THE EFFECT OF NATURAL VENTILATION ON REDUCING RADON LEVELS WITHIN AN EXISTING DWELLING

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1 Introduction

Radon levels within a dwelling of traditional construction located in South Devon have been monitored intermittently over a period of several years. This paper discusses the characteristics of radon gas, presents the results of a series of monitoring tests and demonstrates a broad relationship between radon concentration and the amount of naturally induced ventilation within the test house. Variation in typical levels in different rooms is examined.

1.1 Characteristics of Radon Gas

Radon is a naturally occurring inert radioactive gas, produced by the decay of naturally occurring elements in rocks and soil. Because it is invisible, odourless and tasteless radon gas is difficult to detect and requires devices that can measure alpha particles or the indications of its progeny.

Radon gas can pose a risk of lung cancer to inhabitants of dwellings where concentrations are found to be over the government stated action level of 200 Bq m^{-3} (400 Bq m^{-3} for the workplace) (Ionising Radiation Regulations (IRR),1985)

Radon 222 is part of a decay chain that is initiated by the disintegration of Uranium 238, naturally occurring in rocks and soil, through many different elements, culminating in Lead 206. Radon 222 is the only element in this chain to be mobile because it takes the form of a gas. Radon 222 has a half life of approximately 4 days and is the only radon isotope that has a long enough half life to travel into a dwelling and pose a risk. Because of this, when 'radon gas' is mentioned it is the Radon 222 isotope that is being described. Among Radon 222's short lived progeny, only Po-218 and Po-214 are described as 'alpha emitters'. These two metallic elements can be inhaled and because the poor penetrating power of the alpha particles they emit, the ionising energy will be deposited within a few cell diameters, causing mutation or killing the cell outright (Lao,1990). This damage can contribute to an increased long-term risk of cancer and combined with smoking the risk can be heightened, as can be seen in table 1.

Lifetime Risk of Lung Cancer Potentially Induced by Radon over a Lifetime period			
Radon Conc (Bq m^{-3})*	Smokers	Non-Smokers	Total Population
20.00	1 in one hundred	1 in one thousand	3 in one thousand
100.00	5 in one hundred	5 in one thousand	1.5 in one thousand
200.00	10 in one hundred	1 in one hundred	3 in one hundred
400.00	20 in one hundred	2 in one hundred	6 in one hundred

* (Bq m^{-3} = the SI unit becquerel per cubic metre which equates to one disintegration per second per metre cubed)

Table 1 (National Radiological Protection Board (NRPB),1990)

1.2 Sources of Indoor Radon Gas

Radon gas within dwellings generally tends to come from three main sources: the ground upon which the house is built, the building materials that make up the dwelling and if the building takes its supply locally, water for drinking and bathing.

Radon gas from the ground is thought to contribute the largest percentage of radon concentration within dwellings. Normally radon gas will migrate to the surface and be diluted by the surrounding air. The amount of migration will depend on the permeability of the soil: a loose dry sandy soil will provide a better migratory path than a water logged clay soil. The major mechanism to allow radon to enter a home in that of convection. During the winter months the air of the interior of dwellings is warmer than the exterior air causing a convective flow from inside a dwelling out through any leakage paths. This will draw up any radon from the ground, causing increased concentrations of the gas. The amount of radon gas entering a home can increase or decrease, depending on the external wind force and direction. Extract fans can increase ventilation rates within a home, exacting similar effects to wind pressures and natural convection paths.

Building materials, particularly any that are based upon certain igneous rocks, can increase radon levels within a dwelling. Many such materials, such as those featured in the test house, are often found in the chimney stack and surround, possibly uncovered as a feature.

Water supplied to the home can contain radon in solution, but as the radon has a half life of about four days and most water in reservoirs and the supply system will take longer than that to reach the household. It is therefore unlikely there will be any appreciable increase in radon concentration from this source. Only dwellings that rely on a very local water supply will be at risk. This risk will be at its greatest when the water is at relatively high temperature, as the solubility of Radon in water decreases with increasing temperature (Lao,1990).

1.3 Solutions to radon problems

Measures to prevent or reduce the incidence of high concentrations of radon gas within dwellings are varied in their scope and approach. Radon can be prevented from entering the building or the high concentrations can be dealt with once the radon gas has entered the occupied space. (NRPB 1990)

To divert or change the flow path of radon gas three main techniques can be employed. Obvious gaps, cracks and holes in floors can be sealed to try to prevent the radon from entering the building. In practice however this technique tends not to be as effective as some other techniques when tackling an existing property. This stems from the great difficulties in locating the major flow-paths of radon gas and the limitations in obtaining access around fixed structures such as cupboard plinths and understair spaces. However when a property is being constructed, passive measures, such as the application of an appropriate grade of membrane under or within a floor and wall, will be a cost effective solution to radon control.

For radon levels up to about 700 Bq m^{-3} (Stephen,1995) a second technique, positive pressurisation can be an attractive solution. This technique employs the use of a small fan unit to blow filtered air (normally from the roof space) into the building. This solution works in two ways, increasing the inside air pressure of the dwelling and to some degree excluding the radon gas and diluting any radon that does infiltrate the building. This system does have other advantages, with the use of suitable filters, it supplies air containing less particulates and often combating condensation (the main use to which this technique was originally developed). For positive pressurisation to work effectively a building needs to be reasonably airtight. If the air intake is positioned within the roof void the high summer time air temperatures, along with any remnants of timber preservatives, can be taken into the occupied zones of the dwelling. The occupier has decided that at a later date a positive pressurisation system will be installed using an air intake from the gable end wall of the test house thus avoiding many of the system's possible disadvantages.

A third solution is the use of an under-floor sump. This comprises a chamber built under the floor of the property linked by pipework to the outside air, sometimes left without a suction device, but more commonly fitted with an electric fan to draw out the radon laden air. Another variation on this theme is the use of under-floor depressurisation which uses a similar fan unit but attached to a pipe that draws air from the space under a suspended floor. Both of these solutions are particularly effective if the material under the dwelling is permeable (BRE,1992). These solutions are relatively inexpensive when applied to new-build projects but the level of disruption and expense can be considerable for existing dwellings.

Once radon has entered the building the most obvious solution is to increase the ventilation rate within the living spaces, diluting the gas by either natural or mechanical means. As can be observed in the section referring to the radon measurement series, a succession of natural ventilation measures were used in the test house over an extended period.

2. The Investigation

2.1 Description of the test house

General Description

The test house is semi detached stone built traditional cottage, erected around the end of the 17th Century. The cottage is two storey, providing 3 bedroomed living accommodation with the normal range of modern facilities - kitchen, bathroom, living room etc. The properties construction is typical of its type for the area, with local stone walls beneath a proprietary slate covered trussed roof.

The cottage has been modernised over the years with the addition of a single storey lean to rear extension housing the kitchen and utility areas. More recent alterations include the installation of new concrete floors and a downstairs internal lavatory.

A particular feature of the test house is a partial flying freehold where a section of the first floor (Bedroom 1) oversails the main entrance to the adjoining cottage.

Location

The house is located on the south east edge of the Dartmoor national park, an area of the UK known to have above average radon concentrations.

Construction Features

Main Roof Structure

The main roof structure comprises traditional 'A' frame timber trusses supporting a framewood of softwood purlins and 50 x 50mm softwood rafters. As is typical for properties of this type and age, the roof construction is relatively slender, and considerable deflection is evident in the roof slopes as a result. Evidence of wood boring beetle infestation was observed during the inspection with considerable damage being visible to some members. The roof structure was sprayed with preservative paste some years ago

Main Roof Finishes

The roof slopes consist of fibre cement slates on timber battens. The underside of the battens is lined with a bituminous slating felt. The roof coverings appear to be in good order.

Roof Void

Access to the roof void is provided via a hatchway located in the ceiling of Bedroom 3. Approximately 75mm of fibreglass insulation is laid between the ceiling joists. A fibreglass water storage tank with loosely fitted eps insulation, is installed within the roof void.

Ancillary Construction

A single stone chimney stack serves the main fire. All flashings to the stack are lead.

Lean to Roofs

The rear lean to roof is clad with fibre cement profiled sheets supported on a lightweight timber framework. No access to inspect the roof structure was available. A second slate covered lean to roof is provided over the rear entrance.

Main Walls

The main walls comprise of local stone bedded in lime mortar to a typical thickness of 500mm. Evidence of the presence of a silicon injected damp proof course was observed at the base of the walls. The front wall is tyrolean rendered and painted. The walls are in fair condition although some soft pointing is present on the side gable wall.

External Joinery

The doors and windows are single glazed painted softwood throughout with the exception of a relative new draft stripped double glazed window to bedroom 2.

Internal Construction

The ground floors are modern screeded concrete. A damp proof membrane has been installed and the floor showed no signs of damp staining. The floor level. in the kitchen is approximately 100mm lower than in the lounge - a single step being provided in the rear living room doorway.

The rear ground floor partition between the living room and kitchen is soli, damp staining is not apparent.

Ventilation

All the windows have opening casements to provide ventilation. Trickle vents are not installed except for bedroom 2. The windows and external doors were draft stripped some time ago using self adhesive foam, however gaps between the frames and the foam strips are evident and generally the draft stripping measures are considered ineffective. The loft hatch and front door letter plate are not draft sealed.

Mechanical extract ventilation is installed in the ground floor lavatory only.

The main roof loft is provided with limited ventilation through a single air brick in the gable wall. Additional air flow to the loft space is likely to be achieved through the unsealed verges.

Heating

The main heating system within the dwelling is provided by electric storage heaters in the primary living and sleeping spaces.

An open fireplace is a major feature in the living room. Unusually a ducted ventilator is installed in the base of the hearth to improve the draw of the fire. The ventilator is ducted direct to the exterior through the side wall. An iron flap is provided to control the fire ventilation.

Services

The premises are provided with mains electricity, a local water supply and septic tank drainage. The service entries are all separate at ground floor level and are not ducted.

2.2 Monitoring equipment

Two forms of monitoring equipment were used in the test dwelling.

Over the period of the initial three tests, alpha -track detectors were used, both supplied and analysed by the National Radiological Protection Board. These detectors use a plastic film which is 'etched' by any alpha particles or radon progeny that strike it. These tests were long term, varying for between 3 to 12 months.

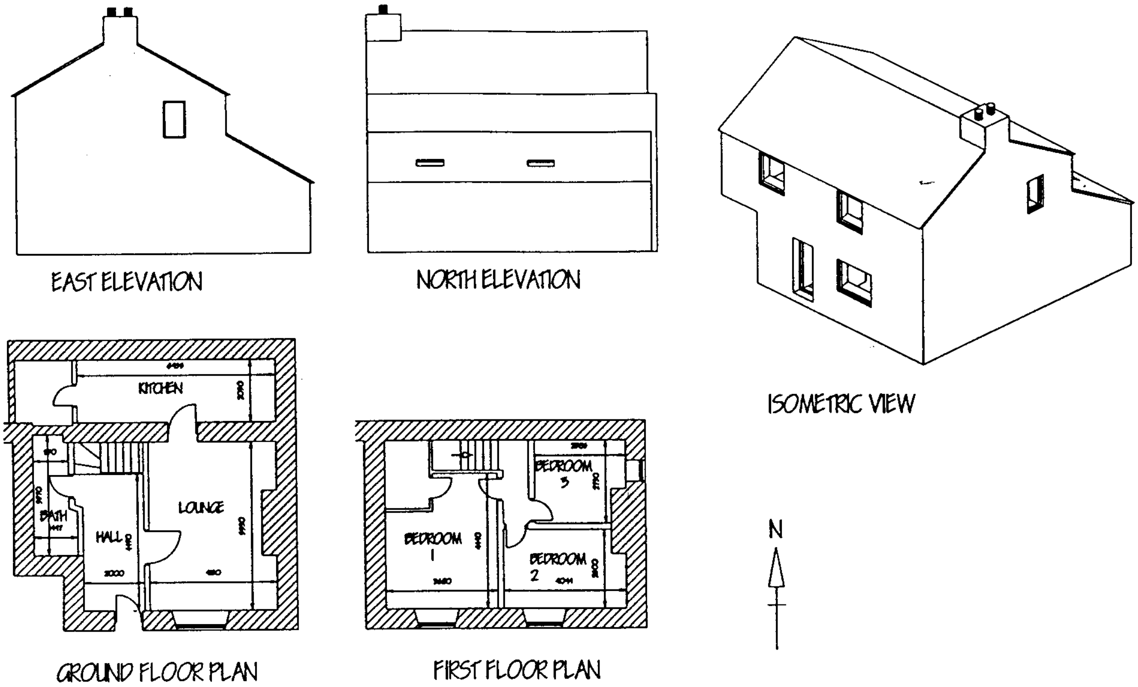
The final monitoring was carried out using an 'Alphaguard' radon detector (Genitron Instruments) which utilise a pulse ionisation chamber achieving an accuracy of about +/- 7%. This detector does have the advantage over the track detectors of taking measurements every 10 minutes, enabling radon concentration to be related to factors such as internal conditions, time of day, occupant behaviour etc. The detectors also monitor simultaneously, air pressure, temperature and humidity, combined with software which will allows a statistical analysis of the results.

2.3 Radon measurement series

The National Radiological Protection Board (NRPB) began to develop its programme of radon measurements in dwellings in the early 1980's. The test house was included in a pilot study. Two sealed detecting pots were placed in the lounge and one in bedroom 1 in June 1982. After six months they were removed and replaced with new ones for a further six months. The result of this first test averaged out at just over 200 Bq m^{-3} (Table 2).

	June - Dec ‘82	**Dec - June ‘83**
Lounge	211.00	390.00
Bedroom 1	120.00	120.00

Table 2: Results of Test 1 June 1982-June83, Bq m^3



At about that time the government's recommended action level was halved from 400 to 200 Bq m^{-3}, and the occupier considered that, although the result of test 1 hardly exceeded the new action level, steps should be taken to reduce the concentration. Accordingly the air valve on the fireplace hood in the lounge was closed when the fire was not in use, but the air intake vent was left open (see description of test house). These two measures considerably reduced the updraft of the chimney and hence the induced negative pressure in the lounge, although the butterfly valve in the hood, and cracks in the register plate-masonry joints, would not have provided a perfect seal. The fireplace was used considerably less frequently (around twice a month in winter) since its considerable demand for air would have created quite large negative internal pressures (relative to the outside air pressure) drawing in soil gas. In addition, windows were left open more frequently, particularly upstairs.

In 1990 a second test was carried out by the NRPB. Two of the later style yellow plastic detectors were placed in similar locations as before, for a period of three months from August to November. 1990. At this stage the NRPB had developed techniques to extrapolate results of a three month test in a given season to an equivalent annual average value. For this second test the annualised radon level was 140 Bq m^{-3}. However there was some doubt about that technique of analysing and correcting measurements from only three months and so the NRPB recommended a further test which took place between December 1991 and May 1992, giving 110 Bq m^{-3}.

At approximately one half the 'action level' the occupier felt the measures taken had caused a welcome reduction. However, noting that any recommended level is necessarily arbitrary (and also that advisory safe levels in many areas of risk seem regularly to be revised downwards as more is learned over time) he felt that a further reduction would be desirable. A greater awareness of the convection driven mechanism for admitting radon led to more ventilation being provided on the ground floor by removing the letter box seal and fixing it open, and when convenient opening ground floor windows in preference to those on the first floor.

A fourth series of tests was carried out in 1996 with the Alphaguard Radon Monitor (Genitron Instruments). Figs. 4 & 5 are results from the lounge, giving a (weighted) average of 86 Bq m^{-3}. Bedroom 1 results are in Figs 6 & 7, averaging to Bq m^{-3}. No attempt has been made to allow for seasonal variations in these figures and so comparison with earlier NRPB results must be made with caution. Figs. 8 & 9 were taken in the lounge (under staircase) cupboard which is situated in the centre of the ground floor and has low rates of ventilation. Fig. 10a is from the bathroom, with 10b showing humidity over the same period. Radon levels in a carport and open courtyard outside the test house recorded a mean level of 15 Bq m^{-3} and 5 Bq m^{-3} respectively showing how very high rates of dilution by outside air reduce radon levels effectively to zero.

3. Discussion

Generally the lounge and bedroom 1 radon levels are a little lower than they had been in 1991, presumably due to extra ground floor ventilation.

Second, possibly surprisingly, any daily variation seems considerably lower in magnitude than trends occurring over several days. This may indicate that the daily routines of the occupants (periods when house is empty, heating cycle of storage heaters and so on) do not have a dominant effect. It may be that weather conditions, and in particular wind speed and direction, are more significant.

Third, it appears from Fig. 8a that there is no significant contribution to radon levels from the water supply. Closer analysis may reveal a correlation between the humidity peaks coinciding with baths and showers and radon levels, but it is clear from inspection that there is no strong relationship. A daily variation is very apparent from the records taken in the lounge cupboard. (Figs 8 especially, & 9). One would expect higher radon levels in this area of poor ventilation, but it is surprising why the peaks in the early hours should be so strong. The cupboard door is opened about five times a day. Apparently that causes sufficient air change to bring the night-time 600-800 Bq m^{-3} levels down to those typical of the lounge itself.

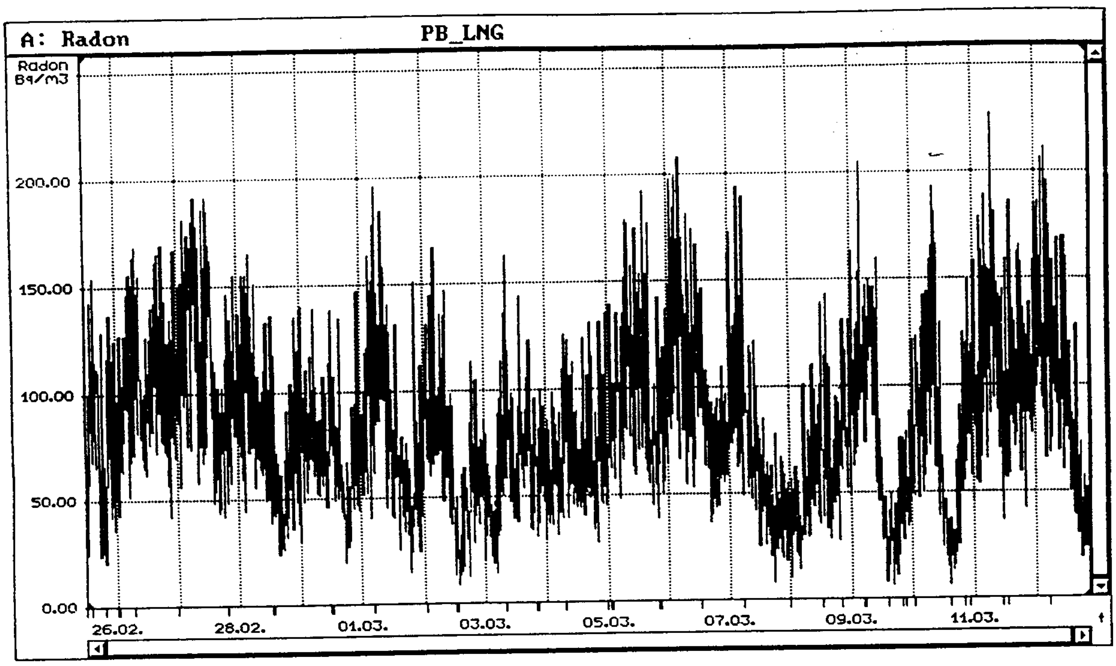


Fig 4 Radon Concentrations in the Test House - lounge, 26/2/96-11/3/96 Bq m^3

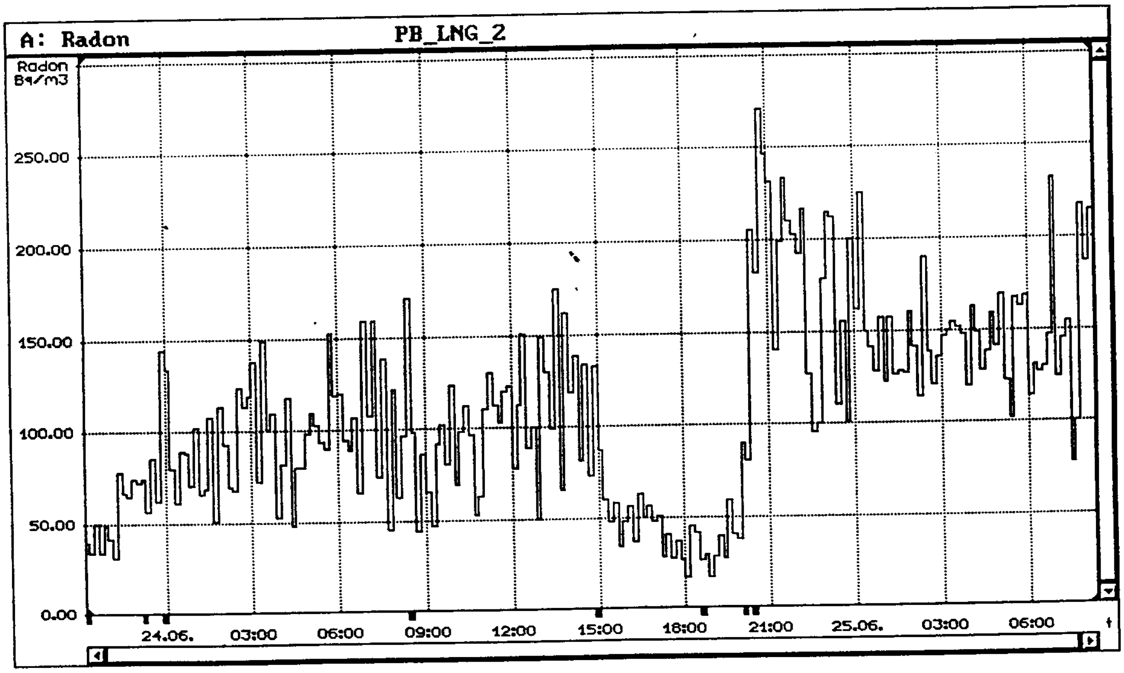


Fig 5 Radon Concentrations in the Test House - lounge, 24/2/96, daily cycle, Bq m^3

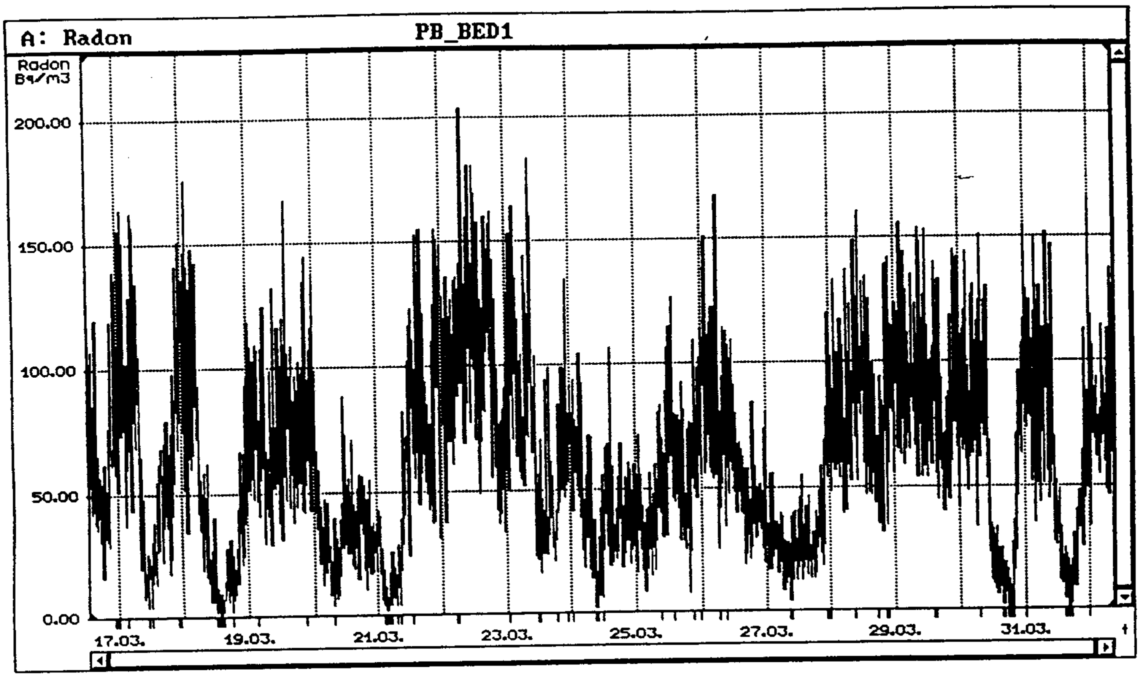


Fig 6 Radon Concentrations in the Test House - Bedroom 1, 17/3/96-31/3/96 Bq m^3

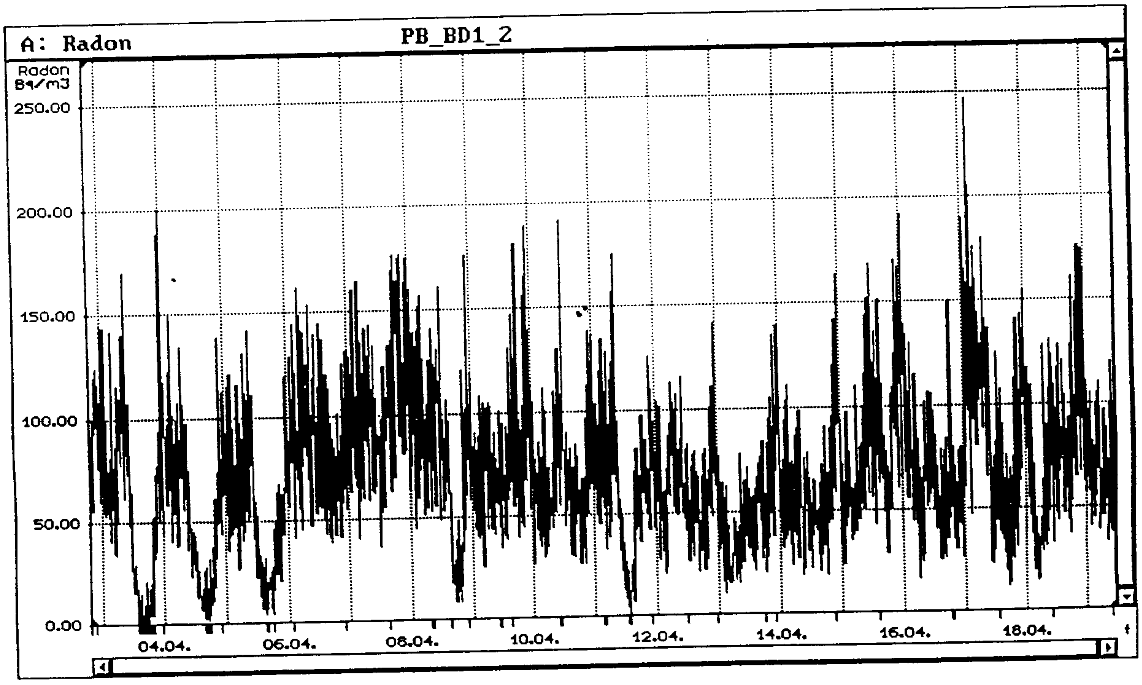


Fig 7 Radon Concentrations in the Test House - Bedroom 1, 4/4/96-18/4/96 Bq m^3

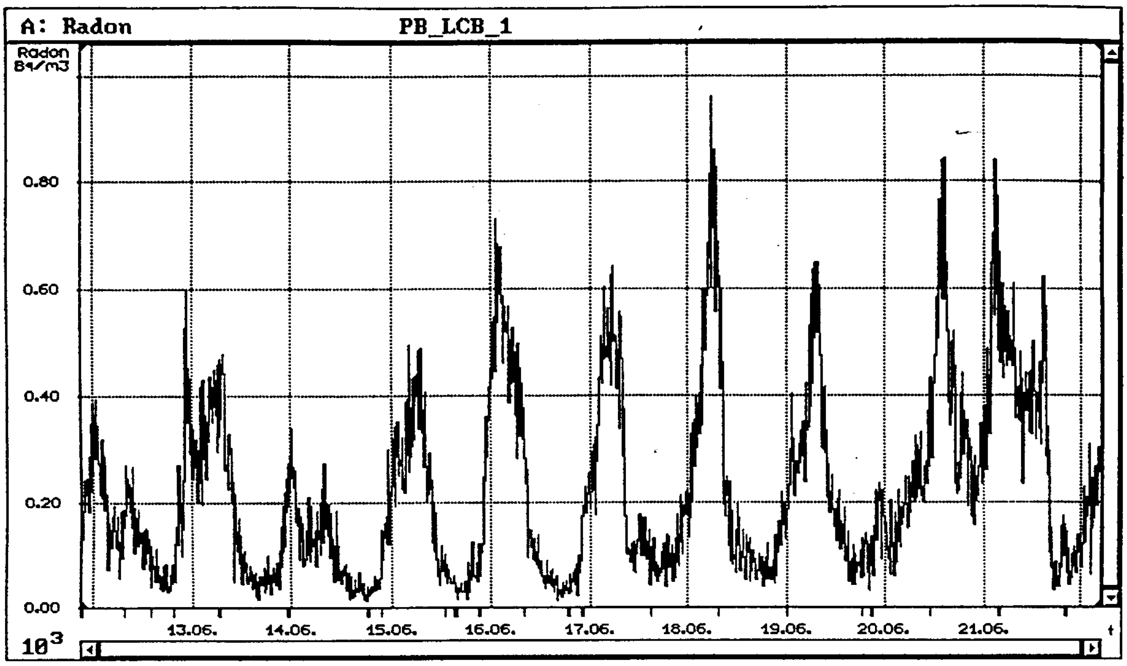


Fig 8 Radon Concentrations in the Test House - Under-stair Cupboard, 17/3/96-31/3/96 Bq m^3

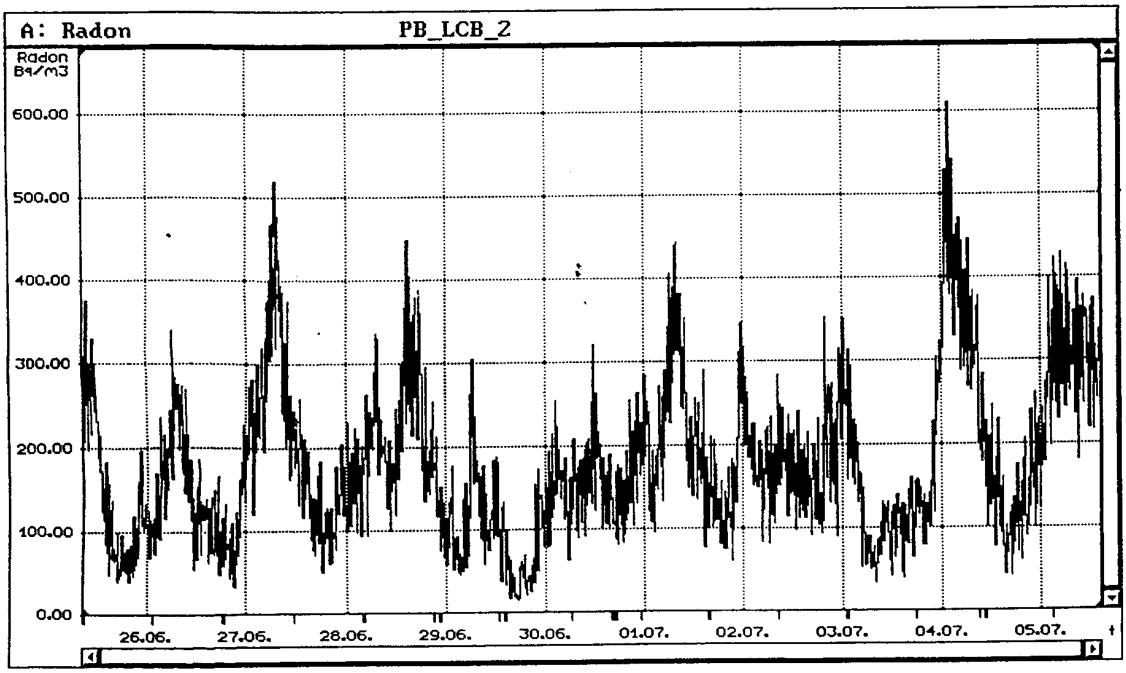


Fig 9 Radon Concentrations in the Test House - Under-stair Cupboard,26/6/96-5/7/96 Bq m^3

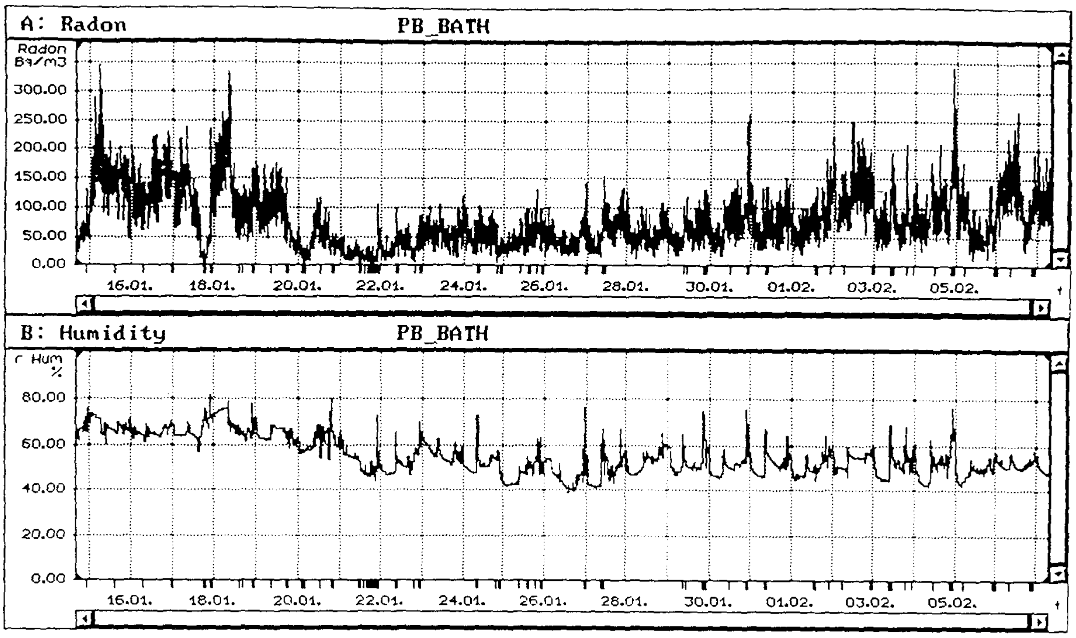


Fig 10a & 10b Radon Concentrations and humidity levels in the Test House - Bathroom, 26/6/96-5/7/96
radon measurements Bq m^3 & % relative humidity.

4. Conclusion and Future Work

The results indicate generally that ventilation is likely to be a key parameter in the control of indoor radon.

However, just as air change rates vary greatly with weather conditions, so do radon levels. In addition, it will be clear that the occupants have lost the amenity of regular use of the traditional fireplace, and there are heating and possibly security implications to providing ventilation at ground floor level. Plans exist, therefore, to provide a positive ventilation system that will give a controlled rate of supply of air, enabling a controlled compromise to be reached between air supply rate and heating costs. Modifications will be necessary to seal the ventilation apertures introduced in (as previously mentioned the radon solutions section) the fabric of the test house to permit the efficient working of this system. Radon levels will be reduced both by dilution, and by the positive preservation effect on the whole house and to maximise the latter, better draftproofing and sealing will be needed, especially to the chimney. As an additional benefit the occupants (some of whom suffer from allergies such as hay fever) will benefit from an environment of clean, filtered fresh air.

It is difficult to draw detailed conclusions from this work on the relative effect of different factors. There is considerable variability in weather, season and occupants' routines, and (in the final test series) no concurrent measurements were possible in different rooms. Other work, based on better controlled test facilities, is more likely to reveal detailed relationships. However it is believed that the results from this 'real life' setting form a useful insight to the effectiveness of small scale practical measures introducing changes in the patterns of natural ventilation and their contribution to a useful overall reduction in radon gas concentrations.

Acknowledgements

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