Radon control in European countries – a RADPAR questionnaire study

<u>HOLMGREN O.</u> & ARVELA H.

Radiation and Nuclear Safety Authority – STUK, Laippatie 4, 00880 Helsinki, Finland

Abstract. Radon control methods aim at reduction of indoor radon concentrations in existing buildings and in new construction through remedial and preventive measures. This paper contains the analysis of the reduction efficiency of the current methods used in European countries. The study arises from the EU project "Radon prevention and remediation" (RADPAR). Radon control status varies to a great extent between various countries. The number of dwellings with elevated indoor radon concentration ranges typically from tens of thousands to a million. The percentage of these houses already remediated is between 0 and 15%. The number of houses where preventive measures in new construction have been applied varies from a few to over 200 000. The most efficient remediation and prevention method is the active sub-slab depressurization (SSD), where the reduction of radon concentration is typically 60–95%. Other methods, such as sealing entry routes and improving ventilation, are less effective: here the reduction of radon concentration is typically 10–60%. The efficiency of passive SSD is lower, usually 20–50%. Nevertheless, wide use of passive SSD and sealing entry routes can be recommended in new construction due to their positive impact on the radon exposure of the population through relatively simple means. However, particularly research data on the current situation of radon prevention, i.e., the number of houses with preventive measures and the efficiency of the prevention measures, is presently still quite inadequate. Assessment of the techniques and also the surveys aiming at exploring the impact of remedial and preventive measures is greatly needed in order to promote the work at national level in Europe.

KEYWORDS: (Radon, radon remediation, radon prevention)

INTRODUCTION

Radon is a common problem in indoor air. The main source of indoor radon in buildings is the subjacent soil gas. The building materials make only a minor contribution in most cases. The level of radon in a building is, however, to a large extent influenced by the properties of the building itself and its usage. Critical building characteristics are, for example, coupling to the ground and air exchange rate, and to a smaller extent also air tightness of building envelope, ventilation system and occupant living comfort preferences.

Radon control methods aim at reduction of indoor radon concentrations in existing buildings and in new construction through remedial and preventive measures. Present methods for radon reduction in existing buildings and radon prevention in new buildings have been developed over the last 30 years since the observation of high residential radon concentrations in the beginning of 1980s (Angell, 2011; Arvela, 2010; Rahman & Tracy, 2009). While most techniques using sumps and barriers should function in principle, the limited evidence presently available shows that there is considerable variability in their effectiveness. Missing guidelines or building codes, defective installation and poor adherence to the relevant building code guidelines are the major contributors to this problem in some EU Member States.

This paper arises from the project "Radon prevention and remediation (RADPAR)" (RADPAR, 2011). The general objective of this three-year project is to assist in reducing the significant public health burden of radon-related lung cancers in EU Member States. More specific objectives include:
1) improvement of radon prevention and remediation strategies that are currently applied,
2) development of radon risk communication strategies and approaches for different population target

groups, 3) assessment of the cost-effectiveness of existing and potential radon prevention and remediation strategies, 4) improvement of the effectiveness of radon control strategies through the design and use of training courses for radon measurement, prevention, remediation and cost-effectiveness analysis, 5) assessment of the potential conflicts between energy conservation in buildings and reduction in radon exposure.

The work is divided in various work packages: improving policies and strategies to promote effective radon prevention and remediation, improving radon risk communications strategies in the EU, assessment and standardization of radon control technologies, and analysis of cost-effectiveness and health benefits of radon control strategies.

In order to evaluate the above discussed problems concerning the radon control, to reduce potential conflicts between energy saving construction and radon reduction, and to inform building professionals, the following objectives will be carried out in RADPAR Work Package 6: i) Assessment of potential conflicts between energy conservation in buildings and radon exposure reduction, ii) Establishment of measurement protocols for radon control technologies, and iii) Design of training courses for radon measurement, prevention, remediation and cost-effectiveness analysis.

This paper presents preliminary results of the assessment of current techniques used for reduction of indoor radon concentration in existing and new houses with regard to radon reduction efficiency (Holmgren & Arvela, 2010). Only the most common remediation and prevention methods are discussed in this paper. Several other methods and combinations of methods were also reported but are not included here.

RADON REMEDIATION AND PREVENTION TECHNIQUES

The methods of indoor radon remediation are normally based on the following principles: depressurization of the soil under a floor construction and decreasing of soil air radon concentration, sealing of entry routes, improvement of air exchange rate and/or decreasing under-pressure level in living spaces and combinations of these methods.

The sub-slab depressurization (SSD) system is one of the most efficient and common remediation methods to reduce radon concentration in indoor air. A basic SSD system consists of a sump, an exhaust pipe and a fan, see Fig. 1. The sump is excavated under the floor slab and is filled with coarse gravel. The fan is used to draw radon-laden air from the sub-slab ground through the exhaust duct. This affects the indoor radon level in two ways: i) it dilutes the radon concentration of the soil air under the slab and ii) it creates a negative pressure difference under the slab compared to the dwelling, which reduces the air flow from the sub-slab soil into the house. Numerous variations of the SSD exist, depending on the foundation type and practical possibilities for installing the radon sump and exhaust pipework.

Improving ventilation in living spaces may include various measures. Sometimes just opening the fresh air vents is adequate to lower the indoor radon levels. This increases the ventilation and also decreases the under-pressure of the dwelling. Improving ventilation may also be carried out by adding fresh air vents, opening more or adding exhaust vents and increasing mechanical ventilation. One should be careful, however, when increasing mechanical ventilation. Despite the increased air exchange, the radon concentration may even rise if the under-pressure of the house is increased enhancing thus entry of radon-laden air from the sub-slab soil. Improving ventilation in cellar or in crawl space is also a commonly used remediation method.

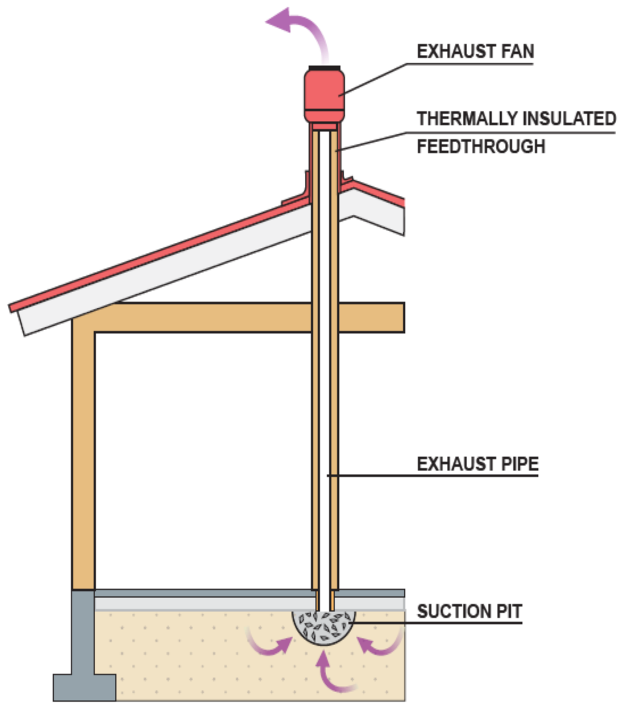

Figure 1. Sub-slab depressurization system to reduce indoor radon concentration.

Typical entry routes of radon include cracks, gaps, holes and pipe penetrations in the floor slab and in the walls in contact with soil. The possible gap in the joint of floor slab and foundation wall due to drying shrinkage of the concrete slab is the most significant entry route. Porous foundation and basement walls made of light-weight concrete blocks offer also a significant entry route. Sealing entry routes aims at reduction of leakage flows of radon-bearing soil air into living spaces. Sealing may be very demanding since, in many cases, the results are satisfactory only when the entry routes have been sealed almost completely. Floor joints with foundation and basement walls made of porous light-weight concrete blocks are difficult to seal with normal methods.

In new construction, passive and active SSD systems are common prevention methods used in most of the studied countries. In a preparatory SSD system, a radon sump or a radon piping (i.e., a network of flexible perforated pipes) is installed in a layer of coarse gravel beneath the floor slab during the construction of the house. The exhaust duct of the system can be sealed inside the house or it can be led through the house onto the roof to open air. In the later case, the system is called a passive SSD since the stack and wind effects induce flow in the exhaust duct resulting in sub-floor ventilation and depressurization. If the indoor radon level still exceeds the reference level, the system can be activated by installing a fan to the exhaust duct (called here an active SSD).

Membranes above or below the floor slab are commonly used as a radon prevention method in European countries according to the RADPAR questionnaire responses. In Finland, membranes do not cover the whole base floor area, but instead, a strip of reinforced bitumen felt in the floor-wall joint is used. In many cases, a damp proof membrane provides an adequate radon-proof barrier along with its general function of excluding moisture. In all cases, air tightness of joints and pipe penetrations are important as well as airtight connections to walls.

RADPAR QUESTIONNAIRES

In the RADPAR project, information on different subjects was collected using several questionnaires. In this paper, information from a questionnaire dealing with radon remediation and prevention methods was utilized. The questionnaire was sent to all RADPAR partners in 14 different countries (Austria, Belgium, the Czech Republic, Finland, France, Germany, Greece, Ireland, Italy, Norway, Portugal, Spain, Switzerland, and the UK). Responses with varying amount of information were obtained.

The questionnaire was divided into two parts: remediation of existing dwellings and prevention in new building. Both parts contained the following set of questions:

- National situation: action (target) levels for radon remediation (prevention), number of dwellings exceeding the action level (remediation part only), number of houses with remediation (or prevention) measures.
- Methods used for remediation (or prevention), radon reduction factors of each method and any qualitative information on potential impact on energy consumption.
- References: guides, brochures, research reports, website links and other relevant documentation.

There was also a third part for additional information.

The radon reduction factor *R* in [%] (or reduction efficiency) is defined by

$$R = \frac{C_{before} - C_{after}}{C_{before}} \cdot 100 \text{ [\%]}, \qquad (1)$$

where C_{before} and C_{after} are indoor radon concentrations [Bq/m^3] before and after the remediation (or without and with prevention method), respectively.

RESULTS

The status of radon control in each country is presented in Table 1. The number of dwellings exceeding the national action level of 400 Bq/m^3 varies between 0.4% and 2.6% of the total number of dwellings. In the countries where lower action levels than 400 Bq/m^3 applies, greater percentages are also found, except in the UK. The greatest number of dwellings remediated was reported by the UK, where 15 000 dwellings have already been remediated. In the UK and Ireland, guidelines for radon prevention in new construction have existed for a long time, since 1991 and 1998, respectively. In Ireland, roughly 700 000 dwellings have been built since 1998 when the law with a building code including new guidelines for radon prevention was enacted. However, no accurate data of the actual prevention activity exists.

Table 1. National situation of radon control: action and target levels for remediation in existing and for prevention in new building, total number of dwellings N_t both in low-rise residential and apartment buildings, number of dwellings exceeding the action level N_e, number of dwellings already remediated N_r and number of houses with preventive measures.

Country	Action (Reference) / Target level	Number of all dwellings			
		Total number, N_t	Exceeding, N_e (N_e/N_t)	Remediated, N_r (N_r/N_e)	Preventive measures
Austria	400 / 200	3 700 000	89000 (2.4 %)	25 (0 %)	15 (0 %)
Belgium	400 / 200	5 040 000	20000 (0.4 %)	1000 (5 %)	
Czech Republic	400 / 200	3 900 000	76000 (1.9 %)	4000 (5.3 %)	210000 (5.4 %)
Finland	400 / 200	2 450 000	59000 (2.4 %)	4500 (7.6 %)	60000 (2.4 %)
Greece	400 / 200	5 630 000			
Portugal	400 / 400		2,6 %		few
Switzerland, 400	400	4 000 000	75000 (1.9 %)	500 (0.7 %)	
Switzerland, 1000	1000 / 400	4 000 000	7500 (0.2 %)	500 (6.7 %)	5000 (0.1 %)
France	300 / -	32 760 000	969000 (3 %)		
Ireland	200 / 200	1 930 000	91000 (4.7 %)		699000 (36.2 %)
Italy	200 / -	22 000 000	902000 (4.1 %)	450 (0 %)	
UK	200 / 200	23 000 000	100000 (0.4 %)	15000 (15 %)	
Norway, 200	200	2 270 000	163000 (7.2 %)		
Norway, 100	100 / 100	2 270 000	427000 (18.8 %)		
Germany	100 / 100	39 900 000	1930000 (4.8 %)	1000 (0.1 %)	1000 (0 %)

Switzerland: 1000 limit value, 400 guideline value for existing buildings after mitigation and for new construction.

Italy: no officieal value, recommendation 200.

Norway: action limit 100 and maximum limit 200.

Germany: voluntary action and target level of 100.

Table 2 summarizes the reduction factors of the most common radon remediation methods. Sub-slab depressurization is the most efficient remediation method with a typical reduction factor of 60–95%. Improving ventilation in living spaces reduces radon concentration on average by 10–60% and decreasing under-pressure by 20–70%. Different remediation methods based on improving ventilation in living spaces are most effective when the room air ventilation has initially been inadequate. House pressurization is not a commonly used remediation method. Depending on the air tightness of the house envelope, house pressurization requires considerable air flows blown into the house to be effective. In some countries (e.g., in Finland and Norway), the pressurization of the house is not even permitted in the building code due to risk of condensation of moisture into the house envelope. Improving ventilation in cellar or in crawl space reduces radon concentration on average less than 60%. Sealing entry routes is not a very efficient remediation method either: it reduces radon concentration on average only by 10–60%.

Table 2. Radon remediation methods and their radon reduction factors reported by different countries. The national values have been summarized into a single typical range numerated in the Summary column.

	Reduction factor (%), Typ. range									
Method	**Summary**	AT	BE	CZ	FI	FR	IT	NO	CH	UK
Sub-slab depressurization	**60-95**	80	90	85-95	65-95	89	60-95	50-95	90	89
Improving natural ventilation in living spaces	**10-50**			< 30	15-55	49		10-50		33
Improving mechanical ventilation in living spaces	**10-60**				5-55	61	20-95	10-20		
Replacing the existing natural room air ventilation by a mech. exhaust ventilation	**10-40**				15-45			10-20		
Installation of a new mech. supply and exhaust ventilation with heat recovery system	**30-60**	60		30-60	30-65			10-80		
House pressurization (higher pressure indoors than under	**50-80**	80					60-95			
Improving ventilation in cellar	**20-60**	50		25-50	20-55	47	60-90	10-50	75	
Decreasing under-pressure in the house	**20-70**	50						10-50	25	60
Sealing entry routes	**10-60**	10		10-40	10-55	55		10-60	25	41
Improving crawl space ventilation	**40-60**	50			40-65	47	60-90	10-80	75	47

Table 3 summarizes the reduction factors of the most common radon prevention methods. The sub-slab depressurization (SSD) is a common radon prevention method in many countries. The passive SSD reduces radon concentration on average by 20–50% compared to the situation where the sump or piping is capped or there is no provision for the SSD. The active (a fan assisted) system is the most efficient prevention method with a typical reduction factor of 70–95%. Radon-proof insulation with a membrane reduces radon concentration on average by 50%. Concerning the effect of sealing-based methods, research data are lacking and hence a wide range for the typical reduction factor has been adopted in Table 3.

Table 3. Radon prevention methods and their radon reduction factors reported by different countries. The national values have been summarized into a single typical range numerated in the Summary column.

	Reduction factor (%), Typ. range						
Method	**Summary**	CZ	FI	NO	PT	CH	UK
Passive sub-slab depressurization	**20-50**		30-40	0-20	20-50	50	
Active sub-slab depressurization	**70-95**		70-90	70-95	40-70	95	
Radon proof insulation, membrane below floor slab	**30-70**					50	
Radon proof insulation, membrane above floor slab	**30-70**	30-70		0-90	30-60	50	50
Sealing the joint of floor slab and foundation wall using membranes	**30**			0-90		30	
Sealing the lead-throughs in structures with soil contact	**50**			0-90		50	

CONLCUSION

The key results on the assessment of current radon reduction techniques used in European countries have been presented in this paper. Radon control status varies to a great extent between various countries. The number of dwellings with elevated indoor radon concentration ranges typically from tens of thousands to a million. The percentage of these houses already remediated is between 0 and 15%. The number of houses where preventive measures in new construction have been applied varies from a few to over 200 000.

The most efficient remediation method is the active sub-slab depressurization (SSD) and radon well, for which the reduction of radon concentration is typically 60–95%. Other methods, such as sealing entry routes and improving ventilation, are less effective: the radon reduction factor is typically 10–60%. The efficiencies of prevention methods are analogous to those of remediation. The active SSD is the most efficient prevention technique. The efficiency of the passive SSD is lower, usually 20–50%. However, wide use of passive SSD and sealing entry routes can be recommended in new construction due to their positive impact on the radon exposure of the population through relatively simple means. Radon-proof insulation of the base floor with a membrane and sealing pipe penetrations reduces radon concentration on an average by 50%.

Wide variability of radon reduction factors were reported by many of the countries in the study. However, typical reduction factors between different countries are in good agreement. Since the results are based on the questionnaire responses by a limited number of people, data may be partly inaccurate or defective. In addition, the radon reduction factors may vary depending on the region and country due to differences in geology, climate and specially in the methods of building.

In particular, research data on the present situation of radon prevention, i.e., the number of houses with preventive measures and the efficiency of the prevention measures, is currently still quite inadequate. Assessment of the techniques and also the surveys aiming to explore the impact of remedial and preventive measures is greatly needed in order to promote the work at national level in Europe.

ACKNOWLEDGEMENTS

This paper arises from the project "Radon prevention and remediation" (RADPAR) which has received funding from the European Union, in the framework of the Health Programme. RADPAR colleagues are acknowledged for answering the questionnaire.

REFERENCES

Angell, W. J. (2011). Indoor radon prevention and mitigation. In Jerome O. Nriagu (Ed.), *Encyclopedia of environmental health* (pp. 208-217). Burlington: Elsevier. doi:DOI: 10.1016/B978-0-444-52272-6.00096-9

Arvela, H. (2010). Indoor radon sources, remediation and prevention in new construction. Paper presented at the *Proceedings of IRPA 2010,* Helsinki, Finland. 2991-3013. Retrieved from http://www.irpa2010europe.com/proceedings.htm

Holmgren, O., & Arvela, H. (2010). *Assessment of current techniques used for reduction of indoor radon concentration in existing and new houses.* (Interim report. European Commission. Radon Prevention and Remediation - RADPAR) Helsinki, Finland: Radiation and Nuclear Safety Authority.

RADPAR. (2011). *Radon prevention and remediation.* Retrieved August 11, 2011, from http://web.jrc.ec.europa.eu/radpar/

Rahman, N. M., & Tracy, B. L. (2009). Radon control systems in existing and new construction: A review. *Radiation Protection Dosimetry, 135*(4), 243-255. doi:10.1093/rpd/ncp112