CONSEQUENCES OF INCORRECT DESIGN AND UNQUALIFIED REALIZATION ON RELIABILITY AND EFFECTIVENESS OF RADON REDUCTION MEASURES

Martin Jiránek, Czech Technical University, Faculty of Civil Engineering, Praha
e-mail: jiranek@fsv.cvut.cz

Abstract

Factors responsible for failures of radon remedial and preventive measures were studied on several unsuccessfully protected houses. Presented paper tries to summarize sources of failures. Possibilities how to improve the effectiveness of failed measures are also discussed.

1. INTRODUCTION

Realization of remedial and preventive measures against radon started in the Czech Republic 25 years ago. Up to now several thousands of existing houses have been remediated and even more new houses have been provided with preventive measures. Long-term measurements of indoor radon concentration that had been carried out several years after installation of protective measures revealed that in a notable number of houses the protection was not successful. Greater amount of failures has been found among houses, in which the protective measures were applied before 1995, when the first version of the Czech technical standard ČSN 73 0601 “Protection of houses against radon from the soil” was issued. Better results obtained during the last ten years can be also attributed to new information that grew out from several research projects focussed on the improving of the efficiency of various mitigation measures.

Presented paper tries to shed some light on the sources of failures. In general, failures can be attributed to lack of knowledge and experience (especially in the initiation stage of the remediation), incomplete diagnostic measurements, incorrect design or unqualified realization. The importance of each source had been studied on several unsuccessfully protected houses. In each house a detailed inspection was performed in order to find out the way and quality of protective measures realization and whether the design requirements were met. Based on the thorough analysis facts responsible for failures were clarified. In some cases a numerical modelling was used for the simulation of the influence of the remedial and preventive measures on the radon transport from the soil into the house. Possibilities how to improve the effectiveness of installed measures are discussed and the final reduction of indoor radon concentration is presented.

2. CASE STUDY

Case No. 1 - a new single-family house built in 2004 on the building site, where radon concentration in the soil gas was 134 kBq/m^3. The house was founded on the strip foundations among which the gravel layer was placed. Over the foundations 100 mm thick reinforced blinding concrete was poured. The protection against radon was based on two layers of bitumen membranes (one with the aluminium foil and the second with the glass fibre reinforcing fabric) applied over the entire surface of the blinding concrete.

Indoor radon measurements carried out in the completed house showed concentrations from 782 Bq/m^3 to 1064 Bq/m^3. Detailed investigation revealed that radon penetrates through the leakages in the radon-proof insulation, especially around pipe penetrations, since majority of them was installed additionally after the insulation had been laid. Furthermore, applied insulation was not protected against perforation during following construction works. Besides poor workmanship also the design of the protection was not qualified. In spite of the fact that the Czech technical standard ČSN 73 0601 [4] requires ventilation of highly permeable sub-floor layers, in this case the ventilation of the sub-slab gravel layer was not designed.

Improving of the airtightness of the radon-proof insulation by sealing of leaky places would not be efficient, since it is highly improbable that we had succeeded in finding of all imperfections. Therefore the remediation was based on the active soil depressurization. The air from the subsoil is extracted by means of two radon sumps located under the swimming pool and the bathroom, where a lot of penetrations exist, and 4 perforated tubes drilled into the sub-floor gravel layer from the chase excavated along the walls adjacent to the terrace. Sumps and pipes are connected by a PVC pipe running in the soil to an exhaust fan located outside the house above the terrain (Fig. 1).

After the soil depressurization system had been installed, indoor radon concentration decreased well below the action level 100 Bq/m^3 (Fig. 2).

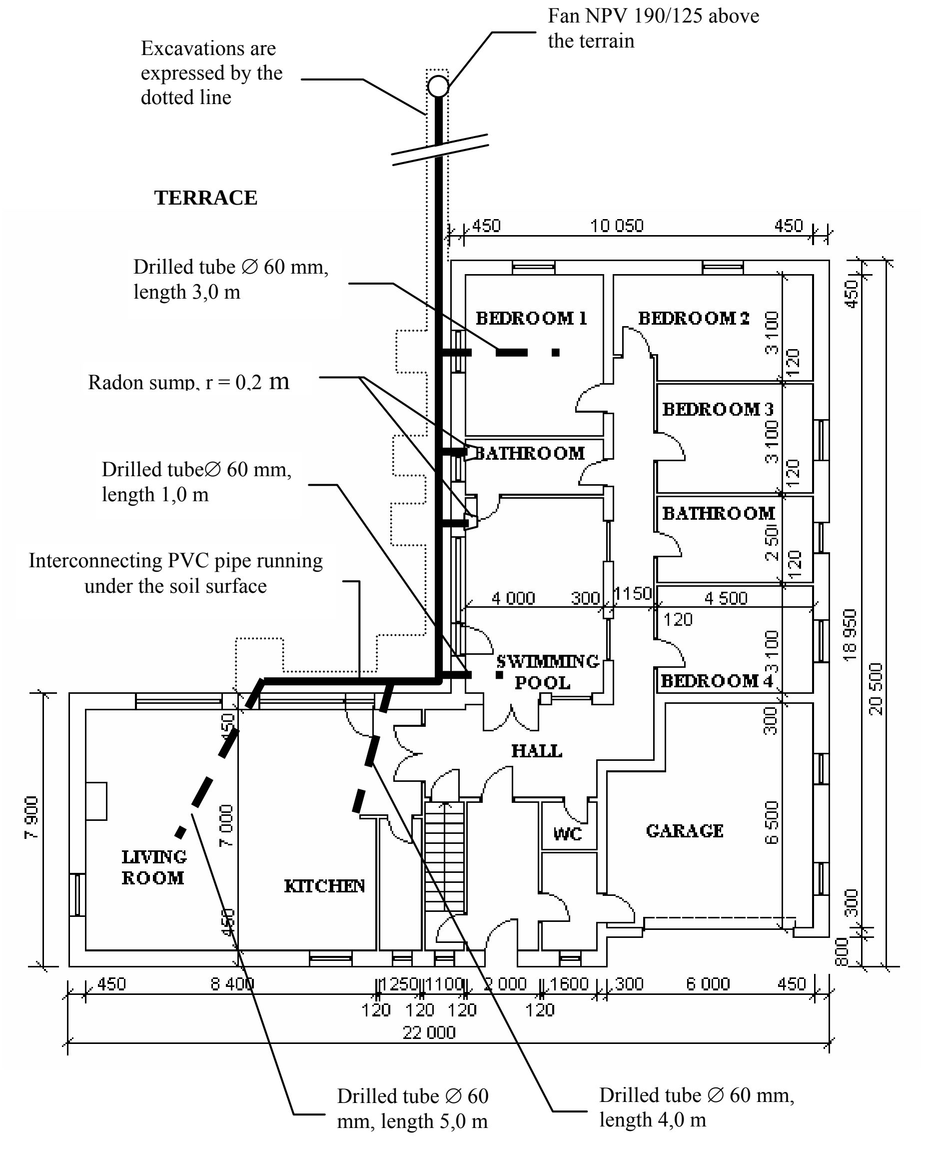


Fig. 1. Ground floor plan of the house with the soil depressurization

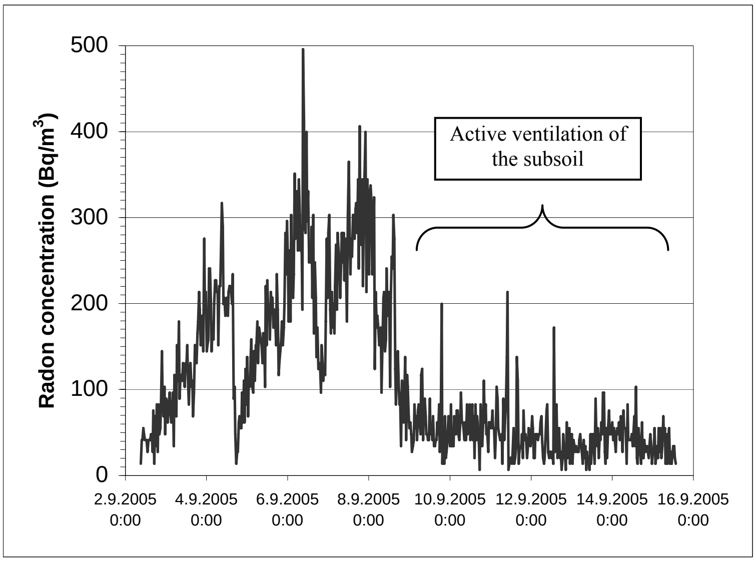


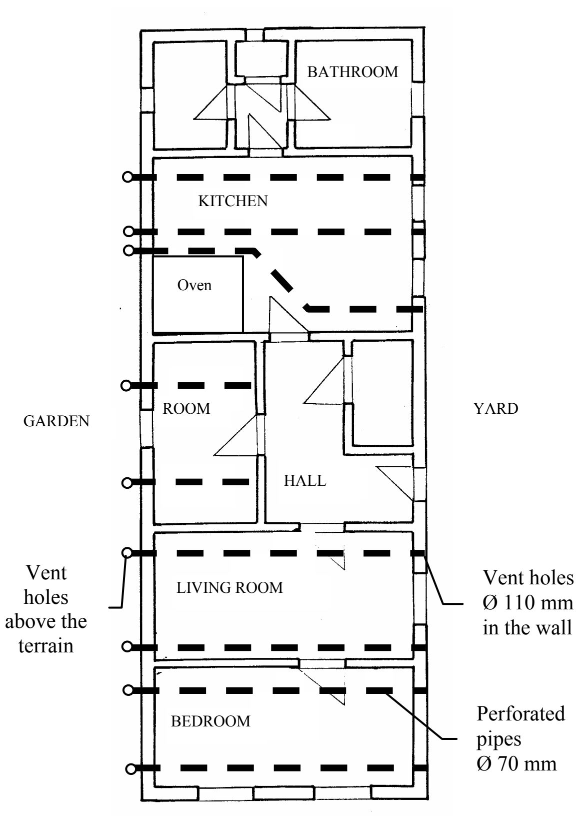
Fig. 2. Radon concentration in the swimming pool during active ventilation of the subsoil [3]

Case No. 2 - an old single-family house built approximately 80 years ago. Indoor radon concentration prior to mitigation varied from 1670 Bq/m^3 to 3242 Bq/m^3. The mitigation was composed of the reconstruction of floors and installation of passive soil ventilation. Existing floors were replaced by new ones made of the following structure: 250 mm thick layer of gravel with perforated pipes, 100 mm reinforced concrete, radon-proof insulation made of 1,5 mm thick HDPE membrane (not applied under walls), polystyrene 50 mm, concrete 50 mm and floor covering. Perforated pipes inserted into the drainage layer run crosswise the house from one longitudinal wall to the other (Fig. 3).

Indoor radon measurements performed after the mitigation measures had been completed showed that the reduction was not sufficient, because radon concentrations reached up to 2098 Bq/m^3. Detailed diagnostic measurements revealed that radon is transported mainly through wall/floor joints, where concentrations around 3 kBq/m^3 were measured [1]. No air movement inside the perforated pipes was observed. Radon index of the building site was determined as high (the third quartile of the soil gas radon concentration measurements is 160 kBq/m^3, soil permeability is medium).

The main reason of the failure is the presence of the wall/floor gaps together with the inefficient soil ventilation system. Under certain circumstances (vent holes on windward side, outlets on lee side blocked by snow cover, etc.) the system can induce overpressure in the drainage layer (mainly on the windward side), which can enhance radon transport into the house. Drainage layer due to its high permeability also increases the radon transport compared to the original soil.

The efficiency of the original mitigation was increased by converting the passive soil ventilation into an active one. Existing perforated pipes were on the garden side of the house connected to the fan located outside the house above the terrain. The connection was realized by means of the horizontal PVC pipe running under the soil surface (Fig.4). All vent holes on the yard-facing wall were blocked in order to minimize the amount of the external air passing through the subsoil. During active ventilation indoor radon concentration decreased well below 200 Bq/m^3.



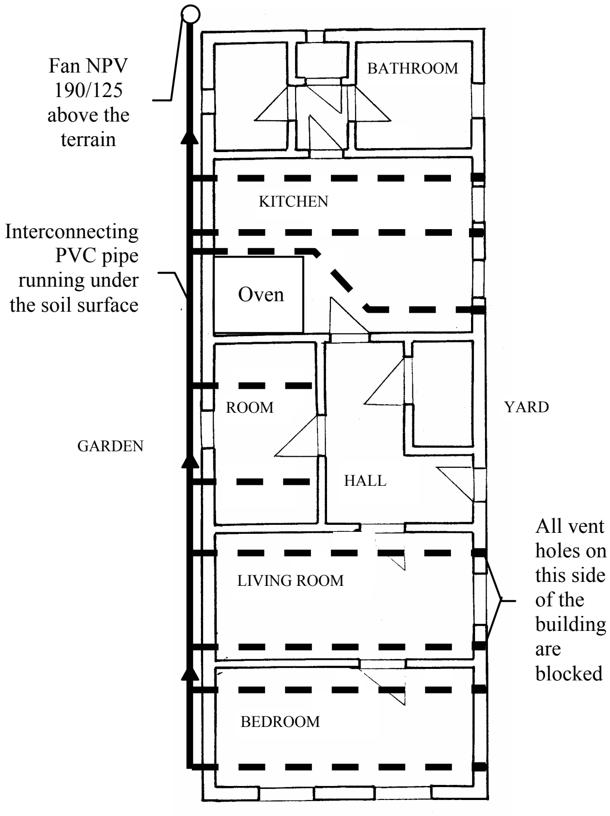


Fig. 3. Ground floor plan of the house with the soil ventilation system adopted during the first attempt at mitigation

Fig. 4. Increasing the efficiency of the soil ventilation by converting the passive system into an active one

Case No. 3 - an old single-family house built in 1927 with a small cellar under the study room. Ground floor radon concentration prior to mitigation varied from 750 Bq/m^3 to 1640 Bq/m^3. The mitigation installed in 1994 was based on the reconstruction of floors on the ground floor. Existing floors were replaced by new ones made of the following structure: 150 mm thick layer of gravel, an air gap under the corrugated boards resting on concrete footings, 100 mm reinforced concrete slab, radon-proof insulation made of two layers of bitumen membranes (not applied under walls), polystyrene 50 mm, concrete screed 50 mm and floor covering (Fig. 5 and 6). The air gap was passively ventilated by means of 7 vent holes in the perimeter walls and one vertical exhaust pipe terminating above the roof. In addition, the door from the hall to the cellar was sealed and the cellar – outdoor ventilation was improved.

Ground floor radon concentration registered immediately after mitigation by electrets exposed for 3 days varied from 680 Bq/m^3 to 850 Bq/m^3. Concentrations measured 4 years later in 1998 by track detectors exposed for one year ranged from 720 Bq/m^3 to 1050 Bq/m^3. Nearly the same values were obtained in 2006. This leads to the conclusion that the passive ventilation of the air gap within the ground floor is not efficient.

In 2006 the passive ventilation was changed 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 air gap. During active ventilation indoor radon concentration decreased well below 200 Bq/m^3.

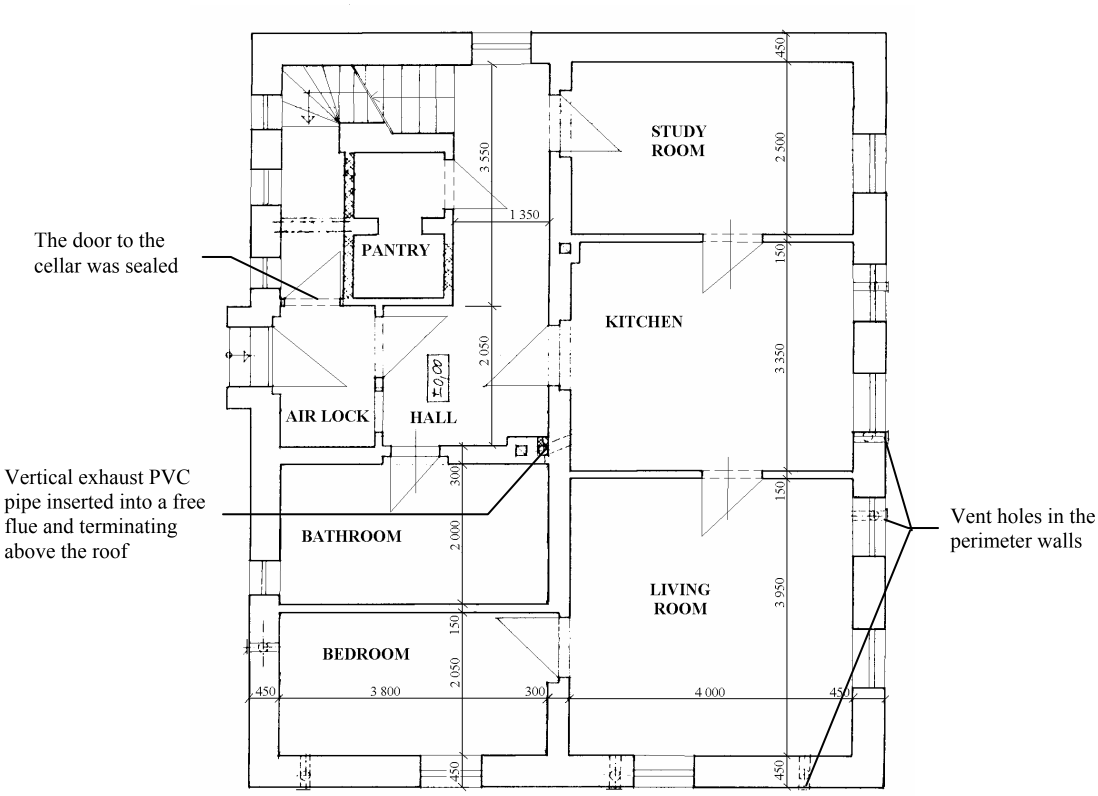


Fig. 5. Ground floor plan of the house with the layout of vent holes

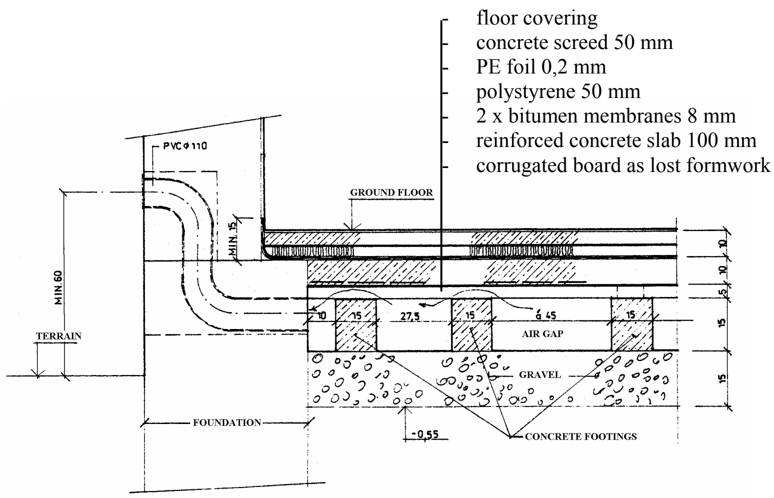


Fig. 6. Structure of the ventilated floor installed into the house in 1994

Case No. 4 - a new single-family house built in 2000 on the building site, where radon concentration in the soil gas varies around 180 kBq/m^3 and the soil is highly permeable. The house was founded on the strip foundations among which the gravel layer was placed. Protection against radon should create passive soil ventilation made of perforated pipes inserted into the gravel layer (Fig. 7). The pipes are opened to the outdoor air through free transversal joints between plinth blocks. The gravel layer was covered by 100 mm thick reinforced blinding concrete on which the radon-proof insulation formed by HDPE membrane with dimples was applied.

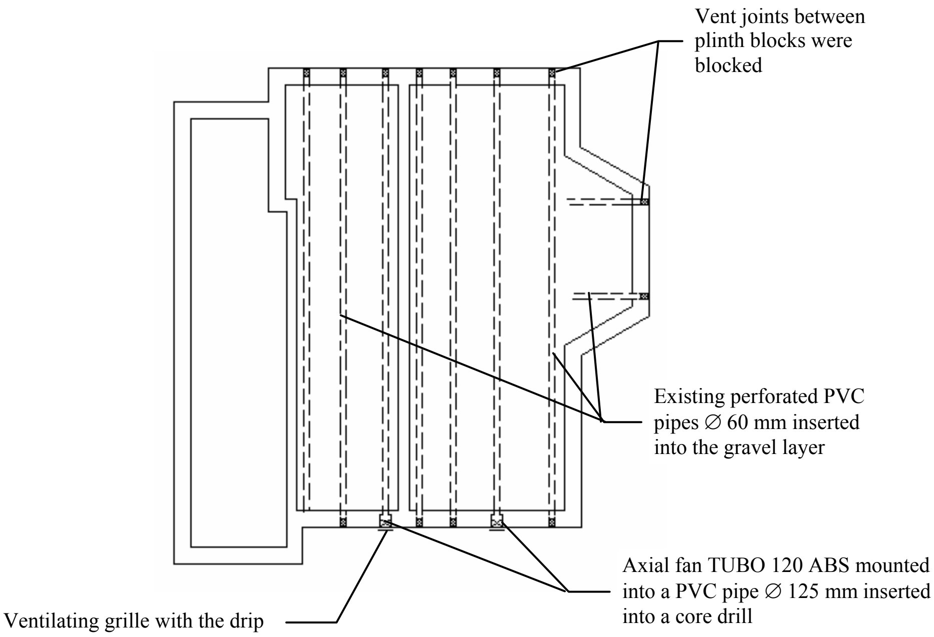


Fig. 7. Plan of foundations, layout of perforated pipes and location of fans

Ground floor radon concentrations measured immediately after the house had been completed ranged from 315 Bq/m^3 to 750 Bq/m^3. Detailed investigation revealed that radon penetrates through unsealed joints in the radon-proof insulation and around pipe penetrations. This can be attributed to the unqualified design of the protective measures. According to the Czech technical standard ČSN 73 0601 it is not allowed to use plastic membranes with dimples for radon barriers, because it is nearly impossible to provide airtight joints between membranes. Passive soil ventilation through free joints between plinth blocks is in general not convenient, the less so for mountain regions, where the snow cover effectively blocks vent joints during the substantial part of the year.

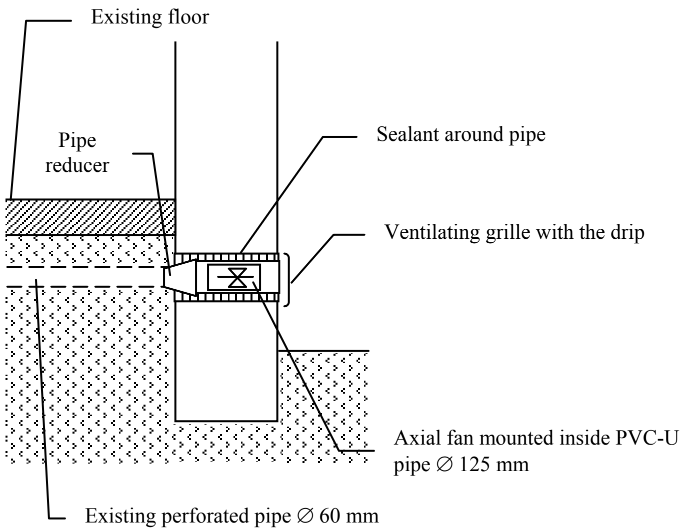


Fig. 8. Installation of fans inside core drills

Since sealing of leaky places in the radon-proof membrane is not feasible, the remediation was based on changing the way of soil ventilation into an active one. Since the sub-floor space under the habitable rooms was divided into two compartments, two small axial fans were used for the extraction of the soil air. Fans were inserted into core holes drilled in the plinth blocks at places, where are the chosen perforated pipes opened to the outdoors (Fig. 8). The remaining vent joints were blocked in order to achieve greater underpressure within the gravel layer. During active ventilation indoor radon concentration decreased well below 200 Bq/m^3 (Fig. 9).

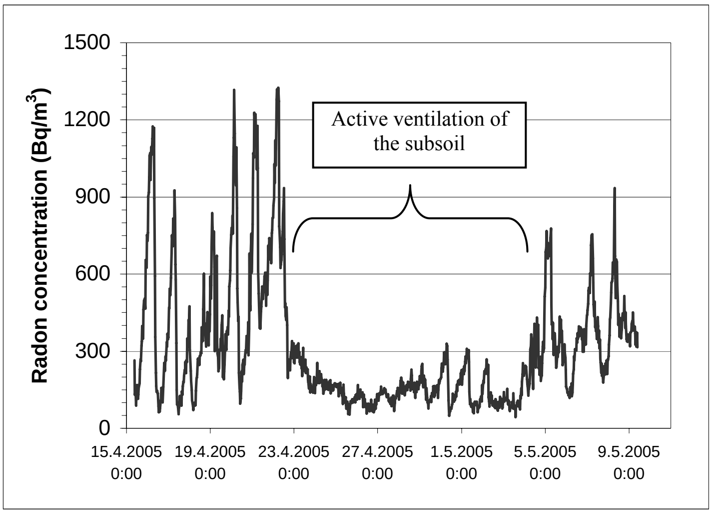


Fig. 9. Radon concentration in the living room during active ventilation of the subsoil [2]

3. CONCLUSIONS

The analysis showed that different remedial measures are prone to failure from different reasons, which are summarized in Tab. 1. Radon-proof insulation usually fails, if it is not applied continuously, if joints and pipe penetrations are not carefully sealed and if insulating materials have poor quality and no tests on radon barrier properties. 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. In spite of the fact that long-term functionality and durability tests had not been undertaken the passive ventilation of sub-floor layers and air gaps was formerly preferred. This faulty approach led to a lot of failures, because in the light of recent experience passive ventilation can only be applied under certain conditions and not as a general solution in any case.

The paper describes also some possibilities how to convert faulty measures into effective ones. Passive sub-slab and air gap ventilation can be usually very easily converted into a 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. Low effectiveness of radon-proof insulation can be commonly solved by installation of an active sub-slab depressurization. Experience in this field was documented by the comparison of indoor radon concentrations measured before remediation, after installation of faulty measures and after improvement of their effectiveness.

Findings presented in this paper update and extend our knowledge about the sources of failures of radon remedial measures. Obtained information could contribute to longer durability and higher functionality and reliability of radon remedial measures.

Tab. 1. Sources of failures of radon remedial and preventive measures

Protective measure	**Factors responsible for failures**
Radon-proof insulation	• Leakages in joints and around pipe penetrations • Partial application (insulation is not applied over the entire surface in contact with soil) • Perforation of insulation during following construction works • Use of insulating materials that were not tested on radon diffusion • Application of membranes with aluminium foil, polymercement coatings, plastic membranes with dimples, EPDM membranes • Use of low quality products
Sub-slab ventilation/depressurization	• Passive ventilation with inlet and outlet holes in external walls only (without vertical exhaust) • Installation of radon sumps in low permeable soils • Inappropriate geometry of drainage pipes and drilled tubes (designed with no respect to the tightness of floors and vertical profile of soil permeability)
Floor gap ventilation/depressurization	• Use of plastic membranes with dimples for the construction of air gaps • Radon penetration through wall/floor joints, if the floor air gap is partitioned by walls • Passive ventilation with inlet and outlet holes in external walls only (without vertical exhaust)

Acknowledgement

The work reported here was supported by the research project MSM 6840770001 “Reliability, optimisation and durability of building materials and structures”.

REFERENCES

[1] Froňka A., Moučka L.: Diagnostic Measurements in the house Hrazánky 14. National Radiation Protection Institute, Praha, 2001

[2] Neznal M., Neznal M.: Measurements of Indoor Radon Concentration in the house Jindřichov 126 after installation of radon reduction measures. Radon v.o.s. comp., Praha 2005

[3] Neznal M., Neznal M.: Measurements of Indoor Radon Concentration in the house Louňovice 296 after installation of radon reduction measures. Radon v.o.s. comp., Praha 2005

[4] Czech technical standard ČSN 73 0601 Protection of houses against radon from soil, ČNI 1995, 2000, 2006