RADON MITIGATION TECHNIQUES FOR NORWEGIAN HOUSES

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ABSTRACT

Results of an experimental study of different techniques to reduce the radon levels in Norwegian houses are reported. A total sample of 30 detached houses, representing a broad range of different types of Norwegian houses accordring to construction techniques and architecture, were selected for the study. In this sample of houses, earlier measurements had shown average radon concentrations ranging from about 500 Bq/m³ to 15 000 Bq/m³. Passive measurements of radon were performed at different stages in the process. In a few houses more extensive measurements were carried out. This included contineous measurements of radon, radon daughters and air exchange rate, and grab sampling measurements of unattached fraction of radon daughters. Of the different solutions studied, the methods based on sub-slab ventilation/depressurisation were found to have the best reduction effect on the radon level in indoor air.

INTRODUCTION

In 1988, an extensive study on mitigation techniques for Norwegian houses was started. The study was organised as a collaboration between the Norwegian Building Research Institute and the National Institute of Radiation Hygiene. The aim of the study was to evaluate between different possible mitigation methods/techniques to reduce the radon level for different types of Norwegian houses and to give recommendations.

So far, most of the research work on mitigation methods/techniques in the Nordic countries have been carried out in Sweden (1,2). Most of the recommendations in Norway have been based on experience from there. However, the buidling stocks are quite different. The most important difference, as far as radon is concerned, is the fact that most detached houses in Sweden do not have a basement, while probably more than 80% of detached houses in Norway do have.

MATERIAL AND METHODS

SELECTION OF HOUSES

In Norway there is about 1.6 million dwellings. According to census data from the Central Bureau of Statistics (3), about 85% of the Norwegian housing stock is detached and undetached houses. In the most rural municipalities the percentage is nearly 100%. However, in Oslo, the largest town in Norway, about 65% of the dwellings are in blocks of flats. Influx of radon from the ground is found to be the most important source of indoor radon in detached and undetached houses. In houses where the radon concentration is found to be considerably higher than normal, the contribution from other sources can usually be neglected. For dwellings in blocks, on the other hand, building materials are usually the main source of indoor radon. However, in most cases the radon concentration is very low compared to detached and undetached houses. Therefore, blocks of flats were not included in the experimental sample of our study.

Most of the houses were selected from earlier and recent measurements from the National Institute of Radiation Hygiene. It was important to get a, as far as possible, representative sample of typical houses according to construction technique, architecture, age of the house and geology. It is assumed that the final sample of 30 houses meets these requirements fairly good. In table 1, the houses is classified into three categories according to type of house and radon concentration. As shown, most of the houses have basements.

TABLE 1. THE SAMPLE OF DETACHED HOUSES.

	NUMBER OF HOUSES Radon concentration (Bq/m^3)[1]		
	< 1000	1000-5000	> 5000
With a basement floor below ground level	14	11	2
Concrete slab directly on ground	2		
On crawl space		2	

1)Representative averages of radon concentration for each house.

THE MEASUREMENTS

Passive measurements of radon were performed at different stages in he mitigation process in all of the 30 houses. The ETB-method, which is a combination of activated charcoal and TLD (4), were used in the measurements. The integration time in the measurements was between 7 and 10 days. In order to minimize the influence on the measurements from short term variations in the radon level, it was essensial that the they were performed at about equal meteorological/-climatical conditions. The uncertainties in the individual measurements were estimated to be about 15% at the 95% confidence level.

In a few selected houses, more extensive measurement programs were performed. This included contineous measurements of radon and radon daughters and measurements of the air exchange rate. At the diagnostic stage in the process, grab sampling measurements of radon were found to be especially valuable in characterising the source. The method and equipment has been described in an earlier paper by Stranden and Berteig (5).

RESULTS AND DISCUSSION

Generally, mitigation techniques may be divided into four groups:

(1) removal of radon sources
(2) methods to reduce the radon influx from the ground
(3) methods to increase the air exchange rate
(4) removal of radon daughters by electric fields/electrostatic filter

Methods involving a removal or exchange of source material from the building site and/or near the house may have a considerable reduction effect on the radon level in future houses if it is done at the site before the buidling work is started. For existing houses this kind of solution will usually be too expensive and too disruptive. However, for houses with a basement floor below ground level, where alum shale or other materials with a very high exhalation rate of radon has been used as filler on the outside of the foundation wall, removal or exchange of the source may be a successful solution.

If the air exchange rate is at a normal level, the relative reduction effect on the indoor level of radon by increasing the air exchange rate will usually be very low. Energy saving aspects, climatic conditions and indoor comfort limits the possibility to increase the air exchange rate in most situations. Due to an increase in the energy costs, and the campaign for saving energy in the 70's and 80's, a large proportion of old houses have been retrofitted in the last decade. At the same time period, modern houses have been made energy efficient. According to studies in Sweden (6), this may have reduced the air exchange rate in a significant part of the housing stock. In tight houses with no mechanical ventilation systems, average air exhange rates down to 1/10 of the normal level have been reported. In such houses, the effect of an increase in the air exchange rate to normal values, may lead to a reduction in the radon concentration by an order of magnitude. It is, however, important that the ventilation systems do not increase the underpressure inside. If so, then the influx of radon from the ground may increase.

For most houses in our study, diagnostic measurements showed that influx of radon from the ground was the most important source of radon. In 28 out of the 30 houses, different methods to reduce the influx from the ground were chosen. One of the main objectives of our study was to quantify the effect of different low cost solutions. This of course, did have an impact on the individual choice of solution. In several houses the mitigation process had to be carried out in different steps, starting with the cheapest possible one. In table 2, a general view of the different solutions is shown. In the following, a few examples from our study will be discussed in more detail.

TABLE 2. CLASSIFICATION OF THE DIFFERENT MITIGATION TECHNIGUES IN OUR STUDY

Category of mitigation solution	Number of houses
Sealing of cracks and openings in the foundation wall and the slab	3
Changing the pressure differences between indoor air and the ground 1)	20
Changing the ventilation conditions	2
A combination of different solutions 2)	5

1) Including four different methods: pressurize basement and/or crawl space (5 houss) sub-slab ventilation (13 houses), outdoor well (2 houses) and wall ventilation (1 house).
2) Combinations of sealing and sub-slab ventilation.

In figure 1, the reduction effect of a step-wise solution is illustrated in a house with a basement. The first step was based simply on sealing visable cracks and openings in the concrete slab and the foundation wall. In one of the rooms in the cellar, the average radon level was reduced from about 4,000 Bq/m^3 to 800 Bq/m^3. In this room a higly permeable wall of light expanded clay aggregate blocks, with direct contact below the slab, were assumed to be an important entry route. Most of the reduction effect can probably be explained by the plastering of this wall. However, the radon level was still too high and further actions were found necessary. As a second step, a sub-slab ventilation system (7) was installed. Due to the small base area of the house (about 80 m^3) and considerations about the permeability of the ground, one central exhaust pipe was assumed to give a sufficient suction. The pipe was connected to a fan on the loft. The flow rate was measured to 50-60 m^3/h. These type of solutions reduces the influx of soil gas by reducing the pressure differential between the basement and the ground and by reducing the concentration of radon below the slab by ventilation. After this second step, the radon concentration was reduced to about 150 Bq/m^3 in the basement and to about 100 Bq/m^3 on the first floor. On the average, in the four rooms where passive measurements were performed, the radon concentration was reduced by more than 90%. The actions were concluded to be very successful.

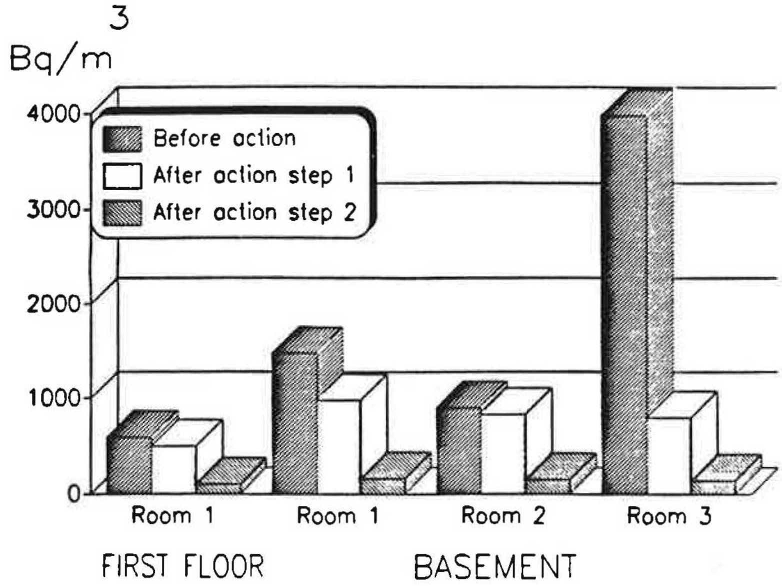

Figure 1. A two-step solution in a house with basement. Step 1: Sealing of cracks and openings in the concrete slab and the foundation wall. Step 2: Sub-slab ventilation (one exhaust pipe).

Figure 2 illustrates the effect of a pure solution based on sub-slab ventilation/-depressurisation. In this example, two exhaust pipes were connected to the fan on the loft. The fan is identical to the one in the previous case. For one of the rooms in the basement, the radon level was reduced from about 2,700 Bq/m³ to below 100 Bq/m³. This is a reduction of nearly 97%. The average radon concentration in the main living room on the first floor was reduced from 840 Bq/m³ to 80 Bq/m³. The solution was concluded to be very successful.

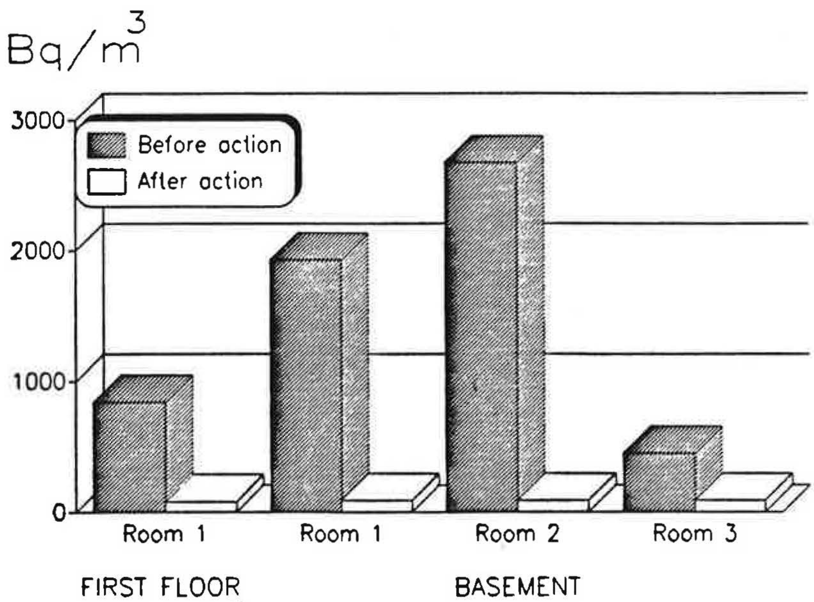

Figure 2. The effect of sub-slab ventilation/depressurisation (two exhaust pipes) in a house with basement.

It is important that the capacity of the fan is as low as possible. Not only because of energy saving, but also due to problems in the cold winter months if large quantities of cold air are beeing sucked beneath the basement floor. Outdoor temperatures below -30°C in the coldest winter months are not unusual in several parts of Norway. Our results have shown that fans with a very low capacity (about 30 Watt/60 m^3/h at Δp about 100 Pa) may be sufficient to solve the radon problem in many situations.

In one of the houses, the radon level was found to be very high. From contineous measurements, short time concentrations of radon up to 190 000 Bq/m^3 were found in the basement. Grab sampling measurements of radon and radon daughters confirmed these results. From passive measurements, the radon level in the basement was found to be between 10 000 and 15 000 Bq/m^3. Grab sampling measurements showed that an old and dry floor drain (without a water trap) in the basement floor probably was one of the main entry points. This floor drain was directly connected to alum shale rich soil. Since the floor drain was not in use any more, the first step was then to glog it and try to seal all visable cracks and openings in the concrete slab and the foundation wall. The results of this first step is illustrated in figure 3. In one of the rooms in the basement the radon level was reduced by almost 80%. In the other room in basement, sealing of the floor was found very difficult due to presence of numerios cracks and openings in the slab. In this room the average radon concentration was found to increase by about 15%. In addition to further sealing of the floor and the walls, an almost identical sub-slab ventilation/-depressurisation system as the example in figure 2, was installed. As illustrated, the radon concentration was reduced by nearly 95% in the basement and by about 90% on the first floor. However, the radon level is still too high and further work is needed. One of the possibilities is to increase the flow rate capacity of the fan.

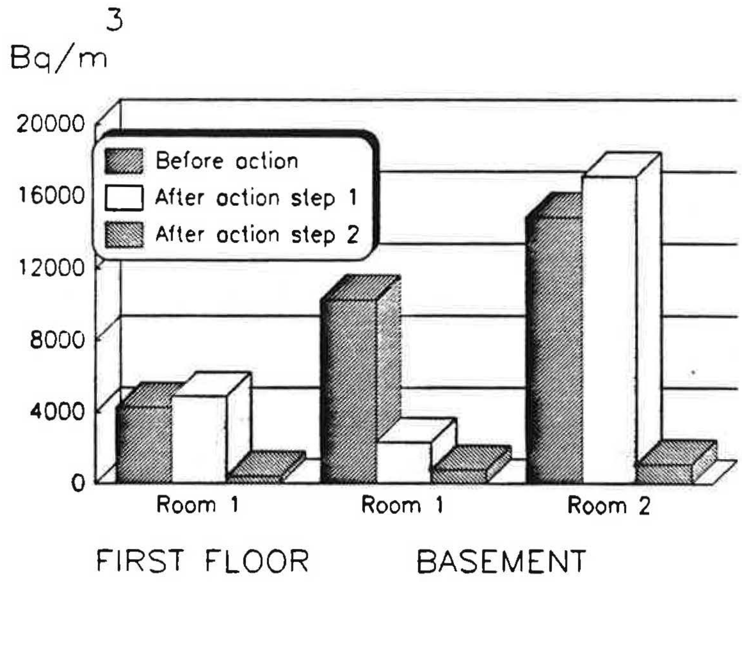

Figure 3. A two-step solution in a house with a basement. Step 1: glogging of a floor drain in the basement floor and sealing of different cracks and openings in the concrete slab and the foundation wall. Step 2: Sub-slab ventilation (two pipes).

The effect of sub-slab ventilation in the other houses where this type of technique as studied, was generally found to be successful. However, in a couple of houses were the ground most probably has a very low permeability, and the sealing of different cracks and openings in the slab were found to be very difficult, there was only a very slight reduction in the radon level.

For two of the houses in our study, the effect of a soil gas ventilation well on the outside of the foundation wall, were studied. The effect for one of these houses is ullustrated in figure 4. The well was at 3m depth and 1m in diameter. The exhaust pipe (diameter and lenght of 0.1m and 3m respectively), which was placed in the centre of the well reaching below basement floor level, was connected to a small fan (28 Watt) on the top. The flow rate was measured to about 50 m^3/h. In one of the rooms closest to the well in the basement, the radon concentration was reduced from 1300 Bq/m^3 to slightly below 350 Bq/m^3. On the first floor where the living room, bedrooms and kitchen were located, the radon level was reduced from 420 to 240 Bq/m^3.

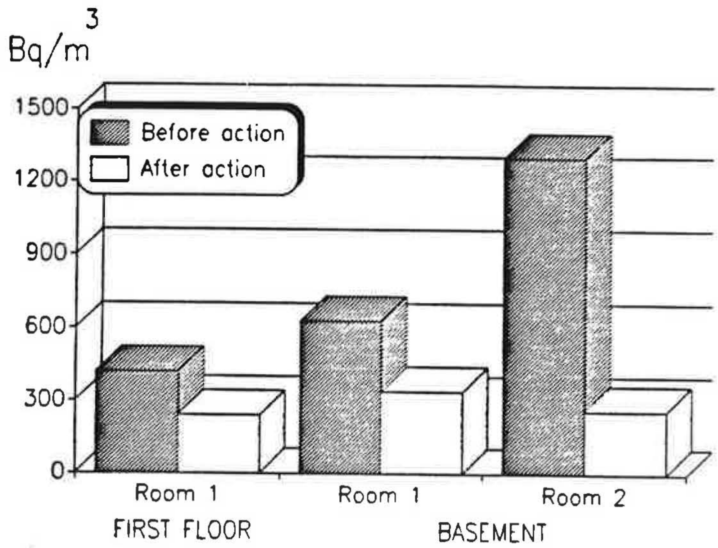

Figure 4. The effect of an outdoor soil gas ventilation well in a house with a basement.

In five houses, different techniques to pressurize the basement and/or the crawl space by supply of fresh air from the outside, were investigated. Due to the climatic condtions it was found necessary to include a heater unit in the fans, which of cource increases the energy costs. Preliminary results from these exsperiments seems to show that these types of solutions may have a relatively slight reduction effect on the radon level. In figure 5, the effect of pressurizing the basement and the crawl space in a house on alum-shale ground is illustrated. The fan (99 Watt) was installed in the foundation wall at the basement level. The flow rate was measured to 310 m^3/h. The radon concentration in the basement and the first floor were reduced by 50% and 30%, respectively. One of the main explanation of this low reduction effect may be leakage between the basement and the first floor.

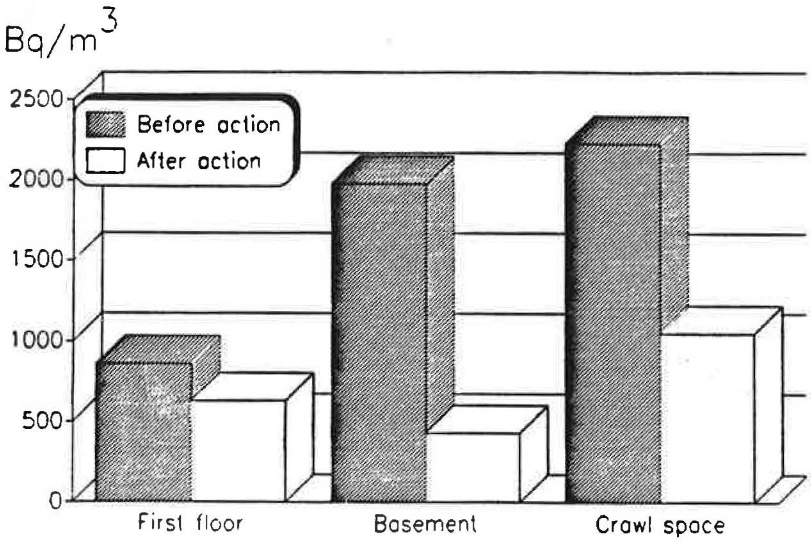

Figure 5. An example of a solution based on pressurizing the crawl space and the basement.

CONCLUSIONS

From the results and discussion of our study the following conclusions may be drawn:

1. Sealing of viseable cracks and openings in the slab and the foundation wall is recommended as a first step in any mitigation process. However, the results of our study shows that sealing alone in most situations will not be sufficient to solve the entire radon problem. This is especially true in cases where the radon level is very high.

2. Sub-slab ventilation by exhaust pipes connected to a small fan were generally found to be the most successful technique in our study. In most cases it is sufficient with only one or two exhaust pipes and a very small fan (30 Watt/60 m^3/h).

3. Preliminary results of our exprimental studies of techniques based on pressurizing crawl space and/or basement by supply of outdoor air have shown to have a relatively low reduction effect on the radon level.

The final results of our study will be presented later.

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REFERENCES

1. National Institute fo Radiation Protection, National Board of Health and Welfare, National Board of Physicsl Planning and Building. Radon in dwellings, interim report 1987. Report SSI 87-17, National Institute of Radiation Protection, Sweden (in Swedish).

2. Ericson, S-O, Schmied, H. and Clavensjø, B. Modified technology in new constructions and cost effective remedial action in existing structures to prevent infiltration of soil gas carrying radon. Radiat.Prot.Dosim. 7(1/4): 223-226, 1984.

3. Central Bureau of Statistics, Census data, Personnal Communications 1986.

4. Stranden, E., Kolstad, A.K. and Lind, B. The ETB dosemeter, a passive integrating radon dosemeter combining activated charcoal and TLD. Radiat.Prot.Dosim. 5(4): 241-245, 1983.

5. Stranden, E. and Berteig, L. Radon daughter equilibrium and unattached fraction in mine atmospheres. Health Phys. 42: 479-487, 1982.

6. Swedjemark, G.A. The equilibrium factor F. Health Phys. 45(2): 453-462, 1983.

7. Sanchez, D.C. and Henschel, D.B. Radon reduction techniques for detached houses - technical guidance. U.S. Environmental Protection Agency Report EPA/625/5-86/0019, Center for Environmental Research Information, Cincinnati, OH, 1986.