A Nationwide Radon Survey in Finland - Prevention in new Construction

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Abstract. The practical guidelines and building code for radon prevention and were revised in Finland in 2003 to 2004. Thereafter, local prevention requirements have become more strict and preventive measures more common and prevention practices more effective. Consequently, indoor radon concentrations in new construction have been markedly reduced. In this survey, the indoor radon concentration was measured in 1 561 new low-rise residential houses. The houses were randomly selected from housing register and represented 7% of houses that received building permission in 2006.

The results of this study provide evidence of a strong impact of radon prevention measures. The average radon concentration of all houses measured, which were completed in 2006 to 2008, was 95 Bq/m^3, the median being 58 Bq/m^3. The average was 33% lower than in houses completed in 2000 to 2005. The decrease was 47% in provinces with the highest indoor radon concentration and 26% elsewhere in the country. In houses with a slab-on-ground foundation that had both passive radon piping and sealing measures carried out using a strip of bitumen felt in the joint between the foundation wall and floor slab, the radon concentration was on average reduced by 57% compared to houses with no preventive measures.

Preventive measures were taken in provinces with the highest radon concentration in 92% of houses, elsewhere in 34% of houses. The average activity in the whole country was 54%. Slab on ground is the prevailing type of foundation and necessitates careful radon prevention measures throughout the country. The most serious defects were observed in prevention practices in houses with walls made of lightweight concrete blocks that were in contact with soil. The results emphasize the importance of building codes that require radon prevention in new construction.

KEYWORDS: radon, indoor air, sample survey, new construction, radon prevention

INTRODUCTION

High indoor radon concentrations are characteristic of the Nordic countries Finland, Sweden and Norway. In Finland the percentage of residential houses exceeding the reference level for new construction, 200 Bq/m^3, was 16% in a national random sample survey carried out in 2006-2007 (Mäkeläinen et al. 2009). The national average and median for low-rise residential buildings were 121 Bq/m^3 and 75 Bq/m^3. In 6 of the 20 Finnish provinces, the percentage exceeding 200 Bq/m^3 was 25–50%, the median concentration ranging from 120 Bq/m^3 to 200 Bq/m^3. Permeable soil types, the uranium concentration in soils and the cold climate are the main reasons for elevated indoor radon concentrations.

Slab-on-ground is by far the most prevalent type of foundation for newly-constructed low-rise residential houses in Finland, accounting for 65% of houses. The key feature of this foundation type regarding radon prevention is the gap between the floor slab and foundation wall (Figure 1). This gap promotes the flow of radon-bearing soil air into living spaces. When taking into account the leaking foundations of semi-basement houses and basement houses, altogether 80% of Finnish low-rise residential buildings represent a foundation type with a high radon risk. Preventive measures in new construction are thus an essential part of attempts to reduce radon concentrations in Finnish housing.

The building code for radon prevention and the associated practical guidelines were revised in Finland in 2003 to 2004 (Building Information Ltd. 2003, Ministry of environment 2004). Thereafter, preventive measures have become more common and prevention practices more effective. Therefore, STUK carried out in 2009 a random sample survey of new construction (Arvela et al. 2010, 2011). This presentation gives a brief summary of the survey.

Regulations and guidance

The revised building code for foundation structures requires that radon should be taken into account in all construction work in Finland. Houses should be designed and constructed so that the indoor radon concentration is kept below 200 Bq/m^3.

The revised guidance for radon-resistant new construction focuses on practices needed in houses with slab-on-ground foundations as well as in houses with walls in contact with soil. The essential preventive measures are the installation of preparatory radon piping below the floor slab and sealing of the joint between the floor slab and the foundation wall using a strip of bitumen felt (Figures 2 - 4). In a passive radon piping system, the discharge is open above roof. The temperature difference and wind create an air flow, which reduces the radon concentration in the pore air of the sub-slab gravel. When needed, one can install a radon fan in the discharge of the piping which, when active, effectively reduces the indoor radon concentration.

MATERIALS AND METHODS

In this survey, the indoor radon concentration was measured in 1 561 new low-rise residential houses. This includes 1070 detached houses and 491 dwellings in terraced houses (N=333) and semi-detached houses (N=158). The houses were randomly selected from the database of the Population Register Centre of Finland and represented 7% of the 22 716 houses that received building permission in 2006. The selected houses were occupied by November 2008. Altogether, 3 000 dwellings were selected for this study, and an invitation to participate in the study was sent to the house owners. Radon measurements lasted for two months from March to May 2009. The alpha track detector that was used records the average radon concentration over the measurement period. The standard questionnaire of the STUK radon measurement service was used to gather information on the foundation type and other house characteristics. A special questionnaire for radon prevention illustrated, for example, with Figures 2 - 4, was designed to obtain information on preventive measures taken, sealing work and the installation of radon piping.

The results of the new construction survey (2009) were compared with the previous nationwide survey of the total housing stock. This former survey is referred to below as the sample survey (2006) (Mäkeläinen et al. 2009). In the survey, carried out in 2006 - 2007, 2866 dwellings were measured, 2267 low-rise houses and 599 apartments. In the selection, a simple random sampling from the population registry was utilized. The geographical distributions of houses in these two surveys are quite similar.

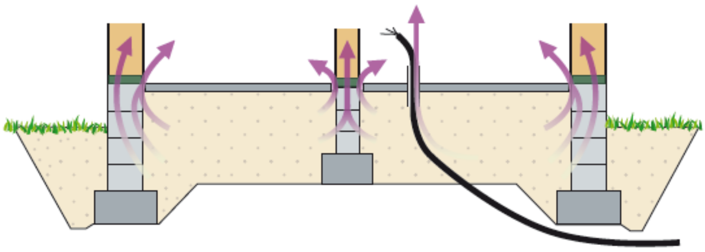

Figure 1. Entry routes of soil air in a Finnish slab-on-ground foundation. The foundation wall is constructed of permeable light-weight concrete blocks.

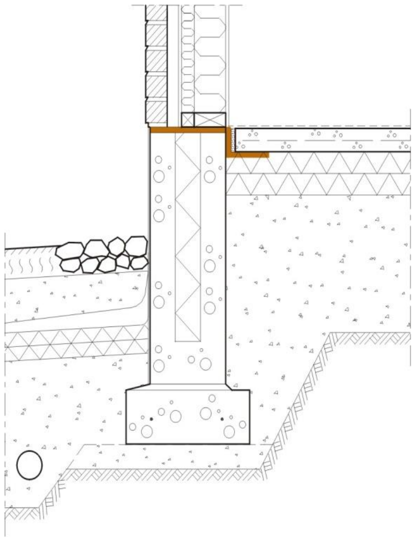

Figure 2. Sealing of the gap between the foundation wall and floor slab according to the Finnish guidelines.

Figure 3. Installation of a strip of bitumen felt in the joint of foundation wall and floor slab according to the Finnish guidelines.

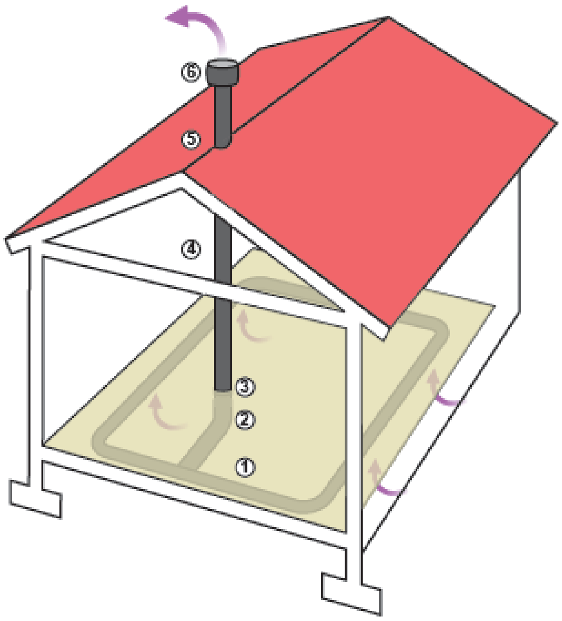

Figure 4. Radon piping in the Finnish radon prevention guidelines

Table 1. Average and median radon concentration and percentage of houses exceeding 200 Bq/m^3 in the new construction survey (2009) for the six provinces of Finland with the highest radon concentration (Zone 1) and elsewhere in the country (Zone 2). Comparison with the winter measurement of houses completed in 200 to 2005 in the nationwide sample survey (2006).

	Radon concentration (Decrease in levels in the new construction survey, compared with the sample survey (2006), % or percentage points, pp)		
Survey and region	Average Bq/m^3	Median Bq/m^3	Percentage exceeding 200 Bq/m^3
New construction survey (2009)			
Zone 1	125 (47%)	74 (55%)	16.5 (25 pp)
Zone 2	83 (26%)	53 (28%)	8.4 (3.8 pp)
Whole country	95 (33%)	58 (33%)	10.6 (8.8 pp)
Sample survey (2006), winter concentration			
Zone 1	237	166	41.9
Zone 2	112	74	12.2
Whole country	142	87	19.4

Zone 1: Provinces of Itä-Uusimaa, Kymenlaakso, Päijät-Häme, Pirkanmaa, Etelä-Karjala and Kanta-Häme; Zone 2: Other provinces

RESULTS

Radon concentration

The average radon concentration of all houses measured, which were completed in 2006 to 2008, was 95 Bq/m^3, the median being 58 Bq/m^3, Table 1. The average was 33% lower than in houses completed in 2000 to 2005. The decrease was 47% in those provinces with the highest indoor radon concentrations and 26% elsewhere in the country. The decrease compared to houses completed in 1980 to 1999 was more than 40%. The percentage of houses exceeding the reference level of 200 Bq/m^3 had also markedly decreased, from 16% to 11%.

Indoor radon concentrations in low-rise residential houses grouped according to the year of construction are presented in Figure 5. The statistics for the years 1949 – 2005 are from the previous sample survey (2006) and the last results for 2006 – 2008 from this new construction survey.

Radon concentrations were by far the lowest in houses with a reinforced uniform floor slab and those with a crawl space. In both of these classes, the average radon concentration was below 45 Bq/m^3 and the median below 30 Bq/m^3. In houses with a slab-on-ground foundation the average was 96 Bq/m^3 and the median 68 Bq/m^3. In semi-basement and basement houses with walls in contact with soil, the average and the median were 151 Bq/m^3 and 100 Bq/m^3, more than 50% higher than in houses with a slab-on-ground construction. The main reason for these elevated values was the defective measures for radon prevention in the block walls in contact with soil. Leakages of radon-bearing soil air through walls in contact with soil can also be seen in the percentage of houses exceeding the reference level of 200 Bq/m^3. This figure was 22 %, as compared to 11 % for single family houses with slab-on-ground

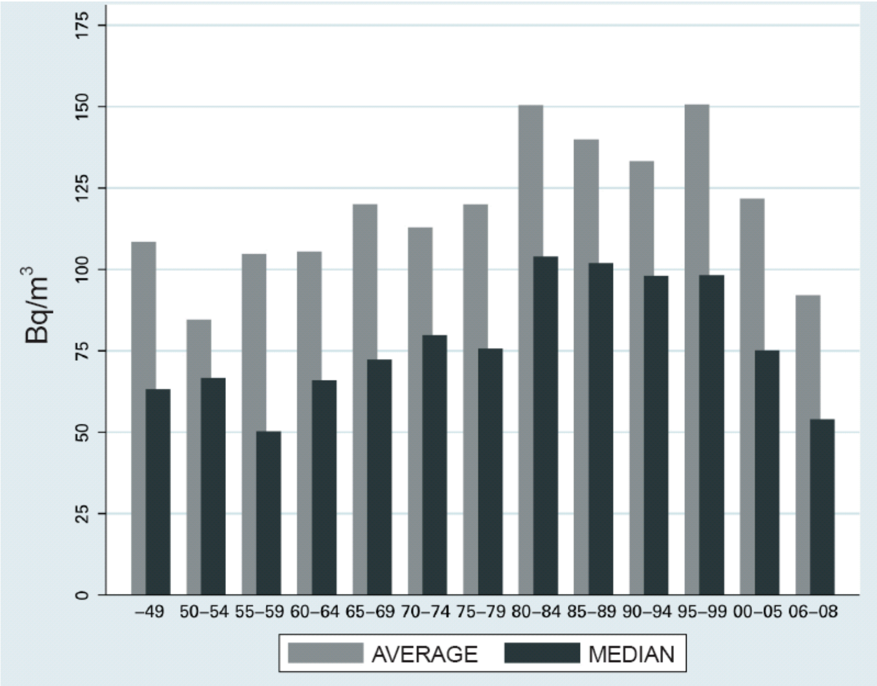

Figure 5. Radon concentration in low-rise residential houses according to the year of construction based on the national Finnish sample survey in 2006 (1949–2005). The last bar (2006–2008) represents the results of this new construction survey (2009).

Impact of radon-resistant new construction

Preventive measures had been carried out in 54% of single family houses with slab on grade. The percentage was 92% in the six provinces with the highest indoor radon concentration and 38% elsewhere in the country. Nationwide, the new regulations issued in 2003 to 2004 have doubled the level of prevention activity. Table 2 shows the prevention activity in the Finnish provinces.

The impact of preventive measures was assessed through a comparison of indoor radon concentrations in houses with prevention compared to those where no preventive measures had been taken. In this comparison, local reference values from the indoor radon database, including 87 000 houses throughout Finland (Valmari et al. 2010), were utilized. The reference values used were median radon concentrations of the postal code areas.

In single family houses with slab-on-grade foundations, passive radon piping and the installation of a strip of bitumen felt reduced the indoor radon concentration by 55%, Table 3 and Figure 6. The average reduction for radon piping with no sealing measures was 40%. The effect of prevention can also be clearly seen in the percentage of houses exceeding the reference level. In houses that had taken preventive measures the percentage exceeding this level was 8%. In relation to the local reference values, this percentage was 29%. Higher percentages exceeding the reference level were most common in semi-basement and basement houses, in which radon entry through block walls in contact with soil is the main factor causing the elevated radon concentrations.

Table 2. Radon preventive measures in the provinces of Finland with the highest radon concentrations (Zone 1) and elsewhere in the country (Zone 2) for detached houses with slab-on-ground foundations, new construction survey (2009).

Provinces	Passive radon piping installed %	Radon piping and bitumen felt sealing installed %
Zone 1: Itä-Uusimaa, Kymenlaakso, Päijät-Häme, Pirkanmaa, Etelä-Karjala ja Kanta-Häme	92	83
Zone 2: Elsewhere in the country	38	32
Whole country	54	46

Table 3. Effect of preventive measures on the indoor radon concentration of detached houses with slab-on-ground foundations in the new construction survey (2009). The results are compared with the local reference values from the national database of Radiation and Nuclear Safety Authority (STUK).

Feature	Preventive measures			
	No measures	Passive piping and sealing	Passive piping	Passive piping or closed piping
Number of houses	230	166	111	55
Radon concentration, average Bq/m^3	90	82	98	99
Radon concentration, median Bq/m^3	68	53	59	86
Radon concentration, local reference value, median, Bq/m^3, 1)	58	128	106	112
Ratio of radon concentration to local reference value, median	1.19	0.46	0.56	0.67
Regression factor 2)	1.27	0.54	0.76	0.78
Radon reduction, % 95% confidence limits 3)	0 %	57 % (43% -71%)	41 % (24% -58%)	39 % (20% - 58%)
Percentage exceeding 200 Bq/m^3 in 2009 study, %	8	8	14	11
Percentage of local reference values exceeding 200 Bq/m^3, %	7	29	26	24
Percentage exceeding 400 Bq/m^3 in 2009 study, %	1.3	1.2	1.8	0
Percentage of local reference values exceeding 400 Bq/m^3, %	1.4	9.7	8.1	7.9

1) Median of the measurements carried out in the postal code area, from the STUK database. If the number of measurements was below 10, the municipal median was used.
2) Coefficient from linear regression analysis. Ratio of the measured radon concentration to the local reference value. The intercept term is set to zero.
3) Radon reduction for the preventive measures has been calculated as the ratio of the regression coefficient to the coefficient of the “No measures” class. The confidence limits have been calculated by summing the 2 STD errors in quadrature with the “No measures” class.

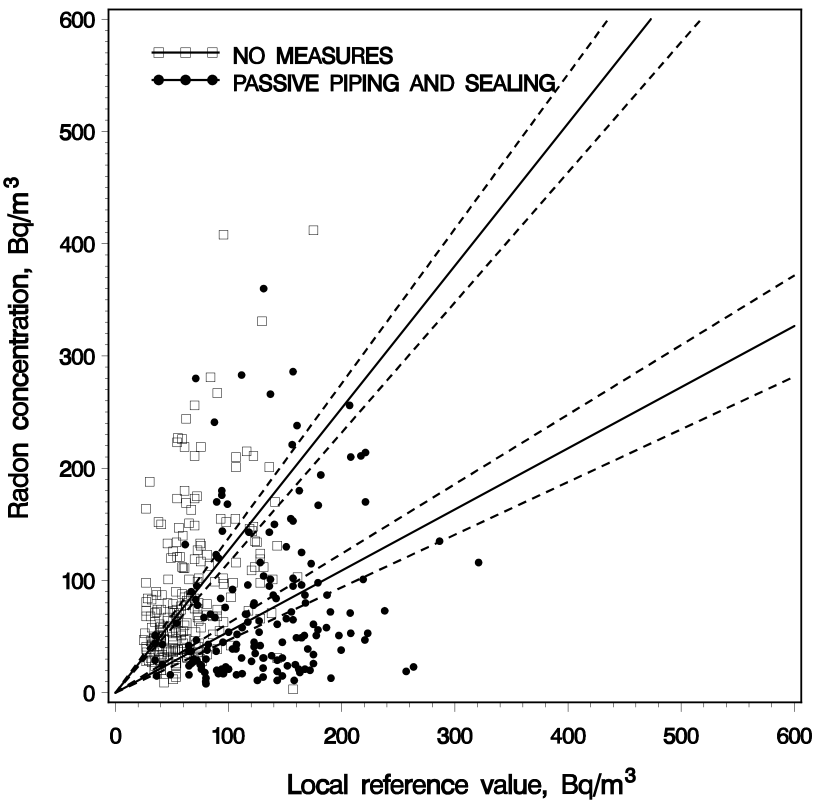

Figure 6. Radon concentration in the study houses and local reference values, new construction survey 2009. Regression lines are fitted for houses without preventive measures and houses with passive radon piping and sealing carried with a strip of bitumen felt.

CONCLUSIONS

According to the results of this study, there is high variation in the prevention activity in different areas of the country. Local authorities require prevention measures commonly in those areas with the highest radon concentrations, which has also resulted in a considerable decrease in indoor radon concentrations. On the other hand, in those areas where no prevention has been taken, indoor radon concentrations have remained as before or have even increased. Radon-resistant new construction practices represent economic investments that also have moisture-related advantageous effects. Prevention measures may decrease also the entry of other harmful substances from soil into living spaces. The effect of passive radon piping is so significant that installation of the piping and bitumen felt is recommended throughout the country. Builders should require architects and all participants in building projects to implement radon prevention measures according to the current guidelines.

Sealing of lead-ins in the floor slab was found to be relatively uncommon, and the sealing measures for block walls in contact with soil were generally defective. However, the impact of the preventive measures will increase as the experience of construction companies develops.

The results of this study provide evidence of a strong impact of radon prevention measures. The practices detailed in the prevention guidelines have reduced the indoor radon concentration in the houses that received building permission in 2006 by tens of percent in comparison with houses built earlier. The requirement for radon prevention in connection with the application for building permission and the widespread and skilled implementation of preventive measures throughout the country could result in an average of 50% reduction in indoor radon concentrations compared to the present housing stock with no prevention. This would considerably reduce exposure to radon and the harmful health effects of indoor radon in the coming decades.

ACKNOLEDGEMENTS

Questionnaire data of EU RADPAR project (Executive Agency for Health and Consumers) has been utilized in the comparison with other surveys.

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