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Original Research

Indoor Radon Concentrations in Concrete Slab Buildings Situated in Green Hills Housing Estate in Białystok, Poland

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Abstract

We performed measurements in 16 houses (12 concrete-slab houses and 4 brick houses) and within each house we performed measurements in one or more rooms from cellar to ^{4th} floor. In total, the study includes 279 indoor radon measurements. The method of alpha track detectors was used in this investigation. The measurements were performed in housing of the same construction of concrete slabs in one part of Białystok. Approximately 12 million people in Poland live in such concrete slab buildings. It was observed that mean radon concentrations in brick houses were higher (by 24%) than in concrete slab buildings situated in the same housing estate. The results for the Green Hills housing estate are believed to be representative for all concrete slab buildings in northeastern Poland.

Keywords: indoor radon, concrete slab buildings, Poland

Introduction

Radon (^{222}Rn), formed during radium disintegration, is a naturally occurring radioactive element, a noble gas which provides the largest contribution to the effective dose absorbed by the population of Poland from the ionizing radiation (approximately 38.7%) [1]. Radon can enter the inside of a building in different ways, i.e. the soil on which the building is built, building materials for its construction, and water and gas used in the household. The soil- indoor air transport takes place by means of diffusion and convective flow [2-8]. Diffusion can occur through a non-damaged layer of the concrete (the cellar floor) as well as through the cracks in concrete slabs. On the other hand, the convective flow of radon in the room occurs together with the convective flow of the air, which is caused by the difference of pressures due to differences between the outdoor and indoor temperatures [9, 10]. Wind can be another factor that causes pressure differences [11]. The amount of radon formed in building material and released to the air inside the building depends on the content of ^{226}Ra and the amount of radon exhalation. Radon, formed in walls and ceiling, diffuses to the indoor air [12]. Water used in the household is less important as far as indoor radon concentration is concerned. Mean values of radon concentrations in water established for the Białystok region is about 7000 Bq/m^3 [13]. Thus, radon present in waterworks slightly increases radon concentration in dwelling houses supplied with water.

Radon concentration in homes depends on many factors, like radon potential of the geologic ground, the type of building construction, its tightness, and the kind of building materials [14].

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Buildings show high architectural design diversity, and although they are similar as far as the outside aspect is concerned, they differ regarding materials and technology. The so-called “concrete slabs” technology, used in Poland in 1972-90, resulted in building housing estates of similar buildings in every town. It is estimated that 90% of all buildings were built using industrial methods, including eighty percent (i.e. 72% of all buildings) using concrete slabs, which differs as far as technology, wall structure and their tightness are concerned, as compared to traditionally built houses. The concrete slab method is based on manufactured production of typical concrete construction elements used for a block of flat construction. The body of the building is made up of the slabs at the building site. On the other hand, brick houses were built in a traditional way of joining the bricks together with use of mortar. There was only stack ventilation in both types of buildings. Concrete slab houses were constructed as a result of high demand for flats and their decoration is far from satisfactory. It is estimated that in Polish population about 12 mln inhabitants live in houses of “concrete slab” technology (169 thousands houses with 375,000 flats) [15]. “The Green Hills” is a housing estate that consists of approximately 160 buildings localized in an area of about 2 km^2. Most of them are 4-storey houses built using the same “concrete slab” technology. These buildings contain from 60 to 80 flats. The group consisted of identical buildings with several flats on each floor and usually one family in each flat. To compare possible differences of radon concentrations dependent on the kind of the building, the measurements also were carried out in brick houses situated in the same area.

The aim of the study was to assess radon concentrations in concrete slab houses and their comparison with that in brick houses in the same housing estate as well as to observe radon concentration dependence on such factors as window types, wall and floor covers, and ways of ventilation.

Experimental Procedures

The Measurement of Indoor Radon Concentrations in Flats

The method of alpha track detectors was used to measure radon concentrations in the air in flats. The method is based on exposure of the foil made up of different materials, known as nuclear foils, which record the radiation presence for an established period (usually longer than a month). The phenomenon of violation of detector structure material by alpha particles penetration is used in the detectors. Other kinds of radiation do not cause such defects. The tracks can be observed and counted under the microscope after appropriate chemical processing. The density of tracks is proportional to radon concentration [16]. The examinations were conducted with CR-39 detectors in NRPB chambers were used. Foil calibration was performed in the radon chamber in the H. Niewodniczański memorial Institute of Nuclear Physics in Kraków. After exposure, the foils underwent etching in 7 N of KOH solution at 70°C for 8 hours. The calculation was performed using the program of automatic picture analysis according to Lucia [17, 18]. The size of the field on the foil to be read was 0.5-1 cm^2. The accuracy of radon content measurement in the air of examined rooms by this method is approximately 10% [19]. A whole-year simultaneous exposition of all detectors was incorporated in the measurements. One measurement was performed in each flat in the living room. Thus, there were 187 flats in 12 concrete-slab buildings examined. As for the cellars, 24 measurements were carried out. Four brick houses underwent 59 measurements in flats and 9 in the cellars. The studies were possible only when the owners gave their consent and were cooperative. Unfortunately some detectors were lost and therefore we observed the difference in the number of measurements on particular floors. The measurements were performed in 211 rooms of 12 concrete slab buildings and in 68 rooms of 4 brick houses.

Measurement of Radon in the Soil

The measurement of radon concentrations in the soil air was conducted at a depth of 1 m in 8 places, evenly distributed among examined buildings. Alpha-GUARD PQ 2000 apparatus, whose ionizing chamber was 0.56 dm^{-3} in volume, was used for the measurement. The soil samples were also taken to determine the content of ^{226}Ra.

Measurement of Ra-226 Content in the Soil

As noted above, at the sites of radon measurements the samples of soil were collected from the depth of 1 m to measure ^{226}Ra contents. Then they were prepared (dried and sifted) and put into Marinelli containers of volume 1700 cm^3. ^{226}Ra content in soil samples was measured using a MAZAR-95 analyzer. Counting for the analysis of the registered spectrum was collected for 2000 s. In order to decrease the measuring error, the counting was repeated 6 times.

Results and Discussion

We conducted 279 measurements of radon concentrations in the air of homes in the Green Hills housing estate. Information concerning flat construction, window types, wall and floor covers as well as ventilation methods was also gathered.

The distribution of radon concentrations in the buildings in the area of the examined estate was lognormal. Radon concentrations were measured in 211 rooms of concrete slab houses and we did not observe significant differences in mean radon concentrations between particular buildings. The differences of radon concentrations on particular floors of the "concrete slab" buildings were analyzed. The results are presented in Table 1.

Annual radon concentration arithmetic mean was 33 Bq/m^3 in living quarters of concrete slab buildings. The value is lower than annual mean value estimated for Poland (48 Bq/m^3). The highest radon concentrations were observed in cellars in all buildings and the arithmetic mean was almost twice as high as those on the remaining floors. There was a tendency of radon concentrations to drop from the cellars to the third floor in all buildings. The regularity was observed for mean values as well as radon concentrations in particular staircases in examined buildings. Due to voluntary cooperation of the flat owners we could not obtain a full comparison of vertical concentrations in a given staircase. However, there was an unexpected increase in radon concentration values on the fourth floor in the single buildings. It could be explained by different constructions of ventilation system. In "concrete slab" buildings, there are two ventilation chimneys in each vertical segment. Flats from three floors are connected with one chimney (the ground floor, the second and the fourth floors) and two other floors (flats from the first and third floors) are connected to the other ventilation system. It is possible that the difference of underpressure, that causes the exchange of the air from the IV floor, is so small that it is reflected in the increase in radon concentrations as compared to the III floor. On the other hand, a dysfunction of the ventilation system is also possible. In that case, the air would pass from downstairs flats to the flats on the IV floor instead of being pushed out of the rooms. Big changes of stack ventilation functioning can occur due to alterations performed by the owners. Such dysfunctions can occur in cases of an electric fan installed in the kitchen or bathroom.

The second examined group consisted of brick houses. We conducted 68 measurements of radon concentrations in those buildings. The changes of radon concentrations on particular floors were analyzed and the results were presented in Table 2. Radon concentrations have decreasing tendency together with the increase in height in brick buildings. The highest mean radon concentration also occurs on the level of the cellar. There was no radon concentration increase on the fourth floor in brick houses as it was observed in almost all slab buildings.

Table 1. Distribution of radon concentrations on particular floors of the "concrete slab" buildings. AM – arithmetic mean, GM – geometric mean, M – median, SD – standard variation.

Floor	Number of measurements	AM [Bq/m^3]	M [Bq/m^3]	SD [Bq/m^3]	GM [Bq/m^3]	GSM	MAX [Bq/m^3]	MIN [Bq/m^3]
cellar	24	60	54	28	54	1.6	136	23
0	37	38	37	11	37	1.3	75	23
1	46	33	32	8	32	1.3	54	19
2	40	31	28	10	30	1.3	57	20
3	36	30	29	7	29	1.3	48	18
4	25	34	32	9	33	1.3	55	19
Living part	187	33	32	9	33	1.3	75	18
Total	211	36	32	15	34	1.4	136	18

Table 2. Distribution of radon concentrations on particular floors in brick buildings.

Floor	Number of measurements	AM [Bq/m^3]	M [Bq/m^3]	SD [Bq/m^3]	GM [Bq/m^3]	GSM	MAX [Bq/m^3]	MIN [Bq/m^3]
cellar	9	104	102	28	100	1.4	134	54
0	23	50	47	12	49	1.3	75	35
1	10	40	39	6	40	1.2	54	32
2	7	35	31	9	34	1.3	49	26
3	10	33	33	9	33	1.3	48	21
4	9	30	30	6	29	1.2	42	17
Living part	59	41	40	12	39	1.3	74	17
Total	68	49	41	26	44	1.5	134	17

However, in brick houses, each flat has its own stack ventilation duct and is ventilated in the same way. Thus, it seems that the ventilation system and its efficiency are of great importance and it can change radon concentration in the building [20-23]. Radon concentrations observed in brick buildings were higher than those measured in "concrete slab" ones. The biggest differences were between the arithmetic means of radon concentrations in the cellars and the ground floors of the particular types of buildings. We found that the differences disappeared together with the height of the building. On average, radon concentrations in brick buildings were approximately 24% higher than those in slab buildings (Mann-Whitney test $p<0.005$) and it was the result of bigger tightness of brick buildings. Most probably, the differences of radon concentrations between brick houses and slab buildings are not due to the construction material as the differences of radon concentrations disappear on higher floors. Radium concentration measurements in constructing material, used in northeastern Poland, did not show significant differences between radon concentrations in prefabricated elements and bricks [24].

Radon emission from the walls is the sum of complicated processes occurring in the material and depends on radon concentrations, but also on the density, porosity, and humidity. All the factors influence the size of surface exhalation.

The data set of all registered radon concentrations in the Green Hills buildings (both in concrete slabs and brick houses with cellars) showed the following values: arithmetic mean (AM = 39 Bq/m^3), geometric mean (GM = 35 Bq/m^3), median (M = 32 Bq/m^3). Radon concentrations in the buildings were determined on the basis of all-year observation. The maximum value of radon concentrations was stated in the cellar and it was 136 Bq/m^3.

A part of the measurements (n = 33) were conducted in cellars to observe what radon values inflow to the building. Table 3 shows the value of radon concentrations collected in the living parts of the buildings (without cellars).

Radon concentration in the soil air and radium content in the ground measurements were carried out in the same places at 8 stations in the estate of the Green Hills. The stations were apart from each other by approximately the same distance and located on 3/4 of the estate area. The results are presented in Table 4.

The soil air radon concentration showed random distribution in particular measurement sites. However, the whole range of fluctuation was included in the normal radon potential according to Slung classification [7, 25]. Any significant differences between radon concentrations in the soil of concrete slab buildings and brick house localizations were observed. The ratio of the soil air radon concentrations 20 kBq/m^3 to its concentration in the cellars 60 Bq/m^3 of slab buildings was 337. On the other hand, the same ratio in brick houses was 194. It seems that the ground, although containing small amounts of radium and the normal radon potential, dominates as far as radon inflow to the cellars is concerned. Mean radium concentration in soil of the examined housing estate was close to the value appointed for the northeastern region (about 11 Bq/kg) [26]. As the soil radon concentrations show the normal radon potential in the whole area of the examination, the differences of radon concentrations in both types of buildings are probably caused by technology and material used for construction. It should be assumed that the tightness of foundation and concrete slabs on which the building constructed is larger in concrete slabs building than in brick houses. Many authors stated the relationship of radon concentration in the building air on the type of construction and building materials [27-29].

The Analysis of Other Factors Affecting Radon Concentrations in Flats

Analysis was limited to concrete slab buildings. As there are many reports concerning the influence of decorating the walls, floors, window tightness, etc. on radon concentrations, we tried to establish the relationships in the homogenous housing estate. The distribution of radon concentrations in the group of flats in the concrete slab

Table 3. Values of radon concentration obtained in living parts of all buildings ("concrete slab" + brick buildings) in "The Green Hills".

Number of measurements	AM [Bq/m^3]	M [Bq/m^3]	GM [Bq/m^3]	SD [Bq/m^3]	Max [Bq/m^3]	Min [Bq/m^3]
246	35	33	34	11	75	18

Table 4. Radon concentrations in the soil air and ^{226}Ra content in the ground in the estate of the Green Hills.

Number of measurements	Estate	AM	M	MIN	MAX	SD
8	Radon [kBq/m^3]	20	19.7	4	38.5	13.2
8	^{226}Ra [Bq/kg]	11.4	11.9	3.6	18.7	5.1

buildings were analyzed regarding window types. Two types were taken into consideration: traditional wooden windows, usually draughty, and modern double-glazed ones. The results are presented in Fig.1.

It was observed that higher radon concentrations occurred in flats with double-glazed windows. The mean radon concentrations on each examined floor in flats with traditional windows were on average more than ten percent lower than in flats with double-glazed windows. When two sets of flats were compared, one with traditional windows and double-glazed windows, radon concentrations were about 16% higher in flats with double-glazed windows and the difference was statistically significant ($p< 0.05$). Double-glazed windows are more tight than traditional ones and decrease the air exchange between the outside and the inside. The intensity of air exchange depends on the efficiency of ventilation systems, the tightness of joints of wall elements and windows, as well as the habits of flat ventilation [19, 21, 28]. The influence of building tightness on the registered values of radon concentrations was observed at the end of the 1970s, when energy-efficient construction was developed in western countries due to the world energy crisis [30, 31].

Radon concentration differences caused by flat ventilation were also determined. The inhabitants were asked about their habits of flat ventilation while the detectors were established for the exposure. Data were then analyzed and the ways of ventilation could be divided into two groups. One way is opening the windows for a short time and in this groups the windows are usually closed (specifically in winter) while the other way is to have the windows opened (opened slightly in one or two rooms) for best part of the day regardless the season of the year. The comparison of radon concentrations in the two types of ventilation in flats on the same floor level did not show any statistically significant differences. However, the comparison of radon concentrations in of the all set examined flats with short and long time of ventilation (AM=36 Bq/m^3 and AM=31 Bq/m^3, respectively) showed slightly higher values in flats with short time of ventilation, and the values are statistically significant ($p<0.05$). Although concrete slabs buildings were not constructed as energy-efficient and the visual assessment of the tightness of slab joints reveals numerous defects, obtained differences of radon concentrations show the effect of window tightness and ways of ventilation.

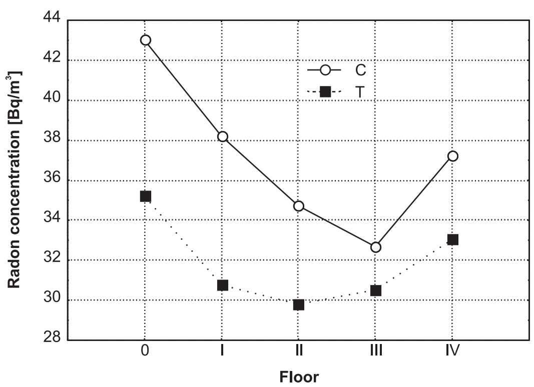

Fig.1. Arithmetic mean radon concentrations on particular floors in flats with traditional (T) and double glazed (C).

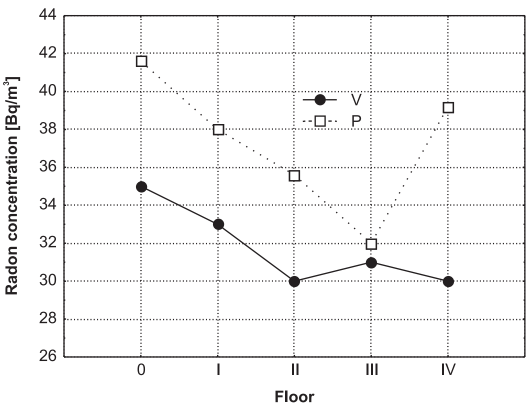

Fig. 2. Comparison of arithmetic mean radon concentrations in rooms with all-paper and emulsion wall covers. V- vinyl wall papers, P- painted.

The way of walls finishing inside the building was also taken into account while analyzing radon concentrations in flats. The examined flats were divided into two groups: flats with walls covered with vinyl wall-papers and those painted with emulsion. The results are presented in Fig. 2.

Radon concentrations in flats with walls covered with emulsion were approximately 10% higher than that in flats with wall-paper. The differences were not big but they are statistically significant ($p=0.012$). Thus, it seems that radon inflow to flats with wall-paper is slightly smaller as compared with radon in flats with emulsion-covered walls. The results are similar to those reported by other authors [32-36].

Radon concentrations in flats with parquet floors and those with fitted carpet were compared and there were no differences observed.

Conclusion

Radon concentrations in flats in the Green Hills estate (AM = 35 Bq/m^3) are below the annual mean value established for Poland (AM = 48 Bq/m^3). The value of radon concentration arithmetic mean in concrete slab buildings was found to be even lower (AM = 33 Bq/m^3). The comparison of radon concentrations in concrete slab houses and brick buildings (AM = 41 Bq/m^3) shows a difference of 24%, which is statistically significant.

It can be assumed that radon concentration distribution in two types of buildings noticed in the Green Hills housing estate can concern all concrete slab buildings in northeastern Poland. Thus, the Polish population in this region inhabiting slab buildings is probably less exposed than it is shown in other reports as far as mean radon concentrations are concerned.

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