



# 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  $61 \text{ Bq m}^{-3}$ , maximum was  $160 \text{ Bq m}^{-3}$ . 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  $300 \text{ Bq m}^{-3}$  [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  $59 \text{ Bq m}^{-3}$ , geometric mean was  $36 \text{ Bq m}^{-3}$  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  $300 \text{ Bq m}^{-3}$  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  $200 \text{ Bq m}^{-3}$  [10].

Bem et al. [11] found maximum  $139 \text{ Bq m}^{-3}$  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.

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Đurčík 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  $57.5 \text{ Bq m}^{-3}$  and  $34.5 \text{ Bq m}^{-3}$  in the kindergartens, respectively. They found higher than  $200 \text{ Bq m}^{-3}$  (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  $200 \text{ Bq m}^{-3}$ . However, in 16 kindergartens it was between 800 and  $5600 \text{ Bq m}^{-3}$  [13, 14] Vaupotic et al. [15] remediated two kindergartens where the average heating season indoor radon concentration was about  $2000 \text{ Bq m}^{-3}$ . 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  $300 \text{ Bq m}^{-3}$  indoor

radon concentrations in the studied period. Arithmetic mean was  $132 \text{ Bq m}^{-3}$ , maximum was  $1415 \text{ Bq m}^{-3}$  [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,  $300 \text{ Bq m}^{-3}$  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.

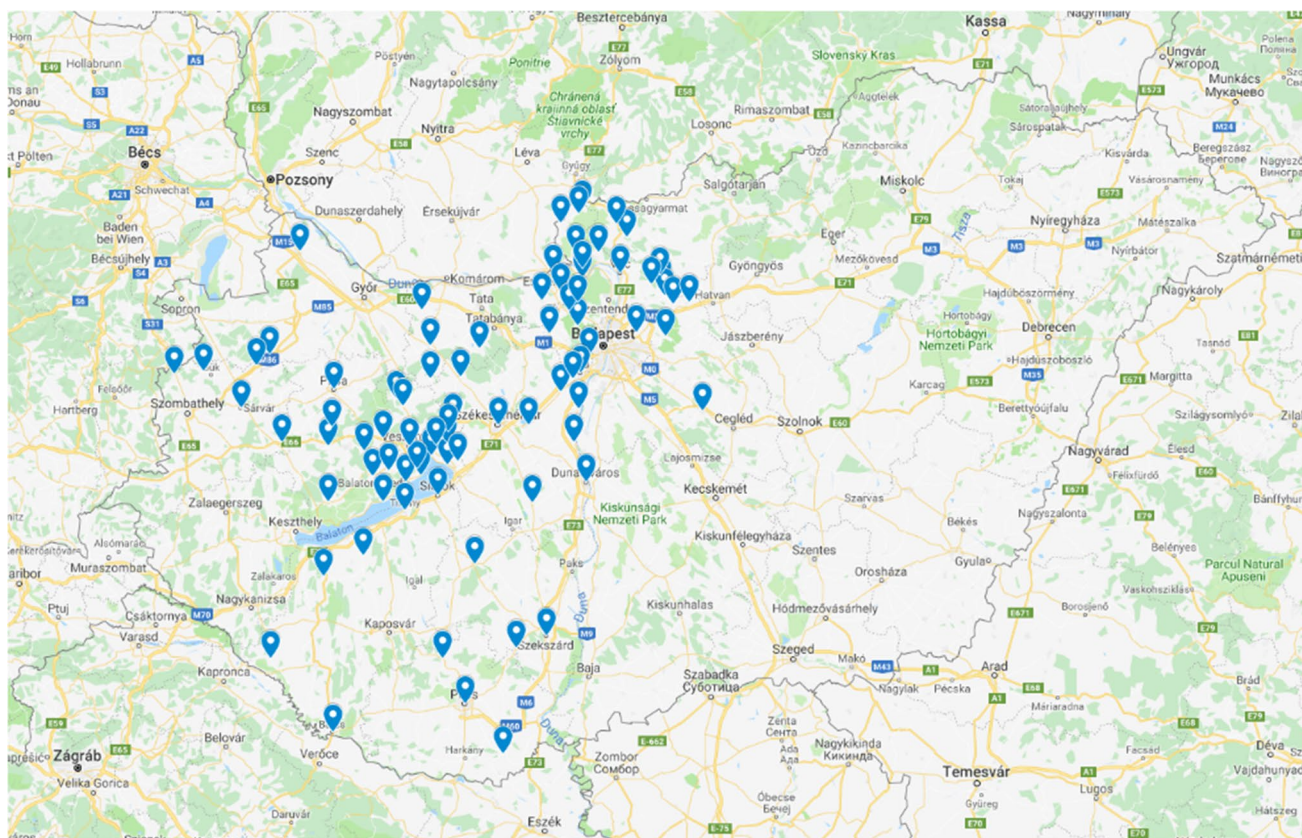


Fig. 1 Location of the studied kindergartens

## 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

**Table 1** Number of the studied kindergartens and rooms in the different administrative divisions (counties) and the building levels where the detectors were placed

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)	2	0	0	0	0	2	0
Fejér	10 (11)	5	1	4	0	1	18	0
Győr-Moson-Sopron	2 (2)	2	0	0	0	0	2	0
Komárom-Esztergom	12 (14)	7	1	4	0	1	20	0
Nógrád	2 (2)	0	0	2	0	0	6	0
Pest	21 (24)	0	1	19	1	0	60	3
Somogy	5 (6)	5	0	0	0	0	5	0
Tolna	3 (3)	3	0	0	0	0	3	0
Vas	5 (6)	5	0	0	0	0	5	0
Veszprém	26 (30)	3	4	18	1	0	67	2
Total	88 (100)	32	7	47	2	2	188	5

**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
Fejér	19 (9.7)	17	2	0	0	0
Győr-Moson-Sopron	2 (1)	2	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)	3 (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)

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.

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  $\text{mm}^{-2}$ ) was carried out by the “IDES” scanner-based evaluation system, which was developed at the Institute of Radiochemistry and Radioecology [21].

The own background of the CR-39 detector was 0.5 tracks  $\text{mm}^{-2}$ . 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  $\text{m}^{-3}$  for this type with 3-month exposure time, the value of LLD is 44.5 kBq h  $\text{m}^{-3}$ . The sensitivity of CR-39 detectors (Baryotrak 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

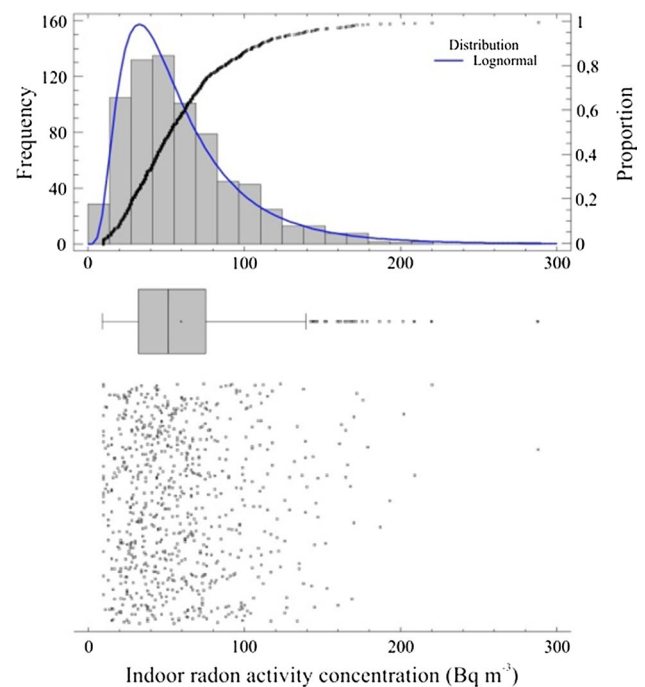
### Raw indoor radon activity concentration data (each room, each season, individually)

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  $\text{m}^{-3}$ , geometric mean is 50 Bq  $\text{m}^{-3}$ , the maximum value was 288 Bq  $\text{m}^{-3}$ , 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



**Fig. 2** Histogram, quantile plot, box-whisker plot and scatter plot of the raw indoor radon activity concentration data (each room, each season, individually). Blue line is the density function of the fitted lognormal distribution

rooms of the 88 studied kindergartens. The arithmetic mean of indoor radon activity concentration is 60 Bq  $\text{m}^{-3}$ , geometric mean is 52 Bq  $\text{m}^{-3}$ , and the maximum value is 160 Bq  $\text{m}^{-3}$ . 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  $\text{m}^{-3}$ , geometric mean is 54 Bq  $\text{m}^{-3}$ , and the maximum value is 160 Bq  $\text{m}^{-3}$ . These average values are similar the measurement results found in 63 other countries introduced by Zhukovsky et al. [9].

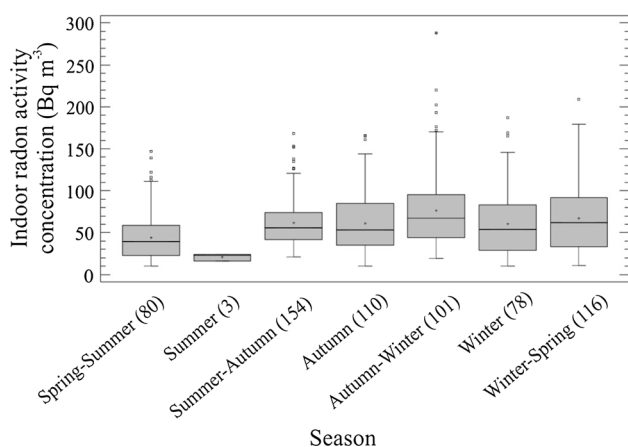
Highest annual average radon concentration was found in the offices (74 Bq  $\text{m}^{-3}$ ) and the lowest one in the gyms (46 Bq  $\text{m}^{-3}$ ), however, there is no statistically significant difference between the radon concentrations of different types of rooms according to the Kruskal-Wallis 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  $\text{m}^{-3}$ ) (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

**Table 4** Summary statistics of the indoor radon activity concentration data

	Raw indoor radon data (each room, each season, individually) ( $\text{Bq m}^{-3}$ )	Annual average indoor radon data in the different rooms ( $\text{Bq m}^{-3}$ )	Annual average indoor radon data in the kindergartens ( $\text{Bq m}^{-3}$ )
Count	742	195	88
Minimum	10	14	16
LQ	33	36	39
GM	50	52	54
Median	52	52	56
Average	60	60	61
UQ	76	78	78
Maximum	288	160	160
SD	37	31	29

LQ lower quartile, GM geometric mean, UQ upper quartile, SD standard deviation



**Fig. 3** Box-whisker plot of the raw indoor radon activity concentration data in the different seasons. Numbers in the brackets on the X axis are the number of measurements

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  $160 \text{ Bq m}^{-3}$ , average is  $63 \text{ Bq m}^{-3}$ ). 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) ( $45 \text{ Bq m}^{-3}$ ) than in rooms with draughty (old) windows ( $64 \text{ Bq m}^{-3}$ ) (Fig. 4c).

Those rooms where slag is built-in have the highest annual average radon concentration ( $72 \text{ Bq m}^{-3}$ ) than rooms without it ( $55 \text{ Bq m}^{-3}$ ). Rooms with no information on built-in slag have higher annual average indoor radon concentration ( $63 \text{ Bq m}^{-3}$ ) 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.

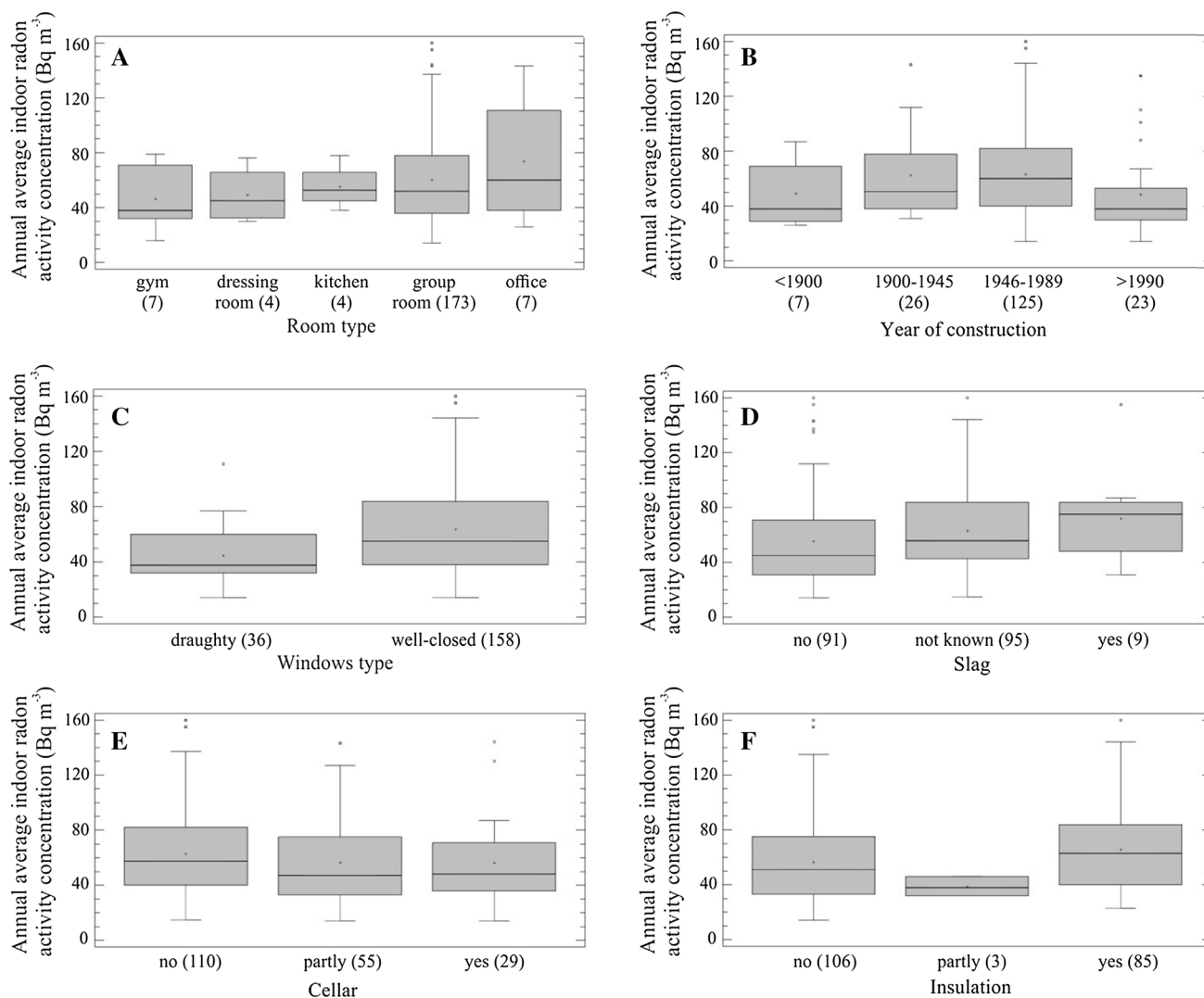
In kindergartens where there is a cellar underneath, the annual average indoor radon concentration on the ground floor is lower ( $56 \text{ Bq m}^{-3}$ ) than in those where there is partially or no cellar at all (both are  $63 \text{ Bq m}^{-3}$ ) (Fig. 4e). However, they are not significantly different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

Kindergartens with insulation show a little bit higher values ( $66 \text{ Bq m}^{-3}$ ) than without insulation ( $56 \text{ Bq m}^{-3}$ ) 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  $33 \text{ Bq m}^{-3}$ , respectively) and higher in brick, rubble and adobe construction ( $62$ ,  $70$  and  $77 \text{ Bq m}^{-3}$ , respectively) (Fig. 5).

## Conclusion

None of the studied 88 kindergartens in the 76 towns had higher than  $300 \text{ Bq m}^{-3}$  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

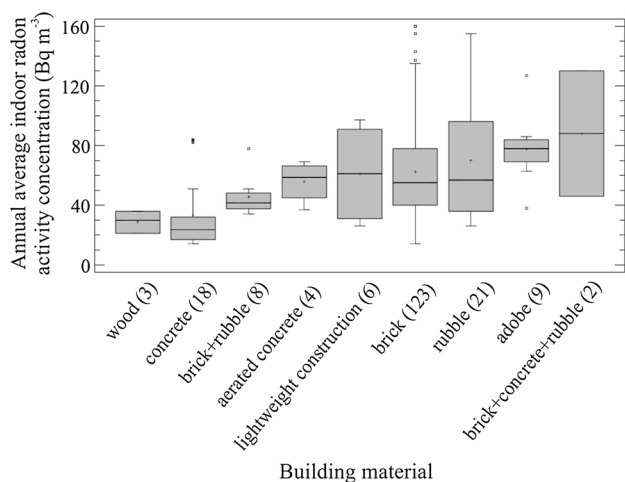


**Fig. 4** Multiple sample comparison of annual average indoor radon activity concentration and the kindergarten parameters. **a** Type of rooms. **b** Year of construction. **c** Windows type (ventilation fre-

quency). **d** Slag built-in. **e** Presence of cellar. **f** Presence of insulation. Numbers in the brackets on the X axis are the number of measurements

values were found in kindergartens built between 1946 and 1989 ( $155$  and  $160 \text{ Bq m}^{-3}$ ). 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 ( $72 \text{ Bq m}^{-3}$ ) than in those where slag is not built-in ( $55 \text{ Bq m}^{-3}$ ). Well-closed windows caused higher indoor radon concentration ( $64 \text{ Bq m}^{-3}$ )

than draughty ones ( $45 \text{ Bq m}^{-3}$ ). Regarding the building material, annual average radon activity concentration is less in wood, concrete ( $26$  and  $33 \text{ Bq m}^{-3}$ , respectively) and higher in brick, rubble and adobe construction ( $62$ ,  $70$  and  $77 \text{ Bq m}^{-3}$ , 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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