Radon monitoring in a historical building in Košice city, Slovakia – a case study

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Abstract. It is known that the highest contribution to the yearly radiation dose for the population derives from natural radioactivity. About 50% of that is estimated to be caused by exposure to radon (Rn) and its products. Human exposure to indoor Rn is currently considered a relevant research topic, because of the associated epidemiological aspects. This paper aimed at Rn concentration measurement in a selected building in Košice city, Slovakia. The continuous monitoring of indoor radon levels was performed over a period of 40 days. The measured concentrations ranged in a wide interval up to 92 Bq/m³. The WHO limit value of 100 Bq/m³ wasn’t exceeded. Analysing the possible sources, both contributions of radon from the building materials and radon from the soil was observed.

1. Introduction
Nowadays, it is known that a correlation exists between exposure to natural radiation and several types of cancer, but it is still uncertain whether a threshold exists for effects. A radioactive isotope of radon $^{222}\text{Rn}$ is present in variable concentrations everywhere on earth, atmosphere, rocks, soils, waters and building materials [1]. Rn concentration in the atmosphere ranges between 0.37 and 16 Bq/m³ [2], with a mean of 8 Bq/m³ for continental areas.

For most people, the greatest exposure to radon occurs in the home where people spend much of their time, though indoor workplaces may also be a source of exposure. The concentration of radon in buildings depends on the local geology, for example the uranium content and permeability of the underlying rocks and soils; the routes available for the passage of radon from the soil into the building; the radon exhalation from building materials and the rate of exchange between indoor and outdoor air, which depends on the construction of the building, the ventilation habits of the occupants, and the air-tightness of the building [3]. The average volume activity of $^{222}\text{Rn}$ in dwellings differs in countries and varies from 10 to 100 Bq/m³ [4].

Building materials can be an important source of radon concentrations, since the raw materials used to the manufacturing of the most building products (concrete, brick, stone) contain primordial radioisotopes of thorium, potassium and uranium. Radon occurs an intermediate step in the normal radioactive decay chains of thorium and uranium whereas being the immediate decay product of radium. Thorium and uranium are two of the most common radioactive elements on Earth, while also having three isotopes with half-lives on the order of several billion years. The decay of radon produces many other short-lived nuclides, known as radon daughters, ending at stable isotopes of lead [5].

Radon originating from the underground layers enters buildings through cracks in the floors or at floor-wall junctions, gaps around pipes or cables, small pores in hollow-block walls, cavity walls, or sumps...
or drains. Radon levels are usually higher in basements, cellars and living spaces in contact with the ground. However, considerable radon concentration can also be found above the ground floor [3]. Radon concentrations vary considerably between adjacent buildings, as well as within a building from day to day and from hour to hour. Because of these fluctuations, it is preferable to estimate the annual mean concentration of radon in indoor air by measurements for at least 3 months. Residential radon levels can be measured in an inexpensive and simple manner by means of small passive detectors. Measurements need to be based on national protocols to ensure consistency as well as reliability for decision-making. Short-term radon tests, done in compliance with national protocols, can be valuable when making decisions during time-sensitive situations, such as home sales or to test the effectiveness of radon mitigation work [3, 5].

This paper focuses on the investigation of the radon indoor levels in a selected historical building in the summer season.

2. Materials and methods
The sampling site was in building located in the downtown of Košice – Poštvá Street (Figure 1). The construction was built in 1956 according to the project of architect Ferdinand Zbušek. At present, the building is a residential building with several apartments, reconstructed inside. The main bearing walls are original, as the building stands in a historic centre in a protected area and no major renovations were allowed here.

Radon activity measurement was performed in an apartment on the 4th floor over a period of 40 days from 1.6.2021 to 9.7.2021. The apartment with a total area of 74 square meters had two rooms, living room connected with kitchen, balcony, and bathroom.

![Figure 1. The sampling site and the location of the measuring equipment.](image-url)

The measurements were performed under normal operation not excluding the presence and moving of inhabitants and the apartment was naturally ventilated most of the time during the measurement by a USB Radon Probe TSR 4M (Tesla, Czech Republic). No ventilation tube/ducts were in any room during the monitoring. The normal operational conditions in the apartment mean that the inner doors in the monitoring apartment were opened or closed according to the request and habits of the inhabitants during the measurement. The USB Radon Probe equipment designed for continuous measuring of radon concentrations in buildings was placed 150 cm above the floor. A portable probe basis is a measuring chamber with a semiconductor photodetector. Radon enters the chamber by diffusion through the input filter on the bottom of probe. The probe measures in autonomous and time continuous way. Short-term average radon concentration results were processed based on 2-minute intervals (1 hour moving average). Long-term moving average of radon concentration was calculated based on the 24-hour moving average. The probe saved time records of these radon concentration values including values of humidity and temperature within its internal memory (typically at an interval of 1 hour). Bottom of the probe was ensured not to be covered [6]. The concentrations of radon were compared to the WHO limits...
and also confronted to the mass activities of the main radionuclides (\(^{226}\text{Ra},^{232}\text{Th}\) and \(^{40}\text{K}\)), which were studied in building materials collected from the basement of the same building in our previous study [7].

3. **Results and discussion**

The indoor temperature in the monitored room ranged from 20 to 30°C with an average of 24.6 °C (Figure 2). Average indoor relative humidity was 50.68% with a maximum of 62 % and a minimum of 38% as seen in Figure 2.

![Figure 2](image-url)

**Figure 2.** Trends in temperature and humidity during monitoring.

The measured volume activities of radon are illustrated in Figure 3. The values ranged from 0 to 92 Bq/m\(^3\) with an average value of 10.73 Bq/m\(^3\) (Fig. 3). The average concentration in European countries ranges from 10 Bq/m\(^3\) to over 100 Bq/m\(^3\) as reported in [8]. The variation in the measured values is probably due to the natural air exchange. The measured average radon concentration in this study corresponds also to the concentration, which is typical in a well-ventilated place, similar to the outdoor values (typically 10 Bq/m\(^3\)) [9]. The limit value of 100 Bq/m\(^3\) recommended by WHO wasn’t exceeded during these days and thus no significant health risk regarding the radon exposure was observed for the inhabitants in the monitored apartment. Another monitoring will be performed during the winter season, when the natural ventilation is much less intensive and the radon indoor concentrations could likely reach the higher values.
As mentioned before, the mass activities in building materials (brick and stone) from the studied building were investigated in our previous work [7]. The results of the content of radionuclides in the samples (539.89, 11.13, and 57.05 Bq/kg for $^{40}$K, $^{226}$Ra, and $^{232}$Th, respectively) proved an acceptable level and the gamma index $I_\gamma$ was 0.5, which was lower than the limit value ($I_\gamma \leq 1$). For the estimation of exposure due to the radon gas emanation from building materials, an alpha index $I_\alpha$ (Eq. 1) was applied [10,11].

$$I_\alpha = \frac{A_{Ra}}{200} \text{Bq/kg} \quad [-]$$  \hspace{2cm} (1)

where $A_{Ra}$ represents a mass activity of radium measured in the material. The radium content is of importance since the radon itself is the decay product of radium. Its most stable isotope, $^{222}$Rn, has a half-life of only 3.8 days, making it one of the rarest elements.

$I_\alpha$ in our study was calculated to reach the value of 0.05, which is significantly lower than the limit value. Alpha index $I_\alpha$ of value equal to 1, stated as a recommended value, relate to radium mass activity of 200 Bq/kg. Materials with Ra concentration lower than 200 Bq/kg could not cause indoor radon concentration higher than 200 Bq/m$^3$. Considering the $I_\alpha$=0.05 found from the materials analysis, the average radon activity linked to the emanation from the building materials can be estimated at about 10 Bq/m$^3$. This value, based on radium content in the materials strong correlate to the average value measured in the apartment. The maximum radon level of 92 Bq/m$^3$ can likely originate from the other source, e.g. soil foundation.

4. Conclusion
This paper presents the results of monitoring the radon concentrations indoors, in a selected apartment in a historical building during the summer season. The average radon concentrations (10.73 Bq/m$^3$) were much lower than the permissible limit, and reflected the average concentrations in ventilated rooms. Even the maximum concentration of 92 Bq/m$^3$ measured, did not exceed the permissible limit. When analysing the possible sources, both contribution of radon from the building materials and radon from the soil was observed.

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