Indoor radon levels in Hungarian kindergartens

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Abstract
Annual average indoor radon activity concentration was studied in 88 Hungarian kindergartens in 76 towns of 10 different counties. Annual average indoor radon activity concentration in the kindergartens was 61 Bq m⁻³, maximum was 160 Bq m⁻³. In the kindergartens the seasonal variation of radon is not so strong like in dwellings, because of the permanent ventilation and the closed period during the summer break.

Keywords Indoor radon concentration · Kindergartens · Radon survey, CR-39

Introduction
The main part of the natural background radiation is from the radon (Rn-222) isotope, which is a colorless, odorless and chemically inert noble gas. It is the one gas in the U-238 decay series. In closed places—like homes or workplaces—it can accumulate and mainly through its daughter isotopes (e.g. Po-214, Po-218) can increase the lung cancer risk which was evidenced by the epidemiological studies [1–5]. The World Health Organization (WHO) identified the radon as the second leading cause of the lung cancer after the smoking [6].

In order to reduce the lung cancer risk several international organizations published recommendation about the acceptable indoor radon concentration. In the actual recommendation of the European Union (which is the same as the International Atomic Energy Agency’s recommendation) the reference level of indoor radon concentration is 300 Bq m⁻³ [7].

The new EU directive obligate the member countries to prepare and continuously review a Radon Action Plan, which includes the country’s medium- and long-term actions to reduce the lung cancer risk of the radon exposure. Therefore, the monitoring and controlling of indoor radon concentration are emphasized in dwelling and workplaces, respectively. In this regard, the kindergartens are special: they are workplaces and living place at the same time [8].

Zhukovsky et al. [9] made a literature review of indoor radon measurements in kindergartens and schools in 63 countries, of which 42 are European, but Hungary is not among them. The detectors used for the surveys were diverse, LR-115, charcoal, Radhome Si Det, Makrofol, Electret, Lucas cell, but mostly CR-39. The average population weighted arithmetic mean of radon was 59 Bq m⁻³, geometric mean was 36 Bq m⁻³ and the geometric standard deviation was 2.7 in these 63 countries [9]. They found that the estimated number of objects with radon concentration higher than 300 Bq m⁻³ in children’s institutions is about 1.5% that is 5 times higher than in the dwellings.

Studies in foreign countries showed that some percentage, 3–10% of the studied kindergartens have higher indoor radon concentration than the reference level applied in the country [10–16].

One of the largest studies was conducted in Norway, where radon concentration in 3660, out of totally approx. 6500 kindergartens in the country, was measured using etched track detectors. However, only in the heating season for two months. They found that 9.2% of the kindergartens were above 200 Bq m⁻³ [10].

Bem et al. [11] found maximum 139 Bq m⁻³ in the winter season in 106 Polish kindergartens based on measurements. They used Plastic Pico-Rad detectors with activated charcoal, which were exposed for 48 h during winter.
Ďurčík et al. [12] assessed radon risk in 388 kindergartens and 257 basic schools by long-term (12 months or 6 months containing winter) indoor radon measurements in Slovakia. They used LR-115 and CR-39 detectors. The arithmetic and geometric mean of EER (equilibrium equivalent radon) were 57.5 Bq m⁻³ and 34.5 Bq m⁻³ in the kindergartens, respectively. They found higher than 200 Bq m⁻³ (their action level) in 13 kindergartens [12].

Vaupotic et al. [13, 14] performed systematic measurements of indoor radon concentrations and gamma dose rates in 730 kindergartens and play schools in Slovenia. They used alpha scintillation cells, but in cases with an increased instantaneous radon concentration, the additional methods of track-etch detectors and alpha spectroscopy were applied. Only 50 kindergartens have radon concentration higher than 200 Bq m⁻³. However, in 16 kindergartens it was between 800 and 5600 Bq m⁻³ [13, 14] Vaupotic et al. [15] remediated two kindergartens where the average heating season indoor radon concentration was about 2000 Bq m⁻³. Radon concentration was reduced successfully by 80% [15].

Ivanova et al. [16] measured indoor radon concentration by CR-39 in 296 kindergartens in Bulgaria but only for 3 months from February to April. They found 6% of the studied kindergartens with higher than 300 Bq m⁻³ indoor radon concentrations in the studied period. Arithmetic mean was 132 Bq m⁻³, maximum was 1415 Bq m⁻³ [16].

Several studies in Hungary dealt with radon measurements and dose assessment in indoor places like residential homes, public places (hospital, libraries, temples, schools and kindergartens), workplaces, caves, mines, wine cellars. But only a few measurements were performed in kindergartens and the kindergarten data were not published separately from other indoor data [17, 18]. However, it is well known that children are one of the most sensitive to all kinds of harm, including ionizing radiation. Thus knowledge about the harmful radon in kindergartens, self-evident aim of us all.

In this study we examined 88 kindergartens in 76 towns in the middle and western part of the country (Fig. 1) to check if there is any of them which has radon concentration above the reference level, 300 Bq m⁻³ in Hungary (487/2015. (XII. 30.) Govt. Degree). Another aim of the project was to study that is there any correlation between indoor radon concentration and different parameters of the kindergarten such as building type, windows type (ventilation frequency), year of construction, type of the rooms and presence of cellar, insulation, and slag built-in.
Material and methods

Site description

Selection of the studied kindergartens based on the previous indoor radon [18, 19] and geogenic radon potential [20] surveys. The kindergartens closest to the locations, where the highest soil gas radon activity concentration or geogenic radon potential or indoor radon concentration in dwellings was determined, were selected.

At the beginning of the survey every major of the cities/towns/villages on the selected areas was contacted via e-mail and they were informed about the survey. The participation was voluntary.

Study design

In this study the indoor radon measurement was carried out in 195 rooms of 88 kindergartens, which were in 10 different counties out of the 19 counties of the country (Table 1). The most measured kindergartens were in Veszprém and Pest counties (30 and 24%, respectively) and the least were in Baranya, Győr-Moson-Sopron and Nógrád counties (2%, 2–2 kindergartens in each). Basically, indoor radon concentration was measured in 3 rooms in order to characterize the kindergarten as accurately as possible. However, we also had considered the size of the building, so we measured in one (36%), two (8%), three (53%) or four (2%) rooms. Because the main part of the indoor radon is from the soil in the most cases, and the conventionally accepted method to measure the indoor radon concentration is measuring on the ground floor, we performed the measurements basically on the ground floor (96%). In some cases, we also performed measurements in the basement (1%), where for example the gym was placed, or in the first floor (3%) (Table 1). In some kindergartens located in the hilly areas we performed measurements on different floors because of the rising ground level (Table 1).

In the 88 kindergartens the measurement was performed in 195 rooms with different function (group room, office, kitchen, dressing room, gym) (Table 2). The most measurements were in group rooms (173), where children stay most, the least was in dressing rooms and kitchens (4–4) (Table 2). The remaining 14 rooms were 7 offices and 7 gyms.

Building characteristics

At the beginning of the radon survey a questionnaire was filled with the contacts of every kindergarten. This form contains the most important building’s parameters, which are presented in the Table 3.

Most of the studied kindergartens were built between 1946 and 1989 and only 3 before 1900. The most commonly used building material is the brick (67%) the remaining 33% used rubble, concrete, adobe, aerated concrete, lightweight construction or wood. More than half of the kindergartens do not have cellar (59%) and 26% of them has partly. About half of the kindergartens do not have external insulation the other half do (Table 3). In 78.5% of the kindergartens have well-closed windows, which means usually new types of plastic windows and 20.5% have draughty windows (old-type wood windows).

Indoor radon measurement

Radon activity concentration was measured by CR-39 track detectors in each season for one year, Autumn: September-November, Winter: December-February, Spring: March-May, Summer: June-August. The predefined measurement

| County           | Number of the kindergartens (N/%) | Number of the measured rooms (N) | Level where the detector is placed (N) |
|------------------|-----------------------------------|----------------------------------|---------------------------------------|
|                  |                                   | 1 2 3 4                          | Basement Ground floor First floor     |
| Baranya          | 2 (2)                             | 0 0 0 0                          | 2 0                                   |
| Fejér            | 10 (11)                           | 5 1 4 0                          | 18 0                                  |
| Győr-Moson-Sopron| 2 (2)                             | 2 0 0 0                          | 2 0                                   |
| Komárom-Esztergom| 12 (14)                           | 7 1 4 0                          | 20 0                                  |
| Nógrád           | 2 (2)                             | 0 0 2 0                          | 6 0                                   |
| Pest             | 21 (24)                           | 0 1 19 1                         | 60 3                                  |
| Somogy           | 5 (6)                             | 5 0 0 0                          | 5 0                                   |
| Tolna            | 3 (3)                             | 3 0 0 0                          | 3 0                                   |
| Vas              | 5 (6)                             | 5 0 0 0                          | 5 0                                   |
| Veszprém         | 26 (30)                           | 3 4 18 1                         | 67 2                                  |
| Total            | 88 (100)                          | 32 7 47 2                         | 188 5                                 |
period was one year from September 2015 to September 2016, however, in many cases, the measurements shifted due to the late re-posting of the detectors. This caused changes in the predefined measurement periods. First placement of detectors were basically done personally—except for in case of remote locations, to where the detectors were sent by post—when the questionnaire was also completed. Replacement of detectors between the seasons was always done by post. Detectors were placed on a shelf about 1.5-2 m height and 15–20 cm from the wall.

### Table 2 Number and type of the measured rooms in each county

| Country              | Number of rooms (N/%) | Type of the room (N) | Group room | Office | Kitchen | Dressing room | Gym |
|----------------------|-----------------------|----------------------|------------|--------|----------|---------------|-----|
| Baranya              | 2 (1)                 | 2                    | 0          | 0      | 0        | 0             | 0   |
| Fejér                | 19 (9.7)              | 17                   | 2          | 0      | 0        | 0             | 0   |
| Győr-Moson-Sopron    | 2 (1)                 | 2                    | 0          | 0      | 0        | 0             | 0   |
| Komárom-Esztergom    | 21 (10.8)             | 18                   | 1          | 1      | 0        | 1             |     |
| Nógrád               | 6 (3.1)               | 3                    | 0          | 2      | 0        | 1             |     |
| Pest                 | 63 (32.3)             | 55                   | 2          | 1      | 3        | 2             |     |
| Somogy               | 5 (2.6)               | 5                    | 0          | 0      | 0        | 0             |     |
| Tolna                | 3 (1.5)               | 3                    | 0          | 0      | 0        | 0             |     |
| Vas                  | 5 (2.6)               | 4                    | 0          | 0      | 0        | 1             |     |
| Veszprém             | 69 (35.4)             | 64                   | 2          | 0      | 1        | 2             |     |
| Total                | 195                   | 173                  | 7          | 4      | 4        | 7             |     |

### Table 3 Building characteristics of the studied kindergartens

| Parameters of building characteristics | Categories                  | Number of kindergartens (N/%) | Number of rooms (N/%) |
|---------------------------------------|-----------------------------|------------------------------|-----------------------|
| Year of construction                  | Before 1900                 | 3 (3)                        | 7 (4)                 |
|                                       | 1900–1945                   | 9 (10)                       | 26 (13)               |
|                                       | 1946–1989                   | 54 (61)                      | 125 (64)              |
|                                       | After 1990                  | 11 (13)                      | 23 (12)               |
|                                       | Not known                   | 11 (13)                      | 14 (7)                |
| Building material                     | Brick                       | 59 (67)                      | 123 (63)              |
|                                       | Rubble                      | 7 (8)                        | 21 (11)               |
|                                       | Concrete                    | 7 (8)                        | 18 (9)                |
|                                       | Adobe                       | 3 (3.4)                      | 9 (5)                 |
|                                       | Brick + rubble              | 3 (3.4)                      | 8 (4)                 |
|                                       | Aerated concrete            | 3 (3.4)                      | 4 (2)                 |
|                                       | Lightweight construction    | 2 (2.3)                      | 6 (3)                 |
|                                       | Brick + concrete + rubble   | 2 (2.3)                      | 2 (1)                 |
|                                       | Wood                        | 1 (1.1)                      | 2 (1.5)               |
|                                       | Not known                   | 1 (1.1)                      | 1 (0.5)               |
| Presence of cellar                    | Has cellar                  | 12 (14)                      | 29 (14.9)             |
|                                       | Partly has cellar           | 23 (26)                      | 55 (28.4)             |
|                                       | Has no cellar               | 52 (59)                      | 110 (56.7)            |
|                                       | Not known                   | 1 (1)                        | 1 (0.5)               |
| External insulation                   | Has insulation              | 41 (47)                      | 85 (44)               |
|                                       | Partly has insulation       | 1 (1)                        | 3 (1.5)               |
|                                       | Has no insulation           | 45 (51)                      | 106 (54)              |
|                                       | Not known                   | 1 (1)                        | 1 (0.5)               |
| Windows type                          | Draughty                    | 18 (20.5)                    | 36 (18.5)             |
|                                       | Well-closed                 | 69 (78.5)                    | 158 (81)              |
|                                       | Not known                   | 1 (1)                        | 1 (0.5)               |
After the radon exposure the detectors were chemically etched in sodium-hydroxide solution (8 h, 90 °C, 6.25M). After the chemical treatment, the detectors were cleaned with distilled water and alcohol. The determination of the track densities (tracks mm\(^{-2}\)) was carried out by the “IDES” scanner-based evaluation system, which was developed at the Institute of Radiochemistry and Radiocology [21].

The own background of the CR-39 detector was 0.5 tracks mm\(^{-2}\). The minimum measurable radon activity concentration was influenced by the type of the diffusion chamber. During this survey the NRPB type was selected. The minimum measurable radon activity concentration is 20.6 Bq m\(^{-3}\) for this type with 3-month exposure time, the value of LLD is 44.5 kBq h m\(^{-3}\). The sensitivity of CR-39 detectors (Baryotak type) was between 1.5 and 1.7 depending on the storage time before the measurement. The calibration process and the determination of the calibration factor was carried out in the own calibration chamber with a certified radon source.

**Results and discussion**

**Raw indoor radon activity concentration data (each room, each season, individually)**

First column of the Table 4 shows the summary statistics of the raw data (each room, each season, individually). The arithmetic mean of indoor radon activity concentration is 60 Bq m\(^{-3}\), geometric mean is 50 Bq m\(^{-3}\), the maximum value was 288 Bq m\(^{-3}\), which was an autumn-winter measurement on the ground floor, where the building material is rubble, the windows are well-closed, there is slag built-in and there is no cellar and insulation. Figure 2 shows the histogram, quantile plot, box-whisker plot and the scatter plot of the raw indoor radon activity concentration data (each room, each season, individually). Raw data has lognormal distribution \((p = 0.17)\) according to the Kolmogorov-Smirnov Test (Fig. 2).

Figure 3 shows the seasonal variation of the raw indoor radon activity concentration data. It has an expected pattern, lowest in summer and highest in autumn, winter and spring. Seasonal variation of radon in kindergartens is less than in residential homes [18, 22, 23]. In Hungary the mechanical ventilation is not typical, such as e.g. in Norway [24], but the windows are open all day, even in winter, in tilt position. This can be the reason of the small seasonal variation.

**Annual average indoor radon activity concentration in the studied 195 rooms of the 88 kindergartens**

Second column of the Table 4 shows the summary statistics of the annual average radon concentration in the 195 rooms of the 88 studied kindergartens. The arithmetic mean of indoor radon activity concentration is 60 Bq m\(^{-3}\), geometric mean is 52 Bq m\(^{-3}\), and the maximum value is 160 Bq m\(^{-3}\). Third column of the Table 4 shows the summary statistics of the annual average radon concentration in 88 studied kindergartens. The arithmetic mean of indoor radon activity concentration is 61 Bq m\(^{-3}\), geometric mean is 54 Bq m\(^{-3}\), and the maximum value is 160 Bq m\(^{-3}\). These average values are similar the measurement results found in 63 other countries introduced by Zhukovsky et al. [9].

Highest annual average radon concentration was find in the offices (74 Bq m\(^{-3}\)) and the lowest one in the gyms (46 Bq m\(^{-3}\)), however, there is no statistically significant difference between the radon concentrations of different types of rooms according to the Kruskal-Wallis Test (Fig. 4). Note that the highest annual average indoor radon concentration values (high outliers) were found in the group rooms (155 and 160 Bq m\(^{-3}\)) (Fig. 4a).

We checked if there is any difference between in the radon concentration of the kindergartens regarding the year kindergarten was built (Fig. 4b). We selected four groups of the years. First group is kindergartens built before 1900, before the economic and social development bringing our country similar to Western countries. Second is 1900–1945, years of the two world wars. Third is 1946–1989 after the Second World War until the regime change in Hungary. It
is well known that during these years slag and fly ashes from heavy industry were built in the houses and any type of buildings as filling material in the ceiling or the floor countrywide in Hungary. The fourth group is the kindergartens constructed after 1990. Lowest concentrations were found in kindergartens built after 1990. Highest values were found in kindergartens built between 1946 and 1989 (155 and 160 Bq m$^{-3}$, average is 63 Bq m$^{-3}$). Among these kindergartens 24 have no slag built-in, 4 have slag built-in and in case of 33 kindergartens it is not known if there is slag built-in or not. Based on the measured radon results, it is conceivable that where there is no information about the built-in slag there is slag just they do not know about it.

As it was expected annual average indoor radon concentration is higher in those rooms where the windows are well-closed (new windows) (45 Bq m$^{-3}$) than in rooms with draughty (old) windows (64 Bq m$^{-3}$) (Fig. 4c).

Those rooms where slag is built-in have the highest annual average radon concentration (72 Bq m$^{-3}$) than rooms without it (55 Bq m$^{-3}$). Rooms with no information on built-in slag have higher annual average indoor radon concentration (63 Bq m$^{-3}$) than those without slag and lower than rooms with built-in slag (Fig. 4d). This result also supports the above mentioned assumption that where there is no information about the built-in slag there is slag just they do not know about it.

In kindergartens where there is a cellar underneath, the annual average indoor radon concentration on the ground floor is lower (56 Bq m$^{-3}$) than in those where there is partially or no cellar at all (both are 63 Bq m$^{-3}$) (Fig. 4e). However, they are not significantly different according to the Kruskal-Wallis Test.

Kindergartens with insulation show a little bit higher values (66 Bq m$^{-3}$) than without insulation (56 Bq m$^{-3}$) but not a significantly different annual average indoor radon concentration values according to the Kruskal-Wallis Test (Fig. 4f).

Regarding the building material, radon activity concentration is less in wood, concrete (26 and 33 Bq m$^{-3}$, respectively) and higher in brick, rubble and adobe construction (62, 70 and 77 Bq m$^{-3}$, respectively) (Fig. 5).

**Conclusion**

None of the studied 88 kindergartens in the 76 towns had higher than 300 Bq m$^{-3}$ annual average radon activity concentration (Hungarian reference level), even in individual seasons. Arithmetic and geometric mean of indoor radon concentration of this survey is similar to find in 63 other countries. The seasonal variation of indoor radon in the studied kindergartens was not so strong, like usually in the dwellings, because of the continuous ventilation and the closed period in summer in the kindergartens. Highest
Values were found in kindergartens built between 1946 and 1989 (155 and 160 Bq m⁻³). It is well known that during these years slag and fly ashes from heavy industry were used as filling material in the ceiling or the floor in buildings countrywide in Hungary. This is also supported by the fact that in the kindergartens where slag is found we got higher values (72 Bq m⁻³) than in those where slag is not built-in (55 Bq m⁻³). Well-closed windows caused higher indoor radon concentration (64 Bq m⁻³) than draughty ones (45 Bq m⁻³). Regarding the building material, annual average radon activity concentration is less in wood, concrete (26 and 33 Bq m⁻³, respectively) and higher in brick, rubble and adobe construction (62, 70 and 77 Bq m⁻³, respectively). Comparing the results from this survey with data from other European survey (which was introduced in this paper), the arithmetic and geometric mean was similar in each survey.
Fig. 5 Box-whisker plot of the annual average indoor radon activity concentration regarding the different building materials (in the order of the average). Numbers in the brackets on the X axis are the number of measurements.

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