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RADON PREVENTION AND MITIGATION IN FINLAND: GUIDANCE AND PRACTICES

Hannu Arvela, Heikki Reisbacka and Petteri Keraenen
Radiation and Nuclear Safety Authority - STUK
PO Box 14, 000881 Helsinki
Finland

ABSTRACT

Two new Finnish mitigation guides have been issued. The first guide gives basic information and practical examples on all mitigation methods and results achieved. The second guide is a detailed guide for design and implementation of sub-slab-depressurization (SSD) in low-rise residential houses. The presentation includes many examples from the guide for SSD and radon well and other methods. The most efficient methods are SSD and radon well, typical radon concentration reduction factors being 70 - 90%. Radon well is effective only on soils where air permeability is high enough; e.g., on gravel and in esker areas. A single radon well can reduce radon concentration in many dwellings at a distance up to 20 - 30 meters. Sealing entry routes and ventilation or pressure-reduction-based measures resulted in lower reduction factors but play an important role in mitigation practices.

The national prevention guide and results achieved are presented. The guide is based on the following measures: use of bitumen felt in the joint of foundation wall and floor slab, sealing of penetrations and installation of radon piping. Radon prevention is essential and required in the whole country.

1. Introduction

Finland belongs to the countries of high indoor radon concentrations. Cool climate, long heating season with no long-term airing through windows, building soils with high air permeability and foundation structures promoting flow of radon-bearing air from soil to indoor spaces are the main reasons for high indoor radon concentrations. Approximately 50,000 dwellings, 3% of all dwellings, exceed the action limit of 400 Bq/m^3. Most of these are low-rise residential buildings. Similar problems are found in flats with the slab of the bottom floor in contact with the ground.

The reference limit for design and construction of new buildings is 200 Bq/m^3. The number of houses in Finland exceeding this limit is 200,000, which is 18% of single-family houses. Preventive measures should be taken in all buildings in the whole country in order to avoid new dwellings that need mitigation.

The first indoor radon mitigation studies were carried out in the mid 1980's. These studies resulted in first mitigation reports which gave basic information of active sub-slab suction installations. Both STUK and the Ministry on Environment published mitigation guides in the 1990's. The STUK guide gave an overview of all methods and the results achieved. The guide of the Ministry focused on sub-slab depressurization (SSD), design and implementation.

Both guides have been revised in 2008 (Arvela and Reisbacka 2008, Ministry of Environment 2008). The ministry guide is a detailed guideline for design. The STUK guide refers to the ministry guide and gives key principles for design and implementation. Table 1 gives the contents of the guides.

Table 1 *Key contents of the mitigation guides*

STUK guide Indoor radon mitigation	**SSD guide, Ministry of Environment** Indoor radon mitigation in low-rise residential buildings. Sub-slab depressurization.
1. Introduction -Radon entry, ventilation depressurisation 2. Efficiency of mitigation methods 3. House inspection before mitigation 4. Sub-slab depressurization - Principle, design, suction pits, location of pits, exhaust piping and fan, installation - SSD through foundation wall 5. Radon well - Design, results, examples 6. Sealing entry routes - Practical guidance, materials 7. Crawl-space ventilation 8. Ventilation-based methods - Mechanical and natural ventilation, examples 9. Cellar ventilation 10. Radon mitigation in blocks of flats -depressurisation problems, ventilation, SSD, radon well 11. Workplaces and large buildings - Brief overview 12. Methods used in house inspection 13. Prices of mitigation 14. Radon prevention in new building	1. Introduction 2. Overview of mitigation methods 3. Design principles 4. Designing a SSD - Foundation and floor construction - Load-bearing walls - Need of sealing work - Number and location of suction pits 5. Practical installation - Normal suction pit and deep suction pit 6. Implementation - Dimensioning of air flows - Improvement of the efficiency 7. Air exchange

- Brief overview	

2. Results achieved in indoor radon mitigation

The STUK guide reports mitigation results in 400 dwellings based on a detailed mitigation questionnaire sent to house owners in 2000-2001. Figure 1 shows a summary of the results.

Sub-slab depressurization (SSD) and radon well are the most efficient methods. Typical reduction factors for both methods are 70 - 90%. In difficult cases additional sealing work is needed in order to achieve a low radon concentration. The reduction factors for other passive methods are clearly lower, as shown in Figure 1.

SSD can be implemented through both floor slab and foundation wall. The ministry guide focuses on the implementation of SSD through floor slab. The STUK guide gives examples and guidance also for foundation-wall installations. SSD's have been installed in many cases through foundation wall in terraced houses where the floor slab area is not large. The reduction factors are typically above 80%.

Installation of a preparatory radon piping has become increasingly common in houses built during the last ten years. Activation of this piping through an exhaust fan has resulted in high reduction factors typically above 80%.

A radon well is constructed outside of the house, and the well sucks air from soil from a depth of 3 - 4 metres. Figure 2 shows the principle of a radon well. This ventilation decreases the radon concentration of soil air below the house foundation efficiently. A single radon well can reduce radon concentration in many dwellings at a distance up to 20 - 30 meters. A radon well is effective only on soils where air permeability is high enough; e.g., on gravel and in esker areas.

Radon reduction methods based on ventilation reduce radon concentration either through increased ventilation or lowered house vacuum level. A reduction factor above 50% has been achieved only in cases where the original air exchange rate has been defective or when the house vacuum level has been high. Typical reduction factors have been 10 - 40%. Increasing the operation time or power of mechanical ventilation and opening existing or installing new fresh air vents are typical measures. Installation of new fresh-air vents does not result normally in reduction factors above 50%.

Sealing entry routes aims at reduction of leakage flows of radon-bearing soil air into living spaces. Sealing may be very requiring. In many cases the results are qualified only when the entry routes have been sealed almost completely. Best results have been achieved in houses where the foundation wall is of cast concrete. Floor joints with foundation walls of porous light-weight concrete cannot be sealed with normal methods.

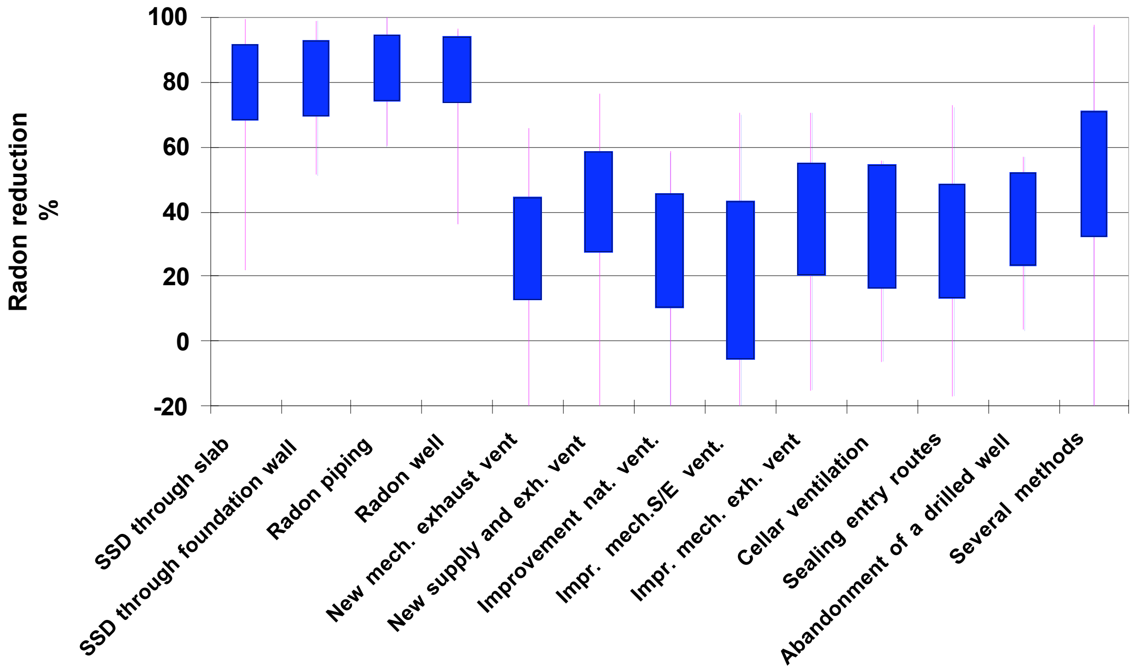

Figure 1. *Radon reduction factors achieved using various mitigation methods, minimum, 25th percentile, 75th percentile and maximum. The results are based on a questionnaire study of 400 houses. Well designed and implemented mitigations result in reduction factors which are better than the typical reduction factors in the figure.*

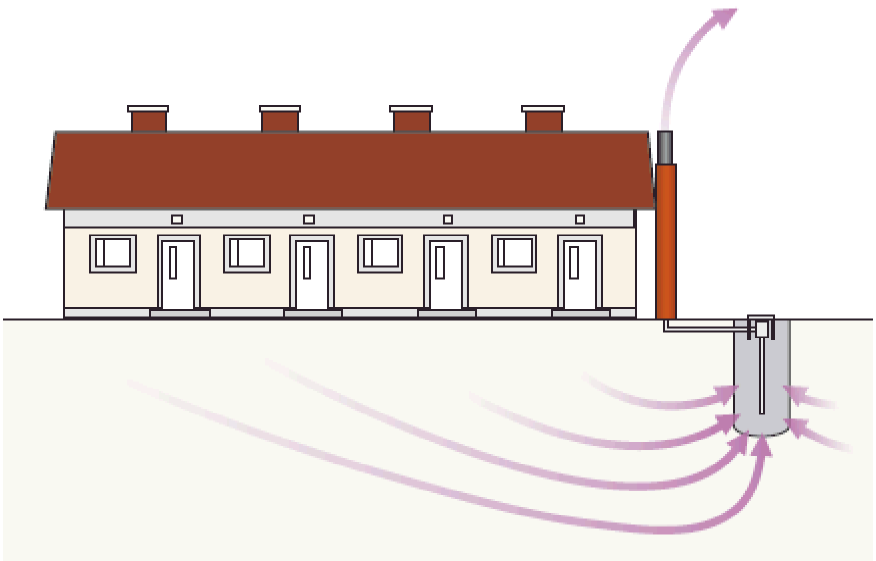

Figure 2. *Principle of a radon well. A radon well ventilates soil air and decreases radon concentration in soil air in a large area.*

3. Radon prevention

3.1 Brief history of radon-resistant construction in Finland

In the new (1990-) housing stock indoor radon concentrations are higher than in older houses. This is due to prevalent use of slab-on-ground foundation. In the 1950's cellar houses and crawl space were the prevalent foundation types. Today 200,000 single-family houses (18%) exceed the radon concentration limit for new buildings, 200 Bq/m^3. Radon-resistant new construction is a key issue when aiming at low indoor radon concentration at the national level.

The first guide for radon-resistant new construction was published in 1996. The key measures were sealing the gap between the floor slab and foundation wall with elastic sealant and installation of radon piping. However, the sealing practice was too tedious and did not become common. At the same time installation of radon piping has become more common. Sealing practices were studied in a wide joint venture. These studies resulted in a revised guidance published in 2003 (Building Information Ltd).

3.2 Radon prevention guidance

The guidance focuses mainly on radon-resistant construction of slab-on-ground foundation which is the big radon challenge in the Finnish foundation construction. The guide gives also basic facts for crawl-space construction: good ventilation and properly sealed floor construction. Use of light-weight concrete blocks makes radon mitigation more difficult. Sealing of the gap between the floor slab and foundation wall is not effective, because leakage flows find an alternative route through the porous foundation wall and wall structures. This emphasizes the need for prevention work.

The revised guidance gives three main prevention measures. First, the joint of the foundation wall and floor slab should be sealed using a strip of bitumen felt (Fig 3). Second, all penetrations should be sealed carefully. The third measure is installation of a preparatory radon piping beneath the slab. Figure 3 shows also the recommended sealing practice for cellar walls. Bitumen felt should be used also on the outer surface of the cellar wall in case the foundation wall is of porous light-weight concrete blocks. In case of the cellar wall being of cast concrete, this is needed only on the grounds of moisture prevention. The guidance aims at low indoor radon concentration through qualified sealing work.

3.3 Prevention practices

Installation of radon piping has become more common since the mid 1990's. Since 2003, when the new sealing practice was issued, use of bitumen felt has also become one of the regular practices required in the building permission process especially in southern Finland. Experience from the radon campaigns, which local authorities and the Radiation and Nuclear Safety Authority organise together, show that in many areas the radon piping is installed in more than half of the new buildings.

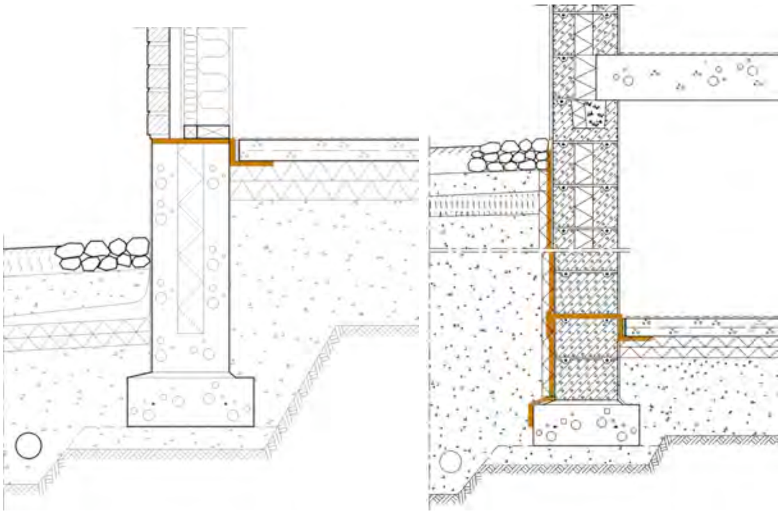

Figure 3 *Sealing of the joint of the foundation wall and floor slab using a strip of bitumen felt in a slab-on-ground foundation (left) and in a cellar foundation (right).*

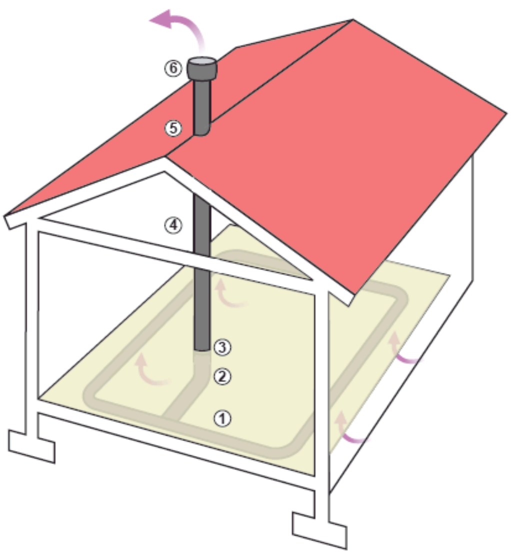

Figure 4 *Preparatory radon piping. An exhaust fan should be installed in case the sealing work is not effective.*

Figure 5 *Handling of bitumen felt and seaming of the strips in the corner.*

3.4 Tracer-gas studies

STUK has carried out tracer-gas studies in houses where preventive measures have been taken. Tracer gas containing 95% of nitrogen and 5% of hydrogen was used. The houses studied were provided with sub-slab piping, and the tracer was led under the slab using a fan which quickened the flow of diluted tracer into piping and sub-slab gravel. The method is very sensitive and finds also leakages of minor importance. The studies showed that the non-seamed bitumen felt strips in corners were leaking. The method does not clearly show the leakage rate and the importance of the finding. However, it shows that the corners should be sealed more carefully by heating the strips and using bitumen glue. The leakage studies also showed that omissions in sealing of the penetrations for electric cables and water pipes were very common.

3.5 Defects in radon piping efficiency

The efficiency of radon piping is normally high, typically 70 - 90%, as shown in Figure 1. Use of very coarse crushed masonry materials as filling beneath the floor slab and also beneath foundations has created a new problem. Standard radon piping is no longer capable of creating a good sub-slab vacuum. In a cold climate, the air flow created by the exhaust fan is restricted to the limit of potential substructure and sub-soil temperature problems. This observation emphasizes the need for careful sealing work.

3.6 Summary on prevention

The current experience shows the importance of all prevention measures: use of bitumen felt, sealing of penetrations and installation of preparatory radon piping. The key challenge today is the introduction of prevention practices in all building activities and carefulness in sealing work.

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Mitigation publications will be available on website: www.stuk.fi