Building Research Establishment Report

#10206

Surveying dwellings with high indoor radon levels:

a BRE guide to radon remedial measures in existing dwellings

C R Scivyer, MCIOB

Building Research Establishment
Garston
Watford
WD2 7JR

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

BR 250
ISBN 0 85 125 582 5

First published 1993

CONTENTS

INTRODUCTION

This Report is one of a series giving practical advice on methods of reducing radon levels in existing dwellings. It is aimed specifically at builders, surveyors and building specialists surveying for and prescribing remedial measures for dwellings. It supplements guidance available in *The householders' guide to radon*[1], obtainable from local environmental health officers or from the Department of the Environment.

The Report has been prepared on the basis of experience gained in remedial work on more than 100 dwellings following advice given by BRE, and of discussions with others in the field, notably the National Radiological Protection Board (NRPB) and Cornwall County Council. Work is continuing, particularly dealing with suspended timber floors, basements and ventilation systems. Results will be incorporated into revisions of this Report as they become available.

The Report offers advice for most construction situations. Inevitably, there will be situations where no obvious solution applies, and in such cases you should telephone the BRE Radon Hotline (0923 664707) for further advice.

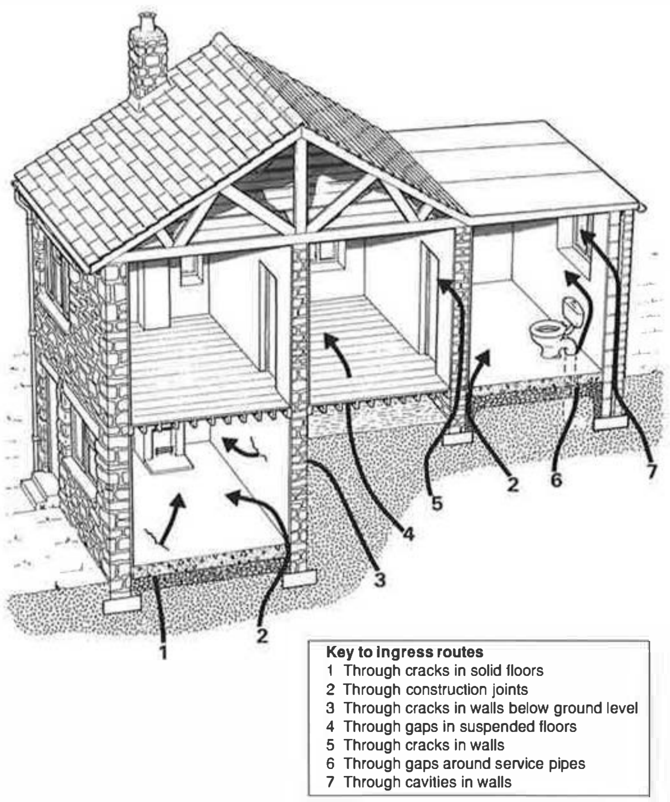


Figure 1 Routes by which radon enters a dwelling

BACKGROUND TO RADON

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. 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 low. Radon that enters enclosed spaces, such as dwellings, can reach relatively high concentrations.

The floors and walls of dwellings contain a multiplicity of small cracks and holes (Figure 1) formed during and after construction. The air pressure inside the dwelling is slightly lower than that outside, because of the heating of the dwelling and the effect of the wind. The fact that the air pressure in the soil is higher than that in the dwelling causes radon-laden air to flow through cracks and holes in the ground into the dwelling.

For further information on radon, contact the National Radiological Protection Board, Chilton, Didcot, Oxon, OX11 0RQ.

Measuring radon in dwellings

Before carrying out any radon remedial measures it is important to ascertain whether the dwelling actually does have a high radon concentration. The Department of the Environment suggests an action level of 200 Bq/m^3 for dwellings, and recommends that remedial measures be taken where levels are higher than this. The local environmental health officer will be able to tell you whether the dwelling is in an area with high radon levels. If it is, then the building itself should be monitored. Experience has shown that radon concentrations in adjacent buildings, even adjoining ones, can differ by as much as ten times, so measurement results from neighbouring properties are not reliable indicators.

Indoor radon levels can fluctuate from season to season, from day to day and by the hour. As a consequence, it is advisable to monitor radon levels over as long a period as is practical. The ideal is to monitor for three months using etch-track (plastic) detectors. The NRPB recommends that this be done before any remedial action is considered.

Although long-term monitoring is strongly recommended, short-term and instantaneous monitoring methods can be useful when surveying a building. However, the results must be treated with care. They are likely to be of limited value, as they will be greatly influenced by the weather conditions at the time of measurement. They should be used only by surveyors who have undergone relevant training. Those considering using short-term or instantaneous monitoring techniques are advised to seek advice from the NRPB.

The initial radon monitoring to provide a whole-house average should not be carried out in a basement or cellar, unless it forms one of the two main living spaces: living room or bedroom.

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, and further information can be found in a BRE Report on the subject[2]. In existing dwellings, remedial measures are necessary.

There are five main ways of reducing the amount of radon entering a house:

- Installing a radon sump
- Sealing
- Increasing underfloor ventilation
- Installing a positive pressurisation system
- Improving ventilation

They are not all suitable for all types of house, nor are they suitable for all levels of radon. The five methods are briefly described here, and then discussed in greater depth later in the Report. Each solution is accompanied by the typical radon reduction factors they can achieve.

A radon reduction factor is:

$$\frac{\text{Average radon level before carrying out work}}{\text{Average radon level after carrying out remedial work}}$$

For example, if the original radon level of 450 Bq/m^3 were reduced to 150 Bq/m^3, the reduction factor would be 450 divided by 150, which is 3. The reduction factor gives an indication of the likely effectiveness of a particular solution. So, to reduce the radon level in a house with a radon level of 800 Bq/m^3 to below 200 Bq/m^3 you will need to use a solution with a reduction factor of at least 5.

Radon sump
With solid floors you can reduce the pressure beneath the floor 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 existing level. For radon levels above 1200 Bq/m^3 it is likely to be the only solution. It applies mainly to solid floors, although a sump can be used with a suspended timber floor if there is a layer of concrete or membrane covering the soil beneath it. The average reduction factor is 19.

Sealing
You can seal the floor to prevent the radon getting through gaps and cracks. It 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. Sealing is not recommended for suspended timber floors. The average reduction factor is 2 to 3.

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. It is suitable for radon levels up to 700 Bq/m^3 using natural ventilation, and up to 850 Bq/m^3 with fan assistance. The average reduction factor is 2 to 3.

Positive pressurisation
You can pressurise the house with a fan drawing from the loft space or from outside. This method is again generally effective only at moderate radon levels, up to about 700 Bq/m^3. It is difficult by this means to reduce radon levels to much less than one-third of the original level. The average reduction factor is 3 to 4.

Ventilation
In some cases it is possible to change the way in which the house is ventilated, to avoid, as far as possible, drawing air and radon through the floor. However, as this depends on the way in which the occupier lives in the house it is not generally a reliable remedy. It may be suitable for radon levels up to 400 Bq/m^3. The average reduction factor is 2 to 3 (see also Figure 2).

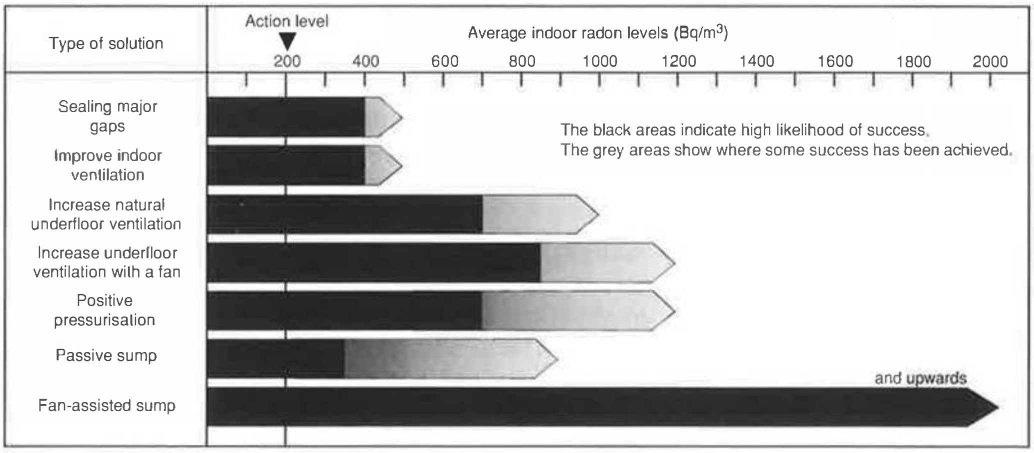


Figure 2 Guide to the likely effectiveness of solutions

SURVEYING A HOUSE WITH A RADON PROBLEM

It is important to find out as much as possible about the property being surveyed. The radon survey form and checklist in Appendix A will be useful as you gather information. The survey can be divided into two parts:

Background information

Construction survey

Background information

To be able to recommend the most appropriate solution for a property, you will have to carry out a survey of its construction. This will indicate what the building comprises. However, to understand fully how the house functions, you will need more information, much of which will be obtained only by speaking to the houseowner.

Before carrying out the construction survey you should consider the following points:

- Indoor radon level
- Type of property
- Existing knowledge
- Existing radon remedial measures
- History and geology of the site
- Site exposure
- Layout of property
- Existing condition of the property

Indoor radon level

You must know the indoor radon level before you begin. The level of radon to be reduced will, to a certain extent, dictate the solutions that can be considered. The houseowner should be able provide you with the radon level and confirm where the readings were taken.

Type of property

The type of property will influence the choice of remedial measures because, as with many construction problems, the more complicated the building the more difficult the solution is likely to be. A simple box-like structure, say a small two-storey detached house, is likely to be the easiest to deal with. For such a property there will be several appropriate solutions.

Unfortunately, from a radon point of view, houses are often more complicated than this. To make them more aesthetically pleasing, designers incorporate staggered floor layouts and other features. It is common in hilly areas for houses to be constructed with floors at various levels. In some cases these houses will have an upside-down room arrangement, with the living accommodation upstairs and the sleeping accommodation downstairs. Elsewhere, usually in older properties, there are other features such as basements. During its lifetime a house may be altered or extended. All these things compound a radon problem. Consideration should be given to neighbouring properties, especially where the house is part of a terrace or semi-detached. Some solutions can have an adverse effect on the next-door property, for example noise from fans or a system that increases the neighbours' radon level.

Existing knowledge

It is important to find out what information is already available. Always ask the houseowner what he or she knows about the history of the home. Over the years many alterations might have been made to the house. Extensions and changes to the internal layout can hide important construction details such as foundation walls, cellars and wells. Similarly, the replacement of services such as underfloor ducted warm-air heating systems may not be observed by the surveyor.

With more modern houses, ask the houseowners whether they have a set of drawings for the property. Drawings can be invaluable in identifying key features of the construction, such as foundation type, floor type, approximate location of services, and so on. It is also worth asking whether anyone knows who built the property. If the builders are still in business, they may be able to provide additional information. If the houseowner does not have a set of construction drawings, the builder may have a set. Also, the builder may be able to help to identify the routing of services, the type of sub-floor fill used, and other ground conditions.

You should identify whether the house was constructed using a proprietary or non-traditional system. Houses constructed using precast concrete panel, timber- or steel-framed systems are quite common. Systems should be identified to ensure that the structural integrity of the property is not impaired when radon protection measures are installed. A series of Reports[3] has been published by BRE in recent years giving general guidance on surveying non-traditional houses.

Existing radon remedial measures

When surveying a property, try to find out whether the householder has made any changes, either in lifestyle or to the building, since receiving the results of long-term radon measurements. This knowledge can help to explain the results from any instantaneous or short-term monitoring carried out as part of the survey. Inappropriate action by the householder may have increased radon levels, and should be noted.

Things to look for include:

Sealing of floors
Sealing around service entries
Increased natural ventilation
Mechanical ventilation
Positive pressurisation or sump system

History and geology of the site
Knowledge of the history and geology of a site may prove useful. Buildings constructed on made-up ground, for instance, may have fully reinforced floor slabs or be of raft construction. In such cases, take care not to impair the structural integrity of the building.

Houses built on the site of previous buildings may have complicated foundations, or thick floor slabs where the new floors have been laid over earlier ones. In such cases, you will need to give careful thought to the way in which any excavation work is carried out.

Past mining activity can affect the radon level in a building. There have been cases of buildings built over or alongside old mine workings. In such cases, sump systems may not be the best solution. The system may draw its air from the old workings, in which case it might not adequately depressurise the underfloor area. Reference to a mine survey could help to identify these buildings.

The type of soil beneath the dwelling can influence the level of radon within the dwelling, and may have a bearing on the effectiveness of some solutions. Clay soil or a high water-table often results in low radon transmission. However, this is not always the case. Some houses have both clay soil and a high water-table as well as having a high radon level. In such cases a sump system may not prove effective.

Site exposure
Try to gain some appreciation of the overall site exposure of the property. This will come from three sources: conversations with the houseowner, the builder's local knowledge, and on-site observations.

The information could be important for determining the type of solution and its location. Houses in exposed locations are likely to have better ventilation characteristics. However, this is not always the case. For example, an appropriate solution for a house on an exposed site, with a suspended timber floor, might be increased natural underfloor ventilation. From a radon point of view this is likely to be most effective. However, it might lead to lifting carpets and draughts within the house, so making it an unacceptable solution. Similarly, providing additional vents to the underfloor space of a house in a sheltered spot might bring little improvement in the underfloor ventilation.

Layout of the property
Look carefully at the layout of the house when planning radon remedial measures. This will be important when your are considering where to route pipework or where to locate fans or sumps. Things to consider include the location of built-in cupboards and existing service runs, the position of water storage tanks, and the location of rooms, both side-by-side and one above the other. Find out which rooms are used and for what purpose. It is preferable to keep fans away from bedrooms and other rooms which people expect to be quiet. Consider also the outdoor environment. Extract systems should not exhaust near to windows or doors, alongside areas like patios that people use a lot, or where there is any risk of annoying the neighbours. Consider also the shape of the building. Steps and staggers in the floor plan may help or hinder the location of radon reduction systems. Upside-down houses (with sleeping accommodation on the ground floor and living accommodation above) may pose additional problems.

Existing condition of the property
It is important to establish the condition of the property being remedied. This will help you to select the most appropriate solution and, probably more importantly, it can ensure that any existing defects in the property are identified. This can help to reduce problems later.

A typical example would be an inadequately ventilated suspended timber floor which is suffering from wood rot. Such a floor would benefit, both structurally and in terms of reducing radon levels, from the introduction of additional air vents. However, if the wood rot is not treated the floor could still fail at a later date. If the houseowner is not made aware of the rot problem before work is undertaken, then the builder may end up being wrongly accused of having caused the problem while installing the radon remedial measures. The same, of course, applies where any structural components such as walls are disturbed during remedial work.

Construction survey of the dwelling
The construction survey should be aimed at identifying likely radon entry routes and establishing how the building is constructed, while also considering what solutions might be appropriate and acceptable to the householder. The survey of the house will need to be thorough, but will be limited largely to parts of the house where the floors or walls abut the ground.

Before you can specify the optimum solution for a dwelling, you will need to survey a number of construction features:

- Ground-floor type
- Service entries and exits
- Walls
- Ventilation and heating
- Basements and cellars
- Stepped construction
- Wells
- Conservatories

Ground-floor type
As already stated, radon enters a building primarily from the soil below. The ground-floor construction is likely to have a major effect on the way the radon enters, and will influence the choice of remedial measure to apply. It is therefore important to ascertain

as accurately as possible the type of construction of the ground floor. There are four principal types of floor:

Solid
Suspended concrete
Suspended timber
Composite

In many houses a combination of several types will be found.

Solid floors

The construction of a solid floor will depend largely on its age. Originally, floors would have been made of packed earth. Later floors were made of bricks or stone or slate flags laid directly on the soil. Often the joints between the flags were filled only with soil. In the late 19th century the first in-situ concrete floors began to appear. They were not constructed like a modern concrete floor. Typically, they consisted of little more than a thin screed of concrete laid over the soil. Such floors were liable to severe cracking. In some cases the thin screed of concrete was topped with wooden blocks laid on a bed of bitumen. By the beginning of this century it was becoming more common for thicker concrete slabs to be used.

In recent years the in-situ concrete floor has been further improved to prevent the ingress of dampness. Typically, it comprises a layer of fill (usually crushed stone or clean hardcore), a damp-proof membrane (usually of polyethylene sheet), and a 100 mm to 150 mm layer of concrete with a sand/cement screed or timber topping. The latest floors may include some insulation, either above the screed, below the screed or beneath the slab (see Figure 3).

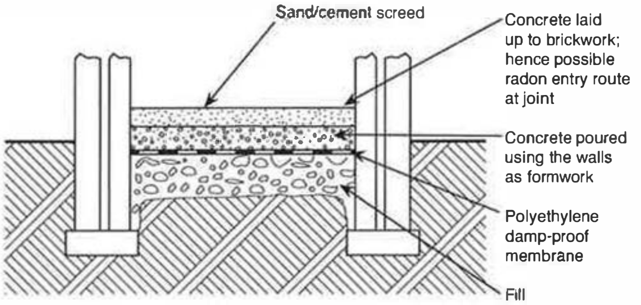


Figure 3 Typical modern in-situ concrete floor construction

Where there is a risk of subsidence, due to past mining, industrial or other activity, the floor may be of raft construction. A raft foundation is a concrete slab, thickened in a downward direction at the perimeter and at other positions where loadbearing walls are built off it. Rafts are often difficult to distinguish from ordinary solid floors. They can sometimes be identified by a concrete plinth running around the perimeter of the building immediately beneath the brickwork. However, it should be noted that it is common for the bottom courses of a blockwork wall to be rendered in such a way as to look like a plinth.

The characteristics of each type of solid floor will influence radon entry. For example, the earlier floors comprising a thin screed will be susceptible to cracking. Similarly, each joint in a stone flag floor is a potential radon entry route. Another more common feature with in-situ concrete floors, except where the floor forms part of a raft foundation, is that the slab is likely to have been laid within the perimeter walls of the building. As a consequence, there is always a joint gap where the wall and floor meet. Even with careful construction it is likely that when the concrete floor slab cures there will be a slight shrinking of the slab. This will leave a small gap all the way around the edge of the slab where it meets the external walls. Although the width of this gap is small, its total length around the house is large, so it represents a significant potential radon entry route.

Similarly, the floor slab is likely to have been broken into several bays for the purpose of construction, particularly in larger areas. Where this is the case, there will be daywork joints between the different sections of floor slab, and these too are potential radon entry routes. Floors formed as part of a raft foundation may have been constructed in stages. Therefore it cannot be assumed that because the floor is of raft construction it will not allow radon entry. Daywork joints are often obscured by screeds or other kinds of topping and door thresholds.

Where a concrete floor has been built on ground which is susceptible to movement, for example clay, then the concrete may have been reinforced to help to prevent cracking. In such cases there are unlikely to be problems with cracks in the bulk of the floor. Radon is more likely to enter through joints at the edges and through gaps around service entries and exits where they penetrate the floor. Identifying reinforced floor slabs becomes important when a sump system is to be installed. Ideally, any excavation should be kept to a minimum.

In most cases steel mesh will have been used for reinforcing. However, there may be areas, particularly with raft foundations, where the slab has been thickened to provide greater strength, and thicker bar reinforcement has been used. It is usually acceptable to make minor cuts in mesh reinforcement, but if more substantial reinforcement is found advice should be sought from a structural engineer before cutting.

Unless very detailed construction drawings are available, reinforcement is unlikely to be identified before excavation takes place. Therefore, if more substantial reinforcement is found when breaking out, it would be advisable to move the excavation sideways by 300 to 500 mm. This reduces the risk of affecting the structural stability of the floor. In addition, the slab is likely to be thinner at the new position, making it easier to excavate.

As with any remedial work, it is important to check that there are no services buried in the floor where excavation is proposed.

Suspended concrete floors

In recent years there has been a move towards the use of suspended concrete floors composed of reinforced concrete beams with concrete infill blocks (beam-and-block) (Figure 4).

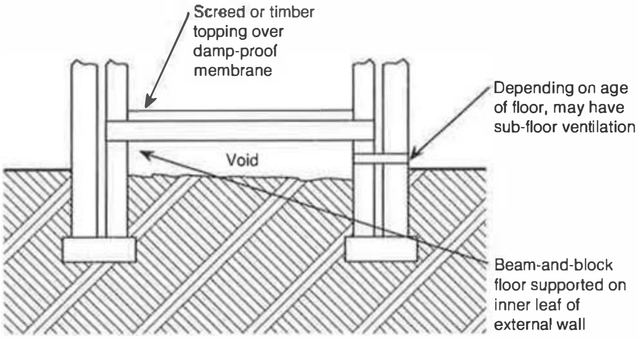


Figure 4 Typical suspended concrete floor construction

It is considered good practice for such floors to have underfloor ventilation. This has become a requirement for houses built to the standards set by the National House-Building Council (NHBC). As a consequence, many suspended concrete floors can be identified from the airbricks located around the perimeter of the building. Suspended concrete floors built earlier are less easy to identify and may be mistaken for solid floors. Similarly, suspended concrete floors are often topped with timber boarding (sometimes described as composite floors). It is therefore important to find out whether the houseowner has any details of the floor specification. As with solid concrete floors, radon might enter through gaps around service entry and exit routes. With beam-and-block floors, whole or half blocks may have been left out to provide for services, leaving large entry routes for radon.

Suspended timber floors

For the purposes of this Report a suspended timber floor is assumed to comprise timber boarding or other wood-based loadbearing sheet material, fixed to timber joists supported by or from the foundation walls. Timber floors which simply form the finish to a solid floor are discussed in the next section, 'Composite floors'.

Construction methods for suspended timber floors have evolved over many years, so the age of the floor can give an indication of the problems likely to be found.

Suspended timber floors built before the 1950s were typically constructed of plain-edged boarding. They are likely to have lots of cracks and gaps for radon to pass through. Timber is unlikely to have been treated with a preservative to reduce the risk of dry rot or any other kind of decay. Sub-floor ventilation was often inadequate and so did not prevent rotting, particularly if the ground beneath the floor was not covered to prevent moisture from the ground increasing the humidity under the floor.

More modern floors have been constructed using tongued-and-grooved boarding or sheet products such as chipboard. They are less leaky than their predecessors. More often the timber will have been treated with wood preservative. Underfloor ventilation is likely to be better and the ground beneath the floor has probably been capped with a covering of concrete, gravel-covered polyethylene sheet or (as is common in Scotland) a thin coating of bitumen (see Figure 5).

Once again, radon can enter via gaps around services entering or leaving the building through the floor. Timber floors probably suffer more from service

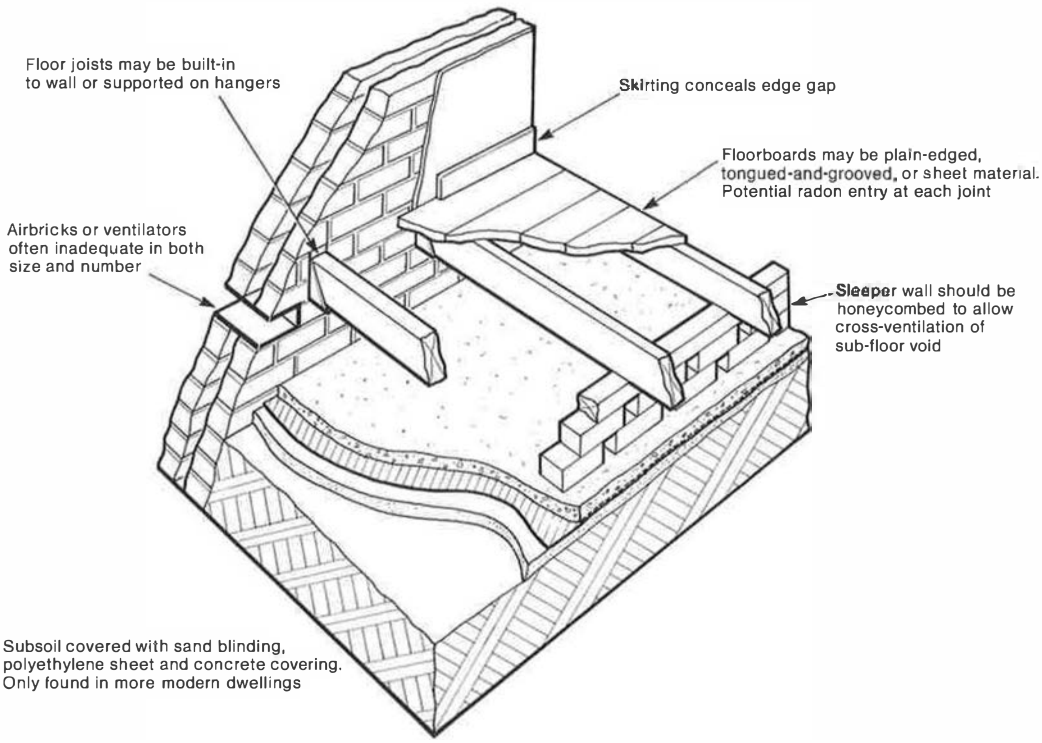


Figure 5 Typical suspended timber floor construction

entries than concrete floors do, as heating pipes are often routed beneath timber floors with penetrations for each radiator. It is also not uncommon to find vents cut into suspended timber floors. These are 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 means of ventilation provided above or below the floor.

When looking at a suspended timber floor, try to gain access to the underfloor space. Often you will find that somebody has had to gain access at some stage in the past, and that the houseowner can tell you where to find access panels hidden from view by carpets or furniture. Where this is not possible, an optical probe can be used. What you need to know is whether the ground has been capped with concrete. Also, the depth of the underfloor space can be determined to see whether it is possible to get under the floor to carry out work. Access will also allow the surveyor to establish whether internal walls and sleeper walls are honeycombed to allow through-ventilation. It may be possible to see whether there are any other communicating spaces, for example openings behind dry-linings, service ducts, openings around service entry or exit points. The structural condition of the timber floor can also be assessed. Unfortunately, most underfloor voids are too shallow to provide adequate access.

Composite floors
These usually comprise timber or other finish material laid over a structural floor of solid or suspended concrete. The drawback with such floors is that it is difficult to identify exactly what construction has been used without breaking open the floor. However, once the construction has been identified, the available solutions are likely to be the same as those described earlier for concrete floors (see Figure 6).

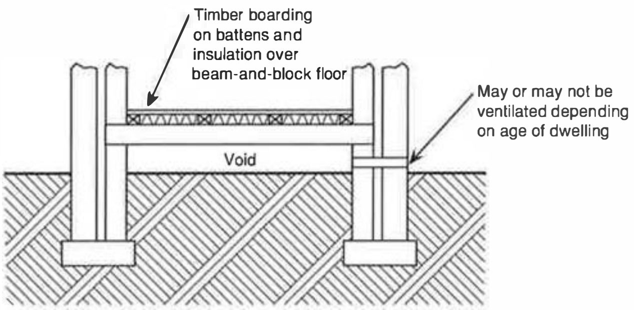


Figure 6 Typical composite floor construction

Mixed floor types
In many cases houses have more than one type of floor construction. It is quite common for the kitchen and WC to have solid concrete floors while the living room and dining room have suspended timber floors. Similarly, modern extensions are likely to have concrete floors. The combination of flooring will be determined largely by when the house was built and whether it has been modified or extended over the years. Houses with a mix of floor types are probably the most difficult to deal with.

Although it is possible to find a multitude of different combinations of flooring, two are particularly common:

- solid concrete floor/suspended timber with concrete covering the subsoil, and
- solid concrete floor/suspended timber with no concrete covering the subsoil.

In both cases it is likely that there will be underfloor vents on only one side of the house. This is frequently so in older, terraced properties.

Service entries and exits
Service entries and exits are mentioned at various places in this Report, but as they can be major radon entry routes they are worth considering separately. All services that penetrate floors or walls that are in contact with or adjacent to the ground, should be identified and checked to see whether they are adequately sealed. Services to consider include gas, water, electricity, oil, telephone, soil, waste, heating, and cable television.

It is common practice, when a concrete floor slab is constructed, to leave holes in the slab through which services can be routed later. Unfortunately, when the services are installed the holes are not always filled. Similarly, baths installed on the ground floor may have their water traps set down into the concrete slab. Often the excavation goes right through the slab.

Service penetrations are, of course, not limited to concrete floors. Timber floors as well as walls should be considered.

Typically, service entries are screened from view by cupboards, boxing-in or bath panels. As a result, they may be difficult to find, but because they can be major radon entry routes it is important to locate them and to seal around all services where they enter or leave the building. **Do not seal-up deliberately ducted vents such as BAXI-type air supply ducts.**

Walls
Although radon enters a building primarily from the soil below, through gaps and cracks in the floor, the walls may also contribute to the problem. It is therefore important to try to determine the construction of the walls and their finishes when surveying for radon. Both the type of wall construction and its location within the house can have an effect on radon entry. There are principally two ways in which radon can enter a building through the walls: vertically from the soil below via cavities, gaps or cracks in the wall, or horizontally from soil lying against the wall where the wall forms a retaining wall, as may be the case with a basement or a house dug into a hillside. Attempts to seal a wall are unlikely to prove effective in reducing radon levels, unless the wall forms part of a basement or stepped construction.

It is important to identify the wall construction also for the purposes of determining the type of measures that can be installed. For example, a solution which involves routing pipework through the wall or installing underfloor ventilators, may require you to break through thick walls, and may prove extremely expensive.

The type of wall construction will depend largely on when it was built and where in the country it is located. Wall construction can be divided into two types, solid and cavity. These can be loadbearing or non-loadbearing. Loadbearing walls are designed and built to support structural loads such as the roof or suspended floors within the building. Non-loadbearing walls, often of lightweight construction, are designed and built to divide or enclose the building without carrying any loads. In addition, the walls can be internal, dividing the space within the building, or external, enclosing the building (see Figure 7).

Solid walls
There are principally four types of solid wall:

Rubble-filled stone
Solid stone
Cob
Solid brick

Points to consider:

- The fill in a rubble-filled wall is often incomplete or will have settled, so there are many cracks and fissures through which radon can travel. Care is needed when breaking through a rubble-filled wall to avoid local collapse. Because of the irregular sizes of the pieces of stone, an oversized hole will probably be necessary. This will obviously need additional making good.
- Where you have to make holes to take pipework through stone walls, drilling may be appropriate, although experience has shown that drilling can prove expensive, and some drilling equipment may not be able to cope with rubble-filled walls.
- Again, when cutting through cob, great care is needed to prevent local collapse of the wall. With cob it is also important to ensure that any penetration is made good afterwards, to prevent moisture ingress. Excessive moisture ingress could lead to collapse of the wall.

Cavity walls
The main types are:

Brick/block
Block/block
Brick/brick
Stone or reconstituted stone/block
Timber frame
Prefabricated system

Points to consider:

- As part of any radon mitigation system, it is important to ensure that the cavity is sealed around any pipework that penetrates the wall. This is to prevent movement of air in the cavity instead of under the floor.
- The cavity may have been filled with insulation material during or after construction. Where this is the case, it is important to ensure that any insulation material disturbed during installation of radon remedial measures is fully reinstated to prevent damp problems (see later section on 'Wall insulation').
- With timber-framed walls, give some consideration to maintaining the integrity of the vapour barrier within the wall.

Prefabricated wall systems are found most often in dwellings originally constructed for local authorities, but also in privately funded dwellings. They include prefabricated concrete systems made up of concrete planks or wall-sized panels, and steel-framed houses which come in a variety of different forms. Because it is important to avoid causing structural damage, it is a

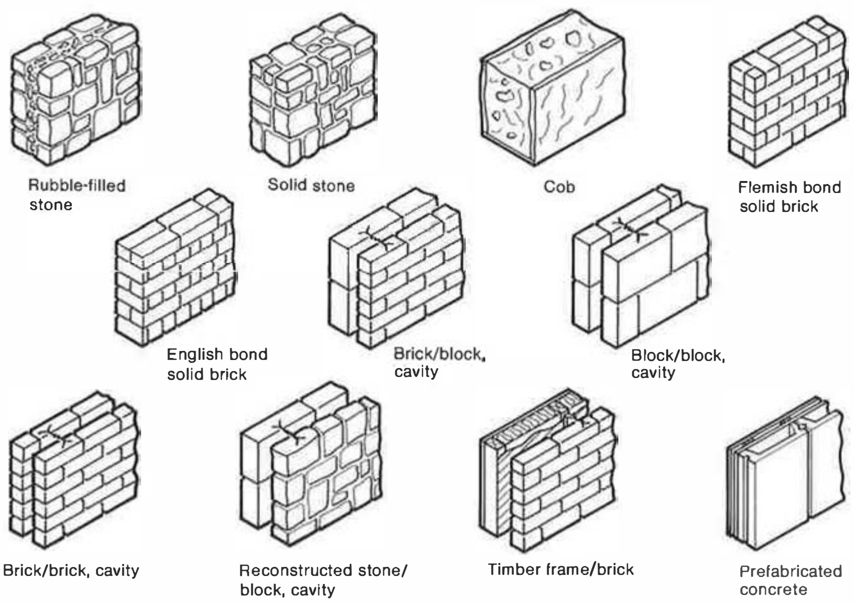


Figure 7 Generic wall types

good idea to seek advice before breaking through walls of prefabricated construction. In recent years BRE has prepared a series of Reports giving advice on structural surveying of non-traditional housing systems[3].

Retaining walls
The retaining walls of dwellings with basements, or those which have been dug into sloping ground, should be examined for likely radon entry routes. With more modern properties damp-proofing measures are likely to have been incorporated into retaining walls. In such cases the damp protection may act as a reasonably good barrier to radon. This will certainly be the case if the wall has been fully tanked with asphalt. The houseowner may have drawings which show this. In older houses it is likely that retaining walls, particularly in basements, will not have any damp protection and that it will be expensive to rectify the situation. It may be worth considering sealing basement walls if the householder intends to inhabit the basement regularly. However, from a radon point of view, other solutions are probably more appropriate (see later sections on 'Basements and cellars' and 'Stepped construction').

Internal walls
Surveying internal walls and internal finishes to external walls can prove difficult, particularly in older properties. However, it can be extremely important when you are trying to understand how radon enters and moves around a building. It is common for external walls to be finished internally with a dry-lining of plaster and lath or plasterboard on battens. Radon entering the building through gaps at the joint between the wall and floor can travel up the void at the back of the dry-lining. Any remedial measures would need to take this into account. For example, there would be no point in sealing the joint between the floor and the dry-lining, as radon would still be able to travel up the back of the dry-lining. It is also quite common for services to be boxed-in or located within hollow partition walls. Where the services penetrate the floor, radon can enter and travel up inside the service ducts.

Wall insulation
Walls can be insulated in various ways. In more modern homes, insulation material is built-in during construction. In older houses it is installed later, either as a blown cavity fill or fixed externally and rendered. It can be difficult to identify insulated walls, but the houseowner may be able to help. From a radon point of view, the type of insulation is important only if the wall has to be penetrated to install a radon reduction system. If that is the case, and the insulation material is board or quilt, it should be carefully cut to minimise damage. Where a loose blown fill has been used, you will have to ensure that a minimum of insulation material falls out of the wall. Any shortfall should be made up. This can be achieved by using an expanding polyurethane foam. It is important to avoid leaving gaps in the wall insulation, to prevent damp problems.

Wall finishes
How a wall has been finished can give a clue to its construction. Unfortunately, it can also hinder identification. In exposed locations, external walls may have rendering or stucco covering the outer face, with dry-lining on the inner face. Dry-lining usually comprises plaster and lath or plasterboard on battens fixed to the internal face of the external wall.

Damp-proof courses
The position of damp-proof courses should be identified, so that radon remedial measures can be designed to avoid them. Where it is impossible to avoid damaging the damp-proof course, you should make provision for reinstating it afterwards.

Ventilation and heating
In addition to surveying the structure of the house, it is important to consider the way in which it is ventilated and heated. Obviously, houses need to be ventilated to get rid of normal household pollutants such as cooking smells, cigarette smoke and excess water vapour which can lead to condensation and mould growth. Obviously, too, houses need heating. However, poor ventilation and heating practice can actually increase the amount of radon entering the house, so during the survey you should pay particular attention to the following (see also Figure 8):

- *Windows*
  Look for a combination of ground-floor windows that are well sealed or rarely opened, and upstairs windows that are poorly sealed or left open for prolonged periods.
- *Extract fans*
  Check whether extract fans are used for prolonged periods in kitchens, WCs or bathrooms. Look for oversized extract fans. Extract fans, appropriately sized and used for short periods, are unlikely to contribute greatly to radon problems unless the house is particularly airtight. An appropriately sized axial or propeller-type fan for a typical house should have an impeller no greater than 150 mm in diameter. Extract fans should not need to be run continuously.
- *Chimneys*
  Find out whether open fires are used, especially with unrestricted chimneys; also whether unused chimneys are left open.
- *Loft hatches*
  Look for poor sealing around loft hatches and around services entering the roofspace through the ceiling.
- *Sub-floor ventilation*
  Inspect timber floors to see whether vents have been cut in them. As discussed earlier, adequate ventilation of underfloor spaces should be provided. Regardless of radon, it is important with suspended timber floors to minimise the risk of rot. The existing underfloor vents should be located. You

will often find they have been obstructed by vegetation, soil or items such as garden furniture or piles of logs. In particularly exposed locations it is not uncommon to find that the householder has deliberately blocked the vents to reduce draughts indoors. In some cases, the ventilators may have been fitted with sliders so that they can be closed during windy weather. Often these seize up, obstructing the airflow. Many older houses or those in exposed locations have minimal ventilation provided. If vents have been cut in the timber floor in an attempt to improve the circulation of air, these can be major radon entry routes.

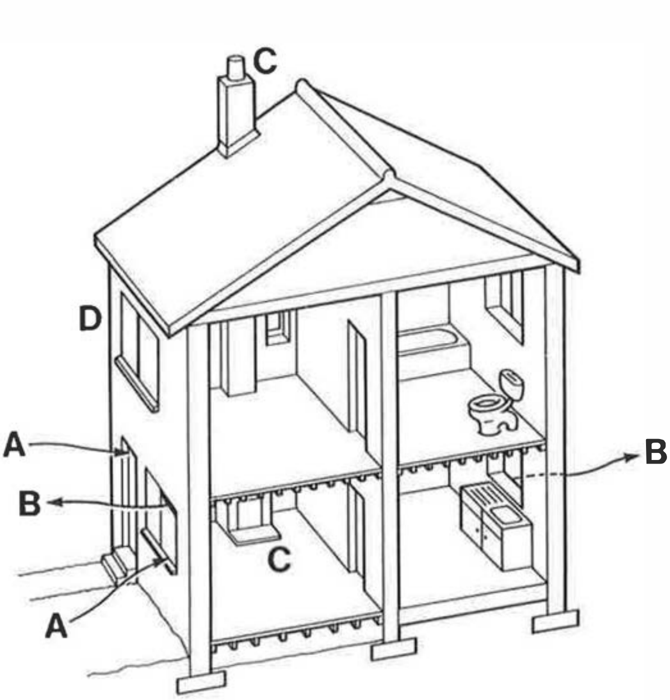
- *Redundant heating or ventilation systems*
  Heating ducts routed through the solid concrete floors of houses with ducted warm-air systems. Such systems are usually built-in when the floor is cast. It is therefore common for the ducting to be laid directly on the fill beneath the floor. The ducting itself is often loosely jointed, which means that radon has an easy route into the house. The action of blowing warm air through the ducting may also help to draw the radon in. Ducted warm-air heating systems have in recent years gone out of favour, so when they need to be replaced, alternative forms of heating may be installed. The old ducting and ventilation grilles are simply left in the floor. Although no longer in use, they can still provide an easy entry route for radon. By sealing the ventilation grilles and installing a fan, it may be possible to use the ducting as a sump system.

Basements and cellars

Houses with basements or cellars are relatively uncommon in the United Kingdom, usually being found only in older properties. Wherever they do occur, they are likely to be major contributors to the radon problem. There are a number of reasons for this.

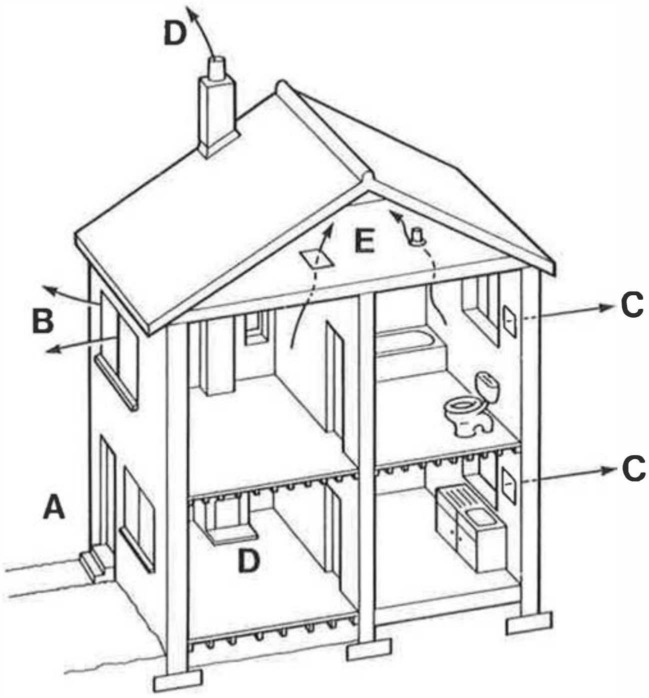
- The walls and floor of a basement are directly in contact with the ground. So, for a house with a basement beneath the whole of its ground floor, the area of the building in contact with the ground is probably three times that of a similarly sized house without a basement, and the potential for radon entry is far greater.
- Basements are often little used and poorly finished. The walls in particular often feature a myriad 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.

When carrying out a survey for radon it is important to ascertain as accurately as possible the construction of the basement walls and floor. In addition, the exact location of the basement beneath the house should be established. In many cases it extends under only part



Good ventilation practice will help to limit radon entry

A Leave some cracks around doors and windows, use ground-floor windows for ventilation
B Fit trickle ventilators in ground-floor windows
C Cap-off and seal up unused chimneys
D Seal cracks around first-floor windows.



Poor ventilation practice will increase radon entry

A Ground-floor windows sealed
B First-floor windows unsealed
C Extract fans used for long periods
D Use of open fires especially with unrestricted chimneys, unused chimneys left open
E Poor sealing around traps and pipes in roof

Figure 8 Good and poor ventilation practice of the house; in other cases it extends beyond the main walls of the house. An example of the latter is where a coal hole is located beneath the pavement at the front of a town house.

As mentioned earlier, the initial radon monitoring carried out to provide a whole-house average should not be carried out in the basement, unless it forms one of the two main living spaces: living room or bedroom.

Stepped construction
It is quite common, particularly in hilly areas, for houses to be dug into sloping ground. In such cases any walls that are in contact with the ground should be considered as likely to allow radon entry. In more modern properties damp-proofing measures have probably been incorporated into these retaining walls. In such cases the damp protection may act as a reasonably good barrier to radon. This will certainly be the case if the wall has been fully tanked with asphalt. The houseowner may have drawings which show this. In older houses it is unlikely that damp protection will have been applied, and it will be expensive to rectify the situation.

Wells
These are really of interest only if they are located within the house. Where this is the case, they are likely to be a major radon contributor. There are two reasons for this. First, the water in the well may contain high concentrations of radon. For information on radon in water you should contact the NRPB (address in section on 'More information' page 19; see also page 1). Secondly, the total area of the side of the well in contact with the ground may prove to be as great as the overall floor area of the house. It may be possible to deal with the problem by treating the well as a sump.

Conservatories
Although for planning and building control purposes there are no specific requirements for conservatories, they can play a part in influencing the radon level in a house. It is unlikely that the main point of entry for radon will actually be in the conservatory, so measures are best applied to the house first.

There are several points to look out for when surveying for radon remedial measures.

- If the conservatory is built on to a house which has a suspended timber ground floor, it is important to make sure that the underfloor vents do not open into the conservatory.
- In many cases the conservatory floor construction will comprise a solid concrete floor of minimal thickness. Even if the rest of the house has a good floor, radon could still enter the house via the conservatory. One reason for this is that it is quite common for the door between the conservatory and the main house to be left open, allowing any radon that enters the conservatory to enter the house.
- There will, of course, be a joint between the conservatory floor and the house, through which radon may enter. Also, in some conservatories, the floor slab will have been constructed with large openings to allow plants such as vines to be cultivated indoors. Obviously these openings could be major radon entry routes.

Having carried out a full survey of the property, you will need to decide which solution to apply. The previous sections of this Report have discussed what to look for, and have described briefly the options available. This section outlines the points you should consider when choosing a solution, and discusses the options in more detail.

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

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

You should also point out to the houseowner that whichever solution is adopted there can be no guarantee that it will reduce the radon level. It may be necessary to tackle it in stages. To illustrate some of the options that are available, fictitious case studies are described in Appendix B. Figure 9 gives an indication of the likely effectiveness of solutions based on floor type.

A considerable amount of knowledge has been built up over the last few years in dealing with houses with high indoor radon levels. Research continues, as does the development of appropriate solutions, particularly with regard to timber floors. Until the results of this work become available BRE offers the following advice.

Solutions can be divided into two types.

- Generic solutions:
  - Sealing
  - Positive pressurisation
  - Sumps
  - Underfloor ventilation
  - Ventilation

- Solutions for complicated situations:
  - Floors of mixed construction
  - Basements
  - Stepped construction
  - Conservatories

Generic solutions

Sealing

It would seem sensible to try to seal all obvious cracks, gaps and holes in the floors and walls, to prevent radon from entering the building. Sealing a large hole can produce a dramatic reduction in the radon level. However, in practice it has been found that the reduction is not always as large as had been hoped for. Sealing solid floors has produced reductions of a half to two-thirds on average. The reasons for this are not entirely clear, but probably have something to do with the fact that it is difficult to ensure that all the cracks have been found, or that the sealing treatment of any crack is fully effective. It is difficult, for example, to seal floor-edge gaps without removing skirting boards.

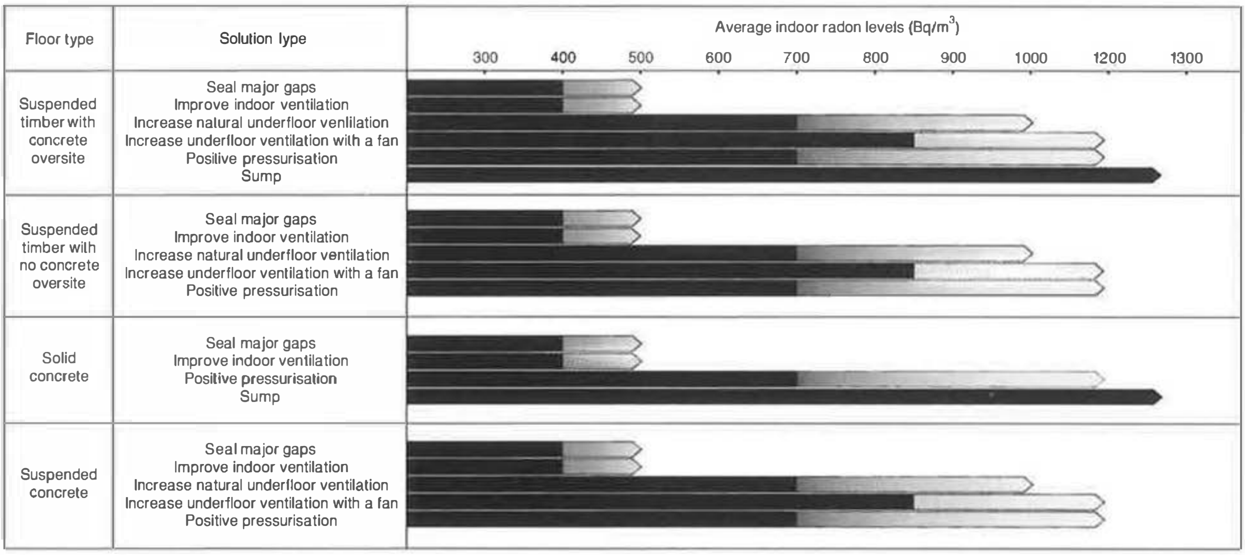


Figure 9 Effectiveness of key solutions for main types of floor construction. This diagram gives an indication of the levels of radon that can successfully be reduced using a variety of solutions described in this Report. These are only indicators. In many cases conditions have been such that higher levels of radon have been dealt with using these solutions. The black areas indicate a high likelihood of success, while the grey areas show where some success has been achieved

In particular, cracks and joints behind kitchen units, built-in cupboards and boxed pipework can easily be neglected, perhaps because they are difficult to get at, and yet they may provide major flow paths for radon. It is also difficult to get at cracks and joints under staircases. To gain access you may have to move cupboards fixed to the floor, and this may be disruptive and costly. Trying to seal cracks by removing cupboard plinths and working through the low openings will rarely be successful. Boxed pipework should be opened at ground level so that you can make a proper assessment of the sealing requirements.

Although other solutions may be more appropriate, it is still worthwhile sealing all major leakage paths. With suspended concrete floors this is likely to involve only the sealing of gaps around service entry or exit points. With suspended timber floors, it again means sealing gaps around service entry or exit points, but also, possibly, major joints between floorboards. With suspended timber floors, sealing must be accompanied by proper ventilation of the underfloor space. Sealing of the bulk floor area using impervious sheet materials such as polyethylene is not recommended because of the risk of causing rot in the timber.

In spite of the disappointing results reported, sealing remains an attractive remedial treatment for radon levels up to 400 or 500 Bq/m^3. Sealing can be cheap in terms of materials, may not cause too much disruption, and is passive; in other words it costs nothing to run. Tracing and sealing all the cracks can be time consuming, but it is an attractive option for houseowners carrying out their own remedial measures as the material costs are low. If a builder is employed it will be more expensive.

Further guidance can be found in a BRE Report on sealing floors[4].

Positive pressurisation
For radon levels up to about 700 Bq/m^3 positive pressurisation may be an attractive option. In a positive pressurisation system a small fan blows filtered fresh air (typically air from the loft space) into the house (see Figure 10). These systems were designed originally to reduce condensation, but they are now used also to reduce radon concentrations. It is claimed that they can increase the air pressure in the house sufficiently to exclude radon. Although this might be achieved in a house that was particularly airtight, in many houses the fan will simply increase the ventilation rate and therefore dilute the radon. Either way it is quite effective.

For a positive pressurisation system to be acceptable to the householder, you will have to consider its location and operating characteristics. Some consumer resistance has developed because of systems which produce a cold zone in the house in winter (and sometimes a hot zone in summer). The problem can be overcome by using a fan fitted with a small heater, but

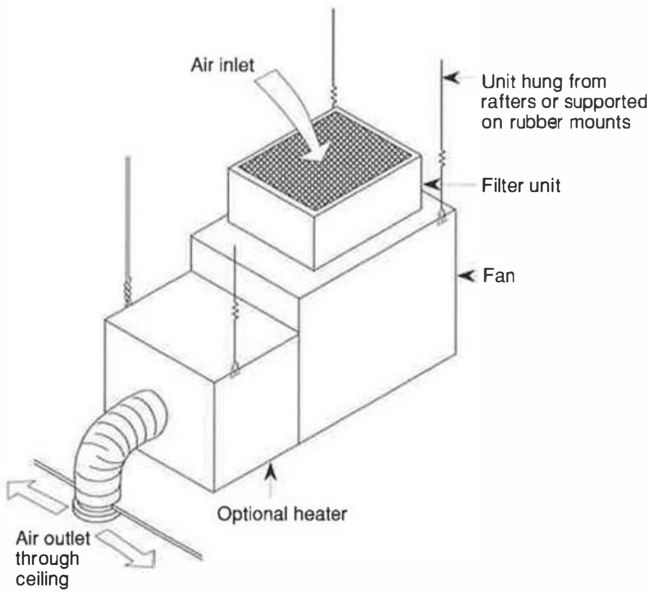


Figure 10 Typical positive pressurisation system

these are normally electric and may be expensive to run. Nevertheless, many householders find positive pressurisation (with or without a heater) a satisfactory solution. A secondary benefit may be reduced condensation in winter. It should be noted that leaving upstairs windows open for extended periods may reduce the effectiveness of positive pressurisation. It is also important to ensure that the roof void is adequately ventilated. Manufacturers can advise on the sizing and installation of systems.

Sumps
For houses with high radon levels, and where sealing or positive pressurisation would be inappropriate, a radon sump system may be the answer. The purpose of a radon sump is to reverse the air pressure difference between the ground under the floor and the occupied rooms, so preventing radon-laden air from entering the dwelling. Essentially, it comprises a hole in the ground beneath the floor slab, linked by pipework to the outside. Suction is applied by an electric fan in the pipeline, to draw out radon-laden air. Sumps work most effectively where the fill beneath the slab is especially permeable. Foundation walls which compartmentalise the area beneath the floor can reduce the effectiveness of a sump system, so you should try to identify walls where this may occur.

There are three generic types of sump system:

Mini-sump (see Figure 11)
Standard sump (see Figure 12)
Externally excavated sump (see Figure 13)

In some cases it is possible to use the suction effects of the wind over the pipe outlet and a natural stack effect in the pipework to operate the sump system passively. However, passive sump systems are less successful than those fitted with fans. They are probably appropriate only for lower levels of radon. A passive system which fails to work can easily be upgraded later by installing a fan.

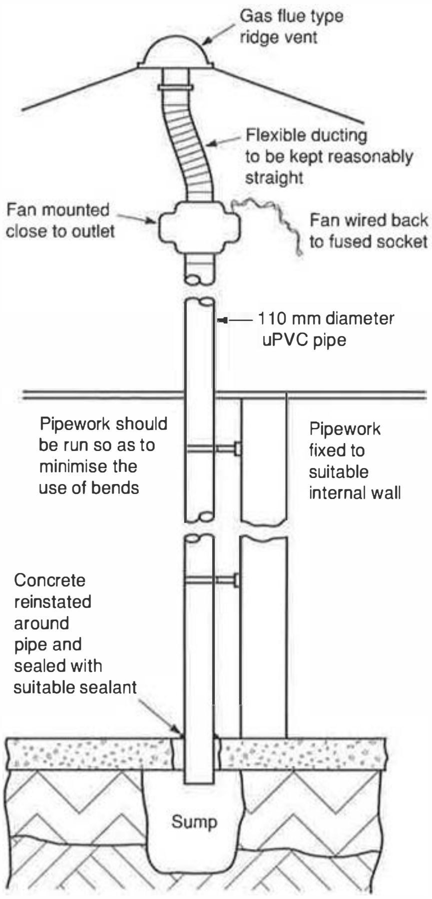


Figure 11 Mini-sump system

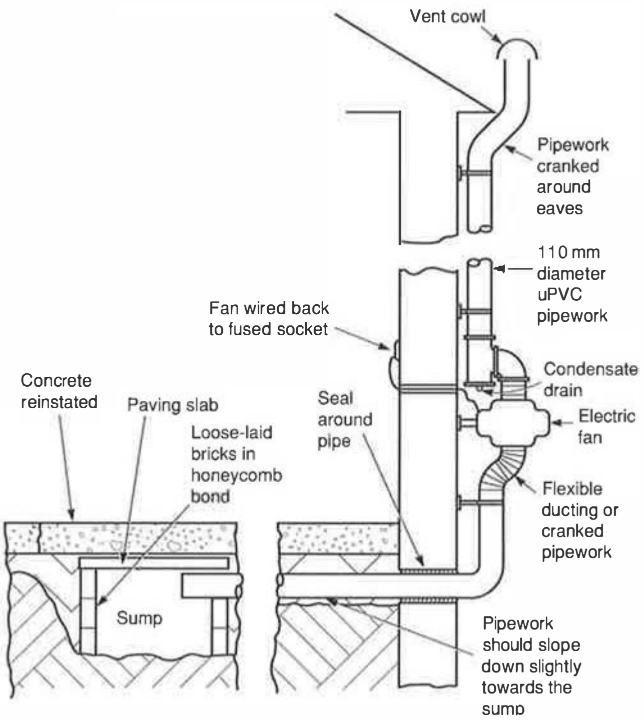


Figure 12 Standard sump system

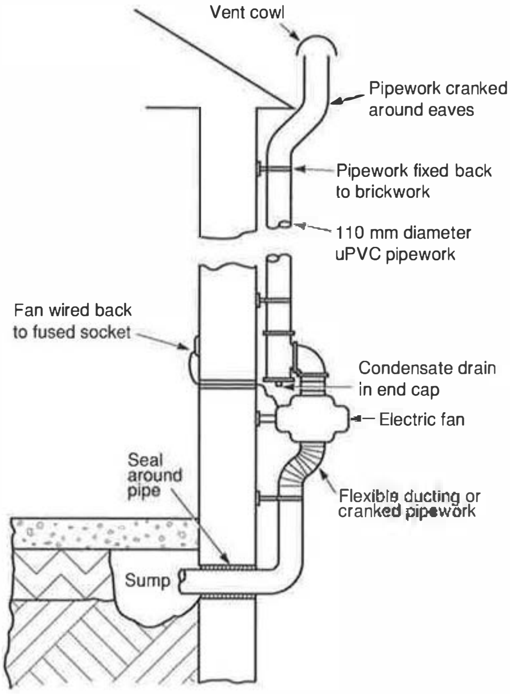


Figure 13 Externally excavated sump system

Sump systems can be used with suspended timber floors where they have a covering of concrete over the soil below. They would normally be considered only where the radon level is particularly high or where improvements to the ventilation have failed to lower radon levels. As with a solid floor, the system would comprise a hole in the ground (beneath the concrete which covers the ground under the floor) linked by pipework to the outside. Suction would again be applied by an electric fan in the pipeline, to draw out radon-laden air.

Where the floor does not have concrete covering the ground underneath, you should not install a sump system without carrying out extensive work to cover the ground. Attempts have been made to cover the ground beneath a timber floor with a membrane of polyethylene sheet held in place with gravel, and to locate a sump beneath it. Results from the few installations so far completed have been mixed. Generally, they proved extremely difficult to install and were therefore expensive.

As mentioned earlier, some houses have ducted warm-air heating systems located within the ground floor (see Figure 14). Ducted warm-air systems have in recent years gone out of favour, so when they need replacing it is common for alternative forms of heating to be installed. The old ducting and ventilation grilles, although no longer in use, are simply left in the floor, and can provide an easy entry route for radon. However, by sealing the grilles and installing a fan you can use the ducts as a large sump. Of course, this solution should be considered only where radon levels are especially high. Simple sealing of the redundant system may prove adequate in itself (see Figure 15). To a limited extent the same solution can be applied to other redundant sub-floor voids such as wells and basements.

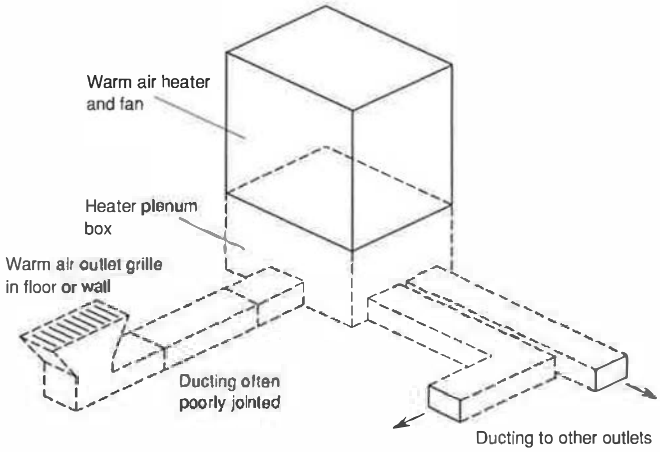


Figure 14 Typical layout of a ducted warm-air heating system

Radon fans and pipework should be located where noise disturbance will be minimal. All fans create noise and vibration. Clearly, the louder the noise and greater the vibration and the closer the fan is to the listener, the greater will be the potential problem. Selection of a quieter fan can help, but its location is more important.

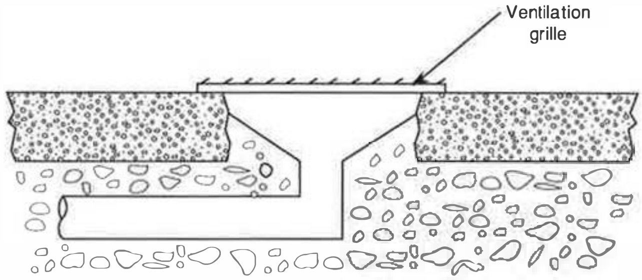
Systems, especially the fans, should be positioned as far as possible from any noise-sensitive area, and mounted on a part of the structure which does not respond to vibration. Ideally, the fan should be fixed to a heavy structure such as a concrete, blockwork or brickwork wall. Soft or flexible fixing to a roof truss, beam or rafter may also be appropriate. Avoid fixing to a lightweight internal partition or ceiling. Design the system to avoid bends unless they are strictly necessary. Noise transmission can be reduced further by using flexible couplings between the fan and ductwork, and by supporting the fan on non-rigid mounts.

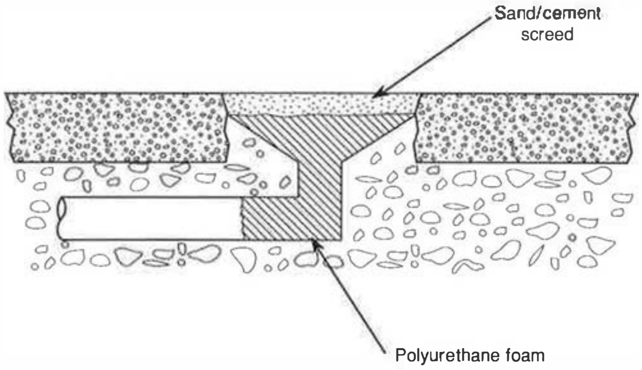
Pipework to sump systems should be self-draining, to avoid condensation damage to fans and noise from bubbling condensate trapped in U-bends. Keep fans close to outlets to reduce condensation, and ensure that the maximum length of pipework is under suction, minimising the risk of re-entrainment.

Note the risk in some extreme cases, where houses are airtight and have open-flued appliances or open fires, that a sump could draw flue gases back into the house. It is obviously vital that this should not happen. Further research is being carried out in this area. In the interim, BRE recommends that you avoid locating a sump beneath a room with an open-flued appliance or an open fire. In addition, you should ensure that the sump fan you install is not oversized. For further advice on this matter, telephone the BRE Radon Hotline (0923 664707).

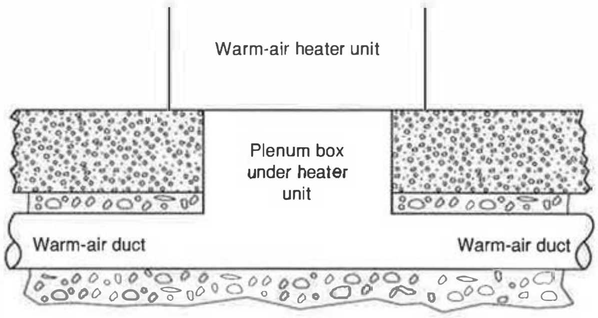
A BRE Report[5] gives comprehensive guidance on radon remedial measures in existing dwellings, including the installation of radon sumps.

Floor and wall grilles





Heater unit plenum and ducts



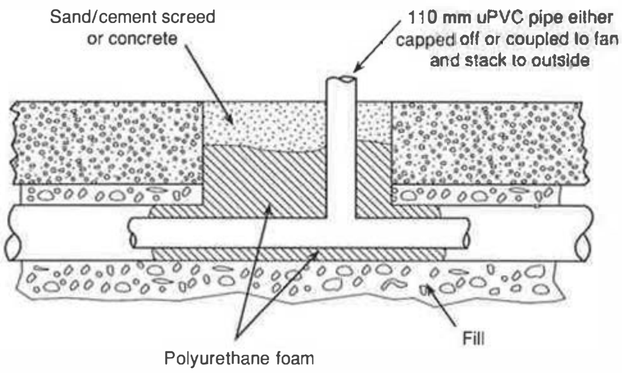


Figure 15 How to convert a redundant ducted warm-air heating system into a sump system

Underfloor ventilation
If the floor is of suspended timber or suspended concrete construction, with little or no provision for underfloor ventilation, then the most appropriate solution will be to improve the ventilation. With a timber floor, improved ventilation will not only reduce the indoor radon level, it will also help to reduce the risk of timber rotting.

Where the radon level is only just above the recommended action level, say 200 to 300 Bq/m^3, a reduction to below the action level might be achieved by clearing obstructions from existing vents. 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 cranked ventilators (see Figure 16). Remember that increased breaking out will be required to fit the cranked vents.
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.

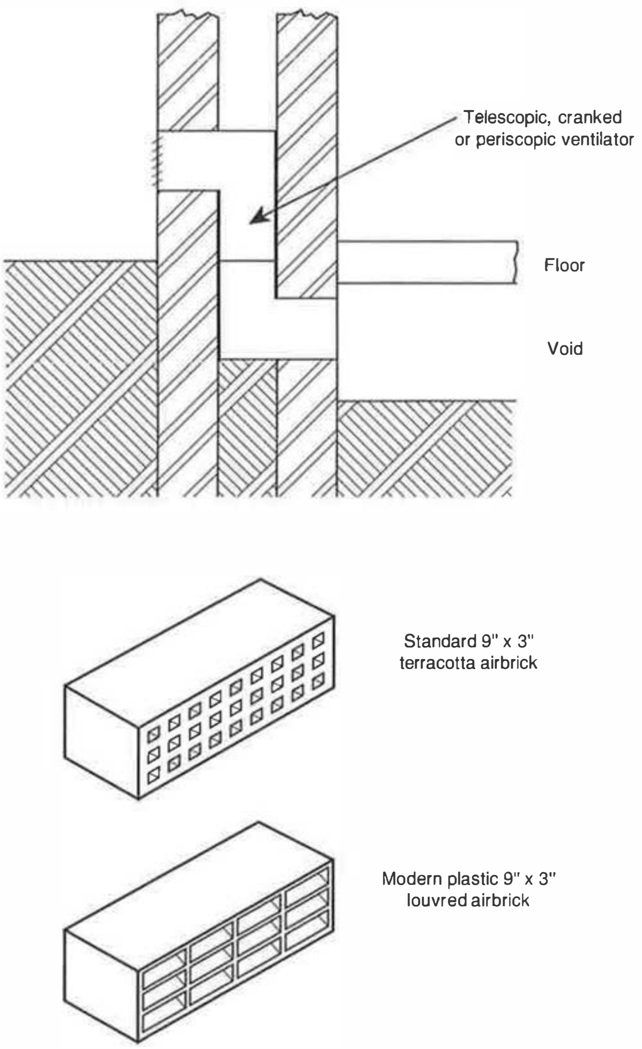


Figure 16 Types of airbrick

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. Plastic louvred ventilators are preferable to clay airbricks, as they usually offer greater open area and fewer of them will be needed (see Figure 16). Replacing terracotta airbricks with the same overall size of plastic louvred airbrick is a convenient way of improving the ventilation under a floor without the need to break-out many new airbrick openings. Do not leave vents without some form of vermin guard.

Vents should not be cut into suspended timber floors; ventilation should always be provided beneath the floor.

If natural ventilation proves inadequate in reducing the indoor radon level, then you may have to install an electric fan to increase the airflow under the floor. Fans can be installed to suck or blow. Where a fan is used to suck air from the sub-floor void, the operation of open-flued combustion appliances may be affected. In that case, blowing may be more satisfactory. Experience with blowing is limited, but in some cases it may prove more effective than suction. There could be problems of draughts inside the house with the system blowing. On the other hand, suction applied by an oversized fan could draw warm moist air from the house down into the underfloor space, bringing potential timber rot problems.

When considering increasing the air movement under 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.

Ventilation
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.

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

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

Any unused chimneys should be blocked up, as they tend to draw air out of the room. If you decide to block them up permanently, you should also take action to prevent condensation from building up inside the chimney. Cap the chimney stack with a chimney-pot hood and provide a small ventilation opening of about 50 mm × 20 mm in the blocked-up fireplace. A BRE Defect Action Sheet[6] deals with this in greater detail.

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

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

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

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.

Solutions for complicated situations

Floors of mixed construction

In principle, the solutions applied to houses with floors of a single construction type can be applied to those of mixed construction. However, a number of anomalies need addressing. It is not possible to provide in this Report solutions for every combination of floor types. The following are therefore suggested solutions relating to the more common examples. It may be possible to adapt them to suit other, less common, situations.

Solid concrete floor/suspended timber with concrete covering the subsoil

The basic points for solid concrete and suspended timber floors will apply. Sealing major cracks or gaps in both floor types, and improving the ventilation beneath the suspended timber area, should be considered as a first step. As discussed earlier, this is likely to be effective where radon levels are less than 400 Bq/m^3. For levels up to about 700 Bq/m^3 positive pressurisation may be an appropriate option. A third option, because the suspended timber floor has a layer of concrete covering the ground beneath it, is to install a radon sump system.

Solid concrete floor/suspended timber with no concrete covering the subsoil

Although this construction is similar to the previous one, the lack of any covering to the soil beneath the floor means that your options are limited. The simple solutions of sealing major cracks or gaps, improving the ventilation beneath the suspended timber area, and positive pressurisation remain appropriate. However, a sump system can really be considered only for the solid-floor part of the house. If the greater part of the total ground-floor area is solid, then a sump system may be effective. Even so, there is a chance that the main radon entry route will be through the suspended timber floor, in which case the sump is unlikely to have much effect. If a sump is to be used, it should be located well away from the suspended timber area, in order to achieve maximum depressurisation of the subsoil.

Another solution may be to provide a sump under the concrete floor as well as powered underfloor ventilation to the timber floor. Attempts have been made at manifolding such systems, so as to use only one fan. However, for both systems results have so far been mixed. It is likely that for such a system to work successfully it will have to be carefully balanced.

Basements

The type of solution that can be applied to houses with basements will be determined by several factors: the size and location of the basement, to what extent it is utilised, the construction of the basement walls and floor, the ground floor and, to a certain extent, the radon level.

The most obvious solution may appear to be to seal up cracks and gaps in the basement walls and floor. It is worth trying to seal major gaps, but to do more may prove both difficult and expensive. If the basement is being renovated for frequent use, then it may be worthwhile tanking it. Tanking, which involves coating the walls and floor with a waterproof barrier, is likely to be expensive. It could, however, prevent problems of dampness as well as reducing the radon level in the basement. Unfortunately, in cases where the basement is beneath only part of the house, sealing the basement alone may solve only part of the problem.

With moderate levels of radon, increased ventilation may be the appropriate solution. If the basement is unheated and little used, then this may be done by installing air vents, increasing the size and number of existing vents, or fitting a fan to increase the air movement. If the basement is occupied, then increased ventilation may not be acceptable. In such cases, an active solution such as a sump system or positive pressurisation may have to be used, even though the radon level is low.

With high levels of radon, it is likely that a sump system will be required. The number and location of sumps will depend on the house. It will probably be easier to install such a system in the basement than elsewhere. If the basement extends under only part of the house, the system installed there is likely to influence the radon level only in that part of the house. However, if the adjacent ground floor is of solid concrete, the sump system in the basement could be manifolded to deal with this additional part of the house (see Figure 17). If the adjacent ground floor is of suspended timber construction, it may be necessary to deal with the timber floor separately.

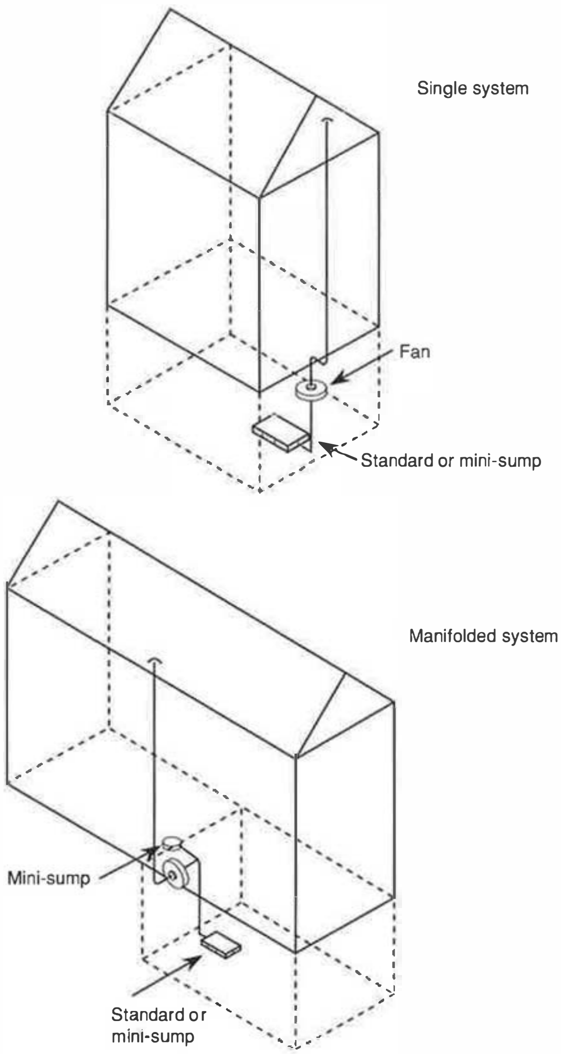


Figure 17 Single and multi-sump systems for use in basements

Stepped construction
Houses of stepped construction can be difficult to deal with. The type of solution will be determined largely by the layout of the house and its construction. In most cases, the house will have an upper and lower ground floor with a step in between. However, there may be a number of levels with floors in contact with or adjacent to the ground. Typically, these floors will be of solid concrete, suspended timber, or a mix of the two.

The most obvious solution might appear to be to seal up cracks and gaps in the retaining walls and ground floors. It is certainly worth trying to seal up major gaps, but to do much more may be difficult and expensive.

With moderate levels of radon and suspended timber ground floors, increased sub-floor ventilation may be the appropriate solution. This could be achieved by increasing the size and number of existing vents, or by fitting a fan. It may be necessary to install a sump system or positive pressurisation, even though the radon level is low.

As with basements, high levels of radon probably mean that a sump system is required. The number and location of sumps will obviously depend on the house. It is likely that the most appropriate location for a sump will be near to any change in level. If necessary, several sumps can be manifolded to deal with the area beneath each floor level and behind retaining walls. If several sumps are manifolded, the system may need to be balanced.

Conservatories
When dealing with radon in a house, you should deal with the conservatory at the same time, although it is unlikely that the main point of entry for radon will actually be in the conservatory. Remedial measures are best applied to the house first.

There are really only two measures to consider for the conservatory. First, ensure that underfloor vents from the house do not open into the conservatory. Where they do, they should be blocked up and alternative underfloor ventilation should be provided. Do not block up vents without providing alternative vents, as this could lead to more radon in the house and the rotting of floor timbers. Alternative ventilation might be provided by routing pipes from outside, under the conservatory floor. Secondly, consider sealing the joint between the conservatory floor slab and the house. Also, holes deliberately left for plants, and any other major cracks and gaps in the floor, should also be sealed (see Figure 18).

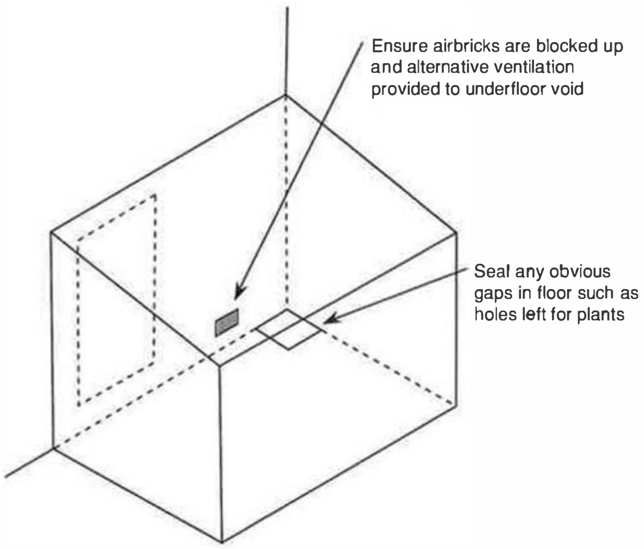


Figure 18 Dealing with conservatories

RETESTING FOR RADON

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

ACKNOWLEDGEMENTS

Thanks to the many householders and others who have assisted in the research on which this Report is based.

Thanks also to Mr T J Gregory of Cornwall County Council, for allowing access to, and measurement results from, many County Council properties, and to Mr K Cliff of the National Radiological Protection Board, for assistance with long-term radon measurements.

I should like to thank the BRE radon team, A Cripps, R Hartless, K Noonan, L Parkins, P Pye, R Stephen, B Stringer, P Welsh, and M Woolliscroft, for their assistance in preparing this Report.

REFERENCES

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

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

3 **Building Research Establishment.** Contact the BRE Bookshop (address below) for more information about a series of Reports on non-traditional housing.

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

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

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

MORE INFORMATION

Research into radon is continuing and further Reports in this series are planned. In the meantime further guidance is available from:

BRE Radon Hotline. Telephone 0923 664707

BRE Bookshop, Building Research Establishment, Garston,Watford, WD2 7JR.
Telephone 0923 664444
(see back cover for some available titles)

The Radon Survey, National Radiological Protection Board, Chilton, Didcot, Oxfordshire, OX11 0RQ
(for advice on radon risks and monitoring)

APPENDIX A
Checklist and survey report form for a house with a radon problem

Checklist

1 Test for radon ☐

2 Consider
- Type of property ☐
- Owner's knowledge of past history of the house ☐
- Any existing radon remedial measures ☐
- History and geology of the site ☐
- Exposure of the site ☐
- Layout of the property ☐
- Existing condition of the property ☐

3 Survey
- Ground floor construction ☐
  - Solid ☐
  - Suspended concrete ☐
  - Suspended timber ☐
  - Composite ☐
  - Mixed floor types ☐
- Service entries and exits ☐
- Walls ☐
  - Solid ☐
  - Cavity ☐
  - Retaining ☐
  - Internal ☐
  - Insulation ☐
  - Finishes ☐
  - Damp-proof courses ☐
- Ventilation and heating ☐
- Basements and cellars ☐
- Stepped construction ☐
- Wells ☐
- Conservatories ☐

4 Choose a solution
- Sealing ☐
- Positive pressurisation ☐
- Sumps ☐
- Underfloor ventilation ☐
- Ventilation ☐

5 Retest for radon ☐

Survey form

Figure 19 shows the 2-page BRE radon survey form. It is reprinted, full size, at the back of this Report, so that it can be more easily photocopied for personal use.

Building Research Establishment

Radon survey report form

File number:

Date of survey:

Survey carried out by:

Address of property:

Name of occupier:

Telephone:

Name and address of owner if different from above:

Year of construction:

Type of property: (house/bungalow/flat)

Name and address of builder or system producer (if known):

Site exposure:

Known history and geology of site:

Original 3-month radon level:

Constructional details: (approximate dimensions only)

Floor: (type and dimensions)

Walls: (type, insulation, location, thickness)

Service entries/exits: (gas, water, electricity, telephone, soil, waste and heating)

Ventilation sources: (to subfloor voids, gas appliances, kitchens, bathrooms, etc)

Windows: (well sealed, leaky)

Type of heating:

Flues/chimneys:

Any other points: (basement, well, occupants, etc)

Diagnosis of radon problem and suggested remedial measures:

Additional information required if a specification is to be drawn up for carrying out remedial works.

— annotated and dimensioned sketch of parts of the house to be effected by remedial works, to indicate construction materials.
— positions of any services around remedial works.
— any special conditions to be included in the specification.

Figure 19 The BRE radon survey report form

APPENDIX B
Case studies

Case study 1
(Figures 20, 21 and 22)
This fictitious property near St Ives in Cornwall was monitored for three months by NRPB and found to have an average radon level of 600 Bq/m^3. A constructional survey of the property was carried out, details of which are presented here together with an isometric view. The radon level at 600 Bq/m^3 is in the middle ground where several solutions might be appropriate.

It is unlikely that simple sealing will significantly reduce the radon levels in this house. It may help in the part of the house with solid floors, but is likely to be disruptive and expensive as the house has a fitted kitchen and most service entries are behind panelling. Sealing of the bulk area of suspended timber floor is not advised, but any obvious major gaps should be sealed.

As it is difficult to identify where radon enters, assumptions have to be made. It would be logical to assume that the timber floor is a major source of entry. If this were the case, then providing additional underfloor ventilation would be an appropriate solution. Even if this were to prove inadequate in solving the radon problem, it would nevertheless help to reduce the risk of rot in the timber floor. It would therefore be an appropriate first step. All the work could be carried out externally, with minimum inconvenience to the householder, although breaking through the stone wall may be difficult. If remonitoring shows that this solution has been partially effective, it may be worth upgrading it by installing a fan to ventilate the underfloor space mechanically .

Another alternative might be to install a positive pressurisation system. It is impossible from a visual inspection to tell how airtight the house is. The householder has made sure that the property is not obviously draughty, but its chimneys and timber floor will reduce the effectiveness of a pressurisation system. The householder does not like draughts, and keeps the house very warm. As a consequence, any draught produced with pressurisation may not be acceptable.

As most of the ground floor is of solid construction, it may be appropriate to install a sump system. This could be installed internally in the utility room, with pipework run up through cupboards to exhaust through the roof. The sump itself could be linked to the adjacent sub-floor areas by breaking through the walls just below floor level. Such a system is an attractive option, as it is likely to prove effective and work can be carried out in a single stage.

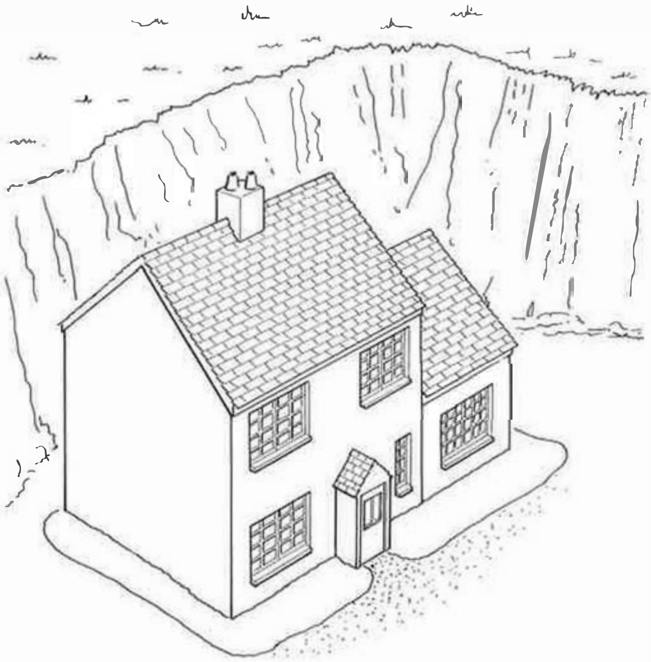


Figure 20 Case study 1, near St Ives, Cornwall

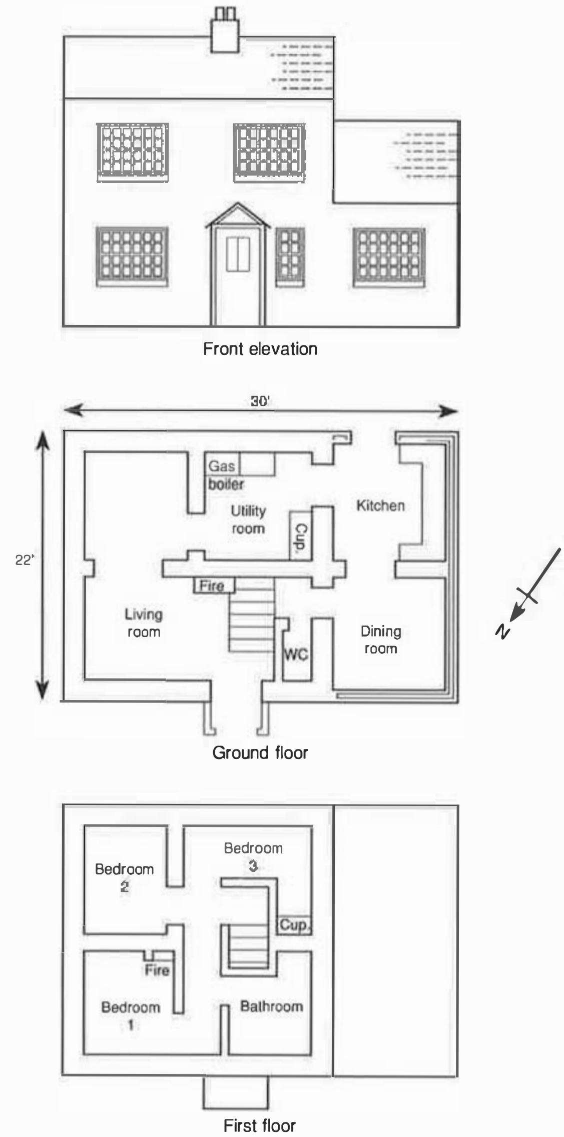


Figure 21 Case study 1, elevation and plan

Building Research Establishment

Radon survey report form

File number: *Case study 1*

Date of survey:

Survey carried out by: *R Mann*

Address of property: *Kimberley, Wheal Barrow, Nr St. Ives, Cornwall*

Name of occupier: *Mr & Mrs Treffusis*

Telephone:

Name and address of owner if different from above: *Owner occupier*

Year of construction: *1870 Extended 1965*

Type of property: (house/bungalow/flat) *Detached house*

Name and address of builder or system producer (if known)**:** *Not applicable*

Site exposure: *Front facing NW towards sea, cliff location. Sheltered at rear*

Known history and geology of site:

Former mine manager's house, located in tin mining area. Driveway possibly former access to mine.
Householder obtained breakdown from NRPB. Living room 800 Bq/m^3 and bedroom 460 Bq/m^3.

Original 3-month radon level: *600 Bq/m^3*

Constructional details: (approximate dimensions only)

Floor: (type and dimensions) *Most of living room suspended timber. Utility room + WC old concrete floor may not be original. Kitchen, dining room and rest of living room modern concrete.*

Walls: (type, insulation, location, thickness) *Old part of house 600mm rubble-filled stone. Extension rendered block/block cavity. Spine wall in original house loadbearing. All walls plastered internally except granite fireplace in living room. Sleeper part of spine wall under living room timber floor is perforated.*

Service entries/exits: (gas, water, electricity, telephone, soil, waste and heating) *Gas, water, electricity all enter through floor in utility room. WC + bathroom soil + waste exit through floor, kitchen waste through wall. Telephone enters via wall. Soil stack boxed in throughout.*

Ventilation sources: (to subfloor voids, gas appliances, kitchens, bathrooms, etc) *Two airbricks to underfloor areas, one at front one at rear. Low-level balanced flue through wall. Ventaxia kitchen extract fan rarely used.*

Windows: (well sealed, leaky) *Windows at front and extension doubleglazed, others single glazed draught stripped.*

Type of heating: *Gas central heating with radiators in each room. Pipes through suspended floor but above solid floors.*

Flues/chimneys: *Two chimneys, with feature fireplace in living room and open fire in bedroom1 (bedroom fire rarely used)*

Any other points: (basement, well, occupants, etc) *Occupiers retired 5 years ago. House extremely well kept. Lady of the house does not like draughts. Fitted kitchen to a high standard.*

Figure 22 Case study 1: the (fictitious) completed first page of the BRE radon survey report form

Case study 2
(Figures 23 and 24)
This fictitious property on the edge of Okehampton in Devon was monitored for three months by NRPB and found to have an average radon level of 1200 Bq/m^3. A constructional survey of the property was carried out, details of which are presented here together with an isometric view.

A radon level of 1200 Bq/m^3 is relatively uncommon. It is most unlikely that simple sealing will significantly reduce it. As the radon level is so high, without carrying out extensive works the most effective solution will almost certainly be a sump system. Positive pressurisation might be considered as an alternative, but it would require the property to be more airtight than would normally be expected in the UK. Typically, positive pressurisation is not recommended for radon levels in excess of 700 Bq/m^3.

The preferred option would be to install an internally constructed sump in one of the cupboards in the hall. This would give it a fairly central location in the property. The pipework could then be run up through the cupboard to exhaust through the roof. The fan could be mounted in the roofspace. The fan would need to be supported on flexible mountings to minimise noise transmission. This is especially important in this property, as it is in a particularly quiet location and much of its construction features lightweight components. An alternative would be an externally excavated sump system, but that would have the disadvantage that the completed pipework would clutter the appearance of the property.

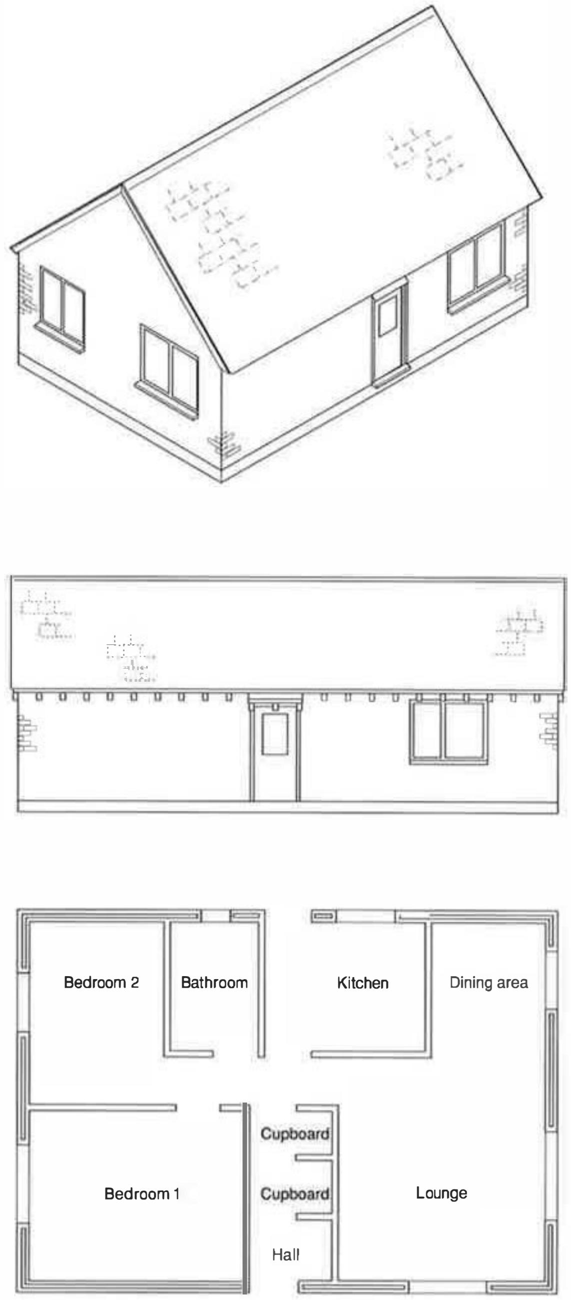


Figure 23 Case study 2, on the edge of Okehampton, Devon

Building Research Establishment

Radon survey report form

File number: Case study 2

Date of survey: 20.10.92

Survey carried out by: R Mann

Address of property: 22 Ambrosia Court, Okehampton, Devon

Name of occupier: Mrs Gentle

Telephone:

Name and address of owner if different from above: Owner occupier

Year of construction: 1988

Type of property: (house/bungalow/flat) Detached bungalow

Name and address of builder or system producer (if known)**:** Bodgitt & Scarper (SW), Plymouth

Site exposure: Moderate, surrounded by other properties on three sides, exposed to SW.

Known history and geology of site: Greenfield site on edge of Dartmoor

Original 3-month radon level: 1200 Bq/m^3

Constructional details: (approximate dimensions only)

Floor: (type and dimensions) Modern in-situ concrete, 100 mm thick on 1000 gauge polyethylene dpm over 100 mm fill. (Drawing available)

Walls: (type, insulation, location, thickness) External walls cavity blockwork, rendered externally, plastered internally. Internal walls all lightweight stud partitions.

Service entries/exits: (gas, water, electricity, telephone, soil, waste and heating) Gas, soil, water through floor but inaccessible without breaking open. Electricity via wall.

Ventilation sources: (to subfloor voids, gas appliances, kitchens, bathrooms, etc) Kitchen and bathroom extract fans rarely used. Balanced-flue gas boiler.

Windows: (well sealed, leaky) Modern hardwood double glazed and weather stripped.

Type of heating: Gas central heating feeding radiators.

Flues/chimneys: None

Any other points: (basement, well, occupants, etc) Property built prior to Building Regulations requirement for radon protection. Located in a very quiet cul-de-sac. Elderly lady occupier.

Figure 24 Case study 2: the (fictitious) completed first page of the BRE radon survey report form

Case study 3

(Figures 25 and 26)

This fictitious property in Redruth, Cornwall, was monitored for three months by NRPB and found to have an average radon level of 600 Bq/m^3. A constructional survey of the property was carried out, details of which are presented here. The radon level, at 600 Bq/m^3, is in the middle ground where several solutions might be appropriate.

It is unlikely that simple sealing will significantly reduce the radon levels in this house. The floor in the kitchen/dining room is in poor condition. Replacing it may be more appropriate than sealing it. If the houseowner is planning to replace the floor anyway, then replacement combined with the installation of a sump might be appropriate. The services in the bathroom and kitchen are poorly sealed where they penetrate the floor. They should be sealed as a first option, but given the poor condition of the kitchen/dining room floor this is unlikely to make any dramatic difference to the overall radon level.

An alternative would be to install a positive pressurisation system. It is impossible from a visual inspection to tell how airtight the house is. However, in this particular case the windows are poorly fitting and the house has a chimney. Both would reduce the efficiency of a positive pressurisation system. Further, the house relies on localised heating. Any draught generated by a fan mounted in the upstairs ceiling may not be acceptable to the householder. Installing a heater in the system might solve this problem, but would increase running costs significantly.

As the ground floor is of solid construction it may be appropriate to install a sump system. The fact that the house is relatively small probably makes it difficult to locate a sump system in a sensible position internally, but it also means that an externally excavated sump located at the rear of the property is likely to be effective. The only difficulty might be locating the pipework and fan externally.

A further option worth considering is to liaise with the neighbouring property owners to see whether a communal sump system serving more than one property would be appropriate. This should be considered only if three-month monitoring has shown that the neighbouring properties have high radon levels.

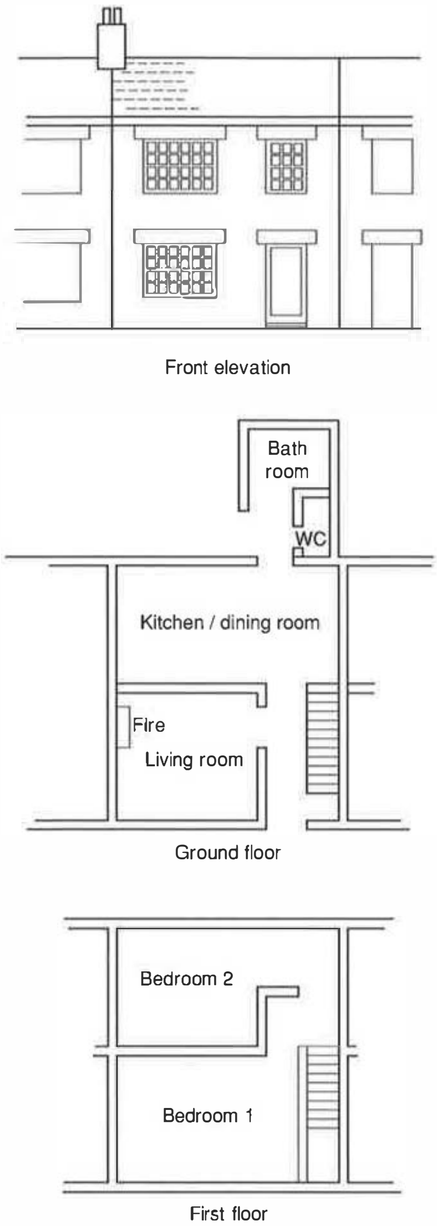


Figure 25 Case study 3, in Redruth, Cornwall

Building Research Establishment

Radon survey report form

File number: *Case study 3*

Date of survey:

Survey carried out by: *R Mann*

Address of property: *24 Trebogus Terrace, Redruth, Cornwall*

Name of occupier: *Mr & Mrs Pengegon*

Telephone:

Name and address of owner if different from above: ————

Year of construction: *1870s*

Type of property: (house/bungalow/flat) *Mid-terrace house*

Name and address of builder or system producer (if known): *Not applicable*

Site exposure: *Moderate — sheltered at rear. Front facing South-West exposed.*

Known history and geology of site:

Extensive mining has taken place locally. It is known that mining activity took place to the rear of the property. A mine survey carried out when the house was purchased shows a shaft beneath the terrace five or six doors along.

Original 3-month radon level: *600 Bq/m^3*

Constructional details: (approximate dimensions only)

Floor: (type and dimensions) *All floors are in-situ concrete. Living room floor recently replaced, includes membrane. Kitchen/dining room old floor in poor condition.*

Walls: (type, insulation, location, thickness)

All external walls appear to be rubble-filled stone. Internal walls timber stud with stone infill. All walls plastered internally.

Service entries/exits: (gas, water, electricity, telephone, soil, waste and heating)

Soil + waste from WC + bath through floor, poor seal. Kitchen waste through wall. Gas, electricity + telephone all through wall above ground.

Ventilation sources: (to subfloor voids, gas appliances, kitchens, bathrooms, etc)

No gas appliances or vents in kitchen and bathroom.

Windows: (well sealed, leaky) *Single glazed and draughty.*

Type of heating:

Open fire in living room. Local electric heating elsewhere.

Flues/chimneys:

Chimney from living room fireplace. Chimney from kitchen bricked up.

Any other points: (basement, well, occupants, etc)

The house was extended in about 1900 to include indoor WC, modified in 1960 to incorporate bathroom.

Figure 26 Case study 3: the (fictitious) completed first page of the BRE radon survey report form

Printed in the UK for HMSO Dd.8380794, 8/93, C15, 38938

Building Research Establishment

Radon survey report form

File number:

Date of survey:

Survey carried out by:

Address of property:

Name of occupier:

Telephone:

Name and address of owner if different from above:

Year of construction:

Type of property: (house/bungalow/flat)

Name and address of builder or system producer (if known)**:**

Site exposure:

Known history and geology of site:

Original 3-month radon level:

Constructional details: (approximate dimensions only)

Floor: (type and dimensions)

Walls: (type, insulation, location, thickness)

Service entries/exits: (gas, water, electricity, telephone, soil, waste and heating)

Ventilation sources: (to subfloor voids, gas appliances, kitchens, bathrooms, etc)

Windows: (well sealed, leaky)

Type of heating:

Flues/chimneys:

Any other points: (basement, well, occupants, etc)

Diagnosis of radon problem and suggested remedial measures:

Additional information required if a specification is to be drawn up for carrying out remedial works.

— annotated and dimensioned sketch of parts of the house to be affected by remedial works, to indicate construction materials.
— positions of any services around remedial works.
— any special conditions to be included in the specification.