Building Research Establishment Report

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Radon in the workplace

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INTRODUCTION

This Guide has been prepared for the Health and Safety Executive (HSE) by the Building Research Establishment (BRE). Following the guidance is not compulsory and you are free to take other action. However if you do follow the guidance you will normally be doing enough to comply with the law. Health and Safety Inspectors seek to secure compliance with the law and may refer to this guidance as illustrating good practice.

In the past, concern about exposure of employees to radon has largely centred on the mining environment. In recent times, with increased knowledge and mapping of radon levels in homes, attention has increasingly turned to radon exposure in buildings used for work purposes. Now there is a considerable fund of information to show that employees in some buildings can receive very significant radiation doses from radon. Surveys show that levels of radon tend to be higher in buildings with small rooms, such as offices rather than larger factory and warehouse constructions. The particular problem is that the nature of the work process gives no clue as to the radon hazard that may exist, and the employer may be unaware of its presence and how to deal with it.

This Guide is aimed principally at employers and those who control buildings used for work purposes, or their representatives. It offers guidance on practical measures for reducing radon levels in workplaces. The guidance should also be of interest and assistance to those, such as surveyors and builders, concerned with specifying and carrying out the necessary remedial measures.

Advice is provided for the majority of building types and construction situations likely to be encountered in larger non-domestic buildings. For buildings where construction is similar to that found in dwellings the guidance published by BRE on remedial measures for dwellings should be used. Inevitably there will be situations where no obvious solution applies. In such cases you are advised to contact the BRE Radon Telephone Hotline on 01923 664707.

BRE prepared this Guide with assistance from the National Radiological Protection Board (NRPB) and Cornwall County Council under contract to HSE. Its contents have been agreed following consultation with many interested parties.

RADON AND ITS HEALTH EFFECTS

What is radon?

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

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

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

Radon-affected areas

For most parts of the UK, workplaces do not have significant radon levels. Significant levels are however likely to be found in areas where domestic levels are high. Monitoring of domestic levels has resulted in areas being designated 'radon-affected areas'. Most workplace monitoring has been carried out in these affected areas. High radon levels will however be found elsewhere, particularly in those areas which have yet to be declared affected areas.

Cornwall and Devon, and parts of Derbyshire, Northamptonshire, and Somerset in England, parts of the Grampian and Highland regions of Scotland, and the District Council areas of Down, and Newry and Mourne in Northern Ireland have already been declared affected areas. Premises in these areas are therefore more likely to have high indoor radon levels.

The factors leading to high indoor radon levels are complex but high radon levels are associated with areas with the highest uranium concentrations and the greatest degree of fissuring or permeability of the geological structure.

Your local authority environmental health department will be able to tell you whether your premises are in an affected area. For further information on the health risks associated with radon and the geographical areas affected, write to the NRPB.

LEGISLATION: EMPLOYER'S RESPONSIBILITY IN THE WORKPLACE

Under the Health and Safety at Work etc. Act 1974 (HSW Act) the employer bears the principal responsibility to ensure the health and safety of employees and others who have access to that working environment. Protection from exposure to radon at work is specified in the Ionising Radiations Regulations 1985 (IRR85), made under the HSW Act. These Regulations apply to work where the level of radon exceeds a defined threshold, in which case the employer is required to notify HSE of such work.

For most practical purposes application of IRR85 occurs where the average radon level, measured in the winter months when the levels are usually at their highest, exceeds 400 Bq/m^3. When measurements are taken at other times of the year seasonal correction factors should be applied. Measurements can be made relatively simply and inexpensively using passive detectors. Such measurements should be carried out where the location, construction and ventilation of the workplace makes elevated radon levels seem likely.

One of the fundamental requirements of IRR85 is to reduce exposures to radiation as low as is reasonably practicable. Where radon levels are found in excess of 400 Bq/m^3, then the first approach should be to apply remedial measures to the building to reduce the radon levels below, and preferably well below, this concentration. Considerable experience has been built up in recent years on effective and relatively inexpensive methods of achieving this. These methods are set out in this Guide to assist you in meeting your legal duties.

Strictly, the threshold for application of IRR85 to radon is expressed in terms of exposure to an atmosphere where concentration in air is averaged over an 8-hour working period. Because of this, special factors may sometimes need to be considered. For instance, radon levels tend to be higher at night than during the day. Because passive detectors provide measurements which are 24-hour averages, radon levels at night are likely to be higher than the measured value, an important consideration for employers of night workers. Also, situations where employees work longer than eight hours per day should receive particular attention in view of the higher annual dose they are likely to accrue. Conversely, for a room normally only used for short periods and where the radon level does not greatly exceed 400 Bq/m^3, exercising control over access to the room may well be a sufficient response. The threshold for work situations is higher than the 200 Bq/m^3 Action Level used for homes, mainly reflecting the shorter length of time that people normally spend in work compared with home.

The requirement to reduce radon exposures to as low as reasonably practicable also applies to those carrying out remedial building work, who could find themselves working routinely in areas with high radon levels. Those responsible for such workers should assess their likely dose and, if necessary, instigate protective measures. Advice on this can be obtained from the local HSE Area Office.

MEASUREMENT OF RADON IN THE WORKPLACE

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. Concentrations will be affected by differences in the construction of the building, its heating and ventilation characteristics and the type of work activity carried out in the building. Highest concentrations are likely to occur in small, enclosed work areas such as offices and computer rooms where ventilation is restricted and heating is generally warmer. Having said this, larger more open areas should not be ignored.

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 for a long period. This can be achieved very simply and cost effectively by using passive detectors for a minimum of one month but ideally for 3 months. It is recommended that this is done before any remedial action is considered. For up-to-date details of companies who can supply detectors you should contact your local HSE area office or local authority environmental health department.

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 monitoring or instantaneous monitoring techniques are advised to seek advice from NRPB.

Having decided to monitor premises it is important to consider carefully where to place the detectors. For small, enclosed work areas such as offices, classrooms or doctors' surgeries, radon detectors should be placed in a selection of ground-floor rooms chosen to reflect the normal occupancy pattern of the building. In small premises the minimum number of detectors for each building is two, one in each of the two most frequently occupied rooms. In larger buildings, further detectors should be deployed so as to place at least one for each 100 m^2 of floor space. As a guide this should correspond very roughly to about one-third of all occupied ground-floor rooms. Detectors need not be placed in rooms that are occupied infrequently such as washrooms, store rooms or basements and cellars, except where used as a workplace for significant periods, for example, for more than half an hour a day on most days. In larger open-plan work areas such as production areas in factories or open-plan offices the number of detectors may be reduced to one for each 500 m^2 of floor area.

Even though they may not be used as workplaces for significant periods of time, it may still be worthwhile measuring radon levels in cellars or other areas with a very high radon potential. The results could help to explain high results obtained elsewhere in the building. Further measurement may be necessary if the occupancy of a room changes in the future.

In general, larger manufacturing or industrial premises are sufficiently ventilated to keep radon to low levels and one or two detectors are adequate for quite large work areas. However, further detectors might be required in any office accommodation in or adjoining the main work area.

Detectors should be placed where they are unlikely to be interfered with but should not be placed in enclosed spaces such as cupboards in an effort to improve security. Employees should be informed what the detectors are for when they are installed to ensure that they are not moved or tampered with.

The protocol described here should be considered as guidance for the majority of situations. There will however be cases where a higher or lower density of detectors will be appropriate. Generally though, measurements arranged according to this protocol should provide sufficient information to plan effectively any remedial work that might be required. Buildings of unusual construction or complex layout may, however, need some additional testing in order to better understand the radon problem. Further testing will normally be necessary on completion of remedial treatment to confirm that radon levels have been successfully reduced.

Purchase and placement of radon detectors should be within the capabilities of regular staff. There should not usually be a need to employ an outside contractor to place detectors. Detectors are usually supplied by post and will need to be returned to the supplier for processing. The company supplying the detectors should provide sufficient guidance to enable correct placement and retrieval of detectors.

IDENTIFYING THE PROBLEM

Having established that the building has an elevated indoor radon level it is important to try to identify the extent of the problem. For smaller buildings this is likely to be fairly easy, radon levels will probably be similar in each workplace. However for larger buildings this is less likely; often it will be found that one part of the building has more of a problem than another. In these cases it becomes more important to try to understand how the radon might be entering the building.

The floors and walls of buildings contain a multiplicity of small cracks and holes, formed during and after construction, through which radon can enter. In addition the air pressure within the building is usually slightly lower than that outside because of the heating of the building and the effect of the wind. This causes radon-laden air to flow inwards through cracks and holes in the building (Figure 1).

It is important to find out as much as possible about the building being assessed. For smaller, simpler buildings this assessment might be undertaken by the employer, but in most cases it is likely that the employer will seek the services of a construction professional, builder or radon specialist to undertake

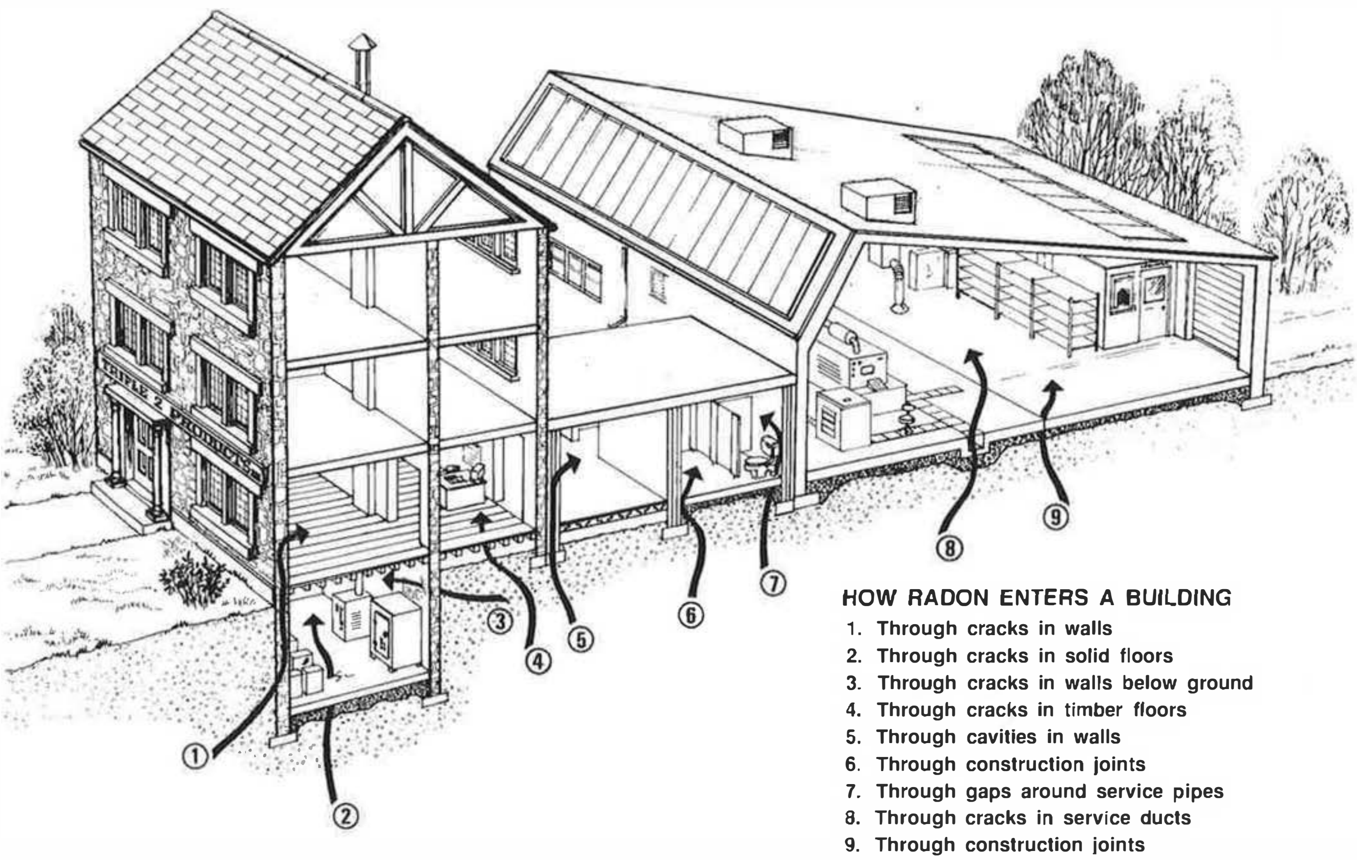

Figure 1 How radon enters a building

the assessment. The assessment can be divided into two parts:

- background information, and
- construction survey of the property.

BACKGROUND INFORMATION

To be able to identify the most appropriate solution for a property, it will be necessary to carry out a survey of its construction. This will indicate what the building comprises. However, to understand fully how the building functions, the surveyor will need some background information, much of which will be obtained only by speaking to the building owner, manager or user. This information will cover the following points.

- Indoor radon level
- Ownership of property
- Type of building
- Building use
- Existing knowledge of the building
- Existing radon remedial measures
- History and geology of the site
- Exposure and nature of the site
- Layout of the property
- Existing condition of the property
- Private water source

Indoor radon level

Before commencing the survey or taking remedial action it is essential to know the indoor radon level. To a certain extent the level of radon to be reduced will dictate the solutions that can be considered. The surveyor will need to know the individual radon levels and where the readings were taken.

Ownership of property

It is important to be aware of who owns the property being assessed, and who has the authority to permit remedial work to be carried out. It may be necessary to consult the tenancy agreement or property manager to establish who is responsible for works of this kind.

Type of building

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 office building no bigger than a detached house, is likely to be easiest to deal with. For such a property there will be several appropriate solutions.

Unfortunately, from a radon point of view buildings 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 buildings to be constructed with floors at various levels. Elsewhere, usually in older properties, there are other features such as basements. During its lifetime a building may be altered or extended. All these things compound a radon problem. Consideration should be given to neighbouring properties, especially where the building is part of a block or terrace. 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.

Building use

The indoor radon level can be influenced by the way in which a building is used. Therefore the surveyor needs to understand how the building is being used: both to help identify how radon enters the building, and to ensure that remedial measures will be acceptable to the building user. There would be little point in recommending measures that would prevent the user from continuing to work in the building, or might interfere with or prevent planned future use of the building.

Different work activities will have different effects on radon levels as the following examples show.

Offices. Heating levels are often relatively high and ventilation levels low, possibly resulting in higher indoor radon levels.

Warehouses, storage areas and vehicle workshops. These are likely to have large entrance doors which are frequently opened. Any radon entering them is likely to be diluted when the doors are open resulting in lower indoor radon levels.

Schools. School buildings tend to be closed up for long periods overnight and at weekends which can allow radon to build up.

Shops. Sales areas within shops may be reasonably well ventilated by customers entering and leaving the premises. As a consequence radon levels may be lower in these areas. However, basement storage areas and offices may suffer from poor ventilation, hence radon levels can be a problem in non-sales areas.

Public houses. These are often old buildings with cellars for storage of drinks. Commonly, the public areas feature extractor fans to remove smoke which if not balanced with incoming air can cause depressurisation leading to an increase in radon level.

Hospitals, residential homes, boarding schools and hotels. As with offices these buildings are often well heated but poorly ventilated which can lead to elevated radon levels.

Workshops and manufacturing. Some manufacturing processes require the use of extract ventilation systems to remove harmful dust and gases from the atmosphere. If insufficient supply air is provided they can create a slight negative pressure within the building and draw radon in. On the other hand, many workshop areas are well ventilated and will not pose a problem. Similarly, some production processes, particularly those associated with food preparation, require high levels of hygiene. It is common in such situations for floors to have been sealed with impervious floor coverings. In these cases radon may also be prevented from entering the building and so indoor radon levels may be quite low.

Bank vaults and safe deposits. To maximise security, bank vaults and safe deposits are often located in basements where radon is likely to be more of a problem. In addition, to make them even more impenetrable designers minimise the numbers of openings into them. This can leave them very poorly ventilated, resulting in high radon levels.

Existing knowledge of the building
It is important to find out what information is already available. Check with the building owner or manager what he or she knows about the history of the building. Over the years many alterations might have been made to the premises. 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 buildings see whether there are drawings available for the property. Drawings can be invaluable in identifying key features of 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 building owner 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.

This information will prove useful in ensuring that the structural integrity of the building is not impaired when installing remedial measures, eg ensuring steel reinforcing in foundation beams is not cut when excavating for the radon sump.

Existing radon remedial measures
When assessing a property, try to find out whether any changes have been made in working arrangements, use of the building or to the building itself, 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 remedial action 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, and
- positive-pressurisation system or sump.

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. Additional precautions may also be needed to protect against landfill gas.

Buildings 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, careful thought will need to be given 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 where buildings have been built over or alongside old mine workings. In such cases, sump systems operating in suction may not be the best solution. The system may draw its air from the old workings, resulting in minimal depressurisation of the underfloor area. In such cases a sump system operating with the fan blowing into the sump may be more appropriate. Reference to a mine survey could help to identify these buildings.

The type of soil beneath the building can influence the level of radon within it, 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 have both clay soil and a high water-table whilst also having a high radon level. Where this occurs a sump system would probably be inappropriate as the soil is likely to be impermeable and there is a risk that the sump itself would become waterlogged.

Exposure and nature of the site
It is a good idea to try to gain some appreciation of the overall nature of the site and exposure of the property. This information could be important for determining the type of solution and its location. For example, an appropriate solution for an office building which is on an exposed site and has a suspended timber floor, might be increased natural underfloor ventilation. From a radon point of view this is likely to be effective. However in extreme cases it might lead to draughts or colder rooms within the building, so making it an unacceptable solution. Similarly, providing additional

vents to the underfloor space of a building in a sheltered location might bring little improvement in the underfloor ventilation.

The nature of the site, whether it is sloping, flat, well-drained or poorly drained can have an effect on the type of solution that can be installed. For example, a sump system is unlikely to be effective where the water table is high unless land drainage is included as part of the remedial works. Buildings on sloping sites often have solid floors that are either dug into the hillside or are partly on made-up ground. Similarly where timber floors have been used it is likely that the underfloor void will vary in depth across the building, making it difficult to access the void across the entire building. Each could affect radon levels and influence the choice of solution.

Layout of the property
When planning radon remedial measures look carefully at the layout of the premises. This will be important when 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 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 a 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. With premises covering several buildings you will need to consider each building separately, and with very large buildings you may need to look at them in separate parts. It is also worth considering how the building might be used in the future so as not to install measures that might restrict future use of the building.

Existing condition of the property
It is important to establish the condition of the property being remedied. This will help in selecting 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 building owner 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.

Private water source
Although not particularly common, some workplaces, such as breweries, may have their water supplied via a private borehole or well. In a radon-affected area it is possible for radon to enter a building via such a supply. Where it is known that a private supply exists further advice should be sought from NRPB or BRE. Normal mains water is unlikely to pose such a problem as it will have been processed to remove any radon.

CONSTRUCTION SURVEY OF THE PROPERTY

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 occupier. The survey of the building will need to be thorough, but will be limited largely to parts of the building where the floors or walls abut the ground.

Before specifying the optimum solution for a building, a number of construction features will need to be surveyed:

- ground-floor type,
- service entries, exits and ducts,
- walls,
- ventilation and heating,
- basements and cellars, and
- stepped construction.

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, and
- composite.

In many buildings 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

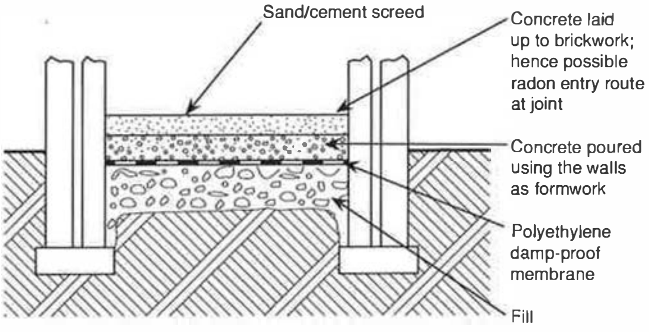

Figure 2 Typical modern in-situ concrete floor construction

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 layer of concrete at least 100 mm thick with a sand/cement screed or timber topping (Figure 2). The latest floors may include some insulation, either above the screed, below the screed or beneath the slab.

Where there is a risk of subsidence, due to past mining, industrial or other activity, or where high floor loadings are expected 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 building 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 joints between the different sections of floor slab, which can allow radon entry. 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. Joints between slabs 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, reclaimed land or where high floor loadings are expected, 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, to avoid damaging the reinforcement.

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, for example, around column bases, 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 comprising reinforced concrete beams with concrete infill blocks (beam-and-block) (Figure 3). It is considered good practice for such floors to have underfloor ventilation. As a consequence, many recent suspended concrete floors can be identified by 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 building

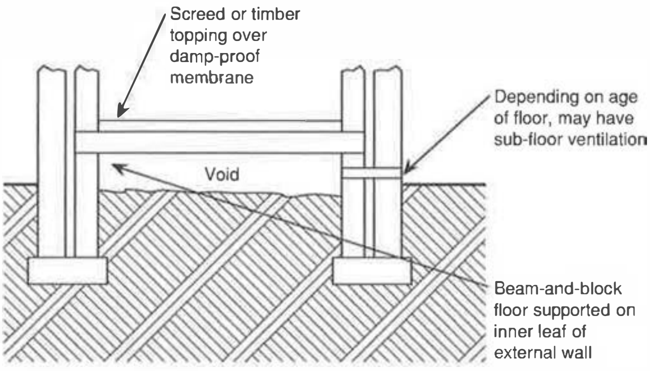

Figure 3 Typical suspended concrete floor construction

owner 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 will 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 (Figure 4).

Once again, radon can enter via gaps around services entering or leaving the building through the floor. Timber floors probably suffer more from service entries than concrete floors 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 and should therefore be sealed up with an alternative means of ventilation provided above or below the floor. Provision of alternative ventilation is of particular importance with combustion appliances.

When looking at a suspended timber floor, try to gain access to the underfloor space. Often it will be found that somebody has had to gain access at some stage in

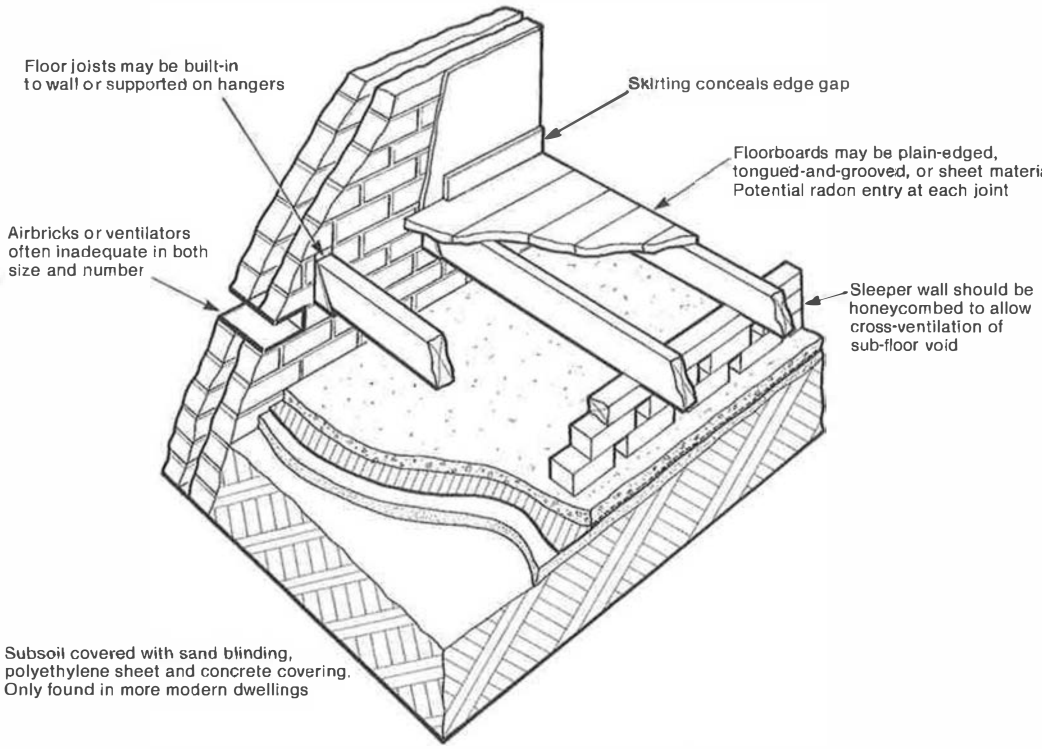

Figure 4 Typical suspended timber floor construction

the past, and that the owner will know where to find access panels hidden from view by carpets or furniture. Where this is not possible, an optical probe can be used. What needs to be known 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 cross-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 should also be assessed prior to remedial work. It is important to make sure that there is no timber rot present otherwise subsequent failure of the floor could be blamed on the radon treatment. 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. Once the construction has been identified, the available solutions are likely to be the same as those described earlier for concrete floors.

Mixed floor types
In many cases buildings have more than one type of floor construction. The combination of flooring will be determined largely by when the building was built and whether it has been modified or extended over the years. Premises 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 building. This is frequently so in older properties.

Service entries, exits and ducts
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. 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 or boxing-in. As a result, they may be difficult to find, but because they can be major radon entry routes it is useful to locate as many as possible and to seal around them where they enter or leave the building. Services that enter the building via the ground floor slab and are then routed directly, via ducting or boxing-in, to upper floors can lead to elevated radon levels on the upper floors. It is worth considering this if radon levels are found to be higher upstairs than on the ground floor.

Having referred to sealing it is important **not to seal up deliberately ducted vents such as air supply ducts to combustion appliances.**

It is quite common in non-domestic buildings to find services ducted through solid ground floors. Heating or refrigeration pipes and power or computer cables are often run in ducts in the floor. If the ducts are poorly constructed then radon can enter through them and flow into the workplace. In highly serviced buildings the ducts can prove to be major entry routes. It is therefore important to consider ducted services when planning remedial measures. Not only can ducts assist in radon entry but their location can influence the type of remedial measures that can be used. For example, if a deep duct runs around the edge of a floor slab it may prove difficult to install an externally excavated sump system. Consideration should also be given to ducting no longer in use.

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 building 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 building 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 breaking through thick walls, which could 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.

Solid walls
There are principally four types of solid wall used in non-domestic buildings:

- rubble-filled stone,
- solid stone,
- solid brick, and
- in-situ concrete.

These points need to be considered.

- 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 extra work to make good.
- Where holes have to be made 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.

Cavity walls
The main types are:

- brick/block,
- block/block,
- brick/brick,
- stone or reconstituted stone/block,
- timber frame, and
- prefabricated system.

These points need to be considered.

- 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 include prefabricated concrete systems made up of concrete planks or wall-sized panels, and steel-framed systems which come in a variety of different forms. Because it is important to avoid causing structural damage, it is a good idea to seek advice before breaking through walls of prefabricated construction.

Retaining walls
The retaining walls of buildings 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 almost certainly be the case if the wall has been fully tanked with asphalt. The owner may have drawings which show this. In older buildings 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 owner intends to use 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 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 buildings, insulation material is built-in during construction. In older buildings 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 owner 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, 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, provision should be made for reinstating it afterwards.

Ventilation and heating
In addition to surveying the structure of the building, it is important to consider the way in which it is ventilated and heated. Obviously, buildings need to be ventilated to get rid of normal pollutants such as smells, cigarette smoke, airborne pollutants from manufacturing processes and excess water vapour which can lead to condensation and mould growth. Obviously, too, buildings need heating. However, poor ventilation and heating practice can actually increase the amount of radon entering the building, so during the survey particular attention should be paid to the following features.

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. Also look for permanently open louvred windows, particularly in production areas.

Extract fans/systems
Check whether extract fans are used for prolonged periods in work areas such as computer rooms, paint booths and workshops, or non-production areas such as kitchens and WCs. Extract fans used for short periods, are unlikely to contribute greatly to radon problems unless the building is particularly airtight. Except where they are being used as part of an industrial process for health and safety reasons or are required to maintain equipment at a constant temperature, extract fans are unlikely to need to run continuously.

Chimneys
Find out whether open fires are used, especially with unrestricted chimneys; also whether unused chimneys are left open. This is unlikely to be a problem with newer buildings, but common in older buildings like schools, offices, and hotels.

Sub-floor ventilation
Inspect timber floors to see whether openings have been cut in them to provide ventilation to combustion appliances. Such openings or vents can be major radon entry routes. As discussed earlier, adequate ventilation of underfloor spaces should be provided, as it is important to minimise the risk of rot. The existing underfloor vents should be located; often they will have been obstructed by vegetation, soil or items stored against the building. In particularly exposed locations it is not uncommon to find that vents were never installed originally or have been deliberately blocked to reduce draughts indoors.

Entrance and loading-bay doors
Check to establish how often entrance doors and loading-bay doors remain open. It is likely that if they are left open for prolonged periods they will be assisting in ventilating the building and helping to dilute the radon.

Redundant heating or ventilation systems
Services ducted through solid concrete ground-floors are referred to earlier. However it is worth mentioning here the need to consider redundant ducting. Of particular interest are ducts used for warm-air heating systems. Such 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.

Plant rooms
Establish the location of plant rooms and the equipment located in them. Where plant rooms are located in basements check that the rooms are adequately ventilated to avoid radon being drawn into the building by open-flued combustion appliances.

Mechanical ventilation and air-conditioning systems
Some commercial buildings, particularly more modern office and retail premises, may have elaborate heating and ventilating or air-conditioning systems, or both. These will vary widely in type and complexity so it is difficult to give specific advice on the role these

systems may play in radon entry and radon remedial work.

Certainly ventilation and air-conditioning plant can have a significant effect on radon levels, and warm-air heating systems may have similar effects. It is the way in which the system is set up which decides its effect on radon levels. Systems which tend to pressurise the building will tend to stop the radon getting in whilst those which tend to depressurise will tend to increase radon entry. Well-balanced systems may help dilute any radon getting into the building. Thus, in principle, the radon level in the building could be reduced by adjusting the set-up of the system in an appropriate way. However, the surveyor will have great difficulty in assessing which, if any, effect the system was producing at the time the radon measurement was carried out.

The main things the surveyor can check is whether all the fans in the system are operating or not. (If a supply system fan has failed then simply repairing and restarting it may well reduce radon levels.) Because of the complexity of these systems and their controls the surveyor may wish to consult a building services engineer or HEVAC engineer to learn more about the design and functioning of the system.

Basements and cellars

Basements or cellars are relatively uncommon in the UK, usually being found only in built-up areas such as town centres where land is at a premium. They tend to be used as storage spaces rather than regular work places. Even so whenever 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 building with a basement beneath the whole of its ground floor, the area of the building in contact with the ground is probably three times that of a similar sized building without a basement, and the potential for radon entry is far greater.
- Basements in non-domestic buildings are often only used for storage and therefore are poorly finished. The walls in particular often feature a myriad of small cracks and gaps, all of which can contribute to the radon problem.
- Basements which are completely below ground are often poorly ventilated, and consequently radon entering them can build up. To aggravate the situation, the floor between the basement and room above is often of suspended timber construction. This enables the radon to flow further into the building.

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 building should be established. In many cases it extends under only part of the building; in other cases it extends beyond the main walls of the building. An example of the latter is where a coal hole or cellar access is located beneath the pavement at the front of a building. In older buildings it is not uncommon to find that parts of a cellar have been sealed up or back-filled.

The use to which the basement is put can prove important in determining its effect on the radon level. For example, if the basement forms an underground car park it is likely to be well ventilated and may not pose too much of a problem, whereas a basement used as a vault may be poorly ventilated to outdoors in order to maximise security which might mean an elevated radon level in the vault.

As mentioned earlier, the initial radon monitoring carried out to identify elevated radon levels should not be carried out in the basement unless it is used as a workplace.

Stepped construction

It is quite common, particularly in hilly areas, for buildings 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 premises 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 almost certainly be the case if the wall has been fully tanked with asphalt. The building owner may have drawings which show this. In older buildings it is unlikely that damp protection will have been applied and it will be expensive to rectify the situation.

CHOOSING A SOLUTION

Having carried out a full survey of the property, a decision will need to be made as to which solution to apply. The previous sections of this Report have discussed what to look for. This section outlines the points to consider when choosing a solution, and discusses the options.

For any solution to be completely effective it must be acceptable to the building user, and it is important to remember this when considering remedial action. A solution which would dramatically change the working environment is unlikely to succeed long term. For example, increasing 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 building. Sub-floor ventilation and sump systems are therefore the most suitable. Simple sealing of cracks may also appear an attractive possibility but is likely to prove less effective.

Many building users may be unwilling to accept a solution that will cause disruption inside the building during installation. Where this is the case an alternative solution will need to be considered. Some may be willing to pay for a system that is more expensive if the chances of success are high and if it means that disruption is likely to occur only once. With some workplaces remedial measures will need to be installed out of hours to minimise disruption, eg shops, schools or offices. The key to finding the most appropriate solution is for the surveyor, or contractor, to discuss with the owner or user the options available, together with the short- and long-term implications of each.

It is important that the client is aware 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. With larger buildings or premises comprising more than one building you may need to consider using several systems to resolve the problem, possibly providing different solutions in different parts of the building to satisfy the clients needs. To illustrate some of the options available, case studies based on real examples are described later in this guide (see **Appendix: Case studies**).

A considerable amount of knowledge has been built up over the last few years in dealing with non-domestic buildings with high indoor radon levels. Research continues, as does the development of appropriate solutions. Until further results of this work become available we offer the following advice.

Solutions can be divided into two types.

- Generic solutions
  - Sealing
  - Positive pressurisation
  - Sumps
  - Underfloor ventilation
  - Ventilation (other than positive pressurisation)
- Solutions for complicated situations
  - Floors of mixed construction
  - Basements
  - Stepped construction

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 reductions are often disappointing. Even so, 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. In particular, cracks and joints behind work units, built-in cupboards, wall panelling and boxed pipework can easily be neglected 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 may mean having to lift floor coverings or 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. So that a proper assessment of the sealing requirements can be made boxed pipework should be opened at ground level. Consideration should also be given to sealing of any service ducts that run through the ground floor.

Although other solutions are usually 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 or vinyl 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 small buildings with radon levels just above the action level. 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 owners carrying out their own remedial measures as the material costs are low. If a builder is employed it will be more expensive.

Positive pressurisation

For radon levels up to about 1000 Bq/m^3 positive pressurisation may be an attractive option. For most buildings positive pressurisation will be achieved by installing a positive-pressurisation system comprising a small fan to blow filtered fresh air (typically from the roofspace) into the building (Figure 5). However if the building has a mechanical ventilation or air-conditioning system it may be possible to adjust the system to achieve the same result by setting the supply air flow rate greater than that of the exhaust.

Positive pressurisation works by one of two mechanisms. It is claimed that it is possible to increase the air pressure within the building sufficiently to exclude radon. Although this might be achieved in a building that was particularly airtight, in many buildings you will simply increase the ventilation rate and therefore dilute the radon. Either way it can be quite effective. Secondary benefits of using positive pressurisation may be reduced levels of other indoor pollutants such as carbon dioxide, reduced condensation and a ‘fresher’ indoor environment.

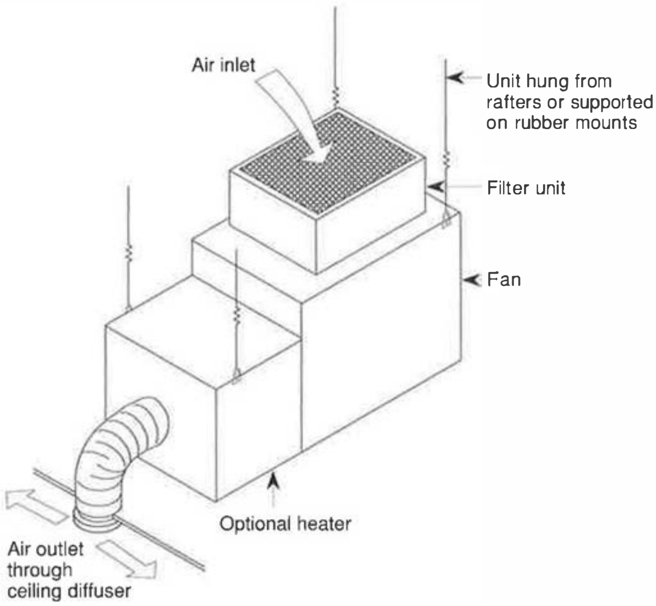

Figure 5 A typical positive-pressurisation system

If a separate fan is used to provide positive pressurisation consideration will have to be given to its location and operating characteristics if it is to be acceptable to the buildings' occupants. Some systems can produce a cold zone in winter (and sometimes a hot zone in summer). The problem can be overcome by installing a fan fitted with a small heater, but these may prove expensive to run. Cold zones are unlikely to arise if an existing ventilation system is being modified, as air will be distributed in a more controlled way through the existing air vents. The overriding factor is to ensure that slightly more air is being supplied than is extracted so as to create a slight positive pressure.

To ensure maximum radon reduction it will be important to ensure that windows are not left open for prolonged periods.

Several UK manufacturers produce positive pressurisation systems and can advise on the sizing and installation of systems. However as relatively few buildings located in the radon-affected areas of the UK have mechanical ventilation or air-conditioning systems, UK experience in modifying existing systems to achieve positive pressurisation for radon is likely to be extremely limited. It is also likely that the cost of employing specialists to carry out this work will prove more expensive than adopting an alternative solution. With very large buildings the extra expense involved in heating the additional air needed may also render them uneconomic.

Where a positive-pressurisation system is located within a roofspace it is important to ensure that the roof is well ventilated as there have been a few complaints of odours coming from positive-pressurisation systems. If roof timbers have recently been sprayed for dry rot then the system should not be activated for a week or so after spraying to give time for ventilation of the roof space to take place. It is also important to ensure that appropriate filters are provided and correctly fitted to deal with dust or other irritants. Filters fitted to such systems will also need to be cleaned on a regular basis.

Sumps

For buildings with high radon levels, and where sealing, improved underfloor ventilation 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 building (Figure 6). 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 as follows.

- Mini sump (Figure 7)
- Standard sump (Figure 8)
- Externally excavated sump (Figure 9)

Construction of the sump system need not be too disruptive. In the case of the mini-sump system, excavation is limited to breaking out a small hole in the floor slab and removing about a bucketful of fill. With the externally excavated sump all of the excavation work is carried out from outside the building via a small hole broken through the external wall. It is likely

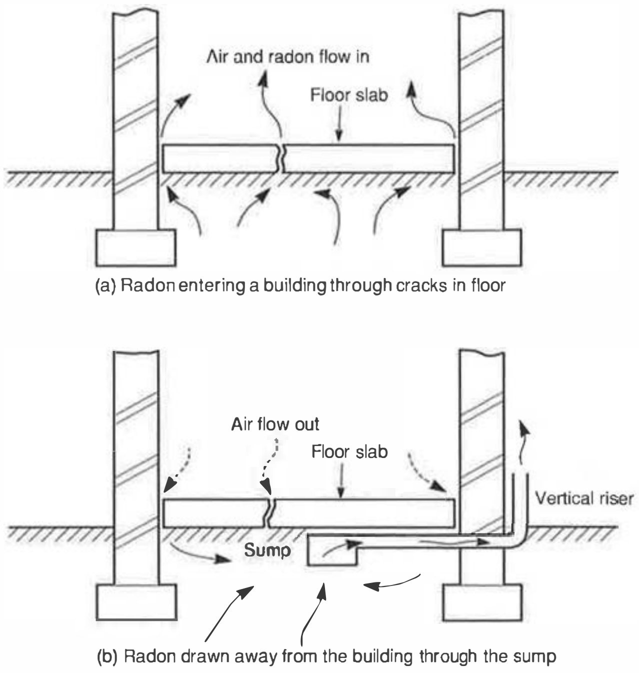

Figure 6 The effect of a radon sump

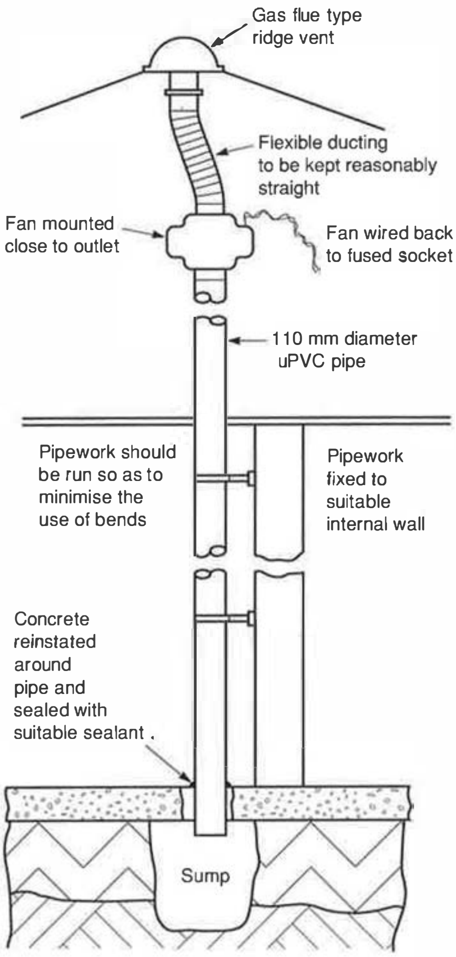

Figure 7 A mini-sump system

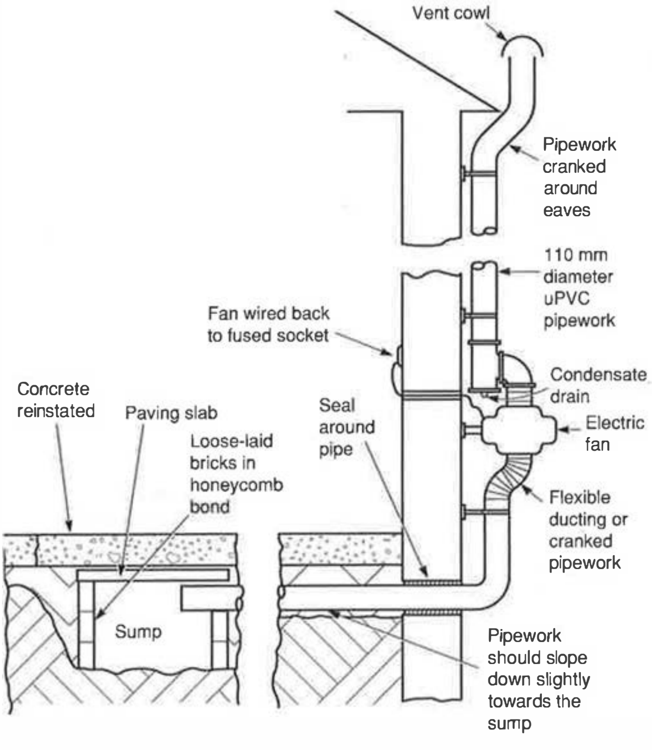

Figure 8 An internal sump with external pipework

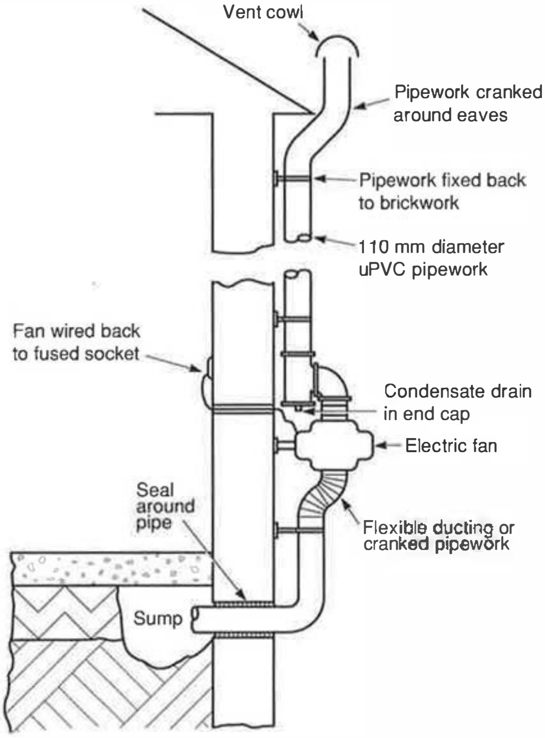

Figure 9 An externally excavated sump

that the standard sump, which can be constructed using bricks and a paving slab or a proprietary prefabricated sump, will only be used where disruption will not pose a problem (Figure 10).

Where the fill beneath the floor is relatively permeable a single sump is likely to be effective over an area of about 250 m^2 or a distance of 15 m from the sump. So for smaller buildings a single sump will be adequate. In larger buildings more than one sump may be required, but usually several sumps can be manifolded together and connected to a single fan.

In some cases, where the pipework is routed up the inside of the building, 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. Having said this, passive sump systems are considerably less successful than those fitted with fans and are therefore probably appropriate only for lower levels of radon. Even so, a passive system which fails to work can easily be upgraded later by installing a fan.

Sump systems are often described as subslab *depressurisation* systems. However, there are cases where it has been found that blowing into the sump and *pressurising* the soil is more effective. The precise mechanism for this is not fully understood but it would appear that positively pressurising the sump is more effective where the subsoil is particularly permeable, as might be the case where there has been past mining activity. As it is difficult to assess soil permeability, we recommend systems be installed which operate by means of suction. If subsequent remeasurement reveals no

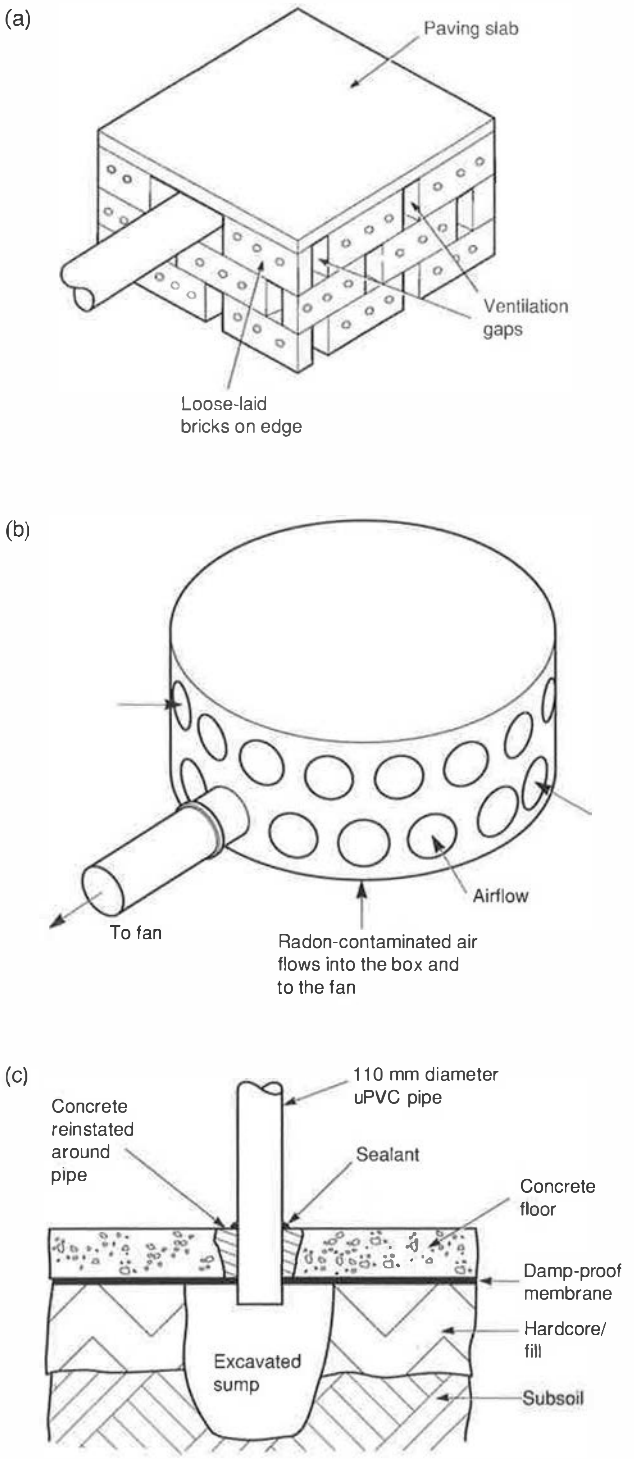

Figure 10 Sump details: (a) standard sump; (b) plastic box sump; (c) mini sump

improvement then it may be worth refitting the fan to blow into the sump since this may give the required effect.

Sump systems can be used with suspended timber floors where they have a covering of concrete over the soil below (Figures 11 and 12). They would normally be considered only where the radon level is particularly high or where improvements to the underfloor 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 timber floor does not have concrete covering the ground underneath, a sump system should not be installed 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. To avoid future problems, when any work is carried out beneath a suspended timber floor, the contractor should ensure that underfloor ventilation is adequate even if other remedial measures are used.

Radon fans and pipework should be located where noise disturbance will be minimal. All fans create noise and vibration. Clearly, the louder the noise, the 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. It is usual to fit a cowl to the sump exhaust to prevent moisture ingress, though this can cause noise problems at the outlet. Where this proves a problem it may be necessary to omit the cowl.

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.

To avoid condensation damage to fans and blockage of pipework by condensate the pipework to sump systems should be self-draining with no U-bends. It may also be prudent to incorporate a condensate drain (see Figure 1). Keep fans close to outlets to avoid condensation damage, and ensure that where the fan is depressurising the system the maximum length of internal pipework and number of joints are under suction, minimising the risk of reintrainment (radon re-entering the building).

It is important to avoid reintrainment because if the radon level in the sump exhaust was measured it could easily be many times greater than the original indoor radon level. Outlets should therefore be located well away from opening windows and doors. Similarly with older buildings where the roof covering does not incorporate sarking, roof outlets must be located so as not to allow radon to be exhausted back towards the roof.

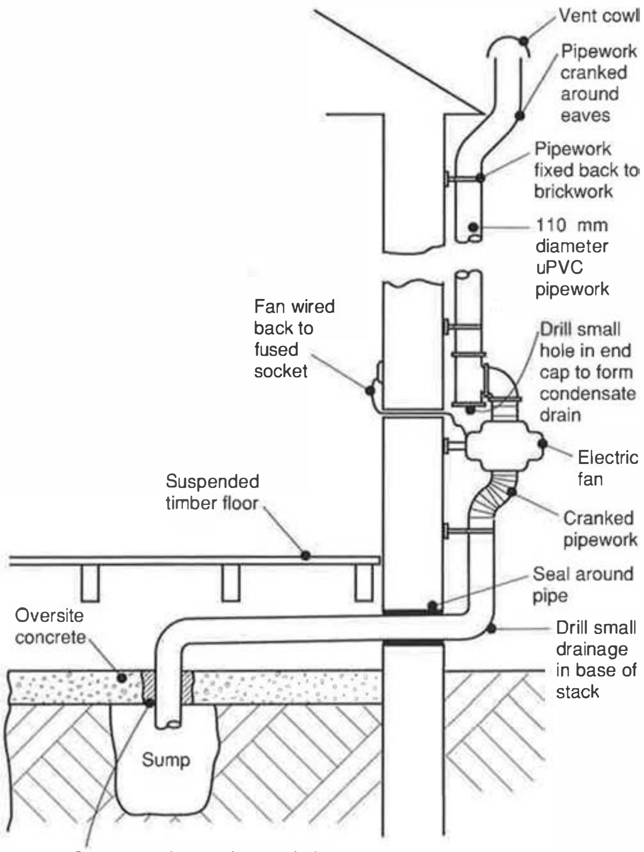

Figure 11 A mini sump beneath a concrete oversite with external fan and ductwork

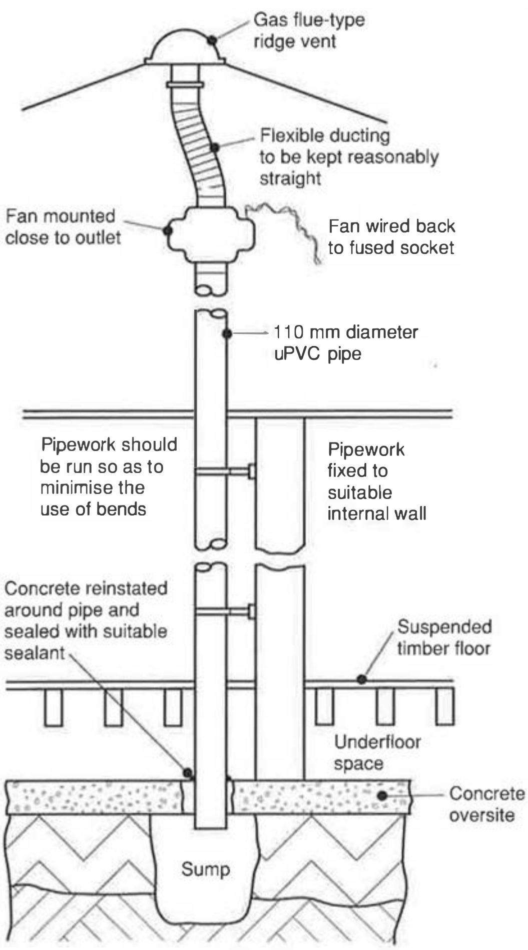

Figure 12 A mini sump beneath a concrete oversite with internal fan and ductwork

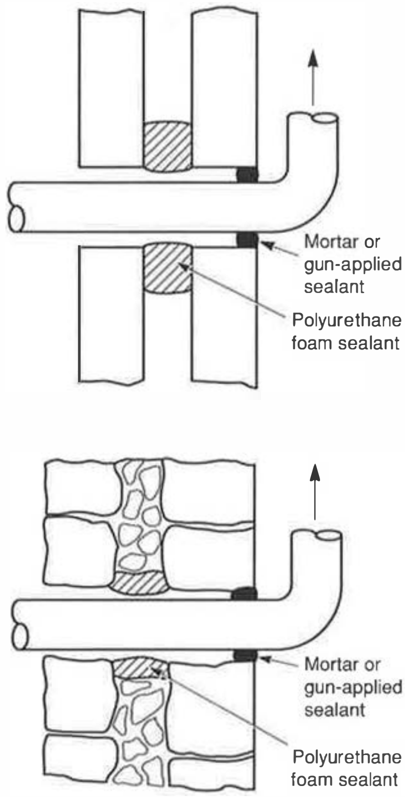

Figure 13 Sealing an externally excavated sump

To maximise the effectiveness of a sump system by avoiding drawing air from the room above it is important to ensure that the pipework is well sealed where it exits the floor. Similarly with an externally excavated sump system avoid drawing air from cavities in the wall by sealing the pipe where it passes through a cavity or rubble-filled wall (Figure 13).

A question that is often asked, is whether radon fans need to run continuously? The answer is that they should be left running unless the building is to be unoccupied for more than a few days. Switching off over the weekend is not recommended as radon levels can build up whilst the building is unoccupied. It could take many hours on the following Monday to reduce the levels again. To ensure continuous running it may be useful to provide an indicator to show when a system has failed.

Note that there is a risk in some extreme cases, where buildings are airtight and have open-flued appliances or open fires, that a sump could draw flue gases back into the building. 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, ensure that the sump fan is not oversized. For further advice on this matter, telephone the BRE Radon Telephone Hotline (01923 664707).

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 400 to 500 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.

Ensure that the vents are installed above ground level. To achieve this it may be necessary to use cranked ventilators (Figure 14). 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.

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 a greater open area and fewer of them will be needed (Figure 15). 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.

Ventilation for a suspended timber floor should always be provided beneath it; vents should not be cut into the floor itself. Where ventilation is required to a combustion appliance in a room with a timber floor, ventilation should be provided above the floor via a wall vent or by ducting beneath the floor (Figure 16).

If natural ventilation proves inadequate in reducing the indoor radon level, then you may choose 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 has proven more effective than suction. There could be problems of draughts inside the building with the system blowing. On the other hand, there is a theoretical risk that suction applied by an oversized fan could draw warm moist air from the building down into the underfloor space, bringing potential timber rot problems.

When considering increasing the air movement under the floor, check whether services routed under the

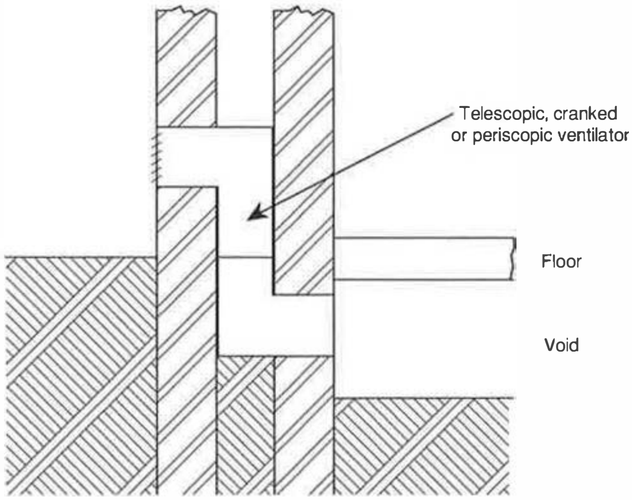

Figure 14 Airbrick with cranked ventilator

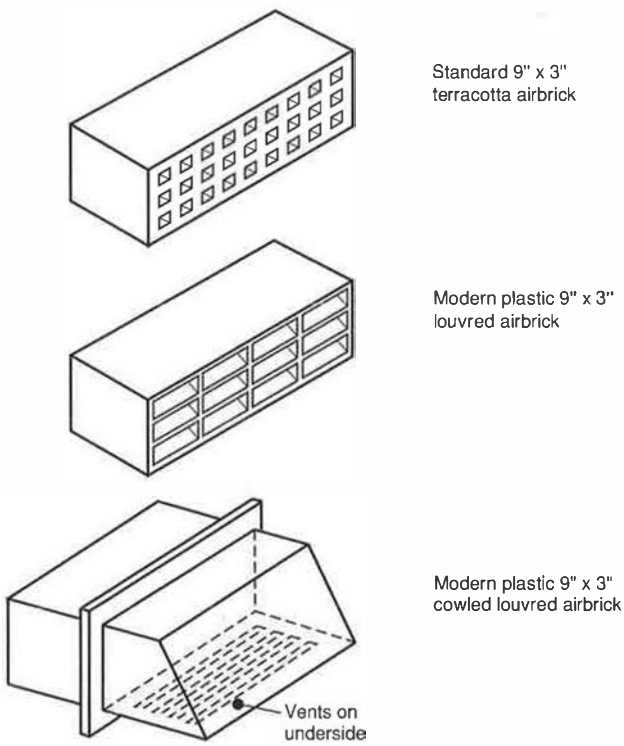

Figure 15 Different types of airbrick

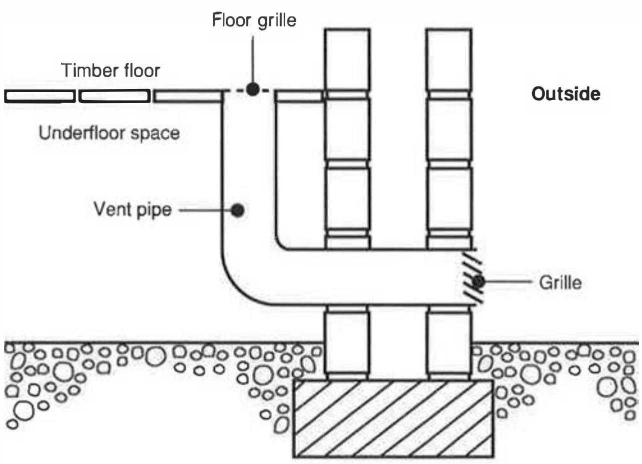

Figure 16 An underfloor ventilated air supply provides outside air to living spaces

floor, particularly central heating or water pipes, could be put at risk from freezing. It may be necessary to insulate vulnerable pipework.

For mechanical ventilation of underfloor spaces, the fan should have a flow rate such that it can exchange the air in the underfloor space between 3 and 10 times an hour. For a small shop or office that is of domestic proportions a fan with an approximate power rating of 75 W is likely to be adequate. The fan may be either axial or centrifugal. There is insufficient evidence to indicate which type is best, but axial fans are inherently more efficient in this application (Figures 17 and 18).

In principle, the use of an axial flow fan is to be preferred for the ventilation of underfloor spaces: these fans are more efficient and quieter. However, because there is often a restricted amount of space beneath the floor, a centrifugal fan may be the only option. For more information regarding fans, contact your local fan supplier. Details can be found in the *Yellow Pages*, heating and ventilation buyers' guides and other similar publications.

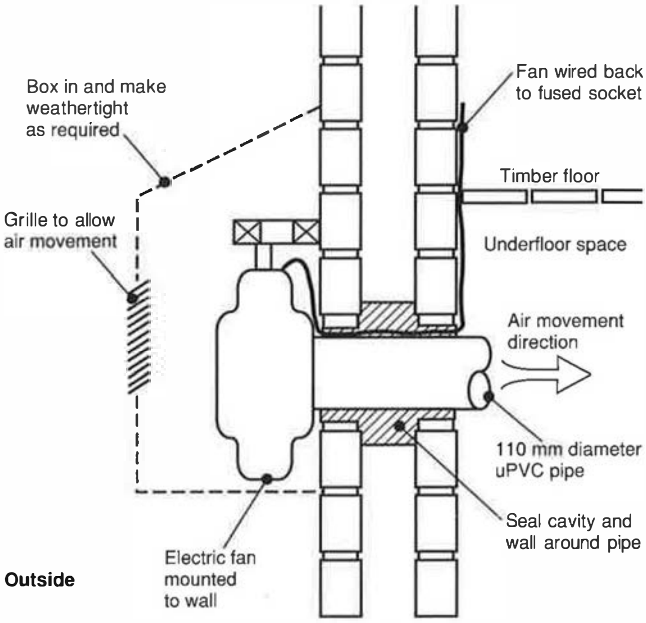

Figure 17 Mechanical supply ventilation with fan mounted outside

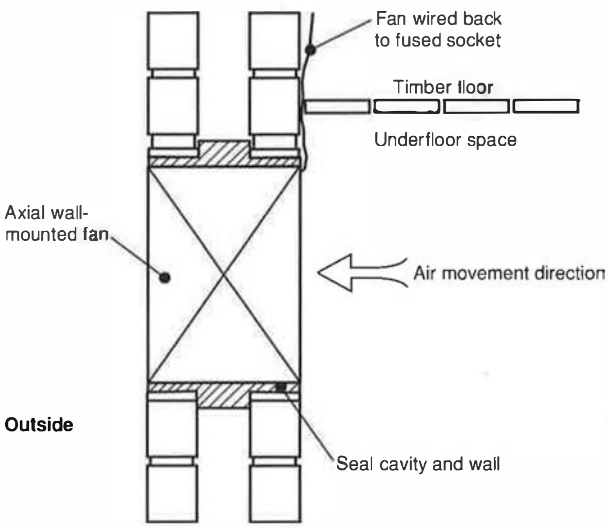

Figure 18 Mechanical extract ventilation with a wall-mounted axial fan

Ventilation (other than positive pressurisation)
While improvements in the way in which a building is ventilated can help to reduce indoor radon levels, increased ventilation can affect indoor comfort and may prove unsustainable. For example, opening lots of windows might help reduce radon levels but it is doubtful that occupants will put up with such ventilation in cold weather. The scope for improvements to the ventilation of buildings is therefore limited.

Simple actions include installing trickle ventilators, capping unused chimneys, and perhaps avoiding using 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 buildings 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. 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 building up inside the chimney. Cap the chimney stack with a chimney-pot hood and provide a small ventilation opening in the blocked up fireplace.

Ensure that extract fans are appropriately sized, and that an adequate supply of fresh outdoor air is provided to avoid depressurisation within the building.

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 in 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. This is especially important for vents to open-flued combustion appliances.

In larger non-domestic buildings it is likely that heating and ventilation equipment such as boilers, chillers and air-handling or air-conditioning plant will be located in separate plant rooms. Boilers and chillers are usually located on the ground floor or in the basement due to the size and weight of the equipment. Commercial boilers usually take in air for combustion from within the plant room. If ventilation to the plant room is poor, radon could be drawn into the room (and building). To prevent this it is important to ensure that the plant room is well ventilated.

Practical experience of dealing with radon in buildings which have complex ventilation plant is extremely limited in the UK. Some work has been done in the USA with mixed results. Assuming the system was operating properly when the radon levels were measured it would be better to use some other means of preventing radon entry into the building, perhaps adjusting the mechanical ventilation or air-conditioning system later as an additional measure in difficult cases. The main reasons for this are that:

(a) performance of such systems will depend greatly on proper maintenance,

(b) adjusting ventilation system air-flow rates may conflict with other health and energy efficiency objectives, and

(c) systems may not have sufficient capacity to effect the necessary changes in air flows to reduce radon concentrations to the required levels.

Another issue which may be considered is that the cost of adjusting a large ventilation system may be greater than installing some other radon remedial measure, and with less confidence of success.

If adjustment of a mechanical ventilation or air-conditioning system is chosen to reduce radon levels then the aim should be to increase fresh air supply air-flow rates and decrease exhaust air-flow rates so as to slightly pressurise the building (or at least reduce any existing depressurisation). Recirculation of air, if used, can continue — it is the difference between fresh air intake and exhaust air discharge to the outside which matters. However, it may be necessary to reduce recirculation to achieve a sufficient increase in fresh air supply; this would depend very much on the design of the system.

These adjustments might be made by manual adjustments of dampers in the air-distribution ductwork or by resetting electronic control or energy-management systems. These are tasks which might best be made with the assistance of a competent building services or HEVAC engineer.

Solutions for complicated situations

Floors of mixed construction

In principle, the solutions applied to buildings 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 in this Report to provide solutions for every combination of floor type. The following points 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 say 600–800 Bq/m^3. For levels up to about 900 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 building. 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 but 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 buildings 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 major cracks and gaps in the basement walls and floor. This is worth trying, 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 building, 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 only just above the action level.

With levels of radon well above the action level, it is likely that a sump system will be required. The number and location of sumps will depend on the layout of the building. It will probably be easier to install such a system in the basement than elsewhere. If the basement extends under only part of the building, the system installed there is likely to influence the radon level only in that part of the building (unless the sump is located in the wall of the cellar). 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 building (Figure 19). If the adjacent ground floor is of suspended timber construction, it may be necessary to deal with the timber floor separately.

Where a building has a small basement which is unused, perhaps a redundant plant room, it may be possible to use the basement itself as the sump. However, if this approach is adopted, the employer will need to ensure that nobody can gain entry to the room as radon levels will rise dramatically in the basement itself once the system is activated. This is despite the fact that the system may have successfully lowered levels in the rest of the building. If any heating or other equipment controls are located in the basement they will need to be moved to an accessible location outside the basement. This may of course prove more expensive than digging sumps into the basement floor or wall as described earlier.

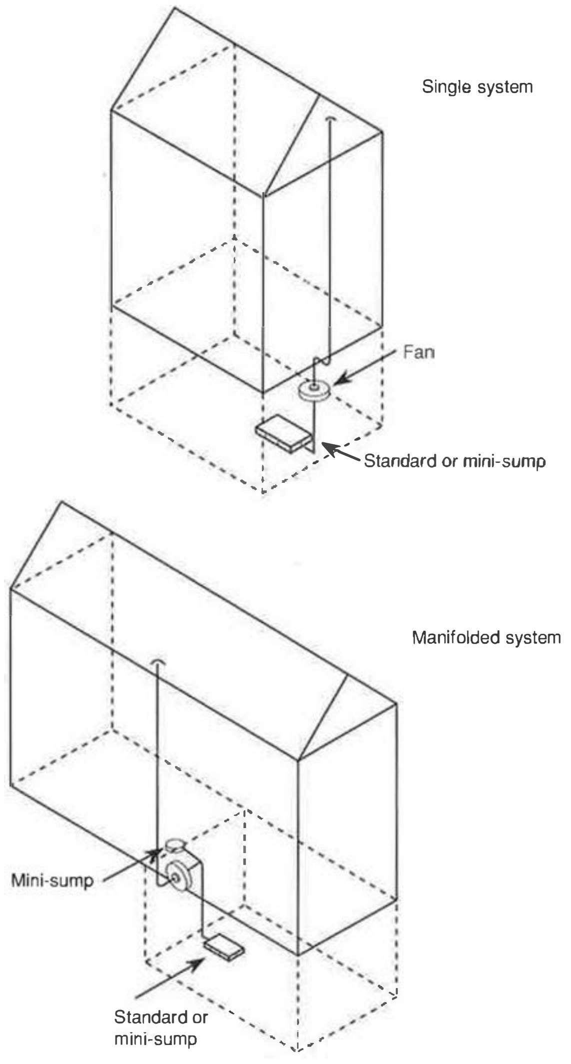

Figure 19 Single- and multi-sump systems for use in basements

Stepped construction

Buildings of stepped construction can be difficult to deal with. The type of solution will be determined largely by the layout of the building and its construction. In most cases, the building 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, levels of radon well above the action level probably mean that a sump system is required. The number and location of sumps will obviously depend on the building. 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.

WHO SHOULD CARRY OUT THE SURVEY OF THE BUILDING AND INSTALLATION OF REMEDIAL WORK?

Where a building is relatively simple, both in construction and the way in which it is used, then the survey can usually be carried out by the building owner, tenant or estates manager. However in cases where the building and its use is more complicated, like the building illustrated in Figure 1, the assistance of a local builder, surveyor, or radon specialist may be needed. If a local builder or surveyor has regularly carried out work at the premises, then it would be useful to contact them to see if they can help. Their past experience in working at the premises could prove useful in determining the measures to be taken.

It is worth noting that many builders have been on courses and attended lectures on radon but do not advertise the fact. They simply treat radon as just another problem to be overcome. This is actually a very good approach as most radon-reduction measures can be installed with no more disruption or expense than dealing with damp problems or treating rot in timber. Many of these builders belong to the Federation of Master Builders (FMB) or Building Employers Confederation (BEC) and will be found listed in the *Yellow Pages*.

If local builders are unable to help either due to inexperience or the complexity of the problem then consider using a specialist radon contractor. There are specialist companies operating in most of the radon-affected areas, as well as a number operating nationally. In the case of large complex buildings, particularly those with mechanical ventilation or air-conditioning systems, it will be worthwhile engaging the services of a consulting engineer.

It is worth considering carefully who is engaged to carry out the work. The following points should be borne in mind:

Local builder

- *Advantages*
  - Travel expenses minimal
  - Regular builder will know the building
  - Local knowledge
  - Labour rates often lower
  - Good knowledge of building matters
- *Disadvantages*
  - Knowledge of radon may be limited

Specialist contractor

- *Advantages*
  - Likely to have considerable radon experience
  - Access to specialist equipment
  - May offer guarantee to lower radon level
  - Likely to carry out detailed survey
  - Experience in carrying out work may mean less disruption
- *Disadvantages*
  - Expertise may not be cheap
  - Travel expenses
  - If a guarantee is offered it will have to be paid for

So how much will it cost? It is of course difficult to offer exact costs for all the different remedial measures discussed in this Guide. Cost will be greatly influenced by who you select to carry out the work, the solution chosen, how easily it can be installed, and the level of finish required. Taking this into account the following is an indication of the likely cost (*1995 prices) for typical solutions applied to medium-sized buildings (about the size of a large detached house). More complex solutions will inevitably cost more.

- Simple sealing of gaps and cracks £30–50+* depending on who does the work
- Increase underfloor ventilation with extra vents £20–50* per vent depending on wall thickness and material
- Install fan to increase underfloor ventilation £200–300*
- Install positive-pressurisation system £400–800*
- Install sump system £350–1500+* depending on type and scale of system

As with any work carried out, quotations should be obtained from more than one company. To assist, a non-profit making and independent self-regulatory body, The Radon Council Ltd, exists for the radon industry. Members of the Council cover all aspects of radon, including supply of specialist components, radon measurement services, radon surveying, and installation of remedial measures. It has prepared a Code of Practice for its members and maintains a list of contractors who can offer radon remedial services. They also run training courses for builders. Representatives from HSE, BRE and NRPB regularly attend Radon Council meetings as observers. The Radon Council can be contacted by writing to:

The Radon Council Limited
PO Box 39
Shepperton, Middlesex, TW17 8AD

or telephone 01932 221212; fax 01932 229779.

Local independent advice may also be sought from environmental health departments of local authorities and HSE area offices.

RETESTING FOR RADON

It is important, once remedial measures have been installed, that the premises are remonitored for radon. Ideally this should be done over a three-month period using the same type of detectors as the original survey and should be placed in exactly the same locations as before. It is therefore useful if the person who placed the original detectors carries out the retest. Contractors may offer to carry out short-term tests to see whether their works have been successful. For particularly complicated situations or where initial radon levels were particularly high, short-term testing may be helpful. However, short-term results can only give an indication of success so long-term test results should be awaited for confirmation.

On completion of remedial measures employers will need to consider setting up a protocol for future monitoring to ensure long-term reductions are achieved. Testing every so many years may be required to ensure that systems continue to function effectively.

ADDITIONAL PROTECTION FOR LANDFILL GAS

In some very rare instances the building being treated is located on or next to a landfill site, in which case additional precautions will be needed to deal with methane. It is therefore advisable to contact the local authority environmental health department before starting work to establish whether the property is near a landfill site. If there is a problem, further advice can be obtained from the BRE Radon Hotline (telephone 01923 664707).

NEW BUILDINGS, EXTENSIONS AND MAJOR ALTERATION AND CONVERSION WORKS

The main aim of this Guide is to offer advice on reducing radon levels in existing workplaces. However many building owners and employers will be considering future expansion plans. These might include erecting new buildings, or making better use of existing premises by extending, or carrying out alteration or conversion works. In each case it would be sensible to consider how radon protection measures can be included in the plans. Taking precautionary measures during construction or when altering a building can help to reduce indoor radon levels, and can make it easier to resolve any future radon problems.

Alteration and conversion works

If a building is to be altered or converted then it may be helpful to test the building for radon before carrying out any work. If it is found that the building has an elevated radon level, reduction measures can then be included as part of the alteration or conversion works. It may well minimise both disruption and cost of installing measures later. For example, if a floor is being replaced as part of the works it would be a simple task to install a sump at the same time.

Although testing prior to carrying out works can be useful, a low result does not guarantee a low result after works are complete. Some works could have an adverse effect on radon levels, and therefore a radon test on completion of works might be appropriate, eg replacing draughty old doors and windows with more airtight units and not providing adequate ventilation could lead to an increase in the radon level. It is therefore important to consider radon when planning alteration works. BRE have prepared guidance for altering or converting houses (*Major alterations and conversions: a BRE guide to radon remedial measures in existing dwellings* (BR 267)) which may also prove helpful for use in non-domestic buildings.

New buildings and extensions

It is important to consider radon when planning a new building or extension in a radon-affected area. Simple protective measures incorporated during construction can significantly lower the indoor radon level of the completed building. Precautionary measures should also be considered so that in cases where protective measures prove inadequate radon levels can be lowered with minimal disruption and cost.

BRE has published guidance on protective measures for new dwellings in support of Requirement C2 of Schedule 1 of the Building Regulations 1991 for England and Wales. No equivalent guidance has been prepared for non-domestic buildings but this is not to say that protective measures may not be needed for non-domestic buildings.

Whilst measures for non-domestic buildings need to be of a more general nature to provide for the large range of building types, uses, size and construction, than for dwellings there are nevertheless several simple measures that can be incorporated into new non-domestic buildings without incurring excessive additional expense. If the building is of a domestic scale then the guidance given in the BRE Report *Radon: guidance on protective measures for new dwellings* (BR 211) is likely to prove useful. For larger buildings the following guidance is offered.

Protective measures

Where a damp-proof membrane is being provided as part of the ground-floor construction the membrane can be designed to double as a radon barrier. This can be achieved relatively simply by extending the membrane across the entire plan of the building including foundation walls, and sealing all service penetrations and joints in the membrane. Care will be needed in detailing at the edges of slabs where the membrane has to be taken through the external wall (Figure 20).

Generally a membrane of 300 µm (1200 gauge) polyethylene (Polythene) sheet will be adequate. (It is acknowledged that some diffusion will occur through the sheet. However, as most radon entry is through cracks, this diffusion can be ignored.) Where there is a

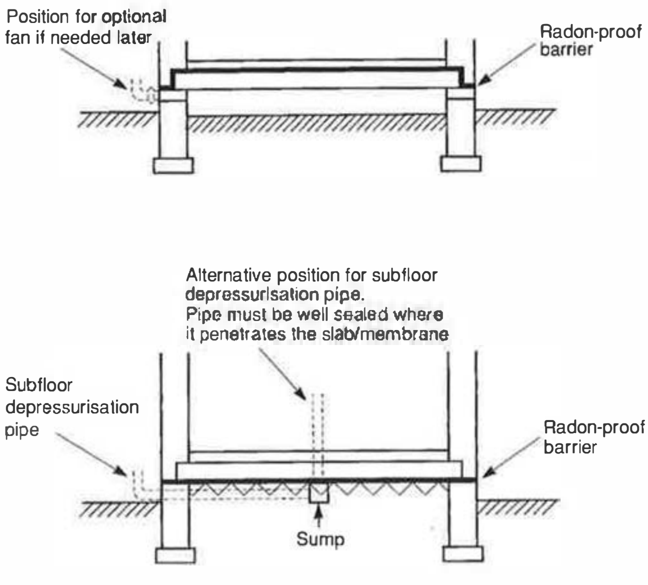

Figure 20 Radon-proof barriers (a) in suspended concrete floor, (b) in in-situ or ground-supported concrete floor

risk of puncturing the membrane, reinforced polyethylene sheet should be considered.

The membrane can be constructed using other materials which match the airtightness and waterproofing properties offered by polyethylene. Alternative materials that can prove suitable include modern flexible sheet-roofing materials, prefabricated welded barriers, liquid coatings, self-adhesive bituminous-coated sheet products, and asphalt. Prefabricated welded barriers are likely to offer a greater confidence in achieving radon-proof joints than the use of polyethylene sheet, but are more expensive. One solution which has been found to be effective is to use polyethylene sheet over the bulk area of the floor jointed to a more robust sheet material for corner and edge details.

When selecting the membrane material consideration should be given to jointing. Some materials are difficult to seal in adverse weather. It is also important that the radon-proof membrane is not damaged during construction. This might be achieved by installing parts of the membrane at a later stage of construction, eg across walls during construction and over the floor areas immediately before laying the screed.

Precautionary measures
In addition to providing a barrier to radon it is worth considering incorporating secondary or precautionary measures. These measures would be provided as a fallback, so that if the radon-proof membrane proved inadequate a remedy could be easily applied.

Where a ground-supported (in-situ concrete) floor is to be constructed, a sump with a pipe to the outside can be provided beneath the slab. This would enable sub-slab depressurisation to be introduced with relative ease at a later date. If clean permeable fill has been used beneath the slab, a single sump is likely to have an influence over an area of approximately 250 m^2, or for a distance of 15 m from the sump when connected to a typical 75-watt centrifugal fan. For larger floor areas more than one sump will be needed. Even so, four or five sumps can often be manifolded together so that only one fan will be needed. At the construction stage only the sump and pipework need be installed. If subsequent testing indicates a high indoor radon level a fan and exhaust stack can be fitted and the system activated.

In the case of a suspended (precast beam-and-block) concrete floor the void beneath the floor can be considered as providing secondary protection. If subsequent measurement shows that there is a radon problem in the building a fan can be connected to the underfloor void. Activating the fan will either depressurise or pressurise the underfloor area, in the same way as a radon sump system beneath a solid floor, or it will increase the underfloor ventilation thereby diluting the radon-laden air beneath the floor.

Timber floors
Experience in dealing with radon in existing buildings has shown that buildings with suspended timber floors can prove difficult to resolve. As a consequence the use of suspended timber floors is generally discouraged for new buildings in radon-affected areas. If timber floors are specified, suitable protection will need to be provided to the soil beneath the floor.

ACKNOWLEDGEMENTS
The authors would like to thank the many building owners and others who have assisted in the research on which this Report is based. Particular thanks go to the Radon Testing and Mitigation Service at Cornwall County Council for allowing access to, and measurement results from, many County Council properties.

Thanks are also due to K D Cliff and D W Dixon of the National Radiological Protection Board for assistance with long-term radon measurements and advice on measurement protocols for workplaces.

We should also like to thank the BRE radon team, including M Bush, A Cripps, M Jaggs, K Noonan, P Pye, R Stephen, P Welsh and M Woolliscroft, for their assistance in preparing this report.

USEFUL READING

1 **Ionising Radiations Regulations 1985.** *Statutory Instrument 1333.* London, HMSO, 1985.

2 **Health and Safety at Work etc. Act 1974.** London, HMSO, 1974.

3 **Health and Safety Executive.** *Radon in the workplace*, leaflet, (IND(G) 123L CSOO 3/92).

4 **Health and Safety Executive.** Information Document (HSE 560/20).

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

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

7 **Welsh P A, Pye P W and Scivyer C R.** *Protecting dwellings with suspended timber floors: a BRE guide to radon remedial measures in existing dwellings.* Building Research Establishment Report. Garston, Construction Research Communications Ltd, 1994.

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

9 **Building Research Establishment.** *Radon: guidance on protective measures for new dwellings.* BRE Report. Garston, Construction Research Communications Ltd, 1991, revised 1992.

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

11 **Building Research Establishment.** Radon and buildings: 1. Spillage of combustion products. *BRE Leaflet XL8.* Garston, Construction Research Communications Ltd, 1994

12 **Building Research Establishment.** Radon and buildings: 2. Minimising noise from fan-assisted radon sump systems. *BRE Leaflet XL9.* Garston, Construction Research Communications Ltd, 1994.

13 **Building Research Establishment.** Radon in buildings: 3. Protecting new extensions and conservatories. *BRE Leaflet XL10.* Garston, Construction Research Communications Ltd, 1994.

14 **Building Research Establishment.** *Positive pressurisation: a BRE guide to radon remedial measures in existing dwellings.* BRE Report. Garston, Construction Research Communications Ltd, 1995.

USEFUL ADDRESSES

For advice on building matters relating to radon:

Building Research Establishment, Garston, Watford, Herts, WD2 7JR.
BRE Radon Hotline: 01923 664707.

BRE publications: CRC Ltd, 33-39 Bowling Green Lane, London, EC1R 0DA. Telephone: 01923 664444; fax 01923 664400.

For advice on remedial measures used in non-domestic buildings:

Cornwall County Council, Radon Testing and Mitigation, County Hall, Truro TR1 3AY. Telephone: 01872 322000.

Somerset County Council, Radon Testing and Mitigation, Somerset Technical Services, County Hall, Taunton TA1 4DY. Telephone: 01823 255194.

For information on radon in the workplace:

Health and Safety Executive, Library and Information Services, Broad Lane, Sheffield S3 7HQ.

or your nearest HSE Area Office (the number will be in your local telephone directory).

Health and Safety Inspectorate, 83 Landas Drive, Belfast.

Chartered Institute of Environmental Health, Chadwick Court, 15 Hadfields, London SE1 8DJ. Telephone: 0171 928 6006.

For advice on radon risks and monitoring:

National Radiological Protection Board, Chilton, Didcot, Oxfordshire OX11 OQR. NRPB Radon Freephone: 0800 614529.

For details of companies who can offer radon remedial services:

The Radon Council Limited, PO Box 39, Shepperton, Middlesex TW17 8AD. Telephone: 01932 221212.

The Federation of Master Builders, Gordon Fisher House, 14/15 Great James Street, London WC1N 4AD.

Building Employers Confederation, 82 New Cavendish Street, London WC1N 3DP.

Appendix: Case studies

The following case studies have been compiled to assist building owners, employers and construction professionals in selecting appropriate radon remedial measures. We have endeavoured to include the key construction types and building uses, and to illustrate most of the remedial measures described in this Guide.

The buildings described in the case studies are fictional. However each case study is based on a real building and describes the background information and problems that regularly need to be taken into consideration, and discusses the solutions installed

A floor layout is provided for each building described. Marked on the floor layouts are the radon measurements before (A) and after (P) mitigation, indicating the successes achieved in each building.

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CASE STUDY 1

DOCTORS' SURGERY

Sump beneath timber floor

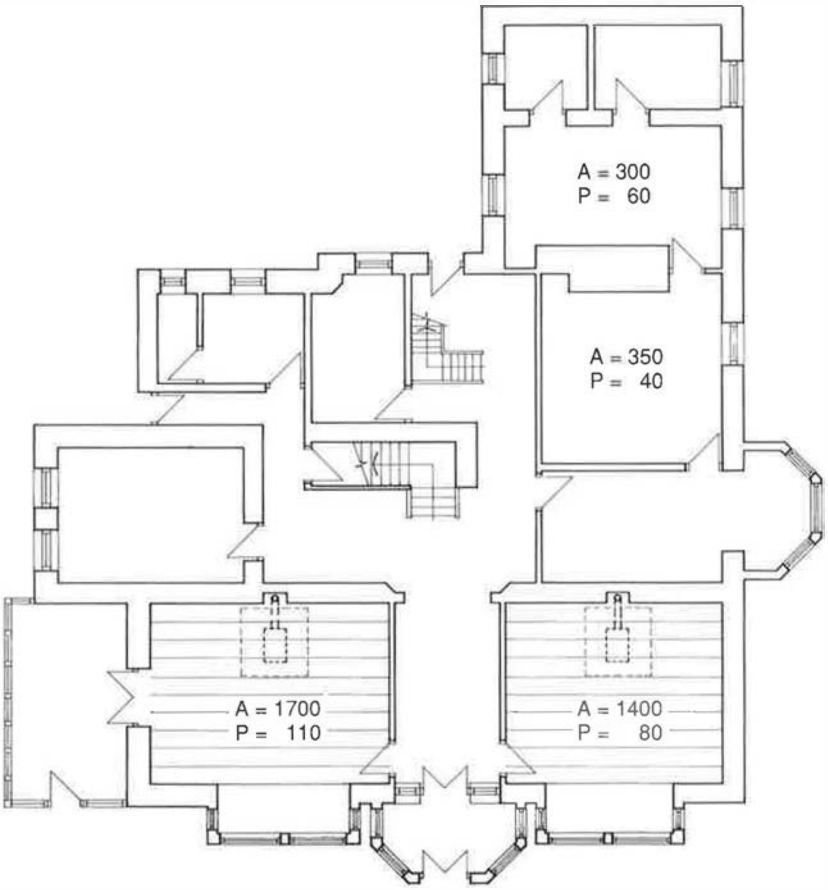

Figure 1.1

Trebogus House was built in 1825 by the wealthy Penberthy family on the proceeds of copper from their nearby mine, Wheal Hopeful, on the outskirts of a small Cornish town. In 1980 it was acquired by the local practice of general practitioners and has been used as a surgery ever since.

The two-storey house is a Grade II Listed Building and in terms of construction is typical of its area and period (Figure 1.1). The external walls are of granite some 600 mm thick, finely cut on the front elevation but rendered elsewhere. The windows are more recent copies of the original single-glazed 4-pane vertical sliding timber sash units. The hipped roof is of natural slate re-layed in 1974 when sarking felt was introduced. At the time, night-storage electric heaters were fitted throughout and (before the Listing) the redundant chimneys were removed and slated over.

The floors of the major rooms at the front of the house are suspended timber with the original 175 mm wide butt-jointed boards covered with carpet or vinyl sheet. The shallow voids beneath the floors have no covering to the solum. The entrance lobby and central corridor floors are solid, covered with Victorian tiles, and what was the kitchen and servants accommodation to the rear of the premises also features solid concrete floors. There are no changes of level on the ground floor and somewhat atypically there is no basement.

The surgery was tested for radon in 1991. The test was carried out for 3 months in the winter using four etch-track detectors placed in full accordance with the NRPB placement protocols.

The following mitigation work was carried out some months after receipt of the results.

Mitigation

Each of the voids below floors to the two front rooms with the highest radon levels were fitted with a sump set into the earth sub-floor. The solum was then overlaid with a 50 mm layer of pea shingle and reinforced polythene membrane carefully lapped and tape jointed at the perimeter and at sheet joints to provide a barrier, with a further 50 mm layer of pea

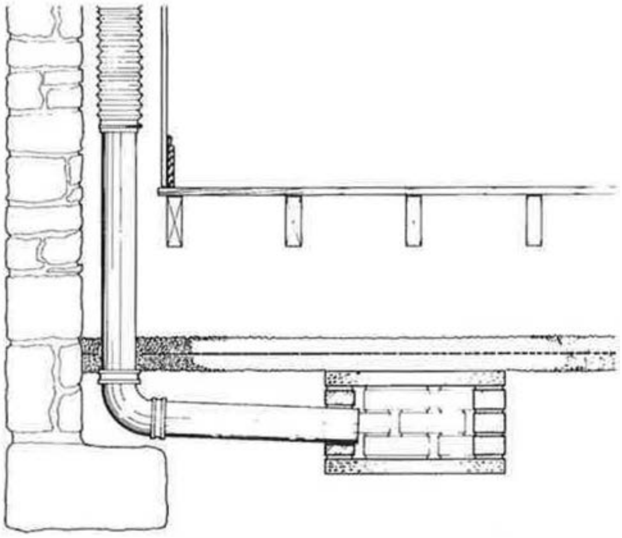

Figure 1.2

gravel to hold the membrane in place. PVC-U pipework of 100 mm diameter was taken from the sump via a bend to the fireplace of the redundant chimney (Figure 1.2).

A flexible pipe was then taken up through the chimney flue into the roof void and to a duct fan mounted immediately below the ridge discharging via a gas-vent ridge tile to the atmosphere.

Additional natural cross-ventilation was provided to the under-floor voids below the timber floor. The building was retested during the winter following mitigation using the same-type etch-track detectors placed in the four original positions.

The timber floors overlaid with vinyl sheet and some areas of carpet which had been underlayed with plastic showed signs of dry rot and sections required replacement. This made the mitigation work below the floor much quicker and easier than in those areas where access was restricted to the shallow void via by a small trap hatch and in some cases necessitating forming openings in sleeper walls sub-dividing the void. In the more accessible void a 'standard' sump was constructed but in the restricted areas a preformed one was fitted. The slate hearths required careful coredrilling to allow the pipes to pass through and the redundant flues proved difficult to clear as they were still blocked by debris from the demolished chimneys. In one instance the chimney breast had to be broken into from one of the rooms; fortunately this did not affect anything covered by the building Listing.

Larger size fans than usual were fitted (145 watt instead of 75 watt) partly because of the large two-storey pipe run but, chiefly because of the increased transmission losses in the flexible pipework as against those in rigid plastic. Special care was taken in the roof void to ensure that the flexible pipework was adequately supported and laid to fall back to the sump.

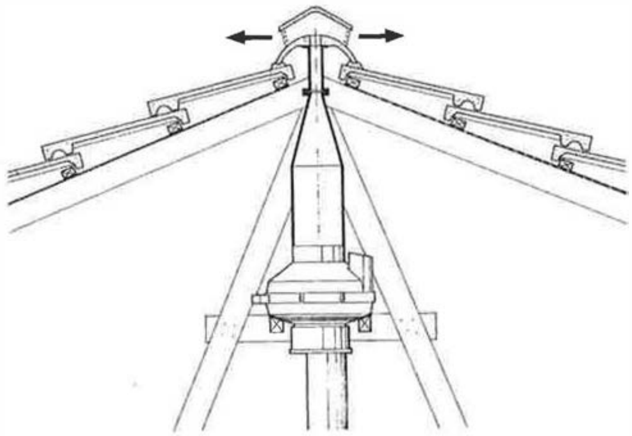

Figure 1.3

In a similar situation elsewhere a large U-bend had been formed by water vapour drawn from the soil condensing in the pipework, the weight of several gallons of water was sufficient to pull the pipework off the flange of the fan causing considerable damage to the ceiling below.

A gas-vent ridge tile outlet was chosen as the least visually obtrusive design. Such outlets with their small cross-sectional area may produce a noticeable whistling sound and have caused annoyance to near neighbours in other situations. They are also unsuitable for unsarked roofs where reintrainment can be a problem (Figure 1.3).

Partly to reduce radon levels but also for improved conditions for the timber floors, additional air grilles were fitted in accordance with the latest Building Regulations requirements to provide cross-ventilation to the underfloor voids. In this case particular care in choice of pattern and fixing was dictated by the building being Listed.

In order to further improve the life of the timber floors, the building owners were persuaded to remove vinyl sheet wherever possible. All rooms are now carpeted with the exception of the treatment room which has a concrete floor anyway. At one stage it was suggested that some of the butt-jointed board floors should be left exposed but the combination of the secondary glazing and the electric heating causing the boards to dry out and shrink, allowing the increased underfloor void ventilation to percolate through the wider joints between the boards, ruled out this option.

As predicted, the reduction in levels in the front of the building have caused a reduction at the rear where no mitigation took place. This was due to contaminated air circulating from one space to another. In another case, it might have proved necessary to provide a further mitigation system at the rear of the premises. This would probably have been best tackled as a second phase after the above work had been carried out and tested.

CASE STUDY 2

PRIMARY SCHOOL

Standard sump system

Figure 2.1

St Ware's Junior and Infant School was built in 1982 next to a small housing estate on the edge of a Cornish village as a replacement for its deteriorating Victorian predecessor.

It has two pairs of classrooms, one pair of which shares a workspace. There is a central hall and a separate administration wing.

Its construction is typical for a school of this age and size (Figure 2.1). Load-bearing cavity walls of fair face brick outside and rendered block inside bear on concrete strip foundations. The floors are 125 mm thick concrete with a single layer of A142 fabric anti-crack reinforcement on a 150 mm layer of imported granite quarry waste hardcore, blinded with sand and overlaid by a simple polythene damp-proof membrane. The concrete is topped by a 50 mm sand–cement screed and floor finishes are mainly a mixture of needle punch carpet and welded vinyl sheet with the exception of the hall which is wood block.

There is a mixture of lay-in-grid suspended ceilings and plasterboard-and-skim items supported by timber joists. The roof is shallow pitch with interlocking tiles on timber rafters with a number of large supporting steel purlins. The windows are single-glazed aluminium units in timber sub-frames.

The school was originally tested for radon in 1986 during the Autumn term using etch-track detectors. The radon levels found were as shown varying from 200 to 1300 Bq/m^3.

Mitigation

A total of four self-contained sub-slab depressurisation systems were fitted in the positions shown. Sumps were all of the 'standard' pattern and each was arranged so that the maximum distance to any point in the building was no more than 20 m and each sump dealt with no more than 250 m^2 of floor area.

The sumps were placed adjacent to major load-bearing internal walls and a short stub pipe was taken from the sump through a hole cut in the adjacent wall below floor level to a void excavated through the hole immediately below the underside of the floor on the other side of the wall (Figure 2.2).

Before replacing the floor a new section of membrane was taped to the exposed edge of the existing membrane.

PVC-U pipework of 110 mm diameter was taken via a bend from the sump up the face of the wall and into the ceiling void. The pipes were enclosed in pre-formed ply boxing sections from floor to ceiling. The pipes were taken from the ceiling to duct fans mounted immediately below the sarked tiles to discharge through a matching tile vent (Figure 2.3).

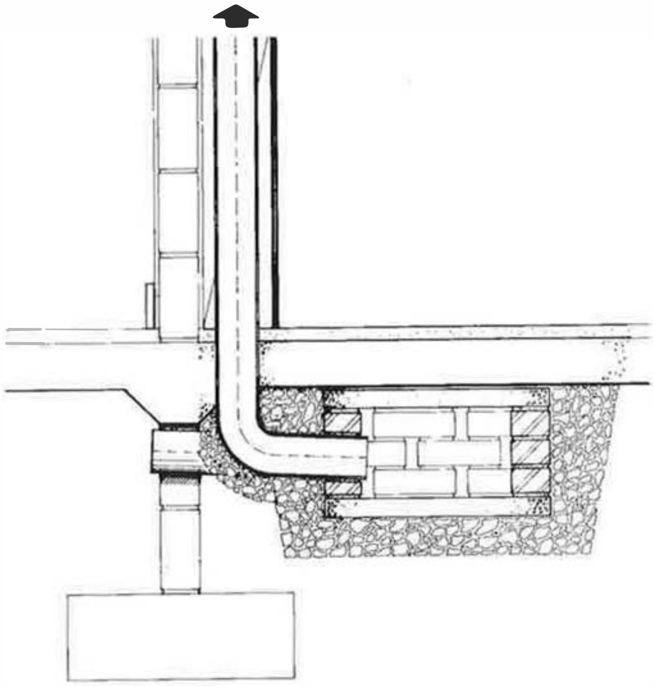

Figure 2.2

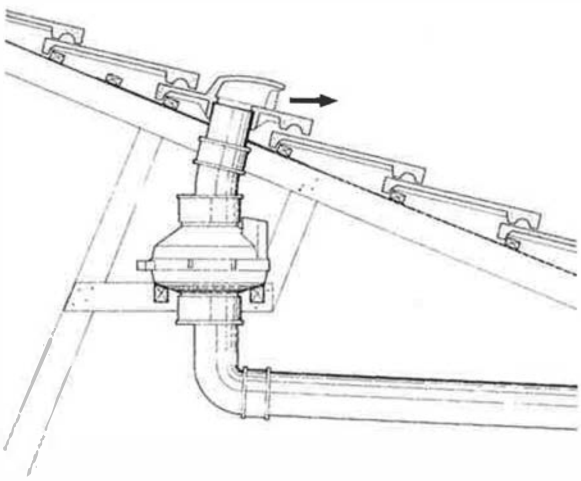

Figure 2.3

The mitigation consultants had obtained some original sketch drawings from the architects showing the proposed foundation layout. This enabled them to locate the position for the sumps with some accuracy. Unfortunately, unbeknown to them, during the original construction a large area of soft ground had been found and the structural engineers had designed a series of reinforced concrete ground beams for one wing. This was not indicated on the original drawings so it was only after the contractor had already cut through 600 mm thick concrete and four 25 mm diameter high-yield steel reinforcement bars that the alteration was realised. The consultants had to adjust the position of the sump by about 1.5 m. Fortunately in this case the reinforcement was able to be welded and the beams replaced without problems of structural collapse or movement.

The vent tiles used are proving less noisy than ridge vents but nevertheless are audible in very still conditions. Following complaints from the next-door neighbour, one of the outlets was relocated on the other side of the ridge using a simple bent pipe outlet (Figure 2.4). Fortunately this more obtrusive design of outlet is not in public view but has meant that what was a short and near-vertical stack has now acquired a long near-horizontal run above the ceiling. Even with rigid plastic pipe, several supports are required to prevent bowing and to avoid condensation being trapped in the system.

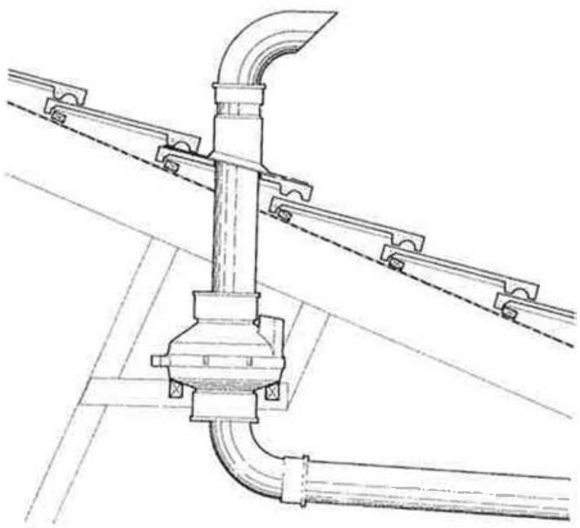

Figure 2.4

Although a separate incident, some time after the work was completed a newly-appointed caretaker fitted an extra sink unit and connected the trap to one of the radon pipes thinking it was the soil vent pipe. His mistake came to light some weeks later when he was called to unblock the sink. For this reason it is now common practice to label all radon pipes. Pre-printed self-adhesive tapes are available for the purpose.

CASE STUDY 3

OFFICES

Sump system

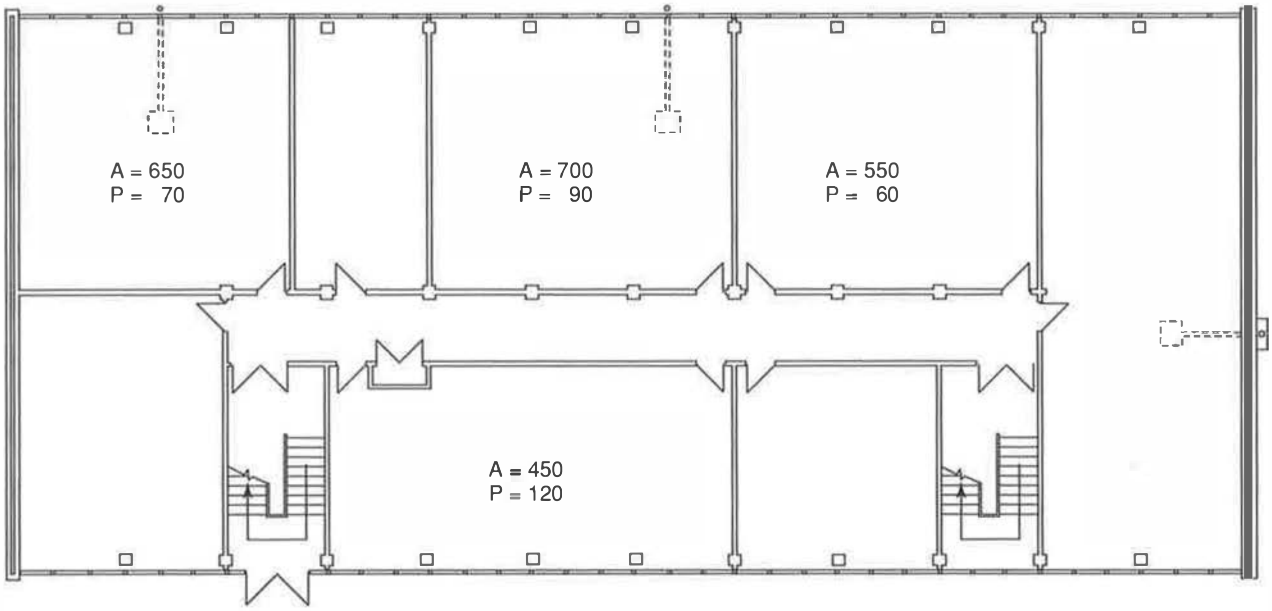

Figure 3.1

Macawber House was built in 1971 on the outskirts of a Northamptonshire town as local government offices. When services were transferred to other premises in 1985, the block was bought by a development corporation and let as office accommodation to a number of separate companies.

The building is four storeys high and is supported on an in-situ-cast concrete frame bearing on concrete pad foundations. The end walls are faced in brick and the side elevations feature curtain walling with fixed and centre-pivot steel windows between square hollow-section steel mullions. The ground floor is a ground-bearing concrete slab and all upper floors are cast-in-situ concrete. It has a flat roof comprising asphalt on wood-wool slabs. The wet-system central heating was originally oil-fired but was converted to a balanced flue natural gas system when the change of ownership took place (Figure 3.1).

A number of the building occupants arranged for their own offices to be tested for radon in 1988 and several high readings were found.

Mitigation work was deferred until the completion of lengthy discussions about how the initial work and running costs should be funded.

The clients were anxious that any work should be completed with the minimum disruption, and with as little visual impact as possible. They also emphasised that they would be happier paying a little more initially for a more robust solution than risk the necessity of further visits and additional work.

Mitigation

Three separate pre-formed plastic sumps were fitted below the floor with 110 mm diameter PVC-U pipework taken to the perimeter again below the floor. Fans of 145 watt were fitted in boxes at low level and the pipework taken through the wall and upwards via a pair of bends. One duct cowl outlet terminated at first-floor level on the rear end wall of the property. The other two outlets were taken up the face of the rear elevation to terminate 600 mm above roof level.

The consultant, given the clients' brief, elected to fit three systems although the floor area at 450 m^2 was such that in other circumstances two similar systems might well have proved adequate.

All the work to install three sumps, the underfloor pipework and reinstatement of the floors was carried out over a single weekend. To improve effectiveness, one of the sumps was linked to a redundant underfloor service duct.

The fan boxes were fitted with insulation internally to reduce the low fan noise even further. The fan controls were also mounted inside the boxes to avoid tampering. A warning light and key-operated isolating switch were mounted externally beside each box.

From the outset it was recognised that taking three pipes up through three pre-cast concrete floors and causing disruption throughout the building would not be an acceptable option. However, mounting the outlets at high level clear of opening windows was known to cause condensation build-up in the long lengths of pipework above the fans. Hence a simple U-bend with a small hole drilled at the lowest point to allow condensate to drain out was introduced in the bottom of the vertical stack of the shorter pipe on the rear end wall. On the two taller stacks a proprietary annular drain coupling unit was fitted with small-bore pipework taken to discharge into a nearby rainwater gully.

Special care was taken to avoid drilling holes for the stack fixing brackets in the steel mullions of the curtain walling, a proprietary clamp being used instead for the purpose. The relative size of the pipe and the mullion also meant that a number of the opening windows had to be sealed shut; fortunately the windows were to rooms rarely used. Because of its proximity to a loading bay a lightweight tubular steel guard was fitted to the pipe at low level to prevent accidental damage by delivery and service vehicles.

CASE STUDY 4

JOINERY WORKSHOP AND OFFICES

Internal standard sump system

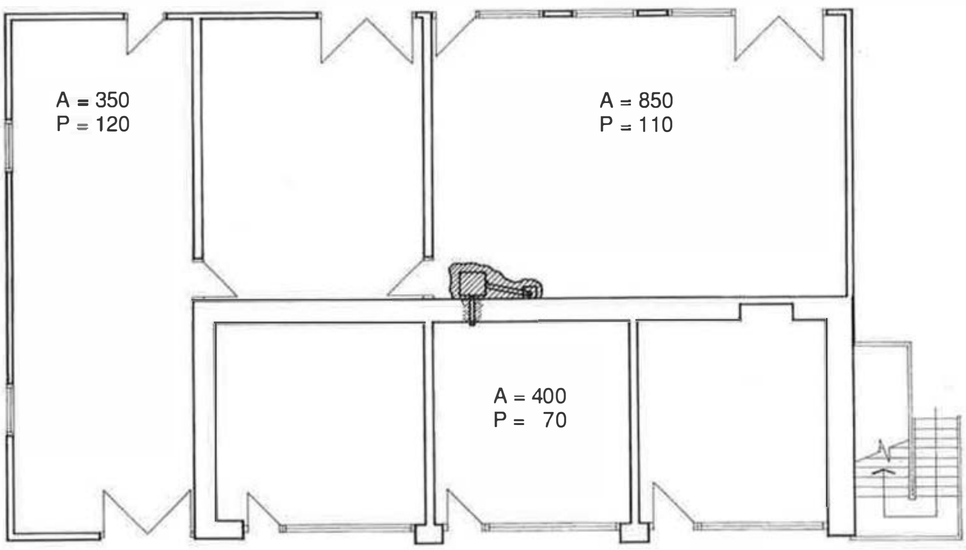

Figure 4.1

New Dorre Joinery Ltd has been operating from a group of five buildings on a small industrial estate in Derbyshire since 1948. The buildings themselves are up to 150 years old and for the most part consist of load-bearing masonry walls with an assortment of window designs. The floors are of poor-quality concrete, in places less than 50 mm thick. Some roofs are slated but the majority are of profiled sheet, asbestos or corrugated iron.

All of the workshops are single storey but one forms part of a block with a two-storey area which was converted to offices in 1988. All blocks were tested for radon in 1989 but only one showed levels above the action level, this one being the block with the upper storey (Figure 4.1). Total ground-floor area of this building was approximately 220 m^2.

Mitigation
A single pre-cast concrete sump with a single stub pipe was fitted in the workshop floor adjacent to the two-storey block where the building had been extended in the past. A 110 mm diameter PVC-U pipe was taken up the wall to a 75-watt fan mounted in a box immediately below the roof. This lower roof was constructed of corrugated asbestos sheeting on timber rafters and purlins. The fan speed control and operating warning light were mounted outside the box at high level. The outlet was taken through the roof to discharge above the eaves level of the upper roof clear of first-floor windows.

The majority of the mitigation work was carried out by the client with the advice of the consultants. The vertical pipe was enclosed in a large but cheap duct to prevent accidental damage.

Instead of using a condensation trap on the long outlet pipe above the fan, the 110 mm diameter PVC-U pipe was enclosed in a second 225 mm diameter PVC-U pipe and the annular space between the two pipes packed with loose insulation (Figure 4.2).

The client had no wish to replace the workshop floor for reasons of cost and disruption to his business. However, the opportunity was taken to patch some of the larger holes and an epoxy coating was painted on, largely as a safety measure independent of any radon requirement.

One reason why this one workshop block exhibited high radon levels may well have been the large extract fans fitted in the roof. Although there were no opening roof lights, care was taken to keep the radon outlets at high level well above the extract fan outlets since the radon fan ran continuously whereas the extract fans ran only intermittently and would offer a reintrainment route when not operating.

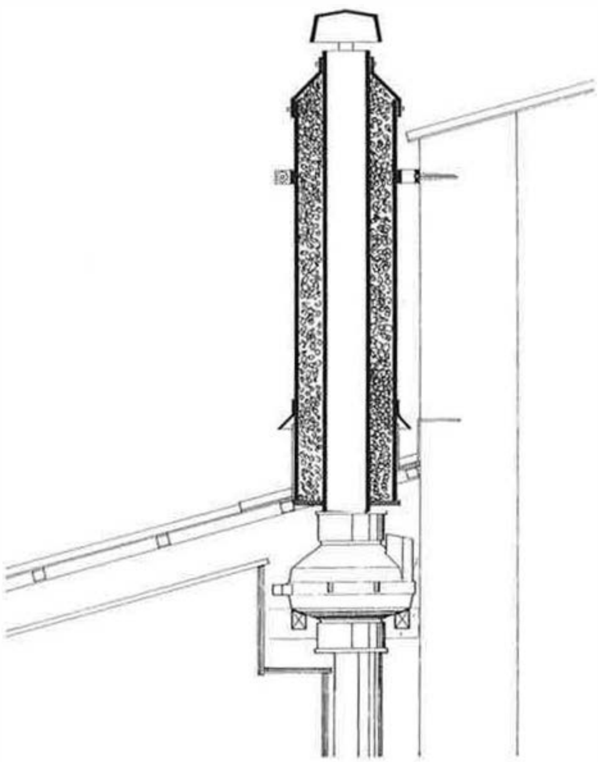

Figure 4.2

CASE STUDY 5

OFFICE BLOCK

Sump system beneath timber floor

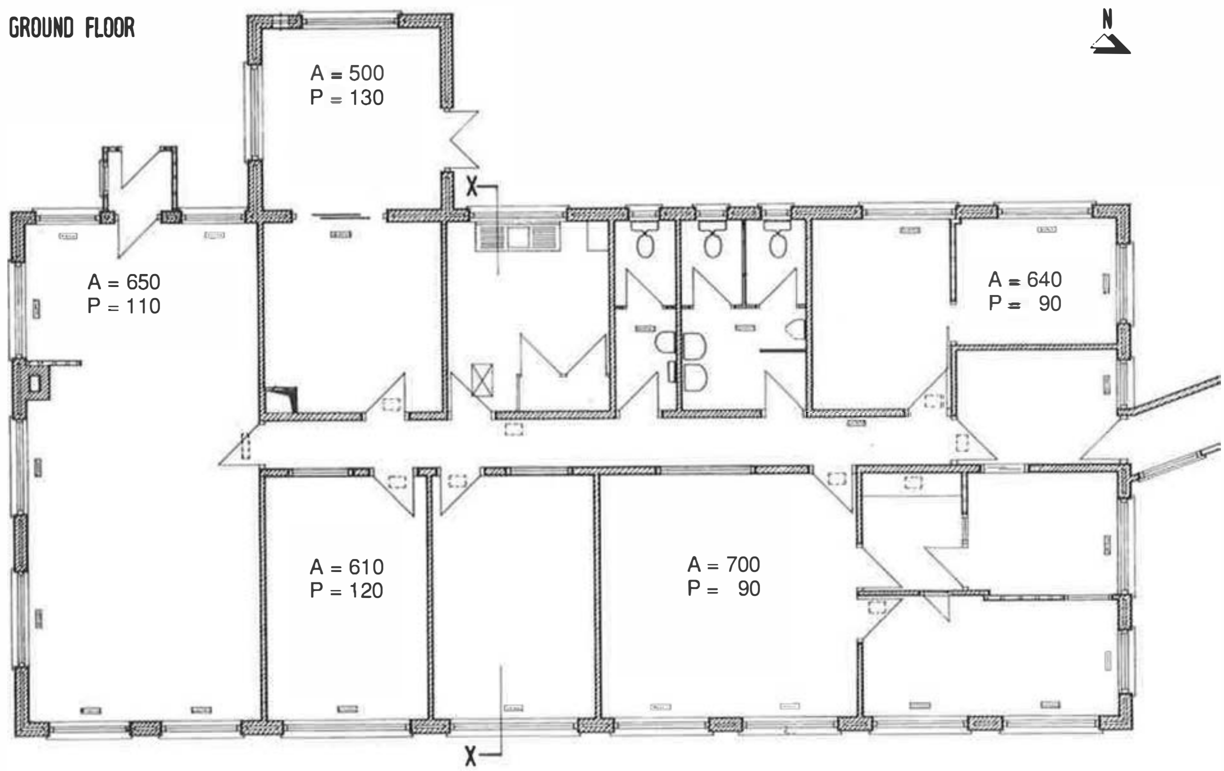

Figure 5.1

Alpha Transport (established 1934) run a fleet of lorries from a disused quarry in rural West Devon. The garages and stores are all constructed on steel portal frames covered with a variety of cladding materials. The offices are housed in a single-storey block built in 1962.

The office block is constructed of load-bearing rendered concrete block walls on strip foundations with recently fitted PVC-U replacement windows. The pitched roof is of unsarked slates on battens and rafters with a plasterboard ceiling on timber joists. The 350 m^2 floor is of tongue-and-groove boarding on timber joists bearing on honeycomb block sleeper walls with oversite concrete to the underfloor void. The heating system was originally a warm-air ducted system discharging through grilles in the timber floor but this was replaced by a more conventional radiator system when the windows were replaced in 1987 (Figure 5.1).

Following advice from the local HSE inspector that high levels of radon had been found in nearby properties, the company had the office block tested. It was felt that the ventilation in the other buildings would be such as to make radon build-up extremely unlikely there.

Uniformly high levels were found in the offices and mitigation work was carried out.

Mitigation

A pair of standard sumps were created below the oversite concrete. PVC-U pipes of 100 mm diameter were taken up through the suspended timber floor and adjacent to the internal partitions to discharge above the roof via vent cowls, the fans being fitted into the roof void immediately below the slates (Figure 5.2).

The uniformly high radon levels found initially were largely due to the original warm-air heating system grilles in the floor allowing radon to percolate through the building. The opportunity was taken to infill these grilles and at the same time to increase the natural cross-ventilation of the underfloor void by fitting additional air bricks and unblocking a number of existing items. The cross-sectional area of ventilation provided now corresponds to that required by the latest Building Regulations for new properties. However, it was felt that void ventilation alone would not achieve sufficient reduction in radon levels.

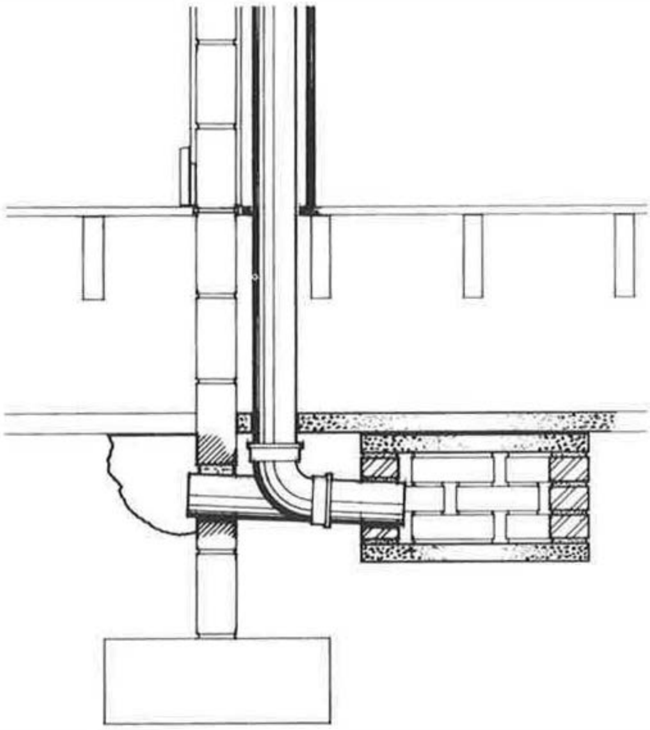

Figure 5.2

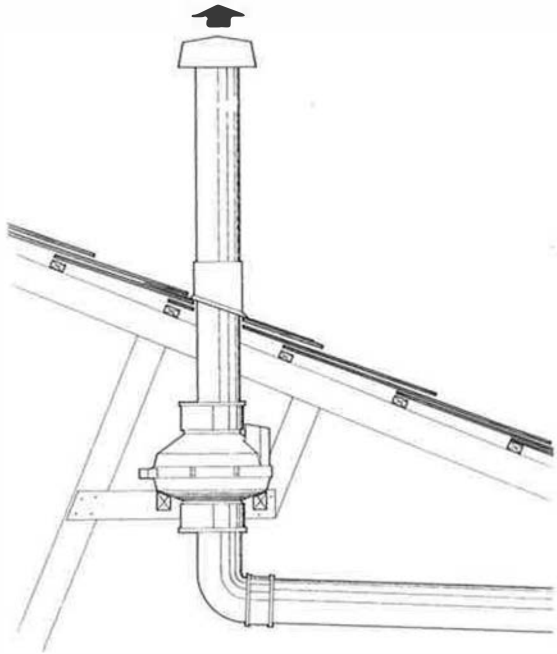

Figure 5.3

The fitting of sumps below the oversite concrete was carried out in exactly the same way as if they had been fitted into a concrete floor. A small area of membrane was fitted above each sump before the oversite concrete was made good although no membrane was fitted originally.

Because the slated roof had no sarking felt below the battens, the height of the outlets above the pitch was increased to reduce the risk of reintrainment (Figure 5.3).

CASE STUDY 6

OFFICE BLOCK

Internal mini-sump system

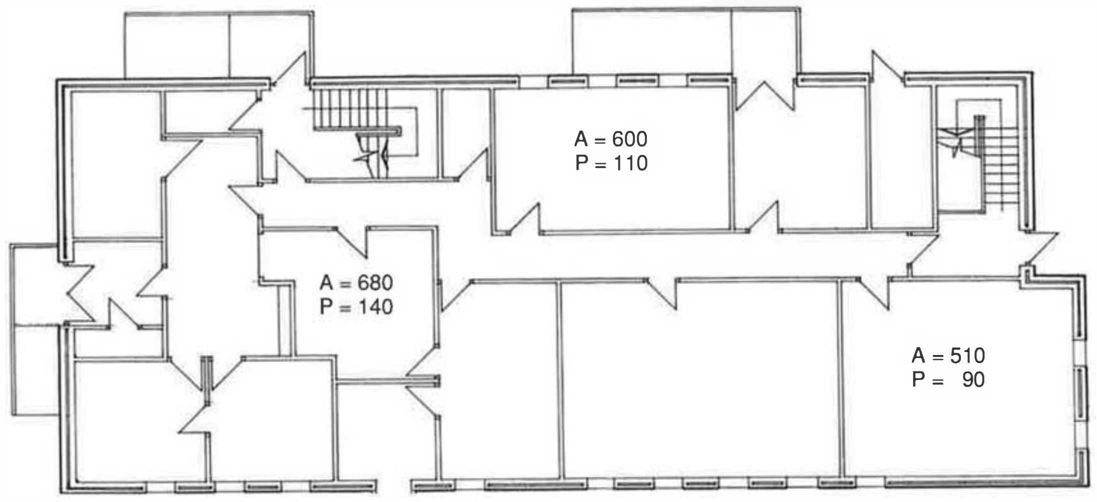

Figure 6.1

The offices for Electron Courier Co occupy a 2-storey block situated at the edge of a business park in Northamptonshire. The block was built in 1980 and is constructed of load-bearing cavity brick walls bearing on strip foundations. The 210 m^2 ground floor comprises a ground-bearing concrete slab, the upper floor being timber boarding on timber joists. The ceilings are of plasterboard and the roof is of three-layer felt and cork insulation on a wood wool slab deck supported on timber joists. The windows are aluminium (Figure 6.1).

Moderately elevated radon levels were found in tests during the winter of 1992. The clients approached a specialist mitigation company who provided a telephone quotation followed up by a written confirmation; they did not visit the building.

Mitigation
A single mini sump was excavated via a core-drilled hole in the concrete floor and pipework was taken up to the roof to discharge below a vent cowl mounted 600 mm above roof level (Figure 6.2).

When the mitigation company arrived on site, they were dismayed to find that the building was heated by underfloor electric cabling. They considered an alternative of core-drilling from the perimeter but the client was unhappy about external pipework, although it could have been fitted fairly unobtrusively. Fortunately the client was able to find a copy of the original heating layout drawing and this showed that the area immediately below the staircase had no heating cabling fitted. The mini sump was constructed beneath the staircase but the only suitable position for the extract pipework was through the Manager's office on the first floor. The simple flat roof construction gave insufficient roofspace to allow the fan to be concealed and the Manager was not prepared to accept a downstand boxing from the ceiling. Eventually it was agreed to retain the existing ceiling level and raise the fan in a boxing which extended above the roof (Figure 6.3).

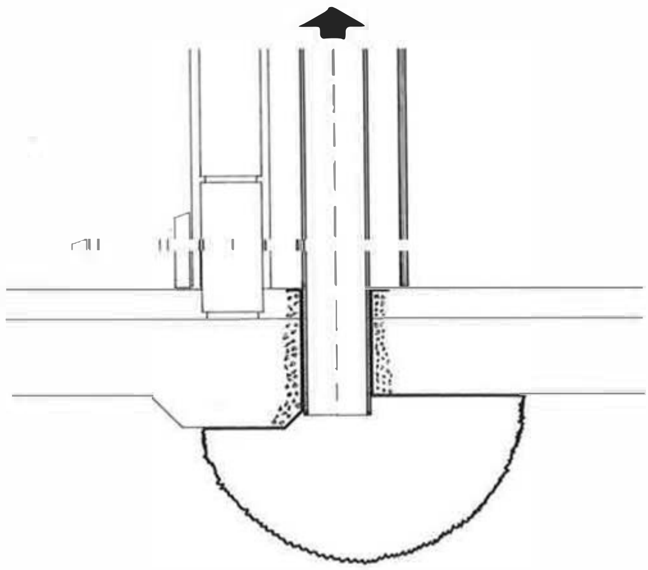

Figure 6.2

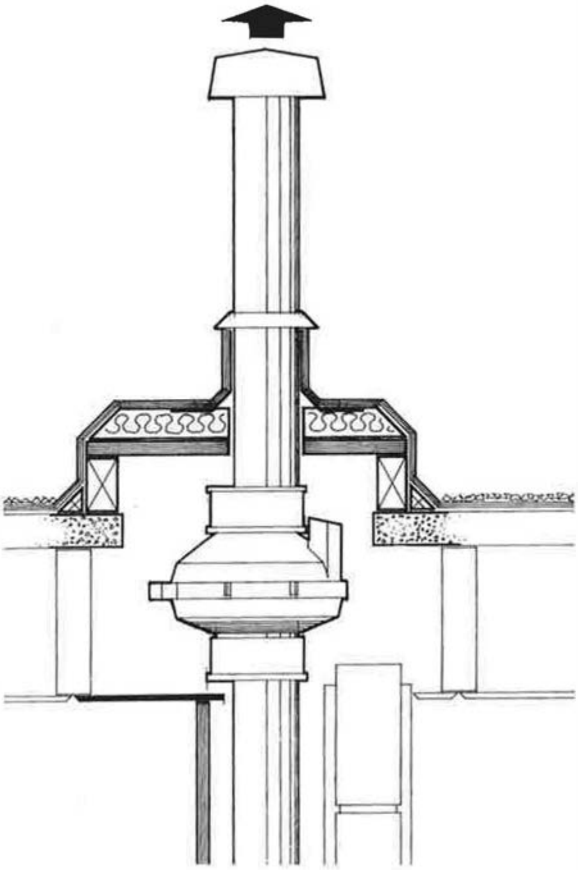

Figure 6.3

CASE STUDY 7

PRIMARY SCHOOL

Mechanical underfloor ventilation

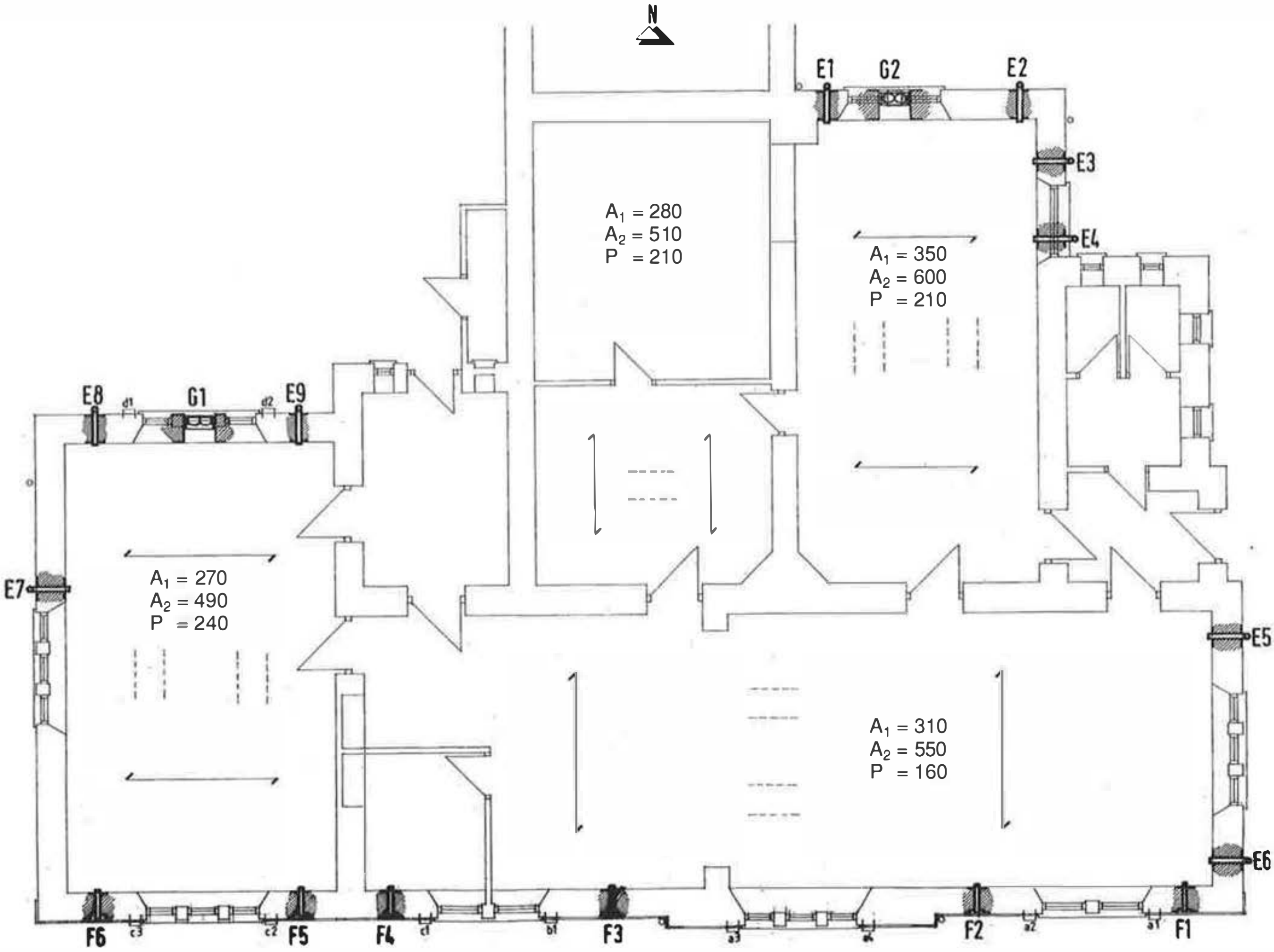

Figure 7.1

Tremmendas Primary School was built in 1889 in response to the 1870 Education Act when the Local Schools Boards were first created. It is a typical small Cornish Primary School in terms of construction. The walls are 600 mm thick granite on only nominal foundations. The windows would have been vertical sliding timber sashes but these were replaced by PVC-U items in 1991. The original high timber-boarded ceilings are still in place but are now concealed by a lay-in-grid suspended ceiling fitted circa 1978.

The scissor-trussed roof is of natural slate, originally unsarked, but felt was introduced when the covering was re-nailed circa 1976. The floor is of suspended timber which was originally made of wide butt-jointed boards but was replaced by narrow tongue-and-groove boarding following an attack of dry rot circa 1964. The boarding is nailed to timber joists on sleeper walls. The underfloor void has no covering to the solum.

Individual oil-fired heaters were replaced by a full radiator system in 1989.

The building was tested as part of the County Council's on-going programme of radon testing and mitigation during the winter of 1987 when levels close to, but not exceeding, the action level were found. The building was retested in 1992 following the alterations to heating and windows and was found to have radon concentrations considerably in excess of the action level (Figure 7.1).

Mitigation
Increased underfloor ventilation was provided, initially passively by installing additional ventilation grilles, but subsequently by installing an axial-flow fan fitted to blow beneath the floor to provide cross-ventilation to the underfloor void (Figure 7.2).

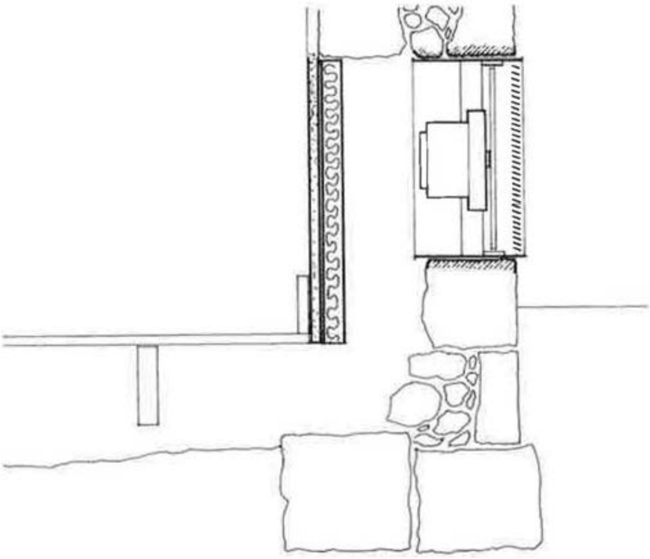

Figure 7.2

The fitting of a new more efficient heating system plus the replacement of leaky timber windows and doors with well-sealing PVC-U replacements raised radon levels in the building by increasing the indoor–outdoor temperature differential. Doubtless the levels would have been even lower before the suspended ceilings were fitted.

The underfloor void was particularly poorly ventilated. The free area for ventilation via the original ornamental cast-iron air grilles was well below that required by current Building Regulations and many of these grilles had been blocked by subsequent extensions and years of playground resurfacing with layer after layer of tarmac.

The initial work involved replacing the original cast-iron grilles with modern plastic vents that give a greater open area for the same size unit. A number of additional grilles were also fitted until the underfloor ventilation was well above that required by Building Regulations. Although this approach has worked elsewhere, subsequent re-measurement showed that in this particular case, radon levels had not been lowered sufficiently. Hence the fan was fitted in an attempt to further increase the underfloor ventilation. This led to complaints of cold draughts from the occupiers, particularly in those areas used by infants. A number of the floors were then covered with needlepunch carpet which resolved this problem.

Suggestions that further reduction in radon ingress could be achieved if the carpet was underlaid with plastic sheet were strongly resisted following the collapse of a similarly treated floor from a dry rot infestation some years earlier. The radon levels are now below the action level.

CASE STUDY 8

OFFICES

Positive-pressurisation system

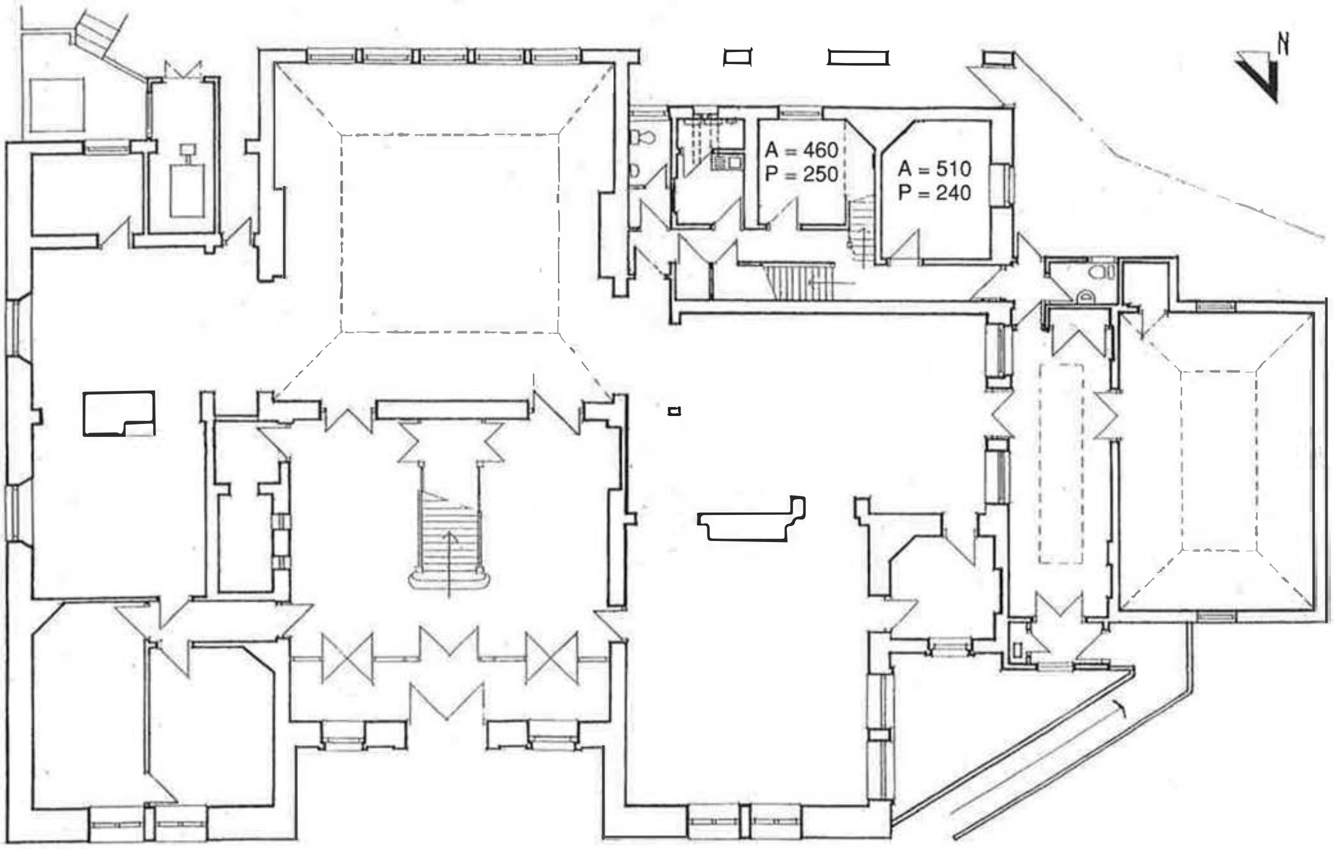

Figure 8.1

The Ramble On Society operate a number of advice bureaux for ramblers in the Derbyshire area which are manned by volunteers. One of their offices occupies part of the ground floor of the 1893 Municipal Library of a small Peak District town.

The offices consist of small rooms at the rear of the premises. The external wall is of local stone 800 mm thick, the floors are carpeted suspended timber over a void with no form of covering to the solum. The small timber windows are fitted with bars to deter intruders and have also been fitted with secondary glazing units by the volunteers themselves. The heating is by night-storage units in the office areas only, the remainder of the building being on a wet system with large cast-iron radiators (Figure 8.1).

The Local Authority arranged for the library including the offices to be tested for radon in 1991. These tests showed marginally elevated levels in these rooms only.

The rooms used by the Society were fitted with a pair of positive-pressurisation units drawing air from the roof void above (Figure 8.2).

Mitigation
The choice of a positive-pressurisation solution was based on a number of criteria as follows.

- Radon levels were only marginally elevated and the reduction factor required was relatively small.
- Ventilation to the rooms was very limited, windows were rarely opened and security bars prevented them from being opened fully.
- Secondary glazing was not particularly well fitted with the result that the panes of glass were difficult to slide.
- The rooms were only used four mornings a week.
- The night-storage heaters ran continuously in an attempt to keep the many files free from the mould affecting the corners of the walls.
- The company offering the positive-pressurisation units promised the Society their money back if the system proved unsatisfactory.

The result of installing the positive-pressurisation system is that the increase in air-change rate coupled

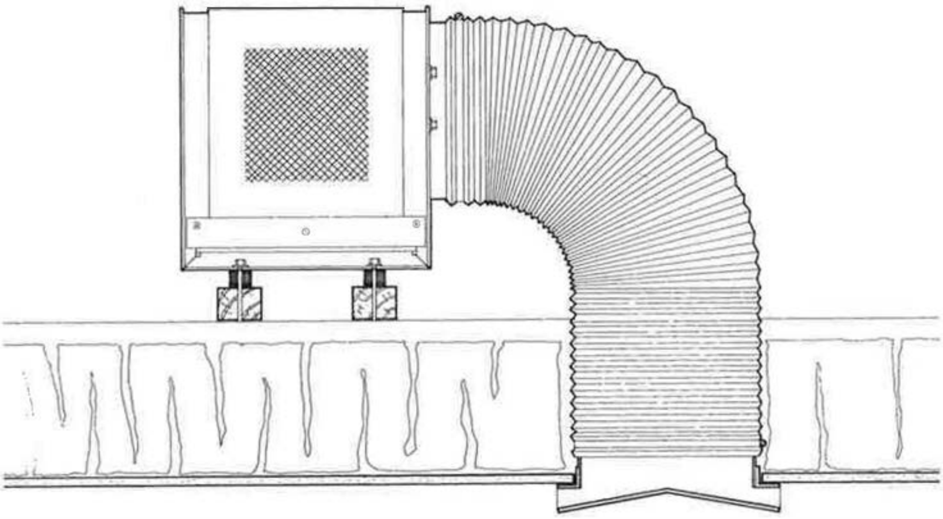

Figure 8.2

with a measure of positive pressurisation has reduced radon concentrations to well below the action level. The mould has also disappeared as a result of this approach being adopted.

Although the cost of running the fans is not especially high the Society enquired as to whether the fans could be run intermittently. Some long-term measurements showed that the pressure changes developed by the fans were almost instantaneous. Radon ingress would be greatly reduced as soon as the fans were switched on and conversely levels would begin to rise very shortly after the fans were switched off. Unfortunately these systems do little to clear the radon allowed to enter the rooms when the fans are switched off. The volunteers are now resigned to running the fans continuously.

CASE STUDY 9

BUILDING SOCIETY OFFICES

Multiple-sump system in basement

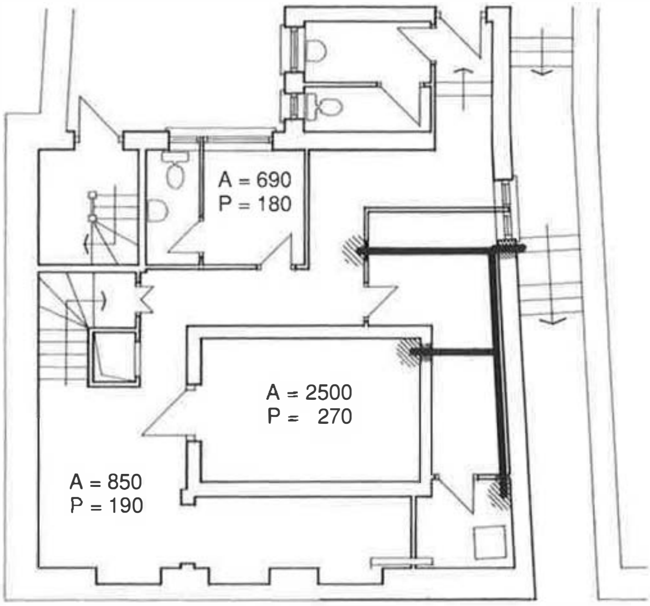

Figure 9.1

The Pennine and Allied Building Society have a total of 21 high street branches, all of which were tested for radon by the Company as a matter of policy over the winter of 1991/1992. Just one branch showed readings in excess of the action level.

The three-storey building concerned dates from circa 1850. It has 600 mm thick masonry walls and aluminium windows, ground-bearing slab basement floor and timber upper floors with sarked slated pitched roof partly hidden behind a parapet to the front elevation only. The central-heating system is powered by a small gas boiler. The building has a small enclosed court at the rear, is attached to a row of shops on one side with a narrow pedestrian alleyway on the other (Figure 9.1).

Mitigation
Initially a single mini sump was formed below the basement floor by carefully core-drilling a hole through the heavily reinforced thick concrete slab. At a later date two similar additional sumps were created. The 100 mm diameter PVC-U pipework was taken across the basement ceiling and through the external wall, up the side elevation and into the roof void. A single 145-watt fan was fitted in the roof void and the outlet taken through a vertical grille in the side elevation wall (Figure 9.2).

Before work commenced a thorough investigation of the whole site was undertaken to ensure that the water table was low enough not to fill the sump system when suction was applied. Generally radon problems and high water tables are mutually exclusive but by no means always so. It was not possible to cut through the floor without damaging at least one of the layers of mesh reinforcement. The exposed bars were painted with primer to prevent subsequent corrosion.

The vertical pipe in the narrow alleyway was enclosed in a top-hat section galvanised steel guard approximately 2 m high with a space left at the base to allow rain-water to escape.

Although the pipework entered the roof void horizontally and exited horizontally via a wall grille, bends were used to keep the axis of the fan near vertical to prevent build-up of condensation in the casing.

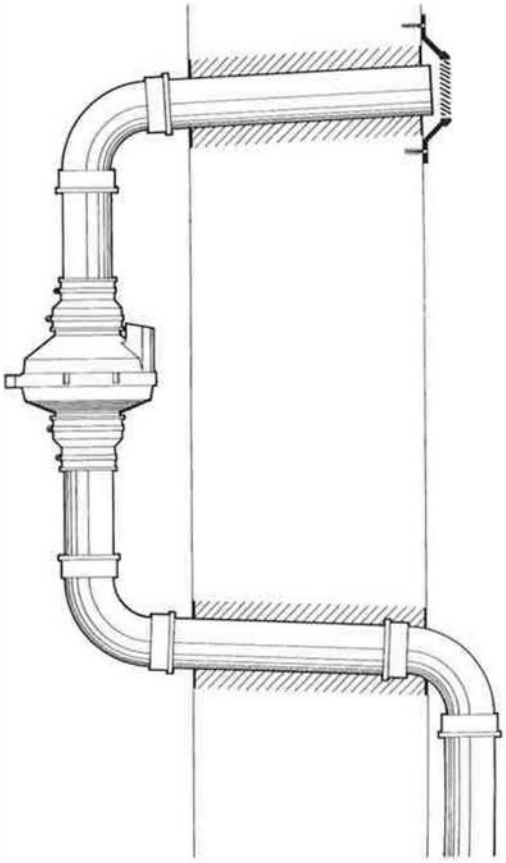

Figure 9.2

The basement floors themselves were in generally good condition but there was a substantial gap at the perimeter. The opportunity was taken to seal this as part of the contract. Two cable entry ducts of earthenware pipe were also sealed with foam over a removable pad in an attempt to eliminate more obvious routes of entry. When the reductions in level were found to be insufficient, two additional sumps were formed in exactly the same way as the first. The pipework was manifolded below the basement ceiling and at each junction an access fitting was introduced with a view to being able to balance the suction of the system to each branch by baffling the line of least resistance should this prove necessary.

It was also noted that combustion air for the heating boiler was being taken directly from the basement. An additional grille and duct was fitted to allow the air to be taken from outside.

CASE STUDY 10

FACTORY AND OFFICES

Modified air-conditioning system

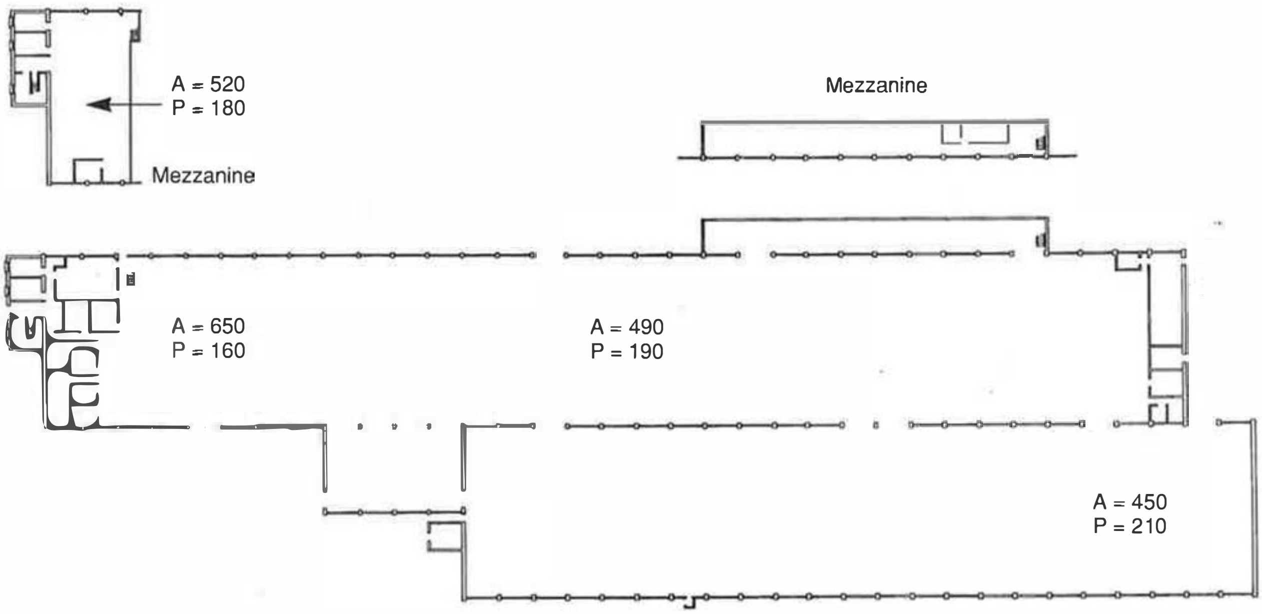

Figure 10.1

NRC Electronics are a subsidiary of an American company and manufacture small batches of prototype hardware for the computer industry.

The factory is on an industrial estate in Northamptonshire and was built for them in 1987. It is fully air-conditioned.

The single block consists of a steel portal frame on concrete pad foundations with profiled steel cladding to both roof and walls. The concrete floor has a number of changes in level and carries a series of ducts and pits below large machines. The air-conditioning system is mounted at high level, and both supply and exhaust air grilles form part of the suspended ceiling (Figure 10.1).

When the building was tested for radon in 1991, moderately high levels were found in every location. The company elected to commission the engineers who fitted the original air-conditioning system to adjust/adapt the existing system to lower the levels by increased air-change rate or positive pressurisation, or both.

Mitigation
The air-conditioning company were interested in being involved with this piece of work which they regarded at least partly as research. The system had been designed to provide high levels of filtration to remove fumes from some of the processes. Whilst it was easy to reduce the air-extract rate, the size of the input side of the system meant that air delivery rates could not be greatly increased with the size of fans fitted. The result was that many man-hours were spent using a radon sniffer and data logger followed by adjustments to the duct system.

Overall, the extraction rate was lowered but additional supply and extract was introduced only to those areas producing fumes. The cost of the additional equipment would have compared favourably with the alternative of fitting sump systems but this was far outweighed by the cost in time of monitoring and adjustment. It is also worth noting that it took 18 months in total before levels could be guaranteed to remain below the action threshold.

In this case the solution proved expensive. However there will be cases where the building is simpler or where the air-conditioning equipment has spare capacity when this approach will prove more cost effective.

CASE STUDY 11

SMALL SHOP

Improved underfloor ventilation

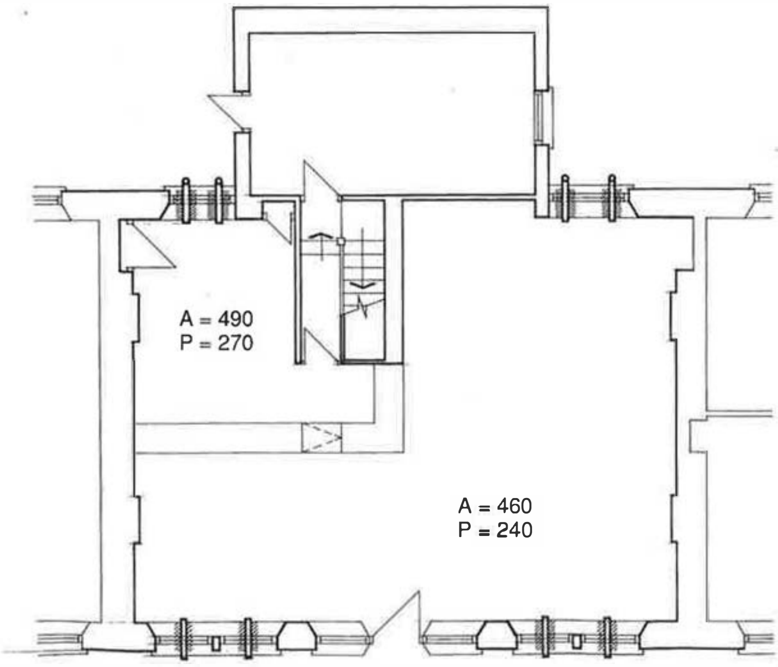

Figure 11.1

Curie's Chemists is a small family business that has traded from its high street premises in a mid-Cornwall market town since the turn of the century.

The building is constructed of local stone and parts date from as far back as the 16th century. The windows are timber vertical sliding sashes. The floors are butt-jointed boarded on joists over a shallow void with no covering to the solum. The roof is of local slate on timber battens, common rafters, purlins, trusses and is unsarked.

The premises were tested during the winter of 1991/1992 and moderately elevated levels were found throughout (Figure 11.1).

Mitigation work was limited to providing additional natural underfloor ventilation.

Mitigation
Since the levels were only moderately elevated the opportunity was taken to increase the underfloor ventilation. Prior to remedial work the only ventilation to the underfloor void had been provided by two small clay air bricks in the front elevation. These were replaced with plastic grilles offering a greatly increased free area for the size of opening, and at the same time several additional grilles were fitted in the front elevation. At the rear, the outside ground level was slightly higher than that of the indoor floor level. In order to provide additional ventilation here a series of cranked ventilation pipes were fitted (Figure 11.2).

The absence of internal load-bearing walls made cross-ventilation in the underfloor void much more effective.

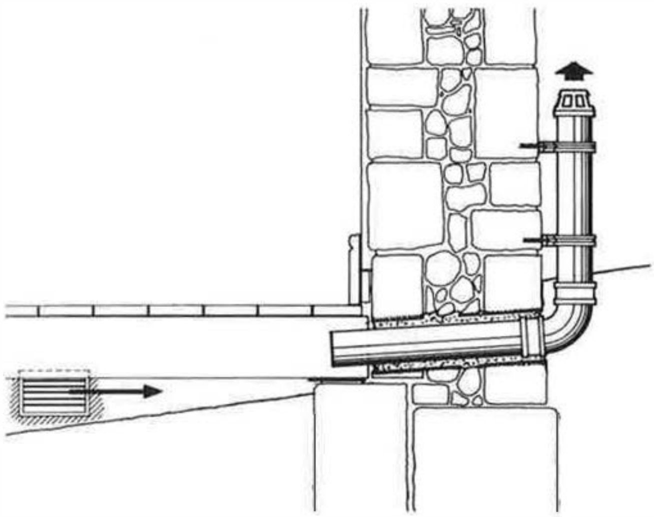

Figure 11.2

CASE STUDY 12

HOSTEL

Simple sealing

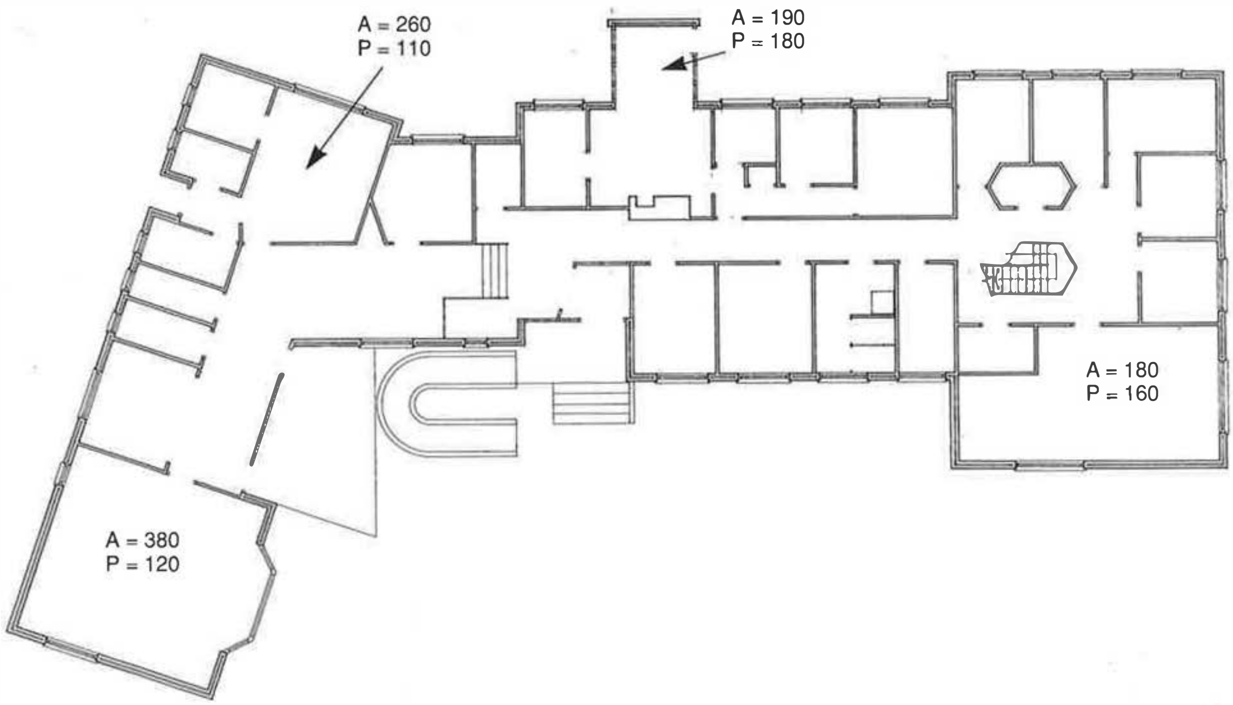

Figure 12.1

Poldhu is a hostel for the mentally handicapped in East Devon built by the Local Authority in 1978. It is two-storey and is constructed of load-bearing rendered cavity block walls built off the ground bearing concrete raft floor slab. It has aluminium windows. The shallow pitched roof is of interlocking tiles on trussed rafters. A gas-fired wet system of central heating provides hot water as well as space heating (Figure 12.1).

The building was tested during the winter of 1989/1990 as part of the Council's radon testing and mitigation programme. Although levels were below the recommended action threshold for workplaces, they did exceed those recommended for housing and since the occupancy was full-time for the residents rather than just working hours, it was felt appropriate to carry out mitigation. It is interesting to note that one high reading was recorded in an upper floor bedroom.

Mitigation
Examination of the original architect's drawings indicated that the floor construction comprised a concrete raft. A survey of the building itself showed the floor to be in good condition. It was found, however, that in the rooms where the highest radon levels had been recorded there were several services penetrating the concrete floor. In each case there were large gaps around the services through which the subsoil could be seen. These gaps were sealed using sand/cement mortar for the larger gaps and gun-applied silicone sealant for the smaller ones. Because the levels were only marginally elevated and the building occupied at all times, the minimal disruption made this solution most attractive.

Further investigation revealed that the single high radon level found on the upper floor was due to ingress of radon around a service pipe on the ground floor, travelling up to the first floor via a service duct. The simple sealing work carried out on the ground floor included sealing around this service entry and resolved the problem in the upstairs bedroom.