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A BRE guide to radon remedial measures in existing dwellings

Dwellings with cellars and basements

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Introduction

This guide is one of a series giving practical advice on methods of reducing radon levels in existing dwellings. It is intended to help surveyors, builders and householders who are trying to reduce indoor radon levels in houses with cellars or basements.

The guide is based on a large body of remedial work carried out to advice given by BRE, and on discussions with others working in the field. The measures it describes are applicable, in principle, to all dwellings and other buildings of a similar scale and construction which have cellars or basements.

Contact details of other organisations referred to are listed at the back of this guide.

Basements and cellars are relatively uncommon in the United Kingdom, but where they do occur they are likely to be major contributors to the radon problem within a building. Experience shows that most houses with high indoor radon levels can be remedied through the use of straightforward building works. These can be carried out by a builder or householder competent in DIY. The cost should not be excessive.

Before reading this guide, for background information on radon, consult *Radon: a householder's guide* and *Radon: a guide to reducing levels in your home,* obtainable from local Environmental Health Officers or from the Department of the Environment, Transport and the Regions. The Government recommends that, if the average radon concentration in a dwelling exceeds 200 Bq/m^3 (the 'action' level), measures should be taken to reduce it. This guide assumes that radon measurements have been made in the building and that the annual average indoor radon level was shown to exceed the action level.

How to use this guide

To help you to find the most appropriate solution for your house, this guide is split into four sections.

A: Background
You should read the whole of this section as it contains important information about radon and its measurement.

B: Identification of types of cellars and basements
Read this section to identify the type of house that you have.

C: Choosing a radon solution
Having identified the type of house that you have, read the part of this section that discusses the different types of remedial measure that might be appropriate for your house.

D: Remedial options
Having identified the appropriate solution for your house, read the part of this section that describes in more detail the practical construction necessary for that solution.

Section A Background

What is radon?

Radon is a colourless, odourless radioactive gas. It comes from the radioactive decay of radium, which in turn comes from the radioactive decay of uranium. Uranium acts as a permanent source of radon and is found in small quantities in all soils and rocks, although the amount varies from place to place. It is particularly prevalent in granite areas but not exclusively so. Radon levels vary not only between different parts of the country but even between neighbouring buildings.

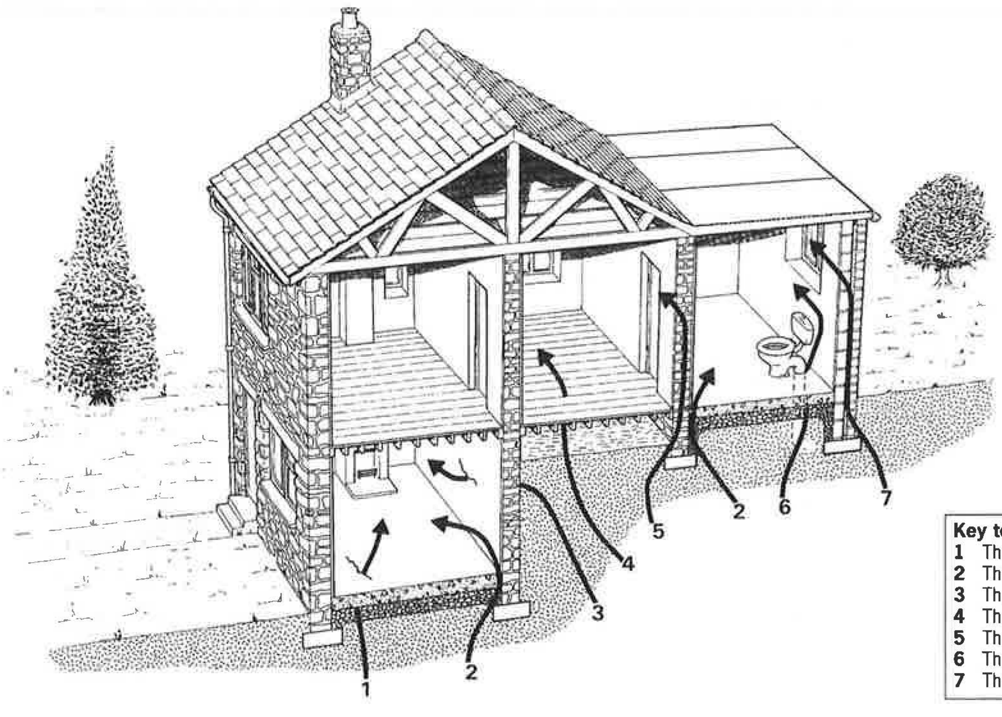
Radon in the soil and rocks mixes with air and rises to the surface where it is quickly diluted in the atmosphere. Concentrations in the open air are very low. However, radon that enters enclosed spaces, such as buildings, can reach relatively high concentrations in some circumstances.

When radon decays it forms tiny radioactive particles which may be breathed into the lungs. Radiation from these particles can cause lung cancer which may take many years to develop. In addition, smoking and exposure to radon are known to work together to increase greatly the risk of developing lung cancer.

The floors and walls of dwellings contain many small cracks and gaps formed during and after construction. Radon from the ground is drawn into the building through these cracks and gaps (see Figure 1) because the atmospheric pressure inside the building is usually slightly lower than the pressure in the underlying soil. This small pressure difference is caused by the stack (or chimney) effect of heat in the building and by the effects of wind.

Measuring radon in dwellings

It is not the role of this guide to discuss radon measurement in detail. It is, however, important to appreciate how and where radon should be measured in order to select the most appropriate solution for a particular building. As radon levels can fluctuate from



Key to ingress routes
1 Through cracks in solid floors
2 Through construction joints
3 Through cracks in walls below ground level
4 Through gaps in suspended floors
5 Through cracks in walls
6 Through gaps around service pipes
7 Through cavities in walls

Figure 1 Routes by which radon enters a dwelling season to season, from day to day, and by the hour, radon levels should be measured over as long a period as is practical. Ideally this should be for three months using etch-track (plastic) detectors. Short-term measurements, of a week or so in duration, can prove useful for diagnosis, although results will be less accurate and should be interpreted with care.

In most cases radon measurements will have been carried out using two detectors, one in the main living room and one in the main bedroom, giving an average result for the house. Unless the cellar or basement fulfils one or other of these roles then they are unlikely to have been monitored. It would be inappropriate to place one of the two detectors within an unoccupied or rarely used basement area, as the levels would probably be higher than those to which the occupants are regularly exposed. It is the average occupancy risk that is of concern, and therefore it is the regularly occupied rooms that should be measured.

Although in most cases you will not have a result for the basement area it can usually be assumed that the radon level in the basement will be greater than that found in rooms that are above ground. There are a number of reasons for this.

- The walls and floor of a basement are directly in contact with the ground. So, for a building with a basement beneath the whole of its ground floor, the area of the building in contact with the ground is probably three times that of a similar-sized building without a basement, and the potential for radon entry is far greater.
- Cellars are often only used for storage and therefore are poorly finished. The walls in particular often feature a myriad of small cracks and gaps, all of which can contribute to the radon problem.
- Basements which are completely below ground are often poorly ventilated, and consequently radon entering them can build up. To aggravate the situation, the floor between the basement and room above is often of suspended timber construction. This enables the radon to flow further into the building.

So, for the purpose of this guide the radon levels referred to are **average whole-house measurements** not individual basement or cellar readings.

Further information on radon risk and measurement can be obtained from the National Radiological Protection Board, Chilton, Didcot, Oxfordshire, OX11 0RQ.

How can radon levels be reduced?

It is better to prevent the entry of radon into a house than to try to remove it once it is present. In practice, this means preventing the entry of radon-laden air from the ground through gaps and cracks in the floors and walls. This can be achieved relatively easily during the construction of a new house by building in a radon barrier. Further advice can be found in BRE Report *Radon: protective measures for new dwellings*. In existing dwellings, remedial measures are required.

There are six main ways of reducing the amount of radon entering a house with a cellar or basement:

- Installing a radon sump system
- Sealing floors and walls
- Increasing underfloor ventilation
- Installing a whole-house positive pressurisation or positive supply ventilation system
- Improving the ventilation of the house
- Improving the ventilation of the cellar or basement

These solutions are not all suitable for all types of house, nor are they suitable for all levels of radon, and in some cases more than one solution will need to be used in resolving the radon problem. This is particularly so where a house is large or has a cellar or basement. The six methods are briefly described here and then discussed in more detail later, in Section D. For each method an indication is given in Figure 2 of the radon levels that can be reduced.

Radon sump

With solid concrete ground floors you can extract the radon-laden air from beneath the floor (depressurising the soil) by using a radon sump. This is generally the most effective method, and in many cases will reduce the radon level to less than one-tenth of the original level. For radon levels above 1200 Bq/m^3 it is often the only solution. It applies mainly to houses with solid floors, although a

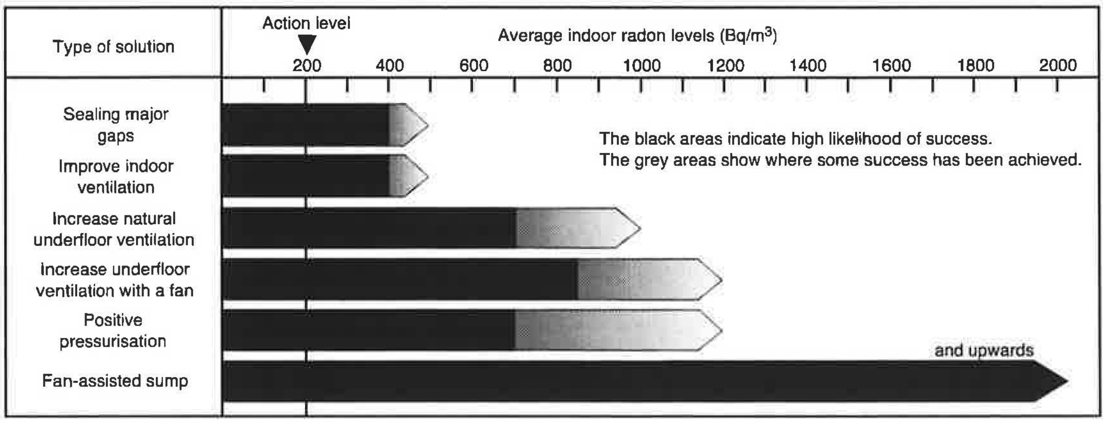


Figure 2 Guide to the likely effectiveness of solutions

sump can be used with a suspended timber floor if there is a layer of concrete or a membrane covering the soil beneath it. In some cases blowing into the sump and pressurising the soil can also prove effective.

Sealing floors and walls

You can seal the floor and walls where they are in contact with the ground, to prevent the radon getting through gaps and cracks. This is likely to be effective only at moderate radon levels, up to 400–500 Bq/m^3. Generally, it is difficult to reduce the radon level to much less than half by this means. Complete sealing of timber floors, eg with a continuous polyethylene (polythene) sheet, is not recommended, though the sealing of large holes is appropriate. Major sealing work to walls and floors in cellars and basements is usually only a viable option where it forms part of work being carried out to convert an unused space into occupied space.

Underfloor ventilation

With a suspended floor you can increase the flow of air beneath the floor. This is generally effective, particularly if it is assisted by a fan. Natural ventilation is suitable for radon levels up to 700 Bq/m^3, and fan assistance for radon levels up to 850 Bq/m^3. This solution is unlikely to be appropriate for use in houses with full cellars or basements.

Positive pressurisation or ventilation

You can pressurise the house using a fan which draws air from the loft space or from outside and blows it indoors. This method is again generally effective only at moderate radon levels, up to about 700 Bq/m^3, and works better in more airtight dwellings.

Improving the ventilation of the house

In some cases it is possible to change the way in which the whole house is ventilated, to avoid, as far as possible, drawing radon up through the floor or walls. However, as this depends on the way in which the occupier lives in the house it is not generally a reliable method. It may be suitable for radon levels up to 400 Bq/m^3.

Improving the ventilation of the cellar or basement

Improved natural or mechanical ventilation targeted on a cellar or basement, where the highest radon levels are likely to be, can prove extremely effective, and offer large radon reductions. Mechanical fans can be used to blow air into, or draw air out of, a cellar or basement.

Retesting for radon

It is important, once remedial measures have been installed, that radon levels in the house are measured again. Ideally, this should be done over a three-month period using two etch-track (plastic) detectors located in the same rooms where the original measurements were made. Shorter-term measurements may prove useful to get a quick indication of the success of the works undertaken. However, you should always follow up with a long-term test. Further information on measurement is available from the National Radiological Protection Board.

You may find that you will need to retest the house more than once. Houses with cellars and basements can sometimes prove difficult to remedy using a single solution. You may have to treat the building in stages, retesting after each stage of work until you have adequately reduced the radon level.

Section B
Identification of types of cellars and basements

What are cellars and basements?

In essence a cellar or basement is a room or usable space beneath a building. Each, however, has its own characteristics.

Types of cellar and basement

The following descriptions will help you to categorise your house. You will need to identify the type of house you have as the remedial solutions given within this guide are based upon these descriptions.

- **Cellars** are unoccupied areas, which may be used for long-term storage, are typically poorly finished and may be damp and lack adequate ventilation. Walls forming a cellar act as retaining walls and are completely or almost completely located below ground level. An example is shown in Figure 3(a).
- **Basements** are occupied spaces, generally reasonably well finished and heated. As with cellars the walls of a basement act as retaining walls and are completely or almost completely located below ground level. An example is shown in Figure 3(a).
- **Full or partial cellars and basements.** Cellars and basements may extend under the whole area of the house (full basement, Figure 3(a)) or only part of the building (partial basement, Figure 3(b)). Occasionally a cellar or basement may extend beyond the floor plan of the building, for example where part of a cellar once formed a coal hole.
- **Semi-basements or cellars** are the same as basements or cellars, but have at least one or more wall exposed to the elements instead of acting as a retaining wall (Figure 3(c)).
- **Stepped constructions** are houses located on a sloping site, for which the lower-level rooms are dug into the sloping ground forming a partial semi-basement (Figure 3(d)).

To help in selecting an appropriate radon solution, the different constructions can be grouped into three types:

- **Type 1: Houses with full, partial or semi-cellars**
- **Type 2: Houses with full or partial basements**
- **Type 3: Houses with semi-basements or of stepped construction**

You should identify the type that best describes your house and then proceed to the appropriate part of Section C for the detailed discussion of features and solutions for that particular type of house.

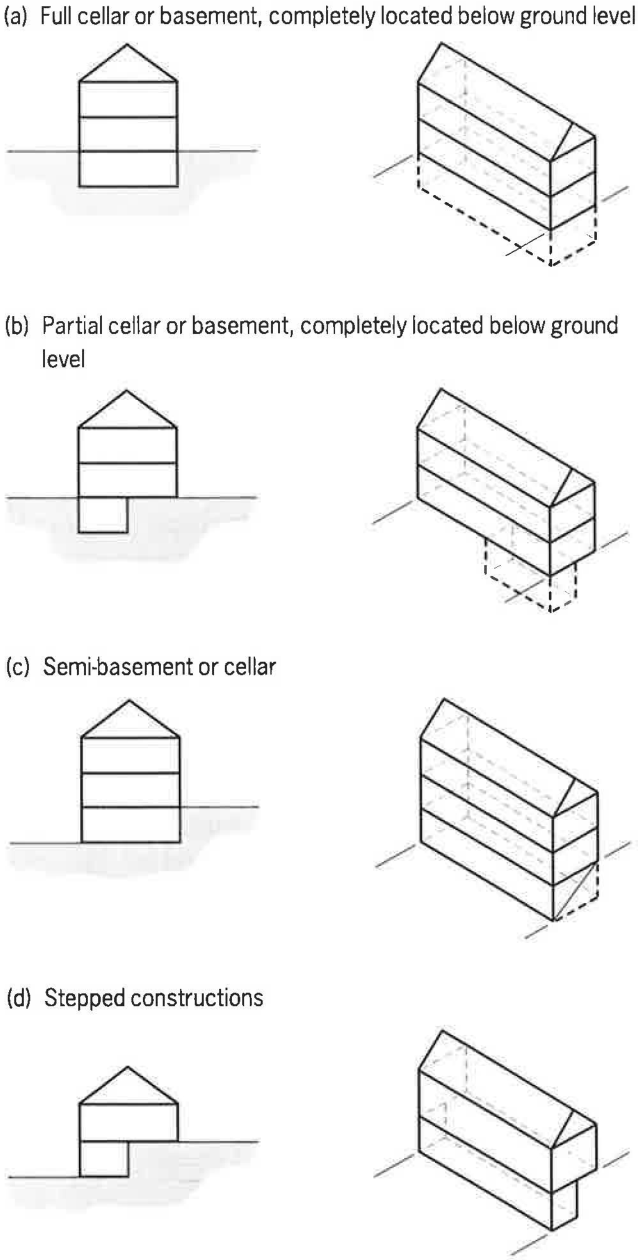


Figure 3 Different kinds of cellars and basements

Section C
Choosing a radon solution

Having read Section B of this guide and decided which house type best describes your house, you should now only need to read here the information relating to your particular house type:

- Type 1: House with full, partial or semi-cellar
- Type 2: House with full or partial basement
- Type 3: House with semi-basement or of stepped construction

Type 1: Houses with full, partial or semi-cellars

Discussion

Having decided that your house has a full, partial or semi-cellar you will need to consider the following in order to select an appropriate solution.

Floor construction

Cellar floors are often poorly constructed and generally in a poor state of repair. In the worst cases the cellar floor simply comprises compacted earth or rock, which offers no barrier to radon. Concrete floors are quite common, but typically with older properties they only comprise a thin layer of weak concrete. Hence radon can enter the building through cracks and gaps in and around the floor slab. Many cellars have stone or slate flag floors, in which the flags have either been laid directly onto the soil below or been bedded in a thin layer of weak concrete. Again radon can enter through gaps between and around the edges of the flags. It is unlikely that you will come across a cellar with a suspended timber floor.

Occasionally the cellar floor will have been replaced or upgraded with a modern concrete floor which includes a damp-proof membrane. Where this is the case it is likely that radon will only be entering through gaps around the edges of the floor where it meets the walls, through the walls themselves or through gaps around services which penetrate the floors or walls.

In some cases the concrete floor of the cellar will have been laid directly over rock. Where this occurs there is unlikely to be a permeable layer of fill material beneath the slab, which would mean that a sump system could not be used as a solution, as it is difficult to excavate a sump and the airflow is restricted.

In many cases the ground floors adjacent to the cellar are of mixed construction, ie some rooms with solid concrete floors and others with suspended timber. This can make it difficult to select an appropriate solution. It is very likely that more than one solution will be needed, eg a combination of improved underfloor ventilation for part of the house and a sump system elsewhere.

Wall construction

Of interest here are the walls within the cellar which act as retaining walls. Cellar walls vary considerably from building to building. In the worst cases the cellar may simply have been dug into the bedrock and the rock forms the walls. Such construction offers no protection against radon. More usually the walls will be of stone or brick construction, typically poorly constructed without any vertical barrier to dampness. Sometimes they are finished internally with a coat of sand/cement render or occasionally plaster, but this is often poorly applied. As a consequence radon can easily enter through cracks and gaps in the walls. Damp ingress through the walls may pose a problem when it comes to choosing a solution.

Ceiling construction

The way in which the ceiling of the cellar is constructed can have an impact on radon levels within the main body of the house. It can also impact upon the solutions that you can use. In most cases the ceiling will comprise nothing more than the suspended timber floor of the room above. At best this may be covered with some kind of wooden or plaster boarding to provide a ceiling. It is rare for the cellar ceiling to be in good condition. As a consequence the ceiling is likely to be leaky, which allows radon to pass up into the house. It is doubtful whether sealing the cellar ceiling will prove effective in significantly reducing radon levels in the house above.

Sometimes the cellar ceiling is formed in vaulted stone or brick, or occasionally constructed in suspended concrete. In these cases the ceiling is likely to provide reasonable resistance to airflow from the cellar into the rooms above.

Should you decide to increase the ventilation of the cellar as a solution and the ceiling is leaky, care will be needed to avoid problems of draughts. Consideration should also be given to potential noise problems associated with locating mechanical fan systems in cellars beneath frequently occupied rooms. If at all possible, fans should be located beneath areas of the house that are not sensitive to noise, eg the entrance hall.

Access to the cellar from the house

Typically access to the cellar is through a door inside the house. It is important that this is draughtstripped to reduce airflow from the cellar into the house. In some cases there will not be a door, resulting in a major radon entry route into the living area. It is quite common to find the cellar staircase located immediately beneath the staircase giving access from the ground floor to the first floor. Walling concealing the staircase is often constructed of timber framing clad in timber boarding which is likely to be leaky. Therefore air can move directly from the cellar to the ground and first floors.

Damp

Cellars are often damp, suffering from moisture passing through poorly constructed walls and floors. Where dampness problems are not too severe then simply increasing the level of ventilation in the cellar can help to dry them out. Excessive moisture should be avoided because it could lead to timber rot in a floor located above a cellar.

Ventilation

Many cellars are poorly ventilated. This is due to insufficient air vents having been provided at the time of construction, and those that have been provided being blocked up. As a consequence the air quality is likely to be poor, which results in musty smells. Increased ventilation can prove effective in reducing radon levels. You will, however, need to consider services that are routed through the cellar, to avoid water pipes freezing in winter. Similarly any increase in ventilation of the cellar using unheated air will have an impact on heating costs for the house.

In addition to considering ventilation of the cellar it may be worth considering ventilation in the rest of the house. Poor ventilation practice can increase radon entry. You should avoid having a combination of well sealed or rarely opened windows downstairs, and poorly sealed or regularly opened windows upstairs, as this can increase the stack (or chimney) effect within the house, which results in radon being drawn into the house from the ground. Similarly, unused chimneys or unsealed loft hatches can increase the stack effect. Ensure that there are no deliberate vents cut through timber floors providing ventilation to combustion appliances such as open fires, as these can be major radon entry routes. Such vents should be sealed and an alternative source of ventilation, such as a through the wall vent, provided. Combustion appliances must be adequately ventilated. (See also comments in Section D, option 3, on spillage from open-flued combustion appliances.)

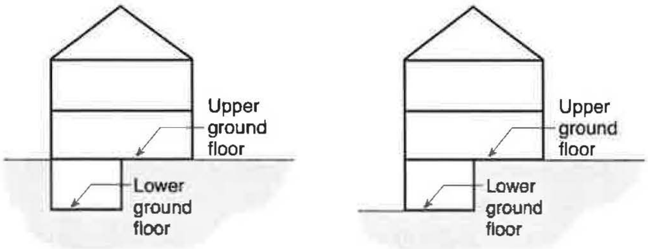
Occupancy of the cellar

In defining cellars we suggested that a cellar is a rarely occupied space. In some cases cellars are used as regularly occupied workshops. In these situations you will have fewer options for reducing radon levels. For example, greatly increasing ventilation may prove unacceptable as it alters the indoor temperature.

Additional points with partial cellars

It should be noted that a house with a partial cellar will effectively have two ground floors, that in the basement (lower ground floor) and that at normal ground level (upper ground floor) (Figure 4). It is quite common to find that a partial cellar is linked to the underfloor space of an adjacent suspended timber floor (Figure 5). It is important to consider this, as any changes in ventilation in the cellar could affect radon levels beneath the adjacent floors and in the rooms above them, and similarly changes in ventilation of underfloor spaces could affect radon levels within the cellar.

Partial cellars pose additional problems in terms of locating solutions. The worst case scenario would be a centrally located cellar, which is located some way from perimeter walls, where you need to connect the cellar to outdoors in order to increase the ventilation or to provide



(a) Partial cellar or basement (b) Partial semi-cellar or basement

Figure 4 Partial cellars, semi-cellars and basements

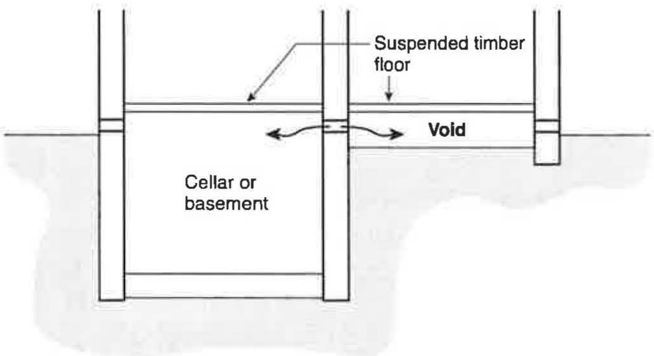


Figure 5 Cellar or basement linked to void beneath adjacent suspended timber floor

an exhaust to a sump system. At best the cellar may be located beneath half of the property, meaning that three of the four cellar walls are adjacent to the perimeter of the building, making installation easier.

Additional points with semi-cellars

Sometimes part of a semi-cellar forms an integral garage. Radon is less likely to enter the main occupied areas of the house through the garage, than through rooms in the cellar area. This is because the garage is likely to be well ventilated. As a consequence, attention to radon entry routes should be concentrated within the cellar area. The garage should not be totally overlooked however, as mechanical solutions can often be located within garages where noise will prove less of a problem. Likewise excavation work associated with sump systems can often be carried out from within the garage, thereby minimising disruption inside the house.

Choosing a solution

This section discusses the merits of the different solutions that are likely to be suitable for a house with a full, partial or semi-cellar.

Sealing to the cellar

Where the house has a low to moderate radon level (up to say 400–500 Bq/m^3) it may be sufficient to carry out simple sealing of the cellar walls and floors (see option 1 in Section D). But, unless there are a few major entry routes, all cracks and gaps found in the walls and floors will need to be sealed if this is to be effective. Cracks and gaps are likely to be reasonably easy to locate within a cellar, as there are unlikely to be any floor or wall coverings to hide them from view. However, owing to poor construction there are likely to be many cracks and gaps needing sealing. As a consequence effective sealing of the cellar is likely to prove difficult and time consuming to achieve in practice.

You should consider sealing between the cellar and the occupied part of the house. This may prove necessary if you are also considering increasing ventilation levels within the cellar. In most cases the floor above the cellar will be of timber construction and major gaps and cracks, particularly large openings around services, will need to be sealed. Less common are vaulted cellars, with concrete floors above. With these there will probably be fewer opportunities for sealing. If the cellar is rarely used, or perhaps not ever used, you could consider sealing the cellar off from the rest of the dwelling.

Sealing to ground floors

In cases where the cellar is only located under part of the house, sealing of adjacent solid ground floors can be considered (see option 1). Sealing floors to the occupied part of the house may be more complicated owing to the need to lift carpets, move furniture and possibly remove skirting boards. Again this is only likely to prove successful with low to medium radon levels (up to say 400–500 Bq/m^3), and where it is possible to seal major gaps and cracks. Large gaps or holes in suspended timber floors can, and probably should, be sealed. However, completely covering a timber floor with an impervious sheet such as polyethylene (polythene) sheet is not recommended; complete sealing of a timber floor could lead to timber rot.

Increased natural ventilation to the cellar

For low to moderate radon levels (up to say 400–500 Bq/m^3), increased natural ventilation of the cellar may be worth considering (see option 4). This works by diluting radon within the cellar. Natural ventilation can be introduced into the cellar through airbricks, wall vents, disused coal holes and, in semi-cellars, vents in windows. If the cellar is completely below ground, air will need to be ducted into it. As the cellar is not used as living accommodation, the localised draughts and reduction in temperature within the cellar caused by increased ventilation are probably acceptable. However, increased ventilation is likely to result in a need for increased heating in rooms above. To minimise problems, and to prevent draughts entering the living accommodation above, you should seal any large gaps in the floor between the cellar and the rest of the house.

Increased natural ventilation to the rest of the house

While improvements to the way in which a house is ventilated can help to reduce indoor radon levels, increased ventilation can affect indoor comfort, so this may not be the best solution. Nevertheless, for low levels of radon (up to say 400–500 Bq/m^3), it may be worth considering. Any changes to ventilation must be permanent; simply changing window opening patterns is unlikely to be sustainable in the long term. (See option 5.)

Increased underfloor ventilation

Suspended timber floors at ground floor level are often poorly ventilated. Increasing underfloor ventilation can help to lower radon levels and will help to reduce the risk of timber rot. For low to moderate radon levels (up to say 400–500 Bq/m^3), it is worth considering increased natural underfloor ventilation (see option 2). This can usually be achieved relatively easily by upgrading existing airbricks or by providing additional ones. In some cases the underfloor void is open to the cellar. If it is, additional underfloor ventilation may also help to ventilate the cellar space. For higher radon levels (above 400–500 Bq/m^3), or where it is difficult to increase the natural underfloor ventilation, you may have to consider mechanical underfloor ventilation (see option 3.)

Mechanical ventilation of the cellar

Where the cellar is large, or the radon level is moderate to high (above 400–500 Bq/m^3), natural ventilation may not be sufficient to lower the radon level adequately. In these cases a mechanical system may be more appropriate.

A fan can be fitted to blow fresh air into the cellar (see option 6). This will have two effects, first to dilute radon in the cellar and secondly to increase the air pressure slightly within the cellar so as to counter the natural flow of radon from the ground into the cellar. If the cellar is not well sealed from the dwelling above, the increased airflow may cause cold draughts within the home. Therefore it is best to seal cellar doors and any larger gaps in the floor above the cellar.

The increased air movement in the cellar will cool the air, so this is generally not an acceptable solution if the cellar is to be used for long periods as, say, a workshop or games room. Care must also be taken that any water pipes are lagged and that goods such as wines stored in the cellar are kept away from the direct fan draught. Increased air movement can, however, help to dry out dampness within the cellar, and may help to avoid fungal growth and timber rot. As such this solution may actually improve the general condition of the cellar, making it a more usable space.

A fan can also be fitted into the cellar to extract radon-laden air (see option 7). This can be achieved in two ways. One is to fit a fan to extract air from the cellar, in which case the cellar then acts as a large radon sump under the house. Alternatively you can fit the fan and also provide additional fresh-air inlets on the opposite side of the house to the fan to provide cross-ventilation and dilution of radon levels.

Extracting radon-laden air can increase the flow of radon into the cellar through the cracks and gaps in the walls and floor, so radon levels in the cellar may become quite high. Therefore extract ventilation should only be considered when the cellar is used for storage and rarely accessed, or when it is sealed from the dwelling above.

With both supply and extract ventilation systems there is a risk of some fan noise. To avoid this fans should not be located under noise-sensitive areas. If noise proves to be a problem you may need to consider fitting a silencer to the fan.

The increased air movement in a partial cellar may also benefit floor voids in any adjacent suspended timber floors. This can be assisted by providing ventilation holes from the cellar. If the radon level is very high or the size of dwelling is such that supply ventilation to the cellar is insufficient to influence the radon level in the adjacent floor void, or both of these, you may have to install a second supply fan to ventilate the floor void.

Changes to the ventilation of a cellar may influence airflow through the earth under adjacent solid ground floors. For example, mechanical extract ventilation from a cellar under one part of the house could result in radon being drawn from the soil beneath the rest of the house, so that the cellar acts as a large sump, reducing the need for action elsewhere.

Whole-house positive pressurisation

Positive pressurisation involves blowing air from the loft space down into the house to reduce the pressure difference slightly between the dwelling and the underlying soil, and to increase ventilation and therefore dilution of radon within the dwelling (see option 8). The system works best in dwellings that are reasonably airtight. It is usually only recommended for use with indoor radon levels up to about 750 Bq/m^3, although if the house is very airtight it might be effective with higher radon levels. You may find that it proves effective in reducing radon levels in the occupied part of the house, but the radon level remains high in the cellar. If this is the case you will need to consider separate works for the cellar or to seal the cellar from the house. An important advantage of using positive pressurisation as a solution is that it is simple to install.

Sump system to the cellar

If the radon level is moderate to high (over say 400–500 Bq/m^3), and the floor of the cellar is of reasonable quality concrete or a good condition stone flag floor, then a sump system is likely to be the most suitable option (see option 9).

It is doubtful that a sump system would be appropriate if the floor comprises severely cracked concrete, is made up of poorly jointed flagstones, has been cut directly from the rock, or comprises exposed earth. For the sump system to work effectively there will need to be some permeable fill beneath the floor slab. Where the water table is above or at the same level as the floor of the cellar, radon is likely to be entering through the walls rather than the floor, so installing a sump would prove ineffective as it would fill with water and prevent the flow of air through the soil. Therefore it would be appropriate to select another option.

If the sump is a viable option it can be located anywhere within the cellar that is convenient. The benefit of this system is that sumps have been shown to be the most effective method of reducing moderate to high levels of radon to below the action level. The sump system should not alter any of the indoor conditions within the cellar or dwelling above, although care may be needed if a boiler or open-flued combustion appliance is used within the cellar.

The exhaust pipework and the fan unit can be located internally or externally depending on preference. Internal fans may need to be insulated to reduce noise, and the routing of pipework may need to be boxed in or carefully routed if taken through the dwelling above. External fans can be boxed in to improve aesthetics, or can be hidden from view with plants.

If the area of ground floor adjacent to the cellar is large, or the sump system fitted to the cellar is not providing adequate radon reduction to the rest of the house, it may be necessary to fit an additional sump to the adjacent solid ground floor. In some cases a sump can be created through the cellar wall under the adjacent solid floor, and can be manifolded to the existing sump system, so only requiring the expense of running one fan. This is termed a multiple sump system.

Replacement floor

If the cellar floor is in a very poor condition, for example severely cracked, poorly jointed and broken flagstones, or perhaps the floor is just compacted earth or cut directly from the bedrock, you may consider laying a new cellar floor (see option 10). The new cellar floor should have a radon-proof membrane included to help to prevent radon passing through the floor slab. This will also double up as protection from damp penetration. If the radon level is high, and because the new floor may not provide a complete barrier to radon (it could by-pass the floor and enter through the walls), you should consider installing a sump beneath the new floor. This can then be activated if radon levels remain high after the new floor has been laid.

As construction will prove expensive and radon reduction is only likely to be significant if you activate the sump, this solution is likely to be appropriate only if you are intending to upgrade the cellar to make it more usable, eg to use it as a workshop or similar.

Where adjacent ground floors are in particularly poor condition you could consider replacing them. It is doubtful, however, whether replacing a single floor will provide a significant reduction in radon levels without the installation of a sump system.

Type 2: Houses with full or partial basements

Discussion

Having decided that your house has either a full basement or a partial basement, you will need to consider the following in order to select an appropriate solution.

Occupancy of the basement

This is likely to have the biggest impact upon the choice of radon solution. Any solution which changes the indoor environment either in terms of increase in heating bills or draughts (as might happen with changes in ventilation) or problems of noise due to installation of a mechanical system, is unlikely to be accepted by the occupiers. Routing of pipework for sump systems may be limited or prove difficult if the basement is regularly occupied.

Floor construction

Basement floors are usually constructed in concrete, the quality of which is varied. Typically in older houses they comprise a thin layer of poor concrete, which is likely to be cracked. Radon can enter the building through cracks and gaps in and around the floor slab. A few basements have stone or slate flag floors in which the flags have either been laid directly onto the soil or been bedded in a thin layer of weak concrete. Again radon can enter through gaps between and around the edges of the flags.

Newer basements are likely to have reasonable concrete floors which incorporate some form of damp protection which may also afford some radon protection. In these cases radon is likely to enter only through gaps around services which penetrate the floor slab, through gaps around the edges of the floor where it meets the walls, or through the walls themselves. The same will apply where the basement floor has been replaced or upgraded with a modern concrete floor.

Sometimes the concrete floor of the basement will have been laid directly over rock. Where this occurs there is unlikely to be a permeable layer beneath the slab, which would mean that a sump system could not be used as a solution as it is difficult to excavate a void, and the airflow is restricted by the rock.

Wall construction

In most cases walls will be reasonably well constructed owing to the basement rooms being occupied. As a consequence radon entry is more likely to be through gaps at wall-to-floor joints, or wall-to-ceiling joints, rather than through cracks in the main body of the walls. Usually the walls will be of stone or brick construction, typically incorporating some form of vertical barrier to dampness, and finished internally with a coat of sand/cement render or plaster. If there are problems with damp ingress, dual remedial works for dampness and radon could be considered.

Some basement walls are lined with plasterboard dry lining, often where a cellar has been converted for regular use. With dry lining there is a cavity between the plasterboard and the wall. Any radon entering through the walls or the joint between the wall and floor can travel up this cavity to the rooms above or into the basement itself.

Access to the basement from the house

Typically the basement will be linked to the rest of the house through an open stairwell. Any radon entering the house through the basement will be free to flow up into the house. Solutions which involve increasing the ventilation in the basement will also affect the ventilation in the rest of the house.

Damp

If the basement suffers from dampness in either the walls or the floors and it is planned to remedy the damp problem, it is likely that the damp treatment will help in reducing radon entry. However, if you are replacing a solid floor to improve damp protection you may need to consider additional measures such as sealing and making provision for a sump system.

Ventilation

Basements are often poorly ventilated. This is due to insufficient air vents having been provided at the time of construction, or those that have been provided being blocked up. Where this is the case the air quality is likely to be poor, resulting in a musty smell. Increased ventilation can prove effective in improving the indoor air quality and will assist in reducing radon levels. However, if the basement is regularly occupied, any significant increase in ventilation would need to be accompanied by increased heating during winter months.

In addition to considering ventilation of the basement it may be worth considering ventilation in the rest of the house. Poor ventilation practice can increase radon entry. You should avoid having a combination of well sealed or rarely opened windows downstairs, and poorly sealed or regularly opened windows upstairs, as this can increase the stack (or chimney) effect within the house, which results in radon being drawn into the house from the ground. Similarly, unused chimneys or unsealed loft hatches can increase the stack effect. Ensure that there are no deliberate vents cut through timber floors providing ventilation to combustion appliances such as open fires, as these can be major radon entry routes. Such vents should be sealed and an alternative source of ventilation, such as a through the wall vent, provided. Combustion appliances must be adequately ventilated. (See also comments in Section D, option 3, on spillage from open-flued combustion appliances.)

Additional points with partial basements

It should be noted that a house with a partial basement will effectively have two ground floors, that in the basement (lower ground floor) and that at normal ground level (upper ground floor) (Figure 4). Radon can enter the house through the basement or the ground floor. In many cases the upper ground floors adjacent to the basement will be of mixed construction, ie some rooms with solid concrete floors and others with suspended timber. This can make it difficult to select an appropriate solution. It is very likely that more than one solution will be needed, eg a combination of improved underfloor ventilation for part of the house and a sump system elsewhere.

A partial basement may be linked to the underfloor space of an adjacent suspended timber upper ground floor (Figure 5). In cases where the basement is not so well finished this link may be visible from within the basement. In other cases it may be out of sight, hidden by plasterboard or other dry lining. It is important to consider this as any changes in ventilation in the basement could affect radon levels beneath the adjacent floors and in the rooms above them. Similarly changes in ventilation of underfloor spaces could affect radon levels within the basement.

Partial basements pose additional problems in terms of locating solutions. At best the basement may be located beneath half of the property, with three of the four basement walls adjacent to the perimeter of the building.

Choosing a solution

This section discusses the merits of the different solutions that are likely to be suitable for a house with a full or partial basement.

Sealing to the basement

Where the house has low to moderate levels of radon (up to say 400–500 Bq/m^3), it may be sufficient to carry out simple sealing of the basement walls and floors (see option 1 in Section D). But, unless there are a few major entry routes, all cracks and gaps found in the walls and floors will need to be sealed. In practice this is difficult and time consuming to achieve. Cracks and gaps can be difficult to locate as they may be hidden by floor coverings, skirting boards or wall coverings.

With partial basements adjacent ground floors may need to be sealed as well. Again, this will require you to lift carpets and remove skirting boards to locate all the cracks and gaps in the ground floor.

Large gaps or holes in suspended timber floors can, and probably should, be sealed. However, completely covering a timber floor with an impervious sheet such as polyethylene (polythene) is not recommended; complete sealing of a timber floor could lead to timber rot.

Increased natural ventilation of the basement

For low to moderate radon levels (up to say 400–500 Bq/m^3), increased natural ventilation may be a solution to consider (see option 4). This works by diluting radon within the basement. Increased natural ventilation can be introduced into the basement through vents in the basement wall or a basement window where the basement extends to just above ground level. Alternatively you will need to supply ventilation by means of ducts.

Care must be taken not to place ventilators where they are likely to cause a draught to the occupants, ie bedrooms and bathrooms. Care must also be taken not to place airbricks too close to the ground level as rain-water may flow into the airbrick causing damp problems for the basement rooms.

Increased natural ventilation to the rest of the house

While improvements to the way in which a house is ventilated can help to reduce indoor radon levels, increased ventilation can affect indoor comfort, so this may not be the best solution. Nevertheless, for low levels of radon (up to say 400-500 Bq/m^3), it may be worth considering. Any changes to ventilation must be permanent; simply changing window opening patterns is unlikely to be sustainable in the long term. (See option 5.)

Increased underfloor ventilation

Suspended timber floors at ground floor level are often poorly ventilated. Increasing underfloor ventilation can help to lower radon levels and will help to reduce the risk of timber rot. For low to moderate radon levels (up to say 400-500 Bq/m^3), it is worth considering increased natural underfloor ventilation (see option 2). This can usually be achieved relatively easily, by upgrading existing airbricks or by providing additional ones. In a few rare cases the underfloor void is open to the basement. If this is the case you should block any openings between the basement and underfloor space.

For higher levels of radon or where it is difficult to provide increased natural underfloor ventilation, then it may be worth considering mechanical underfloor ventilation (see option 3).

Mechanical ventilation to the basement

If the basement is large, or the radon level is moderate to high (above 400–500 Bq/m^3), increased natural ventilation may not be sufficient to lower the radon level adequately. In these cases a mechanical system may be necessary.

A fan can be fitted to blow fresh air into the basement (see option 6). This will have two effects, first to dilute radon in the basement, and secondly to increase the air pressure slightly within the basement so as to counter the natural flow of radon from the ground into the basement.

Unfortunately, increased mechanical ventilation will result in cooling of the basement and, in turn, the rest of the house. Therefore the fan should not be placed in any rooms which are regularly occupied. The alternative would be to provide additional local heating. Even with a heater fitted the fan may cause local draughts and so care should be taken not to fit the fan where draughts might cause nuisance. If you can overcome this problem, increased ventilation would help to improve the general air quality and help to reduce the likelihood of musty smells in the basement.

As with all mechanical systems there is a risk of noise. To avoid this becoming a nuisance the fan should not be located in a noise-sensitive area.

Because of the problems of draughts and the need to increase heating, this solution should probably only be considered if a sump system is not a viable option.

It is unlikely that supply ventilation to a partial basement will reduce the flow of radon through adjacent ground floors, as such ground floors may have to have their own radon reduction system fitted. For suspended timber ground floors the solution may be to increase the underfloor ventilation by fitting additional vents or by installing a second fan to blow beneath the floor. With a solid concrete ground floor the solution may be to seal the floor slab, or to install a sump system. Alternatively whole-house positive pressurisation could be considered.

Mechanical extract ventilation is not appropriate for an occupied basement. This is because the depressurisation effect it will have could result in increased radon levels within the basement.

Whole-house positive pressurisation

Positive pressurisation involves blowing air from the loft space down into the house to reduce the pressure difference slightly between the dwelling and the underlying soil, and to increase ventilation and therefore dilution of radon within the dwelling (see option 8). The system works best in dwellings that are reasonably airtight with low to moderate radon levels. It is usually only recommended for use with indoor radon levels up to about 750 Bq/m^3, although if the house is very airtight it might be effective with higher radon levels. You may find that it proves effective in reducing radon levels in the upper part of the house, but the radon level remains high in the basement. If this is the case you will need to consider separate works for the basement. An important advantage of using positive pressurisation as a solution is that it is simple to install.

Sump system to the basement

If the radon level is moderate to high (above 400–500 Bq/m^3), and the floor of the basement is of good quality, that is to say not severely cracked or made up of poorly jointed flagstones, a sump system is likely to be the most appropriate option (see option 9).

For the sump system to work effectively there will need to be permeable fill beneath the floor slab. You will not be able to establish whether this is the case before excavation work takes place. Where the water table is above or at the same level as the floor of the basement, a sump would prove ineffective as it would fill with water and prevent the flow of air through the soil. You should therefore look at using an alternative solution.

If the sump is a viable option it can be located anywhere within the basement that is convenient. The main benefit of this solution is that sumps have been shown to be the most effective method of reducing moderate to high levels of radon to below the action level. The sump system should not alter any of the indoor conditions within the basement or dwelling above, although care may be needed if a boiler or open-flued combustion appliance is used within the basement. If it is, it may be necessary to provide additional ventilation such as a through the wall vent. Combustion appliances must be adequately ventilated. (See also comments in Section D, option 3, on spillage from open-flued combustion appliances.)

For a house with a partial basement it is probably best to locate the sump within the basement as it is at the lowest point within the house. Provided that the fill surrounding the basement walls and under the ground floor is permeable, a single sump located within the basement should adequately reduce the radon level within an average-sized house. For larger houses or where the soil beneath the house is impermeable, then it may be necessary to install a second sump under the ground floor area. It may be possible to connect it to the system in the basement so that only one fan is necessary. Alternatively you may need to provide a separate system.

The exhaust pipework and fan unit can be located internally or externally according to preference. Internal fans will need to be insulated to reduce noise, and pipework may need to be boxed in or carefully routed to avoid it looking unsightly. External fans can be boxed in to improve aesthetics, or can be hidden from view with plants.

Replacement floor

If the basement or ground floor is in a very poor condition, for example severely cracked, poorly jointed or comprises broken flagstones, you may consider laying a new floor (see option 10). Because of the disruption and cost involved, this should only be considered as a solution if you are intending to replace the floor anyway. The new floor should have a radon-proof membrane included to help to prevent radon passing through the floor slab. This will also double up as protection from damp penetration.

It is doubtful whether replacing a single floor will provide a significant reduction in radon levels. Therefore you should install a sump within the fill below the new floor. The sump can then be activated if radon levels remain high after the new floor has been laid.

Type 3: Houses with semi-basements or stepped construction

Discussion

Having decided that your house has a semi-basement or is of stepped construction you will need to consider the following in order to select an appropriate solution.

In many cases there is no difference between a house with a semi-basement and one that is of stepped construction. Typically both can result in houses in which the lower ground floor only extends beneath part of the house. Houses with semi-basements may, however, have lower ground floors which extend beneath the whole house. Because the two types of construction are so similar they are discussed here together.

Occupancy

This is likely to have the biggest impact upon the choice of radon solution. Occupancy is likely to be the same as for houses built on level sites; in other words all rooms are considered to be occupied spaces. However, the use to which the different levels within the house are put may differ considerably. For example 'upside down' houses are quite common in which the bedrooms are on the lower level and living rooms on the upper level. This could impact on the choices for siting mechanical solutions.

Any solution which changes the indoor environment either in terms of increase in heating bills or draughts (as might happen with changes in ventilation) or problems of noise due to installation of a mechanical system, is unlikely to be accepted by the occupiers. Routing of pipework for sump systems may be limited or prove difficult if the semi-basement is occupied.

Floor construction

It should be noted that a house of stepped construction or with a partial semi-basement effectively has two ground floors – the lower ground floor within the basement, and the upper ground floor to the rooms immediately above and adjacent to the basement area (Figure 6). You will need to consider the floors at both levels. With the upper ground floor it will be those parts of the floor that are located over the ground that you will need to look at.

The lower ground floor is most likely to be of either solid concrete or suspended timber construction. There may be a few cases in newer houses where a suspended concrete floor has been used; also some semi-basements have stone or slate flag floors, in which the flags have either been laid directly onto the soil or been bedded in a thin layer of weak concrete. Where constructed in concrete the quality can be varied. Radon can enter through cracks and gaps in and around concrete floor slabs or through joints in flag floors.

Concrete floors in newer houses are likely to incorporate some form of damp protection which may also afford a degree of radon protection. In these cases radon is likely to be entering only through gaps around services which penetrate the floor slab, through gaps around the edges of the floor where it meets the walls, or through the walls themselves. The same will apply where an old floor has been replaced or upgraded with a modern concrete floor.

In some cases the concrete floor of the house will have been laid directly over rock. Where this occurs there is unlikely to be a permeable layer beneath the slab. Unfortunately this would mean that subslab depressurisation (a sump system) could not be used as a solution as it would be difficult to excavate a sump and it would be less likely to work because of reduced airflows.

Suspended timber floors are commonly used in stepped houses. It is important to check whether the floor is in good condition and is adequately ventilated. With older houses in particular, ventilation may be poor. Even if the upper ground floor is well ventilated, underfloor ventilation to the lower ground floor is likely to have been provided only along one side of the building where the wall is exposed to the outdoors. Increasing the underfloor ventilation may be appropriate in these cases, although to do so may prove difficult unless you use a fan.

It is important to identify whether the floor is a suspended timber floor or a solid concrete floor which has a wooden finish laid over it. If the latter has been used the floor should be treated like a solid concrete floor with regard to radon solutions. In more modern houses the ground floors may be of suspended concrete beam and block construction. Where this is the case it is important to establish whether the floors have underfloor ventilation. If not, then the provision of ventilation should be considered as a possible remedial measure.

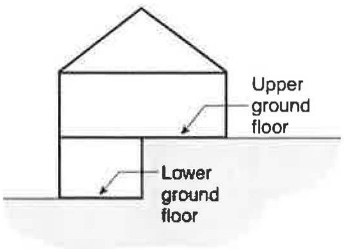


Figure 6 Stepped construction or partial semi-basement

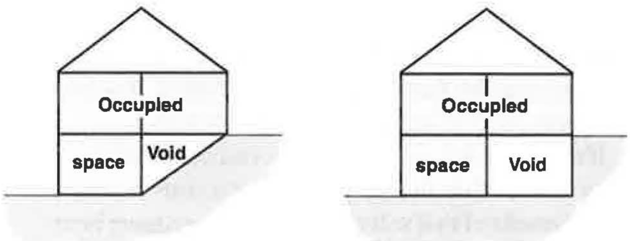


Figure 7 Voids beneath suspended upper ground floor in stepped construction

It is quite common to find that a large void, often the size of a room, has been left beneath the suspended upper ground floor area (Figures 7(a) and 7(b)). It is important to establish whether this is the case, as it could influence what remedial measures can be provided.

Another point to consider is mixed floor construction, where for example the upper ground floor is of suspended timber construction whilst the lower ground floor is solid concrete. You may have to use more than one solution to reduce the radon level.

Wall construction

Of interest here are the walls at lower ground floor level which act as retaining walls. These walls are likely to be reasonably well constructed because the rooms are regularly occupied. As a consequence radon entry is likely to be through gaps at wall-to-floor joints, or wall-to-ceiling joints, rather than through cracks in the main body of the walls.

Usually the retaining walls will be of stone or of brick and concrete block construction, typically incorporating some form of vertical barrier to dampness, and finished internally with a coat of sand/cement render or plaster. If there are problems with damp ingress, dual remedial works for dampness and radon could be considered. Where retaining wall construction is extremely poor, radon could easily enter through cracks and gaps in the walls.

Some lower ground floor walls are lined with plasterboard dry lining, often where a cellar has been converted into a basement. With dry lining there is a cavity between the plasterboard and the wall. Any radon entering through the walls or the joint between the wall and floor can travel up this cavity to the rooms above.

Access to the lower ground floor from the house

Typically the lower ground floor will be linked to the rest of the house by an open stairwell. Any radon entering the lower part of the house will be free to move higher up the house.

Damp

If the lower ground floor area suffers from problems of dampness in either the walls or the floors, and it is planned to remedy the damp problem, it is likely that the damp treatment will help in reducing radon entry. However, if you are replacing an existing floor with a new solid floor to improve damp protection, you may need to consider including provision for a sump system.

Ventilation

Semi-basements or lower ground floor areas are often poorly ventilated. This is due to insufficient windows or other forms of ventilation having been provided at the time of construction. The major problem is that windows and vents can really only be provided along walls exposed to the outdoors. As a consequence the air quality may be poor, resulting in a musty smell. Increased ventilation can prove effective in improving the indoor air quality and will assist in reducing radon levels. However, only a marginal increase in ventilation is likely to be possible if the basement is regularly occupied. Simply opening windows would not be considered a sustainable solution, as the windows are likely to be closed up again during cold weather. Any significant increase in ventilation would need to be accompanied by increased heating during winter months.

In addition to considering ventilation of the basement it may be worth considering ventilation in the rest of the house. Poor ventilation practice can increase radon entry. You should avoid having a combination of well sealed or rarely opened windows downstairs, and poorly sealed or regularly opened windows upstairs, as this can increase the stack (or chimney) effect within the house, which results in radon being drawn into the house from the ground. Similarly, unused chimneys or unsealed loft hatches can increase the stack effect. Ensure that there are no deliberate vents cut through timber floors providing ventilation to combustion appliances such as open fires as these can be major radon entry routes. Such vents should be sealed and an alternative source of ventilation, such as a through the wall vent, provided. Combustion appliances must be adequately ventilated. (See also comments in Section D, option 3, on spillage from open-flued combustion appliances.)

Integral garages

It is common to find that part of the lower ground floor area forms an integral garage. Radon is more likely to enter the main occupied areas of the house through rooms in the semi-basement area than through the garage. This is because the garage is likely to be well ventilated. As a consequence, attention to radon entry routes should be concentrated within the occupied semi-basement area. The garage should not be totally overlooked however, as mechanical solutions can often be located within garages where noise will prove less of a problem. Likewise excavation work associated with sump systems can often be carried out from within the garage, thereby minimising disruption inside the house.

Choosing a solution

This section discusses the merits of the different solutions that are likely to be suitable for a house with a semi-basement or one of stepped construction.

Sealing to the lower ground floor area

Where the dwelling has low to moderate levels of radon (up to say 400–500 Bq/m^3), it may be sufficient to carry out simple sealing of the basement walls and floors (see option 1 in Section D). Unless you manage to seal major entry routes, to be effective all cracks and gaps found in the walls and floors need to be sealed. In practice this is difficult and time consuming to achieve. Cracks and gaps can be difficult to locate as they may be hidden by floor coverings, skirting boards or wall coverings. With partial semi-basements, upper ground floors will have to be sealed as well.

Large gaps or holes in suspended timber floors can, and probably should, be sealed. However, completely covering a timber floor with an impervious sheet such as polyethylene (polythene) sheet is not recommended; complete sealing of a timber floor could lead to timber rot.

Increased natural ventilation of the lower ground floor area

For low to moderate radon levels (up to say 400–500 Bq/m^3), increased natural ventilation of the basement or lower ground floor space may be a solution to consider (see option 4). This works by diluting radon within the basement. Natural ventilation can be introduced into the basement rooms through ventilators in basement windows, or by airbricks through the basement walls. As at least one of the basement walls will be exposed, the provision of natural ventilation should be fairly simple.

Care must be taken not to place ventilators where they are likely to cause an annoying draught to the occupants, for example in bedrooms and bathrooms.

Suspended timber floors at ground level may also benefit from increased natural ventilation. This can be achieved by installing airbricks to ventilate the underfloor void. If the underfloor void is open to the basement (see Figure 5) it may be sensible to close this to prevent radon seeping from the floor void into basement rooms.

Increased natural ventilation to the rest of the house

While improvements to the way in which a house is ventilated can help to reduce indoor radon levels, increased ventilation can affect indoor comfort, so this may not be the best solution. Nevertheless, for low levels of radon (up to say 400–500 Bq/m^3) it may be worth considering. Any changes to ventilation must be permanent; simply changing window opening patterns is unlikely to be sustainable in the long term. (See option 5.)

Increased underfloor ventilation

Suspended timber floors at ground floor level are often poorly ventilated. Increasing underfloor ventilation can help to lower radon levels and will help to reduce the risk of timber rot. For low to moderate radon levels (up to say 400–500 Bq/m^3), it is worth considering increased natural underfloor ventilation (see option 2). This can usually be achieved relatively easily, by upgrading existing airbricks or by providing additional ones. In a few rare cases the underfloor void is open to the basement. If this is the case you should block any openings between the basement and underfloor space.

For higher levels of radon or where it is difficult to provide increased natural underfloor ventilation, then it may be worth considering mechanical underfloor ventilation (see option 3).

Mechanical supply ventilation of the lower ground floor area

In cases where the size or layout of the basement is large, or the radon level is moderate to high (above say 400–500 Bq/m^3), natural ventilation may not be sufficient to lower the radon level adequately. In these cases a mechanical system may be more appropriate.

A fan can be fitted to blow fresh air into the basement to produce a slight increase in air pressure, which can make it difficult for radon to pass through gaps and cracks from the ground. The increase in air movement can also help to dilute radon that has collected. (See option 6.)

The increased air movement in the basement will cool the air, and therefore the fan should not be placed in any rooms which are to be lived in for long periods. To overcome the cooling of the air a heater should be fitted to the fan. Even with a heater fitted the fan may cause local draughts and so care should be taken not to fit this system where draughts will cause nuisance. However, increased air movement can help to dry out dampness within the basement, and may help to avoid fungal growth and timber rot, and thus may actually improve the condition of the basement.

As with all mechanical systems there is a risk of fan noise. To avoid this becoming a nuisance the fan should not be located in a noise-sensitive area.

Owing to the problems of heating the incoming air, this system should probably only be considered if a sump system is not a viable option.

It is unlikely that supply ventilation in the basement will reduce the flow of radon through adjacent ground floors. This is because the basement will generally be well sealed from the soil surrounding it. Therefore ground floors may have to have their own radon reduction system fitted. For suspended timber ground floors with low to moderate radon levels the solution may be to increase natural ventilation, or to install mechanical ventilation to blow or suck radon-laden air from the floor void. If the adjacent ground floor is solid the solution may be to seal the floor slab, or to install a sump system if radon levels are moderate to high. Alternatively whole-house positive pressurisation could be considered.

Mechanical extract ventilation is not appropriate for an occupied basement. This is because the depressurisation effect it will have could result in increased radon levels within the basement.

Whole-house positive pressurisation

This system can be used to reduce slightly the pressure difference between the dwelling and the underlying soil, or to create a dilution effect to the radon-laden air inside the dwelling (see option 8). This system may be enough to reduce the radon to acceptable levels. The slight increase in air pressure may be enough to make it difficult for radon to pass into the basement. However, unless the house is very airtight this is doubtful. It is usually only recommended for use with indoor radon levels up to about 750 Bq/m^3, although if the house is very airtight it might be effective with higher radon levels. This system may be an option to reduce radon in the ground floor of the dwelling supplemented by an additional system to reduce radon in the basement. An important advantage of using positive pressurisation is that it is simple to install.

Sump system
If the radon level is moderate to high (above 400–500 Bq/m^3) and the floor of the basement is of good quality, that is to say not severely cracked or made up of poorly jointed flagstones, the sump system is likely to be the most suitable option (see option 9).

For the sump system to work effectively there will need to be some permeable fill beneath the floor slab, although this will be difficult, if not impossible, to establish without investigation. Where the water table is above or at the same level as the floor of the basement, radon is likely to be entering through the walls rather than the floor. Installing a sump would prove ineffective as it would fill with water and prevent the flow of air through the soil. Therefore it would be appropriate to select another option.

If the sump is a viable option it can be located anywhere under the basement that is convenient. The benefit of this system is that sumps have been shown to be the most effective method of reducing moderate to high levels of radon to below the action level. The sump system will not greatly alter any of the indoor conditions within the basement or dwelling above, although care may be needed if a boiler or open-flued combustion appliance is used within the basement.

As the basement or lower ground floor is the lowest point in the dwelling it is best to locate the sump here. If there is permeable fill surrounding the basement walls and under the ground floor, a single sump should be sufficient to reduce radon entering through both the upper and lower ground floors of the dwelling. If this is not the case it may be necessary to install a second sump under the upper ground floor area. This can be manifolded to the basement sump, so that only one fan is necessary. Where there is insufficient permeability in the soil or hard-core, a second separate sump system may be required.

The exhaust pipework and fan unit can be located internally or externally depending on preference. Internal fans will need to be insulated to reduce noise, and the routing of pipework may need to be boxed in or carefully routed to avoid it looking unsightly. External fans can be boxed in to improve aesthetics, or can be hidden from view with plants.

As at least one of the basement walls is exposed it may be possible to install an externally excavated mini-sump system, which means all excavation work is done outside the dwelling, thus reducing upheaval to the occupants.

Replacement floor
If the basement or lower ground floor, or the upper ground floor, is in a very poor condition, for example severely cracked, you may consider laying a new floor (see option 10). The new floor should have a radon-proof membrane included to help to prevent radon passing through the floor slab. This will also double up as protection from damp penetration.

It is doubtful whether replacing a single floor will provide a significant reduction in radon levels. Therefore you should install a sump within the fill below the new floor. The sump can then be activated if radon levels remain high after the new floor has been laid.

Section D
Remedial options

Option 1: Sealing

Sealing gaps and cracks in walls

Walls can be sealed using gun-applied sealants or using sand/cement mortar. Typically, however, the walls within a cellar are poorly constructed or finished which results in many potential radon entry routes. For example, it is common to find that mortar joints are poorly filled, or have crumbled away over the years. Where this is the case more severe sealing work, such as tanking, rendering or plastering to the walls, would be required. This could also offer improved damp protection for the cellar. Unfortunately this work is likely to prove too expensive unless it is carried out as part of the works associated with the conversion of a cellar into a more usable space.

Where the cellar is situated beneath part of the house, it is common to find that the adjacent ground floors are of suspended timber construction. The problem then is that often the underfloor space is linked to the cellar by openings left between the floor joists which sit on top of the cellar wall. Where this is the case it may prove useful to seal the openings using brick or blockwork. However, it is important to ensure that if you do so you also ensure that the ventilation to the underfloor space is improved to replace any loss of ventilation previously provided through the cellar.

It is important not to seal up any openings that are intended to provide ventilation to the cellar, or to a combustion appliance such as a boiler, unless an alternative source of ventilation is provided. (See also comments in Section D, option 3, on spillage from open-flued combustion appliances.)

Sealing gaps and cracks in floors

- **In-situ concrete floors**
  Sealing of small gaps and cracks can usually be achieved using gun-applied mastic or bathroom sealants. Larger holes will first need to be filled using sand/cement mortar, expanding foam or similar sealant, and any subsequent shrinkage cracks sealed with gun-applied mastic or bathroom sealant. Other sealing such as sealing of the continuous joint between the floor and the wall, is likely to prove difficult and disruptive.
- **Suspended concrete floors**
  These are only likely to be found in relatively modern houses and are usually reasonably well constructed. Even so it is worth looking where services penetrate the floor, as simple sealing of large gaps around services can prove cost-effective.
- **Stone flag or brick paved floors**
  Sealing has to be confined to simple sealing of major gaps around services. Improved jointing between stone flags or brick paviors can help but is unlikely to give significant reductions in radon entry.
- **Suspended timber floors**
  Sealing of suspended timber ground floors with sheet materials such as polyethylene (polythene) sheet is not recommended as it can encourage timber rot. Sealing of major gaps, for example where services pass through the floor or where pieces of boarding are missing, should be carried out. Gun-applied or expanding foam sealants can be used for smaller holes.

In summary, it is likely that sealing of floors is only going to prove cost-effective if there are major gaps and cracks that can be easily filled.

Sealing gaps and cracks in cellar ceilings

If the cellar ceiling comprises nothing more than the open underside of the suspended timber floor to the room above, you will need to provide a ceiling. Providing a ceiling can prove advantageous in reducing cold draughts between the cellar and the occupied rooms above, but is likely to be expensive.

Whether or not the cellar has a proper ceiling it would be worthwhile sealing any large gaps in the floor above, such as around service entries or holes where past services have been removed. This can be carried out using gun-applied sealant, expanding foam sealant, or other void filler. However, if the floor above forming the ceiling is of timber construction, you should not completely seal it by covering with a polyethylene (polythene) sheet, as this could encourage rot in the timbers.

Sealing cellar access doors

The access door between the house and the cellar should be draughtstripped. Where there is simply an open doorway you should install a draughtstripped door. This is likely to have a major impact on the radon levels within the house, as well as reducing heat loss. Providing a door will also allow additional ventilation to be provided to the cellar without affecting comfort in the rest of the house.

Often it is not just the access opening itself that needs consideration. In many cases the stairway between the cellar and house is located immediately beneath the main staircase in the house. Usually the stairway is walled in with timber boarding fixed to timber framing, whilst the main stairs form a ceiling to the stairway. Both are likely to prove leaky. Complete sealing would be difficult to achieve. However, it is worthwhile sealing up any obvious cracks, gaps or holes.

Option 2: Increased natural underfloor ventilation

Where the radon level is only just above the recommended action level, say 200–300 Bq/m^3, a reduction to below the action level might be achieved by clearing obstructions from existing vents or airbricks. For higher radon levels, or where there are not enough vents, the installation of additional vents would be appropriate. This can be done through the external walls just below the floor.

You should ensure that the vents are installed above ground level, and to achieve this it may be necessary to use periscopic ventilators (see Figure 8). Remember that increased breaking out of the walls will be required to fit the periscopic ventilators.

Where vents are provided through cavity walls they should be sleeved. This is of particular importance where the cavity wall has been, or is going to be, insulated.

Ideally, the openings should be provided on at least two opposite walls, and should be large enough to give an actual opening of at least 1500 mm^2 for each metre run of wall. Where the timber floor is at lower ground floor level this may prove difficult to achieve. It may only be possible to provide ventilation along one side of the building.

Mechanical ventilation may need to be considered. Do not attempt to provide ventilation by cutting vents through the suspended timber floor itself; ventilation should always be provided beneath the floor.

Plastic louvred ventilators are preferable to clay airbricks, as they usually offer greater open area and fewer of them will be needed (see Figure 9). Replacing terracotta airbricks with the same overall size of plastic louvred airbrick is a convenient way of increasing the ventilation under a floor without the need to break out many new airbrick openings. Do not leave vents without some kind of vermin guard. Most ventilators are fitted with these – what must be avoided is simply leaving open holes through the walls.

When considering increasing the air movement beneath the floor, you should check whether services routed under the floor, particularly central heating or water pipes, could be put at risk from freezing. It may be necessary to insulate vulnerable pipework.

It should be noted that if increasing the natural underfloor ventilation proves inadequate to deal with radon, a further increase in underfloor ventilation could be achieved with the installation of an electric fan later.

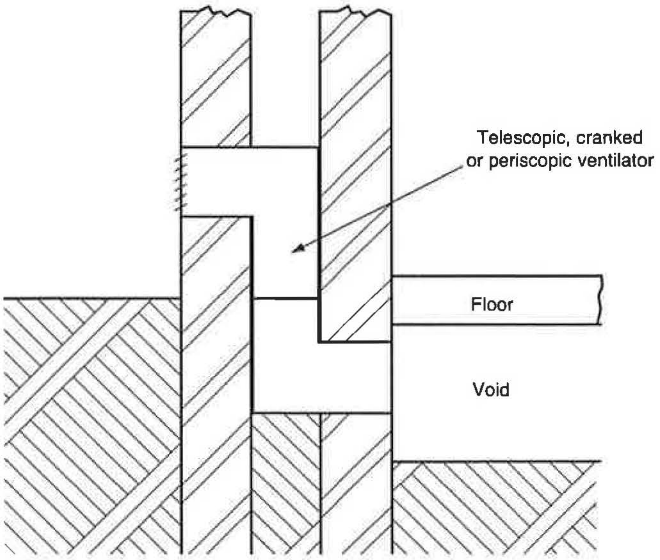


Figure 8 Telescopic, cranked or periscopic ventilator

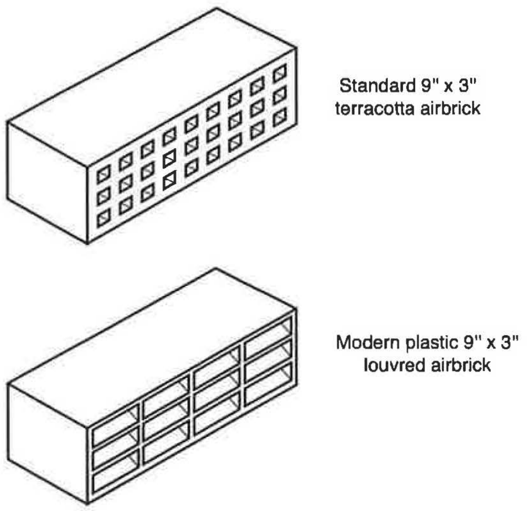


Figure 9 Types of airbrick ventilator

Option 3: Mechanical underfloor ventilation

Extract or 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 suck air from it (extract ventilation). Both extract and supply ventilation 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 involve exactly the same work: the only difference is the way in which the fan is mounted.

To a certain extent the decision whether to supply or extract will be determined by the cellar or basement. For example, if the underfloor space to be ventilated is at upper ground floor level it is important to find out whether the underfloor space is open to the cellar or basement. An increase in suction beneath the floor could inadvertently lead to more radon being drawn into the cellar or basement. It is important to ensure that ventilation of the underfloor space does not adversely affect the cellar or basement and vice versa. Obviously a small cellar or basement under only a small part of the house will have less influence than one which is located beneath most of the house.

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 or bedrooms, and away from windows or doors to prevent any extracted radon from re-entering the house (known as re-entrainment).

A typical underfloor ventilation system can be installed using an in-line-duct fan (see Figure 10). A hole is broken through an exterior wall and a length of pipe (usually PVC-U 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. (An alternative solution would be to use a wall-mounted axial fan, as shown in Figure 11.)

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. This can be done by constructing a weathertight box around the fan. The box will need to be vented to allow air to be supplied to, or exhausted from, the fan. The fan can be mounted beneath the floor and so hidden from view, but this is likely to increase the noise levels in the rooms above and make access difficult for maintenance or replacement. It may be possible to locate the fan within the cellar with air ducted to or from outside with pipework (see Figure 12).

Do not install fans near to airbricks. If an airbrick is too close (ie within 1. 5 m) to a fan that is extracting air from beneath the floor, air from outside can be drawn through the airbrick into the underfloor space and then recirculated to the outside by the fan. This 'short-circuiting' means that the system is unlikely to work effectively. If the otherwise ideal location for the fan is near an airbrick, the airbrick should be sealed.

The exhaust (or intake for a supply fan) can be at ground level, provided that rain-water cannot enter the system and it has a grille to prevent animal entry.

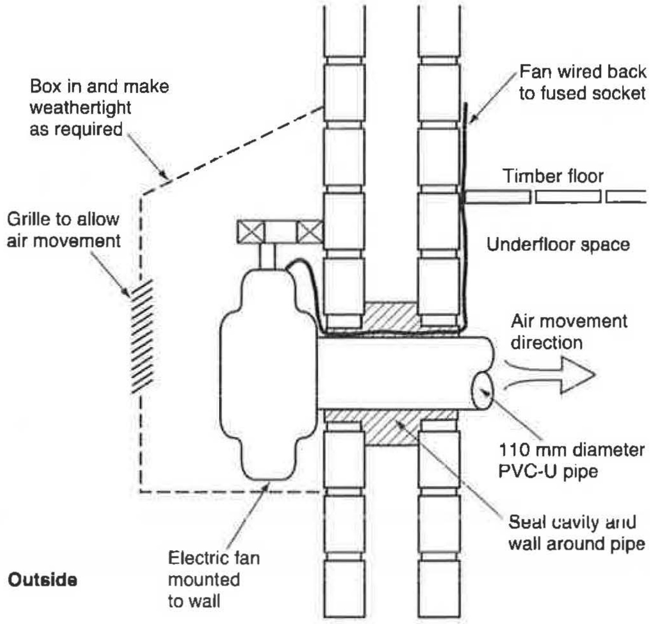


Figure 10 Mechanical supply ventilation with fan mounted outside

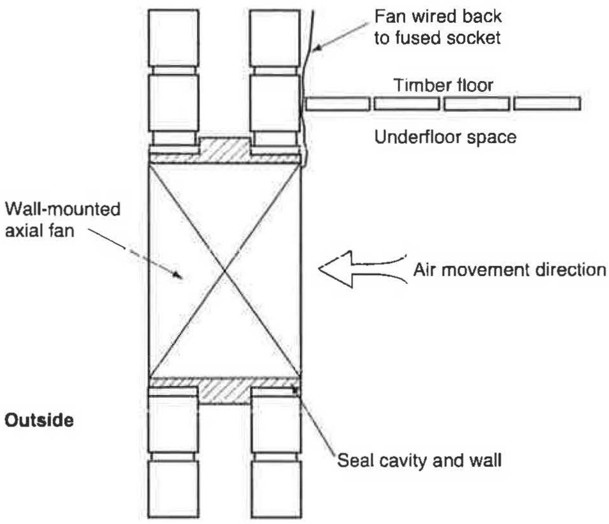


Figure 11 Mechanical extract ventilation with a wall-mounted axial fan

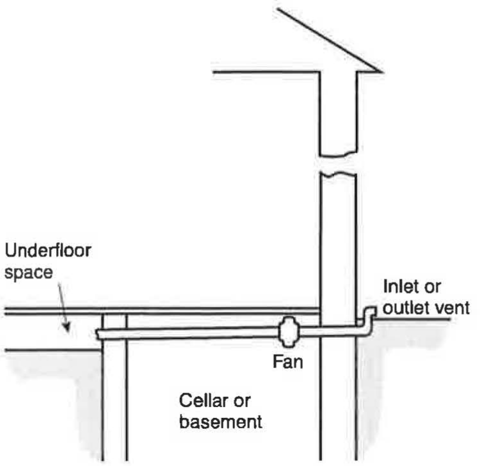


Figure 12 Mechanical underfloor ventilation provided by means of a fan and ducting located within cellar or basement

Alternatively, it can be above eaves level capped by a suitable cowl. Exhausts should always be positioned away from doors or windows to prevent re-entrainment, ie air from the fan re-entering the house. It is also prudent to keep intakes to supply ventilation systems away from doors or windows. 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 re-entrainment.

It is impossible to give a fan specification to suit all buildings or radon levels. For average-sized dwellings a single fan should be adequate. Ideally it should be weathertight and be able to run continuously throughout the year. 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 have an approximate power rating of 75 watts). At the time of writing some highly efficient fans are coming onto the market using high-efficiency brushless dc motor technology. These have the potential to offer the same airflow performance with greatly reduced running cost. Suitable fans of this type will be more expensive to buy but are likely to have a power rating of about 10 to 20 watts. The fan may be either axial or centrifugal. There is insufficient evidence to indicate which is best, but in principle 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. Performance of axial fans decreases significantly if they have to be connected to pipework. Because there is often a restricted amount of space beneath or at the edge of the floor, a centrifugal fan and pipe may be the only option.

Additional points to consider with mechanical underfloor ventilation

Frozen pipes

When considering increasing the air movement beneath the floor, you should check whether services routed under the floor, particularly central heating or water pipes, could be put at risk from freezing. It may be necessary to insulate or relocate vulnerable pipework, or do both.

Spillage from open-flued combustion appliances

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

If a room near the intended 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 system has proved unsuccessful in the past, an extract can still be installed, provided that steps are taken to prevent spillage. These precautions usually mean placing more underfloor airbricks opposite the fan, and providing an underfloor vent which links the appliance to the outside by means of an underfloor pipe, or providing a through-the-wall vent to the room with the combustion appliance. 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 supply ducted from outside (see Figure 13). Further guidance is available in BRE Good Building Guide 25 *Buildings and radon.*

Noise

The fan should be positioned away from noise-sensitive areas, such as living rooms or bedrooms, to avoid noise problems. Fans located beneath floors or within the cellar or basement may need to be fitted with a silencer. Further guidance on minimising noise from fan systems is available in BRE Good Building Guide 26 *Minimising noise from domestic fan systems.*

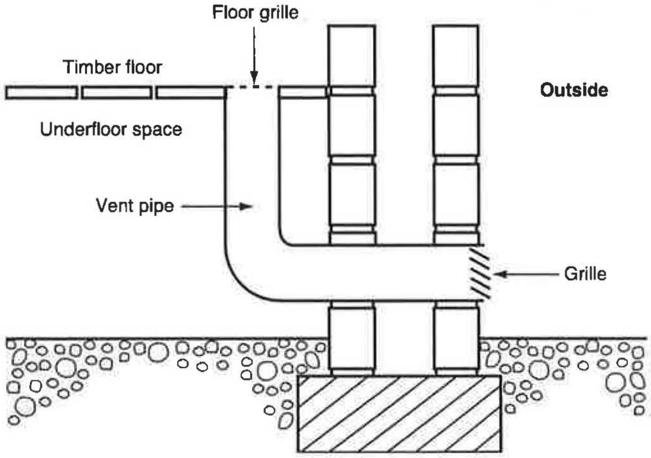


Figure 13 An underfloor ventilated air supply provides outside air to open-flued combustion appliances in living spaces

Option 4: Increased natural ventilation to cellar or basement

Increased natural ventilation can be provided to cellars and basements either by ducting the air from outside, in cases where the outside ground level is at the same or similar level as the ground floors in the house, or by installing through-the-wall vents or permanent vents in windows, where the cellar or basement is partially or wholly exposed to the outside.

When increased natural ventilation is provided, it is important to ensure that ventilation comes from outside the house not from the rooms above. Simply cutting vents in the floor above the cellar is likely to increase the amount of radon moving from the cellar into the rest of the house.

When considering increasing the air movement within a cellar, you should check whether services routed through the cellar, particularly central heating or water pipes, could be put at risk from freezing. It may be necessary to insulate or re-route vulnerable pipework, or do both.

There are effectively two routes which can be taken to duct air from outside down into the cellar: an external route or an internal route. To a certain extent it will depend upon the layout of the property and the ease with which the work can be carried out that will determine which route you take.

Externally ducted natural ventilation

Here the fresh air is ducted down the outside of the cellar or basement wall to enter through the wall (see Figure 14). Ducting is likely to comprise 110 mm diameter PVC-U plastic pipe which should be kept as straight as possible with the minimum number of bends. Alternatively, cranked ventilators could be used (see Figure 15). The advantage of routing the ducting externally is that much of the work can be carried out from outside. For a house with a cellar it means that the occupied part of the house does not need to be disturbed.

Internally ducted natural ventilation

In this case the fresh air is ducted from outside through pipework taken through the room above the cellar (see Figure 16). It is important to note that the air is taken from outside, not from within the house. Ducting is likely to comprise 110 mm diameter PVC-U plastic pipe which should be kept as straight as possible with minimal bends. Routing the pipework internally will be more disruptive inside the house but may prove easier to install than routing it externally.

Installing through-the-wall vents

Holes can be cut through external walls and airbricks installed to provide ventilation. If provided to a cellar, simple open airbricks will be adequate. However, with

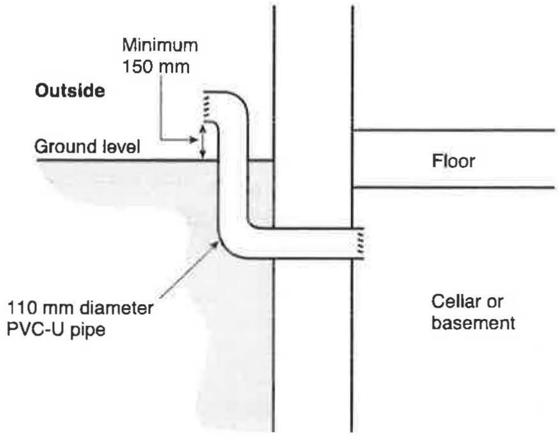


Figure 14 Externally ducted natural ventilation to cellar or basement

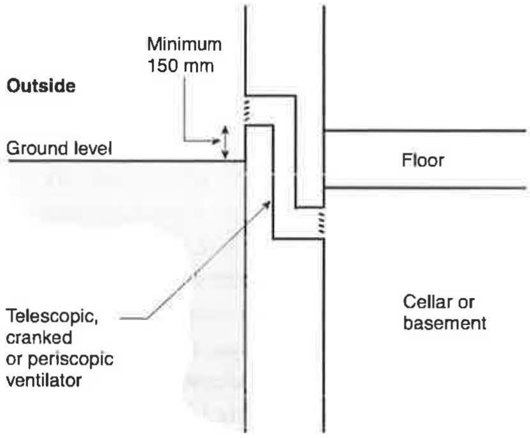


Figure 15 Natural ventilation to cellar or basement provided by telescopic, cranked or periscopic ventilator

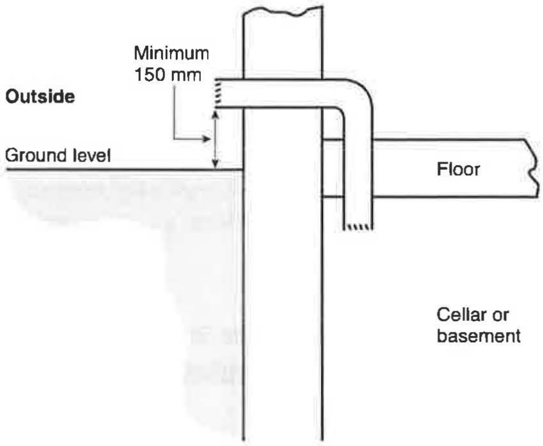


Figure 16 Internally ducted natural ventilation to cellar or basement

occupied basements the vents will need to be fitted with diffusers internally to minimise draughts. Plastic louvred ventilators are preferable to clay airbricks, as they usually offer greater open area and fewer of them will be needed (see Figure 9).

The cellar may already have some ventilation provided by terracotta airbricks. A first step to increase ventilation might be to replace the terracotta airbricks with the same overall size of plastic louvred airbrick. This can be a convenient way of increasing the ventilation without the need to break out many new airbrick openings.

To prevent airflow within wall cavities, vents provided through cavity walls should be sleeved. This is of particular importance where the cavity wall has been, or is going to be, insulated.

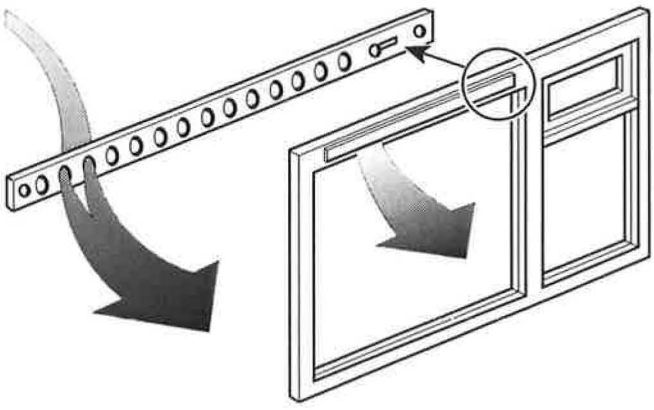


Figure 17 Trickle ventilator for windows

Installing permanent vents in windows

If the cellar or basement has windows along one or more of its walls, a convenient way in which to provide additional ventilation would be to provide permanent vents within the windows. Various proprietary vents are available that can be fitted into the glass of a window, or there are trickle ventilators that can be fitted into the window frame (see Figure 17). If trickle ventilators are to be installed they should be kept permanently open, to sustain the reduction in radon. Ideally they should not be too large, say 4000 to 8000 mm^2 free area per window, and are best located at the tops of windows to reduce draughts.

It is important to note that providing permanent ventilation does not mean simply leaving windows open. This would not be considered to be a sustainable solution: windows are likely to be closed for security reasons and during periods of cold weather.

Ideally vents should be provided on at least two sides of the cellar or basement. The exact number that can be provided will depend largely on whether it is a cellar or a basement that is being remedied, how large it is and its layout. When deciding where to locate the vents you should also consider how the solution might be upgraded if it does not prove wholly successful. The next step might be to install an electric fan over one of the vents (see option 7). It is therefore important to ensure that at least one of the vents is located so that a fan can be fitted later, should it prove necessary.

Option 5: Changes to natural ventilation of rooms above ground level

Recommended actions include installing trickle ventilators, capping chimneys and avoiding open fires, but these are likely to have only a modest effect on indoor radon levels. They should be contemplated on their own only in houses with radon levels close to the action level.

If trickle ventilators are to be installed, they should preferably be located in downstairs rooms. They should be permanently open, to sustain the reduction in radon. Ideally, they should not be too large, typically 4000 to 8000 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 ventilator with a minimum free area of 1000 mm^2 in the blocked-up fireplace.

If the house has an appliance fired by gas, solid fuel, or oil and it discharges into a chimney, make sure that there is an adequate supply of fresh air coming 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.

Ensure that the kitchen and bathroom extract fans are appropriately sized. An appropriate axial or propeller-type fan for a typical kitchen would be no greater than 150 mm in diameter, and for a bathroom or WC about 100 mm. Extract fans should not need to run continuously.

It is not uncommon to find vents cut into suspended timber floors. This has been done either to provide ventilation to a combustion appliance or to increase ventilation of the underfloor space. In both cases the vents can act as major entry routes for radon. They should therefore be sealed up and alternative ventilation should be provided above or below the floor.

When considering increasing the air movement within a cellar, you should check whether services routed through the cellar, particularly central heating or water pipes, could be put at risk from freezing. It may be necessary to insulate or re-route vulnerable pipework, or do both.

Option 6: Mechanical supply ventilation to cellar or basement

For full or partial cellars and basements where the outside ground level is at the same or similar level as the ground floors in the house, supply ventilation will need to be provided by ducting the air from outside. This can be achieved with internal or external ducting. For cellars and basements where at least one wall is exposed to the outside, supply ventilation can be provided by installing a fan in the wall or a window within the cellar or basement.

- **Externally ducted mechanical supply ventilation**
  Here the air is ducted down the outside of the cellar or basement wall to enter below the upper ground floor, with the fan mounted internally (see Figure 18). Ducting is likely to comprise 110 mm diameter PVC-U plastic pipe. The advantage of routing the ducting externally is that much of the work can be carried out from the outside. For a house with a cellar this means that the occupied part of the house does not need to be disturbed.
- **Internally ducted mechanical supply ventilation**
  In this case the air is ducted from the outside by pipework taken through the room above the cellar, with the fan located internally (see Figure 19). Ducting is likely to comprise 110 mm diameter PVC-U plastic pipe. Routing the pipeworking internally will be more disruptive inside the house but may prove easier to install than routing it externally.
- **Through-the-wall mechanical supply ventilation**
  In cases where basement walls are exposed to the outside it may be possible to install a fan within the wall. A wide range of through-the-wall fans is available.

To a certain extent the choice of how you provide supply ventilation is likely to be limited, but this should not affect the effectiveness of the solution. What is more important is to try to ensure that the fan and any pipework are located where they will offer the least noise nuisance and, for an occupied basement, minimal draughts. The fan and any pipework should be located away from noise-sensitive areas such as living rooms or bedrooms. In some cases you may need to consider providing a silencer to keep noise to an acceptable level. For aesthetic reasons it is usually desirable to locate the fan internally. However if this is not possible the fan can be located externally (see Figure 20).

With a regularly occupied basement you will almost certainly need to consider using a system that includes a heater or you may need to increase the level of regular heating. Similarly where the cellar is unoccupied you may need to increase the level of heating in the rest of the house to counter cold draughts.

It is impossible to give a fan specification to suit all buildings or radon levels. For average-sized dwellings a single fan should be adequate. The limiting factor is likely to be whether the space being ventilated is occupied. If it

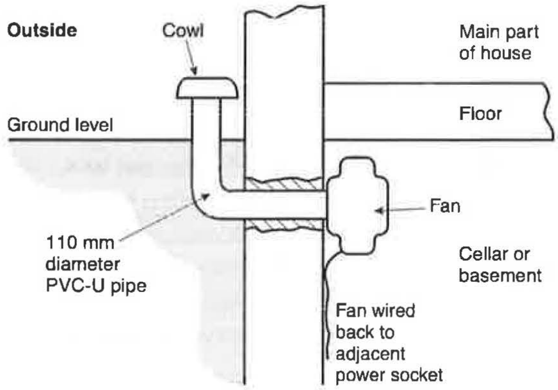


Figure 18 Externally ducted mechanical ventilation to cellar or basement, with internal fan

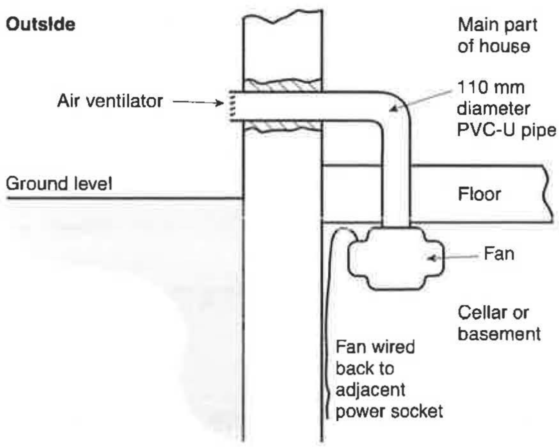


Figure 19 Internally ducted mechanical ventilation to cellar or basement, with internal fan

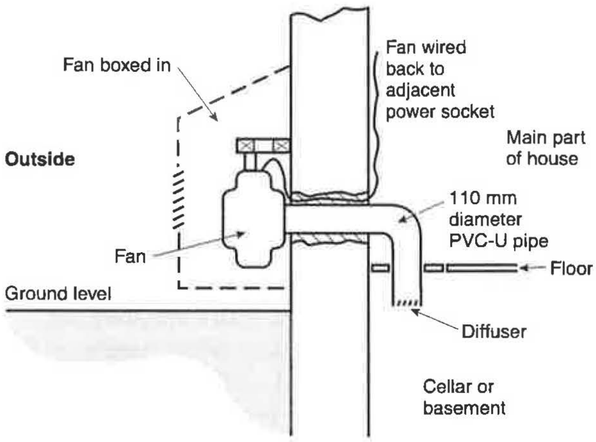


Figure 20 Internally ducted mechanical ventilation to cellar or basement, with external fan

is occupied then you will probably only be able to use a small fan in order to avoid draughts, otherwise use a fan as described in option 3. Whichever fan you use it should be able to run continuously throughout the year.

When considering increasing the air movement within a cellar, you should check whether services routed through the cellar, particularly central heating or water pipes, could be put at risk from freezing. It may be necessary to insulate or re-route vulnerable pipework, or do both.

It has been suggested that you might be able to blow air from the rooms above, down into the cellar to achieve a degree of pressurisation, without introducing cold air. In principle this might work if the cellar is located beneath the whole house. With a partial cellar or basement, or with a stepped house, it is possible that the effect of blowing air down from the room above would be to draw more radon-laden air into the house through floors on the upper ground floor level. There may also be a risk of condensation if the cellar or basement is unheated. Unfortunately we do not have any experience in practice with this approach.

Option 7: Mechanical extract ventilation from cellar

This solution is really only suited to use with unoccupied cellars. For full or partial cellars where the outside ground level is at the same or similar level as the ground floors in the house, extract ventilation will need to be provided by ducting the air to the outside. This can be done internally or externally. For full or partial cellars where at least one wall is exposed to the outside, extract ventilation can be provided by installing a fan in the wall or a window within the cellar.

- **Externally ducted mechanical extract ventilation**
  Here the air is ducted through the wall below ground level and up the outside of the cellar wall to just above ground level, with the fan mounted internally (see Figure 18). Ducting is likely to comprise 110 mm diameter PVC-U plastic pipe. The advantage of routing the ducting externally is that much of the work can be carried out from the outside, and the occupied part of the house does not need to be disturbed.
- **Internally ducted mechanical supply ventilation**
  In this case the air is ducted from the inside by pipework taken through the room above the cellar, with the fan located internally (see Figure 19). Ducting is likely to comprise 110 mm diameter PVC-U plastic pipe. Routing the pipeworking internally will be more disruptive inside the house but may prove easier to install than routing it externally.
- **Through-the-wall mechanical supply ventilation**
  In cases where basement walls are exposed to the outside it may be possible to install a fan within the wall. A wide range of through-the-wall fans is available.

To a certain extent the choice of which route is taken is likely to be limited, but this should not affect the effectiveness of the solution. What is more important is to try to ensure that the fan and pipework are located where they will offer the least noise nuisance. The fan and pipework should be located away from noise-sensitive areas such as living rooms or bedrooms. In some cases you may need to consider providing a silencer to keep noise to an acceptable level. For aesthetic reasons it is usually desirable to locate the fan internally. However if this is not possible the fan can be located externally (see Figure 20).

Increased ventilation within the cellar may lead to problems with draughts in rooms above, and the need to increase heating levels.

When considering increasing the air movement within a cellar, you should check whether services routed through the cellar, particularly central heating or water pipes, could be put at risk from freezing. It may be necessary to insulate or re-route vulnerable pipework, or do both.

It is important to appreciate fully the implications of mechanical extract ventilation applied to a cellar. Unless adequate vents are provided to allow air from the outside to be drawn into the cellar, it is likely that the level of radon within the cellar will increase dramatically. What this means is that radon is being drawn from the soil beneath the house to the cellar before being extracted to the outside. The result is likely to be an increase in radon level in the cellar but an overall reduction in the rest of the house. Provided that the cellar is only accessed on rare occasions for very short periods, this increase in radon level in the cellar should not cause concern.

With mechanical ventilation of the cellar you may find that you need to increase the level of heating you provide to the rest of the house to counter cold draughts.

It is impossible to give a fan specification to suit all buildings or radon levels. For average-sized dwellings a single fan should be adequate, as described for option 3. Whichever fan you use it should be able to run continuously throughout the year and be expected to last for many years.

Option 8: Whole-house positive pressurisation

Positive pressurisation is one of the least disruptive radon remedial measures to install. In most dwellings it involves cutting a hole in the ceiling of a hallway or stairway area, the rest of the installation being carried out from within the roof space. There is no need to lift carpets and little, if any, furniture need be moved. However, the installation needs to be done with care if the house pressurising fan is to perform acceptably.

A typical positive pressurisation system comprises a fan, sometimes with optional heater, connected to a ceiling diffuser by flexible ducting. To minimise potential noise problems fan units are usually provided with anti-vibration mounts, and to ensure that clean air is blown into the house the air intake will be fitted with a filter (see Figure 21).

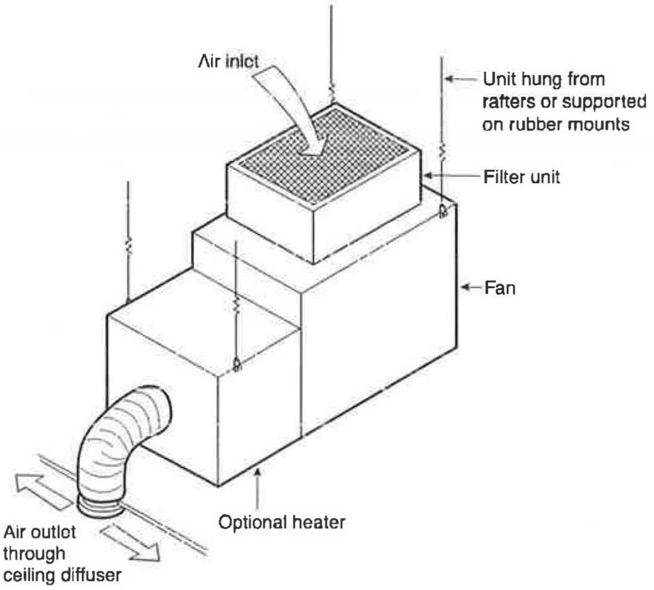


Figure 21 Typical positive pressurisation system

The main thing to decide is the location of the house pressurising fan and ceiling diffuser. These usually have to be quite close together, with only a short length of flexible duct between them. The location can be affected by the proximity of fixtures and fittings in the roof space, eg water pipes, water tanks, flues and structural timbers.

If possible, the diffuser should be positioned so that air travels across the ceiling for a distance of 1 m or more before striking a wall. If the diffuser directs air straight at a nearby wall, there are more likely to be problems with cold draughts.

It may be very difficult to find a suitable location for the fan unit and diffuser in dwellings with no roof space, eg those with flat roofs or rooms open to the roof. It is not advisable to locate the ceiling diffuser in living rooms or bedrooms: cold draughts, and sometimes noise, from the diffuser may lead occupants to switch off the fan unit.

For the system to work properly air blown down into the house must be replaced by air from outside the house. This should not be a problem in houses built since 1975 as roof vents should have been provided. Similarly, houses with no sarking boards or underfelt to the tiles (or slate) roof covering should be adequately ventilated. However, in older houses the amount of ventilation may need to be improved by providing additional roof vents.

Several manufacturers market positive pressurisation systems and can offer detailed advice and instructions on the installation of systems. Additional guidance is also available in BRE Report *Positive pressurisation.*

Option 9: Sump system

A simple mini-sump can be constructed by breaking out a hole in the concrete floor approximately 130 mm in diameter and excavating about a bucketful of fill from beneath the floor. Pipework comprising 110 mm diameter PVC-U is then installed and sealed around where it exits the sump (see Figure 22). A fan is then connected in the pipeline to exhaust to the outside. A simple internal mini-sump system is shown in Figure 23. However, the system can be adapted to suit most house layouts and construction types (see Figures 24, 25 and 26).

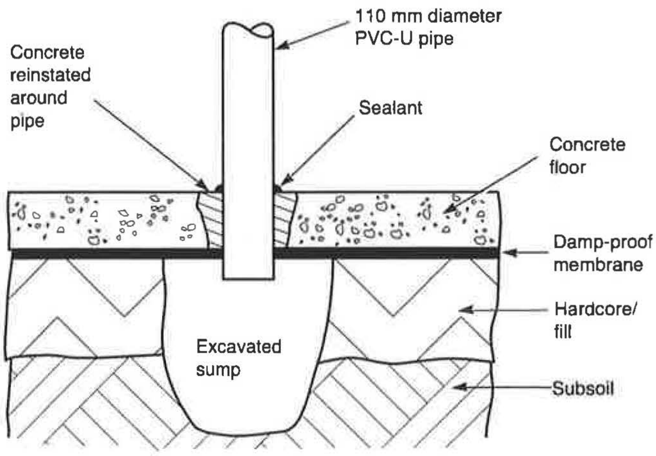


Figure 22 Mini-sump

Points to consider when installing an internal mini-sump system

Sump location

Ideally the sump should be located as near to the centre of the building as is practical. The exact location will depend upon the layout and location of the basement within the building. You may also need to take into consideration how the basement is used so as to avoid noise-sensitive areas. To a certain extent, how you have to route pipework will influence where you can locate the sump.

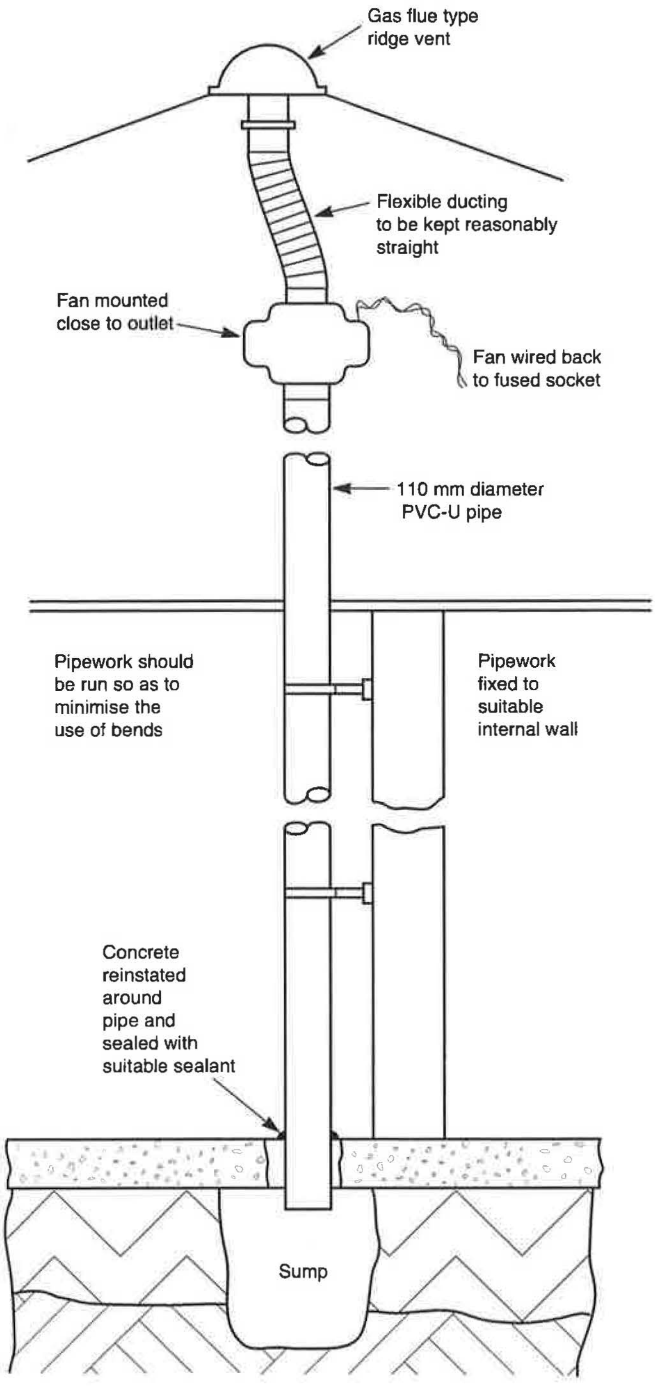


Figure 23 An internal mini-sump system

Fan location

The fan can be located internally or externally. The exact location will depend mainly upon the layout of the building and the need to avoid noise-sensitive areas. Typically the fan will only be located internally if the cellar, basement or lower ground floor area is not regularly occupied, or if it has an area such as a corridor or hallway in which noise is unlikely to pose a problem. Wherever the fan is located it can be boxed in to make it less obtrusive.

Fan type

Typically any non-stalling 'centrifugal in-line duct fan' with an airflow/pressure performance characteristic similar to that given below should prove effective. The

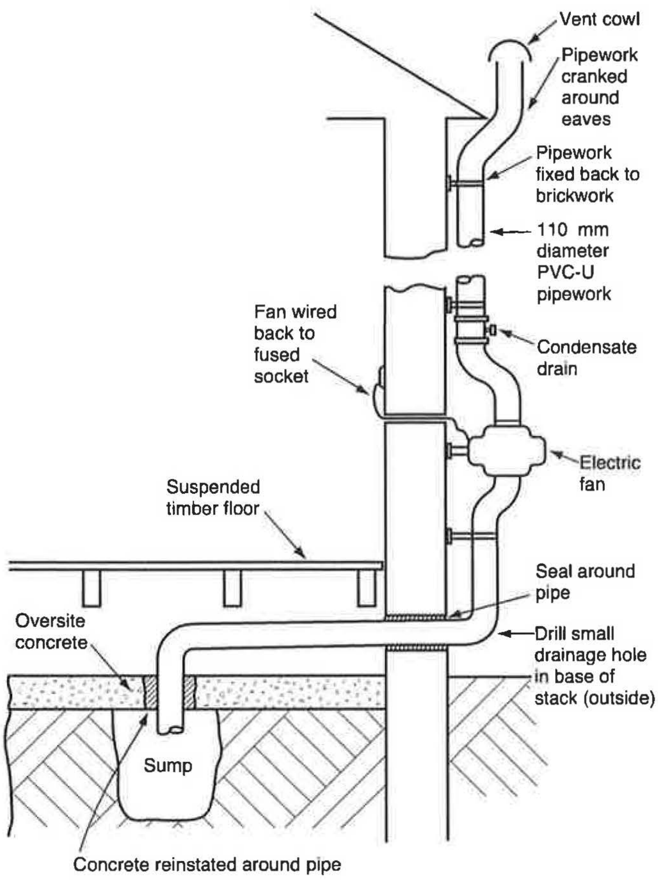


Figure 24 A mini-sump under concrete oversite with external fan and ductwork

fan should be able to work continuously at low flow rates and high pressure differences.

Flow rate (m^3/h)	400	350	300	225	175	100	0
Pressure difference (Pa; static)	0	50	100	150	200	250	300

Experience would suggest that the fan is likely to have a power rating of approximately 75 watts. However, lower-powered fans are becoming available, using high-efficiency dc motors with a power rating of about 10 to 20 watts, with similar airflow performance.

In a few cases it may be possible to route the exhaust pipework from the sump vertically up through the building to exhaust above the roof. Where this is the case and the radon level is low (say up to 400 Bq/m^3) it may be worth running the sump system passively first (ie without a fan, relying on the chimney effect to create sufficient negative pressure). If it fails to reduce the radon level adequately you can always fit a fan later.

Exhaust location

The system can exhaust at high or low level. Ideally it should exhaust at high level, typically just above the eaves. For aesthetic reasons this may be unacceptable, in which case a low-level exhaust can be considered. It is important to note that because the system can draw radon from a large area beneath the building, the amount of radon coming from the sump exhaust is likely to be

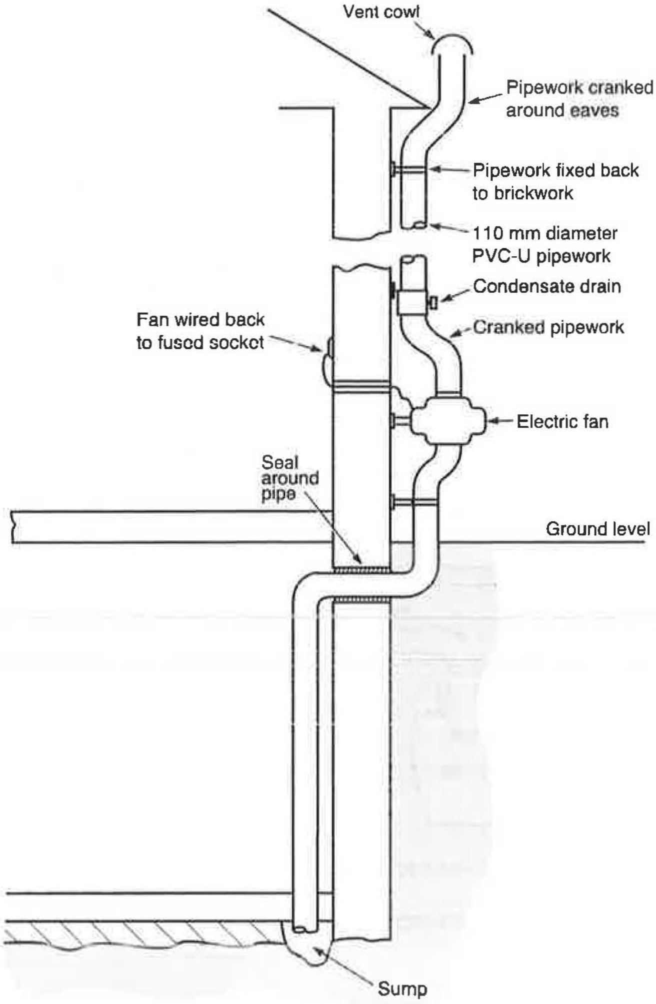


Figure 25 A mini-sump to a full cellar or basement with external fan and ductwork

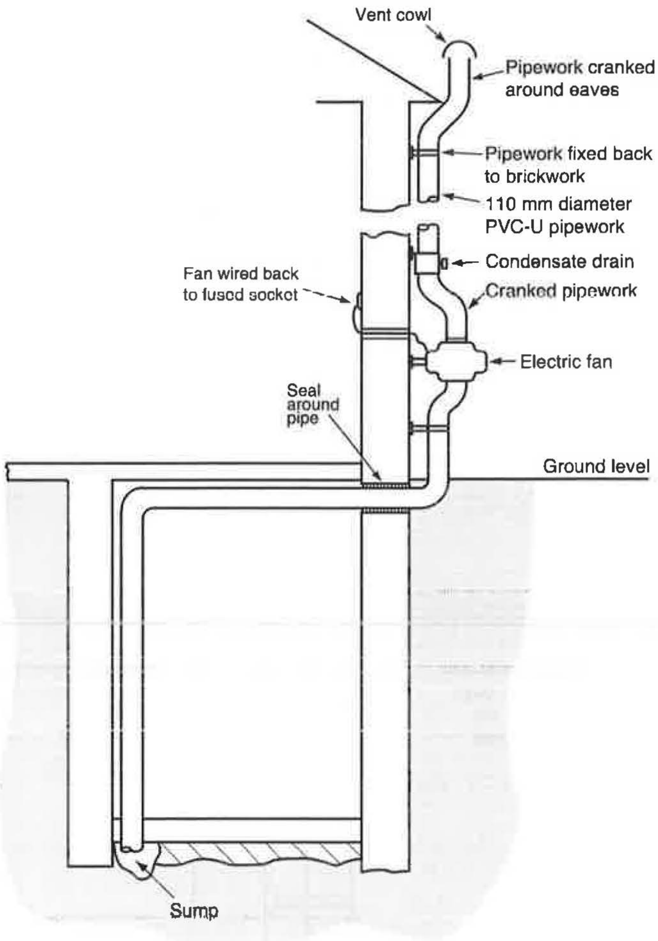


Figure 26 A mini-sump to a partial cellar or basment with external fan and ductwork

many times greater than that originally measured in the house. Therefore, to be acceptable it must not exhaust close to doors, windows or vents, or there may be a risk of re-entrainment (radon flowing back into the house).

Pipework location

The routing of pipework is likely to be dictated by the layout of the house and the position of the sump. Typically pipework will be of 110 mm diameter PVC-U pipe. As a consequence, where pipework is routed through occupied rooms it may need to be boxed in to conceal it. You may need to insulate the pipework in order to minimise noise. The pipework should be sealed around the point where it enters the sump to ensure maximum suction from beneath the floor. Pipework should be self draining to avoid condensation damage to fans and blockage due to condensate trapped in 'U-bends'.

Alternative sump systems

Wall sump

An alternative to a sump located beneath the floor of a cellar, basement or lower ground floor is to locate the sump in a wall, so that air can be extracted from the soil beneath an adjacent floor. A simple wall sump can be constructed by breaking out a hole in the wall approximately 130 mm in diameter and excavating about a bucketful of fill from beneath the adjacent floor. Pipework comprising 110 mm diameter PVC-U is then installed and sealed around where it exits the sump. A fan is then connected in the pipeline to exhaust to the outside. (See Figure 27.)

Externally excavated sump system

Where it is impractical to construct an internal sump, an externally excavated sump can be provided. It can be constructed from outside the building by breaking out a hole in the external wall just below ground floor level approximately 130 mm in diameter, and excavating about a bucketful of fill from beneath the floor. Pipework comprising 110 mm diameter PVC-U is then installed and sealed around where it passes through the wall into the sump. A fan is connected in the pipeline to exhaust to the outside. (See Figure 28.)

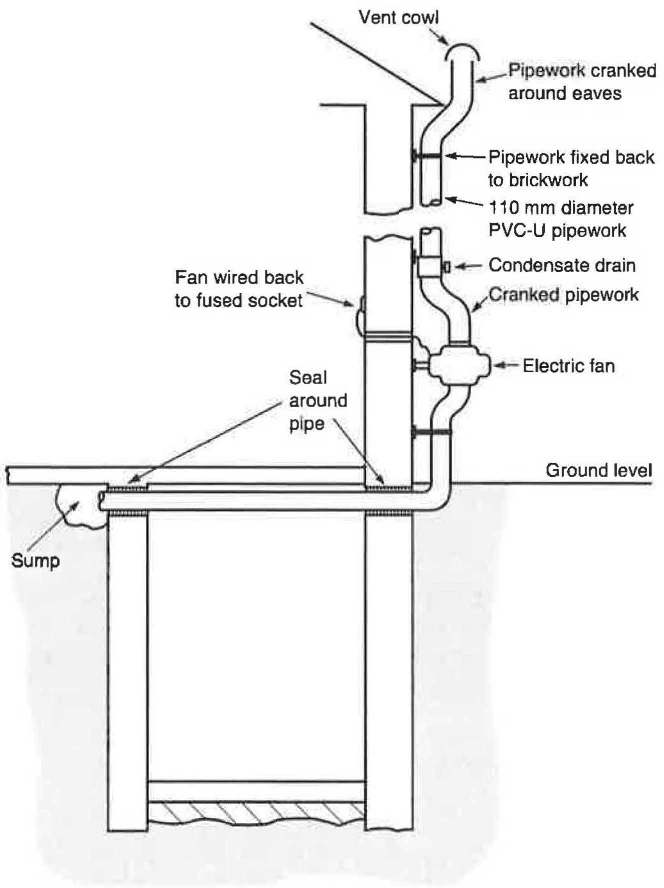


Figure 27 A wall sump system

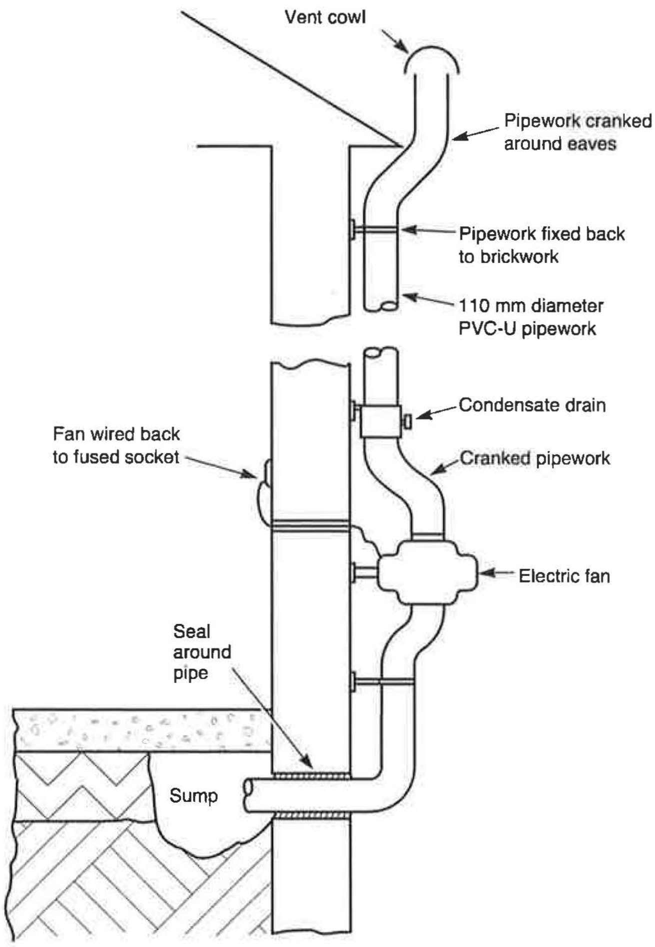


Figure 28 An externally excavated sump

Multi-sump systems

Sometimes, particularly with larger houses or bungalows, it may be necessary to install more than one sump system. Where this is the case it may be possible to connect the two sumps to a single fan so as to reduce installation and running costs (see Figure 29). If the house forms part of a pair of semi-detached houses or forms part of a terrace, a communal solution could be considered. In this case you could link sumps in each house to a common fan and exhaust, again reducing installation and running costs. Further guidance is provided in BRE Good Building Guide 25 *Buildings and radon*.

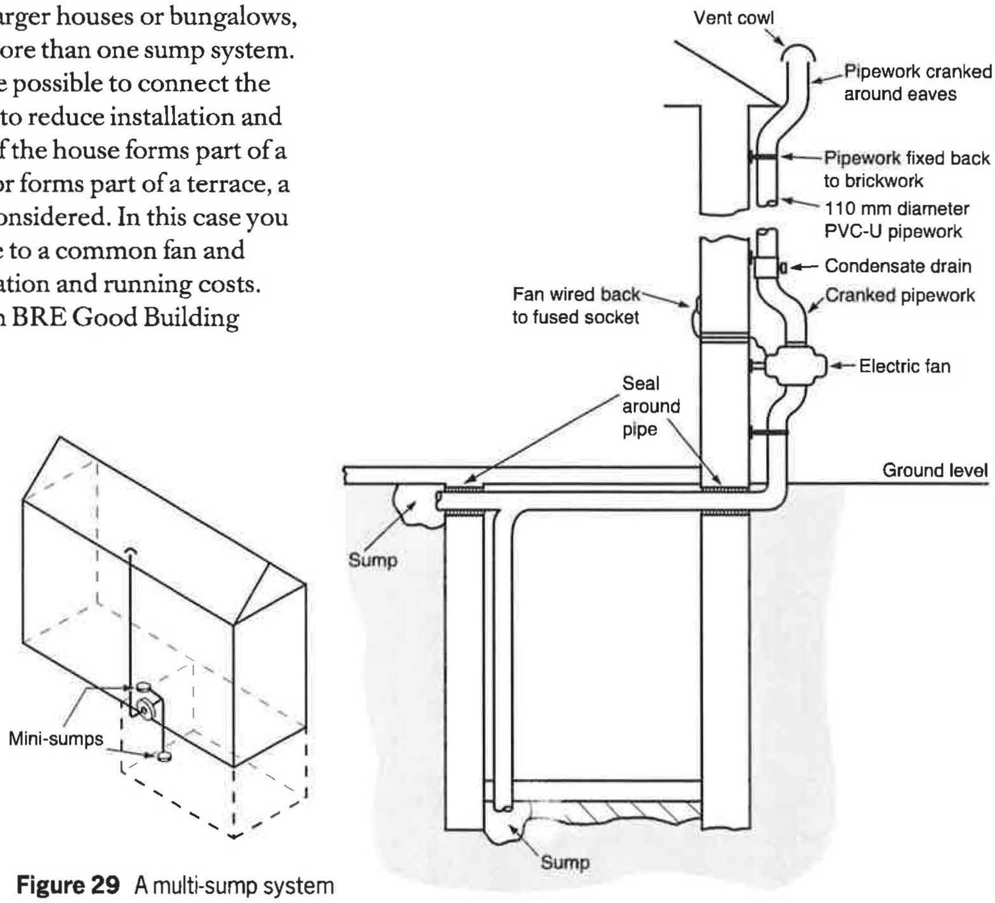


Figure 29 A multi-sump system

Other points to consider

It is usual to refer to a fan as sucking air from a sump. However, it has been found in some cases, particularly where the soil beneath the building is very permeable, that blowing air into the sump is more effective. But, as it is difficult to ascertain how permeable the soil is before installation it is probably best to install the system to operate in suction. If, on retesting, the radon level has not been adequately reduced, then you can try arranging the fan to blow into the sump.

Note the risk in some extreme cases where a house is airtight and has open-flued appliances or open fires, that a sump could draw flue gases back into the house. It is therefore recommended that you avoid locating a sump beneath a room with an open-flued appliance or an open fire and ensure that any required outside air supply to the appliance is present and is not blocked.

In very rare cases where a house needing radon remedial work is on or next to a landfill or old coal mine, additional precautions may be needed to deal with methane that rises from the site. If you have any reason to think that this applies to you, ring the local authority's Environmental Health Department to check. If there is a problem, you will be able to get expert advice from the BRE Radon Hotline by telephoning 01923 664707.

Option 10: Replacement floor

Where an existing floor is in poor condition and it is proposed to replace it with a new concrete floor, possibly as part of refurbishment works to make the space more habitable, you can consider radon protection at the same time. Consider the following points.

Additional sealing

You should provide a radon-proof barrier within the floor construction. This can be achieved using the normal 300 micrometre (1200 gauge) polyethylene (polythene) or other sheet material that is used for damp protection within the floor. You should, however, tape all joints in the barrier and around any services that penetrate the floor. In addition you could consider sealing the edge of the completed floor where it meets the walls. This can be done using a gun-applied bathroom sealant once the floor has cured. To a certain extent it is down to luck whether this work will solve the radon problem in a house, as radon might simply be redirected to enter elsewhere. As a consequence you should consider providing fallback measures such as a sump and extract pipe under the new floor.

Sump system

It would be relatively simple to include a sump beneath the new floor. This can either be as part of a complete system or you could install just the sump and pipework during replacement of the floor. This would allow you to retest the house to see whether the new floor on its own is enough to reduce the radon level before involving you in the expense of providing a fan. Experience would suggest that unless the radon level is relatively low, ie only just above the action level, the new floor on its own is unlikely to resolve the problem completely.

Further guidance is available in BRE Report *Major alterations and conversions*.

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More information

Further guidance on radon is available from:

- **BRE Radon Hotline** Telephone 01923 664707 (advice on remedial and protective measures for buildings)
- **NRPB Radon Freephone** on 0800 614529 or by post from the **National Radiological Protection Board,** Chilton, Didcot, Oxfordshire, OX11 0RQ (advice on radon risks and monitoring)

References and further reading

Department of the Environment, Transport and the Regions

Radon: a householder's guide. London: HMSO or DETR.
Radon: a guide to reducing levels in your home. London: HMSO or DETR.

Building Research Establishment

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Stephen R K. *Positive pressurisation.* BR281, 1995.
Welsh P A, Pye P W and Scivyer C R. *Protecting dwellings with suspended timber floors.* BR270, 1994.

Good Building Guides

GBG25 Buildings and radon
GBG26 Minimising noise from domestic fan systems and fan-assisted radon mitigation systems

Video

Radon, no problem. 1994.