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Radon and radon progeny concentrations in family houses with different heating systems

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Introduction

The interplay of outdoor and indoor conditions on the indoor environment results in a complex contradiction beween energy consumption and indoor air quality. A decrease in the air change rate can decrease the energy consumption, but unfortunately can also increase the indoor pollutant levels when significant indoor sources are present. The concentration of radon in Swedish homes ranges from 1 nCi/m^3 to 12 nCi/m^3, while in U.S. homes it is from 0.2 to 3 nCi/m^3. One reason for this is that Swedish homes, with an air change rate of 0.2-0.8 ach , are tighter than those in the U.S. where the air change rate ranges from 0.5 to 1.5 ach.

Radon-222 is an inert, radioactive, naturally occurring gas which is part of the Uranium-238 decay chain. Radon itself is not generally considered harmful at commonly occurring indoor levels. It decays through four intermediate progeny before it is transformed to lead (Pb-210), which is also not considered harmful at naturally occurring levels. This process is illustrated in Fig. 1. However, this radioactive decay process results in alpha emissions that can damage lung tissue if the immediate progeny are inhaled. Several models have been devised to estimate the risk due to radon exposures among the general population, see NRC (1981). However, a review of these models is beyond the scope of this paper.

The radon release rate is a function of indoor pressure. We therefore can assume that in a single family dwelling that the changing of the indoor pressure due to the chimney effect, will change the radon levels in the house. The chimney by drawing air from the basement, has two effects. First it inhibits air flow from the basement to the upper levels thereby keeping the lower radon levels in the living space. Secondly the chimney provides an exhaust ventilation for the

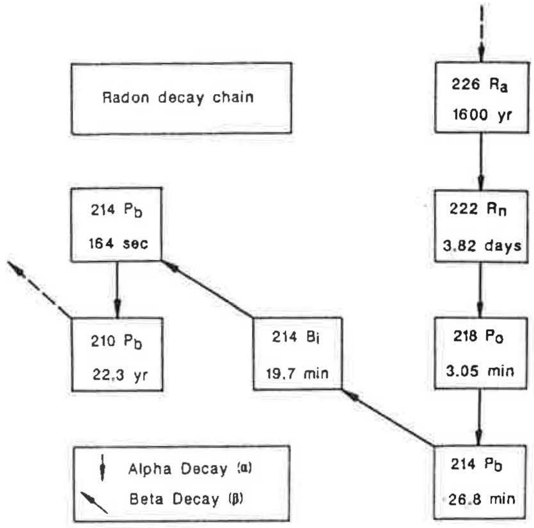

Fig. 1. Principal decay scheme of radon-222 to lead-210.

basement itself, which in turn helps decrease the radon level.

An important question when looking at the radon levels in a single family dwelling is if the boilers' chimney have a positive or a negative effect on the radon levels. This problem is also relavant when looking at the ventilation in the basement during summertime.

This paper employs the multi-room indoor air quality model, together with the interzonal flow rates calculated from the multi-room model MIX , see Li et al (1990), discusses the spreading of radon and its progeny in multi-room one family dwelling with different heating systems..

Characterisation of radon sources

Fig. 2 shows the primary sources and pathways of radon in a residential building. In general, soil, water and building materials are the principal radon sources. Other sources such as natural gas etc. play a relatively minor role, see NRC (1981).

In many cases, the entry of radon-bearing soil gas appears to be the predominant source of radon in houses observed to have

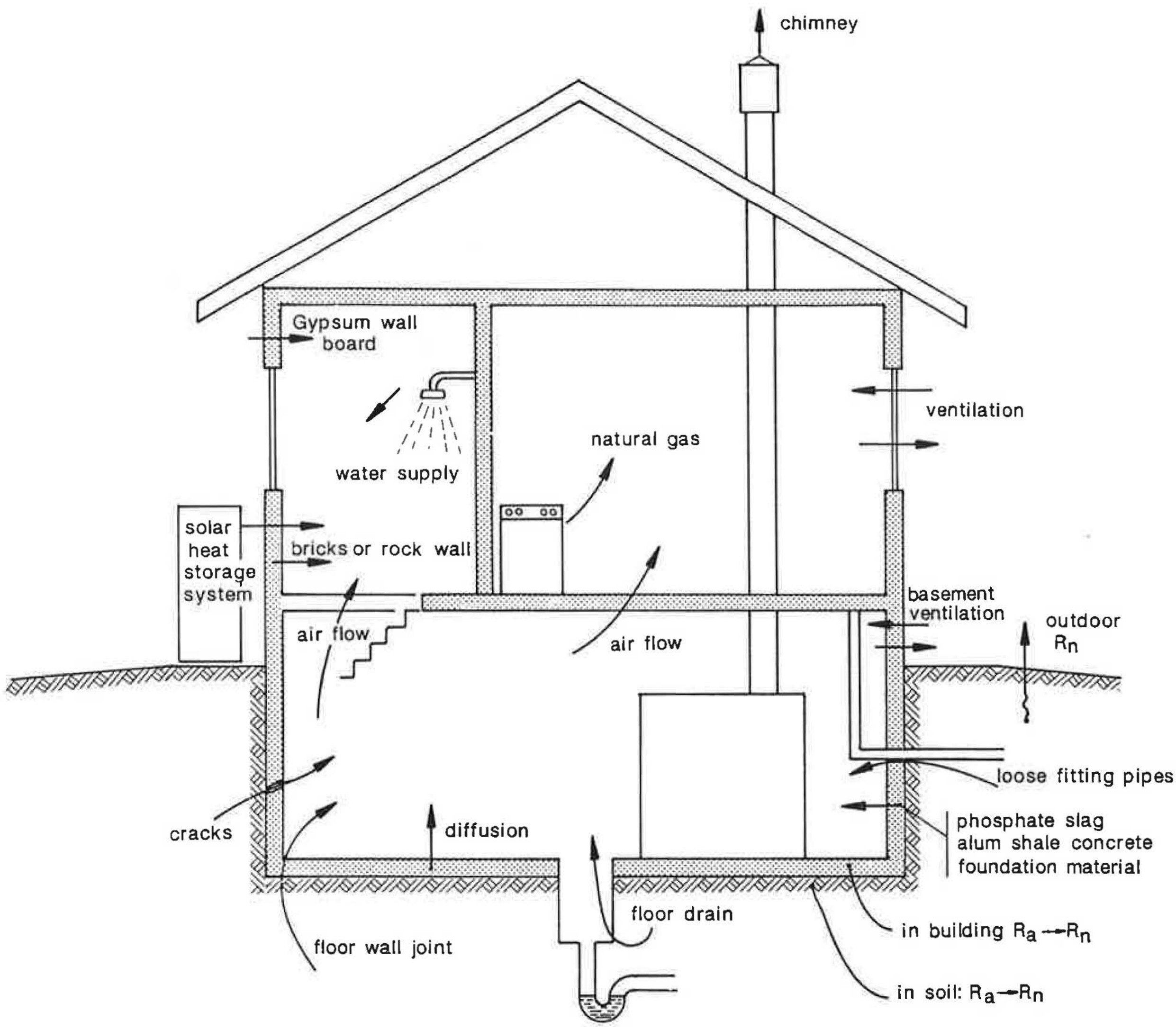

Fig. 2. Summary of radon sources and pathways in a residential building.

high indoor concentration. Radon moves from the soil to the indoor environment either by diffusion or by convection, and the pressure-driven flow of soil radon, is thought to be a major mechanism. It is known that the wind force, thermal force and the mechanical ventialtion force can create a slight de-pressurization in relation to atmospheric pressure. In a typical residential building, it is this pressure differential that partly draws the radon-bearing soil gas into the building, especially near the floor of the house. See NRC (1981). The radon is associated primarily with low rise residential buildings with the concentration levels higher in basements than on upper floors.

An important aspect of indoor air quality modelling is the characterisation of indoor contaminant sources. As the main risk of radon pollution arises from daughter products of radon, the quantity used to describe the actual radiation hazard due to radon decay, is called the "potential alpha-energy concentration". Its unit is the working level, defined as any combination of radon progeny that would produce an alpha energy of $1.3 \cdot 10^5$ mev/L. This is the potential alpha-energy concentration if radon-222 at 100 nCi/m^3 is present with equilibrium amounts of its progeny. The working level can be expressed as

$$WL = F \cdot C_r / 100 \qquad (1)$$

where

WL = working level

F = equilibrium factor
C_r = relative concentration of radon, pCi/L.

The equilibrium factor F = 0.103 RaA + 0.507 RaB + 0.373 RaC, where RaA, RaB and RaC are the relative concentration levels of the radon progeny (pCi/L). The values of F will be unity if the radon is in equilibrium with its progeny, and if the progeny removal mechanisms exist, i.e. an air cleaner, F will be lower. It can be seen that quantitative radon models must include prediction of the radon generation rate and the effect of natural and mechanical means of progeny removal. In addition since the progeny are electrically charged particles, which can attach to airborne particulates or adjacent surfaces, the actual radiation from a given level of radiation is strongly dependent upon indoor particulate levels and air movement. Therefore a detailed model should include the interactions among radon progeny, particulates and air movement.

Multi-room prediction models

It is convenient to represent a building as an assembly of interconnected zones as was done in the modelling of air flow and ventilation in multi-room building, see Li et al (1990). Each zone or room is capable of exchanging air with any other zone or room. In fact, many such zones or rooms are characterised by nonuniform mixing. For example, in one room, stagnant parts may occur due to temperature differences or due to the particular design of the air distribution system. For practical purposes, the system can be regarded as perfectly mixed.

The fundamental equations of multi-room prediction models have been stated by various authors, see for example Li et al (1990), where it also possible to examine the solution for a unsteady state .

Example

In order to evaluate the radon and the radon progeny concenttration, and evaluate the influence of infiltration and ventilation, an model house was simulated. It was a two floor, wood framed construction house with a basement. One room in the basement had a boiler with a chimney. The house was unoccupied and had no appliances. The floor plan and the ventilation system are shown in Fig. 3.

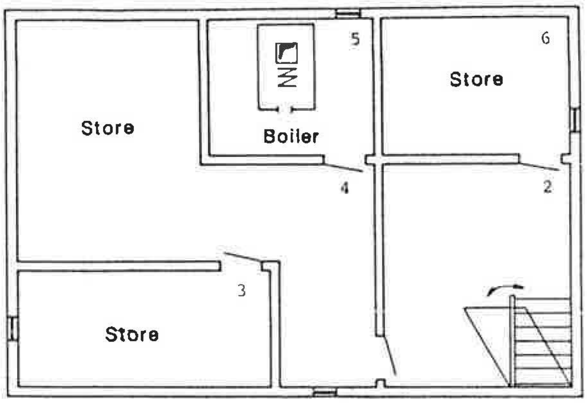

Fig. 3a. The floor plan (basement).

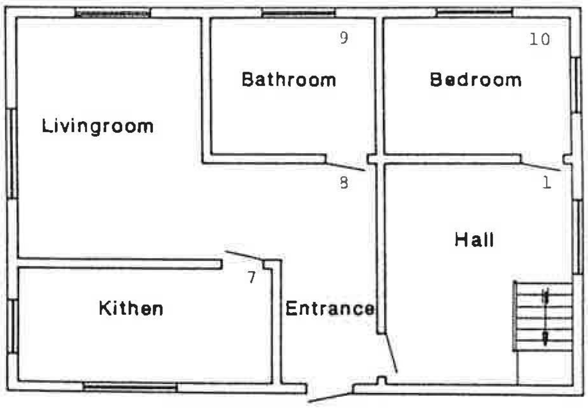

Fig. 3b. The floor plan (first floor).

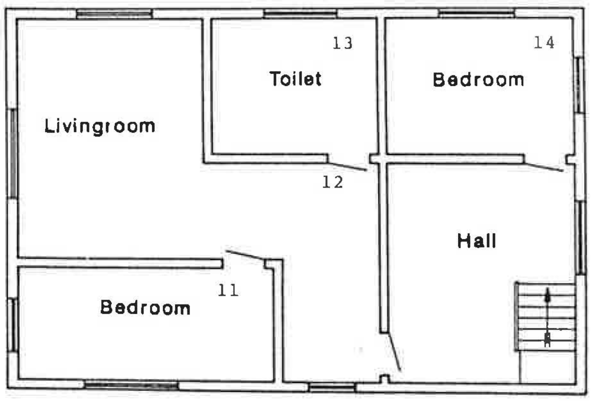

Fig. 3c. The floor plan (second floor).

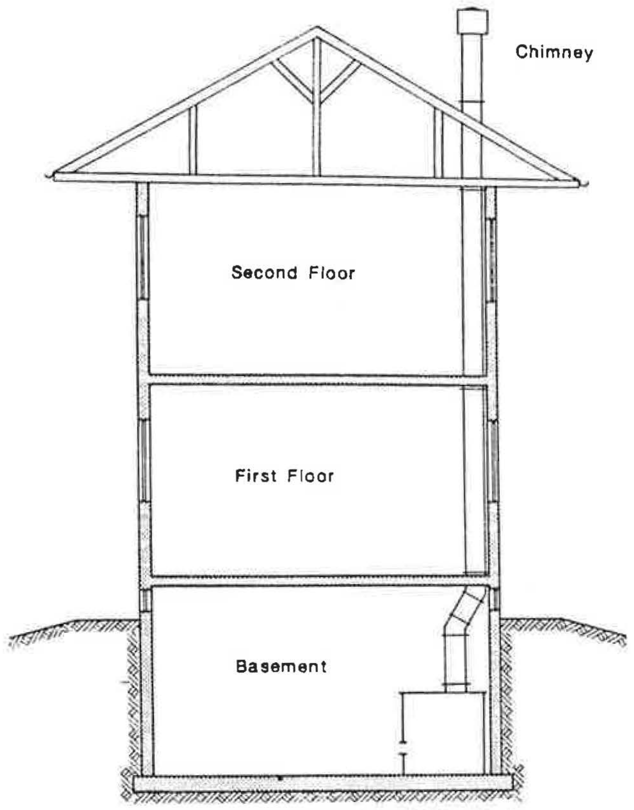

Fig. 3d. The vertical section of model building.

The leakage coefficient k_t (1 m^3/s at 1 pa) of the envelope, the internal no-door wall was k_t = 0.0002. For the ceiling and floor, k_t was also equal to 0,0002. The open door area A_d = 1.2 m^2, the kt for a closed door was 0.0002. The chimney height Hc = 8 m, and the temperature in the chimney T_c = 200 °C.

Soil was considered as the only source of radon, and the emission rate from the soil was constant 0.42 pCi/m^2·s, which was determined to be the average value after reviewing the measuremental results, see NRC (1981). Ventilation and infiltration were assumed to be the only method of radon removal. No account was taken of coupling between the ventilation rate and radon source strength, (that is the influence of indoor pressure). The outdoor radon concentration was neglected. The interzonal air flow and infiltration are calculated from the multi-room model MIX, see Li et al (1990). As an example, we chose the weather data of 1985 for Norrköping, Sweden, for the calculation.

Several cases were selected for calculation as follows.

Table 1. Selected cases for calculation.

Cases	Description
1	All doors open, boiler on
2.	All doors open, boiler off or electrical heating, chimney not sealed
3.	Door to basement closed, boiler on
4.	Door to basement closed, boiler off or electrical heating, chimney not sealed

Results and discussion

The daily average radon concentrations in February 1985 for every room are shown in Figs. 4 to 7. The results from rooms 2, 3, 6, 8, 9 were chosen to give monthly average radon concentrations throughout 1985 and are shown in Fig. 8 for case 1.

The average radon concentrations in the building in February 1985 for all four cases are summarized in Table 2 and are also shown in Fig. 9. It should be noted that the figure given in Table 2 doesn't reflect a realistic measuremental accuracy. From the analysis the following points arise,

o Large differences in the concentrations of radon among different rooms within a residence can exist. The radon concentrations are higher in basements than on upper floors. In the cases shown in this paper, the radon concentrations on the second floor are close to zero.

o A wide range in the concentrations values was expected. This arises because of the wide variation in the air change rate caused by the fluctuating daily and seasonal weather conditions. This can be seen month by month throughout the year. It is clear that a wider variation could occur if the air change rate was altered even more; for example by having some doors or windows left open.

o Closing the door to the basement will decrease the concentration of radon on the

Table 2. Average radon concentrations according to the example calculation in residence in Feb. 1985 (nCi/m^3).

room	case 1	case 2	case 3	case 4
1	0,004	0,568	0,000	0,083
2	4,298	13,530	14,296	20,757
3	7,838	9,124	5,312	9,584
4	7,283	13,325	8,640	15,230
5	6,724	9,639	7,154	11,072
6	7,341	10,903	7,480	13,576
7	0,031	0,328	0,001	0,375
8	0,013	0,341	0,001	0,286
9	0,023	0,342	0,002	0,400
10	0,000	0,000	0,001	0,175
11	0,000	0,000	0,000	0,000
12	0,000	0,044	0,000	0,004
13	0,000	0,043	0,000	0,004
14	0,000	0,000	0,000	0,000

upper floors. This implies that the residents' behaviour or actions will have considerable effect on the radon concentrations.

o The boiler with a chimney plays an important role in the air change rate. It is especially useful in providing exhaust ventilation from the basement where the highr concentrations were found. Comparing cases 1 and 3 (boiler on) with cases 2 and 4 (boiler off) it can be seen that the radon concentrations are much higher in the upper floors with the electric heating system or heat pump system in operation than with the oil-burning boiler heating system.

In practice, the changing of indoor concentration can be quite higher depending on outdoor conditions, related to the operation of the boiler. For the cold weather

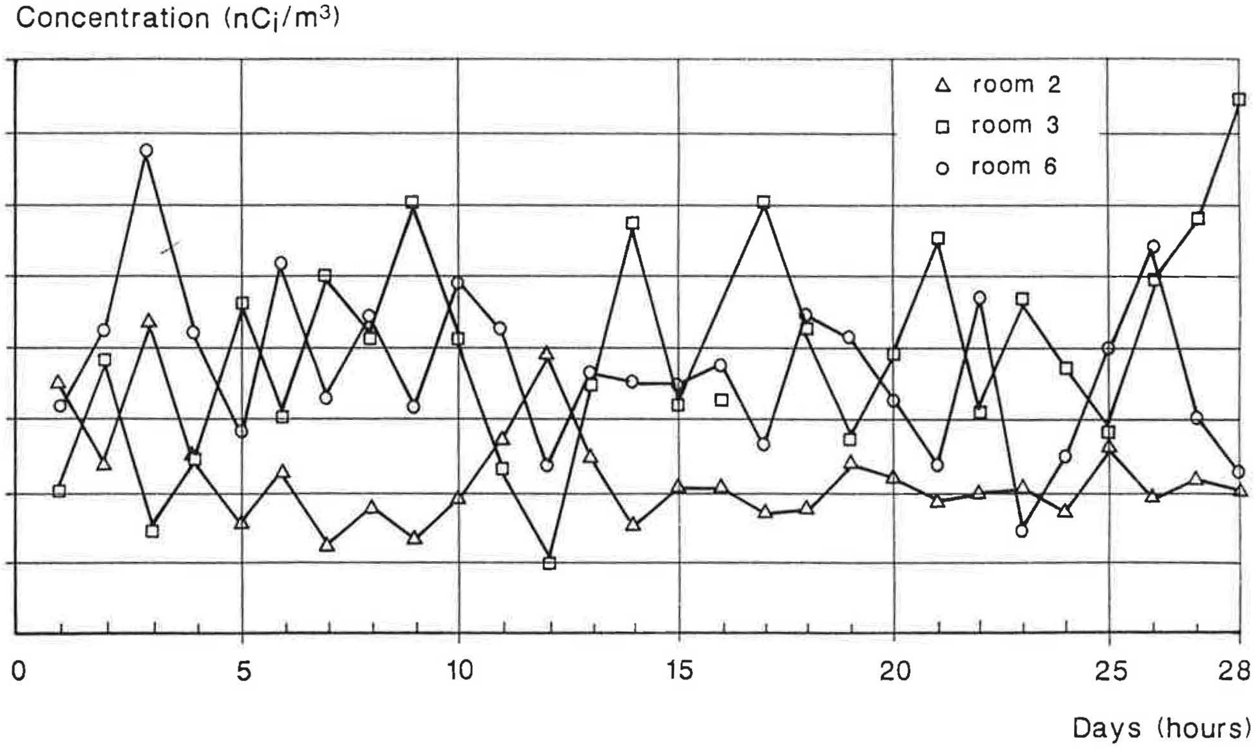

Fig. 4a. Radon and radon pregeny concentration in rooms 2,3 and 6 for case 1.

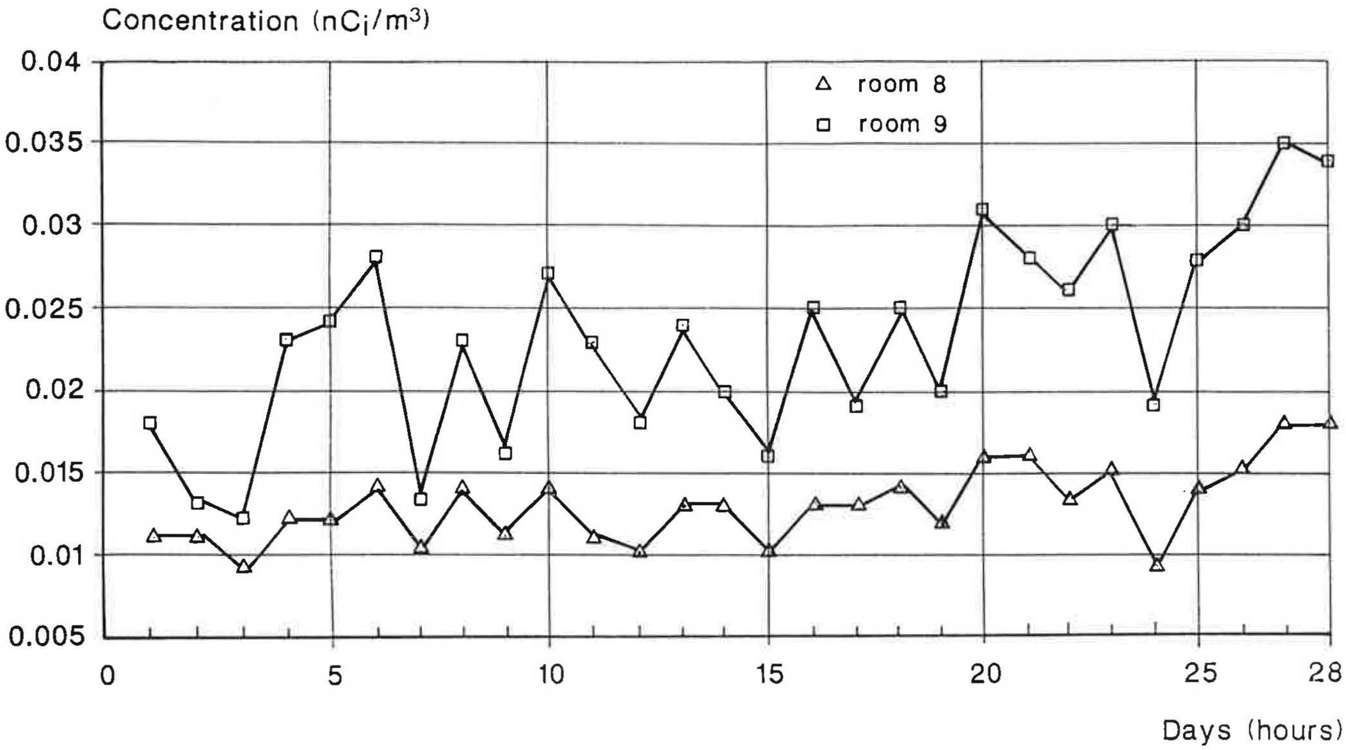

Fig. 4b. Radon and radon pregeny concentration in rooms 8 and 9 for case 1.

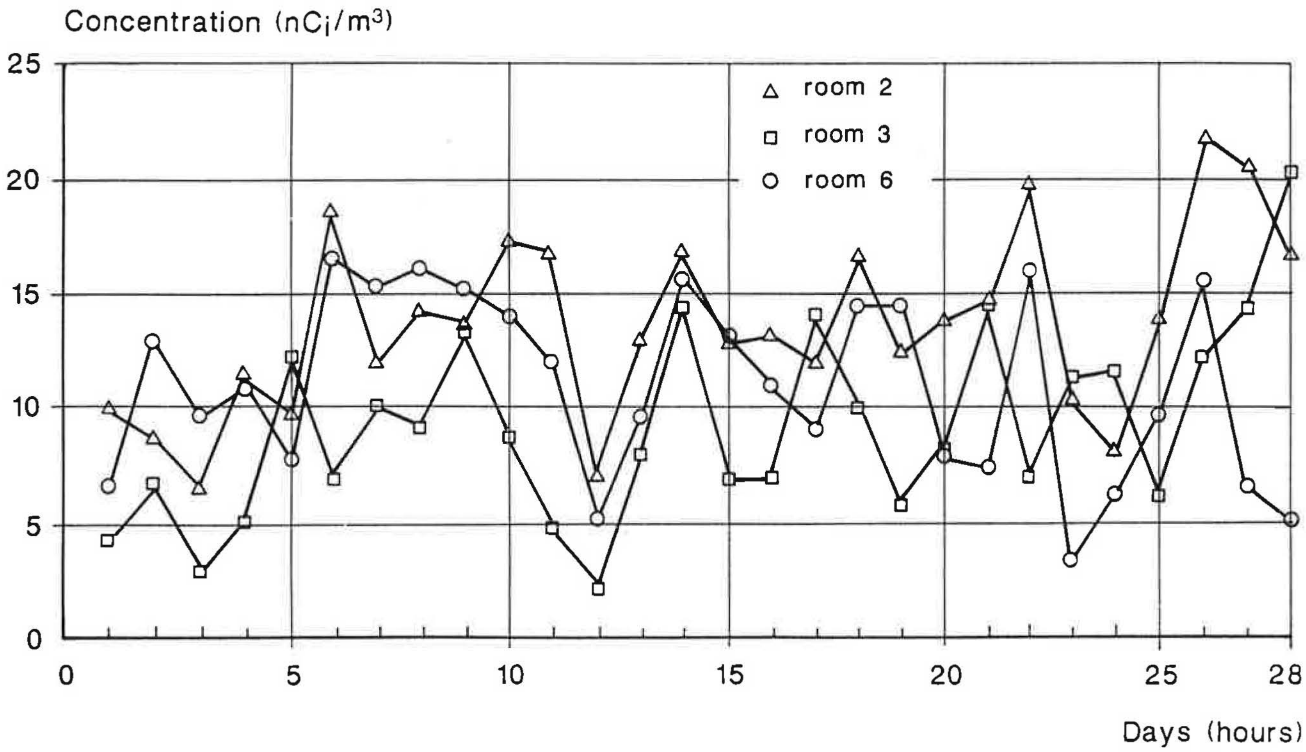

Fig. 5a. Radon and radon pregeny concentration in rooms 2,3 and 6 for case 2.

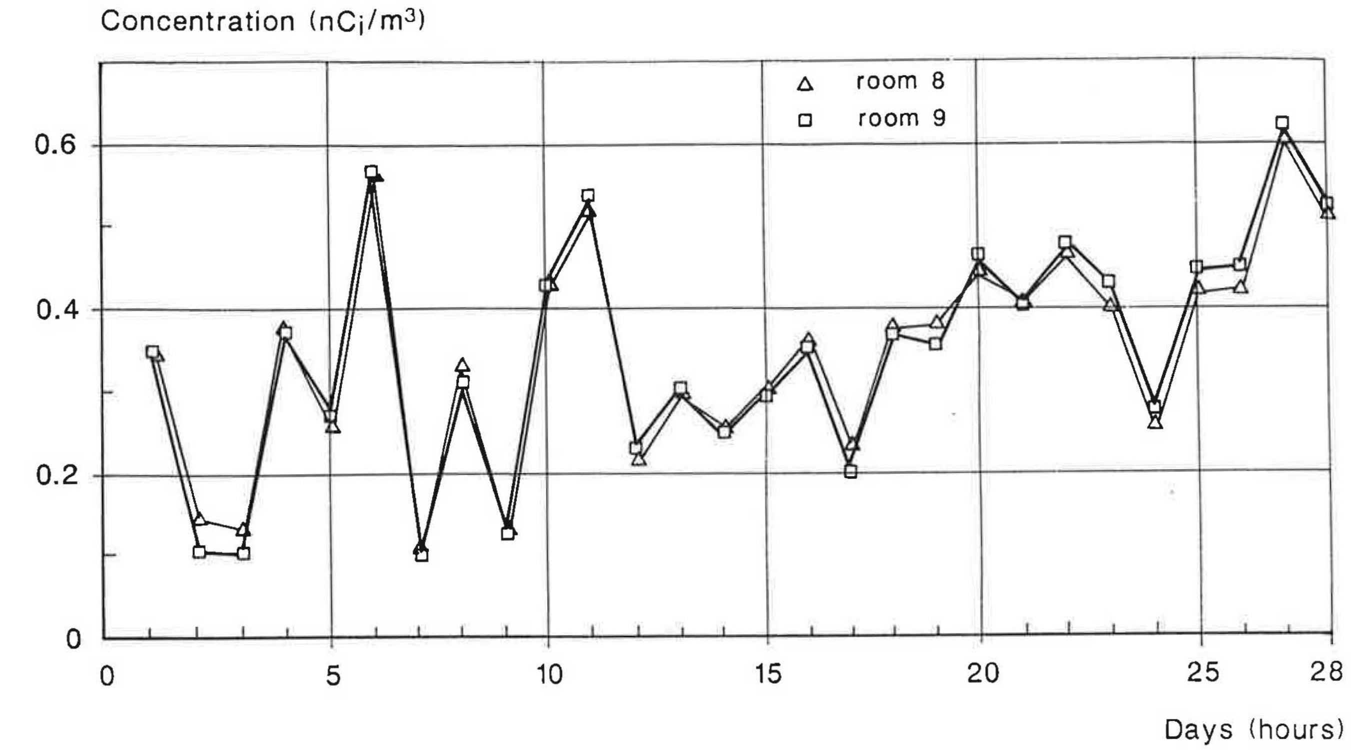

Fig. 5b. Radon and radon pregeny concentration in rooms 8 and 9 for case 2.

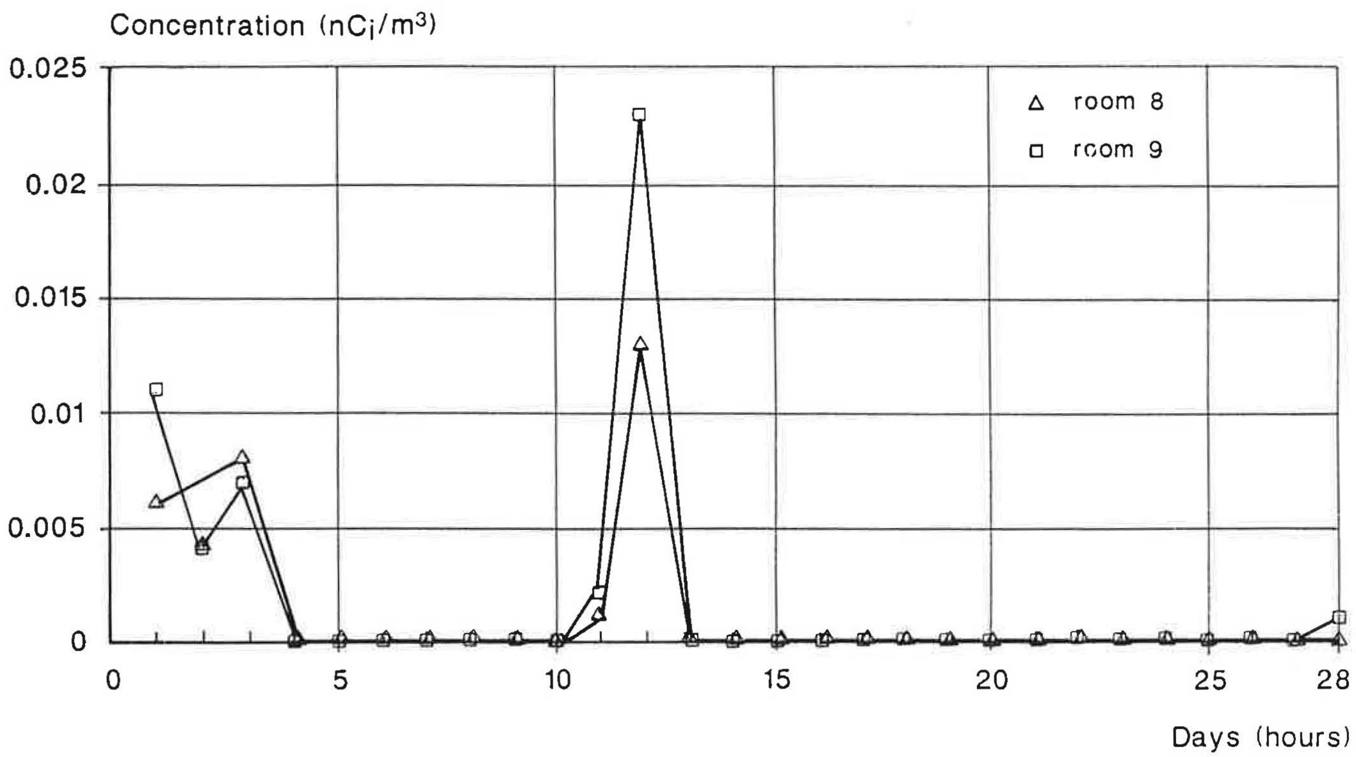

Fig. 6a. Radon and radon pregeny concentration in rooms 2,3 and 6 for case 3.

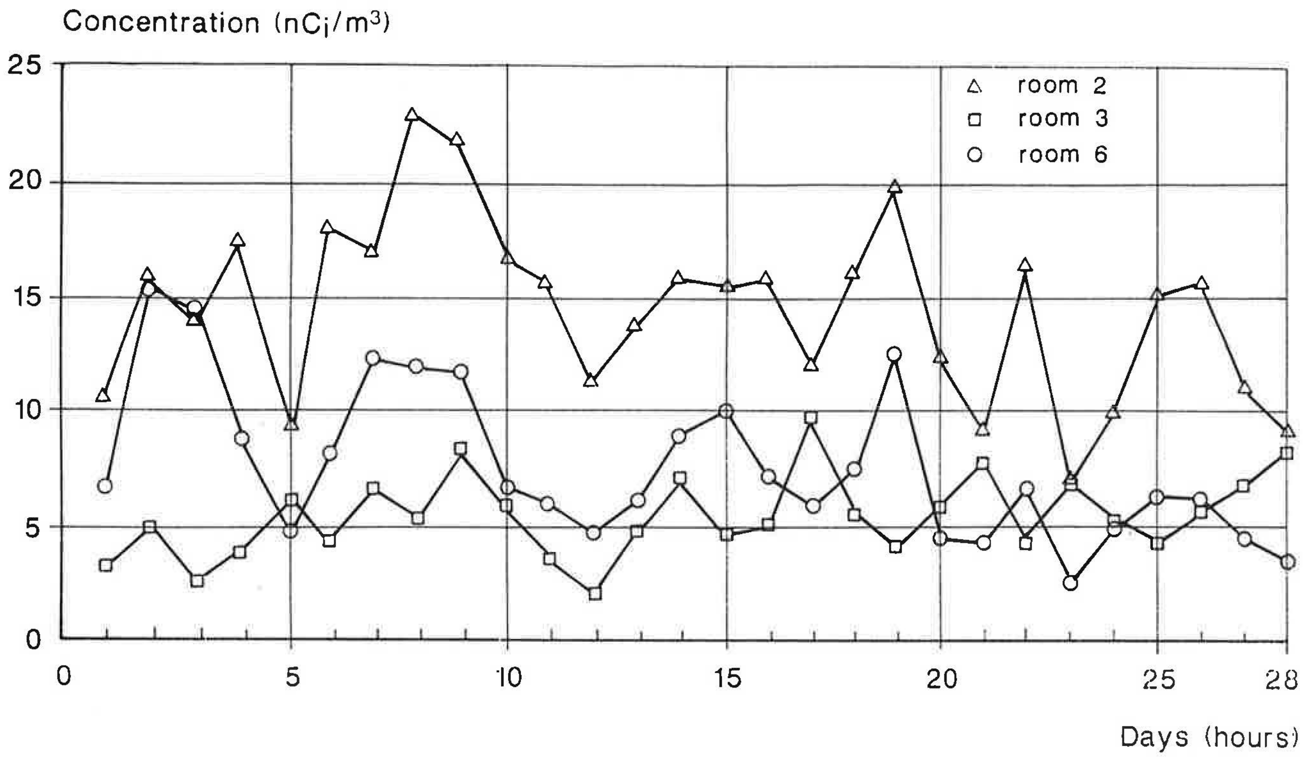

Fig. 6b. Radon and radon pregeny concentration in rooms 8 and 9 for case 3.

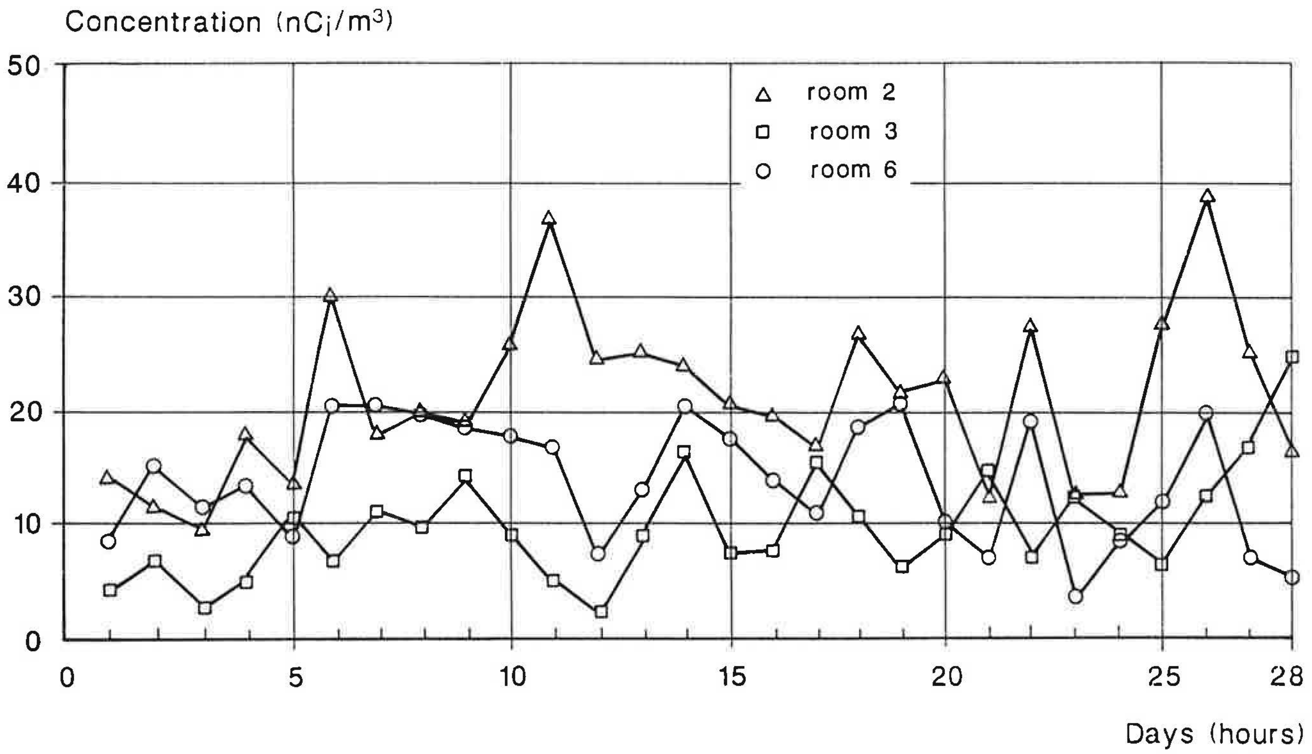

Fig. 7a. Radon and radon pregeny concentration in rooms 2,3 and 6 for case 4.

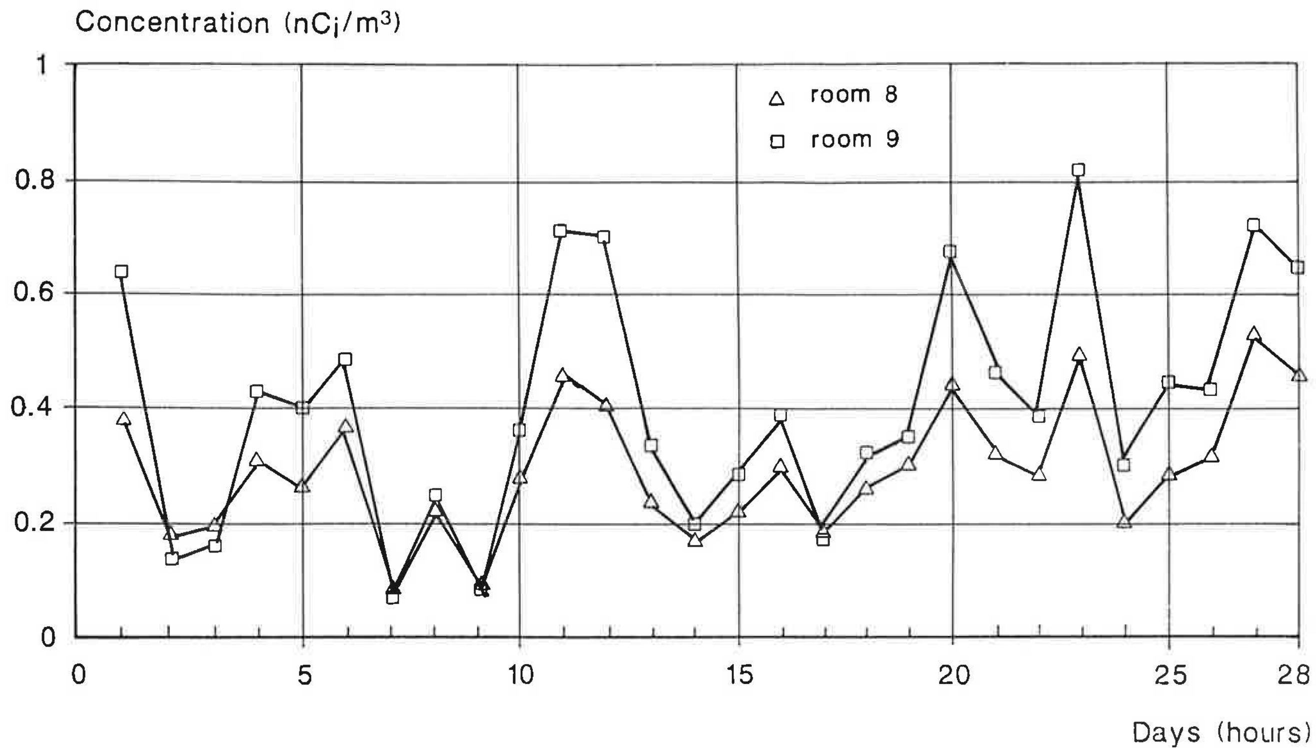

Fig. 7b. Radon and radon pregeny concentration in rooms 8 and 9 for case 4.

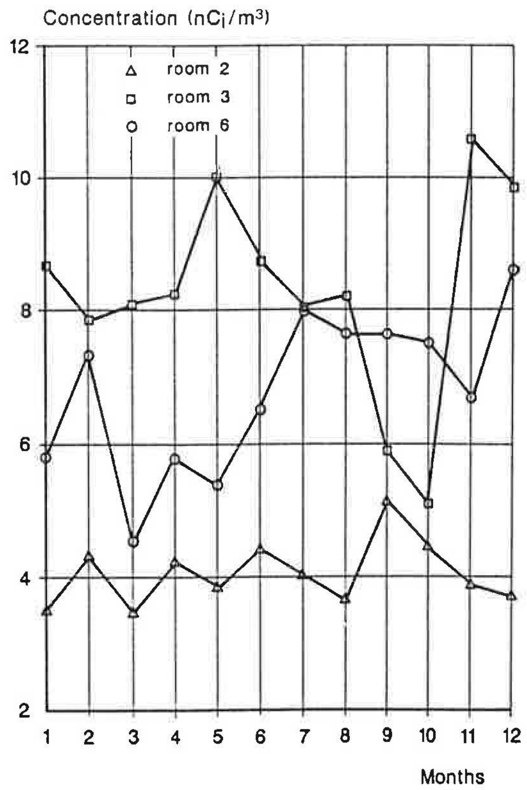

Fig. 8a. Radon and radon pregeny concentration in rooms 2, 3 and 6 for case1 in 1985.

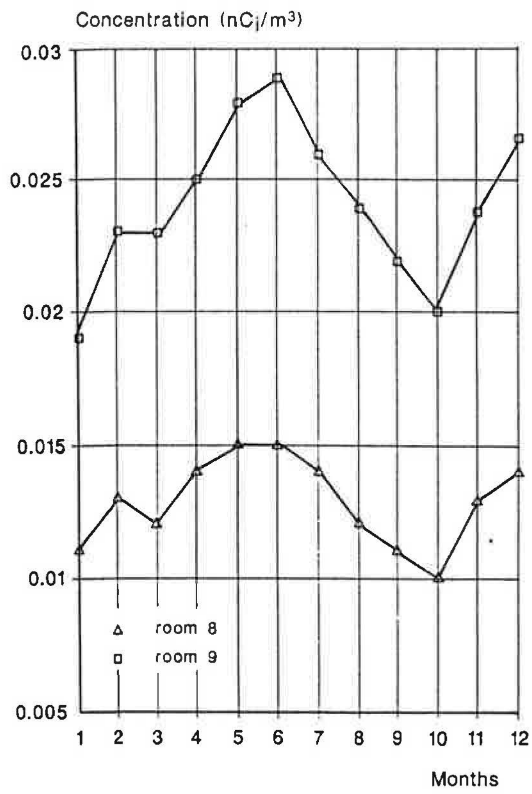

Fig. 8b. Radon and radon pregeny concer. tration in rooms 8 and 9 for case 1 in 1985.

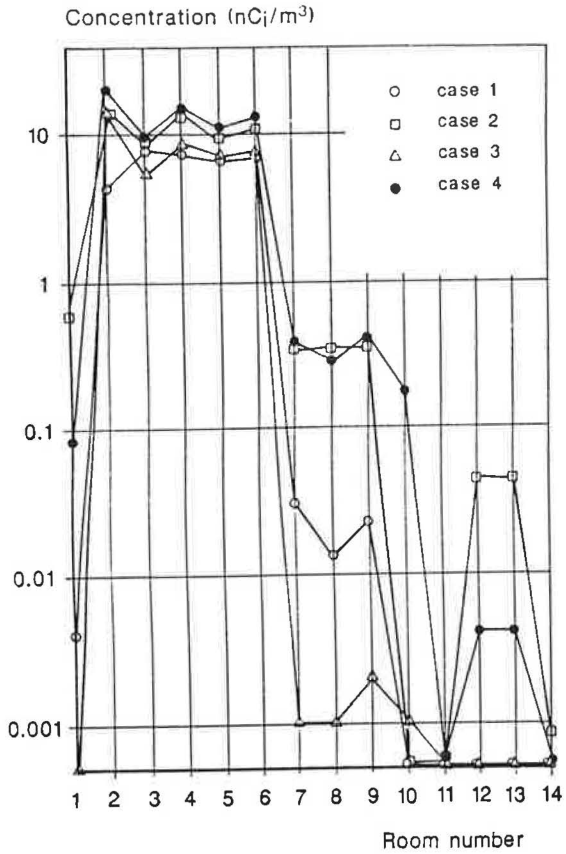

Fig. 9. Radon and radon pregeny concentration in every room for case 1 in Feb., 1985.

such as in winter, the boiler will run a long time, so it can improve the situation, even though there is no airing. For the warm weather such as in the summer, the boiler will run only a short time to provide hot water, but in this case, the boiler's function for ventilation is replaced with ventilation by airing. In fact, even the release rate of radon will increase due to the change of indoor pressure. The chimney is still effective, since the chimney effect changes the air flow direction, air will mostly go from other rooms to the basement. Of course, it is necessary to tight the floor to prevent higher emissions.

Conclusions

The changing levels and distribution of radon concentrations in a residence with an oil-burning heating system has been modelled by the multi-room indoor air quality prediction model and multi-room indoor air flow model.

It has been shown that the radon concentration is dependent upon the air change rate which is in turn effected by the prevailing weather conditions and the number of windows and doors open. Therefore the radon concentration can vary widely within a monthly or a yearly basis. The operation of a boiler with a chimney is an effective means of reducing radon levels in the house.

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