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REDUCTION OF INDOOR RADON CONCENTRATION IN A ROOM USING HEAT RECOVERY VENTILATION

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ABSTRACT

Increased requirements for the energy efficiency of buildings often lead to an increase in the tightness of the building envelope. Tightness of the external cladding has a significant effect on the intensity of air exchange. A lower level of ventilation subsequently worsens the quality of the indoor air and also causes an increase in the indoor radon concentration. This problem can be solved by using ventilation devices with heat recovery. The paper deals with the influence of local ventilation equipment with heat recovery on indoor radon concentration. The case study compares different settings of ventilation equipment from the point of view of pressure ratios between interior and exterior. During the measurements, external weather conditions are also monitored, which may affect the results. The aim of the paper is to evaluate the rate of reduction of indoor radon concentration by using this method of ventilation and determine the correct way to set up the ventilation equipment.

KEYWORDS

Mechanical ventilation, Radon concentration, Energy saving

INTRODUCTION

In times of energy crisis and high energy prices, people are forced to take measures to reduce energy consumption in buildings. Funds to ensure these measures can currently be obtained from the Recovery and Resilience Plan approved by the European Commission. Part of these funds is intended precisely for improving the energy efficiency of family homes and the restoration of public historic and heritage-protected buildings. Investments are also intended for the renewal of the building envelope, the replacement of windows or the provision of a more efficient heat source [1]. With these solutions, it is also important to think about the need for sufficient ventilation as energy-saving measures which usually reduce heat loss through the building envelope and subsequently reduce the rate of air exchange [2], [3]. The purpose of ventilation is to remove contaminants, to create good indoor air quality and to reduce the risk of health problems by introducing and circulating fresh air throughout the building.

Among the health-threatening substances accumulating in the internal environment of buildings is radon. Radon mixes with atmospheric air in exterior. However, in closed indoor spaces it accumulates and increases in harmful concentrations [4]. Among the most important sources of radon in the interior are subsoil, groundwater and building materials. With its products, radon enters the respiratory tract by inhalation, which can subsequently cause cancer. According to the World Health Organization, it is the second most common cause of lung cancer after smoking [5].

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The necessity to deal with indoor air quality while increasing the energy efficiency of buildings was confirmed in a French study [6]. It demonstrated the significant impact of renovation and modernization of buildings on the increase in indoor radon concentrations. The study from the United Kingdom [7] investigated the consequences of reducing the ventilation of buildings by increasing the air tightness of the envelope, demonstrating the possibility of increasing radon concentration by more than 56 %.

It is possible to achieve the required air exchange and reduction of energy losses through ventilation with heat recovery at the same time. The results of a simulation study from Ireland [8] highlight that radon concentrations in buildings could potentially change depending on the ventilation strategies designed during renovations. Currently, there are many central and decentralized recuperation units on the market that can be used for this purpose. The contribution is devoted to measuring the indoor radon concentration in a room that uses a local heat recovery unit for ventilation.

CASE STUDY

The measured room is located on the ground floor of the three - floor administrative building in Banská Bystrica. Based on the radon risk map, there are several places with increased radon risk in the city. What is more, based on the information from recent measurements in the building, an increased indoor radon concentration was measured. The building was built in the 70´s of the last century, but a few years ago, the building underwent a complete renovation of the outer shell. As a part of renovation, the window structures were completely replaced. The contact insulation system was applied to the façade of the building and flat roofs were in insulated.

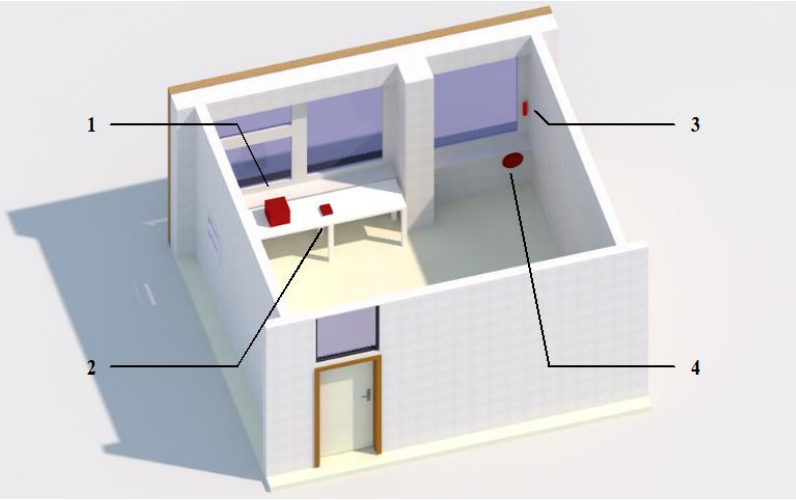

Fig. 1 – Axonometry of the monitored room with the location of the ventilation equipment and measuring devices: 1- Radon monitor AlphaGuard, 2- Testo 400, 3- TFA – Thermo-Hydro Sensor, 4- Prana 150

A local recovery unit Prana 150 is used to ventilate the measured room. It is a two-way recuperation with independent adjustment of the volume of incoming and outgoing air. This unit is intended for the ventilation of smaller spaces up to 60 m² of floor area, while it can provide air exchange with a volume of approximately 100 m³/h. The warm exhaust air removed from the interior transfers heat in the copper exchanger to the supplied air from the exterior, while there is no mixing of the removed and supplied air. The manufacturer indicates the efficiency of the device in terms of energy savings of up to 95 % [9]. The principle of installation of the recovery unit is shown in Figure 2.

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Fig. 2 – Installation of the ventilation device in the prepared place.

MEASUREMENT METHODS

An AlphaGuard radon monitor was used to measure the radon concentration, which enables continuous radon measurement and measurement of selected climatic parameters such as temperature, pressure and air humidity at the same time. This device works on the principle of an ionization chamber [10]. The working space with the collecting central anode is filled with the working charge - air. The examined air passes into the ionization chamber through a filter that allows only radon 222Rn molecules, i.e. without the products of its transformation. The filter also prevents contamination by dust particles. During the transformation of radon, alpha particles are released, which ionize the gas. The resulting positive and negative ions are captured on the electrodes of the chamber. The size of the generated electric charge is proportional to the volumetric activity of radon [11].

The WeatherHub SmartHome System device for wireless observation of climatic conditions was used to record outdoor weather conditions. To verify the temperature and humidity parameters, a TFA – Thermo- Hydro Sensor recorder was used. It was placed on the outside of the window frame of the examined room. The Testo 400 universal instrument for measuring climatic variables was also placed in the examined space. The instrument includes a probe that allows parallel measurement of humidity and temperature in the room in addition to CO_2. The measuring devices used during the experiment are shown in Figure 3.

Fig. 3 – Measuring devices used during the experiment:

1- Radon monitor AlphaGuard, 2- Testo 400, 3- TFA – Thermo-Hygro Sensor

RESULTS

The entire research consisted of several measurements throughout different seasons of the year. Two long – term measurements took place in the winter period and were subsequently supplemented by shorter measurements in April and May.

The first measurement took place between 07. 12. 2021 and 20. 01. 2022 (45 days). Between 22. 12. 2022 – 10. 01. 2022 (20 days) the ventilation device with heat recovery was out of operation.

The other days, it worked in overpressure ventilation mode. The development of the radon concentration in the measured room is captured in Figure 4. Based on the measured values, it can be deduced that the radon concentration values in the interior increased significantly when the ventilation device was turned off.

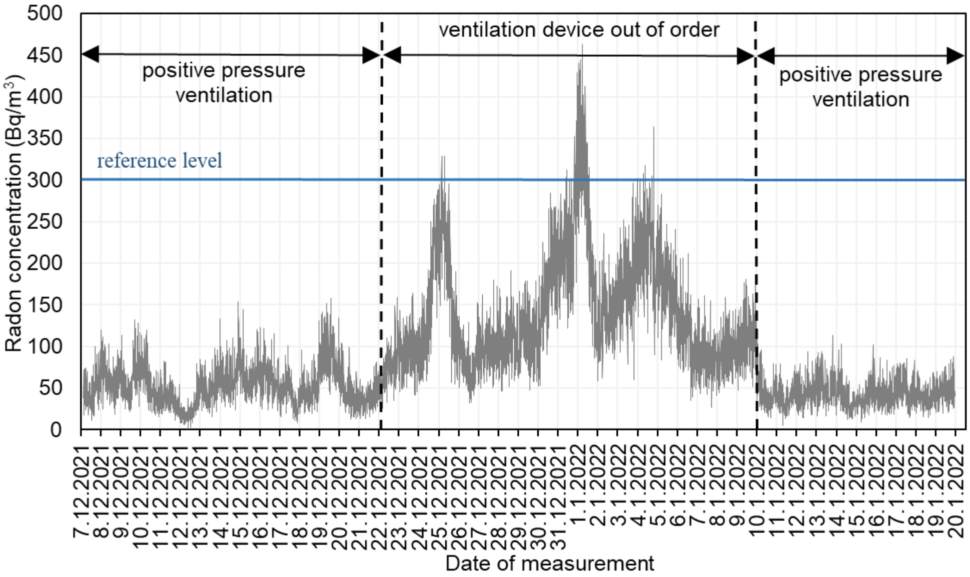

Fig. 4 – The course of the measured values of the internal radon concentration during the first part of the measurement.

In this interval, a value of 300 Bq/m³ was exceeded for six days, while the highest measured value was 463 Bq/m³. During the operation of the ventilation equipment, the highest measured value of the indoor radon concentration was 158 Bq/m³. This represents an almost threefold increase in concentration when the ventilation device is turned off.

A similar increase was also recorded for the other parameters listed in Table 1. However, the increase was not only recorded for the maximum values, but also for the others. The comparison of measured values is graphically displayed in Figure 5. Median measured concentration values increased by 178 % after ventilation was turned off. An average increase of 190 % was measured, and the third quartile of measured values increased by up to 202 %. The median was slightly lower than the mean, indicating the presence of some extreme values. When evaluating these values, radon concentration values were not taken into account on days when the ventilation operation was changed (turning off/on the ventilation system), as these values could distort the values during normal days.

Tab. 1 - Measured values of radon concentration.

Parameter	Radon concentration (Bq/m³) Ventilation device in use	Radon concentration (Bq/m³) Ventilation device out of order
1. quartile (25 %)	34	91
Median	45	125
Mean	49	142
3. quartile (75 %)	60	181
Maximum	158	463

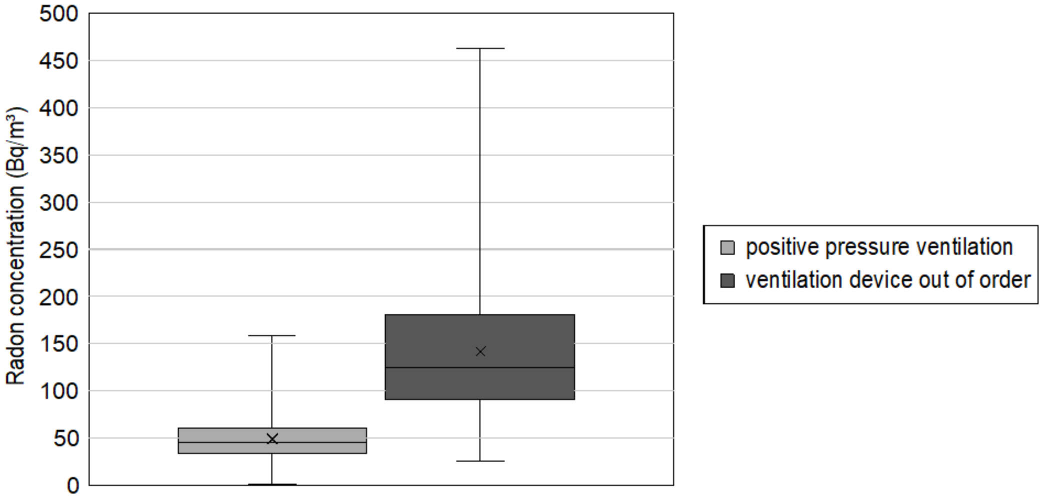

Fig. 5 – Graph of the measured values of the internal radon concentration during the first part of the measurement.

The course of the indoor radon concentration during the day when the ventilation equipment was turned off can be seen in Figure 6. During operation, the concentration value was in the range of 60-80 Bq/m³, then after the ventilation equipment was turned off, the radon concentration began to increase. Within 6 hours, it reached a value of 100 Bq/m³ and within 16 hours it reached a value of 150 Bq/m³. In Figure 7, you can see the opposite case of the course of the radon concentration when the ventilation device is switched on again. The reduction of the radon concentration to a value of 50 Bq/m³, which represents the average measured values, occurred after 14 hours of operation of the ventilation equipment.

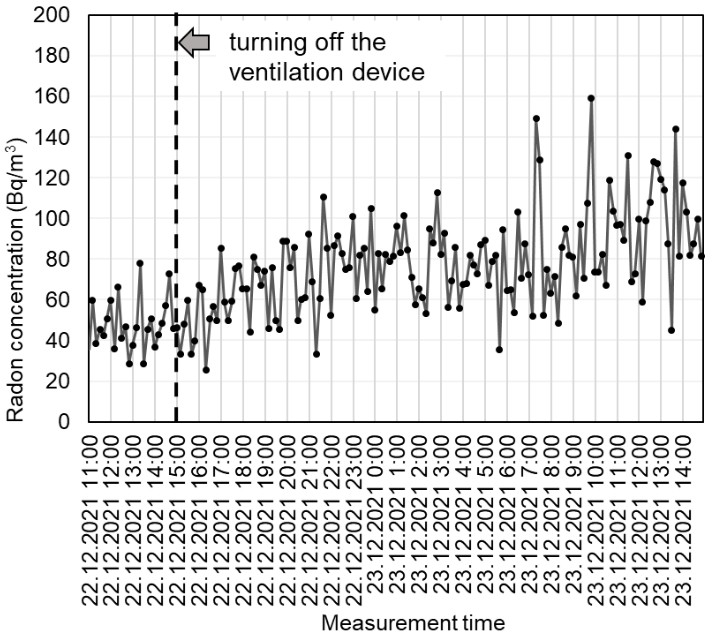

Fig. 6 – Course of radon concentration after switching off the ventilation device.

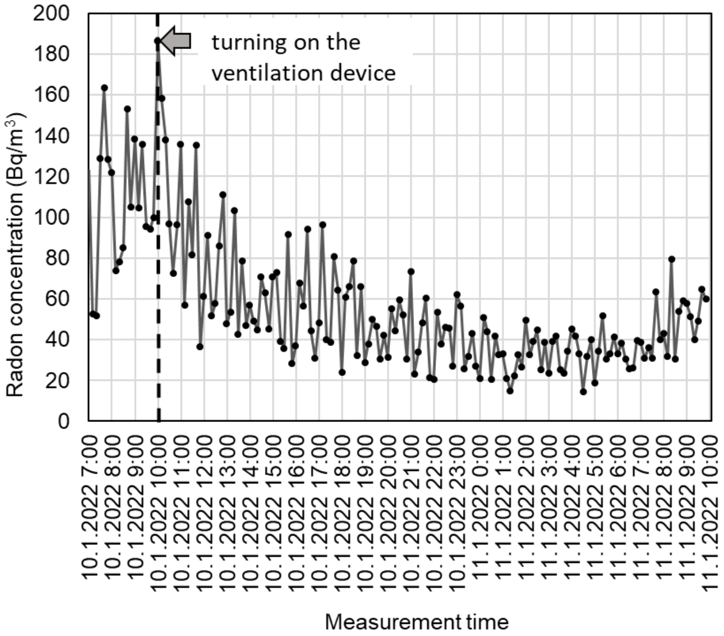

Fig. 7 – Course of radon concentration after switching on the ventilation device.

The second part of the measurements started already during the autumn period. During this time the ventilation device was set in the overpressure ventilation mode. The measurement lasted from 14. 09. 2022 – 13. 11. 2022 and then continued after a short break from 21. 12. 2022 – 12. 01. 2023. During the period from 21. 12. 2022 – 09. 01. 2023 the setting of the ventilation device was changed to equal pressure. The course of radon concentration during the entire measurement is shown in Figure 8.

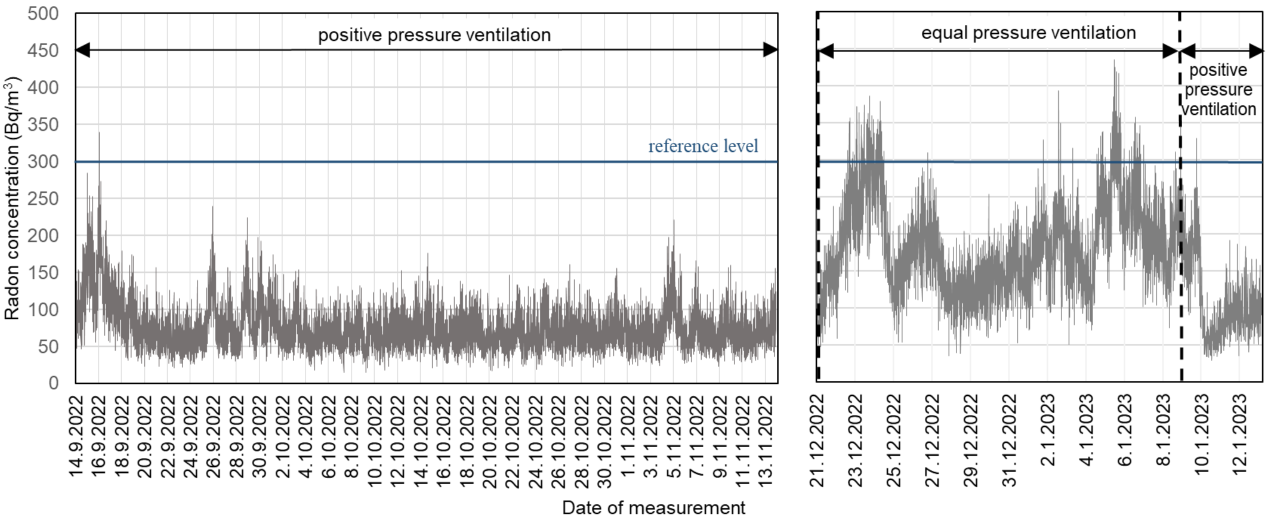

Fig. 8 – Course of the measured values of the internal radon concentration during the second part of the measurement

From the course of the radon concentration shown in Figure 8, the change of ventilation mode resulted in a significant increase in the indoor concentration. The measured values are shown in table no. 2 and their graphic comparison in Figure 9. The positive pressure ventilation was in operation for 20 days, while the radon concentration exceeded the reference level only during 11 days. The highest measured value was 435 Bq/m3. However, the reference value was exceeded one day even with positive pressure ventilation. The median of measured concentration values increased by 151% after ventilation was turned off, while the other parameters also showed a similar increase.

Tab. 2 - Measured values of radon concentration during the second part of measurements.

Parameter	Radon concentration (Bq/m³) Positive pressure ventilation	Radon concentration (Bq/m³) Equal pressure ventilation
1. quartile (25 %)	55	136
Median	70	176
Mean	76	184
3. quartile (75 %)	91	222
Maximum	339	435

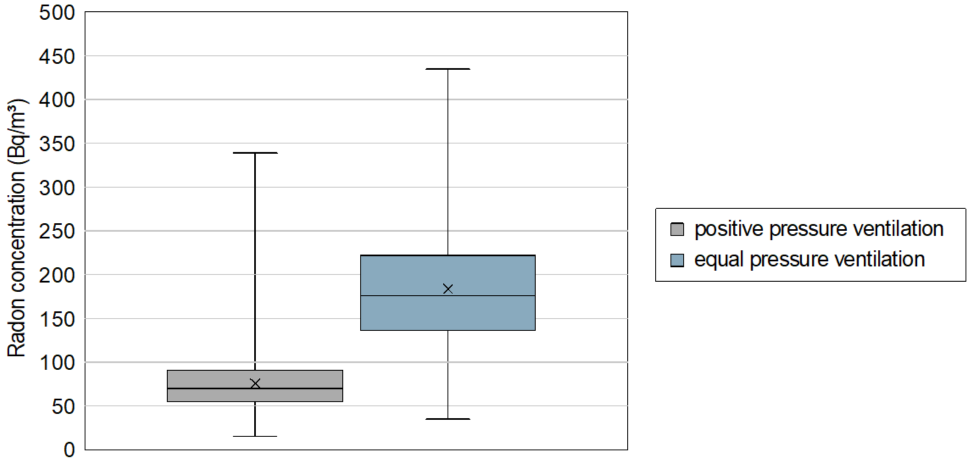

Fig. 9 – Graph of the measured values of the internal radon concentration during the second part of the measurement.

On 01. 09. 2023, the setting of the ventilation device was changed from equal pressure ventilation mode to positive pressure again. Considering the previous measurement, it was assumed, that within a few hours, there will be a significant decrease in the indoor radon concentration. Figure 10 shows the plotted course during the following hours. The radon concentration remains at the same level as during equal pressure ventilation until the morning of the next day. In this case, the drop in the radon concentration occurs only after 24 hours, while the radon concentration subsequently remains at the the level of 40 – 80 Bq/m3.

Due to the weather conditions during these days a delayed drop in concentration was noticed. Figure 11 shows the course of precipitation and outdoor air humidity. The rainy weather on the day of the change in the setting on the ventilation equipment caused that the radon in the soil air was not released to the surroundings but the flooded pores in the soil air caused a greater supply of radon from the subsoil into the building. After the end of the rain and the subsequent drop in exterior humidity, there is also a drop in the indoor radon concentration.

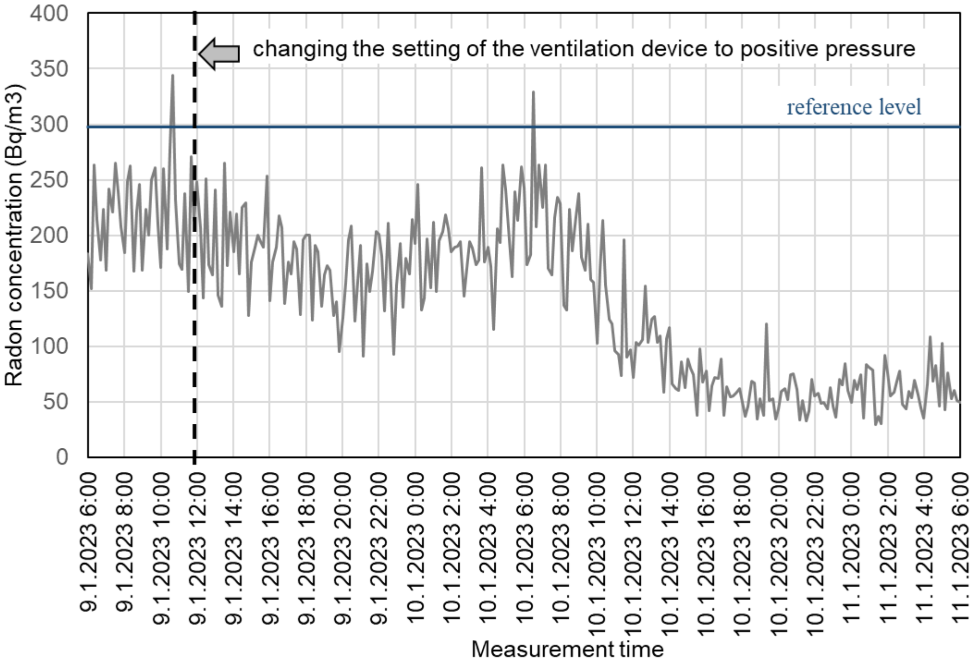

Fig. 10 – Course of radon concentration after turning on the ventilation device in overpressure mode.

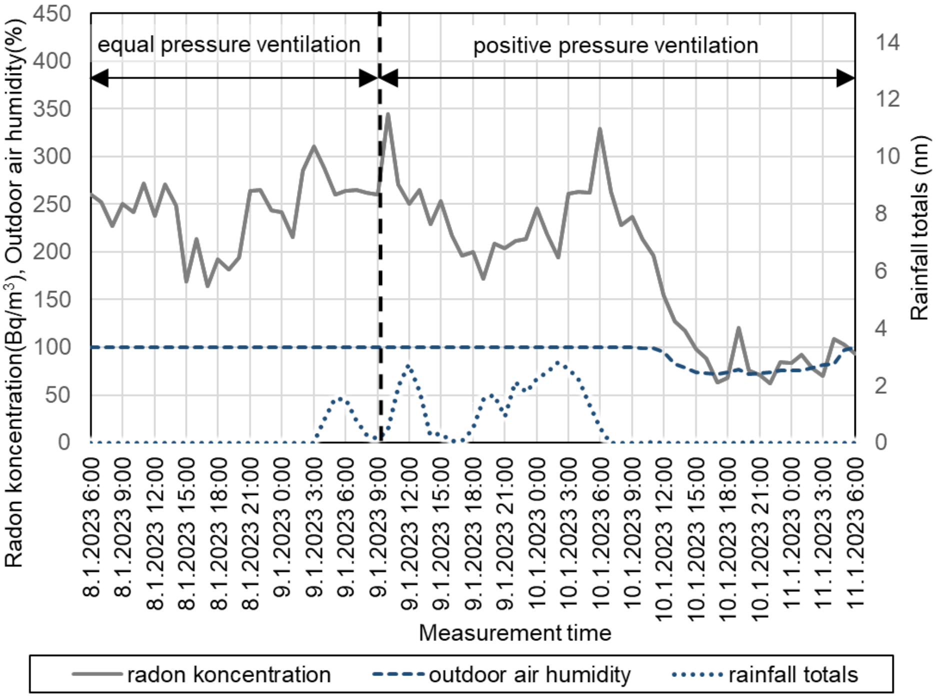

Fig. 11 – Comparison of the course of radon concentration, rain volume and exterior humidity after switching on the ventilation device in overpressure mode.

The last part of the measurements started on 17.04. 2023 and was finished on 15. 05. 2023. During these days, the setting of the ventilation device was changed at approximately weekly intervals. At the beginning, the ventilation was set as overpressure, while at the end the possibilities of setting the ventilation were investigated. During one week, the ventilation was turned off and later the measurement was made in the mode of under pressure (vacuum mode) and equal pressure ventilation. Figure 12 shows the course of concentration during these days.

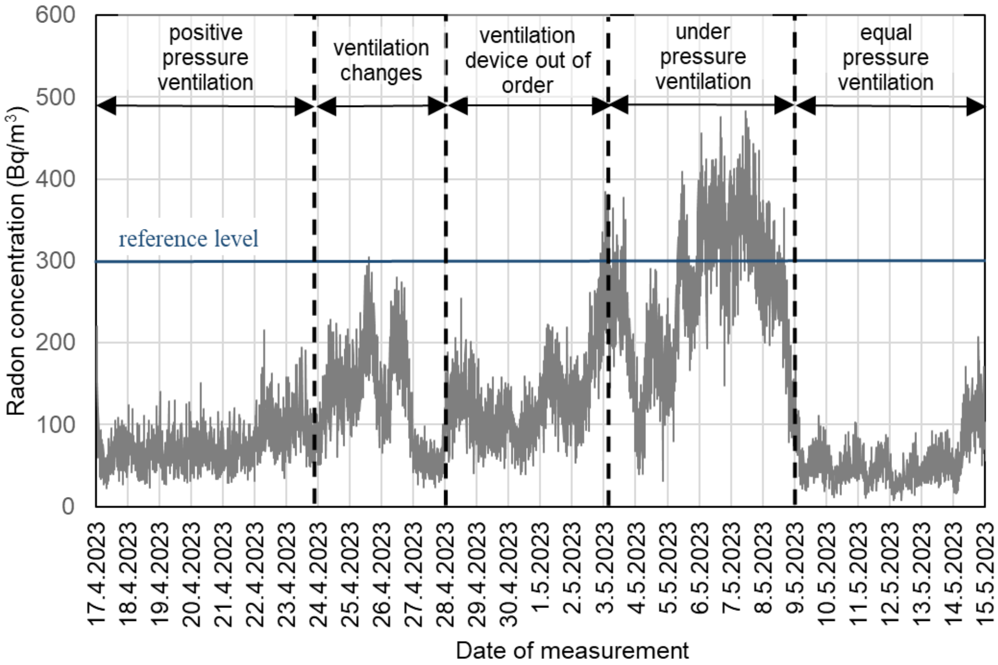

Fig. 12 – The course of the measured values of the internal radon concentration during the third part of the measurement.

In contrast to the previous measurements, in this case the radon concentration was measured also during under pressure (vacuum) ventilation. However, this type of ventilation causes an increase in the supply of radon from the soil air what was also reflected in the course of radon concentration. During this week, the highest indoor concentration value for the entire length of the measurement was measured – 482 Bq/m3. Only one day during this week radon concentration did not exceed the reference level of 300 Bq/m3. The equal pressure ventilation, which in the winter caused an increase in radon concentration, proved effectiveness in decreasing the indoor concentration and kept the values at an average of 55 Bq/m3 in this case.

Tab. 3 - Measured values of radon concentration during the third part of measurements

Parameter	Radon concentration (Bq/m³) Positive pressure ventilation	Radon concentration (Bq/m³) Ventilation device out of order	Radon concentration (Bq/m³) Under pressure ventilation	Radon concentration (Bq/m³) Equal pressure ventilation
1. quartile (25 %)	54	93	194	8
Median	69	124	266	48
Mean	74	134	259	55
3. quartile (75 %)	89	161	325	66
Maximum	220	384	482	208

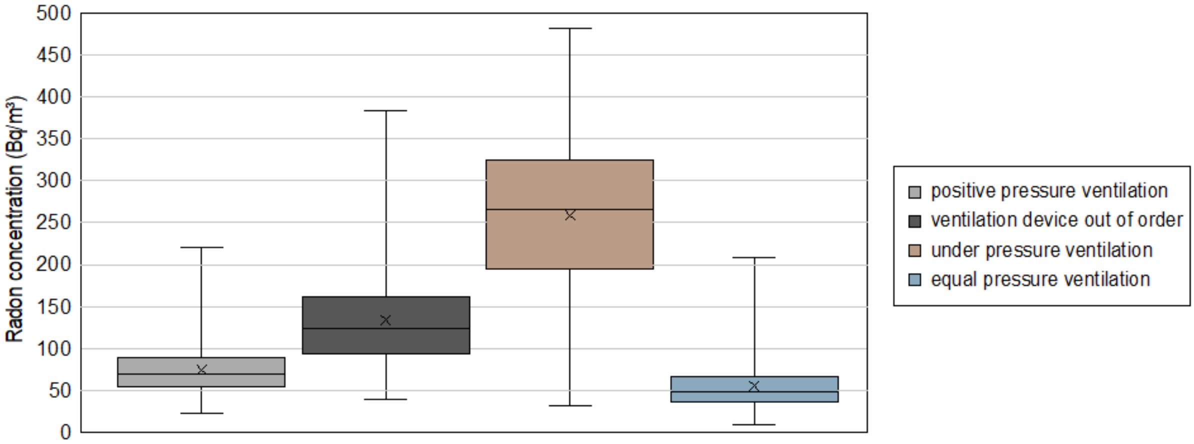

Fig. 13 – Graph of the measured values of the internal radon concentration during the third part of the measurement.

DISCUSSION

Mechanical ventilation with heat recovery helps significantly to reduce indoor radon concentrations and at the same time contributes to energy savings. However, the correct setting of the ventilation unit is important. The volume of incoming and outgoing air causes pressure differences between the interior and exterior and ultimately affects the indoor radon concentration [12], [13], [14]. If ventilation creates negative pressure in the room, indoor concentrations rise above the reference level. In the case of setting the equal pressure ventilation mode, low radon concentrations were measured in the summer. In winter, however, this type of ventilation has not proven to be effective in terms of reducing indoor radon concentration. Positive pressure ventilation is the only one that has proven itself in both summer and winter and was able to significantly reduce indoor concentrations. However, we must take into account the fact that the radon concentration values are very variable and often change significantly over the course of hours.

The way the building is used has also a significant influence on the radon concentration values. Reducing of frequency of use of the investigated space during weekends or holidays can also cause an increase in the indoor radon concentration.

Another factor that could affect the radon concentration values is the external weather conditions and the permeability of the subsoil. It follows from the measurements during rainy days that the radon concentration values increased significantly at this time.

CONCLUSION

From the measurement results and considering the facts that could influence the resulting values of radon concentration in the interior, it can be concluded that ventilation with heat recovery has proven to be a suitable anti-radon measure while simultaneously saving energy and having a positive effect on carbon dioxide and humidity values in the interior. The measurements achieved similar results as in previous studies. It is important to note that with the wrong method of ventilation, its effect on reducing the radon concentration could be reduced or even the opposite. Mechanical ventilation as an anti-radon measure is also suitable to be combined with other passive anti-radon measures (e.g. radon insulation or subsoil ventilation), since in the event of a malfunction of the ventilation equipment, the values can quickly rise above the limits set by the norm. The next experiment could follow up on the obtained results with a computer simulation of this monitored space.

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