shower with those of a shower supplied from a domestic hot water system. To justify your answers you can assume that the shower is rated at 9.5kW; has a flow rate of 7 litres/min and an efficiency of 95%. The hot water tank is heated by a 3kW immersion heater and holds 220 litres of water and has an overall efficiency of 65%. The overall cost of electricity is 8.2p per unit and the specific heat capacity of water is 4200J/kgºC. The initial temperature of water is 9ºC and the final temperature is 65ºC. The shower lasts for 10 minutes. 15

4. A 9.0kW shower has a flow rate of 5 litres per minute. The efficiency is 95% and the temperature of the water is 9ºC. Calculate:
   i). The output temperature of the water;
   ii). The cost of a shower lasting 15 minutes if the cost for energy is 7.6p per unit.
   Assume the specific heat capacity of water is 4180J/kgºC. 10

Total marks 30

