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MODIFIED TECHNOLOGY IN NEW CONSTRUCTIONS, AND COST EFFECTIVE REMEDIAL ACTION IN EXISTING STRUCTURES, TO PREVENT INFILTRATION OF SOIL GAS CARRYING RADON

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Abstract

The general principles and mechanism of how soil gas infiltrates and carries radon from the foundation bed and subsoil into buildings are discussed. The Swedish Building Research Council has funded experiments and evaluation of cost effective remedial actions. The work has concerned existing dwellings with high concentration of radon, resulting from infiltrating soil gas and/or exhalation from building materials. A review and evaluation is given of experience and results acquired up to the summer of 1984. 100 dwellings have been constructed with consideration of possible infiltration of soil gas. In general minor modifications are sufficient to prevent infiltration.

Introduction

In Sweden many dwellings with very high radon concentration in indoor air have been identified. The source of the radon can be emanation from building materials. However, infiltration of soil gas into the house has been proven to be of much greater importance than assumed a couple of years ago. The energy conservation program in Sweden has resulted in tighter buildings, with a decreased ventilation rate. However, it is rare for something to be done about leaks in the basement floor slab or walls and thus a greater part of the ventilation air is infiltrating soil gas (sometimes 1-5 %). The radon level can therefore increase indoors and unacceptable levels can occur even on soils with a normal radon concentration, 5-10 kBq/m^3. Normally houses have an infiltration of $\leq$0,1-0,3 % soil gas, which gives no great problems even if the concentration of radon in the soil gas is higher than average.

Sub-Floor Depression System

Among the many possible remedial actions we have found a sub-floor depression system to be the most generally suitable and cost effective. It has, almost without exception, resulted in a considerable reduction in infiltration of soil gas carrying radon. New structures can be prepared for an easy retrofit of this system.

The sub-floor depression system, which originally came from Canada /1/,/2/ and the US /3/, works because a lower pressure is maintained under the basement floor than above, thus preventing convective infiltration of soil gas into dwellings. We do not believe that diffusion is a major contributor /4/. Normally the pressure indoors at the floor is lower than outdoors as a net effect of the temperature difference (indoor/outdoor) and of the wind pressure on the house. This pressure difference is sufficient to suck soil gas into the house, and even if the radon concentration in the soil gas is not higher than normal, a small fraction of soil gas in the supply air is enough to create a significant increase in the radon concentration indoors. The purpose of the system is to eliminate or reduce the infiltration of soil gas with a minimum of cost and interference. The sub-floor depression system only reduces radon infiltration from the soil and has no effect on radon exhalation from building materials. In some cases, it is therefore necessary to increase the ventilation rate to dilute the radon from some strongly exhalating building materials. This should be done with balanced ventilation to prevent a further depression indoors or else it would counteract the sub-floor depression system. Installation of a ventilation system with heat exchange between outgoing and ingoing air is also recommended to lower the heating costs.

Theory of the Sub-Floor Depression System

The sub-floor depression system consists of two interacting parts, namely the ventilation system above the basement floor in the house which creates the depression and the soil below the basement floor in which the depression decreases with the distance from the suck-hole. We have theoretically analysed the second system in a model which is based on the assumptions that the soil has a homogeneous conductivity and that no leakage occurs through the basement floor. In order to avoid a very high linear pressure drop in the soil near the suck-hole, we have found that it is necessary to suck the air from a cavity, e.g. a half sphere with a radius 0.3 m, under the slab. The convective flow of soil gas is spherical around this cavity. This flow is generally at a distance limited by the water table or a rock surface, leading to cylindrical flow at a greater distance from the suck hole. The result of our theoretical calculations indicates that the area effected by one suck hole seldom exceeds a circle with 5 m radius.

Design of Sub-Floor Depression System

We have found that the practical approach, to design the sub-floor system above the basement floor, is to install a system of PVC-pipes for the distribution of the depression. The diameter of the pipes leading to the suck hole is Ø 50 mm. The pipe diameter must be increased when more than one suck-hole is connected. It is recommended to connect a manometer to each of the suck holes for control of the depression. A fan, with a capacity of maximum 0.04 m^3/s (150 m^3/h) and 300 Pa, is connected to the piping system. The fan requires less than 100 Watts. It is important that the pressurized pipe at the fan outlet is airtight and as short as possible to prevent soil-gas leakage from the installation into the house. When the system was designed, factors like soundlevel and condensation of water were considered. Basement floors are often divided into several sections and therefore up to 5 holes are normally required,

to cover a detached house. To distribute the depression under the basement floor an air flow is required. We have estimated that the maximum flow is in the range of 6-8 · 10^{-3} m^3/s (20-30 m^3/h) per hole.
In Sweden this means that during the winters, cold outdoor air is drawn under the basement floor and footing which could lead to problems like cold floors, frozen soil, which can lift the house and frozen piping systems in the soil. Up till now we have not observed any of these complications. In the survey later presented there is, in some cases, total flow rates of about 0.08 m^3/s (300 m^3/h) involved.

Results

In figure 1 and 2 the results of installing sub-floor depression system in 39 dwellings are shown. Figure 1 shows the roomwise radon concentration before and after installation of the system. Four different types of instruments have been used to measure the concentration of radon, namely WLM 300, continous radon daughter monitor, EDA Instruments Inc; RDA 200, momentary radon daughter detector, EDA Instr Inc; TLD, passive integrating radon monitor, Studsvik Energiteknik and Film, integrating radon/radondaughter detector, Terradex Corp. The concentrations are given as radon Bqm^{-3}. When the radon daughter concentration was measured the value was multiplied by two, as we assumed an equilibrium factor, F, of 0.5. Rooms above and below ground level have been measured separately. In figure 2 the same result is presented as a histogram, showing the number of rooms at the various radon concentration intervals before and after installation. The mean value of the radon concentration has been reduced 8 times, which equals a reduction of 88 %. The result was slightly better in rooms below ground level than above: table 1.

Table 1 Mean radon concentration before and after installation of sub-floor depression system

Radon Bqm^{-3}	before	after	reduction factor	%
53 rooms above ground level	1750	293	6	83
31 rooms below ground level	5047	486	10	90
84 rooms total	2967	365	8	88

We think the above described sub-floor depression system is the most generally applicable method to cope with infiltration of soil gas. However, if the radon comes from a large volume of permeable soil, i.e. an esker with normal or low activity of radium, we think even greater reduction of indoor radon concentration can sometimes be achieved by blowing down fresh air under the basement slab. This will increase the infiltration of air from the soil under the slab through any cracks. But if the positive pressure under the slab prevents any flow of soil gas from further distances to the house, the flow of air blown into the ground can dilute the limited amount of radon released from the soil in the close vicinity of the slab and thus guarantee that infiltration through any cracks will carry only an insignificant amount of radon.

Sealing of obvious leaks

The importance of making, and keeping, houses tight to the soil was illustrated in a group of terrace-houses. The local authorities carried out measurements in a few houses with the open detector Terradex(R) type B. The measured concentrations of radon were much higher than can be attributed to the emanation from the concrete structure indicating a major contribution from infiltrating soil gas. The original air exchange rate was probably 0.1-0.2 h^{-1} indicated by frequent condensation of moisture on the inside of the windows in wintertime. The only obvious infiltration route for the soil gas from the capillarity breaking layer under the slab was the waterpipe Ø40 mm, entering through a hole Ø80 mm in the concrete. Measurements were repeated in a number of houses with one passive integrating TLD-instrument on each floor. In one of the houses the entrance of the waterpipe was sealed. The average of the two measurements in this building was 60 Bq/m^3 of radon, which is in good agreement with what can be expected as a result of emanation from the concrete structure. Before sealing the entrance of the waterpipe the average measured radon concentration in 18 houses was 584 Bq/m^3 on the lower floor and 438 Bq/m^3 on the upper floor. The concentration of radon in the infiltrating soilgas was in average 19 000 Bq/m^3, measured by alfasensitive film in cups covered with a membrane Terradex(R) type M. This indicates that approx. 2 % of the ventilation air infiltrated through the leak, the remaining 98 % being outdoor air free from radon. Approx. 1/3 of the dwellings had radon concentration $\leq$200 Bq/m^3 which can be attributed to emanation if air exchange rate was approx. 0.1 h^{-1}. In the remaining two thirds, the radon concentration was higher, indicating a major contribution from infiltrating soil gas. In 3 of the houses the measurements indicated >1 000 Bq/m^3 radon. Figure 3 shows the radon concentration measured before and after sealing the entrances of the waterpipes in 17 houses. The average radon concentration was hereby reduced by 80 %. Because the contribution from concrete structure was unchanged the effect on the infiltration of radon from the soil must have been higher, probably >90 %. The cost for sealing the entrance of the pipe was 100 SEK and a couple of hours work.

New construction

We have measured the radon concentration in approx. 100 new houses built on soil containing fragments of alumshale with enhanced uranium concentration in areas where infiltration of radon from the soil is a frequent problem in existing structures. Some of the structures have crawl spaces, equipped with forced ventilation with exhaust air. This design seems to prevent infiltration of radon from the soil without any modifications. The remaining houses have a slightly modified design in order to prevent infiltration of soil gas. In no case have we measured any significant infiltration of radon from the soil. The added cost has varied between 0 and 15000 SEK, equivalent to 0-4 % of the building cost.

Conclusions

The above presented results indicate that the sub-floor depression system is an effective low cost remedial action where radon from the soil infiltrates with the soil gas. We are convinced that it is good practice to avoid obvious entrance routes for soil gas into the house independent of the type of soil. This will in general prevent infiltration of radon with the soil gas. The added cost of this practice is minimal. Preparation for easy retrofit of subfloor depression system is often recommended as an extra precaution. When building on soil with high concentrations of radon (≥100 kBq/m³) and/or high permeability and low water table we would recommend avoiding inhabited basements and instead consider a ventilated crawl-space.

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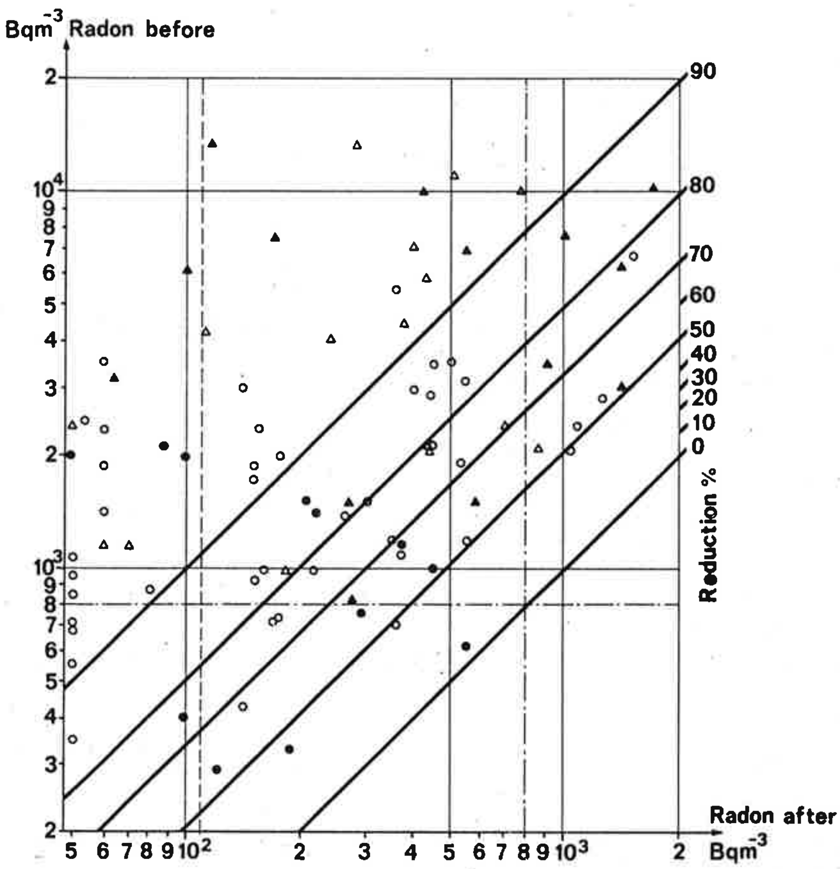

Figure 1 Roomwise radon concentration before and after installation of a sub-floor depression system in 39 dwellings
○ Room above ground level
△ Room below ground level
Black spots indicate participants in remedial actions funded by the Swedish Building Research Council.

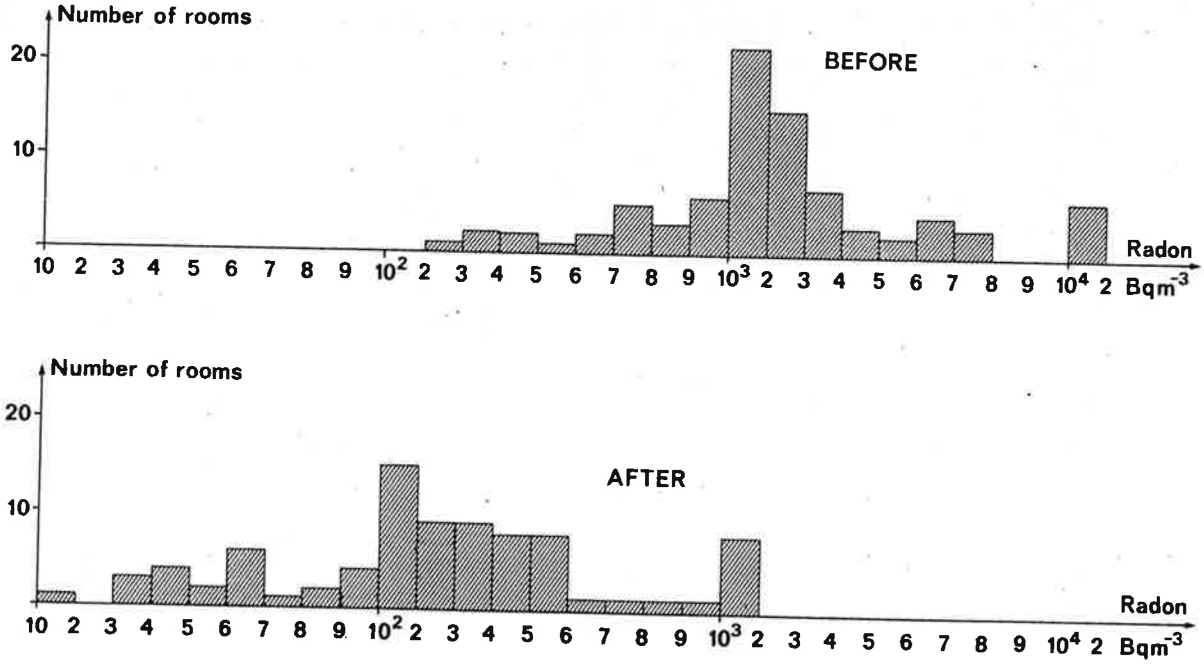

Figure 2
Number of rooms per radon concentration interval before and after installation of a sub-floor depression system in 39 dwellings

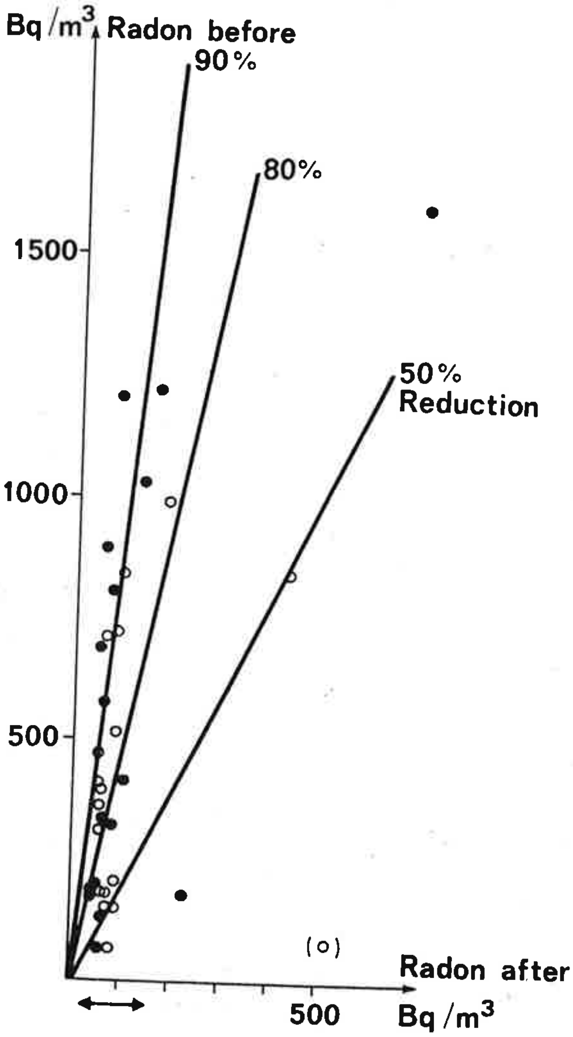

Figure 3
Concentration of radon in indoor air before and after sealing the entrance of waterpipe in 18 terrace houses

↔ assumed contribution from building materials

● measurements on lower floor

○ measurements on upper floor