MEASUREMENTS OF RADON ENTRY PARAMETERS IN THE BUILDINGS

M. Zhukovsky, A.Vasilyev

Institute of Industrial Ecology UB RAS, Ekaterinburg, Russia

Abstract. There are two basic radon entry mechanisms: diffusion due to the gradient of radon concentration in the environment and advection caused by the pressure difference between building envelope and outdoor atmosphere. Air exchange rate between outdoor and indoor atmosphere has significant effect on the amount of radon concentration.

The experimental technique of the assessment of radon entry rate and air exchange rate in the room is developed and experimentally verified. The technique is based on the analysis of time series of radon concentration under active and steady-state conditions of room use. For measurements the radon monitor AlphaGUARD was selected. In the steady state condition natural ventilation in the room is usually less than in the active mode. In the steady state the accumulation of radon is a process of attaining of the equilibrium between radon entry and its removing by ventilation. For assessing of the radon entry rate and air exchange rate in the room it is proposed to use for analysis the whole curve of radon accumulation, not only the value of radon concentration at the end of exposure. A series of measurements of radon concentration is described by nonlinear mathematical regression, characterized by the accumulation of radon in a room in steady-state condition of room use.

For sufficiently long-term measurements, including warm and cold seasons, the dependence of ventilation rate on the difference between indoor and outdoor temperature was studied. For each room dozens of daily radon accumulation curves has been analyzed. It is demonstrated that the study of dependence of radon entry rate on temperature difference ΔT between indoor and outdoor atmosphere allows to estimate the dominant radon entry mechanism – diffusion mechanism (absence of the dependence on ΔT) or convective (Rn entry rate increase at ΔT increase). It is shown that simultaneous measurements of time series of radon concentration and pressure difference between building envelope and outdoor atmosphere allow assessing such room parameter as Effective Leakage Area.

Key Words: radon entry; air exchange rate.

1. Introduction

Radon is a naturally occurring radioactive gas that is formed in radium-bearing materials in soil and buildings. It is well known that the radon and its decay products are responsible for about half the total population dose from natural sources of ionizing radiation (UNSCEAR, 1988). It is proved that radon is the second cause of lung cancer initiation after the smoking (Zeeb and Shannoun, 2009). Radon concentration depends on the radon entry rate and air exchange in the buildings and significantly higher in the indoor atmosphere compared to outdoor.

In this paper the mechanisms of radon entry in the buildings are examined in detail. The purpose of this analysis is determination of the method for estimation of radon entry mechanisms and the critical parameters describing these processes. This paper deals with measurements of indoor radon concentration in the city Ekaterinburg, Russia.

2. Modeling approach for radon entry

There are two basic radon entry mechanisms: diffusion due to the gradient of radon concentration in the environment and advection caused by the pressure difference between building envelope and outdoor atmosphere.

Air exchange rate between outdoor and indoor atmosphere has significant effect on the amount of radon concentration. There are three basic means by which buildings are ventilated (Sherman, 1998c) – mechanical ventilation by exhaust or supply fans, natural infiltration due to the wind, and natural infiltration due to the stack effect.

Description of the processes of radon entry in buildings can be made using the Sherman's concept (Sherman, 1998a, 1998b, 1998c, 1998d) of Effective Leakage Area (ELA) and Radon Leakage Area (RLA).

Airflow Q (m^3/s) entering the room due to the existing pressure difference can be expressed by the leakage area, ELA, and an exponent n, which depends on the aerodynamic characteristics of infiltration and exfiltration areas in the building:

$$Q = ELA\, v_0 \left(\frac{\Delta P}{P_0}\right)^n, \tag{1}$$

Where ΔP is pressure difference which causes the airflow Q and $v_0 = 2.56$ m/s is the (reference) velocity related to the reference pressure, P_0=4 Pa:

$$v_0 \equiv \sqrt{\frac{2P_0}{\rho_0}} \;, \tag{2}$$

where ρ_0 is density of air under the reference pressure. An exponent n range from 0.5 to 1.0 is presented in (Sherman, 1998c). It is noted that for most buildings $0.55 \le n \le 0.75$, as well as a sample value shall be n = 2 / 3.

We can define a Radon Leakage Area (RLA) for radon entry that is analogous to the Effective Leakage Area used for building envelope air leakage:

$$Q_{Rn} = C_\infty RLA\, v_0 \left(\frac{\Delta P}{P_0}\right)^{n_r} \tag{3}$$

where $\Delta P = \Delta \rho g H$, H is height of the building and the difference in air density $\Delta \rho = \rho_0 \frac{T_{indoor} - T_{outdoor}}{T_{indoor}}$ is determined by the temperature difference between the building envelope and outdoor atmosphere. We shall assume that no depletion or other in-soil dilution of radon takes place. For the building with a floor slab, which lies directly on the ground, and buildings with a basement, exponent n_r is assumed equal to one. The index r means that the parameter is typical for radon. For buildings with an underground space and the soil floor, the exponent n_r shall be the same as exponent n for the whole building envelope (Sherman, 1998b).

When compiling the equation describing the accumulation of radon in dwellings, the following main processes were considered (Sherman, 1998b):

- the diffusion entry from the soil and materials of building constructions S_D,
- convective entry due to stack effect,
- infiltration of air with radon concentration (A_{Rn}^{atm}) and ventilation rate Q associated with this mechanisms.

Observed wind effect for the Ural region will be negligible compared to the influence of the temperature difference between the indoor and outdoor atmosphere. Since ventilation of the all studied dwellings is natural, the effect of exhaust ventilation can be ignored.

The general equation describing the process of radon entry in dwellings and concurrent air exchange is very cumbersome. It includes a fairly large number of parameters which are unknown for a specific building. However, we can introduce a number of generalizing coefficients permanent for each individual building. This allows us to write the general equation for the dependence of steady state values of radon concentration as:

$$A_r = \frac{A_{\infty} R L X_S \left[\frac{\Delta T}{T_1}\right]^n + S_D}{E L \left[X_S \left[\frac{\Delta T}{T_1}\right]^n + Y_W \right]} + A_{Rn}^{atm} \qquad (4)$$

For a specific building the ventilation rate due to wind effect is constant and proportional to some value which depends on the distribution of entry and escape areas in the building. In turn, air change rate due to stack effect is proportional to Y_S and dependent on the temperature difference between indoor and outdoor air. Radon entry rate due to stack effect is also defined by the temperature difference and is proportional to some quantity characterizing the position of the neutral plane (the level where the stack effect caused by the pressure difference between indoor and outdoor air is zero). Detailed descriptions of radon entry mechanisms and air exchange, as well as equations for the quantities X_S, Y_S, Y_W can be found in (Sherman, 1998b, 1998c, 1998d).

Using the expression (4) we can find dependence of radon concentration on temperature difference between indoor and outdoor air. Variation of radon concentration depending on temperature difference for different relations between the advective and diffusion mechanisms of radon entry is shown on the Fig. 1.

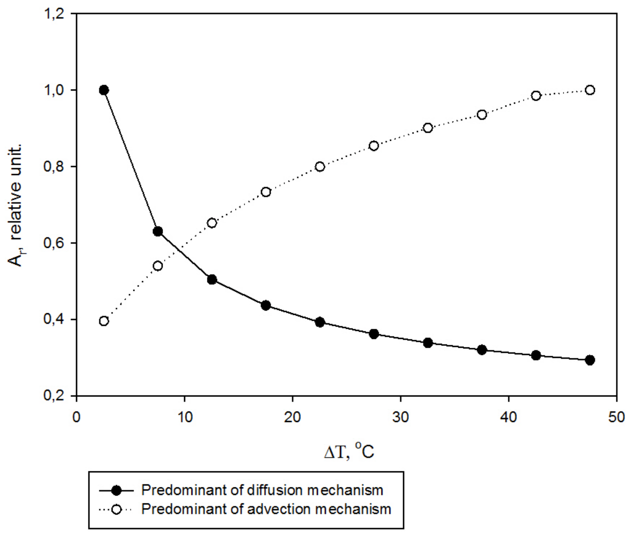

Fig. 1. Dependence of radon concentration on temperature difference for different mechanisms of radon entry

3. Measurements and analysis of experimental data

There are a number of methods and tools for measuring radon concentration in the atmosphere of dwellings. For the purposes of continuous measurements radon-monitor AlphaGUARD was selected. It allows carrying out continuous measurements of radon concentration, atmospheric pressure and room temperature. The measurement interval was set to 60 minutes. Additionally, for number of dwellings AlphaGUARD Multisensor Unit was used, which allowed to measure the temperature and pressure difference between the envelope of the building and the outdoor atmosphere.

The method consists of the continuous measurement of radon concentration, temperature and pressure difference between indoor and outdoor atmosphere.

Series of continuous measurements of radon concentration in buildings in Ekaterinburg, Russia were conducted during five periods: December 2004 – June 2005; May 2008 – September 2009; September 2009 – April 2009; June 2010 – December 2010; January – December 2011. Measurements were performed in seven residential buildings and three laboratories. Continuous measurements were used to analyze seasonal variations.

Five rooms (three laboratories and two residential) with the most significant radon concentrations were selected. A typical form of radon concentration time series for one of the representative room is shown in Fig. 2. For buildings with low level of radon concentration (not exceeding 20 - 30 Bq/m3) there is no possibility to identify any significant dependence of radon concentration on ambient conditions (Fig.3).

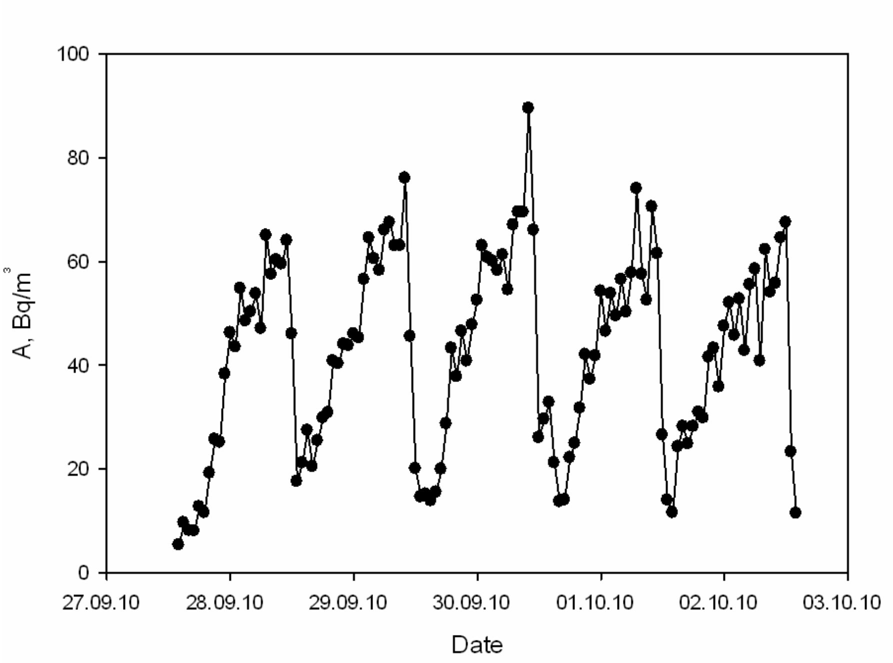

Fig. 2. Typical radon concentration time series

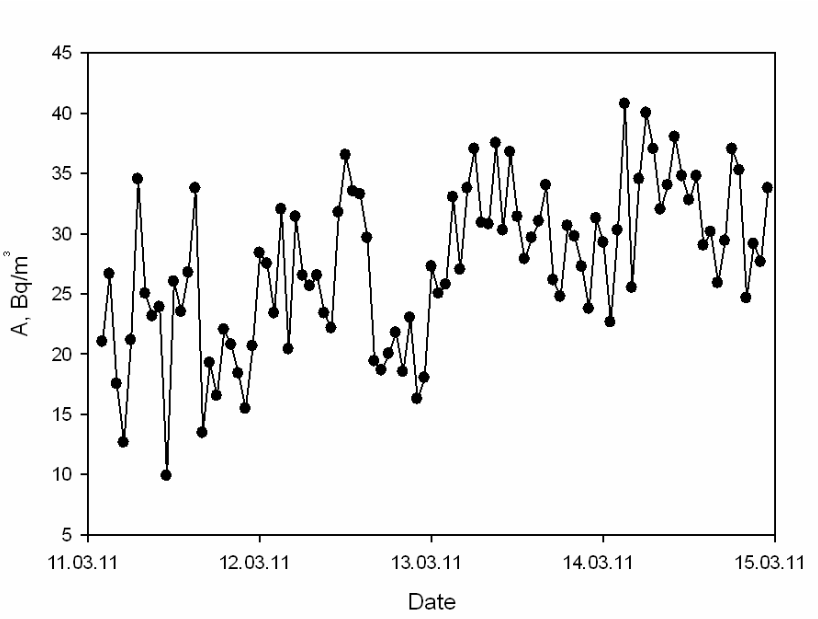

Fig.3. Radon concentration time series for buildings with low level of radon concentration

To determine the intervals of radon accumulation in the general experimental data special software was developed. Block diagram of the program algorithm is shown in Fig. 4. After the identification of the radon accumulation time series, a statistical analysis of accumulating curve was performed. Separate series of measurements were used for calculating the numerical values of the random errors and the asymptotic values of A_0, A_{max} and λ.

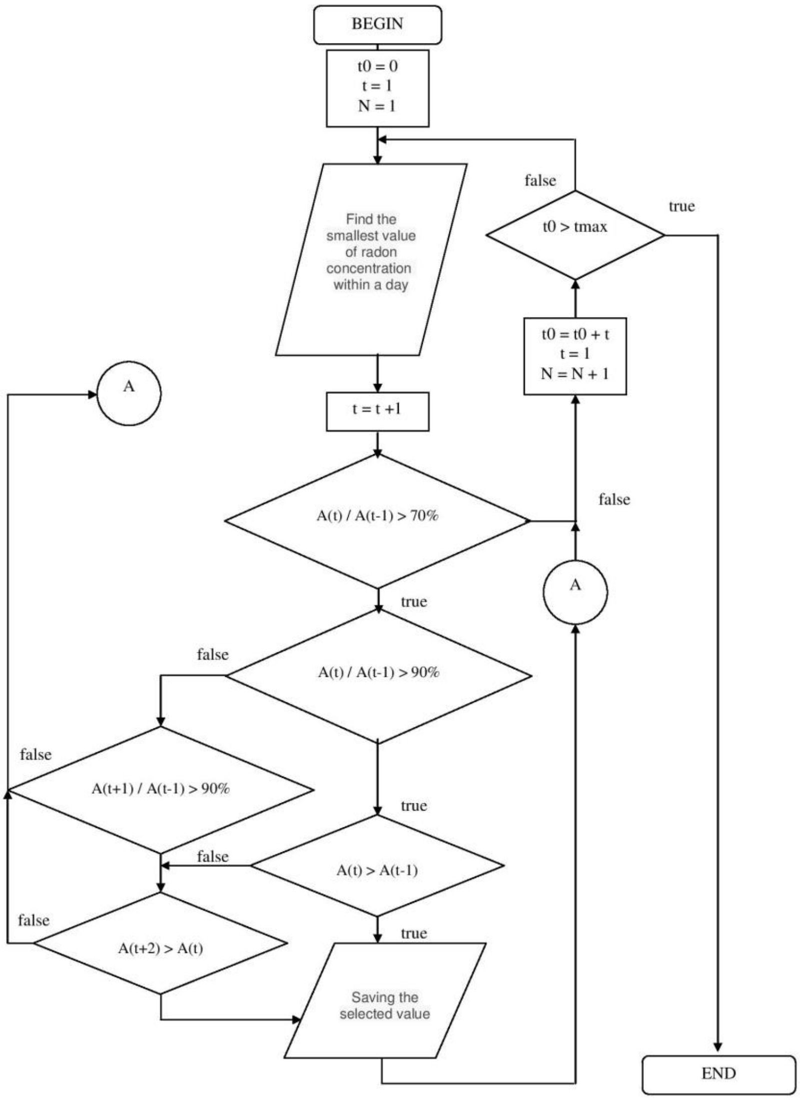

Fig.4. Block diagram of the program for time series analysis

Typically, rooms are used under two conditions: active mode (with human activity in the room) and a steady state (when people leave the room at the end of the day or go to bed). In the steady state condition natural ventilation in the room is usually less than in the active mode. In the steady state the accumulation of radon is a process of attaining of the equilibrium between radon entry and its removing by ventilation. It is proposed to use whole curve of radon accumulation, not only value of radon concentration at the end of exposure. A series of measurements of radon concentration is described by nonlinear mathematical regression, characterized by the accumulation of radon in a room in steady-state condition of room use (Zhukovsky et al., 1999):

$$A(t) = A_{max}(1 - e^{-\lambda t}) + A_0 e^{-\lambda t} + A_{Rn}^{atm}, \quad (5)$$

where A_0 is radon concentration in the initial time except A_{Rn}^{atm}, A_{Rn}^{atm} =10 Bq/m^3 – radon concentration in outdoor air, A_{max} is the maximum radon concentration, which can be achieved in a room under the given conditions, λ is air ventilation rate, h^{-1}.

Equation (5) can be considered as a base for modeling the radon entry and accumulation in the atmosphere of the dwellings. Using the values of A_{max} and λ estimated from the equation (5) we can determine radon entry rate:

$$\dot{A} = A_{max} \cdot \lambda \qquad (6)$$

where $\dot{A}$ – radon entry rate, $Bq \cdot m^{-3} \cdot h^{-1}$.

For sufficiently long term measurements, including warm and cold seasons, one can obtain the dependence of ventilation rate on the difference between indoor and outdoor temperature. For each room dozens of daily radon accumulation curves has been analyzed. The obtained data were grouped according to temperature ranges and presented in Fig. 5. For all rooms under steady-state conditions the rise of ventilation rate under increasing temperature difference was observed.

The dependence of radon entry rate on temperature difference ΔT between indoor and outdoor atmosphere allows to estimate the dominant radon entry mechanism – diffusion mechanism or advective. Fig. 6 shows such dependence for all the surveyed rooms. As can be seen from Fig.6 radon entry rate for rooms 1-3 and 5 remains almost unchanged at increasing temperature difference. Because of that the diffusion mechanism of radon entry in buildings is predominant. But for room 4 there is a significant growth of radon entry rate, which indicates the predominance of the advective mechanism.

A significant amount of additional information on air exchange processes can be obtained by conducting measurements of the pressure difference between the indoor and outdoor atmosphere. Such measurements were conducted in the room 1. Using the estimates of the minimum ventilation rate for corresponding pressure difference it is possible to estimate dependence of the effective leakage area on the temperature difference between the building envelope and the outdoor atmosphere (Fig. 7).

4. Conclusions

The experimental technique of the assessment of radon entry rate and air exchange rate in the room is developed and experimentally verified. It is demonstrated that the study of dependence of radon entry rate on temperature difference ΔT between indoor and outdoor atmosphere allows estimating the dominant radon entry mechanism – diffusion mechanism (absence of the dependence on ΔT) or convective (Rn entry rate increase at ΔT increase). It is shown that simultaneous measurements of time series of radon concentration and pressure difference between building envelope and outdoor atmosphere allow assessing such room parameter as Effective Leakage Area.

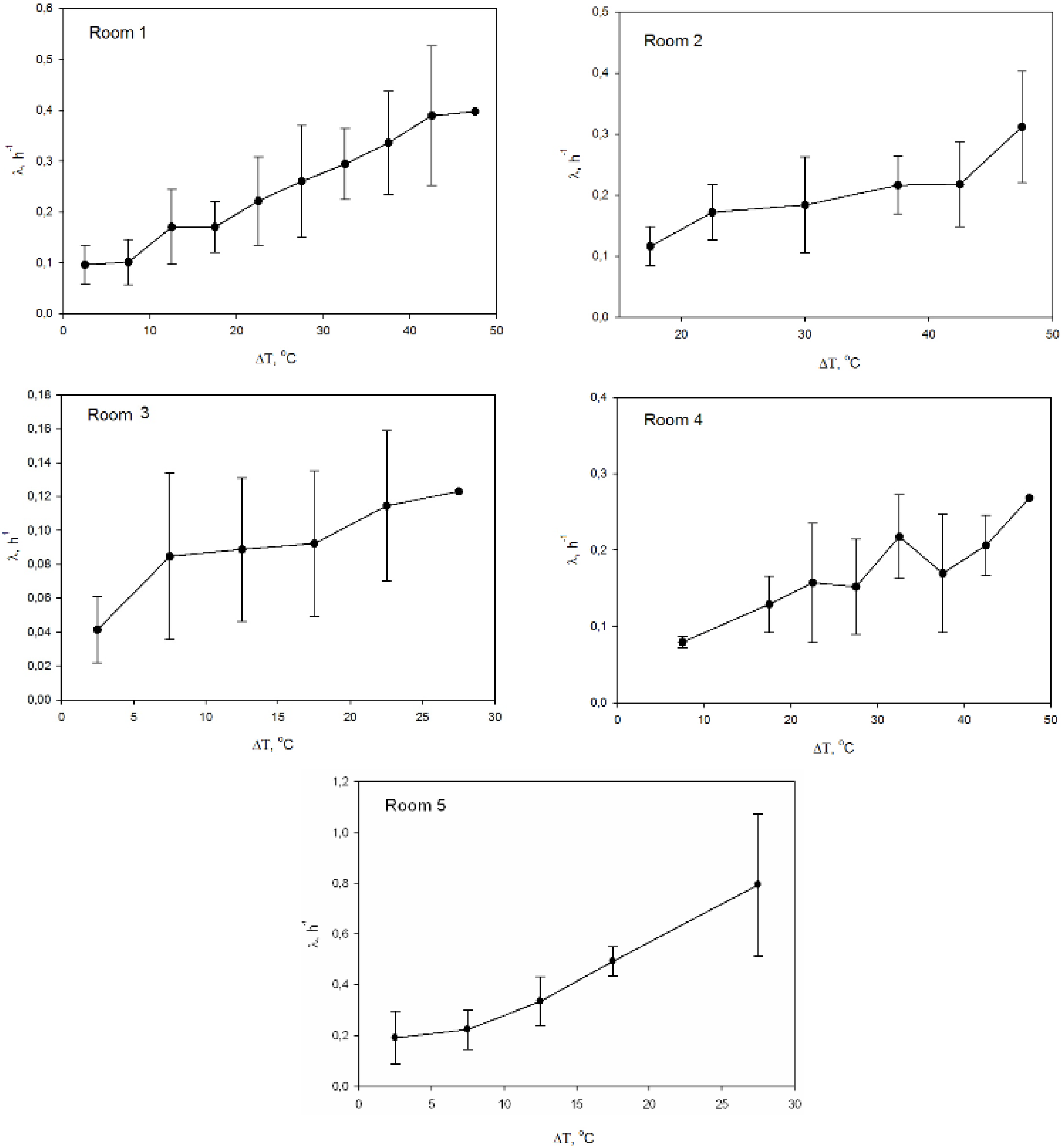

Fig. 5. Dependence of ventilation rate on the temperature difference

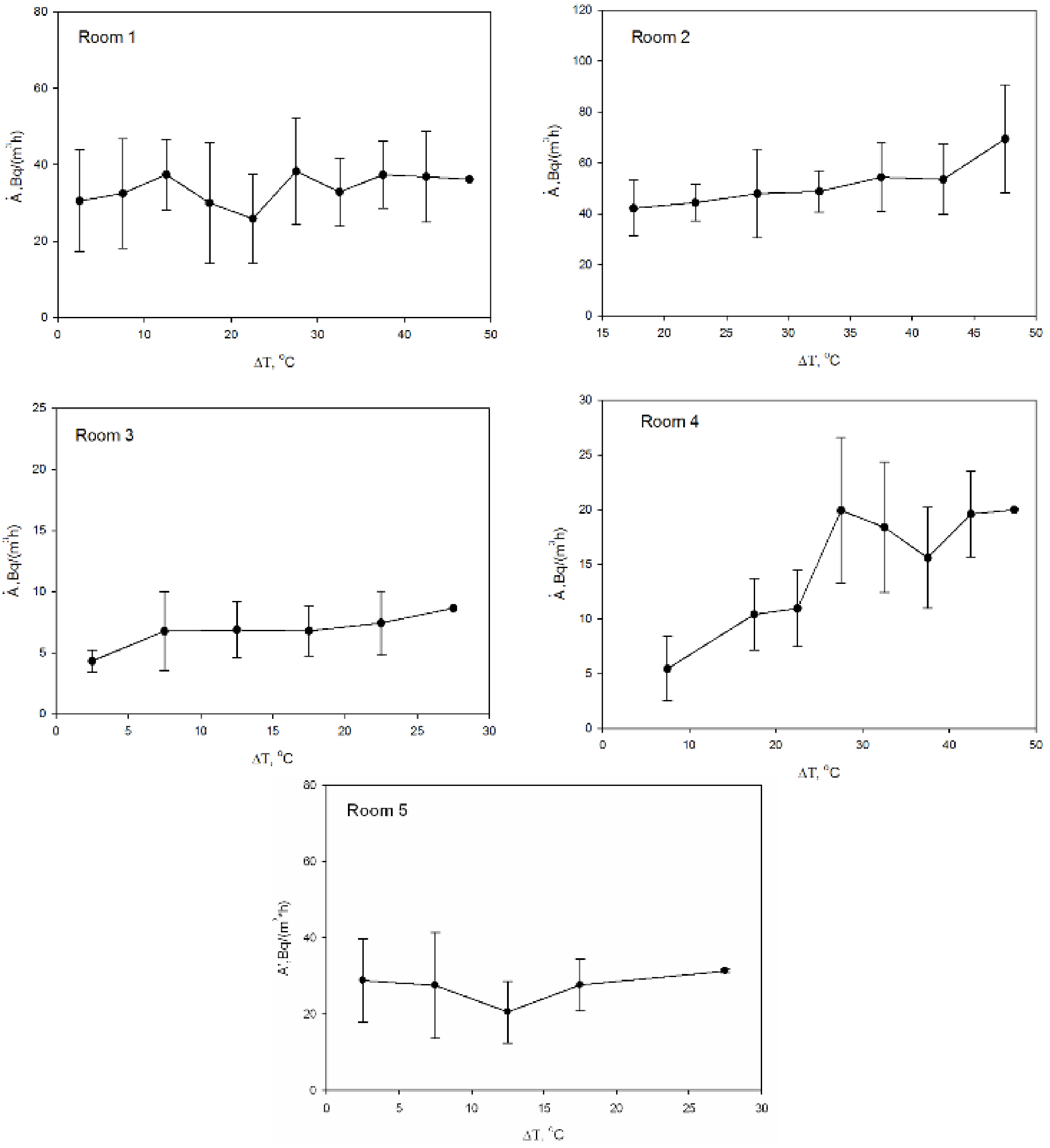

Fig 6. Dependence of radon entry rate on temperature difference ΔT between indoor and outdoor atmosphere

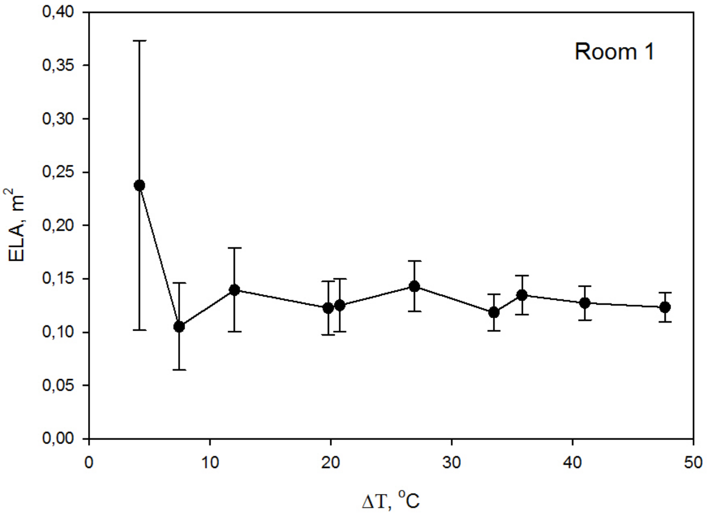

Fig. 7. Dependence of the effective leakage area on the temperature difference between the building envelope and the outdoor atmosphere

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