Radon safety in terms of energy efficiency classification of buildings

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Abstract. According to the results of survey in Ekaterinburg, Russia, indoor radon concentrations above city average level have been found in each of the studied buildings with high energy efficiency class. Measures to increase energy efficiency were confirmed to decrease the air exchange rate and accumulation of high radon concentrations indoors. Despite of recommendations to use mechanical ventilation with heat recovery as the main scenario for reducing elevated radon concentrations in energy-efficient buildings, the use of such systems did not show an obvious advantage. In real situation, mechanical ventilation system is not used properly both in the automatic and manual mode, which does not give an obvious advantage over natural ventilation in the climate of the Middle Urals in Ekaterinburg. Significant number of buildings with a high class of energy efficiency and built using modern space-planning decisions contributes to an increase in the average radon concentration. Such situation contradicts to “as low as reasonable achievable” principle of the radiation protection.

1. Introduction

Despite of elaborated energy efficiency policy in construction industry, a number of issues of the radiation safety of construction are still unresolved due to the introduction of energy-efficient solutions in this sector [1–3]. The problem of the increased accumulation of pollutants in buildings, in particular the problem of indoor radon, is of current interest. Radon is a naturally occurring radioactive gas found in soil and building materials. According to the epidemiological data [4, 5], there is a direct relationship between the lung cancer and indoor radon. Radon is able to migrate and accumulate in buildings. Features of design and operation of various buildings can result in high radon concentrations.

In Russia, the requirements for energy-efficient construction have been established by the government since 1996. In the following years, new standards have been introduced to regulate the resistance to heat loses and air infiltration aimed to decreasing energy consumption. The establishment of new standards led to the application of building solutions that create conditions for increased accumulation of pollutants in new buildings. These solutions include the heat-shielding of building envelope, replacing obsolete doors and windows in dwellings, special requirements for plan decisions for rooms that are part of common household use. This work is focused on the problem of radon exposure in modern energy-efficient buildings in Ekaterinburg, where the energy consumption potential being extremely high. The research focuses on the influence of space-planning
decisions of modern multi-storey buildings of various energy efficiency classes on radon concentration in dwellings.

2. Materials and methods

The radon survey data [6] supplemented by measurements of radon concentration in energy-efficient buildings in Ekaterinburg during the last 5 years was used in the analyses. The total number of buildings in the combined sample was 452. Measurements of the radon concentration were carried out by the track detectors (LR 115). The measurement period was 2–3 months.

To determine the average annual radon concentration, the temperature normalization was carried out when it was necessary [6]. Assigned energy efficiency class, the living and total area, and the number of rooms were found out for each dwelling. According to the data of the companies managing housing and communal services, the total number of buildings with assigned energy efficiency class was 65. The energy efficiency class of a building in Russia is determined by the deviation of the value of the specific heat consumption for heating, ventilation and hot water supply of the building from the standardized level (Table 1).

| Class     | Symbol | Deviation of the value of the specific heat consumption from the standardized level, % | Recommendations |
|-----------|--------|---------------------------------------------------------------------------------|-----------------|
| Very high | A+     | below -60, from -45 to -59,9                                                   | Economic incentives |
|           | A      |                                                                                 |                  |
| High      | B++    | from -35 to -44,9                                                             | Economic incentives depending on the year of construction |
|           | B+     | from -25 to -34,9                                                             |                  |
|           | B      | from -10 to -24,9                                                             |                  |
| Normal    | C      | from +5 to -9,9                                                              | –               |
| Reduced   | D      | from +5,1 to +50                                                             | Modernization of the building after 2020 is advisable |
| Low       | E      | more than +50                                                                | Immediate insulation of the building |

More detailed study was conducted in one dwelling with the highest energy efficiency class "A". This building is distinguished by absence of the water heating system and presence of the mechanical ventilation system with heat recovery. Heating in the house is carried out by means of warm electric floors. In this building, measurements of the radon concentration and the temperature difference between indoor and outdoor atmosphere were carried out in an apartment on the first floor for 1.5 months in step of 1 hour.

The AlphaGUARD radon monitor was used as a measuring instrument. The measurements were carried out in the cold season (January to March 2017). The temperature difference between the indoor and outdoor atmosphere varied from 25 to 45° C. It allowed us to determine the dominant radon entry mechanism and radon entry rate by methods developed earlier [7].

In addition, the methods mentioned allow to determine the air exchange rate in the stationary mode of room use. The air exchange rate in the active mode of room use was adopted equal to one exchange per hour, according to the characteristics of the ventilation system.

3. Results and discussion

Based on the data obtained during the analysis, a diagram showing the distribution of radon concentration values in the dwellings of Ekaterinburg, depending on the energy efficiency class was obtained (Figure 1). According to the achieved results, there is a significant increase in radon concentration in the rooms situated in buildings with high energy efficiency class (B, B+, B++).
Figure 1. Distribution of radon concentration values in the dwellings in Ekaterinburg, depending on the energy efficiency class

Increase of radon concentration in modern buildings is associated with new construction technologies. The use of various construction technologies and various types of building materials (reinforced concrete panels, brick, monolithic concrete etc.) can lead to significant differences in radon concentration levels. As was shown earlier in the work [7], the lowest radon concentrations were achieved in panel block buildings built between 1970 and 1989. The houses of the specified years of construction are distinguished by the highest value of the ratio of living to total area of the building.

At the same time, the areas of common use and office areas in new buildings are usually characterized by low air exchange rate, especially in the cold period of the year. Thus, the leakiness of the entrance doors to apartments, their high air permeability, as well as the ways of utility lines input from public areas create conditions for reducing the contribution of the fresh air to the general air exchange of dwellings. The indirect proof of this hypothesis is the dependence on Figure 2, displaying the effects of space-planning decisions on the achieved values of the radon concentration in the surveyed buildings.

Figure 2. Ratio of living to total area of the building vs radon concentration

According to [7], the part of modern panel block apartments built during the period from 2001 to 2013 does not exceed 30% of the total number of buildings constructed during the period. Thus,
the significant number of buildings with a high class of energy efficiency and built using modern space-planning decisions, contributes to an increase in the average radon concentration, which contradicts the concept of systematic decrease of radiation exposure.

Based on the results of long-term measurements of radon concentrations in a dwelling with energy efficiency class "A", the average value of radon concentration 130 Bq/m$^3$ was obtained. Also, the radon entry rate was analyzed. The radon entry rate was about 35 Bq/(m$^3$·h) in average and almost unvaried with $\Delta T$ in the range from 25 to 45° C. Such estimation fully corresponds to the values obtained earlier for other energy-efficient buildings in Ekaterinburg.

The air exchange rate between the indoor and outdoor atmosphere has a significant effect on the radon concentration. The main driving forces of the air exchange under absence of the mechanical ventilation are the temperature difference between indoor and outdoor atmosphere and wind pressure. As was shown in the works [7, 8], the value of the air exchange rate in buildings with natural ventilation system is sufficiently low (from 0.2 to 0.3 h$^{-1}$ in the stationary mode of room use). For a dwelling with the energy efficiency class "A", a similar result was obtained (Figure 3).

![Figure 3](image-url)

**Figure 3.** Dependence of air exchange rate on the temperature difference between indoor and outdoor atmosphere

According to [2, 3] the use of mechanical ventilation with heat recovery is considered as the main scenario for reducing elevated radon concentrations in buildings. However, in the climate of the Middle Urals in Ekaterinburg, the use of such systems did not show an obvious advantage in terms of reducing concentrations of pollutants.

4. **Conclusion**

According to the results obtained, there is a significant increase in radon concentration in buildings with a high energy efficiency class. Based on the results of the research, the air exchange rate in energy-efficient buildings remains insufficient due to low air permeability of building envelope, entrance doors and windows. The main type of ventilation in new residential buildings in Ekaterinburg is natural ventilation. Residents are forced to control the air exchange in rooms by opening windows or ventilation flow valves (if provided). In turn, outreach work with the public regarding decreasing of energy consumption is conducted in the terms of reducing costs for housing and communal services. In particular, with regard to ventilation systems, the public is advised not to leave the ventilation routes permanently open and mechanical ventilation to be in operation constantly.

Often, the required air exchange is not ensured by the occupants for comfort reasons (during the cold season) or for reasons of reducing costs (even in the case of mechanical ventilation with heat recovery systems). To increase the air exchange rate and reduce energy consumption without decline of living conditions, it may be recommended to use the heat recuperation in ventilation systems (i.e., a system that allows to save thermal energy significantly, by heating incoming fresh air by return air
without mixing them). However, the presence of such ventilation systems is not sufficient, since the mechanical ventilation system is often not used properly both in the automatic and manual mode, which does not give an obvious advantage over natural ventilation.

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