# Reducing indoor radon concentrations by passive subslab ventilation

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The primary objective of our study was to establish whether passive soil ventilation systems installed under existing houses have an effect on indoor radon concentrations. Experiments were conducted in two single-family houses. The soil ventilation under each house consists of the network of flexible perforated pipes laid into the layer of coarse gravel of the minimal thickness 150 mm. Soil air from the perforated pipes is ventilated by means of the vertical exhaust pipe that runs through the heated part of the house and ends above the roof of the house. At the top of the vertical exhaust a wind turbine is mounted in order to improve the stack effect during the windy weather. In addition to the soil ventilation both houses were provided with new floors composed of concrete slab and radon proof insulation made of LDPE membrane.

Immediately after installation of remedial measures radon concentrations in all habitable rooms of both houses were measured from 10th to 17th November 2004 using electret detectors and continuous radon monitors with the exposition time of one week. During this measurement the vertical exhaust pipe was closed. From 17th to 24th November the measurements of indoor radon concentrations were repeated, however with the vertical exhaust open. The long-term behaviour of the passive soil ventilation has been studied by means of indoor radon measurements carried out by RamaRn detectors that are repeatedly placed inside both houses, each time for the measuring period of 3 month. The last measuring period will cover the end of the year 2005. During these measurements the vertical exhaust pipe is open. Results of the first measuring period from December 2004 to March 2005 are summarized in Tab. 1 and 2. These tables provide also comparison between concentrations measured before and after remediation.

***Tab. 1. The effectiveness of a passive subslab ventilation under the house No.1 (Osečany)***

| Room | Concentrations before mitigation [Bq/m$^3$]2) | Soil ventilation off3) 10.-17.11.2004 | | Soil ventilation on3) 17.-24.11.2004 | | Soil ventilation on4) 18.12.2004 -16.3.2005 | |
|---|---|---|---|---|---|---|---|
| | | Concentration [Bq/m$^3$] | Efficiency [%] | Concentration [Bq/m$^3$] | Efficiency [%] | Concentration [Bq/m$^3$] | Efficiency [%] |
| Bedroom | 450 | 1268 | -282 | 184 | 59 | 257 | 43 |
| Kitchen1) | 638 | 1354 | 8 | 169 | 88 | 228 | 84 |
| Living room1) | 2294 | | | | | | |
| Nursery | 350 | 701 | -200 | 130 | 63 | 216 | 38 |
| Average | 933 | 1108 | -119 | 161 | 83 | 234 | 75 |

**Notes: 1) these rooms were reconstructed during mitigation into one room, 2) combination of one year measurements by track detectors and one week measurements, 3) one week measurements using electret detectors and continuous radon monitors [2], 4) three months measurements carried out by RamaRn detectors [4]**

From Tab. 1 it is obvious that radon concentrations in the house No. 1 were in average 19 % higher during the period when the ventilation system was off compared to concentrations measured before mitigation. It is the result of increased permeability of the sub-floor layer. Therefore in this house new floors do not act as a radon barrier. After opening of the vertical exhaust pipe the average indoor radon concentration dropped significantly from 1108 Bq/m$^3$ to 161 Bq/m$^3$. Concentrations measured from December 2004 to March 2005 were still very low, in average around 234 Bq/m$^3$. The mean effectiveness of the passive soil ventilation varies in this house from 75 % to 83 %, which means that indoor radon concentration had decreased to 25 % up to 17 % of the initial values.

***Tab. 2. The effectiveness of a passive subslab ventilation under the house No. 2 (Podhůří)***

| Room | Concentrations before mitigation [Bq/m$^3$]1) | Soil ventilation off2) 10. - 17.11.2004 | | Soil ventilation on2) 17. - 24.11.2004 | | Soil ventilation on3) 20.12.2004 -15.3.2005 | |
|---|---|---|---|---|---|---|---|
| | | Concentration [Bq/m$^3$] | Efficiency [%] | Concentration [Bq/m$^3$] | Efficiency [%] | Concentration [Bq/m$^3$] | Efficiency [%] |
| Bedroom | 840 | 1040 | -124 | 446 | 47 | 154 | 82 |
| Kitchen | 1035 | 744 | 28 | 214 | 79 | 232 | 78 |
| Living room | 1308 | 805 | 38 | 351 | 73 | 103 | 92 |
| Dining r. | 2494 | 864 | 65 | 411 | 84 | 129 | 95 |
| Average | 1419 | 863 | 39 | 356 | 75 | 155 | 89 |

**Notes: 1) combination of one year measurements by track detectors and one month measurements by RamaRn detectors, 2) one week measurements using electret detectors and continuous radon monitors [2], 3) three months measurements carried out by RamaRn detectors [4]**

Tab. 2 shows that after installation of the mitigation measures the average indoor radon concentration in the house No. 2 dropped from 1419 Bq/m$^3$ to 863 Bq/m$^3$ during the period when the soil ventilation was off. It means that in this house new floors contribute to reduction of indoor radon. The mean effectiveness of new floors is 39 %. After switching on the soil ventilation the mean effectiveness increased to 75 % and average radon concentration decreased to 356 Bq/m$^3$. During the winter period from December 2004 to March 2005 indoor radon concentrations decreased in average to 155 Bq/m$^3$ and the effectiveness increased to 89 %.

A number of environmental variables were monitored in each house using Comet MS3+ data loggers in order to determine parameters that could have effect on the performance of the passive soil ventilation. Temperature was measured at four locations in each house – outdoors, at the base of the vertical exhaust pipe, in the subslab drainage layer at the centre of the house and in the drainage layer near the perimeter wall. Pressure differentials were measured between indoors and the base of the vertical exhaust pipe and several points in the drainage layer at different distance from the vertical exhaust pipe. Temperature and pressure differential measurements were collected between 23rd November 2004 and 19th July 2005.

Relationship between underpressure at the base of the vertical exhaust pipe in the house No. 1 and the temperature gradient between the drainage layer and the outside air can be seen in Fig. 1 and 2. Both figures demonstrate positive correlation between temperature differential and underpressure. Measured values of underpressure correspond very well with the underpressure calculated according to the well-known equation:

$$\Delta p_t = g.H.(\rho_e - \rho_s) \qquad [\text{Pa}] \qquad (1)$$

where H is the height of the vertical exhaust pipe [m], g is the gravitational acceleration [9,81 m/s$^2$], $\rho_e$ is the density of the outdoor air [kg/m$^3$] and $\rho_s$ is the density of the subslab air [kg/m$^3$]. For height H = 8 m, $t_e$ = 20 °C and $t_s$ = -5 °C the pressure difference is $\Delta p_t$ = 9,81 x 8 x (1,205 – 1,318) = - 8,9 Pa. For higher subslab temperature $t_s$ = 5 °C equation (1) will give lower underpressure –5,1 Pa. Measured values are slightly lower due to pressure losses in pipes caused by friction and fitting resistance. On the other hand increased wind speed causes an increase in subslab underpressure.

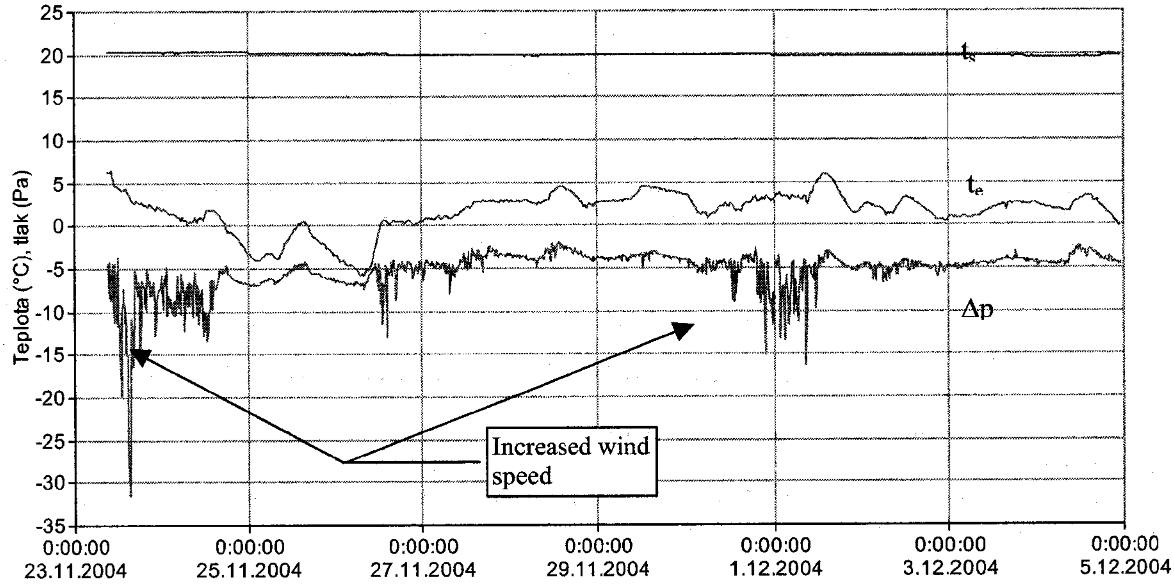

**Fig. 1. Relationship between the underpressure Δp at the base of the vertical exhaust pipe and the temperature gradient between a point in the drainage layer at the centre of the house $t_s$ and the outside air $t_e$ during part of November 2004**

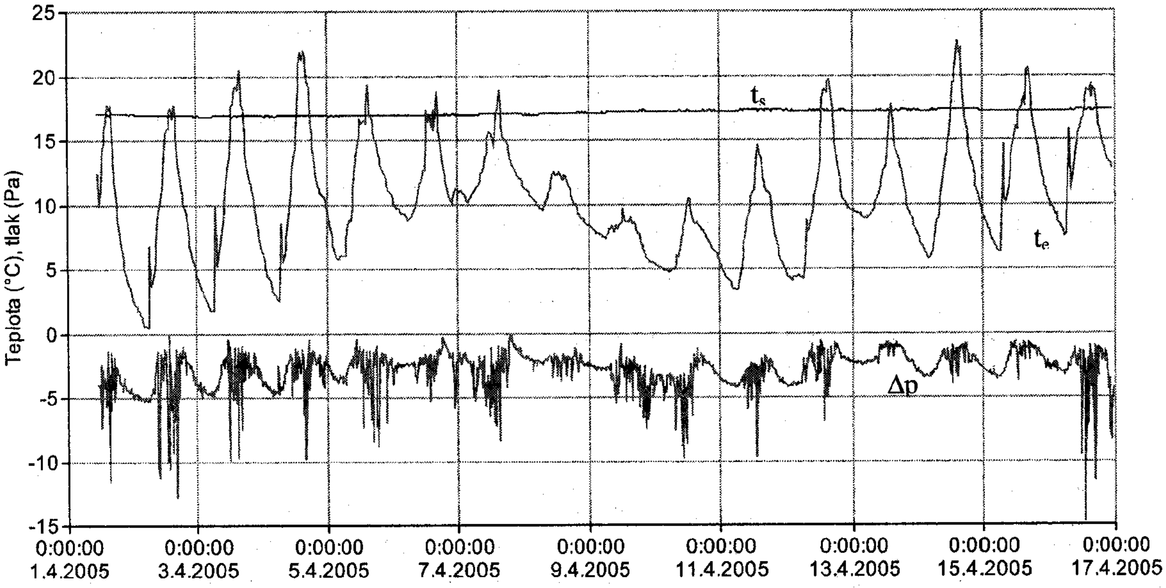

**Fig. 2. Relationship between the underpressure Δp at the base of the vertical exhaust pipe and the temperature gradient during part of April 2005**

## Conclusions

The efficiency of passive soil ventilation systems varies within the year in dependence on the temperature gradient and wind speed. Preliminary results indicate that temperature gradient predominates. However the maximum underpressure at the base of the vertical exhaust pipe caused by temperature differences is not so high. During one-year observation period the maximum temperature related underpressure was only –8 Pa.

The wind effect starts to be noticeable for speeds higher than 5 m/s and more apparent becomes for speeds above 10 m/s. The maximum values of underpressure due to wind forces were measured within the range –20 Pa and –30 Pa for wind speeds from 20 m/s to 25 m/s.

Quite significant variations of the subslab underpressure within one day were observed. The maximum underpressure was measured at late night or early morning when the outdoor temperature was the lowest. Annual variations were also confirmed. During the winter the temperature gradient is higher than in the summer time and thus the subslab underpressure is consistently higher in the winter.

Preliminary results indicate that passive soil ventilation systems with perforated pipes laid into the subslab layer of coarse gravel and vertical exhaust pipe running through the heated part of the house and terminating above the roof can be surprisingly effective. Discovered effectiveness for two houses varied between 75 % and 89 %, which is a better result than 50 % observed for passive mini sump systems [3]. The difference can be explained by the fact that perforated pipes ensure better pressure distribution and soil ventilation compared to simple sumps. This could lead to the conclusion that passive soil ventilation based on perforated pipes can be convenient for houses with indoor radon concentration below approximately 1200 Bq/m$^3$. However there is insufficient data to draw any firm conclusions. Further research in this field is needed.

In new houses passive systems should be preferable to a fan driven ones because they are usually cheaper to install, run and maintain. In addition it is a simple task to add an electric fan later if the passive system does not adequately reduce indoor radon concentrations.

## Acknowledgement

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## Literature

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