EXPERIENCES IN RADON-SAFE BUILDING IN FINLAND

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A study was made of radon-safe building in 300 Finnish low-rise residential buildings using data obtained from a questionnaire study. The study also aims at finding the main defects in design and implementation and how the guidance given on radon-safe building in slab-on-grade houses has been followed. According to the guidance, the prevention of the flow of radon-bearing air from the soil into the house is recommended to be carried out through installation of aluminized bitumen felt and use of elastic sealants. Second, as a precaution perforated piping should be installed in the subsoil of the floor slab. This piping will be connected to a fan if the action level is exceeded, providing an active sub-slab depressurisation system for the house.

The median indoor radon concentration in the houses was 305 Bq/m³. This is 32 % lower than the median of the estimated reference values. The action level of 200 Bq/m³ was still exceeded in 40 % of the houses. In most houses with slab-on-grade the prevention was based only on the installation of a sub-slab depressurisation system. Sealing was performed in a low number of houses. In 80 % of houses with a sub-slab piping connected to an operating fan, radon concentration was below the action level of 200 Bq/m³. In houses with piping but no fan, the corresponding fraction was only 45 %. The corresponding median values of radon concentration in these houses were 55 and 220 Bq/m³. Sub-slab piping without a fan had no remarkable effect on radon concentration. In houses with crawl-space and edge-thickened slab, radon concentrations were low. The choice of foundation system thus significantly affects the indoor radon concentration.

Performing the sealing work is an essential part of radon-safe building. However, sealing measures were carried out in about 30 % of the houses and in many of these houses the work was not carried out along the guideline. However, through performing careful sealing work, good results were achieved without the activation of the sub-slab piping. The importance of complete and careful sealing work should be stressed in advice and guides concerning radon prevention.

Keywords: Radon, radon-safe building, indoor air

INTRODUCTION

Radon-bearing soil air is the main reason to elevated indoor radon concentrations in Finland. The pressure difference created by the indoor-outdoor temperature activates the soil air to flow into dwellings through the gaps and other leakage routes existing in the foundation structures. The choice of the foundation structure and the technique used in the building process affect strongly the leakage rate of radon-bearing soil air. Based on the decision of the Ministry for Social Affairs and Health in 1992, the indoor radon concentration should not exceed 400 Bq/m³ in existing houses, the target for new construction being less than 200 Bq/m³. Because the average indoor radon concentration in single family houses is close to 150 Bq/m³, the target concentration of 200 Bq/m³ is very demanding. In wide areas of the Southern Finland 200 Bq/m³ is exceeded in more than 30 % of the houses. The aim of this study is to explore the effect of substructure of Finnish low rise residential houses on indoor radon concentration and the experiences achieved in radon-safe new building.
MATERIALS AND METHODS

Effect of the substructure

The effect of substructure on indoor radon concentration was studied using the material of a previous study carried out in 1990-1991 (Arvela et al. 1993, Castrén 1994). This study measured the indoor radon concentration in the dwellings of 3074 persons, selected randomly from the Central Population Register. Alpha detectors and two consecutive half year measuring periods were used. Altogether 2171 low rise residential houses and 903 flats were measured. The sample was selected from the population register and not from the housing register. The average number of occupants differs slightly in different types of dwellings and the sample represents not in completely a randomly selected sample from the housing stock. However, the differences are of minor importance, and the houses measured can be considered statistically representative regarding the most important parameters affecting indoor radon concentration. The data concerning the substructures was obtained through a detailed questionnaire sent to the residents.

Prevention study

The data regarding the preventive measures taken in 309 dwellings was obtained from a questionnaire study carried out in 1995-1996 (Ravea and Arvela 1997). The subject group were 612 houseowners who had ordered an indoor radon measurement from STUK and reported that they had taken preventive measures in order to achieve a low indoor radon concentration. Altogether 377 house owners returned the questionnaire. After checking the forms, finally 309 houses with adequate information on the preventive measures were accepted. The study also aimed at finding the main defects in design and implementation and how the guidance given on radon-safe building has been followed. Therefore the questionnaire form included very detailed questions concerning the sealing of the foundation constructions and installation of the sub-slab piping. In order to make comparison with the local existing housing, a reference value was estimated for each of the houses on the basis of former local indoor radon measurements in houses with no preventive measures. Geological and building aspects were considered when estimating the reference values. Alpha detectors with a measuring period of two months was used for indoor radon measurements. The measurements have been carried out during heating period, November-April.

Methods on radon-safe building

One of the main aims of the questionnaire study was to explore how the builders had followed the guidance given on radon-safe building (Ministry of Environment 1994). The guidance aims at radon-safe construction of slab-on-grade foundations. The guidance also deals with cellar- and hillside houses where preventive measures are needed in order to block out the leakage flow of radon-bearing soil air through walls backing soil. The guidance can be applied to more than 80 % of new single family houses because of the prevalence of these substructure types. No special radon technical guidance has been given until now to houses with crawl-space, because the predicted indoor radon concentrations are much lower than in houses with slab-on-grade.

The radon-safe construction comprises two measures. First an air tightness should be achieved using bitumen felt and elastic sealants. Second a preparatory perforated piping should be installed.

The aim of sealing work is to achieve an air tight barrier which prevents the leakage flow of soil air through the substructure. The tightening concerns the foundation wall, the joint between the floor slab and foundation wall, fire place joints, all lead-throughs in the slab. The material of the foundation wall
determines the need for sealing. In the case of tight concrete cast on the spot, only the gap between the foundation wall and floor slab needs to be sealed. In the case light weight concrete blocks are used, also the foundation wall should be sealed by thorough coating of the surfaces with plaster. Otherwise the foundation wall provides an entry route to soil gas into the wall structures and onwards into living spaces.

Figure 1 shows the sealing work required in the case permeable foundation wall material is used. Installation of bitumen felt to the joint between the foundation wall and floor slab is essential. Aluminium bitumen-felt or other felts which do not loose the air-tightness when bending must be used. A cleat (thin board) should be installed to the joint before casting. After removing of the cleat there is a hole and prepared surface for elastic sealants. The joints of the floor slab and load bearing walls and fire place should be sealed using the same technique. In the case the floor slab is extensive and load bearing walls divide it to separate areas, possible expansion joints should also be sealed.

Soil ventilation is a preparatory technique which provides a method to prevent soil air leakage in the case the sealing work does not result in indoor radon concentration below the target concentration. The aim of the soil ventilation is both to ventilate the pore air in the drainage gravel and to create a sub-slab underpressure, which decreases the leakage flow. The ventilation system consists of a perforated suction pipe installed in drainage gravel, a discharge flue with joint elements and a discharge fan. Figure 2 shows the installation of the suction pipe in the drainage gravel. The installation at a distance of 1.5 m from the foundation wall is based in flow calculations and optimisation of the soil ventilation and depressure affecting in the gap between the slab and foundation wall (Kettunen et al. 1990).

RESULTS
Substructure and indoor radon concentration

Table 1 demonstrates the effect of substructure on indoor radon concentration in Finnish low rise residential houses. The differences are significant, radon concentrations being highest in houses with slab-on-grade and in hillside houses. The concentrations are lowest in houses with crawl-space. Table 1 gives also typical building years for different substructure categories. Figure 3 shows the prevalence of the substructures, as a function of the decade when they were built. Table 1 and Figure 3 show that the foundation types most commonly used in the 1980s result in higher radon concentrations than substructures used earlier. Slab-on-grade and hillside house with foundation walls of light-weight concrete blocks are the prevailing substructures in the 1980s. This development has continued also in the 1990s. Typical indoor radon concentrations in these houses are close to or higher than the reference level of 200 Bq/m³ for new houses.

Prevention study

Table 2 shows the preventive measures taken in the houses studied. The most common measure was installation of the sub-slab piping, with no sealing work. However, although the target level of 200 Bq/m³ was exceeded, no fans had been normally installed at the time of the study. The target level of 200 Bq/m³ was still exceeded in 40 % of the houses. The median indoor radon concentration in the houses was 305 Bq/m³. This is 32 % lower than the median of the estimated reference values.
Sub-slub piping with an operating fan provides an efficient preventive measure. In 80% of houses with a sub-slub piping connected to an operating fan, radon concentration was below the action level of 200 Bq/m³. In houses with piping but no fan, the corresponding fraction was only 45%. The corresponding median values of radon concentration in these houses were 55 and 220 Bq/m³, respectively. Sub-slub piping without a fan had no remarkable effect on radon concentration. In houses with crawl-space and edge-thickened slab, radon concentrations were low. The choice of foundation system thus significantly affects the indoor radon concentration.

Sealing was performed in a low number of houses although it is an essential part of radon-safe building. Sealing measures were carried out in about 30% of the houses and in many of these houses the sealing was not carried out along the guideline. However, through performing careful sealing work, good results were achieved without the activation of the sub-slub piping.

Especially in large single-family houses and terraced houses, the radon-technical documents should be planned by professionals because the adverse effects of design errors will be emphasised in such cases. The most common design errors were an insufficient number of suction points, low-powered fans and wrong configuration of the sub-slub piping.

CONCLUSIONS

Modern foundation structures have increased the radon-bearing soil air flow into houses. Crawl-space, nowadays seldom used, is an advantageous foundation construction as regards radon. Slab-on-grade with foundation walls made of porous light-weight concrete blocks, being the most common construction, has increased the soil-air leakage into dwellings. Hillside houses with open stairwells between the ground floor and the first floor have replaced basement houses. Basements were previously more isolated and reduced the radon-rich air flow into living spaces.

Performing the sealing work is an essential part of radon-safe building. The importance of complete and careful sealing work should be stressed in advice and guides concerning radon prevention.

Radon-safe building is a new challenge to builders, designers and building inspection. In order to get good results, documented plans for radon prevention should be required in writing by the building inspection. Advice, guidance material and education should be improved. Building design companies and factories for single-family house elements should also work actively for the promotion of radon-safe building.

REFERENCES


Table 1: Radon concentration in Finnish low-rise residential houses with different substructures, results from the nation-wide study undertaken in 1990-91. The total number of houses, with adequate information for the classification, presented in the table was 1658.

<table>
<thead>
<tr>
<th>Substructure</th>
<th>Percentage of all low rise residential houses %</th>
<th>Percentage of all low rise residential houses exceeding 400 Bq/m³ %</th>
<th>Mean indoor radon concentration Bq/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slab-on-grade, CC, 1969-84, (2)</td>
<td>34</td>
<td>42</td>
<td>170</td>
</tr>
<tr>
<td>Slab-on-grade, LWCB, 1983-88 (2)</td>
<td>8</td>
<td>18</td>
<td>230</td>
</tr>
<tr>
<td>Slab-on-grade, edge-thickened, 1973-83, (3)</td>
<td>9</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Crawl-space, 1928-55</td>
<td>15</td>
<td>7</td>
<td>110</td>
</tr>
<tr>
<td>Basement, door and stairwell, 1952-67</td>
<td>27</td>
<td>16</td>
<td>120</td>
</tr>
<tr>
<td>Hillside house, open stairwell, CC, 1960-79</td>
<td>4</td>
<td>10</td>
<td>250</td>
</tr>
<tr>
<td>Hillside house, open stairwell, LWCB, 1978-88</td>
<td>3</td>
<td>6</td>
<td>280</td>
</tr>
<tr>
<td>All low rise houses</td>
<td>100</td>
<td>100</td>
<td>140</td>
</tr>
</tbody>
</table>

1) Quartiles of building year, 25 % and 75 %, based on 1990 survey  
2) Material of foundation wall, CC=cast concrete, LWCB= light-weight concrete blocks  
3) Foundation wall and floor slab casted simultaneously, number of houses overestimated due to misclassification by home owners, the actual group is in many cases slab-on-grade
Table 2: Median indoor radon concentration and percentage of houses with indoor radon concentration exceeding 200 Bq/m³ and 400 Bq/m³, for different preventive measures. The results are based on a questionnaire study carried out in 1995-96.

<table>
<thead>
<tr>
<th>Preventive measure</th>
<th>Number</th>
<th>Median Bq/m³</th>
<th>Percentage Exceeding 200 Bq/m³</th>
<th>Percentage Exceeding 400 Bq/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sealing of leakages in substructure, slab-on-grade</td>
<td>31</td>
<td>138</td>
<td>32</td>
<td>10</td>
</tr>
<tr>
<td>Slab-on-grade, sealing work + sub-slab piping, no fan</td>
<td>58</td>
<td>155</td>
<td>34</td>
<td>10</td>
</tr>
<tr>
<td>Slab-on-grade, sub-slab-piping, no fan</td>
<td>141</td>
<td>220</td>
<td>55</td>
<td>26</td>
</tr>
<tr>
<td>Slab-on-grade, sub-slab piping, fan operating</td>
<td>21</td>
<td>55</td>
<td>19</td>
<td>10</td>
</tr>
<tr>
<td>Crawl-space</td>
<td>20</td>
<td>70</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Edge-thickened slab</td>
<td>4</td>
<td>66</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Figure 1: Sealing of the joint between foundation wall and floor slab, when the foundation wall is made of permeable material.
Figure 2: Installation of the suction pipe in the gravel layer
Figure 3: Prevalence of substructures as function of the decade when they were built, for the Finnish low rise housing.