MITIGATING THE HIGH RADON CONCENTRATION IN EXISTING HOMES

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Abstract. The article presents the experimental study of the efficiency of mitigating the high level of radon in existing homes using a centralized mechanical ventilation system with heat recovery. The measurements were performed both initially and after the installation of mechanical ventilation systems. The efficiency of reducing the radon level in the house was analysed, calculating the energy saved due to the heat recovery system compared to the conventional one (natural ventilation). The study concludes with a cost-benefit analysis, which shows the payback period of the investment.

Keywords: Indoor air quality, Mitigation systems, Experimental campaign, Centralized ventilation, Heat recovery.
DOI: https://doi.org/10.34641/clima.2022.276

1. Introduction

The impact of the quality of the indoor environment on the occupants has been the subject of much research in various fields. Their purpose was unique, to create a healthy and safe indoor environment. Previous studies have identified numerous indicators of indoor environment quality: indoor air quality, thermal, visual and acoustic comfort.

Poor quality of the indoor environment has been shown to contribute to diseases, which for prolonged exposure, can even have a fatal effect (1). The accumulation of indoor pollutants leads to the appearance of the sick building syndrome. Many studies have shown the connections between indicators of the quality of the indoor environment and the health of its occupants (2, 3).

According to international organizations reports, the World Health Organization (WHO) and the International Atomic Energy Agency (IAEA), radon is considered the main source of human exposure to ionizing radiation due to its inhalation. WHO estimates that between 3 and 14% of lung cancer cases in a country are due to radon (4).

Radon (222Rn) is a naturally occurring radioactive gas from the decomposition of natural uranium present in the ground or rocks. In Eastern Europe, the radon problem is increasingly being researched, becoming a priority for both researchers and the general population (5, 6).

Burghele et al. conducted the first attempt to identify and map radon after performing a series of measurements carried out on soil and drinking water (7). The results of the study were represented in the following figure, laying the foundations of the radon map for updating the European radon map.

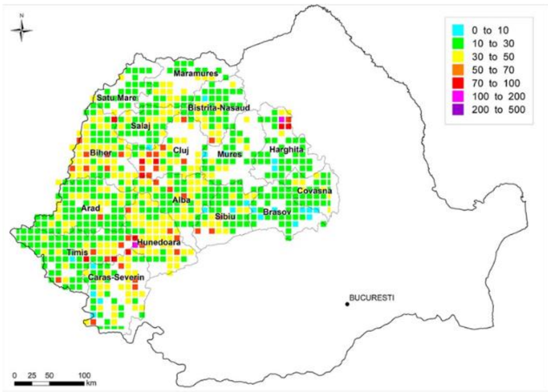


Figure 1 - Romania radon map (kBq/m^{-3} for soil gas)(7)

As we can see in figure 1, the values of radon in the soil vary between 0,2 kBq/m−3 and 179 kBq/m−3, being comparable to those reported for typical European soils (8).

2. International methods and analysis

In Romania, important steps have been taken in determining the effectiveness of methods for reducing the level of radon in homes.

Cosma et al. have experimented with several techniques to mitigate the radon levels for a home in the northwest of the country. Active and passive sub-slab depressurization techniques with gas extractors and cellar ventilation were used. The results showed efficiency of remediation systems values up to 86% (9).

Burghele et al. analysed several methods to mitigate the radon level in homes, through experimental tests. They achieved radon mitigation efficiencies of up to 92% for the active sub-slab depressurization solution, combined with a decentralized ventilation system (10).

Istrate et al. analysed two similar classrooms, from a high school in Bucharest, demonstrating the importance of achieving mechanical ventilation of spaces. The results showed that in the mechanically ventilated room, radon and VOC concentrations decreased 7-8 times compared to the naturally ventilated room (11).

(Vázquez et al. 2011) performed a series of simulations on a pilot house, based on the principles of basement depressurization through collectors. They obtained very good remedial efficiency values (12).

The problems caused by radon have been carefully debated through numerous studies (13, 14) each of them focusing on radon level remediation. Some of these studies are neglecting the energy efficiency of the home, the costs for implementing the remediation system, the thermal comfort in the dwelling and other secondary benefits of using the remediation system.

The house is located in the western part of the country, an area with a strong potential for radon in the soil (15, 16). It is a detached house consisting of 3 bedrooms, 2 living rooms, two cellars, kitchen, hall and two bathrooms. It is a construction made of masonry of brick walls, covered on the outside with expanded polystyrene 50 mm thick, the exterior carpentry is made of PVC with double glazing, with low air permeability.

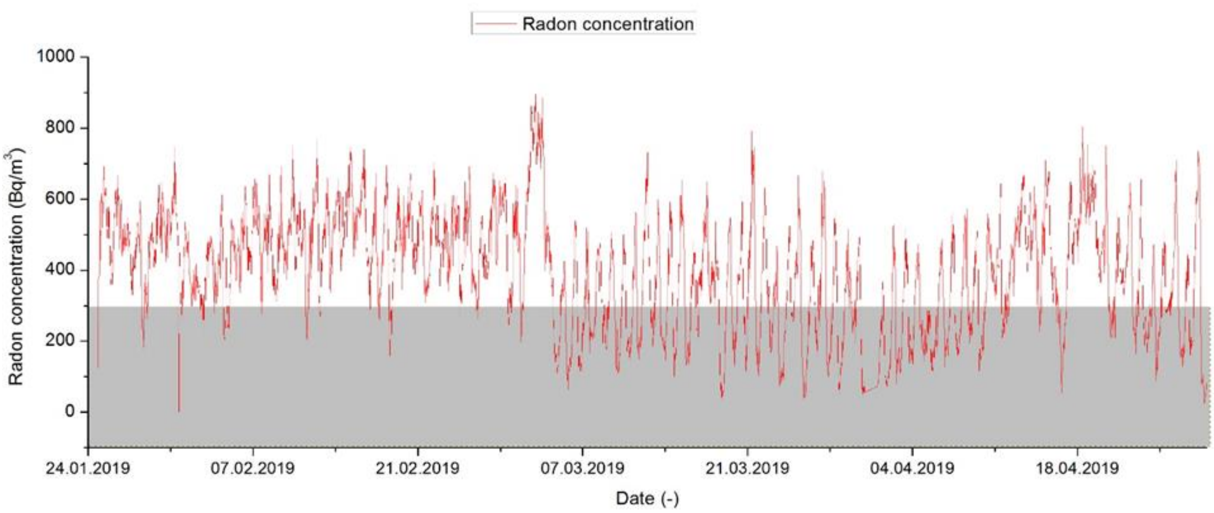
Tunyagi et al. have developed a revolutionary system for measuring and controlling radon in homes capable of continuous monitoring for a series of indoor parameters (radon, VOCs, CO_2, CO, temperature, relative humidity). The equipment is connected to a server, being able to be access any measurement information at any time (real time or period export). All the data regarding previous mentioned parameters, figured in this article, has been measured using this smart equipment (17, 18).

3. Measuring campaign - initial conditions

To find out the preliminary diagnosis of radon, two smart equipment (described above) were installed for monitoring and controlling the radon level, which would serve both sectors (TM01, respectively TM167) of the house. The daily evolution of radon was monitored for 3 months in the cold season, obtaining an average value of approximately 365,5 Bq/m3 (for TM01), respectively 402,5 Bq/m3 (for TM167), values that exceed the threshold imposed by European directives (19).

Even before the installation of equipment for continuous monitoring of radon levels, some preliminary measurements were made to determine the potential of radon. Starting from that point, the occupants of the house became aware of the danger they are exposed to and tried to remedy it through natural ventilation. As we can see in the figure 2 and figure 3, despite attempts to ensure natural ventilation, the limit of 300 Bq/m3 is frequently exceeded.

Figure 2 - Radon concentration 24.01.2019 - 24.04.2019, TM167



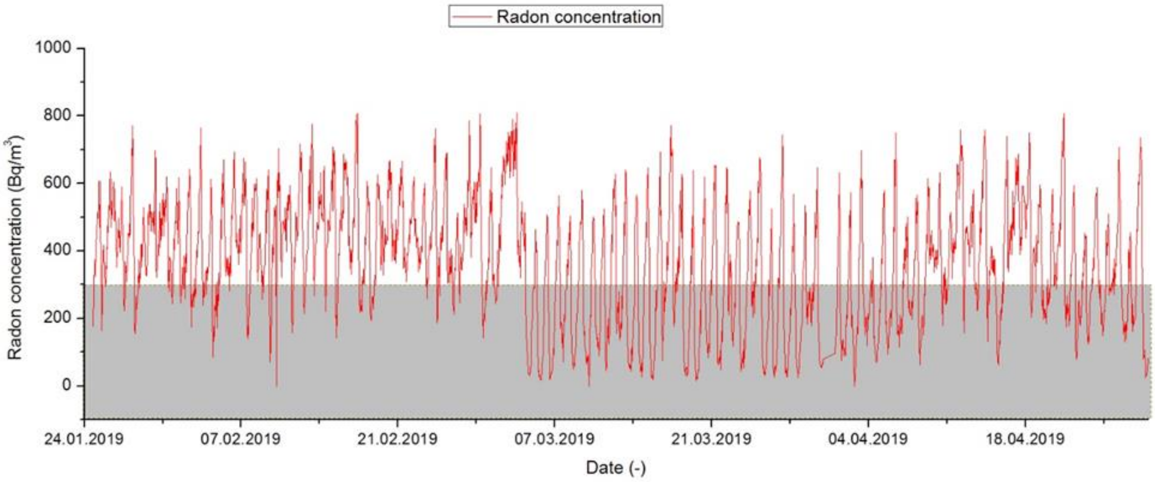


Figure 3 - Radon concentration 24.01.2019 - 24.04.2019, TM 01

Analysing the graphs presented above, can be observed the daily variation of radon due to the use of natural ventilation. This solution can be effective for short periods of time, not being a long-term option. On the other hand, this habit of natural ventilation of the spaces can also affect the level of indoor temperature and relative humidity.

4. Mitigation method and results

The mitigation solution chosen was to install two mechanical ventilation plants, which will serve each part of the house. This equipment has an introduction flow of 150 m3/h, respectively 350 m3/h realizing a good ventilation of the whole house. These ventilation plants are equipped with heat recuperators that positively impact energy consumption, limiting unnecessary losses due to natural ventilation.

The results of the implementation of the ventilation system were remarkably, remedying both the problem due to the high level of radon in the house, and the problems caused by the presence of other pollutants and temperature differences.

As can be noticed in figure 4, the radon concentration level has improved considerably, stabilizing around 165,5 Bq/m3, remaining below the maximum allowed limits, with occasional exceedances.

In the other part of the house, operating at nominal parameters of the equipment for mechanical ventilation, the radon level is maintained at values below the maximum allowed limit. The average value remains below the maximum limit, being approximately 219 Bq/m3, which indicates that this equipment has a good remedial efficiency. The peaks recorded for short periods of time highlight the moments when the centralized mechanical ventilation equipment with heat recovery did not work for various reasons.

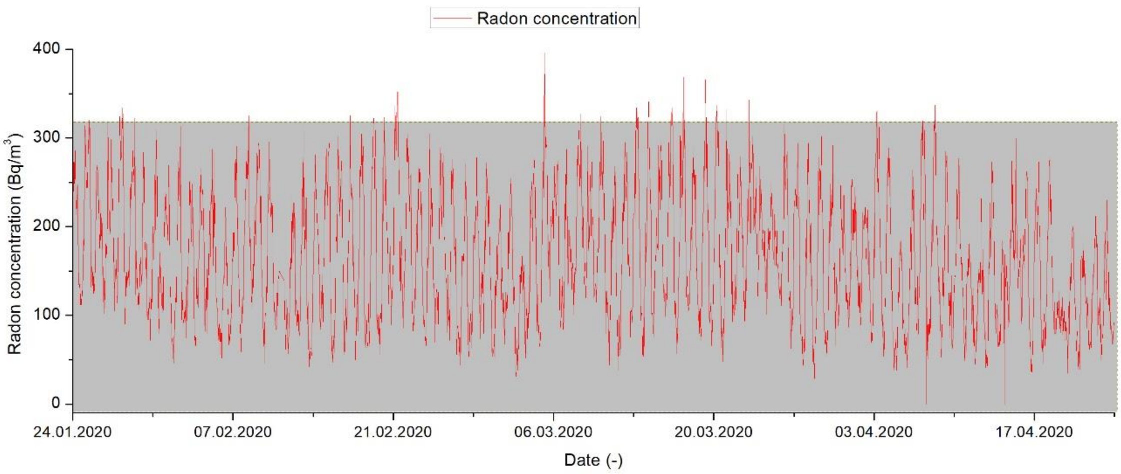


Figure 4 - Radon concentration 24.01.2020 **-** 24.04.2020, TM01 (after mitigation)

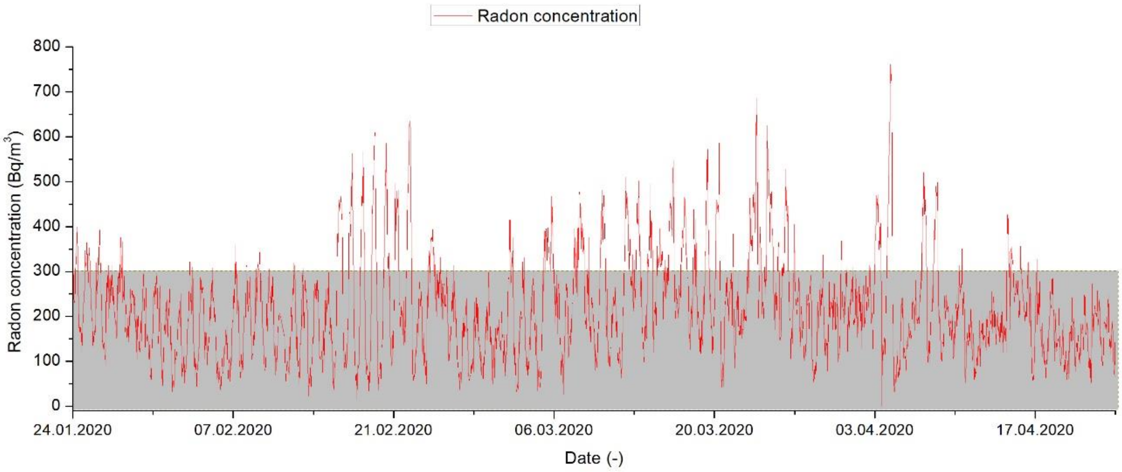


Figure 5 - Radon concentration 25.01.2020 - 01.02.2020, TM167 (after mitigation)

As we can see in figure 4 and figure 5, operating at nominal parameters of the equipment for mechanical ventilation, the radon level is maintained at values below the maximum allowed limit. The average value remains below the maximum limit, being approximately 219 Bq/m3, which indicates that this equipment has a good remedial efficiency. The peaks recorded for short periods of time highlight the moments when the centralized mechanical ventilation equipment with heat recovery did not work for various reasons.

5. Numerical simulation

In order to determine the thermal loads necessary to maintain an optimal indoor thermal comfort, a simulation was performed by a numerical simulation program, reproducing the normal conditions, respecting the specifications of the thermal comfort standards (20).

Figure 6 - Points of view for the analysed house

The simulation provided the real conditions to maximize the correctness of the results obtained. Thus, the data used for the simulation are:

- Construction materials;
- The heating system consists of a natural gas thermal power plant, with an efficiency of 80%;
- The same system was used to prepare domestic hot water;
- A model was established considering only the natural infiltration with a rate of 0.1 air changes per hour;
- The efficiency of the heat recuperator was considered 70%.

To establish the thermal loads for each scenario, a series of simulations presented below were performed:

The first simulation was performed considering only the infiltration rate, not considering any kind of ventilation in the analysed house. As presented above, the lack of ventilation of indoor spaces damages the quality of indoor air. Following the first set of simulations, the thermal load presented in the graph below was obtained through the black line, being able to make the comparison between the scenario in which the house is naturally ventilated and the scenario when the house is not ventilated at all. Significant differences can be observed, which impact the costs of heating the house.

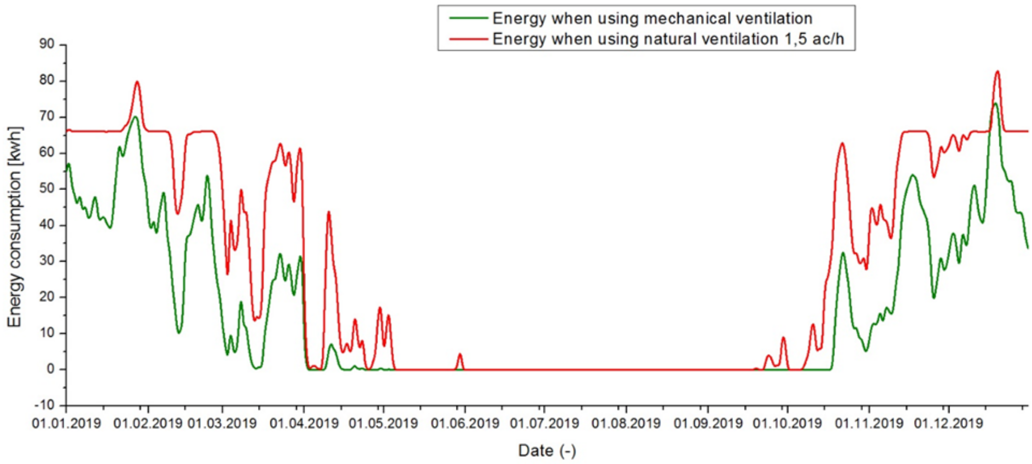


Figure 7 - Energy consumption 01.01.2019 - 31.12.2019

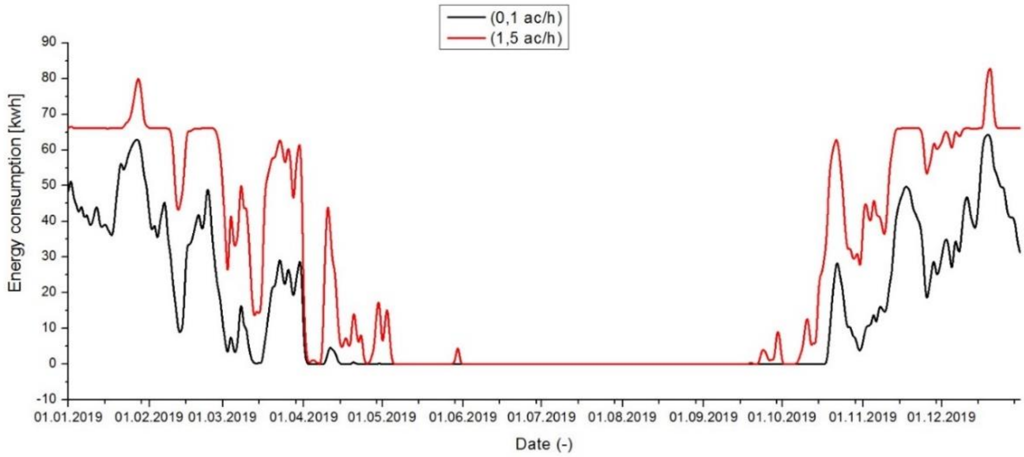


Figure 8 – Energy consumption comparison (01.01.2019 – 31.12.2019)

Considering this problem, an energy simulation was performed using centralized mechanical ventilation to remedy the increased radon level in the analysed home.

The graph presented in figure 7 shows the difference in heating thermal load when the house is naturally ventilated and the thermal load when the house is mechanically ventilated by a centralized mechanical ventilation equipment.

To determine the value of energy savings and cost savings following the implementation of the solution, the monthly gas consumption was exported from the design builder program, for a period of one year, when using both mechanical ventilation with heat recovery and natural ventilation. In the simulation, a gas thermal power plant with an average efficiency of 0.8 was used as heat source

Table 1 - Heating cost analysis

Costs	January	February	march	April	may	June	July	August	September	October	November	December	Total/ year
	€	€	€	€	€	€	€	€	€	€	€	€	€
Monthly fee (ventilation with heat recovery)	427	262	127	9	0,1	0	0	0	0	58	240	388	1509
Monthly fee (natural ventilation)	555	462	360	83	89	0	0	0	0	189	440	548	2647
Money savings/year													1137

6. Conclusions and discussions

Considering all the above, the problem of high levels of radon in homes can be solved by using centralized mechanical ventilation with heat recovery. This method brings multiple benefits, from reducing the level of indoor pollutants (including radon), maintaining the indoor temperature at a constant level, maintaining relative humidity at normal values. All these benefits can be obtained with relatively low energy costs, compared to the use of conventional methods as natural ventilation. The above calculation highlights how the costs, generated by the purchase and installation of equipment to remedy the high level of radon, will be amortized in a short time, compared to the costs of natural ventilation.

7. Acknowledgement

The study is part of the project called Smart Systems for Public Safety through Control and Mitigation of Residential Radon linked with Energy Efficiency Optimization of Buildings in Romanian Major Urban Agglomerations SMART-RAD-EN.

The datasets generated during and/or analysed during the current study are available in the SmartRADON repository, http://app.smartradon.ro.

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