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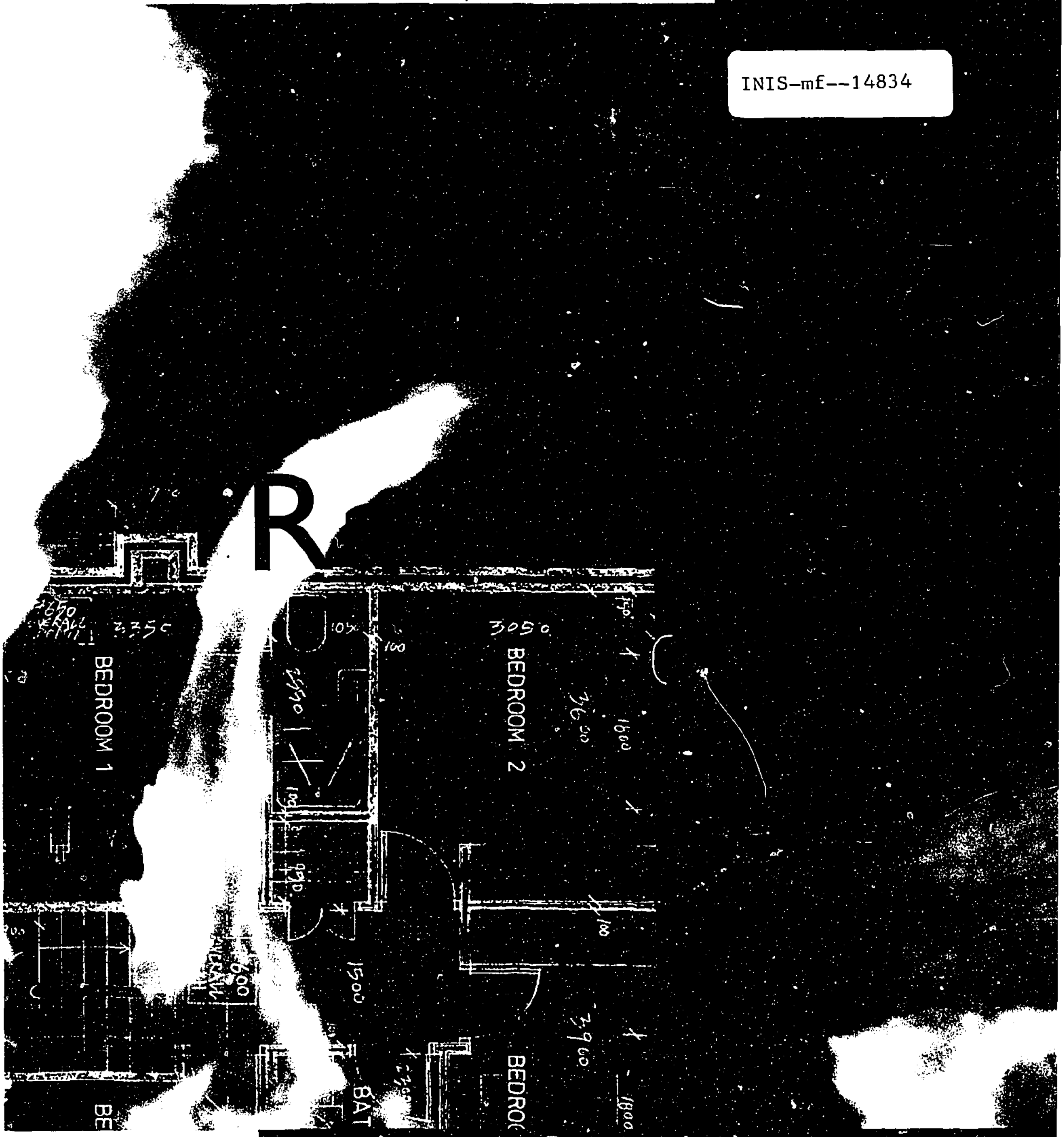

R in Buildings

DEPARTMENT OF THE ENVIRONMENT

Radon in Buildings

Construction Research Section

Nicholas M Ryan

Michael Finn

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Introduction

This guide is intended to inform designers, contractors, householders and other building owners about radon in buildings and to provide guidance where it has been decided to take action to reduce radon levels. It gives some pointers to good practice insofar as it relates to non complex buildings of normal design and construction. Reference is made to the usual ways of reducing levels of radon and guidance is given on sources of further information. It is not intended as a comprehensive document covering all aspects of design and construction to limit indoor radon levels, but rather as a source of basic information to assist in making informed decisions on the subject. This publication does not deal with other performance requirements such as damp proofing, insulation etc. which should also be catered for in design and construction.

This document was first published by the Environmental Research Unit in 1991 and the authors of this edition acknowledge the work of the original author, James J Connell.

Nicholas M Ryan

Michael Finn

August, 1995

1. Facts about Radon

Radon is a naturally occurring radioactive gaseous element which has no taste, smell or colour and requires special equipment to detect its presence. The level of radioactivity in the air due to the presence of radon is measured in becquerels per cubic metre (Bq/m³).

Approximately 90% of the total annual radiation dose received by the general public is derived from natural sources. The single largest component of this dose is that due to radon and its decay products in the indoor environment. On the basis of current Irish data, radon contributes over 50% of the total radiation dose received by the Irish population (reference 1).

When radon is generated in porous rock and soil some of it enters the pore spaces where it becomes a constituent of the soil air. This soil air rises to the surface and is exhaled into the atmosphere throughout our natural environment. In the outdoor environment it is rapidly diluted and dispersed. However, if the radon flux enters the air space of a building then elevated indoor radon levels may occur due to restricted dispersion. For further information on radon gas see reference 2.

2. Indoor Radon Points of Entry

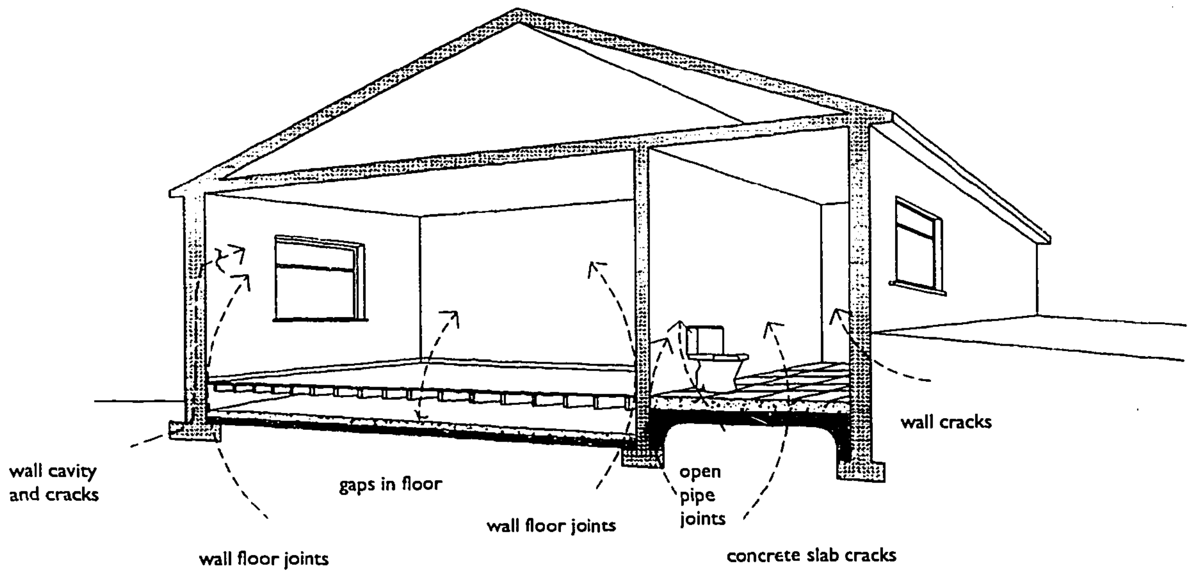
Buildings in general tend to have a slightly lower indoor air pressure compared to that in the ground, this is normally sufficient to draw soil air from the ground into the building.

Radon gas can enter a building by many mechanisms but the most significant are diffusion and pressure-driven flow from the ground beneath and immediately adjacent to the building, provided suitable ingress routes are available. Ingress routes for radon gas are usually cracks and holes in floors and walls, and gaps around service pipes and cables (see Figure 1). In most dwellings with elevated indoor radon concentrations pressure-driven flow is recognized as the dominant mechanism of ingress.

Domestic water and gas supplies, in addition to building materials and infiltration of outdoor air, can also contribute to the indoor radon concentration in a building, but in most cases these are considered minor sources relative to the ground on which the building is constructed.

Radon gas is nine times heavier than air, and therefore is not normally a problem in the upper stories of high rise buildings.

Figure 1: Major Entry Routes



3. Reference Level

Many countries worldwide have adopted national reference levels within the range 200 to 600 Bq/m^3 as recommended by the International Commission on Radiological Protection (ICRP) (reference 3). In 1990, the Government, on the advice of the then Nuclear Energy Board, adopted an annual average radon concentration of 200 Bq/m^3 as the national reference level above which remedial action to reduce indoor radon in domestic dwellings should be considered. This level of 200 Bq/m^3 is also intended to apply to all future dwellings.

Ireland, in common with many countries which do not have significant concentrations of mining industries, has not yet determined a national reference level for workplaces. However, the ICRP recommends that reference levels should be within the range 500 to 1500 Bq/m^3. Differences in the use patterns of workplaces and in their physical characteristics make it difficult to give broad recommendations and those seeking advice should contact the Radiological Protection Institute of Ireland (RPII).

4. Methods of Detection and Measurement of Radon

In order to identify houses with high indoor radon levels as efficiently as possible it is necessary to have information on radon-prone areas or high risk radon areas. Work is currently being carried out by the RPII on a national survey (reference 1) to provide data for 10 km square grids over the whole country. When this is completed it will be possible to predict the percentage of houses in each grid which (in the absence of preventative measures) are expected to have indoor radon concentrations in excess of 200 Bq/m^3. Information on the current state of knowledge is available from the RPII.

Area monitoring of houses, using passive radon detectors to determine the average annual radon concentration in living spaces, is the preferred standard procedure adopted by most European countries for estimating the long-term doses and risks to the general population from domestic radon exposure.

In Ireland the predominant passive radon monitor is the alpha track-etch radon detector or dosemeter. This detector is not radioactive and poses no hazard to the users. It consists of a special radiation sensitive detector which is located inside the lid of a small plastic bottle. The air diffuses into the bottle and the alpha radiation released by the radon gas and its decay products strike the sensitive detector and damage it on a microscopic level. After chemical processing, the radiation damage on the detector is analyzed and the average radon concentration to which the detector was exposed to during the measurement period is determined.

The standard measurement procedure in Ireland for assessing the long-term average radon concentration in a house is to place two passive radon detectors, one in the principal bedroom and the other in the main living room for a minimum period of at least three months. Remedial action should be considered only after long-term (3 months or greater) measurements have been completed.

Indoor radon can also be monitored by active radon measurement techniques, but these are suitable only for monitoring radon fluctuations over short periods and for diagnostic work within a building. Active measurement techniques are not economically viable for the assessment of long-term average indoor radon levels. Further information on measurement can be found in reference 4.

There is evidence linking high indoor radon levels with underlying areas of uranium-bearing granite, shales, phosphate and certain sandstones (reference 5), but these geological indicators are generally indicative and may not be entirely reliable. In fact, the majority of elevated levels of indoor radon found in Ireland to date are spatially associated with limestone bedrock in the West of Ireland, which is not regarded as uranium bearing rock.

On the question of pre-construction site investigation to predict the indoor radon concentration in a planned building, such measurements are feasible but it is not possible, on the basis of current knowledge, to interpret the results adequately. At present, the only reliable method of assessing radon levels is to have longterm measurements performed after construction.

Measurements may be arranged by applying to either of the following:

Radiological Protection Institute of Ireland
3 Clonskeagh Square
Clonskeagh Road.
Dublin 14   *Phone No. 01 269 7766*

or

Department of Experimental Physics
University College
Belfield
Dublin 4.   *Phone No. 01 269 3244*

The measurement of radon levels in a house involves receiving by post a number of alpha track-etch radon detectors with instructions on how they should be exposed. When the measurement period is completed they are returned for processing. The RPII's confidential results are sent by post to the applicant. The charge for this service is currently £15 per house. If it includes advice to consider remedial measures to reduce the radon levels, it is wise to seek professional advice from an architect, engineer or other person possessing the necessary knowledge to provide this advice.

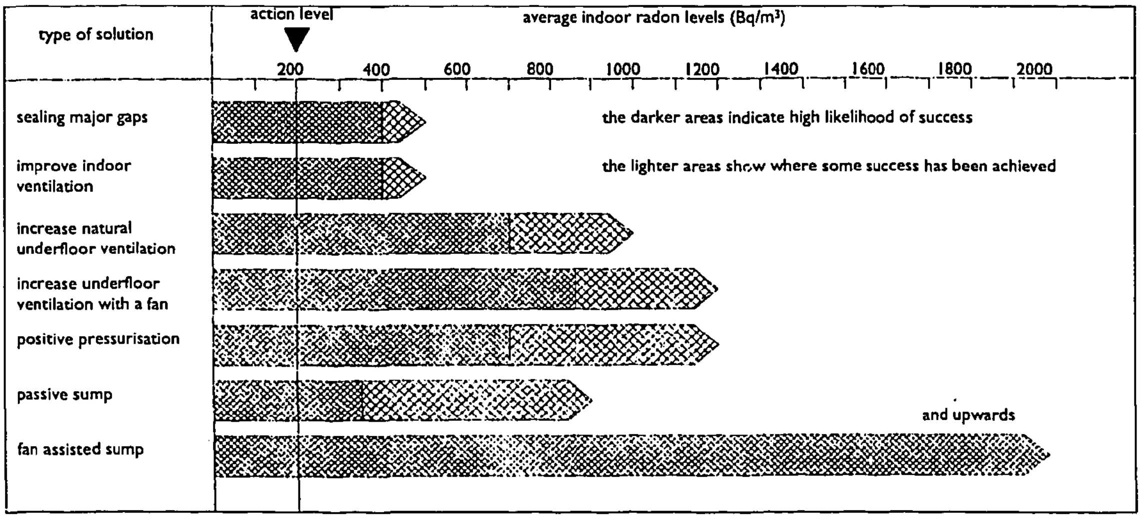
5. Corrective Options

Corrective options are aimed at either preventing radon entering the building or removing radon after entry.

Techniques which prevent radon entry include: sealing soil gas routes into the building; subfloor depressurization with passive or fan-assisted sumps to draw soil gas away from the building before it can enter; and adjustment of the air pressure inside the building to reduce or reverse the driving force which assists the entry of soil gas. The only technique to remove radon after entry described in this document is ventilation of the building.

Information published by the Building Research Establishment (BRE) (reference 6) suggests that the expected effectiveness of the various options are as shown in Figure 2. BRE has also published a document which modifies Figure 2 when dealing specifically with suspended timber floors in dwellings (reference 7).

Figure 2: Guide to the likely effectiveness of solutions



(a) Sealing soil gas routes

Tests have established that the radon concentration and pressure of soil gas are the dominant factors contributing to indoor radon problems and that the most common method of infiltration is through cracks and other openings in the ground floor and adjoining walls.

Sealing soil gas routes - New Buildings

In a new building it should be possible to provide a barrier against gas penetration by installing a fully sealed, low radon permeability membrane across the total floor and wall sections. It is important that this barrier should prevent radon from rising in cavities and in voids of hollow concrete block walls. To achieve this it will be necessary to modify traditional construction practice and ensure a higher than normal level of workmanship. For example, in a cavity wall the normal separate damp proof course in each leaf should be modified to provide a single stepped continuous membrane across the cavity with all joints sealed, this continuous membrane is also required in the hollow blockwork situation (Figures 3, 4, 5 and 6). At internal walls the membrane must be continuous (Figure 7) and at wall junctions the membrane should be mitred and sealed. The membrane and damp proof course arrangements shown in the Figures are possible solutions and illustrate the principle of barrier protection but other arrangements may be equally valid. Precautions should be taken to minimise possible differential movement between walls and concrete slabs and to make provision for this in the membrane at wall and floor joints and especially at movement joints.

Many plastic films are suitable as membranes provided they are of adequate strength and thickness and that all joints are fully sealed. Materials which are likely to be punctured by grit or by unavoidable construction traffic should not be used and in view of the difficulty of achieving gas tight seals under wet or dirty site conditions it is recommended that prefabrication of the membrane should be considered. It is unlikely that systems traditionally used as damp proof membranes will perform adequately as radon barriers.

Service pipes penetrating the membrane should be avoided and where this is not possible the penetrations should be provided with gastight seals.

It may be possible to rely on the integrity of a properly reinforced concrete ground floor raft slab to provide a barrier. The Swedish Council for Building Research has indicated that a concrete slab of conventional good quality, provided it is free from cracks and holes, presents sufficient resistance to radon, even where there is a high sub slab concentration of the gas (reference 8). Where a slab is poured direct onto hardcore a slab with a thickness of 170 mm and incorporating both top and bottom reinforcement would be indicated. All services passing through the slab would require careful sealing and peripheral details should be such as to direct all gas to the outside air and avoid access to wall cavities. The effectiveness of such an approach can be demonstrated only by post-construction measurement of radon levels.

While sealing is the preferred approach for new buildings it is not recommended that it be relied on without a fall-back in the event of the seal being ineffective. Facilities should be provided to withdraw the gas from underneath the floor if this proves necessary. However, every effort should be made to avoid the necessity to activate this facility because of ongoing running and maintenance costs.

Figure 3: Cavity Wall/Floating Slab

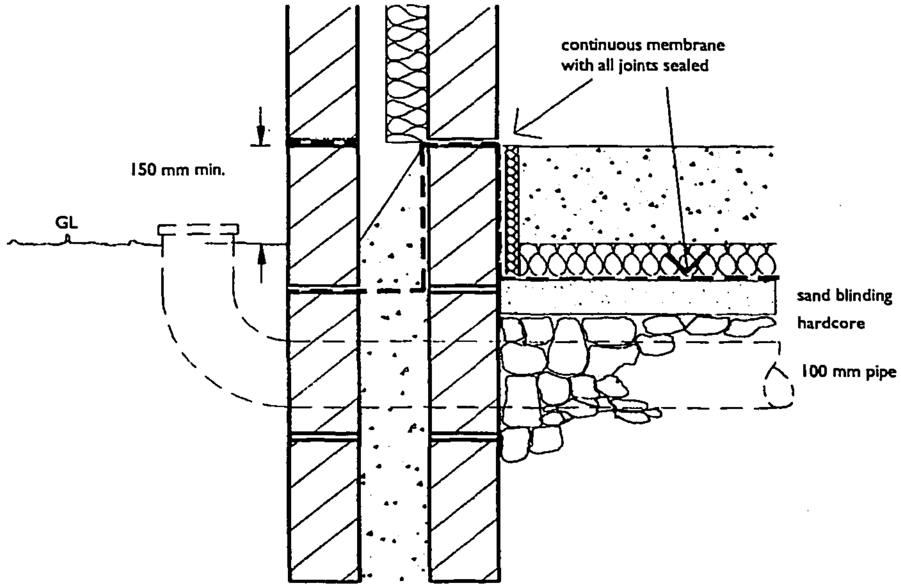


Figure 4: Hollow Block/Floating Slab

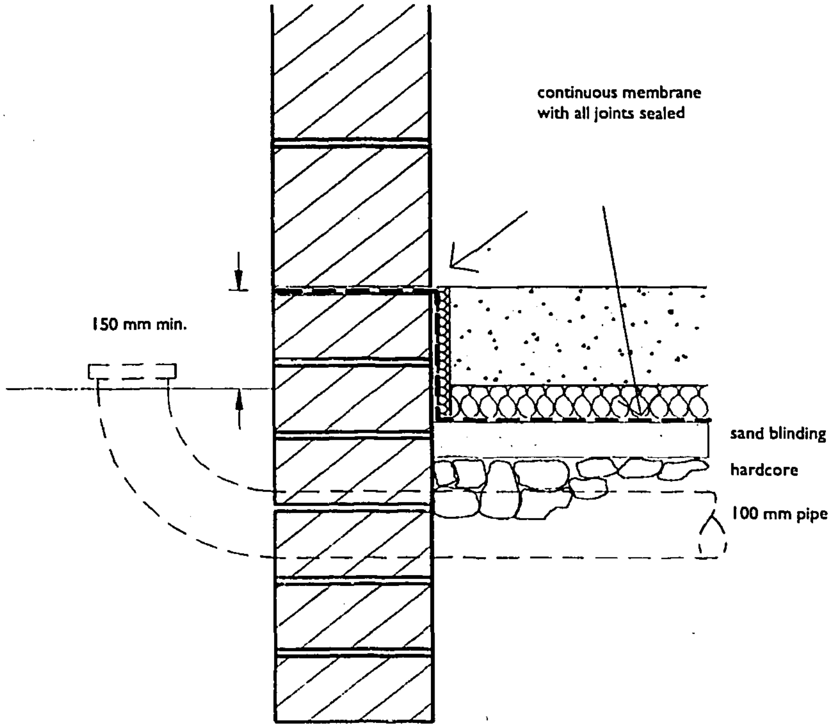


Figure 5: Suspeded Slab

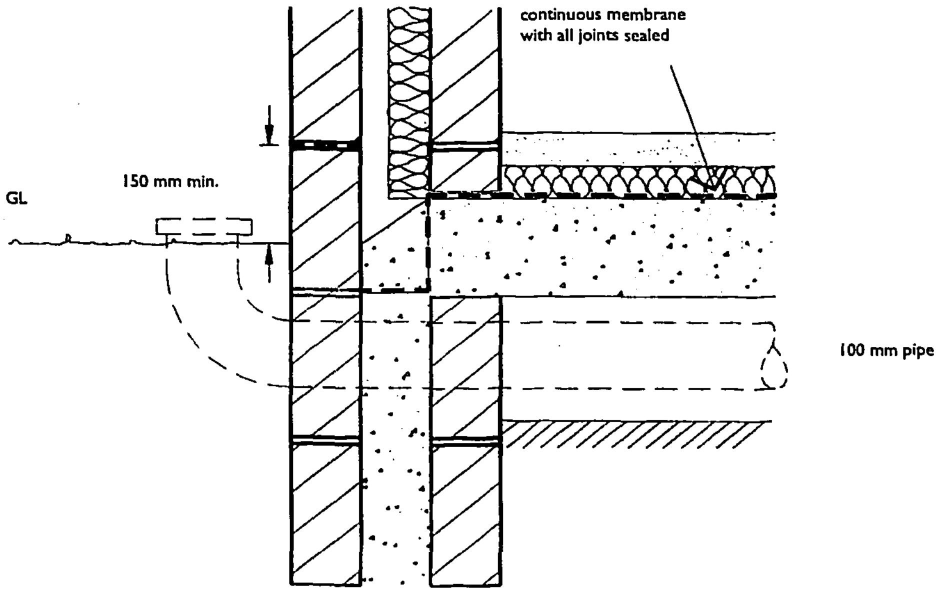


Figure 6: Suspended Timber Ground Floor Junction with External Wall

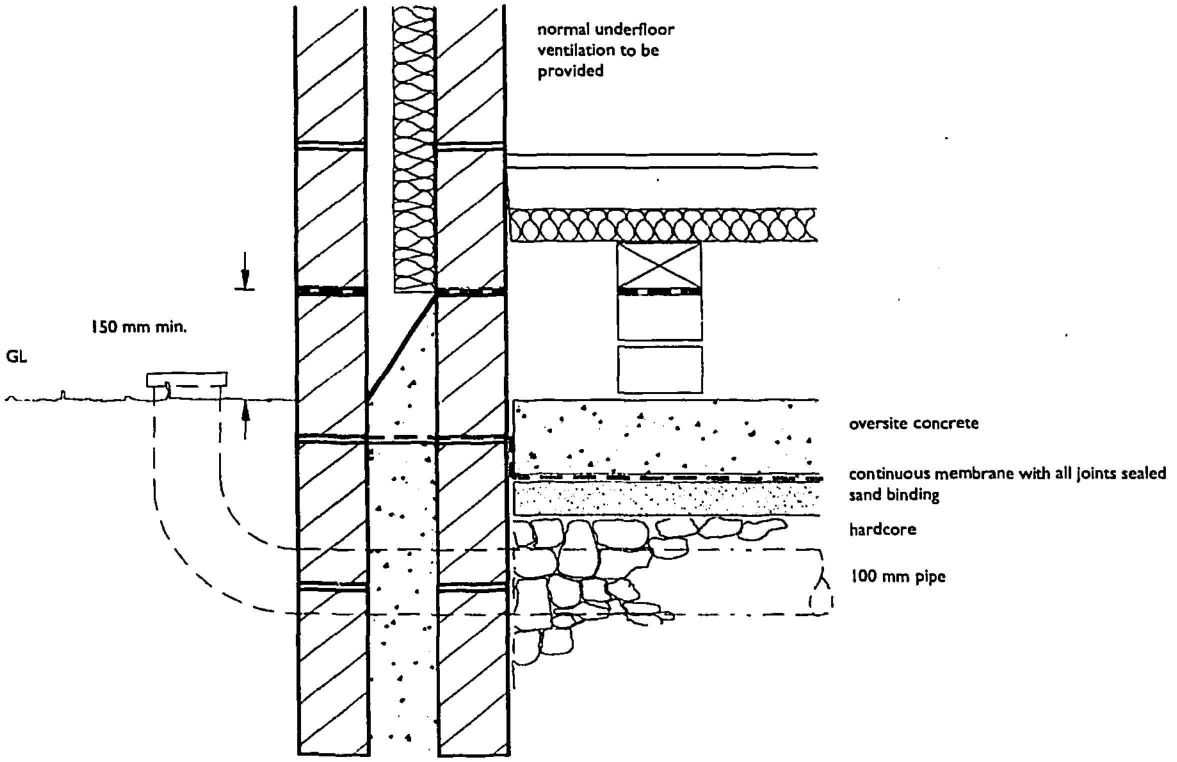
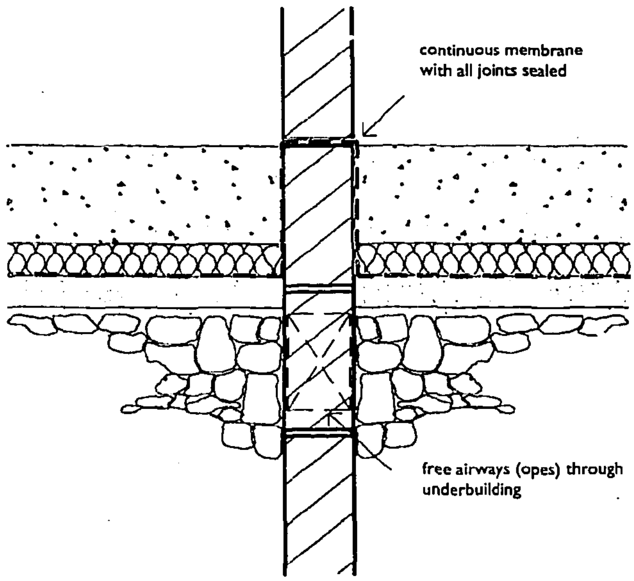


Figure 7: Membrane at Internal Walls



Sealing soil gas routes - Existing buildings

To prevent infiltration in an existing building it is necessary to make the floors and walls more effective barriers by sealing all the points of entry. Unfortunately, this is not easily achieved. Experience has shown that missing even minor openings in the sealing process will compromise the exercise since the gas flow is pressure driven. Nevertheless, by a combination of careful inspection and thorough workmanship, it may be possible to seal all entry routes and prevent the inflow of radon. This process is difficult and requires a degree of quality control which is not normal in construction work.

For existing concrete floors, all coverings, skirtings etc. must be removed in order to ensure that all cracks and leaks are dealt with. Materials for this sealing work should be flexible, permanently elastic and capable of adhering to a variety of surfaces. Buildings are to some degree dynamic in the sense that minor movement may occur from year to year and, unless the sealant is able to flex with the building, cracks will reappear. High quality sealants, such as silicone, polysulphide and polyurethane, are most likely to be successful. See reference 9 for guidance on the selection of sealants.

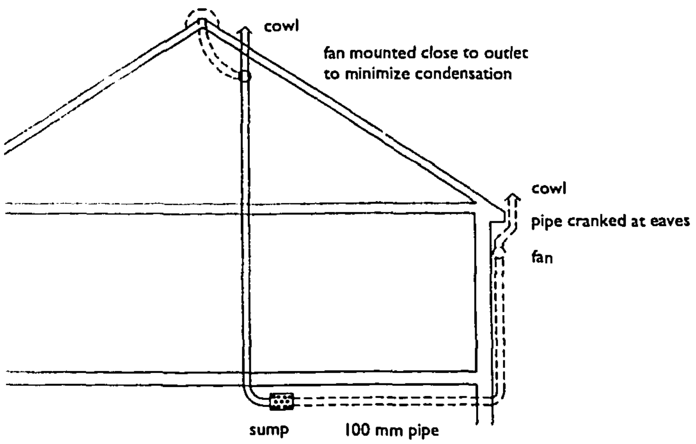
In existing buildings with timber floors it is extremely difficult to seal soil gas routes. Sealing of existing oversite concrete is not normally a practical proposition and it should be acknowledged that other options, including extraction of gas from the underfloor void, may be more appropriate.

(b) Depressurization

Depressurization can be used to eliminate the pressure gradient between the soil and the building in order to prevent the entry of radon.

In a building with a floating concrete ground floor slab, this will usually mean providing, in the permeable hardcore layer under the slab, a sump or collection chamber into which the radon gas is drawn and from which it is piped to the outside air (Figures 3 to 7). An electrically operated fan will normally be necessary to provide the suction, although in certain circumstances the "stack effect" of a pipe taken up through the building may be able to reduce the underfloor pressure sufficiently. A fan-operated system involves the costs of installation, running and maintenance and requires good quality workmanship, with particular attention to sealing pipework joints etc. However, it is the most reliable of current methods when radon levels are high. Where fans are used they should be wired directly to a fused distribution board to reduce the possibility of accidental switch off. All electrical work should be in accordance with ETCI regulations (reference 10). Figure 8 is a diagrammatic sketch of typical layouts for a fan-assisted system.

Figure 8: Typical Layout of Fan -Assisted System

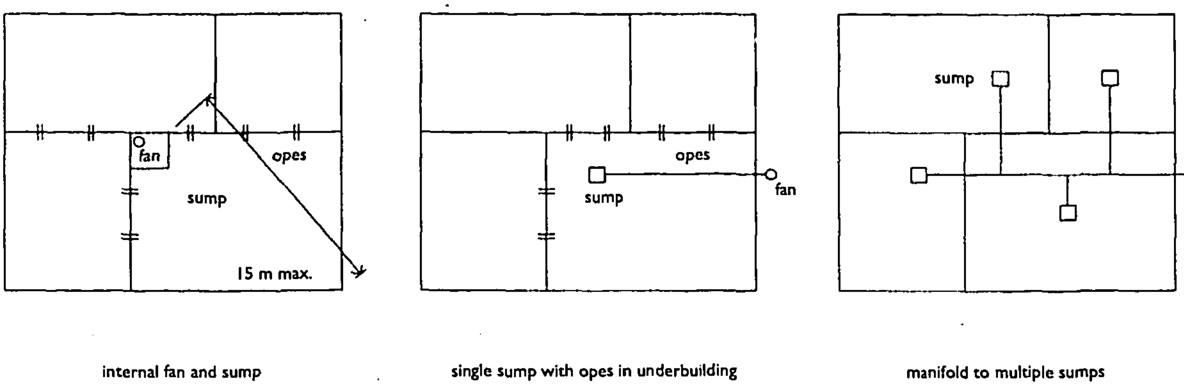


Depressurization - New buildings

Installing a sump when constructing a new building is relatively easy and inexpensive, and is a useful precaution even if later it is found to be unnecessary to activate it. Where clean permeable hardcore is used a single sump is likely to have an influence over an area of approximately 250 m^2 and for a distance up to 15 m from the sump (reference 11) . Obstructions below the floor slab may reduce the effectiveness of the system and it may be necessary to provide free airways through underbuilding or to provide separate sumps in each compartment. To create free airways it is suggested that 12500 mm^2 per metre run of wall (a gap, quarter of a block in length in each 4 blocks) should be adequate. If a number of separate sumps are provided the pipework may be connected to a manifold and to a single fan, see Figure 9.

The recommended underfloor sump consists of either a prefabricated collection box or a site constructed void with a 600x600x50mm concrete paving slab supported on looselaid bricks on edge, spaced apart around its perimeter (Figures 10 and 11). A 100m diameter pipe is inserted into the sump and is extended vertically into the attic space where it is capped until post construction measurement of radon levels show if it is necessary to extend it and fit an extract fan. Where the pipework passes through the concrete floor it is necessary to

Figure 9: Sump Layout Options



form a tight seal between the pipe and the slab or membrane in order to avoid reducing the efficiency of the depressurization by drawing down air from over the slab. Alternatively, the pipework may be taken out through an external wall, turned up and capped until needed. Again the junction between the pipe and the external wall must be sealed to avoid drawing in air from outside (Figure 12). Durability and maintenance problems are likely to be greater when external pipework and fans are used.

Figure 10: Prefabricated collection Box

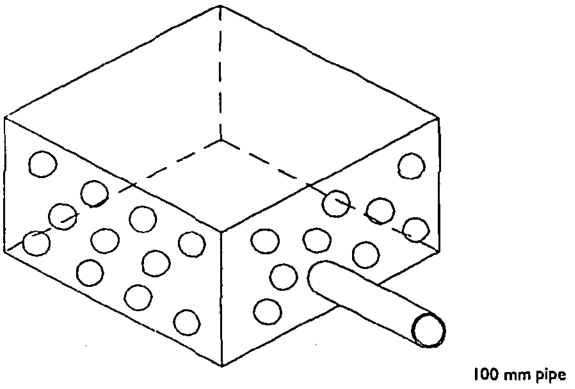


Figure 11: Site Constructed Sump

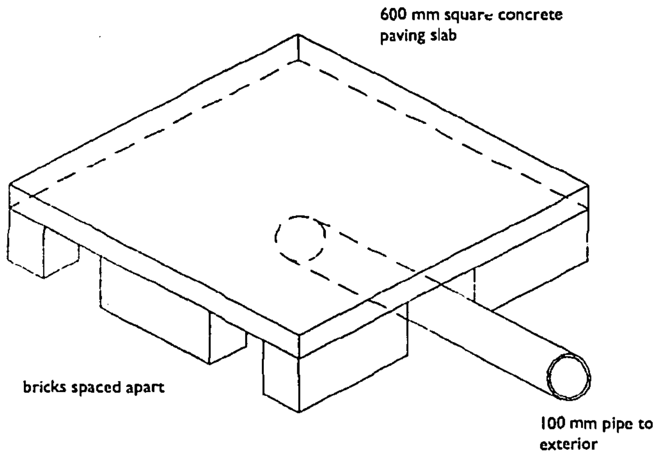
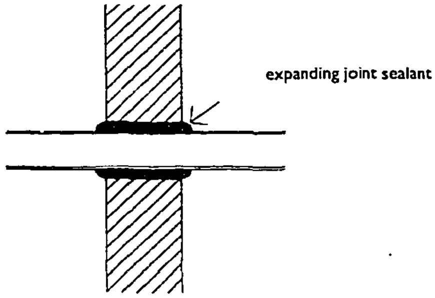


Figure 12: Sealing Pipe through External Wall



The air in the pipework will often be at a higher temperature than the surrounding air in attics or on external walls and this will lead to the formation of condensation in the pipes. It is important to protect the fan from damage due to condensate; this can be achieved by keeping the fan very close to the pipe terminal and, if necessary, by providing for collection/drainage of the condensate in a suitable way.

Depressurization - Existing buildings

Depressurization of the sub-floor of an existing building is similar to that for a new building and the same principles apply (Figure 8). However, care is needed to ensure that underfloor services such as water or electricity supplies etc., are not damaged. Where there is doubt about the permeability of the hardcore it may be necessary to carry out manometric surveys (see reference 12) to determine the area of influence of proposed sump locations.

The building should be surveyed to ascertain those rooms in which high radon concentrations occur and to determine the most suitable configuration of sumps and extraction pipework. It may be necessary to dig sumps internally and in this case proper reinstatement of the damp-proof membrane and sealing of the junction between the old and new concrete will be required.

Where a normal permeable hardcore layer exists under the floor, it may be possible to make pipe connections to this layer at points outside of and adjoining exterior walls (Figure 13). This would involve breaking through the rising wall, extracting fill to create small voids and inserting 100 mm diameter pipes to which a fan is connected at a high level to reduce the underfloor pressure and draw the soil gas out into the open air. Sealing of the pipes to the masonry is essential to avoid drawing in air from outside the building. As an alternative, it may be practical to cut through the floor internally and draw off radon from a centrally located, hand excavated sump (Figure 14). The pipework may be taken up through the roof with a pump fitted as close as possible to the outlet to minimise the danger of condensation above the pump or the possibility of release of gas into the building. Particular attention should be paid to the reinstatement of the concrete around the pipe and a sealant should be used around the pipe to prevent air from inside the building being drawn into the sump.

In the case of timber ground floors it may be possible to depressurize the underfloor void by the use of pipework and fans in the same way as for a concrete floor. However it is probable that more powerful fans would be necessary since it will not be possible to seal the air flow downwards through the floor.

Figure 13: Externally Excavated Sump

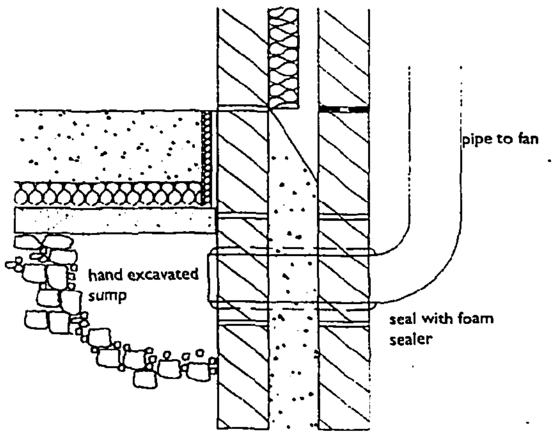
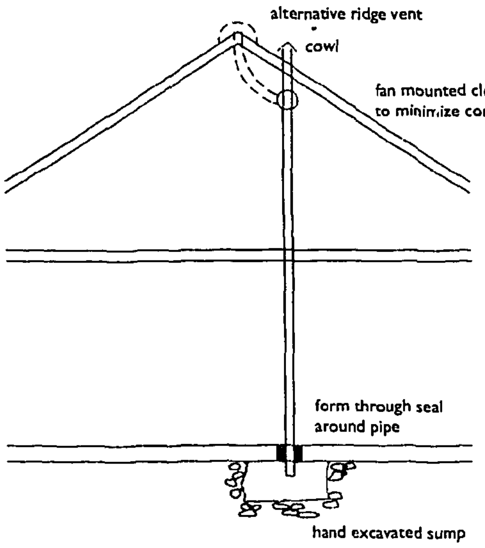


Figure 14: Centrally Located Sump



(c) Underfloor ventilation

Ventilation is the process whereby internal air is gradually replaced by outdoor air. Natural ventilation is driven by pressure differences caused by wind or by differences in air density between indoors and outdoors.

Underfloor ventilation New buildings
For new buildings, the use of a suspended ground floor in either timber or concrete may make provision for underfloor ventilation convenient. However, it may not guarantee the ability to reduce high radon levels to an acceptable level without the use of a fan. Normal underfloor ventilation may be installed initially and, if indoor radon measurements taken after construction show acceptable levels, then no further action is necessary. The normal ventilation rate can be increased by introducing additional ventilators, this may suffice for radon levels up to 700 Bq/m^3.

For levels up to 850 Bq/m^3 fan-assisted ventilation may prove successful (see reference 6). The number of ventilators may need to be reduced on the intake side so as to avoid short circuiting of the air flow. However the precise configuration of the ventilation system depends on the geometry of the space to be ventilated.

Underfloor ventilation Existing buildings
Existing buildings with radon levels up to 850 Bq/m^3, which have a suspended type of ground floor construction, may have an easily remedied situation. The air space under the floor effectively disconnects it from the ground and offers the opportunity of intercepting the rising soil gas and removing it by ventilation before it can enter the building. The underfloor ventilation normally provided to remove rising ground moisture can usually be increased to allow a strong undercurrent of outside air to constantly replace the soil gas as it emerges from the ground. As the increased air movement under the floor would have a cooling effect it may be necessary to install floor insulation to prevent an energy penalty. The ease of adding insulation would depend on the construction details. Should this approach not result in the desired reduction within the building, it would then be possible to resort to fan-assisted internal ventilation or depressurization under oversite concrete.

(d) Ventilation of internal spaces Existing and New Buildings
Increasing the ventilation of living areas, whenever possible, by opening windows on two or more sides of a building is the simplest method of reducing relatively low levels of radon concentration. This will not always be possible for security reasons and in cold weather would be impractical due to discomfort and the increase in heating costs. This additional heating cost could be significantly reduced by installing a mechanically balanced supply/exhaust ventilation system with heat recovery. This would introduce and extract air at approximately the same rates, resulting in a neutral pressure within the building. To operate successfully, a balanced system requires a reasonably well sealed building in order to control air movement, and for radon reduction, it is essential that there are properly designed and located air inlets and outlets to allow incoming air to mix with room air. Mechanical ventilation of this type may not on its own be able to remedy a high level of radon but, as well as generally improving the quality of indoor air, it could be a useful supplementary tool with other systems. However, these systems are relatively expensive to install and it is unlikely that they would find widescale application in this country.

(e) Pressurization Existing and New Buildings
It is generally accepted that the use of extract fans within a house to improve ventilation is counterproductive in dealing with high levels of radon. The net effect is to reduce the pressure in the house and thereby induce more radon from the soil through any available openings in the ground floor. It should be noted also that the effect of open fires and other combustion appliances is to reduce air pressure within a house and for this reason should ideally be provided with a dedicated source of outdoor air.

An alternative approach is to use a fan system to provide a positive pressure throughout the house and in that way reverse the normal inflow of soil gas from under the floor.

In a house with a pitched roof this fan unit could be housed in the attic space and an air stream introduced into the house through a diffuser in the ceiling. Each room would be slightly pressurized and air forced out through crevices in windows, doors and other openings, reversing the normal inflow. Compared with outside conditions, the air in the attic would be warmed by solar gain for most of the year during daytime, but during night time use in very cold weather some prewarming of the air would be necessary. A temperature controlled small electric heater could remove the chill but would add to the running cost. There is available commercially an attic mounted unit which was designed primarily for condensation control but which could in some cases provide the desired pressurization to control radon entry. This system would likely have most success in a reasonably well sealed house where a constant positive pressure could be maintained with a relatively low powered fan.

Some sources have dismissed this approach on the assumption that warm and moist indoor air would be forced into the building fabric giving rise to rot and condensation staining. This result is unlikely except in an extremely "tight" structure with few openings to allow the air to escape a situation which is difficult to achieve in practice. For existing houses without other easy options, this system of pressurization may provide a solution and would be less disruptive than many of the other remedies.

6. Conclusion

If elevated levels of radon have been identified or are anticipated and it has been decided to take some action, the first step may be to seek advice. Unless the appropriate measures can be chosen with confidence, professional advice should be sought from an architect, engineer, or other person possessing the necessary knowledge to provide this advice.

The procedures suggested in this guide should minimise the danger to health caused by radon from the ground. However, post construction measurements of radon levels in an occupied building are the only method of determining the actual average annual radon concentration in that building.

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