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A Report on the Radon Measurement in a Single Family House

Fan Wang, Ian C Ward

Building Science Research Unit, School of Architectural Studies, The University of Sheffield, UK

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Summery: This paper presents the results of a series of measurements made in an occupied family house. Long and short-term measurements of the concentration of radon gas in the cellar and other living areas of the house were carried out. Subsequently a mechanical ventilation system was installed in the cellar and operated in both supply and extract mode with different air change rates. Further measurements of radon concentrations were carried out along with other physical parameters. The results of these tests are reported in the paper and indicate that the rate of ventilation is important in reducing the concentration of radon gas in the dwelling.

1 Definitions/Terms

Fan System / Mechanical Ventilation System: In this paper it refers to the system installed in the cellar of the house. It consists of an in-line centrifugal fan, a speed controller, connecting ducts and a sound attenuator.

Air Change Rate (ACH): It is defined as the total air volume entering the cellar per hour divided by the effective volûme of the cellar. Negative ACH means that the mechanical ventilation system was extracting air from the cellar, while positive ACH means supplying.

Hence positive ACH does not always mean the cellar is being pressurised. For example in natural ventilation state, the cellar is de-pressurised by stack effect, but ACH is positive because the air is introduced into cellar from outdoors.

Average Concentration in Living Area (ACILA): In the paper this parameter is used to represent the radon level in the house. It is the average of all levels measured in the seven rooms which where regularly occupied.

Radon Reduction Rate / Reduction Rate: It is defined as the difference in radon levels measured before and after the application of a mitigation procedure divided by the level before the application.

2 Introduction

Spaces/voids in buildings' substructures, such as basements, crawl-spaces or cellars have been identified as areas where radon gas can enter a building . The mechanisms for radon entry and mitigation measures have been studied and solutions developed. Two remedial measures, pressurisation and de-pressurisation have been shown to reduce the concentration level in existing single family houses with a basement or crawl-space. (1)

• The mechanisms of these two measures are simple. In neutral condition houses are de-pressurised because of the stack effect created by indoor - outdoor temperature difference in winter. The radon in the soil is sucked into the substructures through the floor or walls and then enters the living areas via cracks or staircase. Using the fans in the pressurisation mode increases the pressure in basement hence reduces the radon entry rate, while de-pressurisation dilutes and removes the radon gas and reverses the differential pressures of routes of air flow linking substructure with the rest of building although it may introduce more radon into substructure.

Cellars, unlike the other two sub-structure spaces, have their own characteristics. In the case being considered the cellar is beneath only part of the house. In this case the cellar may not be the only source of indoor radon. The possible cracks in the floor above the soil may also be ways for radon to enter.

A preliminary study using computer modelling indicated that both approaches, either pressurisation and de-pressurisation in the cellar were effective in reducing the radon problem (2). The model, however has not been verified by any physical validation, which requires a series of real site measurements.

It is therefore the intention of this paper to report on the physical modelling carried out in an occupied house and to indicate the benefits or otherwise of varying the air flow rates into/ out of the cellar.

3 The House

3.1 General Description

The building being investigated is a single family end terrace house about 90 years old. It is built of stone and built along an east-west axis. It has three stories and a cellar under part of the ground floor. On ground floor there is a lounge, hallway, dinning room and a kitchen. The timber floor in the hallway is not covered by carpet, and some cracks are visible. The main bedroom is to the north on the first floor, there is a further bedroom, a toilet and a bathroom. There are two bedrooms on the second floor.

There is a conservatory to east facet of the house and access to the front door is through this structure.

All windows are double glazed. Two external doors face east. The one of main entrance links the conservatory and hallway, the other links outdoor and kitchen. Cracks between doors and their frames can be seen. The door to cellar is not well sealed.

3.2 The Cellar

The cellar is principally used as a store and workshop. Usage is very irregular. It contains both gas and electricity meters, water service pipes and electrical distribution.

The cellar is about same size as the lounge directly beneath it under ground level. Access to it is via a stone staircase which is under a wooden staircase (the latter from ground floor to the first floor).

One window is single glazed on the north wall below ground level. Half of the window has been replaced by the mechanical ventilation system ductwork. The walls are stone and painted white. The floor is made of stone slabs

3.3 The Floor on Ground-floor

The floor on ground-floor plays an important role in radon problems in this type of building In this house the floor of dinning room and kitchen is concrete. The age and depth of the concrete is unknown. The house owner recently replaced the floor by a concrete of 4 inches minimum thickness incorporating a plastic membrane. The lounge floor over the cellar is a normal timber on joists construction. The floor of the hallway is very interesting. It is timber, and partly over soil and rock and partly over a door way to the cellar. Cracks on that floor can be easily seen, which are believed to link with both the cellar and the soil.

3.4 The Mechanical Ventilation System

A mechanical ventilation system was installed in October 1984, which consists of an in-line central fan, a controller, an attenuator and two pieces of connecting duct. The system was switched on at a low speed extracting air out of the cellar until the monitor was available in February 1995. Two reasons were as follows.

Firstly, according to the computer modelling, de-pressurisation seemed more efficient than pressurisation when the fan system was running at low speed.

Secondly, at this low speed, the differential pressure across the cellar door (pressure in ground floor minus pressure in cellar)was just slightly positive. The air moved from the hallway down to the cellar, so the radon gas did not travel to the upper floors through this path.

4 Instrumentation and Measurement

Three methods of monitoring were carried out. Long term, short term (or dynamic monitoring) and instantaneous.

4.1 Long-term Radon Concentration Measuring

The long-term radon exposure was measured by using three etch-track detectors placed in the cellar, lounge and main bedroom from 4th December 1993 to 7th September 1994.

4.2 Short-term Radon Concentration Monitoring

The short term monitoring was aimed at measuring the radon concentrations in response to the controlled ventilation. It was carried out in the cellar as only one continuous radon monitor (CRM), Alpha Guard PQ2000 was available.

The cycle of the monitor was 60 minutes in dynamic radon concentration monitoring while the periods were about 2 to 4 days. These intervals were appropriate for the pressure and radon concentration to settle down after a power change of the ventilation system. This was confirmed by the measurement (refer to 5.5) and reference (3)

4.3 Radon Concentrations Measuring

The instantaneous monitoring concentrated on measuring levels in the other rooms in the house using the Alpha Guard. Each reading was the arithmetic mean of a ten minute measuring period.

4.4 Air Change Rate

averages over a period of 9 months which included a summer season. The opining of windows and doors during this time diluted the concentration in the upper floors. On the other hand, the values of instantaneous readings in winter should be higher than the long-term average ones. The increased ventilation in the upper floors had less effect on the radon level in the cellar. Hence the difference between values of long-term and short-term in the cellar are smaller than these in the lounge and the main bedroom.

5.2 Weather Data

The weather data were collected from Buxton. As the wind speed data was only recorded at 9:00 am every day, hence each value could not represent the wind conditions on that day. However they gave some clues to some extraordinary readings of radon levels (section to 6.1). The values of barometric pressure are greater than that measured by the monitor. These differences cannot yet be explained.

Date	Fan Setting	Wind Direction	Wind Speed(m/s)	Temp. C	Barometric Pre. (mBar)	Relative Humidity
06/02	de-pre 2	W	5.0	7.0	1016.2	93
08/02	de-pre 10	N	5.0	6.7	1010.4	88
14/02	de-pre 8	SW	7.5	4.6	999.4	89
21/02	de-pre 5	SW	11.0	2.0	1009.6	89
22/02	de-pre 3	SW	7.5	5.9	1006.1	89
24/02	de-pre 1	WNW	3.0	2.0	995.0	94
27/02	Natural	SW	4.0	2.5	1014.5	100
28/02	Natural	SW	11.0	9.1	1009.5	92
02/03	Pre 3	SW	3.0	-.1	1002.5	92
06/03	Pre 5	W	7.5	2.4	999.6	84
09/03	Pre 8	SW	3.0	2.4	1011.5	84
13/03	pre 3	SW	1.0	6.5	1028.8	78

Table 2 Weather data in the days when the instantaneous monitoring was done.

5.3 Radon Concentration / Air Change Rate in the Cellar

From figure 5.1 it can be seen that the concentration in the cellar increased as the power of the ventilation system was reduced in extracting mode. The radon concentration reached its highest level at de pressurisation fan setting 2. It then dropped as the extraction rate decreased. When the system was switched off, the cellar was under natural ventilation mode and being resulted in it being de-pressurised.

When the ventilation system was supplying air to the basement the increased pressure reduced the rate of radon entering the cellar, while ventilation removed radon out of the cellar. Hence the level dropped dramatically. The pressurisation ventilation seemed better than de-pressurisation if the level in the cellar were the main interest.

5.4 Average Concentration in Living Area (ACILA) / Air Change Rate in the Cellar

The solution to the problem of radon must address the concentrations found in living areas rather than in a intermittently used cellar. A new parameter, average concentration in the living area was introduced to compare the efficiency of the two ventilation approaches which were investigated.

From Figure 5.1 it can be seen that for the same air change rate in the cellar, the average level of radon concentration in all seven rooms on the upper-floors was higher in pressurisation than de-pressurisation mode. This finding suggests that de-pressurisation is a better ventilation strategy than pressurisation.

The concentration decay method was used to measure air change rate in the cellar. SF_6 was released into the cellar and mixed with the air. The decay in the concentration level was measured and the decay curve evaluated.

The accuracy of the method depends largely on how well the gas is mixed with indoor air. In order to ensure good mixing three approaches were used.

Firstly, a small table fan was used to mix SF_6 with indoor air. An evenly distributed tracer concentration was relatively easy to achieve.

Secondly, the tracer was sampled at two locations as shown in Figure 4.1.

Lastly, several tests were carried out when the fan was set at a high level as the air change rates were higher. The average values gave the final ACH for the particular fan power setting.

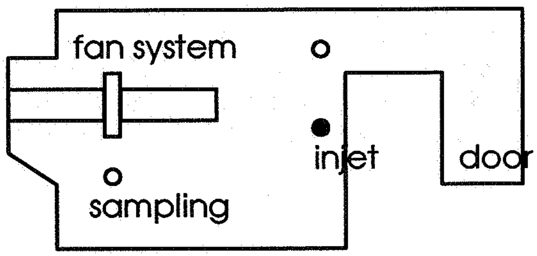

Fig 4.1, Injection and sampling points in the cellar

4.5 Differential Pressure Measurement

Two differential pressures were measured during the tests, one across the cellar door and the other across the external wall. The former represents the pressure difference between cellar and the ground floor while the later represents that between the cellar and outdoors.

Only one point outside the dwelling was taken for differential pressure measurement. The pressure was subject to wind effects, thus fluctuation can be seen (Fig. 5.4.1). Consequently, the measurement yielded a poor correlation between air change rate and wind speed.

The differential pressure across the cellar door was steady at each ventilation mode. The maxium deviation was 41%. This parameter was measured as -16.7 pas. at full power supplying ventilation and 15.5 pas full power extraction. It was 0.7 pas. at speed 2 extracting model, which was believed the best mode.

5 Results

5.1 Long-term Monitoring

The laboratory analysis on the three detectors of long-term monitoring was carried out by BRE. The results were 660 Bq/m^3 in the cellar, 210 Bq/m^3 in the lounge and 190 Bq/m^3 in the main bedroom. The results may have been underestimated by up to 30% because the detectors were issued more than one years ago and age may result in underestimating the exposure.[4]

The values of long-term monitoring are smaller than the other two . This is because the values of the long-term monitoring were the

Room	Cellar	Lounge	Main Bedroom
Long-term	660 +198	210 +63	190 +57
Short-term *	737 ±115		
Instantaneous**		369 ±75	378 ±74

Table 1. Comparison of three types of monitoring of radon concentration level (Bq/m^3)

* Average over 4 days. ** average of 8 readings in two days.

In Figure 5.1 it can also be seen that the ACILAs were higher than that in the cellar in pressurisation mode, such as in Pre 03, Pre 05, Pre 08 and Pre 10. This phenomena can be explained by the fact that other routes for radon entry to upper-floor beside the cracks linking with the cellar exist. This same phenomenon was also reported in work from Princeton University [5].

Figure 5.2 shows the reduction in radon concentration rates for each power setting. This also implies that de-pressurisation is a more efficient remedial approach than pressurisation.

5.5 Concentrations Distribution in Living Area / Air Change Rate of Cellar

From figure 5.3, it is difficult to infer a general pattern of radon distribution. But the levels in the rooms on 1st floor were always the lowest.

Although the radon level in the upper floors depends on the level in cellar, they are subject to the buildings infiltration characteristics and wind conditions. This can be clearly seen in Figure 5.3

5.5 Radon Concentration Short-term Monitoring in the Cellar

From figure A in Figure 5.4, it can be seen that the radon level decreased from about 2500 Bq/m3 within 12 hours when the power setting changed (dep 2 to dep 10), then fluctuated near 1200 Bq/m3 until the next power setting which took place two days later. It seemed that it took a time for the radon level to settle down after a large power change in ventilation system. From all other profiles, no general tendency of increase could be found while the fan power was decreased.

5.6 Radon Level / Barometric Pressure in Cellar

Interestingly, there is a large peak in the radon level when a valley in barometric pressure occurred as seen in figure a, Figure 5.5. Statistical analysis did not indicate that there was any correlation between concentration and air pressure (totally, about 2100 pairs of data of the two parameters in four figures in Fig 5.6).

5.7 Radon Concentration in the Cellar / Differential Pressure Across External Wall

A test was carried out to look at the relationship between radon concentration in the cellar and the differential pressure across the external . This did not provide any significant results. During the measurement period fluctuations in differential pressure varied over a wide range. It can be suggested that to obtain significant results then it would be necessary to measure the air pressure at more than one point outside the house.

6 Conclusions & Suggestions:

The measurements carried out highlighted several aspects of radon control in such situations.

6.1 Mechanical Ventilation in the Cellar

Although the mechanical ventilation in the cellar, both pressurisation and de-pressurisation could be the solution, de-pressurisation was more effective than pressurisation at low power settings (lower air change rates) in reducing the radon level in the living areas in the house.

Higher ventilation rates in the cellar was more effective at reducing the radon concentration in the living spaces in the house although this may have an adverse effect on the heating bills.

Care is needed if there are open-flued combustion appliances in house. The de pressurisation in the cellar may reverse the pressure in chimney hence resulting in spillage.[(6)]. An additional air-brick in the cellar may prevent the spillage as it provides an easy inlet for a cross ventilation in the cellar.

6.2 Simplified Model Study

It is difficult to draw a simple relationship between radon levels in the cellar and the average concentration in the living areas, because of the structural complexity of the building and the unpredictability of the wind conditions.

Further studies on a simplified model under fully controlled conditions is needed to investigate the radon mitigation measures in a wider range before applying them to all other buildings of this type.

6.3 Computer Model Modification

Numerical simulation can be used to study the problems for other house types, provided a adequate model of the building can be developed. The model of the house in BREEZE(2) dose not model the house well, which results in a poor correlation between the measurements and the simulations. Modifications to the model are therefore necessary and should include:

1. Changeable contaminant feeding rate;
2. Multi-route for radon entering into living area;
3. Staircase modelling.

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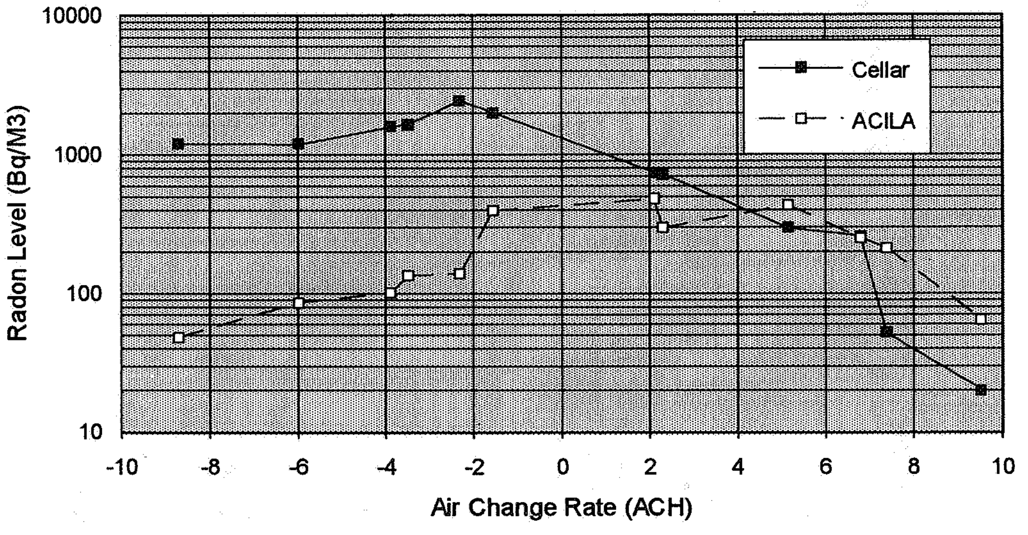


Fig. 5.1 Radon Concentration and ACOLA vs. Air Change Rate in cellar

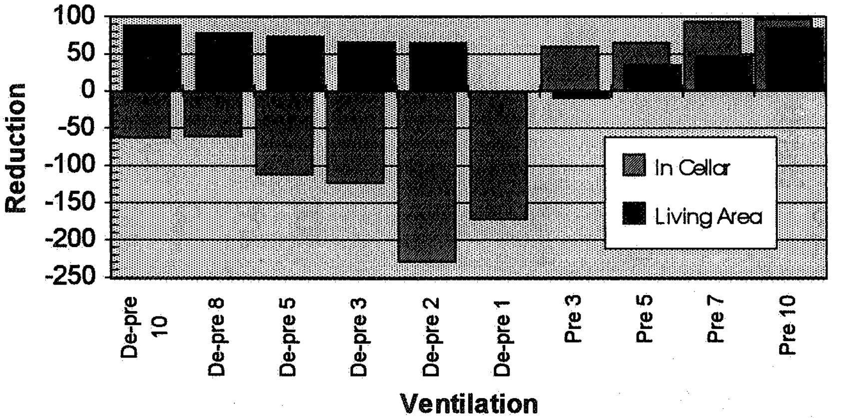
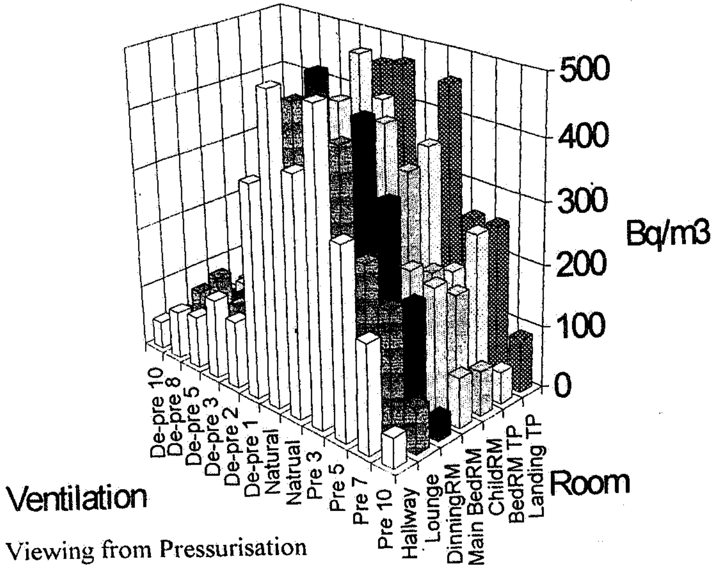
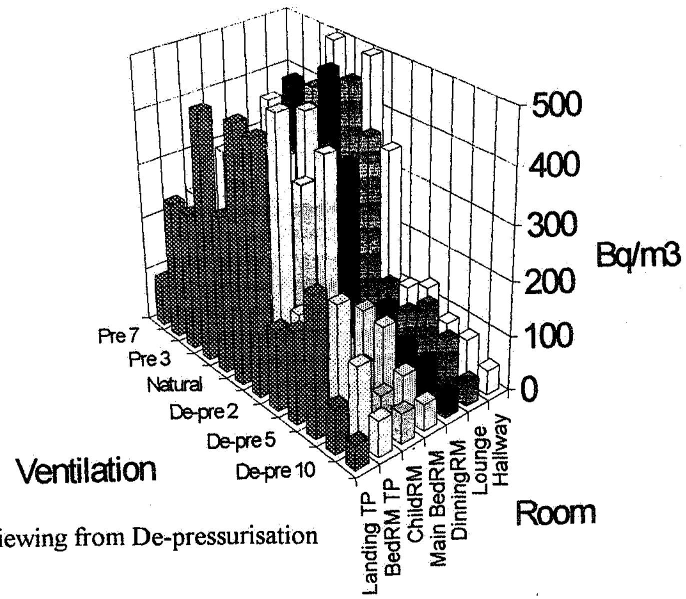


Fig 5.2 Reducation of Radon concentration in Cellar and ACOLA

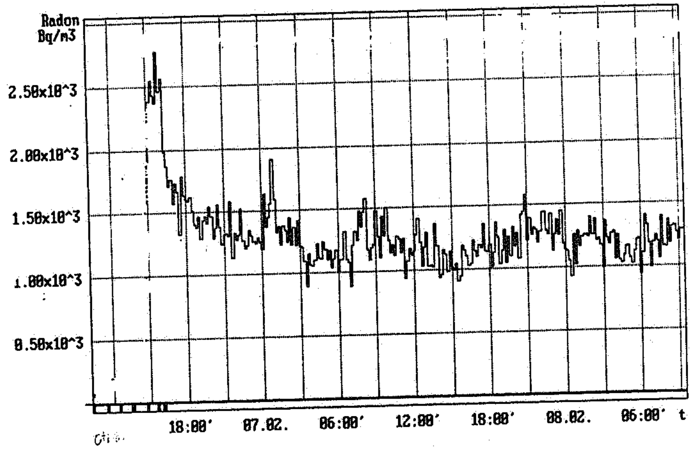


Viewing from Pressurisation

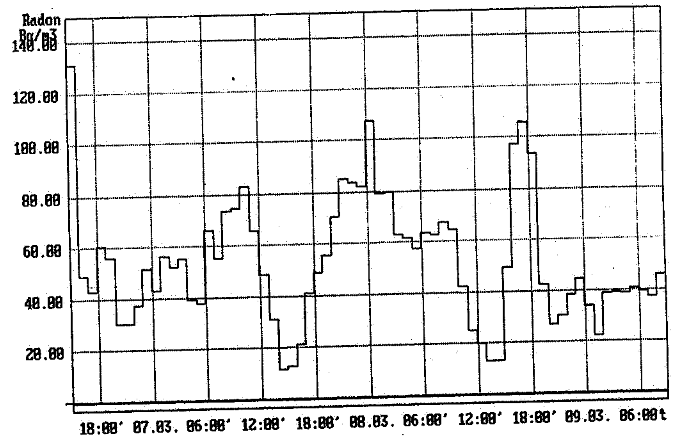


Viewing from De-pressurisation

Fig 5.3 Radon distribution, Levels in seven rooms of the house

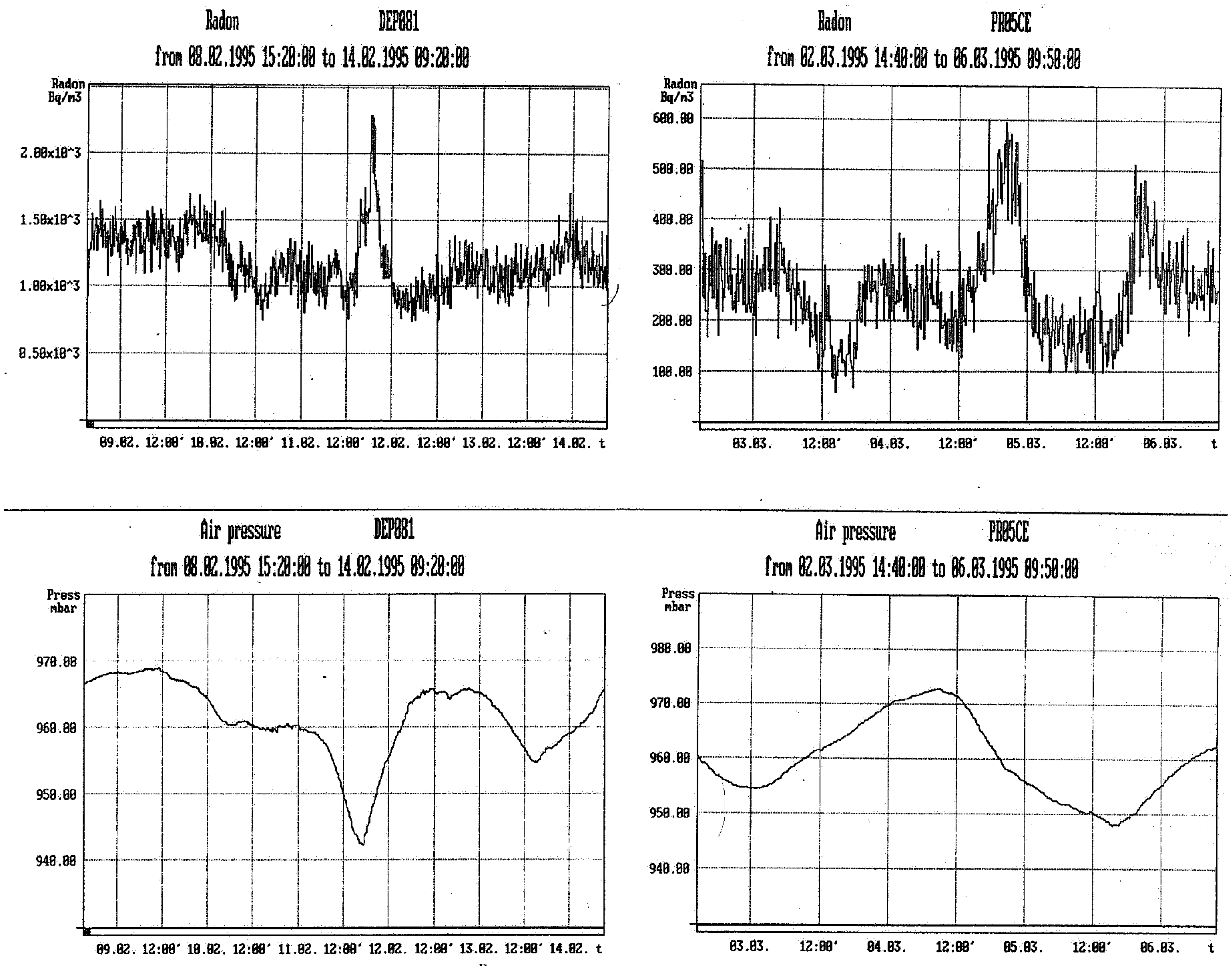


a) after power setting of the system changed from De-pre 2 to De-pre 10



b) after power setting changed from Pre 5 to Pre 8

Fig 5.4 Continuous radon monitoring in cellar after fan power changed



a) fan extracting at power 8 b) fan supplying at power 5

Fig 5.5 Continuous monitoring on radon and pressure in cellar

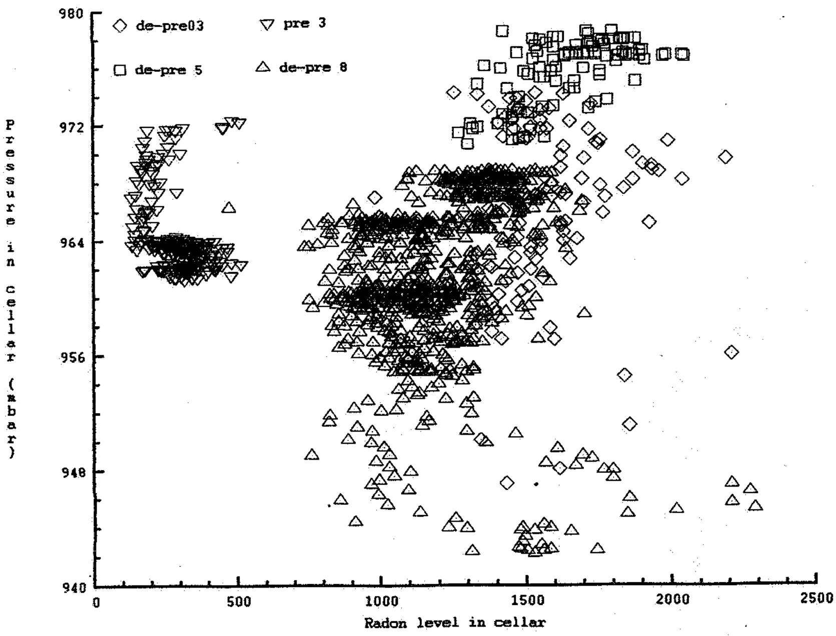


Fig 5.6 Correlation between radon level and barometric pressure in cellar