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Results of Long-term Measurement of Radon in a Room of a Multi-storey Building*

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Abstract: The results of a long-term continual measurement of radon activity concentration in one type of building in Slovakia are reported. The AlphaGUARD radon monitor was used for continuous monitoring of radon activity concentration in indoor air. The extensive set of the radon data was obtained. The indoor radon activity concentrations show the seasonal variations with the maximum in the winter and with the minimum in the springtime till the beginning of the summer. The average daily courses of ^{222}Rn activity concentrations have a form of waves with maximum in the morning and minimum in the afternoon. The analysis showed that the indoor radon in this building had the good response to the outdoor temperature and indoor–outdoor temperature difference. However, the measured radon variations exhibit behaviour that is opposite to the behaviour predicted by theoretical model.

1. Introduction

Radon (^{222}Rn) is the most important natural source of radiation exposure of the population. Hence an appropriate care is taken in the field of radon radiation protection. Residential areas are the greatest source of radon population exposure [1]. Radon gets into enclosed spaces by exhalation from the floors, walls and cracks into the rooms. The radon activity concentration in the indoor atmosphere is not stable. As a rule, in the indoor air, the radon activity concentration is being changed in a relatively short time [2]. Meteorological conditions, building materials and building construction belong to the important factors affecting the radon activity concentration in the indoor air [3]. Being influenced by these factors, the indoor radon activity concentration shows the daily and seasonal variations. The measurement and study of these changes is possible by continual monitoring. In a simplified case, the radon activity concentration is a function of two parameters: radon entry rate and air exchange rate. Both mentioned parameters depend on many different meteorological parameters, but from all of them, the main role has the pressure difference between the indoor and outdoor air. In common situations the pressure difference is dominantly caused by indoor–outdoor temperature differences and by the wind [4]. Measurements of the indoor radon allow the better understanding of the mechanisms influencing the radon activity concentration, testing of the models describing its variations and identification of the radon sources in buildings.

This paper provides the complex view on the daily and seasonal radon variation for one type of dwelling and also it shows the relationship between the radon activity concentration and the indoor–outdoor temperature difference as well as between the radon activity concentration and the outdoor temperature.

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2. Behaviour of radon in indoor air

Under the term ‘indoor air’ we understand the air inside a flat, house or other enclosed area. The main sources of radon in buildings are: underlying rock, building material, outdoor atmosphere and, to a lesser extent, the tap water and natural gas [2].

Radon gets into enclosed spaces by exhalation from the floor, walls, things in the room, from the natural gas, water used in the household and by the air entering the room from the outside. Indoor radon activity concentration varies in time. Under the assumption of homogenous distribution of activity concentration inside a building, the temporal change of activity concentration can be described by the differential equation [1]:

$$\frac{dA(t)}{dt} = \frac{R}{V} - A(t)(\lambda + \lambda_V), \qquad (1)$$

where: $A(t)$ – radon activity concentration in the room at the time t [Bq.m^{-3}], R – radon entry rate [Bq.s^{-1}], V – volume of the room [m^3], λ – radon decay constant [s^{-1}], λ_V – air exchange rate [s^{-1}].

For a steady state condition $dA(t)/dt = 0$ and under the assumption $\lambda_V \gg \lambda$ (because: $0.1\ h^{-1} \leq \lambda_V \leq 3\ h^{-1}$, $\lambda \approx 7.6 \times 10^{-3}\ h^{-1}$) we get the mean ^{222}Rn activity concentration in the room:

$$A \approx R/(\lambda_V V). \qquad (2)$$

Let us consider three interpretations of Equation (2) (depicted in Fig. 1 [4]), in dependence on R and λ_V:

a) $R \approx const.$, $\lambda_V \sim \Delta T$ (ΔT is the indoor-outdoor temperature difference)
   A is indirectly proportional to ΔT with a maximum in the afternoon and minimum during the night,

b) $\lambda_V \approx const.$, $R \sim \Delta T$
   A is proportional to ΔT with a minimum in the afternoon and maximum during the night,

c) $R(\Delta T)$, $\lambda_V(\Delta T)$
   for A we can write $A \approx R(\Delta T)/\lambda_V(\Delta T)$, A can rise or fall as a function of ΔT.

The temporal changes of radon activity concentration for these tree cases are shown in Fig. 1.

From the point of view of the structure and building utilization, two aspects play the key role effecting the radon activity concentration [5]. The first one is the ventilation system that may have an influence on the air pressure difference between inside and outside, forcing the air to flow inside. The second one is the foundation construction that affects the flow of the air between the soil and the building. Other factors are meteorological effects (barometric pressure, temperature, wind speed) as well as residential activities (heating, ventilating).

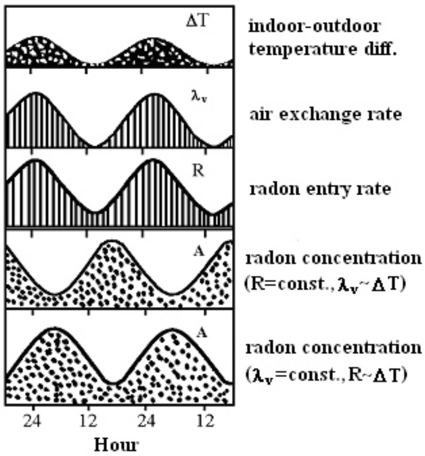

Fig. 1. Variations of indoor radon as a function of R and $_V$ [4, 6].

2. Methods and Sampling Locality

For the monitoring of radon activity concentration in indoor air the radon monitor AlphaGUARD (AG) developed by Genitron Company was used [7]. In AlphaGUARD the cylindrical ionization chamber in combination with DSP-technologies is used for radon concentration measurement. The active volume of the ionization chamber is equal to 0.56 liters. The measured gas enters into the ionization chamber via a large surface glass fiber filter in diffusion mode. The sensitivity of the detector is 0.05 cpm at 1 $Bq \cdot m^{-3}$ of ^{222}Rn activity concentration. The background signal, due to the internal detector contamination, is less than 1 $Bq \cdot m^{-3}$. The monitor can record the ^{222}Rn activity concentration, temperature, pressure and humidity of the room in 1-hour intervals.

The radon activity concentration was measured at workroom in the office building of the Faculty of Mathematics, Physics and Informatics of the Comenius University in Bratislava. The room is situated at the second floor, with north-oriented windows, and is shielded against the direct influence of wind by the other parts of the building. The monitored room typifies the most commonly occurring residential (prefab) areas in Slovakia. According to the character of the room, it can be expected that the radon entry comes mainly from its walls and can be considered constant. The main parameter influencing the radon concentration should be the change of the air exchange rate which is proportional to the indoor-outdoor temperature difference. In this case, the daily radon variations with a minimum in the morning and maximum in the afternoon are expected (see Equation (2) and Fig. 1).

3. Results

The radon activity concentration in the room at FMPI CU was monitored since 1997; the longest record is from period the March 1998 – December 1999 and March 2004 – June 2005. For the room there are characteristic the low radon activity concentrations

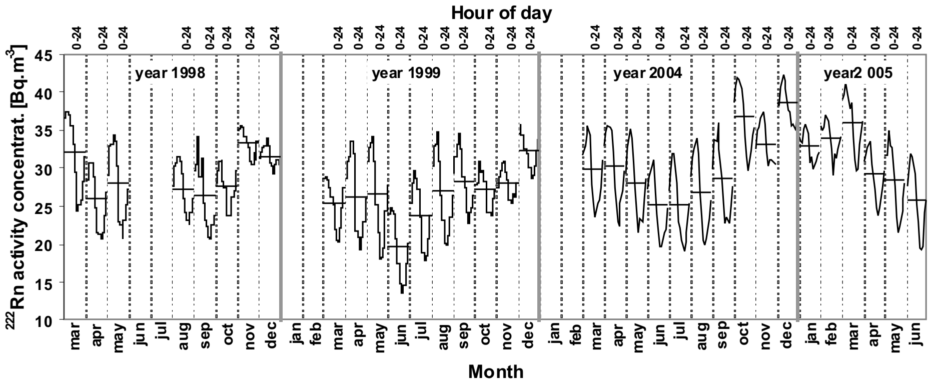

Fig. 2. Average monthly values and daily courses of ^{222}Rn activity concentration in indoor air.

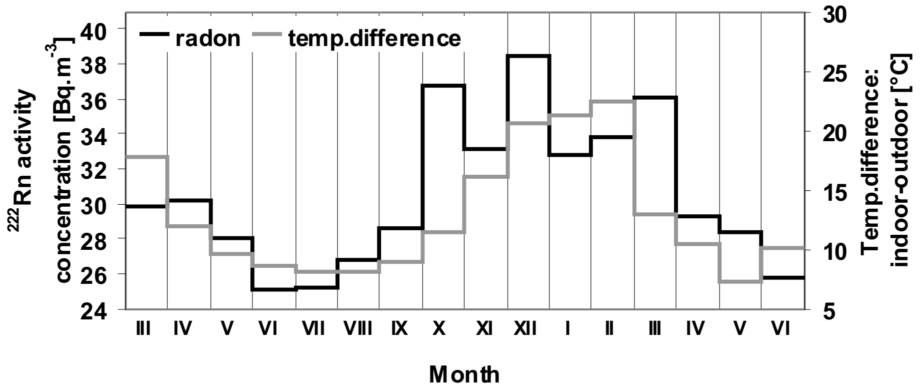

Fig. 3. The monthly mean values of radon activity concentration and the indoor-outdoor temperature differences.

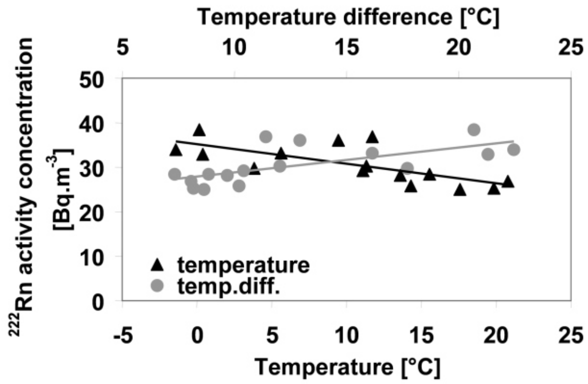

Fig. 4. The relation between monthly mean values of radon activity concentration, the outdoor temperature and the indoo-outdoor temperature differences.

(~30 $Bq{\cdot}m^{-3}$). The yearly and mean daily courses of the radon activity concentration obtained by us are depicted in Fig. 2. The annual courses show seasonal variations with a minimum in the summer months (June – August) and a maximum in the late autumn and winter months (October – February). The amplitude of the annual courses reaches 7 $Bq{\cdot}m^{-3}$. The high values of radon activity concentration in the winter months are caused by high minima of the average daily waves in this time period; the low monthly mean values in the summer months are caused by low placed minima as well as low maxima of the average daily waves in these months. The highest amplitudes of daily waves were observed in the summer months (~6 $Bq{\cdot}m^{-3}$ and $A_{Rn,max}/A_{Rn,min}$ 1.8), the lowest in the winter months (~3 $Bq{\cdot}m^{-3}$ and $A_{Rn,max}/A_{Rn,min}$ 1.2) (Fig. 2).

As can be seen in Fig. 2, the time courses of ^{222}Rn activity concentration in all years show a similar character. The maxima and minima of the radon activity concentration occur approximately at the same time. However, the best agreement between the courses is during April-September, the greater dispersions are observed mainly in the winter months. In this period, the average monthly radon activity concentrations differ from each other by up to 25%.

The long-term trends of the monthly mean values of radon activity concentration and indoor-outdoor temperature differences are shown in Fig. 3. In Fig. 4 the results of the correlation analysis between the monthly mean values of radon activity concentration and the outdoor temperature as well as between the radon activity concentration and the indoor-outdoor temperature difference, are shown. We can see that the monthly mean values of radon activity concentration are indirectly proportional to the outdoor temperature and directly proportional to the indoor-outdoor temperature difference. These results do not confirm the assumption that radon variations are caused only by an air exchange driven by temperature difference between the indoor and outdoor atmosphere.

Further, we studied in detail the daily courses of the radon activity concentration. The daily radon courses obtained by us have a shape of regular waves with a maximum in the early morning and minimum in the afternoon. The daily wave calculated on the basis of all radon data shows a maximum in the early morning (at about 6 o'clock) and a minimum in the afternoon (at about 16–18 o'clock) (Fig. 5).

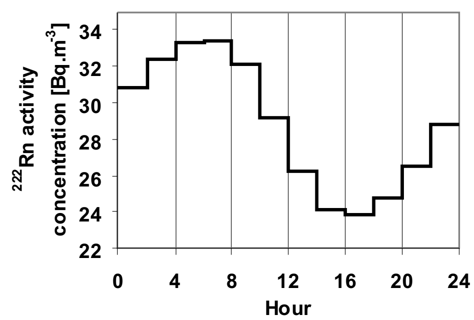

Fig. 5. The mean daily course of ^{222}Rn activity concentration obtained in the investigated room.

The comparison of daily radon courses for the summer period (June 2004 August 2004) and the winter period (December 2004 February 2005) can be seen in Fig. 6. The mean daily wave of ^{222}Rn activity concentration in the winter period has nearly one half amplitude of the mean daily wave in the summer.

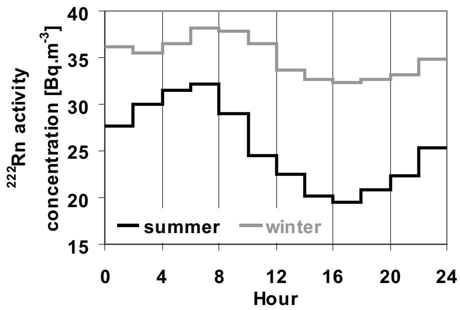

Fig. 6. Comparison of average daily waves of radon activity concentration for the summer (June – August) and winter period (December – February).

In the investigated room the indoor temperature is almost constant throughout the year. Then it is clear that the daily courses of the outdoor temperature show an excellent anti-correlation (R^2 ~ 0.99) to indoor-outdoor temperature differences. The Fig. 7 shows that in the winter period, when the outdoor temperature is lower than in the summer period, an indoor-outdoor temperature difference is higher in comparison to the summer period.

The next picture (Fig. 8) shows: A) the average daily courses of radon activity concentration and the outdoor temperature, B) the average daily courses of radon activity concentration and the indoor-outdoor temperature difference calculated on the basis of all radon data.

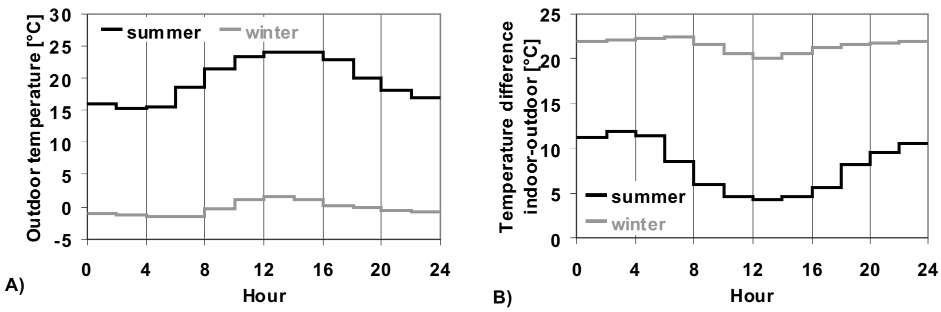

Fig. 7. Comparison of average daily courses of outdoor temperature (A) and indoor-outdoor temperature difference (B) for the summer (June – August) and winter period (December – February).

The radon activity concentration in the workroom of the office building shows a clear anti-correlation (R^2 = 0.49) to the outdoor temperature (Fig. 7A). However, a shift of two hours is observed between the diurnal extremes of temperature and radon concentration,

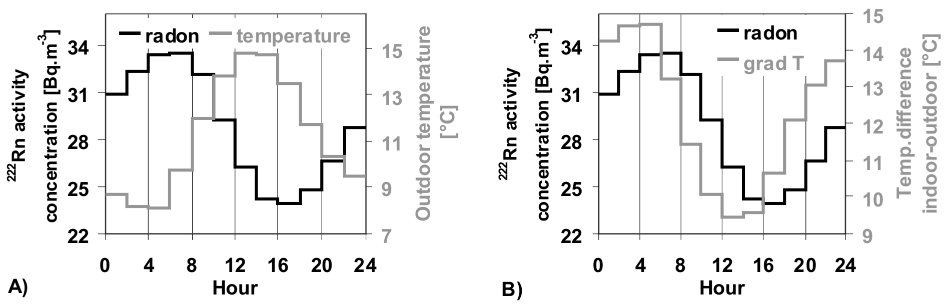

Fig. 8. Comparison of average daily courses of radon activity concentration and A) outdoor temperature and B) indoor-outdoor temperature difference.

too. If the data of the outdoor temperature are shifted by 2 hours forward in time, the anti-correlation coefficient improves to 0.93. The radon activity concentration in the workroom shows a clear correlation ($R^2 = 0.42$) to the indoor-outdoor temperature difference (Fig. 7B). If the data of the indoor-outdoor temperature difference are shifted 2 hours forward in time, the correlation coefficient improves to 0.89.

In the next part, we compared the average daily courses of the radon activity concentration, the outdoor temperature and the indoor-outdoor temperature differences for individual months of one year: April 2004 – March 2005 (Fig. 9). We can see that anti-correlations exist between the radon activity concentration and the outdoor temperature. For the time period from spring to autumn the anti-correlation coefficient between the radon activity concentration and the outdoor temperature is from the range ($R^2 \sim 0.33$–0.54). The highest anti-correlation was found in the months of March, April and October. The weakest anti-correlation was in the months November and December ($R^2 \sim 0.05$).

The average daily courses of the radon activity concentration and the indoor-outdoor temperature differences for individual months are in correlation. For the time period from spring to autumn the correlation coefficient is from range ($R^2 \sim 0.30$–0.55). The highest correlation was found again in the months of March, April and October. The correlation between these time courses was rather weak ($R^2 \sim 0.05$) in the months November and December.

Then it is clear that anti-correlation between the radon activity concentration and the outdoor temperature obtained in the summer period (June – August) was better ($R^2 \sim 0.40$) than anti-correlation in the winter period (December – February) when it was weaker ($R^2 \sim 0.27$). Also for correlation between the radon activity concentration and the indoor-outdoor temperature difference, better correlation coefficient $R^2 \sim 0.31$ was obtained in the summer period than in the winter period ($R^2 \sim 0.20$).

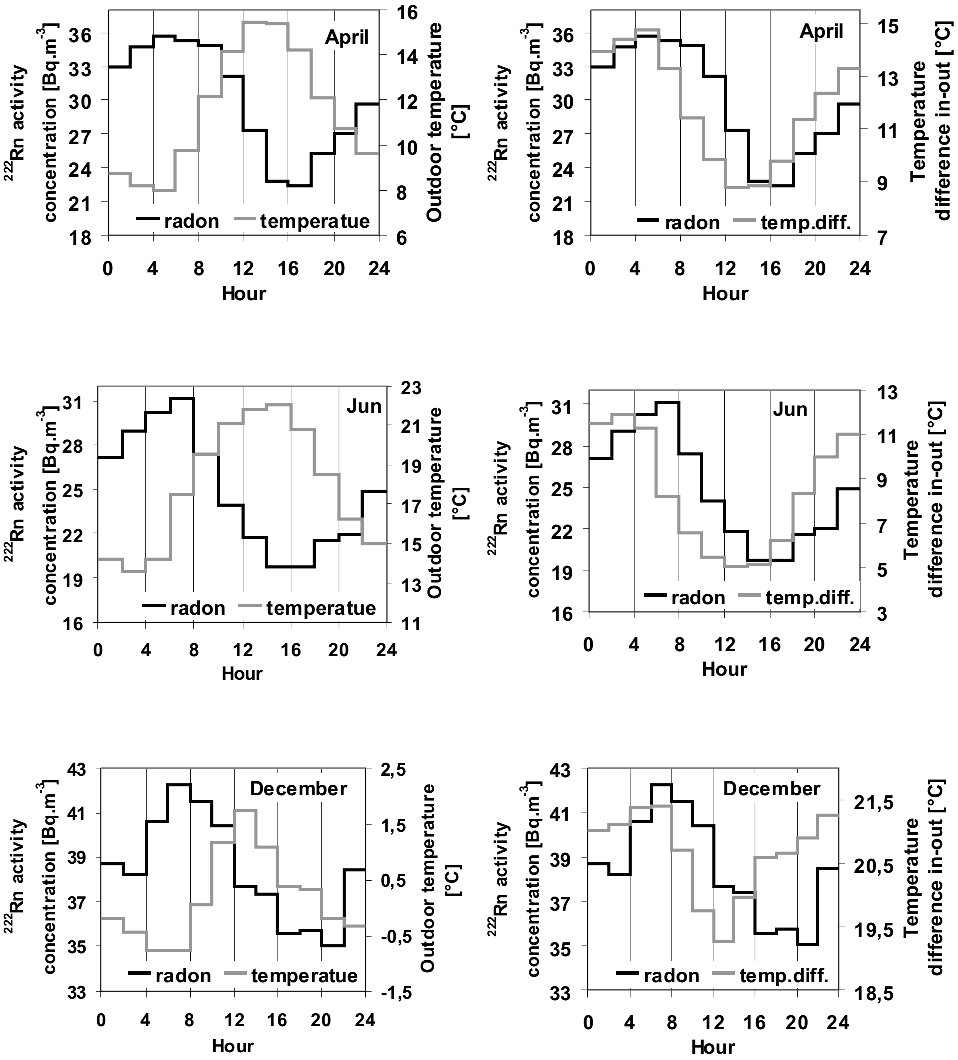

Fig. 9. The daily courses of radon activity concentration, outdoor temperature and indoor-outdoor temperature differences.

4. Conclusion

Long-term continual radon monitoring in a room of a multi-storey building was realized. The most significant source of radon in the room was the building materials; the other radon sources were negligible. The average radon activity concentration in the room was only 30 Bq·m^{-3}. The daily and seasonal variations of the radon activity concentration were found out in this room.

Daily variations show the maximum in the morning and the minimum in the afternoon, seasonal variations show the minimum in the summer months (June – August) and the maximum in the late spring and in winter (October – February). The courses of radon activity concentration show a similar character for all the years. The maximum radon activity concentration was in a good correlation with the maximum indoor-outdoor temperature difference and vice versa.

This result is in contradiction with the conclusions following from Equation (2) [4, 6], but also with the results obtained by H. Arvela et al. [8] in a study of radon in the Finnish homes. According to those works, the highest values of radon activity concentration in a room would occur in the period with the minimal indoor-outdoor temperature difference at a constant radon entry to the room. It seems that there is also other than the above mentioned mechanism which has a significant influence on the exchange processes between the indoor and outdoor atmosphere. In present, this mechanism is being intensively investigated.

Acknowledgements

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