#10207

Protecting dwellings with suspended timber floors:

a BRE guide to radon remedial measures in existing dwellings

P A Welsh, BSc, P W Pye, CChem, MRSC and C R Scivyer, MCIOB

Building Research Establishment
Garston
Watford
WD2 7JR

Prices for all available
BRE publications can be
obtained from:
BRE Bookshop
Building Research Establishment
Garston, Watford, WD2 7JR
Telephone: 0923 664444
Fax: 0923 664400

BR 270
ISBN 0 85125 647 3

First published 1994

CONTENTS

INTRODUCTION

This report is one of a series giving practical advice on how to reduce indoor radon levels in existing dwellings. Its specific subject is radon remedial measures for houses with suspended timber floors. These measures can also be used with other types of suspended floor, although they are not relevant to timber finishes laid directly onto concrete bases. The report is aimed at builders who carry out radon remedial work and householders who are competent at DIY.

The government has recommended that, if the radon concentration in a dwelling exceeds 200 Bq/m^3 (the 'action' level), measures should be taken to reduce it. This report assumes that measurements have been made and that the annual average indoor radon level is known to exceed the action level.

The report is based on a large body of remedial work carried out to advice from the Building Research Establishment (BRE), and on discussions with others in the field, notably the National Radiological Protection Board (NRPB) and Cornwall County Council. It supplements information available in *The householders' guide to radon*[1], obtainable from local environmental health officers or from the Department of the Environment. Other BRE publications give advice on radon sumps[2], sealing cracks in solid floors[3], surveying dwellings with high indoor radon levels[4], and installing protective measures in new dwellings[5].

What is radon?

Radon is a colourless, odourless and tasteless radioactive gas formed from the radioactive decay of uranium. As small quantities of uranium are found in most rocks and soils, radon is found nearly everywhere, although levels vary from place to place. Once formed, radon tends to move upwards through the soil until it reaches the surface, where it is quickly diluted to harmless concentrations by the other atmospheric gases.

How does it get into buildings?

Unless special precautions are taken during construction to provide gas-proof membranes, most floors and walls contain a number of cracks, joints, gaps and holes. Radon from the soil can enter a dwelling through these openings (see Figure 1) and can accumulate to high concentrations in living spaces. Buildings tend to draw radon into them because the pressure inside the building is slightly lower than the pressure in the underlying ground. This small pressure difference is caused by the stack (chimney) effect of warm air rising in the building, and by the effects of wind. The different factors interact in a complicated way, so that radon levels vary not only between different parts of the country, but even between neighbouring buildings.

If a radon survey shows that indoor radon levels are unacceptably high, it is necessary to carry out a detailed survey of the property[4]. Suspended timber floors are usually highlighted as significant routes of entry for radon. This report discusses remedial measures for this and other types of suspended floor, and highlights the problems associated with each method.

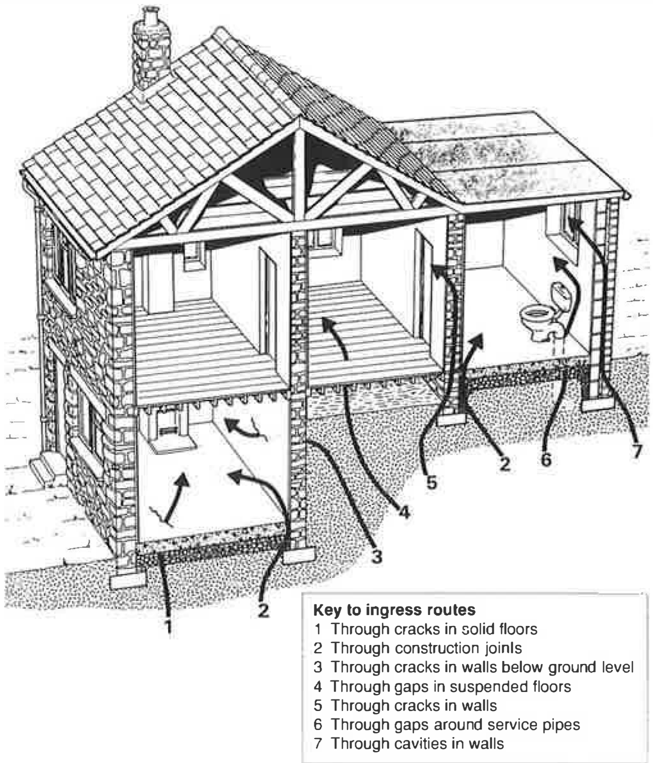

Figure 1 Routes by which radon enters a dwelling

For further information on radon risks and monitoring, contact the NRPB (telephone: 0235 831600; see the section at the end of this report for their full address).

Is protection necessary from other gases?

In some very rare instances, the building being altered is located on or next to a landfill site, in which case additional precautions will be needed to deal with methane. It is therefore advisable to contact the local authority environmental health department before starting work, and establish whether the property is near a landfill site. If there is a problem, further advice can be obtained from the BRE Radon Hotline (telephone: 0923 664707).

SUSPENDED TIMBER FLOORS

A typical suspended timber floor construction is shown in Figure 2. Essentially it consists of timber joists laid on wall plates supported by sleeper walls. The sleeper walls are honeycombed to provide cross-ventilation and airbricks are inserted into the outer walls. Figure 2 also shows a ventilation pipe, installed in an adjacent solid floor, which connects the space underneath the timber floor to an external ventilator. Traditionally either square-edged or tongued and grooved boards were fixed to the joist, but chipboard or plywood boards are used in most modern buildings. Similarly, the timber joists in modern buildings may be supported by joist hangers instead of sleeper walls.

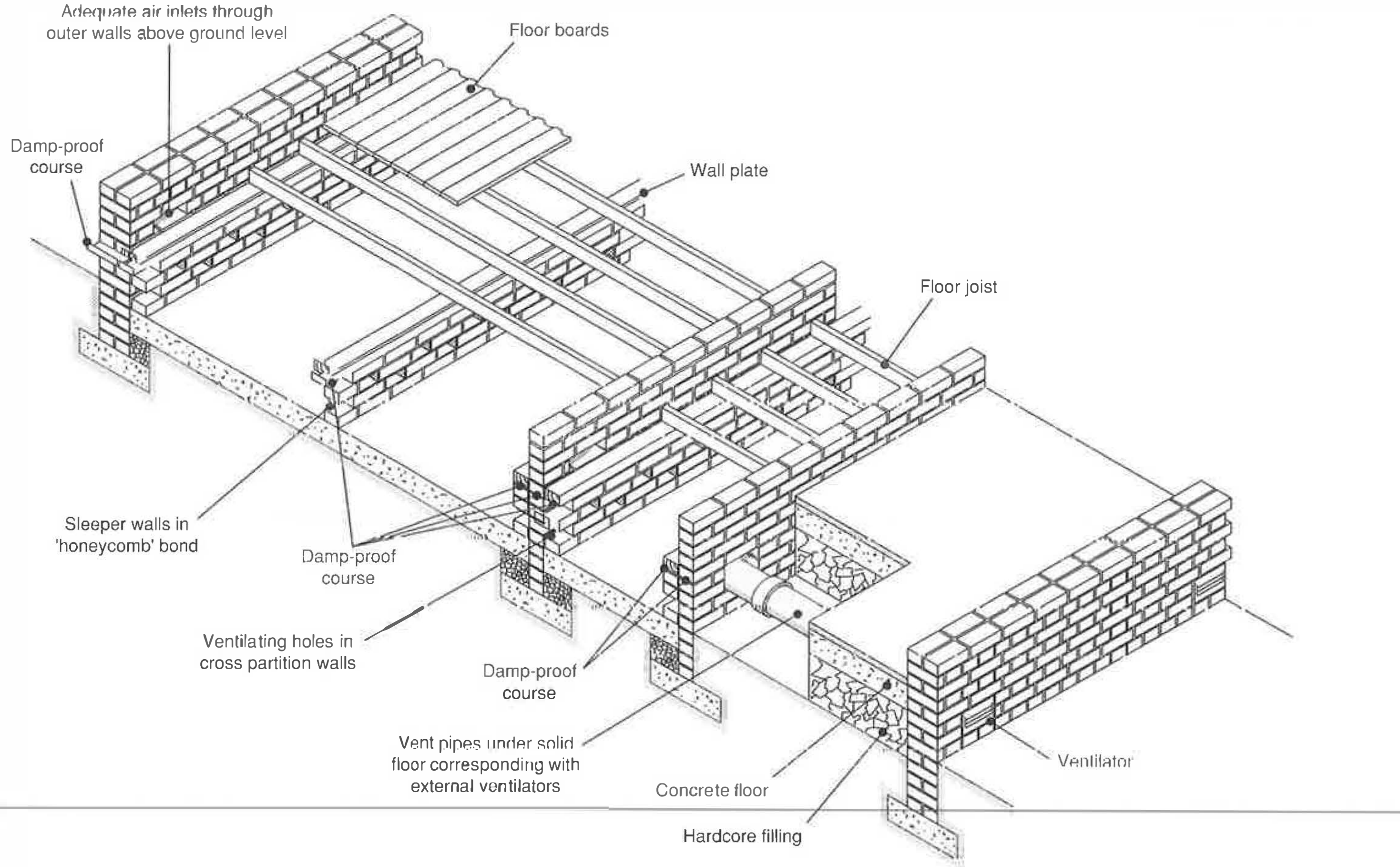

Figure 2 The construction of a typical suspended timber floor

Underfloor spaces are usually divided into several cells by sleeper walls (walls constructed below floor level to support the floor), partition walls (loadbearing walls which penetrate from the dwelling to beneath the floor) and party walls (walls which separate dwellings). Some of these walls will be honeycombed to provide cross-ventilation; others may be solid. In this report, 'sleeper wall' has a more general meaning. It is used to describe any wall which lies below floor level, including partition and party walls.

The risk of dampness in timber floors

Since 1967 the Building Regulations have required a concrete oversite to be installed with suspended timber floors. The oversite must have a minimum thickness of 100 mm. Since 1985 it has been possible to substitute a layer of inert gravel laid over polythene for the concrete oversite: the gravel must be at least 50 mm thick. The point of these measures is to control moisture levels beneath the timber floor. Most floors built before the Second World War do not have a concrete oversite; those built between 1945 and 1966 may or may not have a concrete oversite. Dampness is the main cause of deterioration in suspended timber ground floors. If the moisture content of the timber exceeds 20%, rotting is likely to occur. The provision of damp-proof courses in walls, oversite concrete and ventilation is intended to keep the moisture content as low as possible. **It is therefore essential that no radon remedial measures are undertaken which are likely to increase the moisture content of the timber, and thereby encourage rot.**

Characteristics of floors in older properties

In older properties it is common to find the joists built directly into the end structural walls and not carried on an adjacent sleeper wall. The provision of airbricks for ventilation is frequently well below the current Building Regulations requirement, and this often causes wet or dry rot[6,7]. Similarly, any sleeper walls which are present may be solid, ie not honeycombed and thus prevent cross-ventilation.

In older floors where square-edged boards are used, a considerable amount of ventilation can take place upwards from the underfloor space provided the floor is not covered by an impervious layer. Floors constructed with tongued and grooved boards or chipboard are generally less well ventilated upwards.

Whatever their construction, timber floors suffer more than other types of floor from the provision of service entries. For example, it is common to cut or bore holes through the floor for water and electrical services. Heating pipes frequently penetrate the floor beneath each radiator, and purpose-built vents are often cut into the floor to provide air for combustion appliances or to increase underfloor ventilation. However, gaps between floorboards, gaps at the perimeter between floor and wall or skirting, service entries and floor vents provide easy access paths for radon into the dwelling.

SURVEYING A DWELLING WITH A SUSPENDED TIMBER FLOOR

When looking at a suspended timber floor, it is important to try to gain access to the underfloor space. Often the surveyor will find that somebody has had to gain access at some stage in the past, and that the householder can tell him where to find access panels hidden from view by carpets or furniture. Where access is not immediately possible, an optical probe can be used: what the surveyor needs to know is whether the ground has been capped with concrete, and whether the underfloor space is deep enough for someone to be able to get under the floor and carry out work. Access to the underfloor space will also allow the surveyor to establish whether internal walls and sleeper walls are honeycombed to allow for cross-ventilation. It may be possible to see whether there are any other communicating spaces, eg openings behind dry-linings, service ducts, openings around service entry or exit points, and to assess the structural condition of the timber floor. Unfortunately, most underfloor spaces are too shallow to provide adequate access.

The vast majority of dwellings with suspended floors also have areas of solid floor. In the first instance, remedial measures are usually applied to the area of suspended timber floor because this area is often the major contributor to the indoor radon level. However, if these measures are insufficient to reduce indoor radon to acceptable levels, additional measures can be applied to the area of solid floor.

CHOOSING WHICH SYSTEM TO INSTALL

The likely effectiveness of different solutions

It is impossible to be precise about how much a particular system will reduce the indoor radon level, but typical reductions are shown in Figure 3. More than one method can be used to treat a particular dwelling, eg sealing around the services that pass through a timber floor combined with mechanical underfloor ventilation. However, combinations of methods are not addressed in Figure 3.

Factors to consider when choosing a system

Before choosing a solution, due regard must be given not only to the detailed floor construction but also to the indoor radon level. Not all methods of lowering indoor radon levels are suitable for all situations. Some methods are much more effective than others, but they also tend to be more expensive to install and to run.

For any solution to be completely effective it must be acceptable to the householder. It is important to remember this when considering remedial action: a solution which would completely change the householder's lifestyle is unlikely to succeed in the long term. For example, increasing the ventilation of rooms may make them uncomfortable in winter. Ideally, the remedy should be of a type which does not affect the long-term internal environment of the dwelling. Underfloor ventilation and sump systems are therefore the most suitable choices.

Many householders will not accept a solution which will cause disruption inside the house during installation. Some may be willing to pay for a system which is more expensive and more effective if it means that disruption is likely to occur only once. The key to finding the most appropriate solution is to discuss with the householder the options available, together with the short- and long-term implications of each.

Dwellings with suspended timber floors are the most difficult cases to resolve, and the remedial measures available produce highly variable results. Nevertheless, sufficient is known to make it possible to offer practical advice. This advice will be updated as research continues.

There are seven main techniques which can be used to reduce radon levels in dwellings with suspended timber floors. However, only methods 1–5 in the list on the following page are suitable for the vast majority of dwellings: methods 6 and 7 have distinct drawbacks which are discussed in the relevant sections.

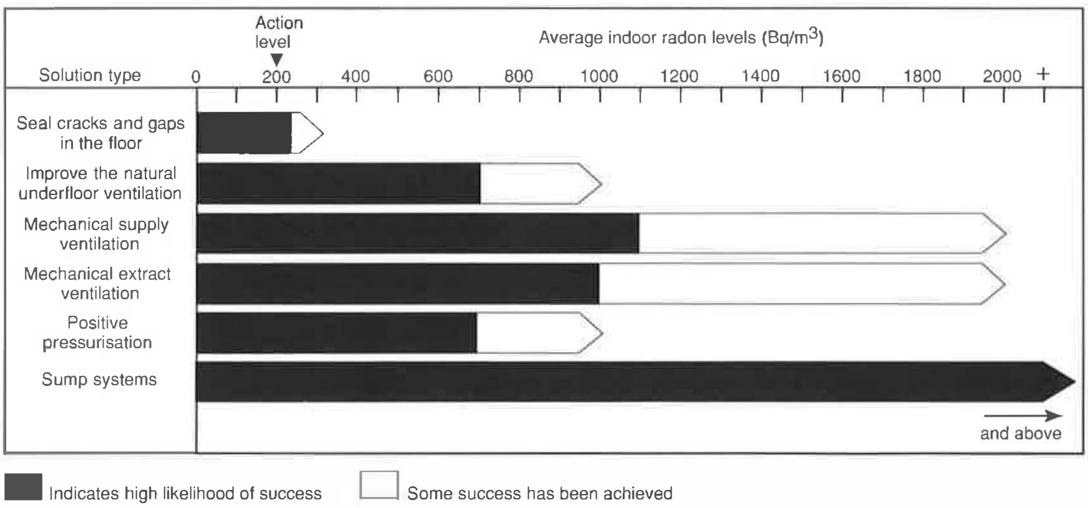

Figure 3 Guide to the likely effectiveness of different radon remedial solutions

The range of solutions available

1 Enhanced natural underfloor ventilation
2 Mechanical underfloor ventilation systems
3 Sump systems
4 Positive pressurisation systems
5 Replacing suspended timber floors with concrete slabs
6 Sealing the timber floor
7 House ventilation

The order in which the various techniques is listed reflects their effectiveness, cost and ease of installation. For example, increasing the natural underfloor ventilation is a cheap and simple solution with no running or maintenance costs. This approach usually reduces radon levels by about 50%, but larger reductions can be achieved. Mechanical ventilation is listed second as it provides the next cheapest solution and has a high success rate. It is listed before sump systems because, even though sump systems are usually more effective than underfloor ventilation, they are not always practical. Fourth on the list is positive pressurisation, an option which is often less effective than options 2 and 3 but has similar costs. Floor replacement is the last of the recommended solutions because it is the most expensive and disruptive option. However, if the timber floor needs replacing, this is probably the most effective solution, when coupled with a sump system. Sealing and house ventilation are discussed last because, although they may provide the cheapest DIY solution, the results tend to be discouraging.

NATURAL UNDERFLOOR VENTILATION

To control air moisture levels beneath timber floors all underfloor spaces should be naturally ventilated to the outside by means of airbricks. The current Building Regulations require a minimum of 1500 mm^2 of free open area per metre run of wall. If the space is insufficiently ventilated the air may become saturated with water vapour from the ground (especially in older houses where there is no oversite concrete), and fungal attack (rotting) may occur if the timber absorbs sufficient moisture.

A secondary effect of underfloor ventilation is that it dilutes the concentration of any radon rising from the ground into the underfloor space. Radon in the dwelling is drawn from the air in the underfloor space: improving the ventilation should therefore lead to a reduction of indoor radon levels. This is borne out by experience which shows that, when the initial underfloor ventilation is poor, substantial reductions in indoor radon levels can be achieved by improving the ventilation. However, regardless of indoor radon levels, householders should ensure that the Building Regulations requirement for underfloor ventilation is fulfilled so that moisture levels are controlled.

Over the years airbricks can become partially blocked by cobwebs, dust and other detritus, as well as being completely blocked by soil heaped against external walls. The building of porches and extensions can also block existing airbricks. Cleaning out and unblocking these airbricks can lead to small reductions in indoor radon levels. The size of the reduction is very variable and depends on the number of airbricks and the degree of blockage, but this action is often successful for dwellings with indoor radon levels of up to 300 Bq/m^3.

For dwellings with relatively high indoor radon levels, or where there are not enough airbricks, it is advisable to install additional vents. They can be incorporated in the external walls, just below the floor. However, it can be expensive to install vents in dwellings with thick stone walls: in these cases it may be preferable to put in a few large vents instead of several small ones.

Ensure that the vents are installed above ground level and below the damp-proof course. To achieve this it may be necessary to use cranked ventilators (see Figure 4).

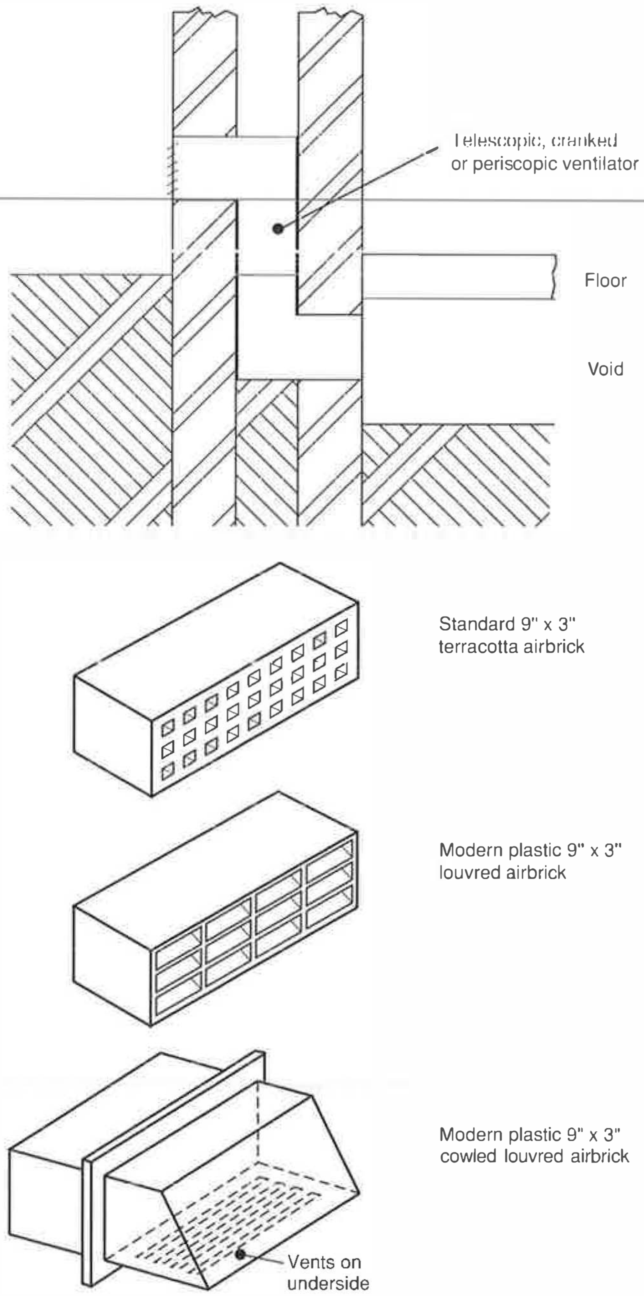

Figure 4 Different types of airbricks

Remember that increased breaking-out will be required to fit the cranked vents. When vents are provided through cavity walls they should be sleeved and any cracks or gaps in the sleeve should be sealed. This is of particular importance where the cavity wall has been or is going to be insulated. If an insulated cavity is breached, disturbance to the insulation should be kept to a minimum, and if any insulation drops out through the hole it should be replaced. Cavities should be sealed to prevent air movement from the cavity.

Ideally the openings should be provided on at least two opposite walls to provide cross-ventilation and to avoid 'dead' areas (see Figure 5). If there are solid, ie not honeycombed, walls below the floor which split the underfloor space into various cells, it is beneficial to ventilate each cell separately. Where this is not possible holes can be broken through the sleeper walls to allow air to move between cells.

Vents should be large enough to give an actual opening to the current Building Regulations requirement of at least 1500 mm^2 for each metre run of wall. Plastic louvred ventilators are preferable to clay airbricks, as they usually offer greater open area and fewer of them will be needed (see Figure 4). Replacing terracotta airbricks with the same overall size of plastic louvred airbrick is a convenient way of improving the ventilation under a floor without the need to break-out new airbrick openings. Do not leave vents without some form of vermin guard.

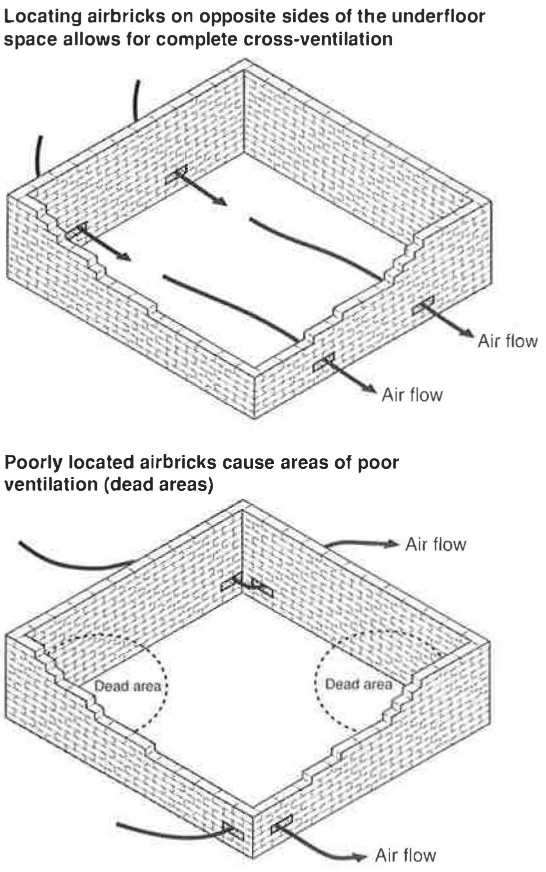

Figure 5 Airbricks must be located to ensure effective cross-ventilation

Vents should not be cut through the suspended floor to link the underfloor space to the interior of the dwelling — ventilation must always be provided to the underfloor space from the outside. If there are existing vents between the underfloor space and the interior, these should be blocked or sealed and, if necessary, replaced with vents to the outside. Alternative ventilation must be provided if the floor vents ventilate a combustion appliance, otherwise combustion products may spill into the living spaces (this possibility is discussed in more detail in the following section).

Sometimes the enhancement of natural underfloor ventilation can produce carpet lift, especially for dwellings in very exposed locations. This may be overcome by installing cowled airbricks (see Figure 4) instead of the usual type, or by laying a wooden sheet material (plywood or hardboard, not less than 4 mm thick) over the timber boards.

MECHANICAL UNDERFLOOR VENTILATION

Extract ventilation and supply ventilation

If natural ventilation does not reduce the indoor radon to acceptable levels, an electric fan can be installed to increase the airflow under the floor. Fans can be installed to blow air into the underfloor space (supply ventilation) or extract air from it (extract ventilation). Fan specifications are discussed in a subsequent section of this report.

Both extract and supply methods have been used successfully, but it is hard to say which is best for any particular dwelling. Success depends on many factors, including soil permeabilities, floor 'leakiness', the number and position of airbricks, etc. The usual approach is to try one method, and if that does not work, reverse the fan, ie use supply instead of extract ventilation or vice versa. Both methods of ventilation involve exactly the same work: the only difference is the way in which the fan is mounted or controlled. The limited results available indicate that, overall, supply ventilation is slightly more effective than the extract method.

Installing the system

When planning the installation of a mechanical ventilation system, the first task is to select where the system is best located. It should be positioned away from noise-sensitive areas, such as living rooms and bedrooms, and away from windows to prevent any extracted radon from entering the house (known as reintrainment).

Figure 6 shows the construction details for a typical underfloor supply ventilation system. A hole is broken through an exterior wall and a length of pipe (usually uPVC pipe) extends through the hole, linking the underfloor space with the outside. If an insulated cavity is breached, disturbance to the insulation should be kept to a minimum, and if any insulation drops out through the hole it should be replaced. Cavities should be sealed to prevent air movement from the cavity. Figure 7 shows a wall-mounted axial fan.

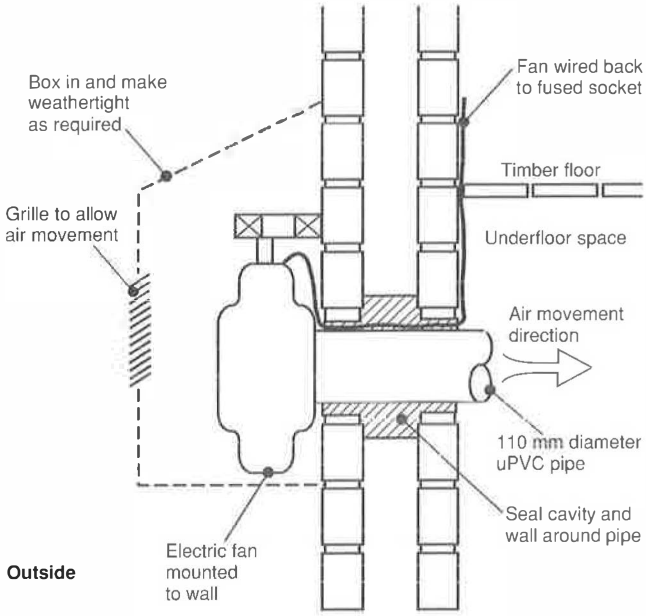

Figure 6 Mechanical supply ventilation with fan mounted outside

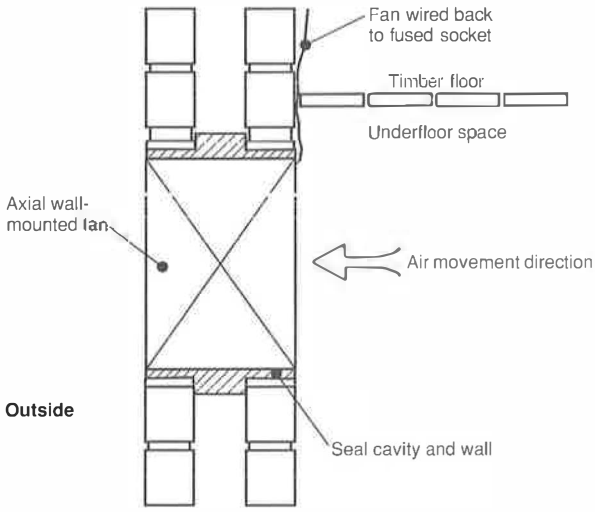

Figure 7 Mechanical extract ventilation with a wall-mounted axial fan

The fan is usually mounted outside, either on the exterior wall or on the ground. If the fan unit is not weathertight it should be made so by boxing it in. The fan can be mounted beneath the floor and so hidden from view, but this is likely to increase the noise level in the rooms above. Do not install fans near to airbricks. If an airbrick is too close to a fan (ie less than 1.5 m away), air from outside can be drawn through the airbrick into the underfloor space and then re-circulated to the outside by the fan. This 'short-circuiting' means the system is unlikely to work effectively. If the fan's otherwise ideal location is near an airbrick, the airbrick should be sealed.

The exhaust (or intake) can be at ground level, provided rain-water cannot enter the system and it has a grille or cowl to prevent animal entry. Alternatively, it can be at eaves level capped by a suitable cowl. Exhausts should always be positioned outside and away from doors and windows to prevent reintrainment. It is also prudent to keep intakes to supply ventilation systems away from windows or doors. This is because you may wish to convert an unsatisfactory supply system into an exhaust system by reversing the fan, in which case the intake will become an exhaust and therefore liable to cause reintrainment.

Problems to consider when installing the system

Frozen pipes

When installing a mechanical ventilation system, it is advisable to lag underfloor water pipes which are near the fan, otherwise the movement of cool air can cause premature freezing. Large gaps and holes in the timber, eg areas around service entries, should be sealed with a gun-applied sealant to prevent bulk air movement.

Spillage from open-flued combustion appliances

An open-flued combustion appliance, such as an open fire, draws air from the room in which it is sited. This air mixes with the combustion gases and travels through a chimney (or flue) to the outside. However, where a fan extract system is used to draw air from the underfloor space, air from the room above may be drawn down through the floor, thereby starving the combustion appliance of its air supply. In some cases, the flow of air and combustion gases up the chimney is reversed, causing the combustion gases to 'spill' into the living spaces. **Spillage of this type is potentially hazardous and should always be avoided.**

If a room near the ventilation system contains an open-flued combustion appliance, it is advisable to use supply, not extract, ventilation. However, if it is not possible to use a supply system, or if this type of system has proved unsuccessful in the past, an extract system can still be installed, provided that steps are taken to prevent spillage. These precautions usually involve placing more underfloor airbricks opposite the fan, and providing an underfloor vent which links the appliance to the outside by means of a underfloor pipe (see Figure 8). If there are any floor vents which provide ventilation to the appliance, these should be replaced with an alternative air supply, eg wall vents or an underfloor vented supply from outside, see Figures 8, 9 and 10. This subject is discussed in more detail in a leaflet available from BRE[8].

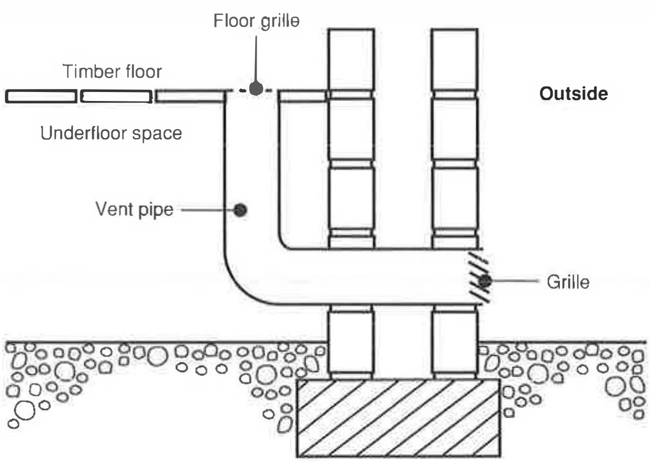

Figure 8 An underfloor ventilated air supply provides outside air to living spaces

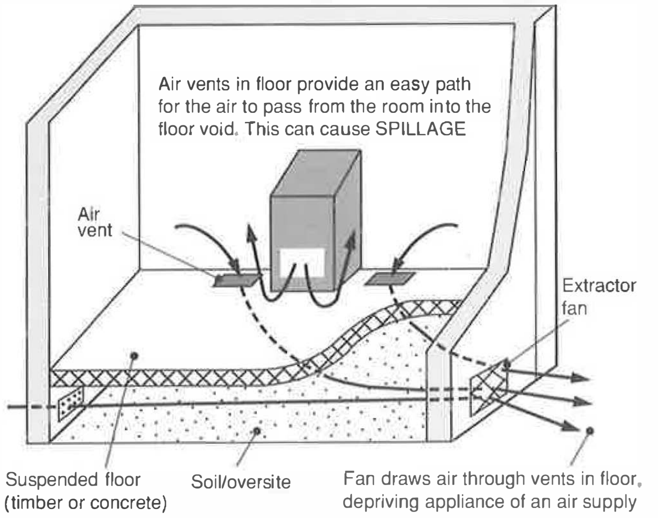

Figure 9 Spillage caused by air flowing through floor vents

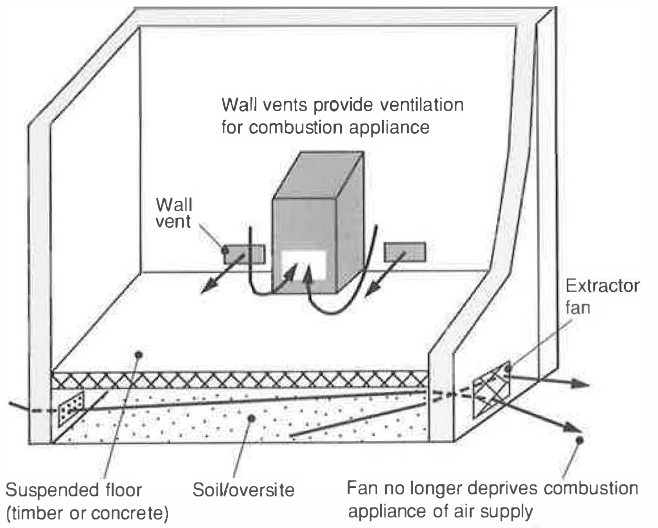

Figure 10 Wall vents providing ventilation for a combustion appliance, thereby preventing spillage

Inadequate cross-ventilation

If the underfloor space is separated into various cells by solid (ie not honeycombed) sleeper walls, cross-ventilation may be prevented. Most sleeper walls are honeycombed or have significant gaps in them allowing cross-ventilation, but if the walls appear well sealed it may be necessary to take steps to ensure the whole underfloor space is affected by the fan. This involves either breaking holes in the sleeper walls while taking care not to compromise the integrity of the structure, or manifolding several pipes to a fan, each leading to an individual cell (see Figure 11).

It may be necessary to use more than one fan or a single, more powerful fan for larger or more complicated dwellings. Fan specifications are discussed in a subsequent section of this report.

There is insufficient evidence available to indicate whether sealing airbricks or opening further ones helps with radon reduction when using mechanical ventilation.

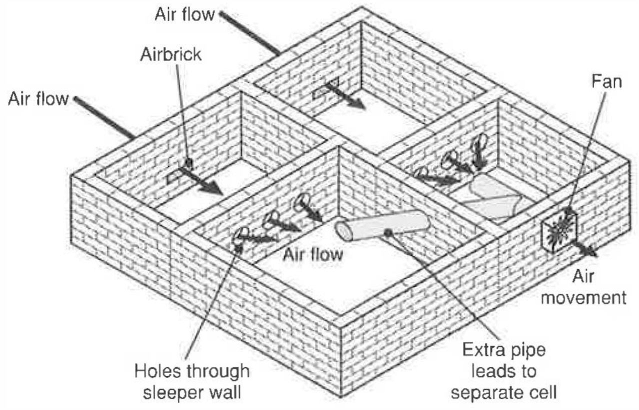

Figure 11 Manifolding several pipes to one exhaust fan is a method of ensuring adequate cross-ventilation

Noise

Often the most noticeable problem associated with any type of underfloor ventilation system is noise. Most of this noise is the result of poor fan installation —which causes vibrations in the building fabric — or it is the sound of air rushing through pipework. Ideally the fan should be mounted away from noise-sensitive areas, on the ground or on a heavy and rigid building component such as an external wall. Noise transmission from the fan to the dwelling can be reduced by using a flexible fan mounting, eg a rubber layer sandwiched between the fan bracket and the building. Do not mount the fan on the underside of the floor if minimising noise is crucial.

Systems using fans connected to pipes can generate the sound of rushing air. This can be reduced by putting silencers in-line with the fan. In addition, the inlet to the pipe can be flared to help smooth the air flow (although suitable components for this are quite difficult to find ready-made.) Axial fans are generally quieter than centrifugal fans but often cannot be used with in-line silencers. Noise from the fan itself can also be a major nuisance, but the disturbance can be minimised by wrapping the fan in insulation and boxing it in (provided the fan does not overheat as a result).

It is difficult to reduce the noise level further after these steps have been taken. More detailed information is available in a BRE leaflet[9]. Although the leaflet deals specifically with sump systems, much of the advice is also relevant to underfloor ventilation systems.

Temperature changes

Extract ventilation can cause warm, moist air from the rooms above to be drawn through the floor. Although extremely unlikely, it is possible that this could cause moisture problems in the timber. Heating bills may also be slightly higher than usual as a result of warm air moving from the living areas into the underfloor space. Supply ventilation, on the other hand, may make floors feel colder, and heating bills may be slightly higher than usual because cool air is being forced upwards into the dwelling. All these problems can be reduced by laying a wooden sheet material (hardboard or plywood, not less than 4 mm thick) over the timber floorboards.

Carpet lift
Some households experience carpet lift as a result of wind moving through airbricks. Increasing the number of airbricks or using supply ventilation can increase the likelihood of carpet lift, although in practice it is rare. It can be prevented by covering the timber floorboards with a wooden sheet material (hardboard or plywood, not less than 4 mm thick). Alternatively, existing airbricks can be replaced with cowled airbricks (see Figure 4).

The neighbours' radon level
When mechanical ventilation is used on a semi-detached or terrace house, it is theoretically possible to aggravate the neighbours' radon levels by altering the radon concentration under their floors. However, there is little evidence of this occurring in practice.

Introduction of spores into living spaces
In some dwellings in America, spores from beneath the floor have been introduced into living spaces by supply ventilation. This can cause health problems, especially if any of the occupants suffer from breathing disorders. The solution is to prevent mould growth by ensuring that the underfloor space is adequately ventilated.

SUMP SYSTEMS

Standard sumps and mini-sumps

Sump systems can be used with suspended timber floors where there is a concrete oversite (or gravel on polythene layer) over the soil below. They are normally considered for use beneath a suspended timber floor only where the indoor radon level is greater than 1000 Bq/m^3, or where improvements to the ventilation have failed to lower indoor radon levels. The system consists of a hole in the ground (ie beneath the concrete or polythene which covers the ground under the suspended floor) which is linked by pipework to the outside (see Figures 12 and 13). Suction is usually applied by an electric fan in the pipeline to draw out radon-laden air.

Standard sumps are constructed from loose-laid bricks capped with a paving slab (see Figure 14); mini-sumps are formed by scooping out about a bucketfull of fill from beneath the oversite layer (see Figure 13). Standard sumps, being considerably larger than mini-sumps, need more excavation and so are usually only installed under new floors. Mini-sumps can be excavated beneath existing floors by breaking a hole through the concrete oversite or through an external wall below oversite level. The purpose of the sump is to prevent the suction pipe from getting blocked and also to spread the pressure field. The pipe linking the sump to the fan can take any route provided the radon-laden air is expelled outside, preferably above the eaves level of the house. To prevent the exhaust gases from entering the house the exhaust should never be in the loft or next to doors or windows. Fan specifications are discussed at the end of this report.

Access under some suspended timber floors is relatively easy so it is often possible to install more than one sump beneath the oversite concrete. All the pipes can be linked to a single fan. Experience shows that multi-sump systems can produce very large reductions in indoor radon levels.

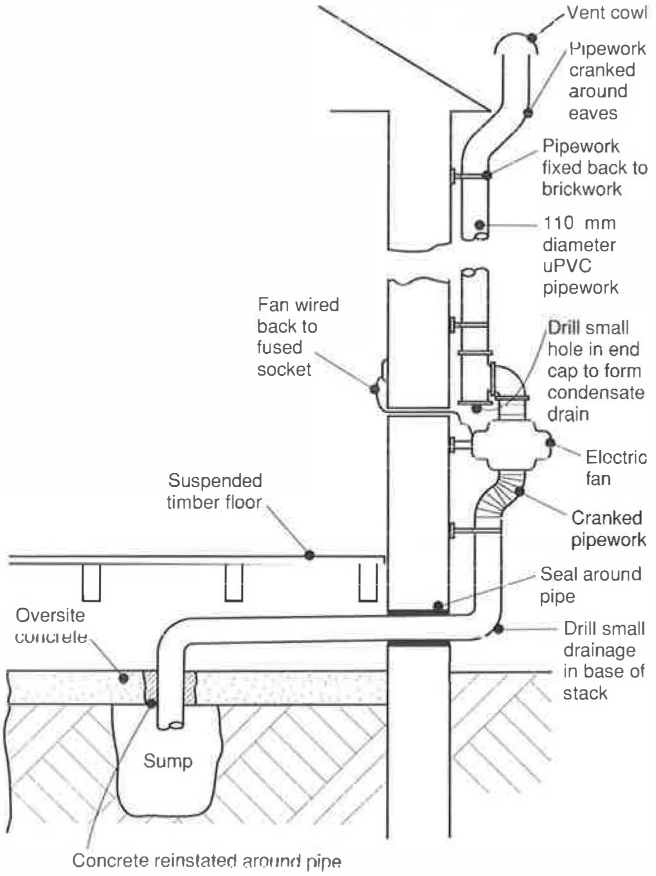

Figure 12 A mini-sump beneath a concrete oversite, with external fan and ductwork

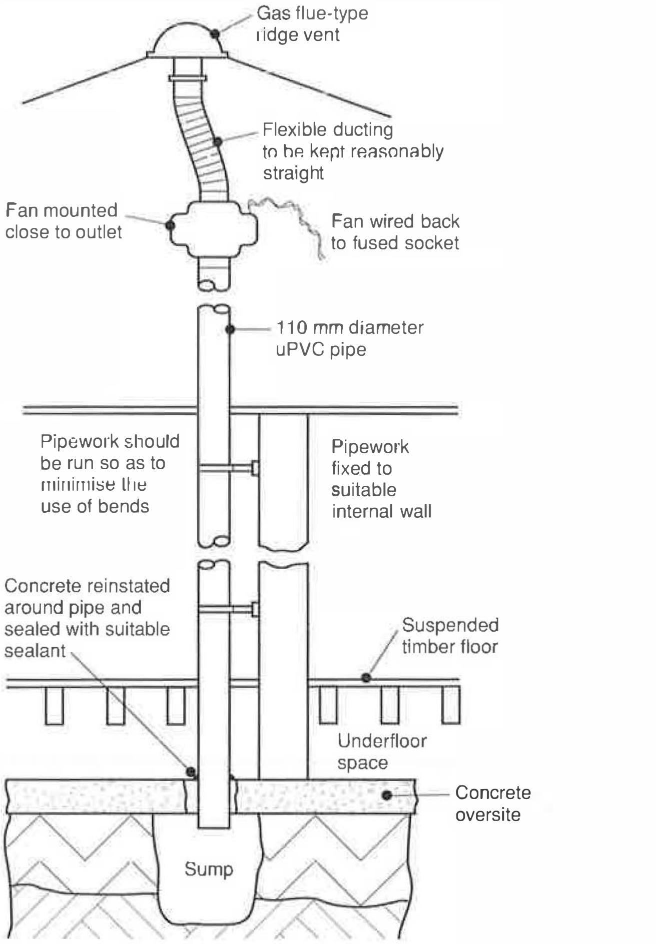

Figure 13 A mini-sump beneath a concrete oversite, with internal fan and ductwork

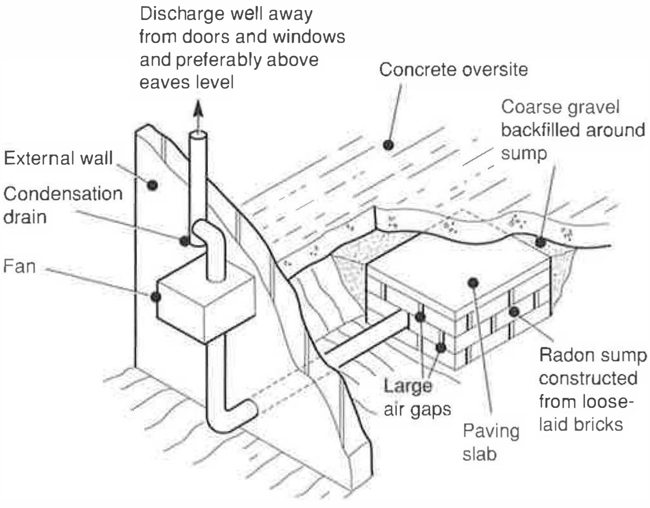

Figure 14 Construction of a standard radon sump

Installing the system

The fan should be as close as possible to the exhaust to ensure that most of the pipe length is under suction. This is particularly important if the pipe runs inside the house because it prevents radon-laden air leaking into the living areas through cracks or gaps in the pipe.

When reinstating the concrete oversite, make a good joint between the old and new concrete and between the concrete and the suction pipe. Be careful to prevent the new concrete filling the sump and blocking the pipe inlet: using a semi-dry mix will help. Where a damp-proof membrane has been broken through, it should be reinstated. Finally, after the concrete has set, the joint between the new concrete and the suction pipe can be sealed with a gun-applied sealant. This helps prevents air leaking out if shrinkage of the concrete and thermal movement of the pipe cause the joint to crack.

Where the floor does not have an oversite covering, do not install a sump system without first covering the ground, either with a 100 mm concrete oversite or with 50 mm of inert gravel on 1200 gauge polythene. The covering alone may not lower indoor radon levels sufficiently, so it is advisable to install a standard sump as a precaution (see Figures 14 and 15). The sump need only be activated if remonitoring proves the oversite is insufficient. In case the sump does have to be activated, there should a pipe running from the sump to the outside which is capped at ground level (see Figure 16). If the underfloor area is made up of several cells, it is best to install a sump beneath each cell. The sumps can usually be linked together with pipes so that a single fan can be used to extract radon all of them (see Figure 17). Where a pipe penetrates the ground, the join between the covering and the pipe should be carefully sealed.

Results from the few installations using polythene to cover the ground have been mixed. Generally, they prove difficult to install because of the cramped conditions beneath the floor, and this also makes them expensive. In the last resort it may be necessary to replace the suspended timber floor with a concrete slab and sump, as discussed in a later section of this report.

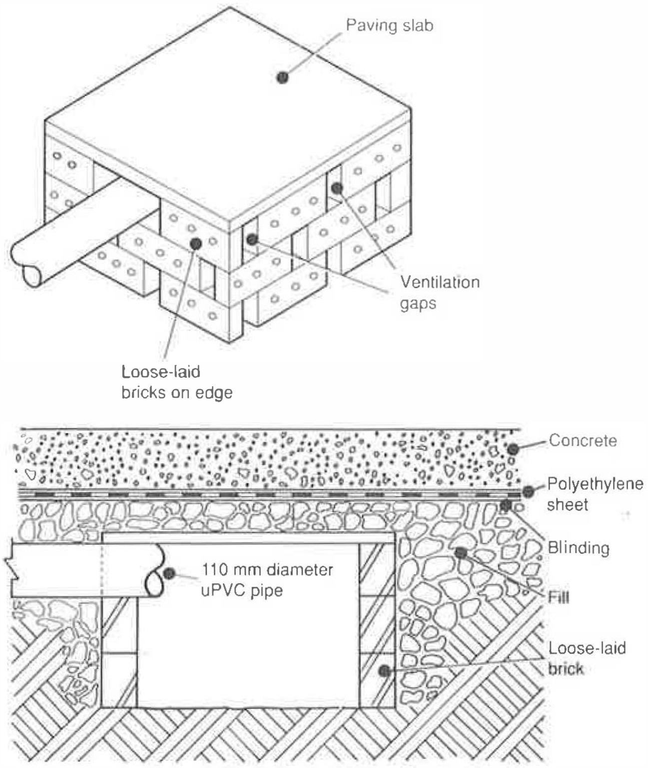

Figure 15 Details of radon sump installation

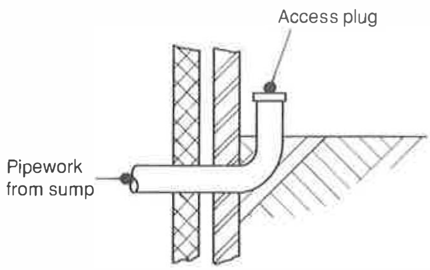

Figure 16 Pipework from a sump capped-off with an access plug just above ground level

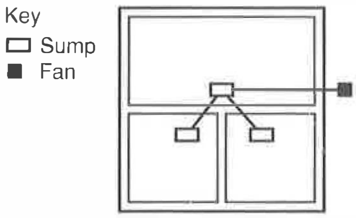

Figure 17 Pipework manifolded to an external fan

Passive and active (fan-assisted) systems

Sump systems can be either passive or active. The passive type should have all pipework running internally through a heated area of the dwelling. The air in the pipe is warmed by the house and it rises, drawing radon out from beneath the floor. This approach usually halves the indoor radon level, but some installations have produced larger reductions. They are usually only suitable for those dwellings with indoor radon levels no greater than 500 Bq/m^3. However, passive sumps are an attractive first option because they can easily be converted into active systems by installing a fan. Fan-assisted sumps are the most effective systems of all, and achieve very large reductions in radon levels.

A report is available from BRE containing more detailed information about the construction of various types of sump system[2].

Disadvantages associated with sump systems
Sump systems have few drawbacks. There is minimal heat loss from dwellings and little likelihood of spillage. Noise, however, is sometimes a problem with fan-assisted sump systems, but this is often due to the poor mounting or positioning of the fan. Fans should be sited away from noise-sensitive areas and mounted on a heavy rigid structure, such as an external wall. A rubber pad can also be placed between the fan and the building component to reduce vibration transmission. Further advice on problems with noise and spillage is available in leaflets from BRE[8,9].

POSITIVE PRESSURISATION

Positive pressurisation is an option in dwellings with indoor radon levels of up to about 700 Bq/m^3. In this type of system a fan blows filtered fresh air — typically air from the loft space — into the dwelling (see Figure 18). Positive pressurisation systems were originally designed to reduce condensation, but they can be used to reduce radon concentrations as well. It is claimed that they can increase the air pressure in the house sufficiently to exclude radon. Although this might be achieved in a house which was particularly airtight, in many houses the fan will simply increase the ventilation rate and therefore dilute the radon. Whichever effect takes place, the result is likely to be a reduction in radon levels.

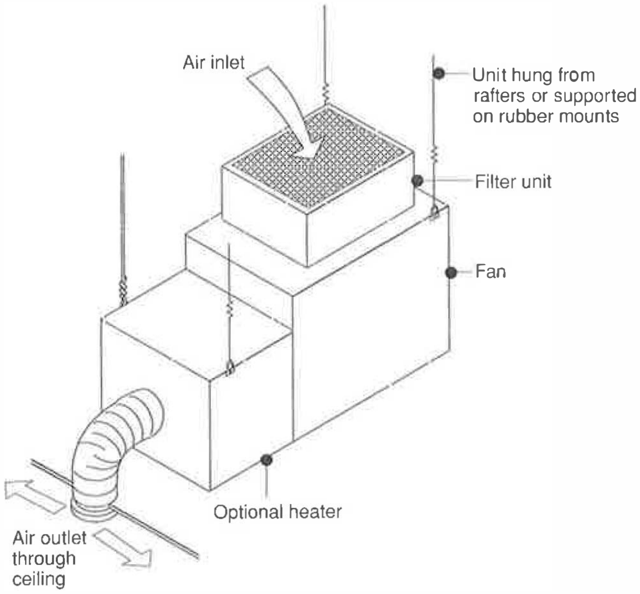

Figure 18 A typical positive pressurisation system

To make a positive pressurisation system acceptable to the householder, you will have to consider its location and operating characteristics. Some consumer resistance has developed because of systems which produce a cold zone in the house in winter (and sometimes a hot zone in summer). This problem can be overcome by using a fan fitted with a small heater, but the heaters are normally electric and may be expensive to run. Nevertheless, many householders find positive pressurisation a satisfactory solution, with or without a heater. There can be a secondary benefit in the form of reduced condensation in winter.

Leaving windows open for extended periods may reduce the effectiveness of positive pressurisation. It is also important to ensure that the roof void is adequately ventilated. Manufacturers can advise on the sizing and installation of systems.

A drawback with positive pressurisation is that it may lead to significantly increased heat losses from the dwelling.

REPLACING SUSPENDED TIMBER FLOORS WITH CONCRETE SLABS

Replacing a suspended timber floor with a concrete slab is an expensive and disruptive solution. However, when combined with a sump system, it is probably the most effective of all the options available. It should only be considered if other methods have failed to reduce radon levels, but the principal objections disappear if the floor needs replacing anyway, eg due to rot problems.

A replacement concrete floor may provide sufficient protection on its own, but as an additional safeguard against radon entry, it is advisable to install a standard sump beneath the concrete slab before it is poured (see Figure 15). A pipe can be run from the sump to outside, where it is left capped (see Figure 16). Therefore, if the slab alone proves inadequate, the sump can be activated by fitting a fan. If there are several floor areas being replaced it is best to install a sump beneath each. These can be linked together with pipes so that a single fan can be used to extract radon from all of them (see Figure 17). Additional information is provided in a recent BRE report[10].

SEALING

On the face of it, it seems sensible to stop radon entering the building by trying to seal all the obvious cracks, gaps and holes in the floors and walls. However, complete sealing of a suspended timber floor using an impervious sheet material, eg polythene, can lead to rot problems, particularly where there is inadequate underfloor ventilation. Sealing large gaps, such as those where services pass through the floor, can reduce indoor radon levels slightly, although the results are generally disappointing. Entire floor areas can be covered with plywood or hardboard, but again the reductions are generally poor and such coverings can be rather impervious. The sealing of large holes as a solution can only be recommended when indoor radon levels are between 200 and 300 Bq/m^3.

In some properties floor vents are installed to link the underfloor space with the living areas. Their purpose is usually to provide ventilation for either the underfloor space or for an open-flued combustion appliance. Sealing these vents can reduce radon levels slightly, but if the floor vents supply air to a combustion appliance an alternative air supply should be provided before sealing. This may involve installing an underfloor ventilation pipe or a wall vent (see Figures 8 and 10).

HOUSE VENTILATION

Improvements to the way in which a house is ventilated can help to reduce indoor radon levels. However, this is rarely a suitable choice because increased ventilation can adversely affect indoor comfort. The range of options includes installing trickle ventilators, capping chimneys and eliminating open fires, but these actions are still likely to have only a modest effect on indoor radon levels. They should only be contemplated on their own in houses which have indoor radon levels very close to the action level of 200 Bq/m^3.

If trickle ventilators are to be installed, they should preferably be located downstairs. They should be permanently open in order to sustain the reduction in radon. Ideally, they should not be too large, typically 4000 to 6000 mm^2 in each room. They are usually located at the tops of windows to reduce draughts.

Any unused chimneys should be blocked up, as they tend to draw air out of the room. If you decide to block them up permanently, you should also take action to prevent condensation from building up inside the chimney. Cap the chimney stack with a chimney-pot hood and provide a small ventilation opening of about 50 mm × 20 mm in the blocked-up fireplace. A more detailed publication on this topic is available from BRE[11].

If the house has an open-flued gas-, coal- or oil-fired appliance which discharges into a chimney, make sure that there is an adequate supply of fresh air into the room from outside the house. Open coal or wood fires, and open solid-fuel-effect gas fires in particular, can draw large volumes of air out of a room, even when they are provided with an underfloor supply of air directly to the fire. In these circumstances closed appliances are preferable, such as room heaters and stoves: generally these appliances consist of a box with a door (which is normally closed), connected to the chimney by a flue pipe. If an alternative form of heating is available, and the householder can do without an open-flued appliance, then it is worth considering blocking up the chimney.

Most modern central heating boilers and some gas fires have balanced flues. These take all the air they need for combustion and get rid of all the exhaust gases through the same metal terminal in the wall. As they draw no air from the house, they are ideal in radon-affected areas. If you plan to install or renew the central heating boiler, a balanced-flue room-sealed type without an underfloor draught is the best choice. This may mean that you have to move the boiler to a suitable external wall, although fan-assisted balanced-flue appliances are available which overcome this problem.

Ensure that kitchen and bathroom extract fans are appropriately sized. An appropriate axial or propeller-type fan for a typical house should have an impeller no greater than 150 mm in diameter. Extract fans should not need to be run continuously.

Vents should **not** be cut through the suspended floor to link the underfloor space to the interior of the dwelling — ventilation must always be provided to the underfloor space from the outside. Existing vents between the underfloor space and the interior should be blocked or sealed and, if necessary, replaced with vents to the outside. Alternative ventilation must be provided for if the floor vents ventilate a combustion appliance, otherwise spillage may occur (this possibility is discussed in the section on mechanical underfloor ventilation systems).

FAN TYPES AND SIZES

Axial and centrifugal fans

Axial fans are widely used as a bathroom or kitchen extract fan. An impeller draws air from one side of the fan and expels it out through the other side (see Figure 19). Centrifugal fans are less common. The impeller is a circular unit with small vanes on the outer edge. As the impeller rotates, air is drawn from the centre of the unit and forced towards the outside (see Figure 20). Usually the inlet is set at 90° to the exhaust, but centrifugal fans are available which have inlet and exhaust in-line.

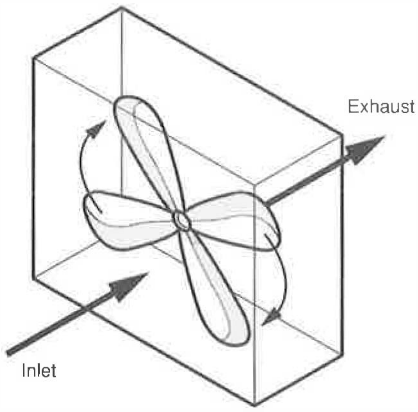

Figure 19 Axial fan impeller

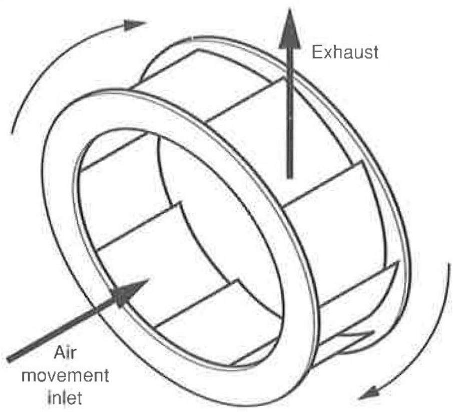

Figure 20 Centrifugal fan impeller

Guidelines for fan specification
It is impossible to give a fan specification to suit all methods, all radon levels and all building types. The guidelines in this section are for average sized dwellings. Larger buildings or more complicated designs may require the use of more than one fan or the use of a single, more powerful fan. For most applications fans should be weathertight and able to run continuously throughout the year. Fan units should also be suitably sealed to protect against internal condensation.

For mechanical ventilation of underfloor spaces, the fan should have a flow rate such that it can exchange the air in the underfloor space between 3 and 10 times an hour (or an approximate power rating of 75 W). The fan may be either axial or centrifugal. There is insufficient evidence to indicate which type is best, but it is believed that axial types should produce the largest reductions, provided there are sufficient airbricks open on the opposite side of the dwelling to allow for adequate cross-ventilation.

In principle, the use of an axial flow fan is to be preferred for the ventilation of underfloor spaces: these fans are more efficient and quieter. However, because there is often a restricted amount of space beneath the floor, a centrifugal fan may be the only option.

For sump systems any non-stalling centrifugal fan with a power rating of approximately 75 W is likely to be suitable. It should be able to work continuously at low flow rates and high pressure differences.

For more information regarding fans, contact your local fan supplier. Details can be found in *Yellow Pages*, heating and ventilation buyers' guides and other, similar publications.

REMONITORING FOR RADON
Once remedial measures have been installed, it is important that the property is remonitored for radon. Ideally, this should be done over a three-month period using two etch-track (plastic) detectors located in the same rooms which were used for the original monitoring. Further information on detectors and monitoring is available from the NRPB.

FURTHER INFORMATION
Research into radon is continuing and further reports in this series are planned. Help with radon-related problems of all kinds is available from the BRE Radon Hotline (telephone: 0923 664707).

Advice on radon risks and monitoring is also available from the The Radon Survey, National Radiological Protection Board, Chilton, Didcot, Oxon OX11 0RQ (telephone: 0235 831600).

ACKNOWLEDGEMENTS
BRE wishes to thank the many householders and others who have assisted in the research on which this report is based. Thanks also to Mr T J Gregory of Cornwall County Council, for allowing access to, and measurement results from, many County Council properties, and to Mr K Cliff of the NRPB, for assistance with long-term radon measurements. The authors would like to thank the other members of the BRE radon team, J K Carey, A J Cripps, R P Hartless, K M Noonan, R K Stephen, B Stringer and M J Woolliscroft, for their assistance in preparing this report.

REFERENCES

1 **Department of the Environment.** *The householders' guide to radon.* London, HMSO, 1992 (third edition). Obtainable from DOE, Room A518 Romney House, 43 Marsham Street, London, SW1P 4QU

2 **Building Research Establishment.** *Radon sumps: a BRE guide to radon remedial measures in existing dwellings.* BRE Report. Garston, BRE, 1992.

3 **Pye P W.** *Sealing cracks in solid floors: a BRE guide to radon remedial measures in existing dwellings.* Building Research Establishment Report. Garston, BRE, 1993.

4 **Scivyer C R.** *Surveying dwellings with high indoor radon levels: a BRE guide to radon remedial measures in existing dwellings.* Building Research Establishment Report. Garston, BRE, 1993.

5 **Building Research Establishment.** *Radon: guidance on protective measures for new dwellings.* BRE Report. Garston, BRE, 1991 (revised 1992).

6 **Building Research Establishment.** Dry rot: its recognition and control. *BRE Digest* 299. Garston, BRE, 1985 (revised 1993).

7 **Building Research Establishment.** Wet rots: recognition and control. *BRE Digest* 345. Garston, BRE, 1989.

8 **Building Research Establishment.** *Radon and buildings: 1. Spillage of combustion products.* BRE leaflet XL8. Garston, BRE, 1994.

9 **Building Research Establishment.** *Radon and buildings: 2. Minimising noise from fan-assisted radon sump systems.* BRE leaflet XL9. Garston, BRE, 1994.

10 **Building Research Establishment.** *Major alterations and conversions: a BRE guide to radon remedial measures in existing dwellings.* BRE Report. Garston, BRE, 1994.

11 **Building Research Establishment.** Chimney stacks: taking out of service. *BRE Defect Action Sheet* DAS93. Garston, BRE, 1987.

Printed in the United Kingdom for HMSO
Dd8390912 11/94 C10 G476 10170