°kelvin

0 K = −273 °C

Thermal or heat energy is energy that is stored in 'hot' matter. We shall see that 'hot' is a relative term. There is a temperature called absolute zero that is the lowest possible temperature. Any matter that is above this temperature has some thermal energy. The kinetic energy of the minute particles that make up all matter produces the effect we call heat.

Convert from °C → °K + 273

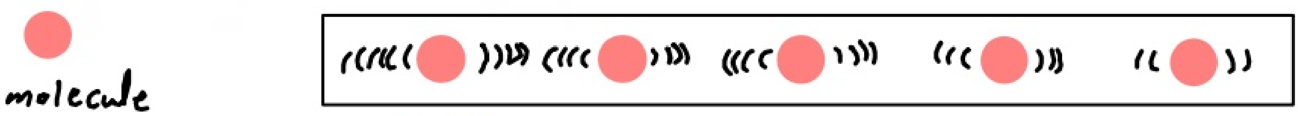
Thermal energy is transferred from a place that is hotter (that is, at a higher temperature) to one that is colder (at a lower temperature). In this chapter, we will look at the different ways in which thermal energy is transferred between places that have different temperatures.

C → K + 273   K → C − 273

CONDUCTION

Thermal **conduction** is the transfer of thermal (heat) energy through a substance by the vibration of the atoms within the substance. The substance itself does not move.

If you have ever cooked kebabs on a barbecue with metal skewers, as shown in Figure 15.2, you will have discovered conduction! The metal over the burning charcoal becomes hot and the heat energy is transferred along the skewer by conduction. In metals, this takes place quite rapidly and soon the handle end is almost as hot as the end over the fire. Metals are good thermal



K.E of molecules
or speed
or vibrational energy of molecules

inc. ⇄

if temperature of the object inc.

▲ Figure 15.2 Metal skewers allow heat to be transferred to parts that are away from the heat.

conductors. If you use skewers with wooden handles you can hold the wooden ends much more comfortably because wood does not conduct thermal energy very well. Wood is an example of a good thermal insulator.

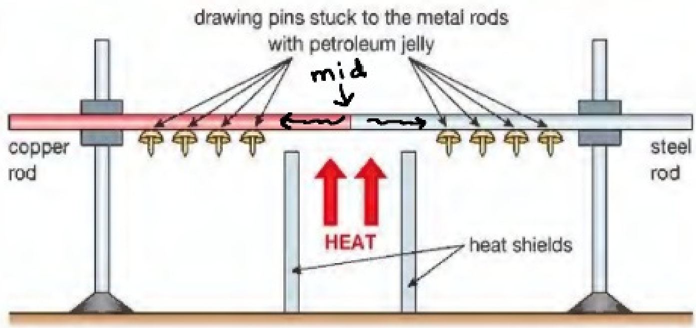
The process of energy transfer by conduction is explained in terms of the behaviour of the tiny particles that make up all matter. In a hot part of a substance, like the part of the skewer over the hot charcoal, these particles have more kinetic energy. The more energetic particles transfer some of their energy to particles near to them. These therefore gain energy and then pass energy on to particles near to them. The energy transfer goes on throughout the substance. This process takes place in all materials.

In metals, the process takes place much more rapidly, because metals have free electrons that can move easily through the structure of the metal, making the transfer of energy happen faster.

ACTIVITY 1

▼ PRACTICAL: INVESTIGATE HOW WELL DIFFERENT METALS CONDUCT HEAT

The metal rods will quickly get hot enough to burn the skin and will remain hot long after the heat is removed.



▲ Figure 15.3 Experiment to show thermal conduction in different metals

Figure 15.3 demonstrates how heat is transferred along the metal rods from the heated ends towards the cooler ends away from the heat source. As the heat passes along the rods the petroleum jelly holding the drawing pins in place melts and they drop off in sequence. This experiment also shows that copper conducts heat better than steel because the drawing pins attached to the copper rod drop off sooner than those attached to the steel rod. The rods should be the same diameter and the drawing pins placed at the same distances from the heat source for this to be a fair test.

EXTENSION WORK

'Free electrons' are electrons that are not connected with any particular atom in the structure of a substance. Metals usually have huge numbers of free electrons per unit volume. Copper, for example, has about 10^{29} free electrons in each cubic metre. As these free electrons carry electric charge as well as energy, it is no coincidence that good thermal conductors are usually good conductors of electricity too.

③ same mass of pins
④ Same type of jelly
controled variables
⑤ Same amount of jelly

(b) Describe how energy is transferred by conduction through the metal strips.

(3)

* vibration of molecules depends on temp
* vibrational energy is transfered to neighbouring and so on . . . .

* Free electrons transfer energy through subst.

DO NOT WRITE IN THIS AREA

idea that atoms in metal have vibrations; idea that vibrations increase in speed/amplitude (when metal is heated); idea that vibrations are passed (along the metal) between particles;	allow ions for atoms allow (free/delocalised) electrons in metal move around allow (free/delocalised) electrons move faster (when metal is heated) allow (free/delocalised) electrons collide with other electrons/atoms (along the metal)	3

the vibrational (1) energy of atoms nearer the source of heat (1) inc., and this energy will pass to the neighbouring (2) particles and so on until it reaches the other end.

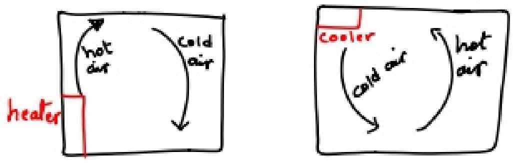
↳ and the free (3) electrons in Metals transfer energy through the substance which make the metals are good conductors.

CONVECTION

Convection is the transfer of heat through fluids (liquids and gases) by the upward movement of warmer, less dense regions of fluid.

You may have seen a demonstration of convection currents in water, like the one shown in Figure 15.4. The water is heated just under the purple crystal and the crystal colours the water as it **dissolves**, which lets you see the movement in the water. The heated water expands and becomes less dense than the colder surrounding water, so it floats up to the top of the glass beaker. Colder water sinks to take its place, and is then heated too. At the top, the warm water starts to cool, becomes more dense again and will begin to sink, so a circulating current is set up in the water. This is called a convection current.

no convection in solids because their particles vibrate about a fixed position



heating at bottom and cooling at top causes convection currents

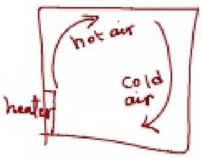
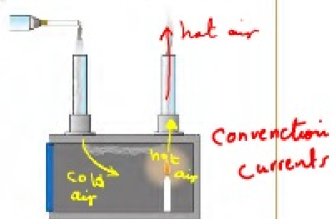


Figure 15.4 Demonstration of convection currents using a potassium manganate(VII) crystal in water



Convection currents

Figure 15.5 Here, air warmed by the candle floats up the chimney on the right and colder air is drawn down the chimney on the left. Smoke from the burning candle shows up the circulation of the air.

EXTENSION WORK

Substances tend to expand when heated because the particles of which they are made have more kinetic energy. As they move around more, the average distance between the particles increases.

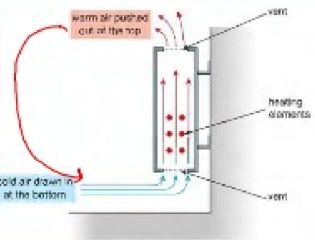


Figure 15.6 A convector heater relies on the effects of convection.

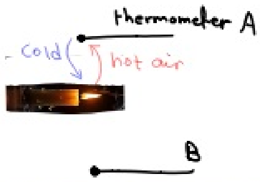
conduction: in solids → metals, liquids, gases

convection: fluids – liquids, gases

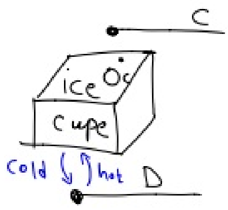
Radiation: gases, vacuum

in liquids → poor conductor → molecules are far a part

gases → much poorer → molecules are very far a part



temp of thermometer A inc. more than B



temp of D decrease more than C

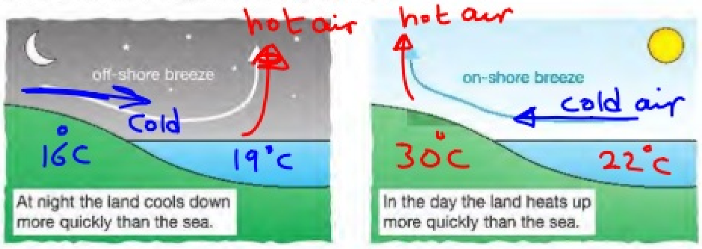
Convection occurs in any fluid substance – that is in things that can flow, such as liquids and gases. Convector heaters (Figure 15.6) heat air, which then floats out of the top of the heater to the top of the room. Cold air is drawn in at the bottom and this in turn is heated. In this way, heat energy is eventually transferred to all parts of the room.

In many cooking ovens, the heating element is placed at the bottom of the oven. It heats the air near to it, and this air rises by convection. The top of the oven is generally warmer than the bottom, so you can cook foods at different temperatures. However many modern ovens are fan ovens, where hot air is blown into the oven and provides an even temperature throughout the oven.

▲ Figure 15.7 A diver wearing a wetsuit to keep warm in cold water

Air and water both allow heat transfer to take place by convection as they are both fluids, but neither are good thermal conductors (they are insulators). This insulating property of both water and air is put to good use in situations where they are not able to circulate easily. For example, woollen clothing keeps you warm because air gets trapped in the fibres. The trapped air is heated by your body and forms a warm insulating layer that helps to stop you losing heat. In the same way, a wetsuit keeps a diver warm because a thin layer of water is trapped next to the diver's skin. (Figure 15.7)

Convection currents are responsible for many everyday events. One example is on-shore and off-shore breezes, also known as sea breezes and land breezes. These are explained in Figure 15.8.



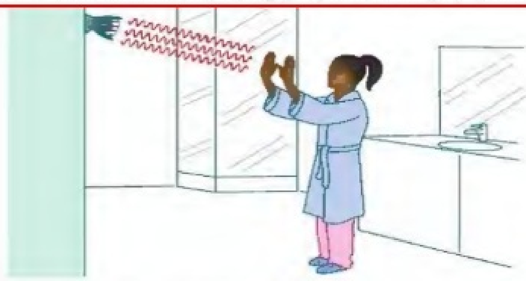
▲ Figure 15.8 At night the air over the warmer sea floats up causing cooler air to flow towards sea.

During the day the situation is reversed. In Unit 5 you will learn that some things heat up and cool down more easily than others.

Another example is convection currents within the very tall 'thunder' clouds that are responsible for the build-up of charge at the cloud base resulting in lightning strikes.

RADIATION

Thermal radiation is the transfer of energy by infrared (IR) waves.



▲ Figure 15.9 Heat is transferred from a heater by radiation.

E·M spectrum

γ	x	UV	visible	IR	Micro	Radio

EXTENSION WORK

The reflector in an electric fire is a special shape, called a **parabola**. You can see parabolic reflectors in torches and radio telescopes, for example.

When you turn on a bathroom heater, as shown in Figure 15.9, you will feel the effect almost instantly. Neither conduction nor convection can explain how heat is getting from the hot part to your hands. Conduction does not occur that rapidly, even in good thermal conductors, and air is a poor thermal conductor. Convection results in heated air floating upwards on colder, denser air.

There are two things you should notice about this example.

1. The heat that you feel so quickly is travelling from the heater in a straight line.
2. The design of the bathroom heater includes a specially shaped, very shiny reflector, similar to the reflector behind a fluorescent light or in a torch.

In this example, heat is travelling in the form of waves, like visible light. Heat waves are called infrared (IR) waves or IR radiation. The army and the emergency services use special cameras, called thermal imaging cameras, that can detect objects giving out IR waves. These cameras show images of people because of the heat radiation from their bodies, even when there is not enough visible light to actually see them. Thermal imaging is also an important tool in the diagnosis of certain illnesses. (Figure 15.10)

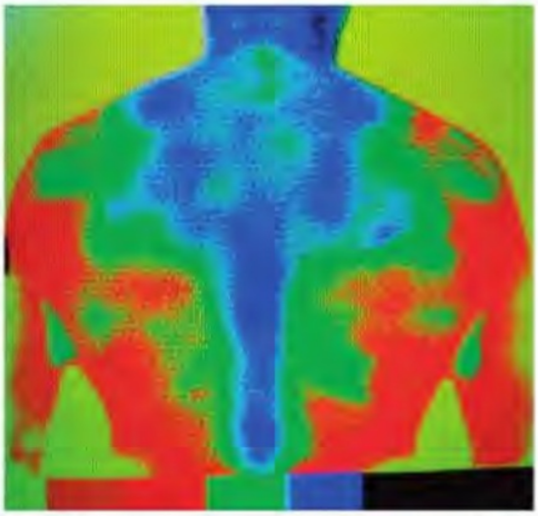


Figure 15.10 This is a thermal image of a patient showing areas of different temperatures.

IR waves are part of the same family of waves as light, radio waves, ultraviolet and so on, called the electromagnetic (EM) spectrum (see page 106). IR waves, therefore, have the same properties as all the other waves in the EM spectrum. In particular, IR can travel through a vacuum and does so at the speed of light (3×10^8 m/s). 3×10^8 m/s , 3×10^5 km/s , 300000 km/s ,

It is important that heat can travel in this way, without the need for matter, otherwise we would not receive heat, as well as light, from the Sun.

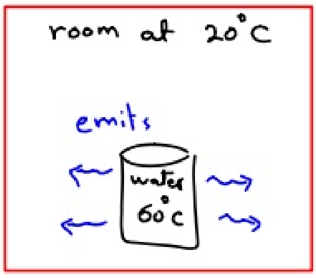
IR waves can also be reflected and absorbed by different materials, just like visible light. Highly polished, shiny surfaces are good reflectors of thermal radiation. White surfaces also reflect a lot of IR. Matt (not shiny) black and dark surfaces are poor reflectors or, to put it more positively, are good absorbers of heat radiation. Figure 15.12 shows how this can be useful in everyday life.

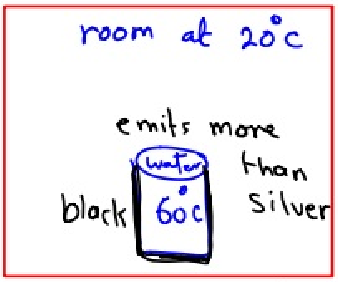
White, shiny	Black, Matt
good reflector	bad reflector
bad absorber	good absorber
bad emitter	good emitter

good emission or reflection ⇒ depends on colour

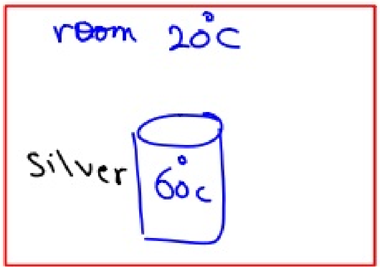
↳ the object emits heat energy if its temp. is greater than surrounding

↳ the object absorbs heat if its temp. is lower than surrounding





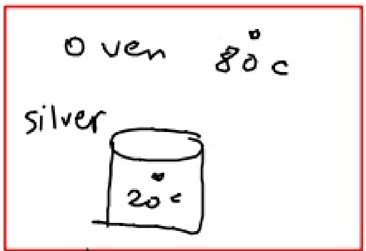
after 2 min its temp is 30°C



its temp is 38°C

than silver

after 2 min ⇒ 40°C

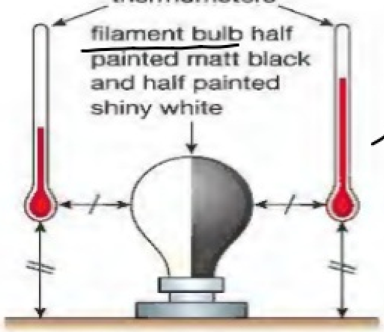


its temp is 32°C

ACTIVITY 3

▼ PRACTICAL: INVESTIGATE HOW WELL DIFFERENT SURFACES RADIATE HEAT

This experiment shows that matt black surfaces radiate heat better than shiny white surfaces.



its temp. inc. more than the other one because black surface nearer to it emits more

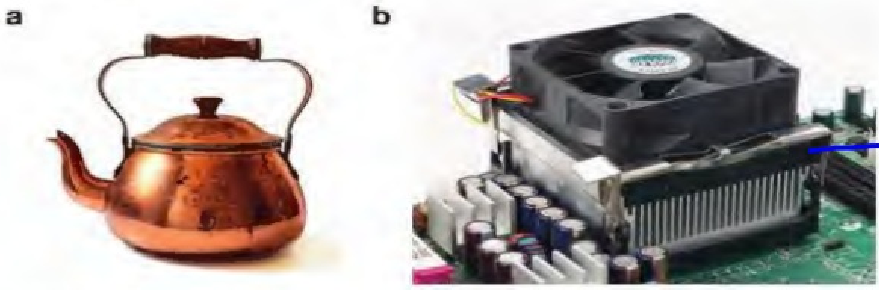
▲ Figure 15.11 Demonstrating that matt black surfaces radiate heat better than shiny white surfaces

Figure 15.11 shows the experiment. Put two identical (same type) thermometers on either side of a filament bulb that has been painted matt black on one side and shiny white on the other.

When you turn on the bulb you will notice that the temperature starts to rise more quickly on the thermometer facing the black side than on the other.

It is important that the thermometers are fixed at the same height and distance from the filament bulb.

▲ Figure 15.12 Shiny and white surfaces reflect thermal radiation, while matt black surfaces, like in the solar heating panels, absorb it.



black to emit more heat so its temp decrease more

▲ Figure 15.13 **a** A shiny kettle stays warmer longer. **b** The heat sink needs to be matt black to lose heat to the surroundings quickly, and so stop the transistor overheating.

If a surface is a good reflector of IR then it is a poor radiator of IR. This means that a hot object with a shiny surface will emit less heat energy in the form of IR than another object at the same temperature with a matt black surface. The kettle in Figure 15.13a has a shiny surface to reduce the rate of heat loss. Heat sinks are used in electronic equipment to stop parts getting too hot. A heat sink is shown in Figure 15.13b. The transistor is fixed to the black metal heat sink and heat is transferred from the transistor to the heat sink by conduction. The matt black surface radiates heat well and the shape of the heat sink helps convection air currents to transfer heat away from the heat sink.

▲ Figure 15.14 A tungsten filament bulb

The amount and type of the energy radiated by a hot object does not only depend on its surface texture (how it feels to the touch) and colour – it also depends on how hot it is. Not only does the amount of energy radiated per second increase significantly with temperature but the nature of the EM waves also changes. At a low temperature most of the radiated energy is in the form of infrared waves (invisible to the human eye). As the temperature of a metal object increases it starts to radiate in the visible spectrum as well. Things that do not burn will start to glow a dull red. As the temperature rises further the colour changes through the visible spectrum, for example, the tungsten filament glows white hot when it reaches ~3000 °C.

You will meet this effect again in Unit 8 Astrophysics.

ENERGY-EFFICIENT HOUSES

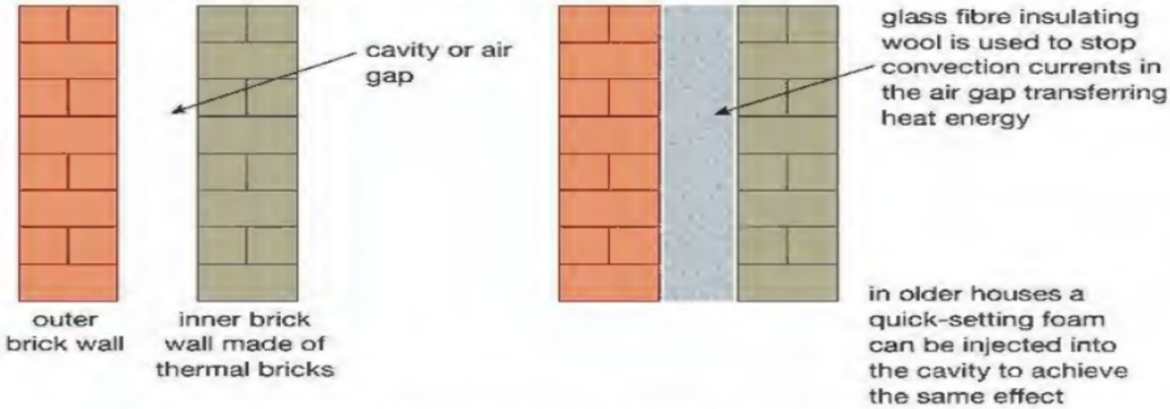
We pay for the energy we use in our homes, schools and places of work. Heating is the main use of energy in our homes and – since most domestic heating systems work by burning fuels like coal, oil and gas – it is the main producer of carbon dioxide. (Even if electric heaters are used, most electrical energy is produced by burning fuels in power stations.) Carbon dioxide is a greenhouse gas and contributes to global warming. It is, therefore, very important that houses are energy efficient.

Energy efficiency means using as much as possible of the energy we produce for the desired purpose. So when we turn on the central heating, we want to keep the insides of our homes warm and not allow the heat to escape. If no heat can escape from a house then we will only need to heat it until it reaches the desired temperature.

The key to energy-efficient housing is insulation. Houses must be designed to reduce the rate at which energy is transferred between the inside and the outside.

HOW HEAT IS LOST

To insulate a house effectively we must look at all the ways in which heat energy can escape. Conduction is the main way heat is transferred between the inside of a building and the outside. Next we need to consider the places where conduction occurs: the walls, the windows (and doors) and the roof.



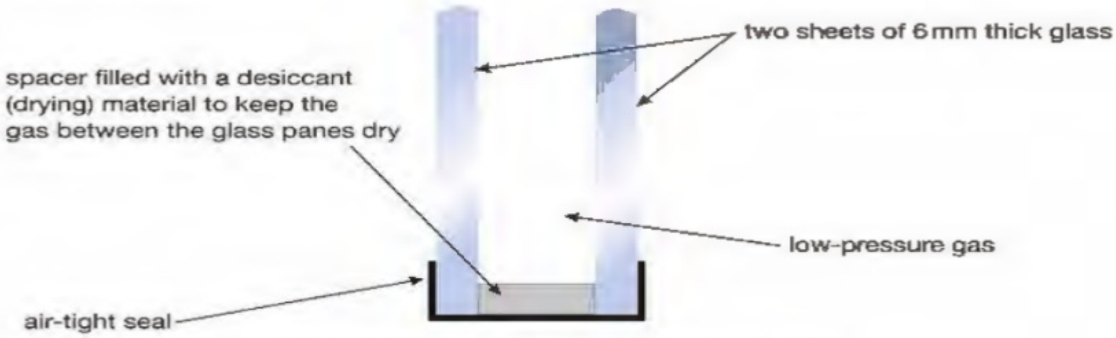
▲ Figure 15.15 Two-layered wall construction, with the gap filled with insulation panels, helps to reduce heat loss by conduction, convection and even radiation.

Heat loss by conduction through the walls can be reduced by using building materials that are good insulators. However, the materials used for building must also have other suitable properties like strength, durability and availability at a sensible price. For walls, bricks are a common building material.

Figure 15.15 shows the typical construction of a modern house in the UK built to follow the current energy efficiency regulations.

As you can see, the wall is made with layers of different materials. The outer layer is made with bricks – these have quite good insulating properties, are strong and will survive bad weather conditions. The inner layer is built with thermal bricks with very good insulation properties – they are also light, relatively cheap and quick to work with. The two layers of brick are separated by an excellent thermal insulator in the form of an air cavity or gap.

The walls also stop heat being lost by convection. The cavity or gap between the two walls is wide enough for convection currents to circulate. This means heat is circulated from the warmer surface of one wall to the colder surface of the other. To stop convection currents, the gap in modern houses is filled with insulating panels made of glass fibre matting. This is a lightweight, poor conductor that traps lots of air. The panels are usually surfaced with thin aluminium foil. This highly reflective surface reflects heat in the form of infrared radiation.



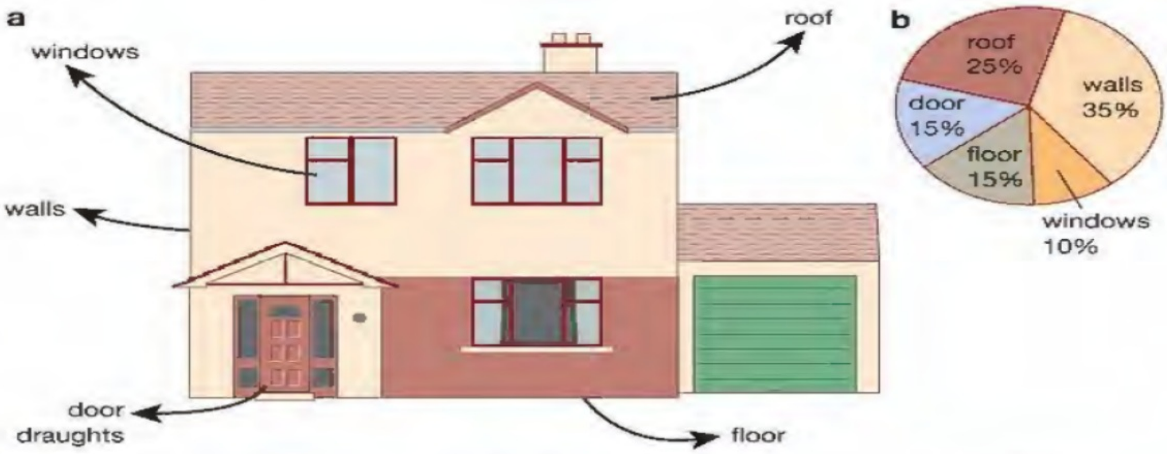
▲ Figure 15.16 Double glazing helps to stop heat escaping from the home.

Figure 15.16 shows a cross-section of a typical double-glazed window, as used in modern houses. Glass is a poor thermal conductor but is used in thin layers. To improve the insulating properties, two layers of glass are used to trap a layer of air. The thickness of this layer is important. If it is too thin then the insulation effect is reduced, but if it is too thick then convection currents will be able to circulate and carry heat from the hotter surface to the colder one. In very cold countries triple glazing is used. Modern double glazing uses special glass to increase the greenhouse effect (heat radiation from the Sun can get in but radiation from inside the house is mainly reflected back again).

Roof insulation in modern houses uses similar panels to those used in the wall cavities, trapping a thick layer of air. This takes advantage of the poor conducting property of air, whilst also preventing convection currents circulating. Again, reflective foil is used to reduce radiation heat loss. Figure 15.17 shows houses built before loft insulation was a compulsory building regulation. In some, the owners have installed loft insulation – you should be able to identify which!

There are other things that can be done to improve the energy efficiency of houses that do not relate directly to the mechanisms of heat transfer discussed in this chapter. For example, thermostats and computer control systems for central heating can further reduce the heating needs of a house. They stop rooms being heated too much by switching off the heat when a certain temperature is reached. Another important energy-saving measure is the reduction or elimination of draughts (air currents) from poorly fitting doors and windows.

With your understanding of how heat travels you can save your family money, keep warm and reduce global warming.



▲ Figure 15.18 **a** How heat energy can be lost from the home; **b** Percentage of energy lost in different ways

INSULATING PEOPLE AND ANIMALS

Earlier in this chapter we saw a picture of a fire fighter in protective clothing designed to reduce the amount of heat getting to their bodies (Figure 15.12). Sometimes we have the opposite problem and want to keep warm. The obvious method of cutting down heat loss from the body is to wear clothes. Clothes that trap air around the body provide insulation because trapped air cannot circulate and is a very poor conductor. A large proportion of body heat is lost from the head, so hats are the human equivalent of loft insulation.

Wind can cause rapid heat loss from the body. It does this by forced convection – that is, making air circulate close to the body surface. It may also cause sweat to **evaporate** from the skin more quickly, causing rapid cooling. (The purpose of sweat is to help the body to lose heat by evaporation, but, if it happens because of strong wind on a cold day, the effect can be life threatening.) These cooling effects of wind contribute to what is called the wind-chill factor. To reduce the wind-chill effect, a piece of wind-proof outer clothing should be worn.

When people do lose body heat at too great a rate they may become hypothermic, which means their body temperature starts to fall. If the heat loss is not significantly reduced the condition is potentially fatal. When people are rescued from mountains suffering from the effects of cold they are usually wrapped in thin, highly reflective blankets. The interior reflective surface reflects heat back to their bodies while the outer reflective surface is a poor radiator of heat. Marathon runners are often covered in these blankets at the end of the race to keep them warm when their energy reserves are low.

Animals keep warm in different ways. You may have noticed birds fluffing up their feathers on cold days in winter. This increases the thickness of the trapped air layer around their bodies, so reducing heat loss by conduction. Some birds, like penguins, will move close together for warmth (Figure 15.19). Other animals will curl into small balls. This cuts down heat loss by making the surface area of their bodies exposed to the cold as small as possible.