Session Title: Radiation Protection of the Public and the Environment

FAILURE OF PREVENTIVE MEASURES AGAINST RADON PENETRATION FROM THE GROUND IN A NEW-BUILT FAMILY HOUSE - A CASE STUDY

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INTRODUCTION

A system of preventive protection of houses against radon penetration from the ground [1] has been in operation for more than 15 years in the Czech Republic. The determination of a so-called radon index of the building site represents the first step. The assessment is based on measurements of soil gas radon concentration and on the determination of soil permeability. During the years, the method was modified several times, especially the recommendation dealing with the classification of soil permeability, but the base remains stable: The soil characteristics are measured in-situ and protective measures are designed with respect to the measured properties of the soil and to the dwelling design. The site-specific, individual approach should enable to propose an optimal preventive strategy corresponding to local conditions. If the radon index is other than low (i.e. medium, or high), the building must be protected against radon in accordance with the Czech Atomic Law. Protective measures should be designed and installed according to the Czech National Standard [2]. Basic principles of the protection can be summarized in the following way:

If the radon index of a building site is low, no special provisions are required. Normal damp-proofing that is designed in accordance with hydro-geological conditions provides sufficient building protection. Nevertheless, the insulation has to be installed over the whole ground area of the building. It is also recommended that the corridor with stairs leading from the underground floor to the upper floors should be separated by the door.

In case of medium radon index of a building site, each high-quality and long-life damp-proofing, with the measured radon diffusion coefficient, may be considered as radon-proof insulation in compliance with CSN 73 06 01. A required insulation thickness is calculated using the known value of radon diffusion coefficient. The insulation must be laid down continuously on the whole area of the structure in contact with soil, i.e. even under walls. Special attention should be devoted to the sealing of joints and pipe penetrations through the insulation. The high-quality insulation may be replaced by a common damp-proofing if some special conditions are met: the house is built with a cellar under the complete house area; no residential rooms are found in the cellar; all year reliable natural ventilation of the cellar is provided; the *cellar entrance from the floors above is provided with an automatic closing door system and with door sealing. The above mentioned approach is considered to be sufficient even in cases when the building site is classified close to the lower limit of the high radon index (the radon concentration in soil does not exceed twice the concentration that separates the medium and high radon index).*

In all other cases, the radon-proof insulation in all structures in direct contact with soil must be completed with either a a sub-slab ventilation system or an air gap ventilation under the insulation. The sub-slab ventilation system should reduce the radon concentration under the foundation plate, or create negative pressure in subsoil compared to indoor air pressure. It is a system of perforated drainage pipes that are inserted into a gravel layer under the foundation plate. To ensure effective operation of sub-slab ventilation, it is recommended to extract the soil air from the sub-slab region by the vertical exhaust pipes. The ventilation system can operate in two ways: a passive ventilation, i.e. the ventilation system is controlled by temperature and pressure indoor/sub-floor differences, or an active one, using a fan. Because the fan is usually installed on the vertical exhaust pipes, each passive system may be easily transformed into an active one.

A failure of preventive protective measures in a new-built family house will be described and analysed in the paper.

DESCRIPTION OF THE HOUSE, PROTECTIVE MEASURES, REMEDIAL MEASURES

A single-family two-storey house was built in the region formed by highly permeable soils with high radon content in the soil air in 1999. Perforated pipes in the sub-slab drainage layer of gravel and a radon-proof membrane made of polypropylene were used to prevent radon entry into the house (Fig. 1). Joints of the membrane were made of self-adhesive bitumen belts.

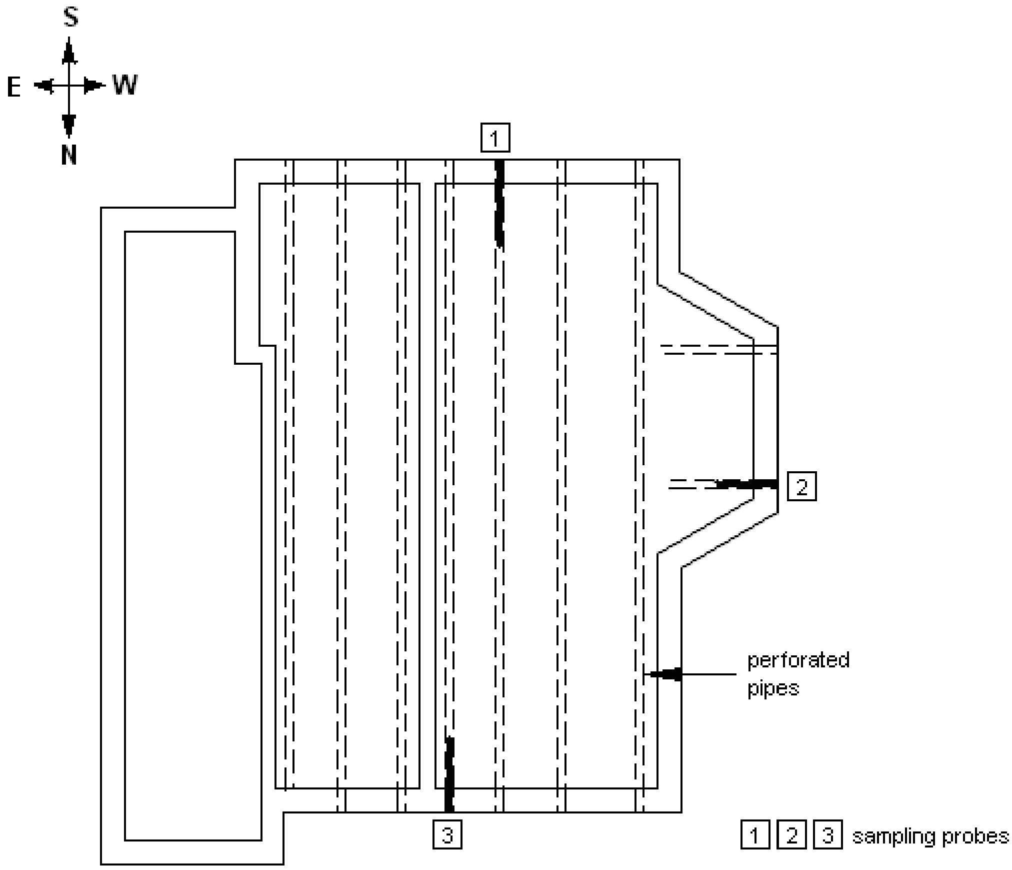


Fig. 1. Layout of perforated pipes in the plan of foundations. Location of sampling probes used during diagnostic measurements.

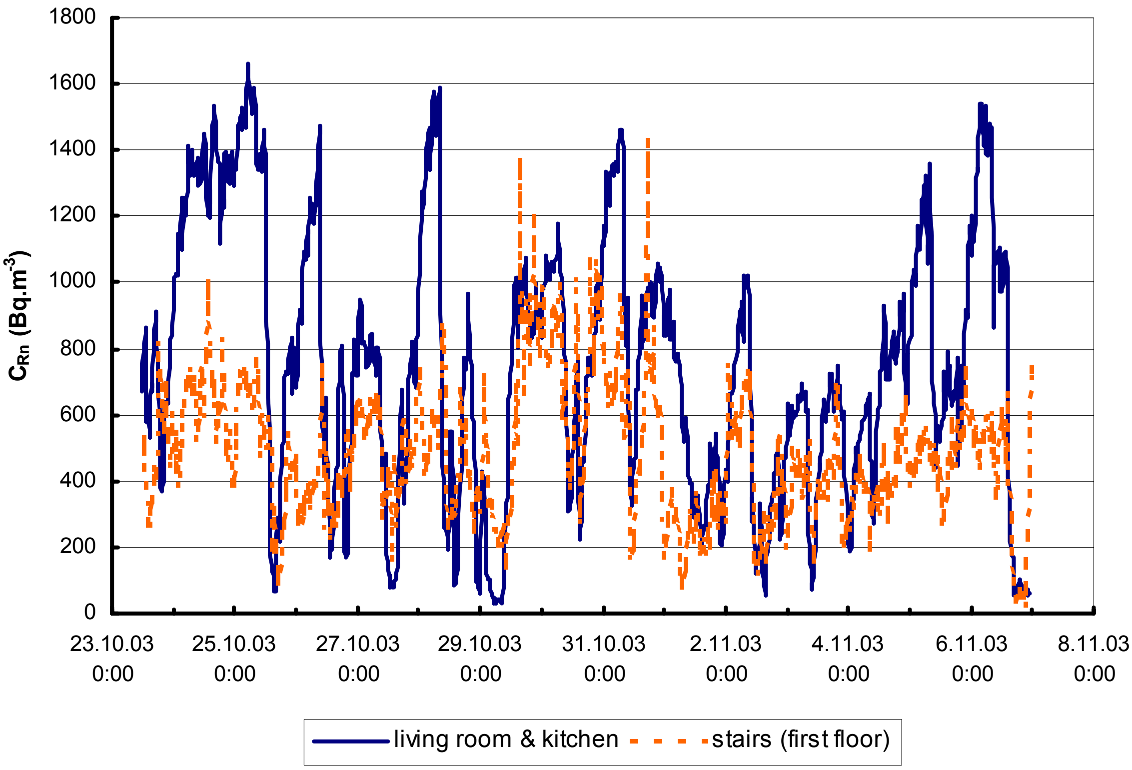
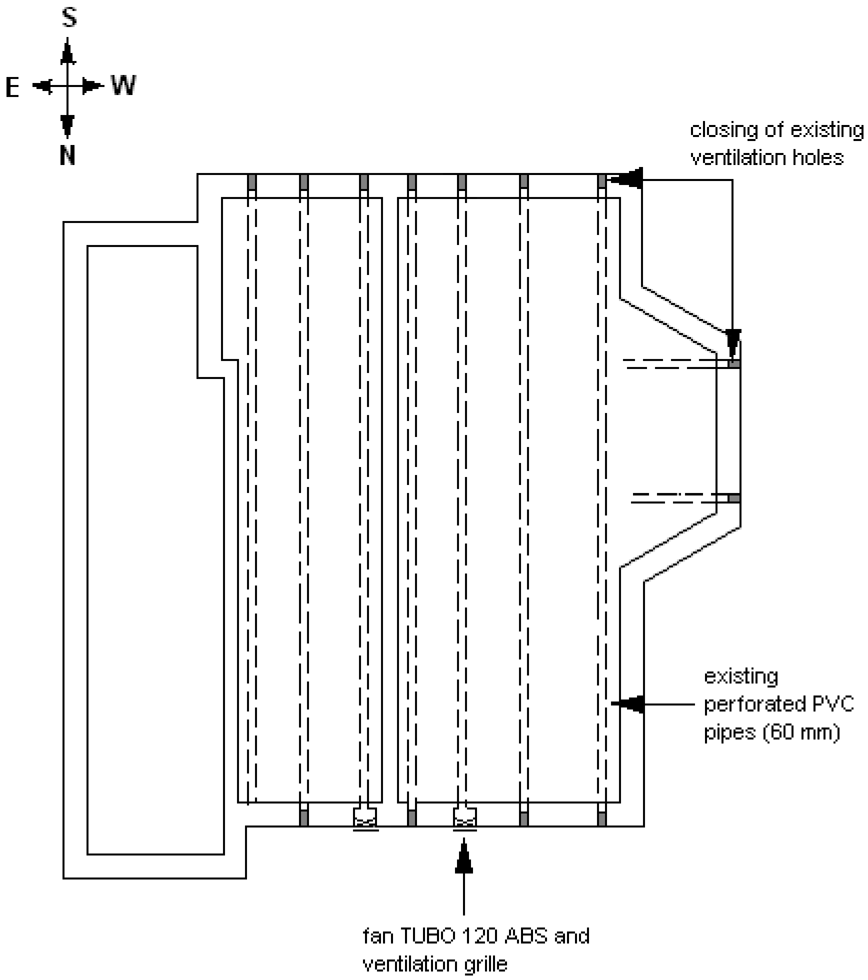


Fig. 2. Indoor radon concentrations (c_{Rn}) in the new-built house, before remediation.

In 2004, a detailed survey and diagnostics measurements were realized to determine reasons of the failure of preventive measures against radon penetration into the house (details are given further). At the end of 2004, a simple remedial action was performed: Two small fans were connected to the perforated tubes changing the original passive sub-slab ventilation system to an active one (Fig. 3).



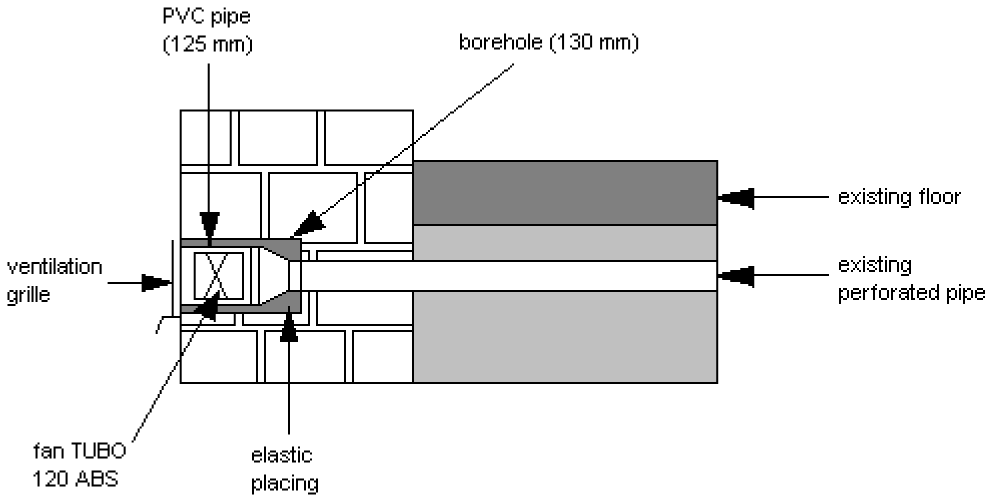


Fig. 3. Remedial action. Two small fans were connected to the perforated tubes changing the original passive sub-slab ventilation system to an active one.

DIAGNOSTIC MEASUREMENTS

As the first step of radon diagnostics of the house, a detailed study of available data (design of preventive measures, photographical documentation describing the construction, results of indoor radon measurements, etc.) has been performed. It was concluded that (i) no radon survey of the building site had been made in the pre-construction phase, and (ii) imperfections during the construction of the house cannot be excluded.

A set of diagnostic measurements consisted of a determination of radon index of the building site, continual measurements of indoor radon concentration, and special techniques that enable to discover and demonstrate leakages in the insulation: determination of radon concentration in air samples collected from leaky structures in contact between floor and wall, ventilation experiments under well-defined pressure conditions using blower door method, and leakage visualization using infrared camera [3]. As can be seen in Fig. 1, three sampling probes were inserted into the drainage perforated pipes and sealed. These probes were used for a follow-up of radon concentration, temperature and pressure in the sub-floor region during the blower door experiments.

The remediation effectiveness was tested by continual measurements of indoor radon concentration.

RESULTS AND DISCUSSION

Measurements of soil-gas radon concentration and of soil permeability in the surroundings of the house have confirmed a high radon index of the building site: soil permeability was high, soil-gas radon concentrations varied from 37 *to 246 kBq/m^3 (depth 0.8 m below the ground surface, 15 measuring points, median 160 kBq/m^3).*

The occurrence of transport pathways between sub-floor region and indoor environment has been demonstrated using different methods. Radon concentrations up to 10 kBq/m^3 were observed in air samples collected from leakages in contact between floor and wall. An example of a leakage visualization using the infrared camera during a blower door experiment in the study room is given in Fig. 4. A colder region above the line between the floor and the wall illustrates a penetration of a colder air from the sub-floor region into the room. Dramatic changes of radon concentration in the sub-floor region during this blower door experiment, which are presented in Fig. 5, also confirm the fact that the tightness of the radon barrier is not perfect. Temporal changes of radon concentration in probes No. 2 and 3 differed from temporal changes in probe No. 1. The difference could be explained by the fact that the probes No. 2 and 3 are closer to the study room in the north-western corner of the house, where the blower door experiment took place. These probes were affected more strongly and the decrease of radon concentration was probably caused by sucking of a clear atmospheric air along non-perfectly sealed probes. In the surroundings of the probe No. 1, radon intake from the ground remained more important.

Another example is given in Fig. 6. Pressure difference in the sampling probe No. 2, that was observed, demonstrate the influence of the blower door fan operation on the sub-floor pressure field. The second blower door experiment was performed in the living room, two days after the first one.

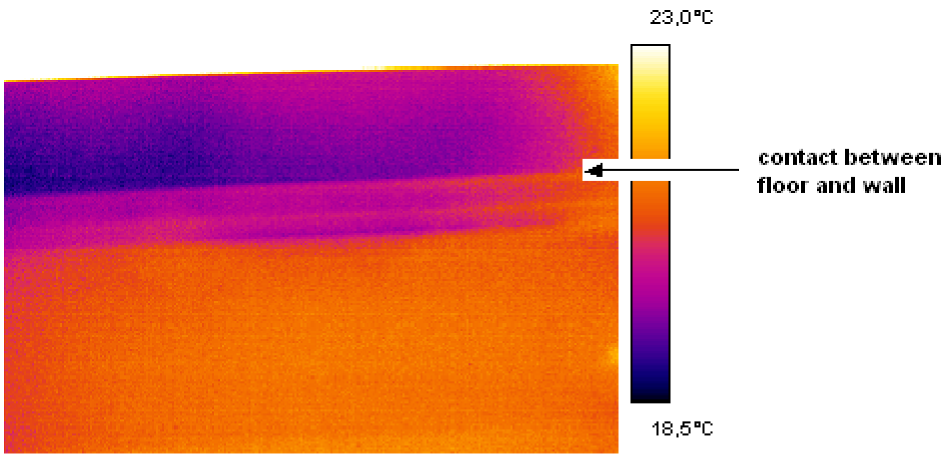


Fig. 4. Leakage visualization using the infrared camera during a blower door experiment in the study room.

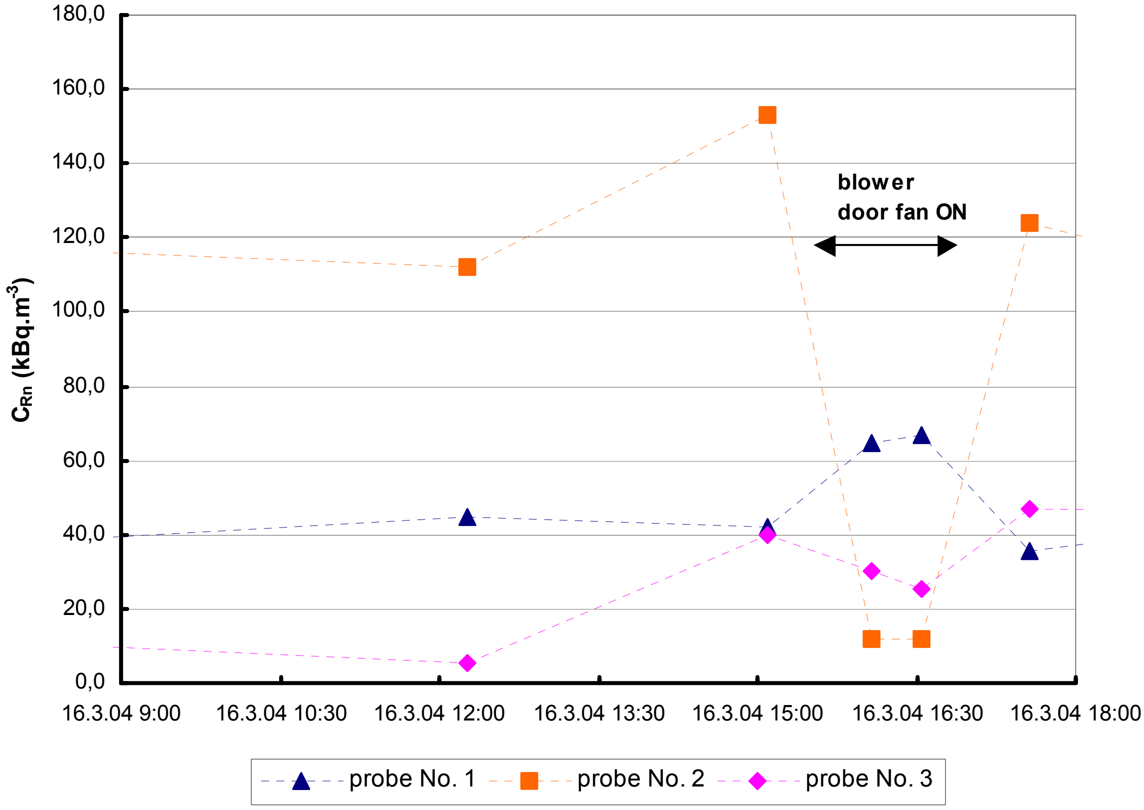


Fig. 5. Temporal variations of soil-gas radon concentration in the sub-floor region during a blower door experiment in the study room.

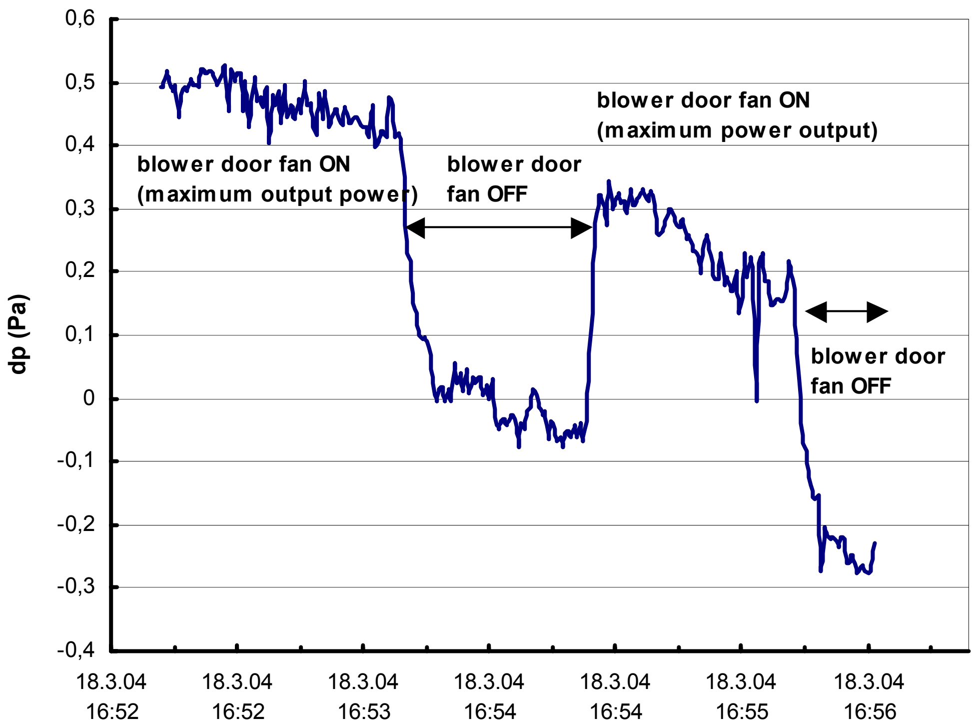


Fig. 6. Pressure difference in the sampling probe No. 2 (influence of the blower door fan operation on the sub-floor pressure field).

Results of continual measurements of indoor radon concentration, that were performed to check the effectiveness of a simple remedial action realized at the end of 2004, are presented in Fig. 7 and in Table 1. A positive effect of the active ventilation of the sub-floor drainage layer on radon concentrations in ground floor habitable rooms is evident. The radon concentrations in the living room and in the study room were about 2 - 3.5 times lower, when the active ventilation was switch-on. The situation in the first floor is more complicated. Rooms in the first floor are influenced by radon intake from the eastern part of foundations, without perforated drainage pipes. The installation of an active ventilation system in this section of foundations would require a more extensive intervention.

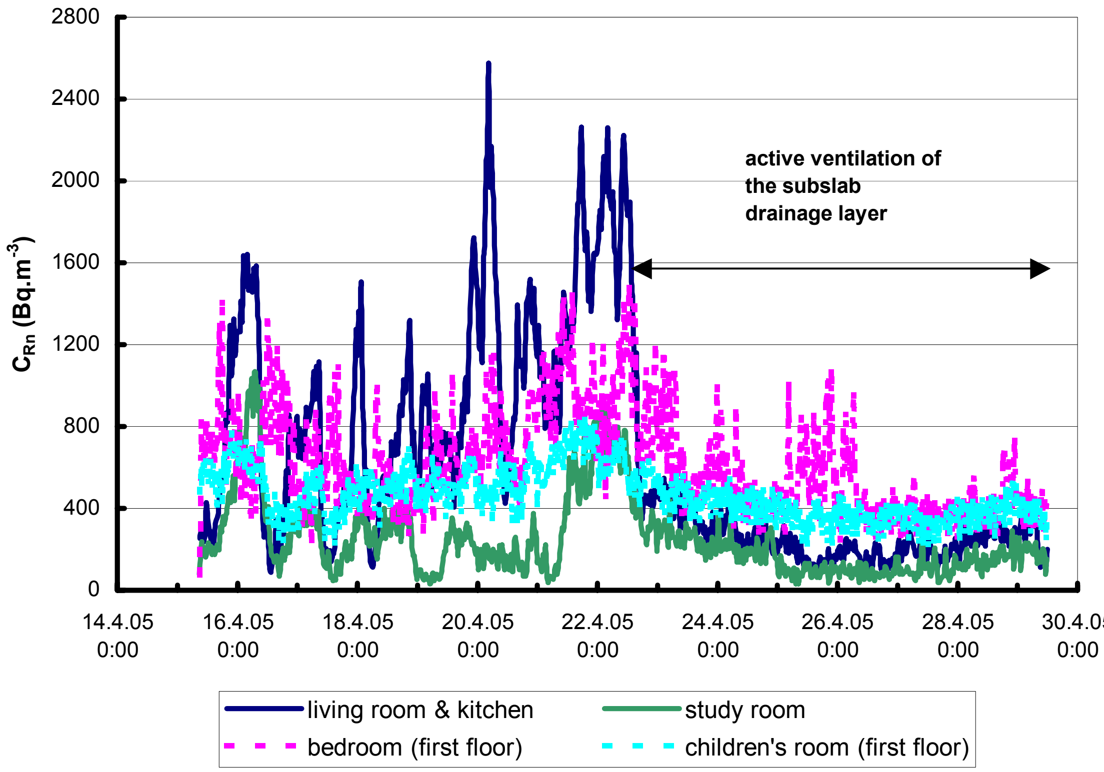


Fig. 7. Influence of active sub-floor ventilation on indoor radon concentrations.

Table 1. Influence of active sub-floor ventilation on indoor radon concentrations.

Mode (time interval)	*c_{Rn} (Bq/m^3)*			
	living room	*study room*	*bedroom*	*children's room*
active ventilation switch-off (15.4.05 9 h - 22.4.05 12 h)	*954*	*322*	*722*	*540*
active ventilation switch-on (22.4.05 12 h - 29.4.05 12 h)	*276*	*166*	*526*	*400*

active ventilation switch-on - last three days (26.4.05 12 h - 29.4.05 12 h)	*220*	*130*	*402*	*368*

CONCLUSION

Detailed measurements of sub-slab parameters, continual monitoring of indoor radon concentration, blower door experiments and other methods were used to find reasons of a failure of preventive protective measures in a new-built family house. The analysis of the results and of other available data has shown three main faults: (a) A radon survey of the building site before the construction of the house was not performed. The information on a real radon potential of the ground was thus not available. (b) Chosen preventive measures were not adequate. A passive sub-slab ventilation instead of a more appropriate active ventilation system was proposed. (c) Imperfections occurred during the construction. Some joints of the polypropylene membrane were not sealed perfectly and the membrane was probably also punctured during the construction of the floor at least in one room.

A simple remedial action has resulted in a significant decrease of average indoor radon concentration. Two small fans were connected to the perforated tubes and the original passive sub-slab ventilation system was thus changed to an active one.

Acknowledgement

A substantial part of the work reported here was supported by the State Office for Nuclear Safety - research project 2/2004.

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