**The Role of Ventilation**
**15th AIVC Conference, Buxton, Great Britain**
**27-30 September 1994**

# Using Pressure Extension Tests to Improve Radon Protection of UK Housing

P Bell*, A Cripps**

* Wimpey Environmental Ltd

** Building Research Establishment

**Using pressure extension tests to improve radon protection in housing.**

P.Bell — Wimpey Environmental Ltd.
A.Cripps — Building Research Establishment.

## Synopsis

In order to demonstrate conformity with the current Building Regulations, many house builders are incorporating sumps beneath the ground floor construction of houses within the designated Radon Affected Areas. These sumps will allow for later depressurisation of the below ground floor construction and thereby prevent radon passage to the internal building environment. There are concerns regarding the costs of these measures and also the potential for these sumps to be used by vermin as nesting sites as well as their effectiveness.

This paper reports on an ongoing study into the effect of different fill materials on sub– slab depressurization. In each test suction is applied at the centre of a floor slab and the resulting pressure field and flow rate is measured. These data give a good indication of the way in which a sump would be expected to perform. The results show that there is significant variation from fill materials described as being the same.

## Symbols

| | |
|---|---|
| Q = Air flow rate | $m^3/s$ |
| t = thickness of fill layer | m |
| $P_i$ = Pressure at point i | Pa |
| $r_i$ = distance from centre of suction hole to point i | m |
| k = permeability of fill | $m^2$ |
| $\mu$ = dynamic viscosity | Pa.s |
| v = Darcy velocity | m/s |
| $\Delta P$ = Linear pressure difference | Pa |
| L = linear distance | m |

## Introduction

Radon is recognised by the Government as a significant public health risk. Background information on radon can be found in the Householders Guide to Radon [1]. The Building Regulations [2] require that builders achieve radon concentrations in dwellings that are as low as reasonably practicable. There is compulsory restriction of radon in all other buildings under health and safety legislation; exposure to radon is restricted by the Ionising Radiation Regulations 1985 [3]. Guidance on how to protect against radon in new buildings is given by BRE [4].

The National Radiological Protection Board (NRPB) estimates that some 100,000 homes in th UK may be above the designated Action Level of 200 $Bq/m^3$ and 10,000 places of work subject to the Ionising Radiation Regulations.

There are a number of ways of ensuring that radon levels in a dwelling are maintained below the Action Level. These fall into three main categories:

1) Dilute any radon below floor level (sub–floor ventilation).

2) Prevent any radon migration across the ground floor to the dwelling interior. (Barrier method or sub–slab depressurization)

3) Ensure that any radon entering the dwelling is removed almost immediately by adequate levels of whole house ventilation. (Interior ventilation method).

All these methods are practical in different circumstances and are used. Wimpey have in the past undertaken some investigations into the performance of radon barriers and the consequences of their use on builders and purchasers alike Ref [5].

This project concerns a programme of work to investigate subfloor ventilation of ground supported floors. It is being funded by the Department of The Environment through the Building Research Establishment. The programme is being undertaken by Wimpey Environmental Ltd, using, where practical, floor slabs constructed by Wimpey Homes Holdings Ltd. It was originally intended to undertake tests on dwellings in affected areas only, however, the relatively low number of dwellings currently being constructed and a general preference for the construction of block and beam floors in the affected areas has meant that a number of tests have been undertaken on floors outside of the designated affected areas, although they have been selected from areas close by.

**Principals and test procedure**

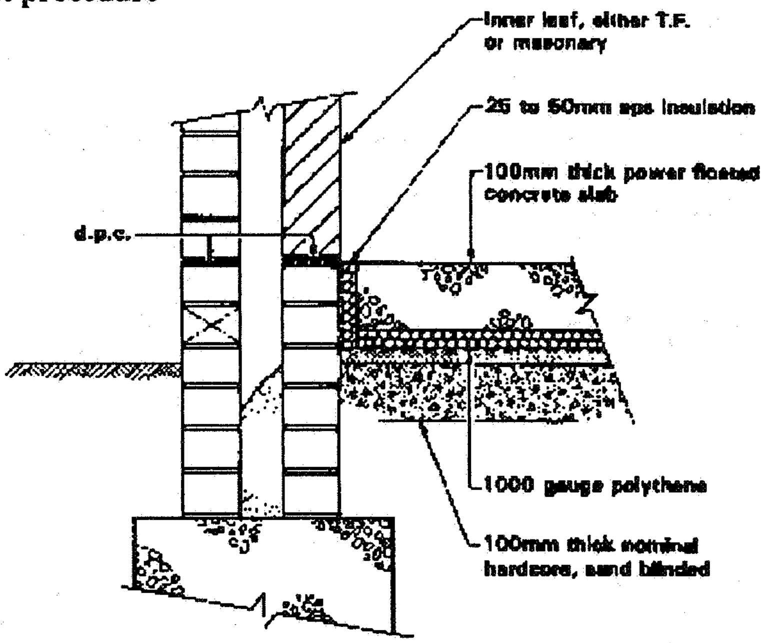


*Figure 1: The key elements of a ground supported floor.*

Depressurising the aggregate fill below the concrete floor, so that it is at a lower pressure than the internal air of the dwelling, will prevent the flow of radon between the fill and the dwelling. This is because the direction of flow of air is downwards through any cracks in the floor slab rather than upwards. It is this upwards flow which carries radon into a dwelling, and which the method aims to prevent.

A suspended floor has a sub–floor void (effectively a sump matched to the size of the floor), and the resistance to air flow in the void is very low. The whole of the void will effectively have the same negative pressure and the method is likely to work, either by depressurisation or by ventilation. However even in these circumstances short circuits and unventilated dead zones may be formed.

With a solid floor the underfloor void is filled with an aggregate material which restricts air movement . For a uniformly–sized fill material the resistance to the air flow will increase as the size of the aggregate is reduced because of the effect of reducing the porosity and increasing the surface area. Similarly the improved packing of aggregates with a large range of sizes results in increased resistance to air flow. For this reason many builders specify that only large, uniform aggregates should be used as floor fills in Radon Affected areas. Wimpey Homes Holdings recommend that ground supported floors include a ventilation layer which is a minimum of 150 mm thick and is made up of 75 mm single size aggregate.

The purpose of this programme is to establish, in Affected Areas, the resistance of typical floor fills to the flow of air, and how this varies with the different grades of the aggregates used for floor fills. From these results it should be possible to optimise the specification of aggregate to meet the radon remediation and constructional requirements. It is also an objective to establish whether the performance of the floor can be characterised by a simple test of this type and whether this can then be used as an indicator of the suitability of ventilation to the fill in the remediation of radon in an existing building.

It was decided to make best use of Wimpey Environmental's position within the Wimpey Group of companies and agreement in principal was obtained from Wimpey Homes Holdings Ltd to undertake tests on floor slabs under construction on their sites within radon affected areas. It is the practice for batches of floor slabs to be built and walls constructed to up to the damp proof course before overbuilding the remainder of the dwelling. It was decided that tests could be best completed at this stage with less likelihood of damage to internal finishes and the lack of internal paint work etc making general remediation easier. The disadvantage of this approach was that weather became a factor and many tests have been aborted because of high wind speeds.

**Test procedure**

The test procedure is a relatively simple one and involves drilling a 38 mm diameter hole in the middle of a floor slab. Checks are made to ensure that the suction hole has penetrated the damp–proof membrane. Into this hole is introduced a specially constructed suction tip which incorporates a dust filter and pressure tap. The perimeter between the suction tip and floor slab is sealed with a mastic seal or foamed sealant. To this is fixed the hose from a powerful domestic vacuum cleaner (VAX 4000) which incorporates an in– line air flow meter along the hose length.

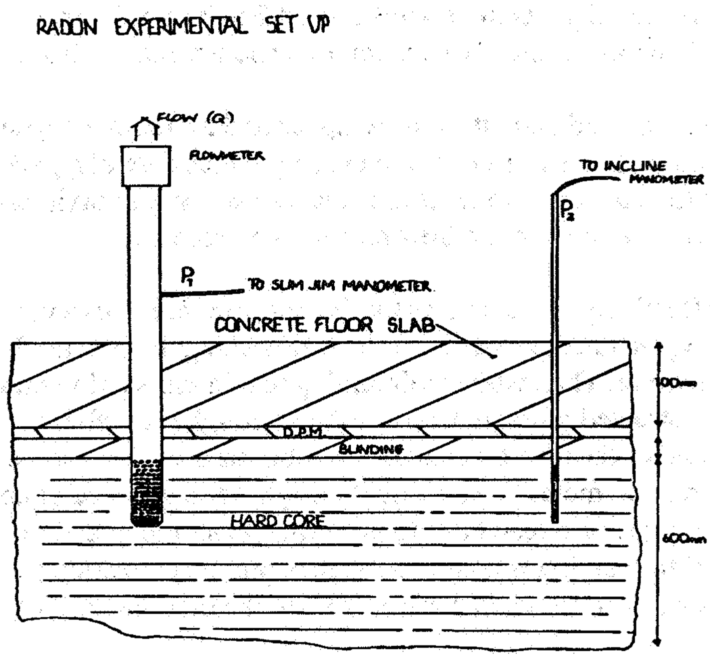


*Figure 2: Schematic of experiment*

Additional 10 mm diameter holes are then drilled radially from the suction hole in a diagonal line towards the floor corner, see Figure 2. Where there are internal footings and structural partition walls, for garages etc then these are avoided, as much as possible, in order to limit the influences on the measured pressures and flows. In general the smaller monitoring holes are drilled in the pattern shown with the separations doubling as the distance from the suction hole is increased; starting at roughly 150–200 mm from the centre of the main suction hole, with the next holes at 300 mm, 600 mm to a maximum separation of 1 m until the edge of the floor slab is reached

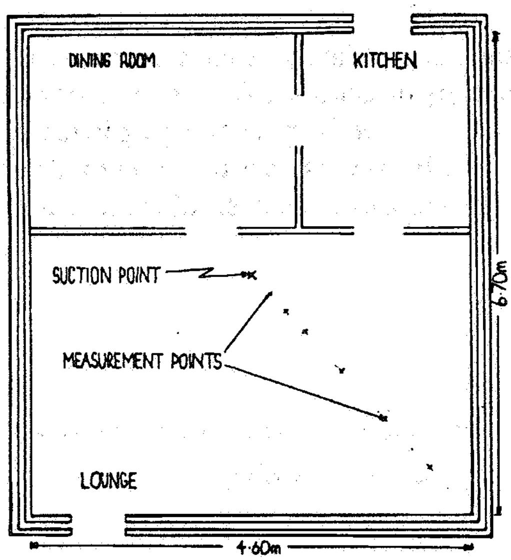


*Figure 3: Diagram of suction and test holes*

The largest floors encountered generally do not exceed 7 to 8 m, with many floors substantially smaller than this. Typically between five and ten sample holes are used.

The vacuum cleaner is switched on at its slowest speed and air removed from the central suction hole. At this stage all the 10 mm diameter sample holes are plugged with small rubber bungs. The suction of the vacuum cleaner is increased slowly until maximum, measurable pressure is attained; the pressure and the flow rate are then recorded.

This base resistance effectively characterises the fill performance. However it is important to assess the extent of the generated pressure field in establishing the potential for this technique as a radon remedial measure. Then while maintaining maximum suction on the vacuum cleaner, a specially constructed pressure tap is pushed through the slab into the fill. In order to prevent blocking the end of the tube by contact with the surface of any large aggregates, the tap is perforated by 3 mm diameter holes along its length for a distance of about 75 mm, as shown in figure 3. Tubing is then lead back to an incline manometer and the pressure generated as a result of the suction is measured at each prepared position. This is repeated for each of the prepared sample holes while keeping any of the other holes well sealed with the rubber bungs.

In radon Affected Areas Wimpey Homes are installing radon sumps within all ground supported floors. Consequently an adaptor was prepared which allows suction to be applied from the vacuum cleaner at the sump outlet. Measurements were then made in exactly the same way as described earlier with the sump as the source of suction. In some cases, because of the density of the slab reinforcements, it was not possible to penetrate the slab with a 38 mm diameter drill, in these cases only measurements with suction applied through the sump could be made.

Samples of the floor aggregate and details of type and supplier were obtained for each site and have been examined for particle size distribution in accordance with BS1377:Part 2:1990 [6].

The programme is still ongoing and to date tests have been undertaken on a total of 40 slabs. The programme target is currently on schedule for a total of 100 slabs to be tested in this way. The results to date are presented here and are encouraging in respect of the generated extensions to the pressure fields. However this is only part of the story with BRE and Wimpey undertaking a more rigorous mathematical analysis of the results.

## Results

### *Total flow resistance*

The simplest way to present the result of the test is to introduce a total flow resistance R (Pa.s/$m^3$), defined by assuming that the flow obeys:

$$Q = P / R$$

Where Q is the total flow in $m^3$/h, P is the total pressure difference generated by the vacuum in

Pa. The results suggest that this floor resistance varies markedly and for the nine sites examined to date we have seen variations between 6 x $10^2$ Pa.s/m$^3$ at one site in Northampton up to 6.8 x $10^6$ Pa.s/m$^3$ at a second site close by, see table 1. Results to date suggest that this simple test parameter may provide sufficient information in assessing the probable performance of sumps in radon remediation.

| Site | Number of Tests | Average value for suction pressure divided by flow rate (Pa.s/m$^3$)x10^6 |
|---|---|---|
| A | 11 | 0.2122 |
| B | 1 | 0.0006 |
| C | 3 | 0.0054 |
| D | 7 | 4.7236 |
| E | 5 | 2.0630 |
| F | 1 | 1.7600 |
| G | 2 | 0.3139 |
| H | 2 | 0.7609 |
| I | 1 | 6.7500 |
| Mean | | 1.8433 |
| Maximum | | 6.7500 |
| Minimum | | 0.0006 |

*Table 1: Resistances to flow measured for 33 floor slabs*

*Pressure fields*

A plot of measured pressure difference against the distance from the hole is shown in figure 4 for one/two of the test sites. One line can be seen to fit well to a logarithmic decay, whilst the other shows more variation from it. This reflects the variability in permeability below floor slabs.

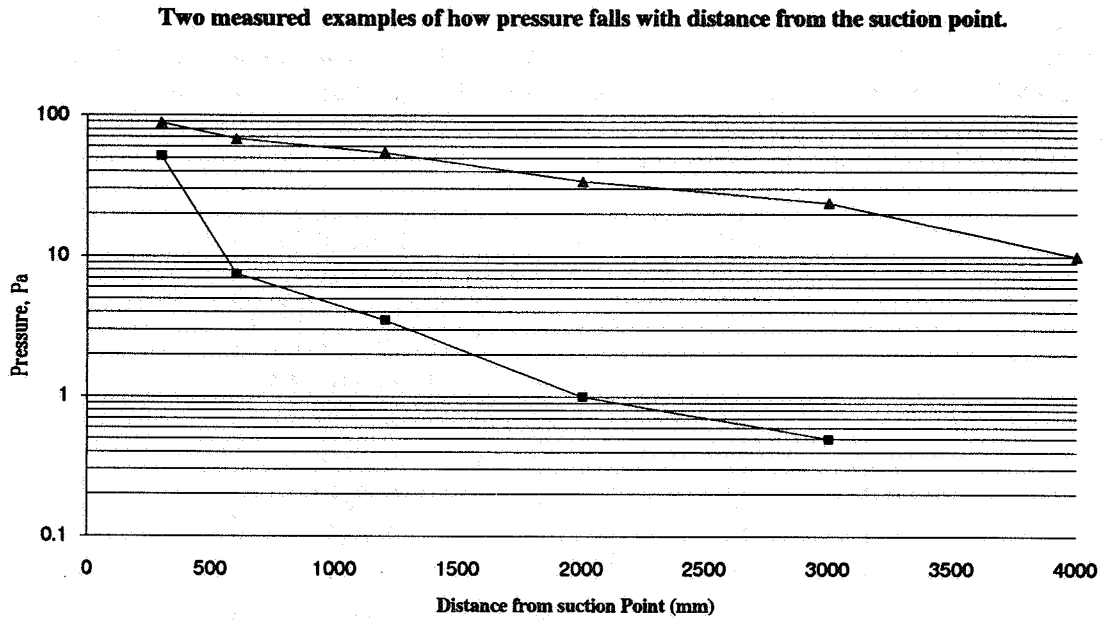


*Figure 4: Graph of pressure at measurement point against distance from suction point*

At the simplest level an assessment of the performance can be made by examining how far the pressure field does extend and this could be used as a criterion for the use of sumps. For example, perhaps the pressure should not fall below 5 Pa at the edge of the floor slab when a suction pressure of 9000 Pa is applied. However this does suggest that testing would be required in every case. If so, this could be simplified by specifying a minimum value for the resistance of the floor material.

The flow of fluids in soils and aggregate materials under the influence of a pressure difference P across a distance L is generally described by Darcy s Law:–

$$v = k/\mu.\Delta P/L \quad (1)$$

where k is a constant for the aggregate called the permeability and the other variables are as defined earlier. Therefore, according to Darcy, the velocity of the air in a fill material will be linearly related to the pressure difference. This does apply in most conditions, but not at high velocities. If Darcy's Law is combined with the continuity equation ($\nabla.v = 0$) then the pressure is governed by Laplace's Equation:

$$\nabla^2 P = 0 \quad (2)$$

Because the floor of the house and the soil below the fill are much less permeable than the fill it is reasonable to assume no flow through them. The suction hole extends down to the base of the fill material, so it is possible to assume no vertical variation in pressure. Solving (2) in cylindrical co-ordinates, and assuming radial symmetry gives:

$$P = (P_1 - P_2) . (\ln r/r_2) / \ln (r_1/r_2) + P_2 \qquad (3)$$

Where

$P_1$ is the pressure at radius $r_1$,
$P_2$ is the pressure at radius $r_2$
P is the pressure at the general point r

Differentiating (3) with respect to r, using Darcy's Law (1) and then multiplying by the area of flow $2\pi r.t$ gives the flow at any radius r

$$Q = 2\pi kt/\mu \, (P_1 - P_2)/\ln(r_1/r_2) \qquad (4)$$

Where $P_1$ and $P_2$ are the pressures measured between each sample radii. Hence if the theory above is reasonable, taking the result from any pair of measurement points, together with the total flow, (which does not change) should give the value of k.

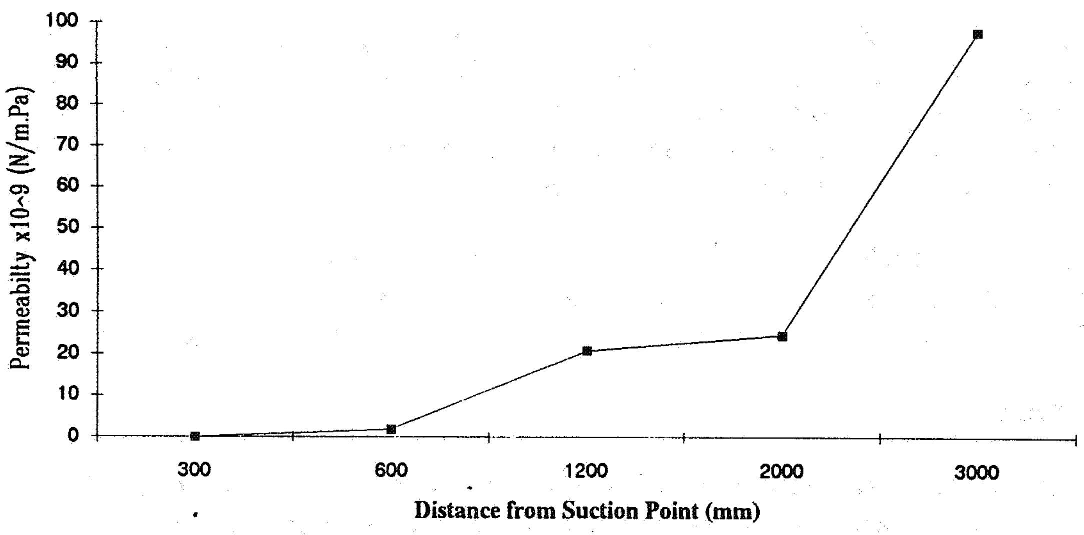


*Figure 5: Variation of calculated k with distance from suction point*

An example is given here of a graph of calculated permeability over viscosity for site A against distance from the suction point. It can be seen that the permeability calculated from (4) is not a constant for the fill but increases exponentially with distance from the suction point.

This behaviour is not common for every floor examined, but deserves further investigation. It results from one of a number of possible effects:

a) Darcy's Law does not apply, because the flow speeds are too high

b) The cylindrical symmetry is poor, so edge effects change the result

c) The flow is not the same at all radii because some leaves the fill at each radius

Each of these points could explain an increased effective permeability away from the suction point. If a) is significant the non-linear Darcy-Forcheimer Law for pressure loss could be used Ref [7]. The effect of b) is hard to calculate, probably requiring a numerical model. c) is also difficult to apply. The argument is that the same flow has been assumed at all radii, that is the flow which is measured at the suction point. However as some of this flow comes from the ground or through the slab the actual flow at any radius will be less than this. Hence the ratio of the central flow over the pressure difference is higher than it would be for the correct flow. To evaluate this effect will involve more computational effort than is possible now.

These are early days, but it is hoped that as the analysis progresses and more floors examined a better understanding of the ventilation performance of floor fill materials will be developed to increase confidence in radon remediation.

## Conclusions

40 of a planned series of around 100 tests of the air flow through fill materials have been carried out, and a preliminary analysis of the results made. These show that there is a wide variety in the resistance of the fill materials to the air flow caused by sucking from the centre of a floor slab. The extent of the pressure extension also varies considerably, and this is the effect which matters most directly to radon remediation.

In future work the details of the make up of the fill materials will be considered along with the reasons why the permeability appears to increase with distance. In addition the use of the total resistance as a measure of the probable success of a sump needs to be considered further.

## Acknowledgements

This work was supported by the Building Regulations Division of the Department of the Environment (DoE), and published with their permission. Views expressed are those of the authors, not necessarily of the DoE.

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