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ORIGINAL PAPER

# Radon exposure in kindergartens in one Bulgarian district

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**Abstract.** The major part of the radiation dose that humans receive from natural radioactive sources is due to inhalation of radon and its decay products. The study focuses on radon concentration (CRn) investigation in kindergartens and nurseries in the district of Montana. The influence of building characteristics on CRn was evaluated. The measurement of the CRn was performed using passive detectors. The survey was carried out between December 2019 and May 2020 with a total number of 602 detectors. The average value of CRn in the premises of the studied kindergartens and nurseries in this district is 125 Bq·m$^{-3}$, and the geometric mean (GM) value is 88 Bq·m$^{-3}$. The buildings that have built ventilation and sewerage systems have lower CRn. The effective doses of the children and workers were evaluated in order to assess the radon exposure.

**Keywords:** Bulgaria • Effective dose • Kindergarten • Passive detector • Radon concentration

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## Introduction

The major part of the radiation dose that humans receive from natural radioactive sources is due to inhalation of radon and its decay products. It has been found that prolonged exposure to high levels of radon ($^{222}Rn$) increased an individual's risk of developing lung cancer [1, 2]. Radon is a naturally occurring gas and comes from the decay chain of uranium ($^{238}U$), which is found in soils and rocks. In the outdoor atmosphere, it presents lower concentrations, but in buildings, the concentration can grow to dangerous levels [3]. The main source of radon in buildings is the geology of the site [2]. On the other hand, the indoor radon concentration (CRn) could vary with the internal surfaces and volumes of the building type and the air change rate [4] as well as with the building factors such as construction, the presence of a ventilation system in the building, etc.

When kindergartens are located in public buildings that carry a relatively high radon exposure risk, this poses a severely problematic situation, because children are particularly sensitive to unhealthy indoor environmental pollutants [5]. Moreover, they spend a large part of their time during the day in kindergarten. Therefore, attention needs to be paid to the monitoring of indoor CRn in such public buildings.

This paper presents a study of the CRn variation in kindergartens in the Bulgarian district of Montana

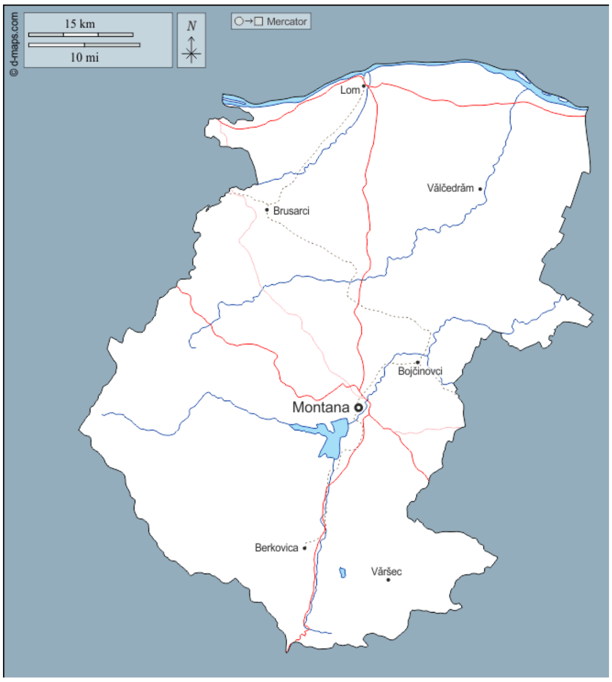


**Fig. 1**. Map of Montana district.

and analyzes the impact of building characteristics, such as the presence of ventilation, implemented energy-saving measures, and sewerage systems, on indoor radon variations. Assessments of the children's and worker's doses from exposure to radon and its decay products by applying the measured radon activity concentrations were performed.

## Research methodology

### Study area

Montana district is located in Northwestern Bulgaria. The district covers an area of 3635.5 km$^2$. Administratively, the district is divided into 11 municipalities: Berkovitsa, Boychinovtsi, Brusartsi, Varshets, Vulchedrum, Georgi Damyanovo, Lom, Medkovets, Montana, Chiprovtsi, and Yakimovo (Fig. 1). The 50 state kindergartens located on the territory of the district have been surveyed. All rooms where children and staff spend their time, located on the ground floor, were measured.

### Radon measurements

The study was carried out using passive CR-39 track detectors, type RSKS, provided by Radosys Ltd., Budapest, Hungary. The sampling period was for four months from December 2019/January 2020 to April/May 2020, and the exact date of placement and collection of the detector was recorded in the protocol for each kindergarten. The detectors were placed about 1 m from the floor and approximately 0.5 m from the ceiling, away from external windows, walls, doors, and heat appliances, thereby ensuring that they would be exposed to the air but remain out of the reach of children. According to the usual procedure adopted for such requirements, passive detectors were placed on a shelf in the room for the 4-month period of exposure. The total number of detectors provided for the study is 656. The percentage of detector loss is 8% and 602 results for rooms in the kindergartens and nurseries were analyzed. The detectors were calibrated in an accredited laboratory and measurements were made according to the ISO/DIS 11665-4 standard [6, 7].

A detailed questionnaire for each surveyed building was made available to the kindergarten and nursery staff, which they were required to fill in; the same needed the following details to be specified: the exact location and characteristics of the building (presence of a mechanical ventilation system and implemented energy-saving measures; types of sewerage system, heating, type of windows, etc.), and habits of the occupants.

### Dose estimation from radon and its decay products

The individual dose was calculated conservatively from the average CRn in kindergartens' premises using standard and recognized methods employing the ICRP dose conversion factor (DCF) and the estimated exposure time (in hours). When the measured concentration of Rn-222 gas is used in the calculation of the dose, the DCF is $6.7 \times 10^{-6}$ mSv·Bq$^{-1}$·h$^{-1}$·m$^3$, as recommended by the International Commission on Radiological Protection (ICRP), assuming the equilibrium factor $F = 0.4$ [8].

The effective dose from radon was evaluated for the period of detector exposure (four months – December 2019 to April 2020). Conservatively, the assumption was made that staff work 8 h/day and 5 days/week, giving rise to a total of 720 h over four months; and that children stay in kindergartens for approximately 6 h/day, giving rise to a total of 420 h over four months.

### Statistical analysis

IBM SPSS Statistics, v.23 was used for performing the statistical analysis. To assess the impact on radon variation, the measurements were grouped, according to the geographical location of municipalities, into nine groups; and, according to the presence of ventilation, heating, sewage systems, and thermal external wall insulation, into two groups ("yes" and "no").

## Results and discussion

### Overall results and effective dose assessment

The statistical parameters of indoor CRn in 602 premises in the measured kindergartens and nurseries are presented in Table 1.

The average value of CRn in the premises of the studied kindergartens and nurseries on the terri-

**Table 1.** Descriptive statistics of indoor radon concentration

| Parameter | CRn |
|---|---|
| Number of rooms | 602 |
| Arithmetic mean (Bq·m$^{-3}$) | 125 |
| Standard deviation (Bq·m$^{-3}$) | 135 |
| Median (Bq·m$^{-3}$) | 84 |
| Minimum value (Bq·m$^{-3}$) | 10 |
| Maximum value (Bq·m$^{-3}$) | 1439 |
| Coefficient of variation (%) | 108 |
| Geometric mean (Bq·m$^{-3}$) | 88 |
| Geometric standard deviation | 2.23 |

tory of the Montana district is 125 Bq·m$^{-3}$, and the geometric mean (GM) value is 88 Bq·m$^{-3}$. A review of 63 national and regional indoor radon surveys in kindergartens and schools in Europe, Asia, Africa, and North America has found the average radon arithmetic mean (AM) for all these surveys to be 59 Bq·m$^{-3}$ [9]. This value is lower than the assessed AM of the CRn for kindergartens and nurseries in the Montana district. The number of premises in which the CRn exceeds the national reference level [10] of the average annual CRn in the air of public buildings and workplaces of 300 Bq·m$^{-3}$ was 30 or approximately 5% of all measurements made. This percentage is lower than that corresponding to kindergarten premises of the three Visegrad countries, where the rooms with high CRn amounted to 7.5% of the total number measured [11]. The CRn in 12 rooms is >500 Bq·m$^{-3}$. In these buildings, measures for reducing the concentrations should be taken. The maximum value of CRn was 1439 Bq·m$^{-3}$, measured in the children's room, and it is approximately five times higher than the reference level.

The effective dose for children and workers was conservatively estimated for four months (the sampling period from December to April), and the results are presented in Fig. 2.

For four months during the winter period, the staff in five kindergartens are likely to receive effective doses due to radon >0.6 mSv, which is the half of annual average from radon inhalation of 1.26 mSv·a$^{-1}$, as assessed by UNSCEAR – 2008 [12]. Children in only one kindergarten are likely to receive an effective dose >0.6 mSv.

## Summary of results by municipalities

The gathered data and descriptive statistics were analyzed using a classification based on municipalities in the district, and the results are presented in Table 2. The highest AM of the CRn in the premises of kindergartens was assessed in the municipality of Brusartsi (AM = 276 Bq·m$^{-3}$), and where the highest

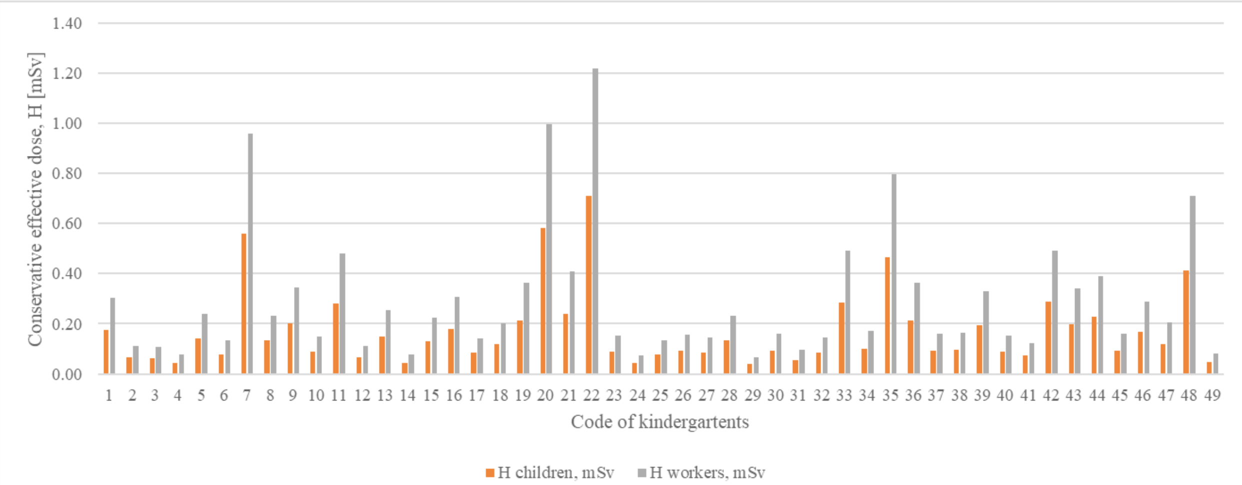


**Fig. 2.** The effective dose for children and workers is estimated for four months by kindergarten-wise presentation.

**Table 2.** Descriptive statistics of indoor radon concentration by municipalities

| Municipalities | Number of premises | AM (Bq/m$^3$) | SD (Bq/m$^3$) | CV (%) | Mediana (Bq/m$^3$) | Min. (Bq/m$^3$) | Max. (Bq/m$^3$) | Test Shapiro–Wilk ($p$) |
|---|---|---|---|---|---|---|---|---|
| Berkovitsa | 123 | 145 | 118.9 | 82 | 107 | 31 | 643 | 0.008 |
| Boychinovtsi | 27 | 200 | 177.9 | 89 | 110 | 31 | 669 | 0.135 |
| Brusartsi | 13 | 276 | 426.2 | 154 | 70 | 13 | 1439 | 0.152 |
| Vulchedrum | 122 | 96 | 96.4 | 100 | 70 | 12 | 824 | 0.165 |
| Varshets | 18 | 124 | 58.2 | 47 | 121 | 36 | 231 | 0.120 |
| Georgi Damyanovo | 20 | 70 | 17.9 | 25 | 64 | 45 | 113 | 0.051 |
| Lom | 89 | 73 | 62.9 | 86 | 56 | 18 | 429 | 0.011 |
| Medkovets | 18 | 246 | 240.4 | 98 | 146 | 54 | 853 | 0.162 |
| Montana | 158 | 130 | 124.6 | 96 | 96 | 10 | 972 | 0.053 |
| Chiprovtsi | 6 | 105 | 69.9 | 66 | 72 | 55 | 234 | 0.153 |
| Yakimovo | 8 | 130 | 134.6 | 104 | 64 | 44 | 380 | 0.012 |

**Table 3.** Descriptive statistics of indoor radon concentration by the common ventilation system, central heating system, thermal external walls insulation, and central sewerage system

| Statistic parameter | Common ventilation system | | Central heating system | | Thermal external walls insulation | | Central sewerage system | |
|---|---|---|---|---|---|---|---|---|
| | Yes | No | Yes | No | Yes | No | Yes | No |
| Number | 87 | 515 | 445 | 157 | 282 | 320 | 474 | 128 |
| Median | 60 | 91 | 87 | 69 | 101 | 68 | 76 | 100.5 |
| Arithmetic mean | 72.1 | 134.3 | 135.9 | 95.5 | 152.8 | 101.1 | 120.4 | 143.4 |
| Standard deviation | 48.0 | 143.0 | 147.3 | 86.9 | 161.1 | 101.8 | 124.2 | 169.6 |
| Coefficient of variation | 0.67 | 1.06 | 1.08 | 0.91 | 1.05 | 1.01 | 1.03 | 1.18 |
| *p*-Value of Shapiro–Wilk | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Minimum | 26 | 10 | 10 | 18 | 10 | 12 | 10 | 13 |
| Maximum | 317 | 1439 | 1439 | 519 | 1439 | 824 | 972 | 1439 |

value of 1439 Bq·m$^{-3}$ was found. The lowest AM of the CRn was measured in the municipality of Georgi Damyanovo (AM = 70 Bq·m$^{-3}$). The measured maximum CRn values above the national reference level [10], presented in Table 2, were observed in eight of the municipalities (Berkovitsa, Boychinovtsi, Brusartsi, Vulchedrum, Lom, Medkovets, Montana, and Yakimovo).

A parametric Shapiro–Wilk test was applied to test the hypothesis for normal distribution of the results of CRn by municipalities. The normal distribution of the indoor radon values in the municipalities of Boychinovtsi, Brusartsi, Vulchedrum, Varshets, Georgi Damyanovo, Medkovets, Montana, and Chiprovtsi has been confirmed. The results of the other municipalities in the Montana district do not follow the normal distribution. The Kolmogorov–Smirnov test was applied to test the log-normal distribution of the data, which did not follow the normal distribution. The test confirmed the log normality of distribution (KS, $p > 0.05$).

The AM in the two municipalities of Brusartsi and Medkovets is >200 Bq·m$^{-3}$, and for Boychinovtsi municipality the average CRn is 200 Bq·m$^{-3}$. These municipalities are located mainly in mountainous areas. A non-parametric Kruskal–Wallis test (KW, $p < 0.0001$) was applied to compare the data by municipality. A statistically significant difference was found between the surveyed groups, which shows that place position influences the CRn in kindergarten buildings. This circumstance is well known for residential buildings and substantiates the proposition that radon priority areas could be arranged based on municipality [13, 14]. In this way, preventive and corrective measures for reducing indoor CRn could be managed more optimally.

### Variation of CRn and building characteristic

The variations of the CRn depend on the various characteristics of the building. The influence of building characteristics on CRn varies from one region to the next [13]. The descriptive statistic by the studied characteristics in the buildings according to the divided groups (presence or not in the building) is presented in Table 3. The normal distribution was assessed using the Shapiro–Wilk test ($p > 0.05$). Not all groups followed a normal distribution.

Figure 3 shows the distribution of average CRn by groups for the presence or absence of ventilation, heating and sewage systems, and thermal external wall insulation. The non-parametric Mann–Whitney test was used to assess the difference between the groups (U, $p < 0.05$), because the value by groups does not follow the normal distribution. A significant difference was found between all the groups (U, $p < 0.001$).

The CRn (AM = 72 Bq·m$^{-3}$) where the common ventilation system is built is approximately twice lower compared to buildings that do not have a ventilation system (AM = 134 Bq·m$^{-3}$). The results confirm the hypothesis that the presence of a ventilation system in the building reduces the concentration of radon, while the presence of a central heating system increases the CRn in the building. The difference between the temperature in the building and the ground increases, when the whole building is heated. This temperature difference increases the underground pressure, which, in turn, increases the movement of radon gas from the soil toward the building.

Results of CRn from rooms located in buildings with a central sewerage system (AM = 120 Bq·m$^{-3}$) are lower than those corresponding to usage of a septic tank (AM = 143 Bq·m$^{-3}$). Radon is likely collected in the septic tank and is transported to the building via a pipeline. The buildings that have built ventilation and sewerage systems have lower CRn, while in a building that has thermal external walls insulation and a common heating system, the CRn is higher.

## Conclusion

This survey represents a study on indoor radon in kindergartens and nurseries in Montana district, Bulgaria. The average value of CRn in the premises is 125 Bq·m$^{-3}$, and the geometric mean value is 88 Bq·m$^{-3}$. The number of premises in which the CRn exceeds the national reference level of the average annual CRn of 300 Bq·m$^{-3}$ is 30 or approximately 5% of all measured cases. To reduce the high CRn, appropriate corrective measures should be implemented. Conservatively evaluated doses of workers in five kindergartens for four months are above those assessed by the UNSCEAR – 2008 annual average from a radon inhalation of 1.26 mSv·a$^{-1}$ [12].

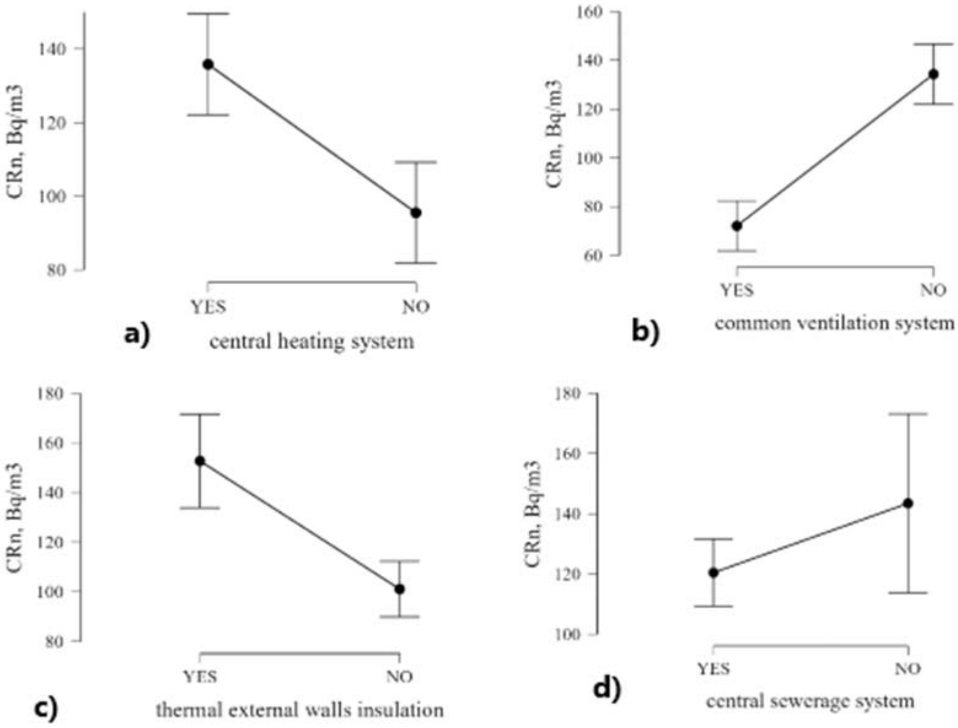


**Fig. 3.** The plots of CRn according to the: (a) presence of central heating system, (b) presence of common ventilation system, (c) presence of thermal external walls insulation, and (d) presence of central sewerage system.

The difference in the measurements by municipalities shows that the geographical location affects the indoor CRn in buildings.

The study found that the central heating system and the thermal insulation of the external walls increased the CRn, while the general ventilation system and the central sewage system reduced the CRn in the studied kindergarten buildings. These findings could be used in planning activities for radon prevention and corrective measures for public buildings in the Montana region.

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**Declaration of interests.** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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