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MITIGATION OF INEFFECTIVE MEASURES AGAINST RADON

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Reasons of low effectiveness of radon remedial measures have been studied on several unsuccessfully remediated houses. Based on the thorough analysis, factors responsible for failures are clarified. The possibilities of how to improve the effectiveness of installed measures are also discussed. Experience in this field is documented by several examples of additionally mitigated houses. After application of additional measures, indoor radon concentration in the studied houses decreased in average 5.3 times. Costs for additional mitigation were at least four times cheaper compared with costs required for installation of original measures.

INTRODUCTION

The first remedial measures against radon were implemented into the Czech houses 25 y ago. Up to now, several thousands of existing houses have been remediated. Long-term measurements of radon concentration inside remediated houses that had been carried out several years after installation of remedial measures revealed that in a notable number of houses the remediation was not successful. Greater amount of ineffective measures and failures has been found among houses remediated before 1995[(1)].

Reasons of low effectiveness and sources of failures have been studied on several unsuccessfully remediated houses located in the old mining towns Jáchymov and Krásno. In each house, a detailed inspection was performed in order to find out the way and quality of remedial measures realisation and whether the design requirements were met. Original design documentation was subjected to a thorough investigation so that the responsibility of designers can be identified[(2)]. Attention was also given to the quality of radon diagnostic and inspection measurements.

DESCRIPTION OF HOUSES

House no. 1 (Jáchymov, Mathesiova street): an old attached house built in 1889. Indoor radon concentration prior to mitigation varied around 1000 Bq m^{-3}. In 1994, new floors with a subslab ventilation system were installed. The soil ventilation was formed by the network of perforated pipes placed into the 300-mm thick drainage layer of coarse gravel. The pipes were ventilated by eight vent holes in the front wall and two vertical exhaust pipes located at the back of the house. Above the gravel layer, the blinding concrete and the radon-proof insulation made of two layers of bitumen membranes with aluminum foil were applied.

Indoor radon concentration measured 4 y after mitigation by track detectors exposed for 1 y ranged from 1760 Bq m^{-3} to 3360 Bq m^{-3}.

House no. 2 (Jáchymov, B. Němcové street): an old attached house built in the beginning of the 20th century. Indoor radon concentration prior to mitigation varied around 2280 Bq m^{-3}. The house was originally mitigated in 1994 by new concrete floors sealed with two layers of bitumen membranes. Furthermore, the soil under the house was ventilated by means of perforated pipes inserted into the gravel layer placed under the slab. The pipes were ventilated by five vent holes in the perimeter walls and two vertical exhaust pipes located at the back of the house.

Indoor radon concentration measured 4 y after mitigation by track detectors exposed for 1 y ranged from 630 to 2080 Bq m^{-3}.

House no. 3 (Jáchymov, Jiráskova street): an old attached house built in the beginning of the 20th century. Indoor radon concentration prior to mitigation varied around 1100 Bq m^{-3}. The house was originally mitigated in 1995 by the floor air gap made of hollow bricks placed over the gravel layer under the whole house area except of the bathroom. The air gap was covered by the concrete slab sealed with a bitumen membrane. Ventilation of the air gap was ensured by means of six vent holes in front and back walls and one vertical exhaust pipe terminating above the roof.

Indoor radon concentration measured 2 y after mitigation by track detectors exposed for 1 y ranged from 960 to 1930 Bq m^{-3}.

House no. 4 (Krásno, Lesní street): an old single-family house with a small cellar built in 1938. Ground floor radon concentration prior to mitigation varied from 630 to 800 Bq m^{-3}. The original mitigation installed in 1995 was composed of the

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replacement of existing floors on the ground floor by new ones with an air gap formed by the plastic membrane with dimples. The air gap was passively ventilated by means of 18 vent holes with the diameter 20 mm located in the perimeter walls. The whole structure of new floors was composed of the following layers: blinding concrete, air gap under the HDPE membrane, concrete screed, thermal insulation, subfloor and floor covering.

Ground floor radon concentration measured 2 y after mitigation by track detectors exposed for 1 year ranged from 650 to 1310 Bq m^{-3}.

House no. 5 (Krásno, Cínová street): an old single-family house built in the beginning of the 20th century. Indoor radon concentration prior to mitigation varied around 600 Bq m^{-3}. The original mitigation installed between 1999 and 2000 was composed of the replacement of existing floors on the ground floor by new ones with an air gap formed by the plastic membrane with dimples. The air gap was passively ventilated by means of vent holes with the diameter 20 mm located in the perimeter walls. The structure of new floors is nearly the same as in house no. 4 with the only exception—thermal insulation is placed directly above the HDPE membrane.

Ground floor radon concentration measured 1 y after mitigation by track detectors exposed for 1 y ranged from 1150 to 2250 Bq m^{-3}.

RESULTS

Detailed diagnostic measurements were performed in the houses studied during the years 2006 and 2007 in order to find out the sources of failures. Additional measures were designed in such a way so that the discovered reasons of low effectiveness of original measures would be eliminated. Effectiveness of the additionally applied measures was tested using continual radon monitors and integral electret detectors. A 2-week measurement period was chosen. During the first week, the active ventilation of the subsoil or floor air gaps was switched on, and during the second week, it was switched off.

House no. 1: Detailed investigation revealed that the failure of the original measure could be attributed to the poor efficiency of the passive soil ventilation and radon exhalation from building materials.

In 2006, the passive subslab ventilation was changed into an active one with the help of a fan installed at the top of one of the vertical exhausts. Vent holes in the perimeter walls were blocked in order to ensure higher underpressure in the subfloor layer. During active ventilation, indoor radon concentration decreased to the mean value 526 Bq m^{-3}. This result is still influenced by the radon exhalation from building materials, which was not affected by the applied measure.

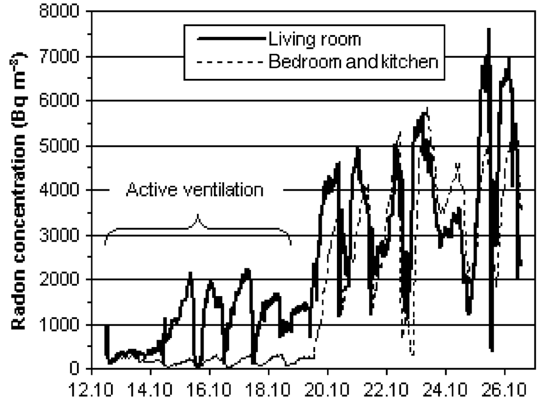

Figure 1. Effect of active soil ventilation on radon concentration in two rooms. Radon still penetrates into the living room from the adjacent house through the dry sidewall.

House no. 2: Insufficient soil ventilation and radon penetration from the adjacent house were identified to be responsible for the poor efficiency of the original measure.

In 2006, the passive subslab ventilation was changed into an active one by means of a fan installed at the top of the vertical exhaust pipe. At the same time, vent holes in the perimeter walls were blocked. During active ventilation, indoor radon concentration decreased to the mean value 297 Bq m^{-3}. The only exception is the living room into which radon penetrates from the adjacent house through the highly permeable sidewall (Figure 1).

House no. 3: Low effectiveness of the original measure was caused by the radon penetration from the bathroom and poor ventilation of the air gap.

In 2006, the passive ventilation of the floor air gap was converted into an active one by means of a fan installed at the top of the vertical exhaust pipe. All vent holes in the perimeter walls were blocked in order to achieve greater underpressure within the gap. Furthermore, the door to the bathroom was sealed. During active ventilation, indoor radon concentration decreased to the mean value 152 Bq m^{-3}.

House no. 4: Results of the diagnostic measurements led to the conclusion that the inefficient passive ventilation of the floor air gap is responsible for the failure of the original measure.

Since the original measure did not comprise the vertical exhaust pipe, the improvement of the air gap ventilation by adding a fan would be complicated. Therefore, the additional measure was based on the installation of the active subslab depressurisation system. The soil air is extracted by means of four perforated pipes drilled beneath the existing floors from the chase excavated along one side of the house (Figure 2). Perforated pipes are connected to a fan by

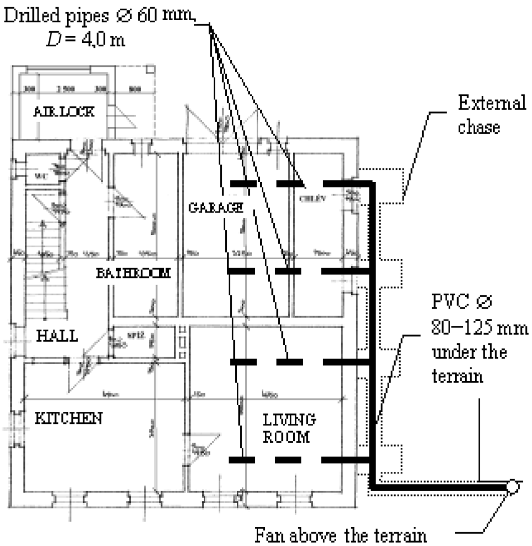

Figure 2. Subslab depressurisation system based on four perforated pipes drilled under the existing floors from the external chase excavated along one side of the house.

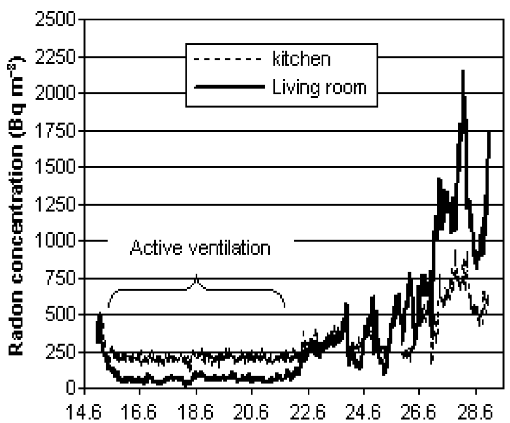

Figure 3. Effect of subslab depressurisation on radon concentration in two rooms.

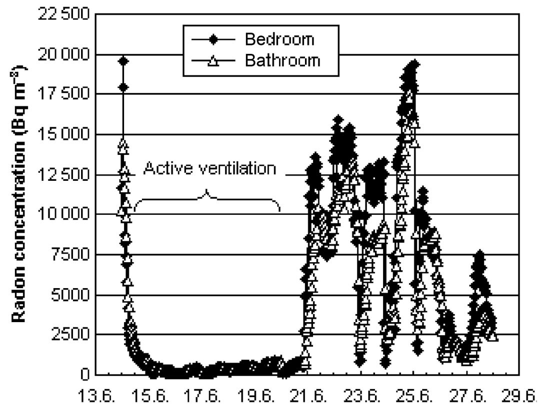

Figure 4. Effect of converting the passive air gap ventilation into an active one.

Table 1. Summary of additionally applied measures at Jáchymov and Krásno.

House no.	C before (Bq m^{-3})	C after (Bq m^{-3})	Addit. measure	Effect. (%)	Addit. costs (EUR)
1	1791	526	SSV-act.	71	1080,-
2	1321	297	SSV-act.	78	1600,-
3	1420	152	AGV-act.	89	1550,-
4	983	86	SSD	91	3000,-
5	1577	281	AGV-act.	82	2350,-

C before, mean value of indoor radon concentration measured by track detectors in all habitable rooms before installation of additional measures; C after, mean value of indoor radon concentration measured by electret detectors or continuous monitors in all habitable rooms after installation of additional measures; SSV-act., activation of passive soil ventilation; AGV-act., activation of passive air gap ventilation; SSD, installation of active subslab depressurisation system; Effect., effectiveness; Addit. Costs, costs for installation of additional measures.

a PVC pipe running in the chase. The fan is installed above the terrain at a distance of 3 m from the house. All vent holes in the perimeter walls were blocked in order to ensure greater underpressure in the subsoil. During active ventilation, indoor radon concentration decreased well below 200 Bq m^{-3} (Figure 3).

House no. 5: Low efficiency of the original measure was attributed to the poor ventilation of the floor air gap and loose joints between sheets of the HDPE membrane that serves as the radon-proof insulation.

In 2007, the passive ventilation of the floor air gap was converted into an active one by means of connection of all vent holes on one side of the house to the fan. Vent holes on the opposite side of the house were blocked. During active ventilation, indoor radon concentration decreased well below 400 Bq m^{-3} (Figure 4).

The effectiveness of all additionally applied measures together with the total costs for the installation of these measures is presented in Table 1.

The effectiveness of additionally applied measures varies from 71 to 91% with the mean value 82%, which means that indoor radon concentration decreased in average 5.3 times. This result is significantly better compared with the effectiveness

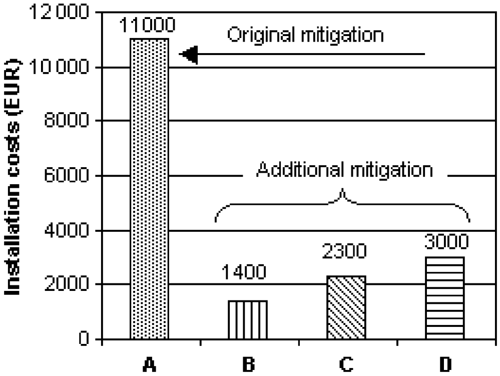

Figure 5. Comparison of installation costs. (a) Costs for the original measure, (b) a fan mounted on the existing vertical exhaust pipe, (c) vertical exhaust pipe is not a part of the original measure, (d) costs for the completely new remediation; existing measure cannot be used at all.

achieved by the original measures. After installation of the original measures, the reduction of indoor radon concentration could only be observed in house no. 2, whereas in the remaining four houses radon concentration became higher. This is the result of highly permeable drainage layers placed under the new floors, because such layers create suitable conditions for significant convective radon transport through wall-floor joints and other leaky places in the radon-proof membrane.

Comparison of installation costs for original and additional measures is presented in Figure 5. It can be seen that installation of additional measures was at least four times cheaper than installation of original measures. Costs for additional measures differ according to the fact whether the original measure could be used for the additional mitigation or not. Enormous costs for original measures can be attributed to the reconstruction of the floor structures in direct contact with the soil, because 12 y ago it was believed that a radon-proof membrane could create a sufficient protection against radon even in the existing houses. New floors usually comprised gravel layer, blinding concrete, radon-proof membrane, thermal insulation, hardboard and a floor covering. Two years ago, when the additional measures were applied, the preference was given to the measures based on active soil or floor air gap ventilation, because it was certain that a radon-proof membrane could not provide an effective protection.

CONCLUSIONS

Sources of failures

Based on the thorough analysis, facts responsible for failures were clarified. In general, failures were attributed to the lack of knowledge and experience, incomplete diagnostic measurements, incorrect design, unqualified realisation and wrong inspection measurements, which were not able to reveal the low effectiveness of installed measures. The analysis showed that different remedial measures are prone to failure from different reasons. Radon-proof insulation usually fails, if it is not applied continuously, if joints and pipe penetrations are not carefully sealed, if insulating materials have poor quality and if radon-barrier properties are not tested. Soil ventilation systems are sensitive to unsuitable design of inlets and outlets and faulty choice of an appropriate form of ventilation. Air gaps tend to fail when they are poorly ventilated and their connection to walls is not carefully sealed. Lot of failures can be attributed to the passive form of the subsoil or air gaps ventilation, which was formerly preferred instead of the forced ventilation.

Additional measures

The effectiveness of nearly all types of measures can be improved. Passive subslab and air gap ventilation can be usually very easily converted into more effective forced ventilation. Labour consumption and obstructions within the living space connected with this improvement are omissible, if vertical exhaust pipe terminating above the roof is a part of the passive ventilation.

Improving the airtightness of the original radon-proof membrane by sealing of leaky places seems to be inefficient, since it is highly improbable that all imperfections will be found during the house inspection. Measures based on radon-proof membranes should be therefore mitigated by other methods, mainly subslab depressurisation.

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