VÉDELEM TUDOMÁNY
KATASZTRÓFAVÉDELMI ONLINE TUDOMÁNYOS FOLYÓIRAT

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RADON EMISSION OF BUILDING MATERIALS AND RECYCLED STRUCTURAL MATERIALS – AN INTERNATIONAL COLLATION

Abstract

Radon is a naturally occurring colourless, odourless, radioactive gas, which is the decay product of radium. The most widely known radioactive sources are uranium, thorium and radium, but ionizing radiation can also be found elsewhere. Any building material of natural origin may contain a certain quantity of radioactive elements. The carriers of this radioactivity are called the NORMs (Naturally Occurring Radioactive Minerals). Reused building materials in many cases include unknown components and thus deserve priority attention regarding radioactivity. In Hungary, 70% of these materials is soil, of which only 15% is being reused. It is advised to utilize them with exceptional precaution, as they may contain dangerous elements regarding radioactivity due to their unbeknown compound. In this article we delineate research and results of various countries; showing relations of high concentration and their dangers, and additionally, their connection to building materials, all with the goal of attracting attention to the hazards of indoor radon concentration.

Keywords: radon, naturally occurring radioactivity in building materials, reused building materials, recycled building materials, sustainability

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RADON-KIBOCSÁTÁS ÉPÍTŐANYAGOKBAN ÉS ÚJRAHASZNOSÍTOTT ÉPÍTŐANYAGOKBAN – NEMZETKÖZI ÖSSZEVETÉS

Absztrakt

A radon a természetben előforduló, színtelen, szagtalan radioaktív gáz, a rádium bomlásterméke. A legismertebb radioaktív források az urán és a rádium, de ezeken kívül jóval kisebb mértékben máshol is megtalálható az ionizáló sugárzás. Minden természetes eredetű építőanyagban jelen lehet valamilyen mennyiségű radioaktivitás. Ennek a radioaktivitásnak a hordozói az úgynevezett NORM (Naturally Occurring Radioactive Mineral) természetben előforduló radioaktív ásványok. A bontott építési hulladékok kiemelt figyelmet érdemelnek radioaktivitás szempontjából, mert összetételük sok esetben ismeretlen. Ezek 70%-át teszi ki talaj Magyarországon, és 15%-a kerül újrahasznosításra. Hasznosításakor ajánlott a nagyfokú figyelemmel való eljárás, mert radioaktivitás szempontjából veszélyes anyagokat is tartalmazhat. A cikkben egyes országok vizsgálatait és eredményeit ismertetjük; bemutatva a magas koncentráció és veszélyeik összefüggéseit, továbbá építőanyagainkkal való relációját, azzal a céllal, hogy a beltéri radon-koncentráció veszélyeire felhívjuk a figyelmet.

Kulcsszavak: radon, természetes eredetű radioaktivitás építőanyagokban, bontott építési hulladék, fenntarthatóság

1. RADON IN OUR SURROUNDINGS

Radon dissolves quickly in outdoor environment, which eventuates that the rate of outside radon concentration cannot be considered as a risk factor; its value is usually below 10 Bq/m^3. The radon concentration of soil is, however, much more notable, due to the decay of uranium in soil leading to the accumulation of radon gas in dense matter, or its solvation in water. The radon levels measured in soil are various: depending on the properties of given soil, it moves on a scale from less than 2000 Bq/m^3 to more than 100.000 Bq/m^3. [1] If radon moves indoors from the soil beneath the building, it is capable of concentration. The radon concentration of indoor environments is between less than 20 and several hundreds of Bq/m^3, but there could be extreme values occurring. [2] Radon could possibly be in relatively shallow depths and/or in high concentrations underground, which results in the potential of getting inside the house through the ground slab before its decay. Radon can leak inside through ground slabs, cracks on walls, various joints of the building, sockets around pipes, through the water system, but it could also originate from building materials (e.g. bricks, slag, etc.). Even less understood the fact, that radon can also be found in our water supplies, in dissolved form. The concentration of the drinking water, however, usually does not top 10 Bq/l, by reason of the high-rate dilution, the adequate storage and handling of public water supplies.

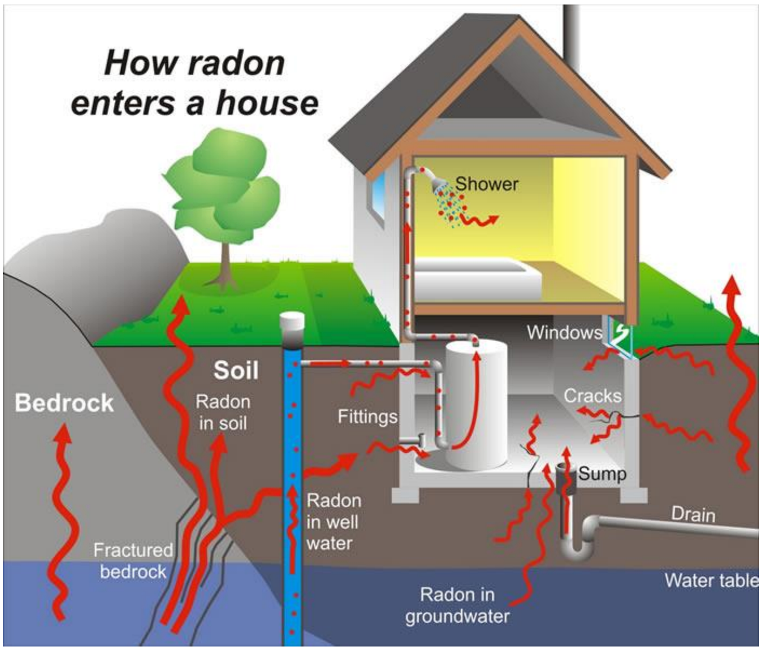

Figure 1: How radon enters our dwellings [3]

2. RADON IN OUR DIRECT HOME ESTABLISHMENTS

The accumulation of indoor radon is strongly bound to the region, the compound and permeability of the soil, the circumstances of the atmosphere and the construction of the building. Typically, higher radon concentration is associated with buildings with proper thermal insulation, equipped with tightly sealing doors and windows, and/or if they were built on ground rich in uranium, thorium or radium. Distance from the ground is also an important factor, as radon being the heaviest known gas, it cannot travel great distances upwards. Hence, basements and ground-floor rooms are mostly exposed to higher concentrations of radon. [4] Hardcore and gravel fill put under the ground slab have higher permeability than soil itself. Therefore, radon is able to move more easily under the concrete slab.

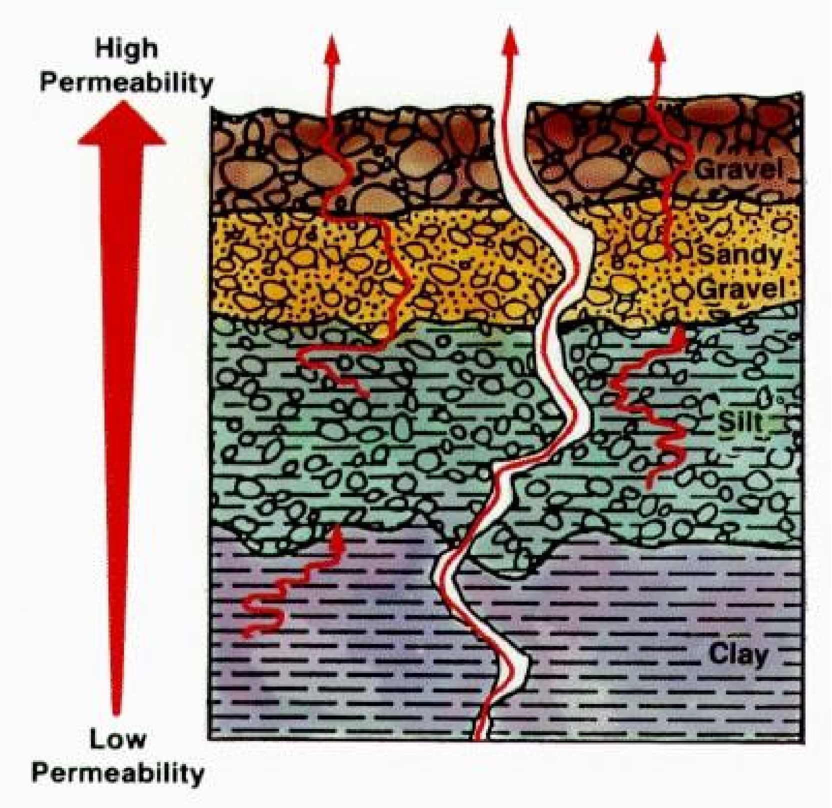

Figure 2: Permeability of different kinds of soil [4]

Gravel fill is used under basements and the trench between basement walls and soil is also often filled with gravel or other permeable matter. This basically gives a three-dimensional entry possibility to radon, making basements the most radon-riskful house parts. This is further complicated if the gravel fills or landfills used at the construction are completely or partially reused construction materials; or if the structural elements of the building are made using recycled building materials or industrial byproducts. In case of these buildings, we may often encounter built-in materials with elevated radiation. These building materials include ground granulated blast furnace slag- and fly ash concrete blocks, or heat insulation fillings made out of power plant- or furnace slags. The relatively high radioactivity of ceramic bricks can be explained with its compounds; 30-60% of brick clay consists of clay minerals, in addition of sand, calcium-carbonates and various oxides. The radioactivity of sand is usually low – except if they contain high amounts of zircon, monazite or xenotime. [5]

3. MEASURING RADON

Since radon gas is colorless, odorless and tasteless, its observation cannot be made by our senses. As a result, special radon measurement devices must be used. Radon concentration measurements are usually divided into two main groups: short- and long-term tests. Short term measurements usually cannot provide fully precise results, but of course they are adequate indicators of the radon accumulation in urgent cases. Radon measurement devices can also be divided into two main categories: active and passive devices. Passive devices do not need electricity or a suction pump to operate, while active devices do – in turn they are capable of monitoring the radon concentration and its change. [6]

Measurements usually determine a radon level, in Bq/m^3. However, it is important to know the value of effective dose, which means the annual radiation a person is exposed to. The following equation is in use:

$$Effective\ dose = radon\ level \cdot time \cdot dose\ equivalent \tag{1}$$

where radon level equals to the indoor radon concentration in Bq/m^3, time equals to the exposure time in hours, and dose equivalent is a value determined by the environment (e.g. workplace, type of dwelling). Dose equivalent calculated with an average 50 Bq/m^3 of radon level on workplaces for one year (2000 hours) gives 0.7 mSv of effective dose as result. [7] This is nearly one-third of the natural radiation dose affecting an average Hungarian in one year. [8]

4. MEASUREMENTS BY COUNTRIES

Hungary

So far two expansive measurements have been made covering the entire area of Hungary. The first was made by István Nikl, associate of the National Frédéric Joliot-Curie National Research Institute for Radiobiology and Radiohygiene (OSSKI); his inspection from 1993 till 1994 included 998 homes, made with traditional and prefabricated technology, regarding building materials such as ceramics, concrete, reinforced concrete, aerated concrete and industrial byproducts. [9] The second research of this degree is linked to Dr. Eszter Tóth. Her investigation centered around ground-level buildings and has tested the radon concentration of 15.277 ground-floor rooms with her associates in the time interval from 1994 to 2004. The utilized building materials used in these buildings were mainly the same as the aforementioned ones. [10]

United Kingdom

The average indoor radon concentration of the United Kingdom is 20 Bq/m^3, which is considered as an uncommonly low level. Despite the low values, more than 600.000 indoor radon tests were registered nationwide [2]. In the main, the examined dwellings were made of classic ceramics, concrete or buildings related to these technologies.

Sweden

The Swedish have been actively concerned with radon since 1955, when the measurement of 300 dwellings took place. This research was conducted by the initiation of Rolf Sievert, of whom the unit of measurement of the effective dose was named. The average indoor radon concentration was 113 Bq/m^3 in 1990 and only 90 Bq/m^3 in 2008. [11][12] The building technologies used of examined apartments were traditional, prefabricated and light structural. As per building materials, mostly ceramics, concrete, reinforced concrete, aerated concrete, calcium silicate masonry, wood and stone were used.

Austria, the Czech Republic, Finland and Norway

These territories have elevated radon concentration, that result in the increase of lung cancer cases. Thus, radon testing and mitigation is even more important within these countries. Their measurement results show nearly identical values. [13] As for technology, the examined dwellings are traditional, prefabricated and light structural in construction. The building materials used are mainly ceramics, concrete, reinforced concrete, aerated concrete, calcium silicate masonry, wood and stone.

United States of America

The United States of America uses a different unit of measurement to nominate the quantity of radioactive matter; this unit is the picocurie per liter. [14]

$$1\ pCi/l = 37\ Bq/m^3 \tag{2}$$

Scientist create radon potential maps with various information, such as sites of bedrock with high uranium content, sites of breaches, radioactivity of air, permeability and radon concentration of the soil, together with the data about indoor radon. For instance, the radon potential maps made of Maryland and Virginia, Fairfax county by the U.S. Geological Survey (USGS) are based on distinct data. The potential of Montgomery county was estimated by the geologists of USGS on the grounds of soil and air radioactivity measurements, geological and pedological maps, in addition of the indoor radon measurements made by residents. [4] The typical construction methods used in these territories are mainly light structural, with a smaller part being traditional, and reused materials on a negligible scale.

China

There are few available data sources regarding indoor radon in China. In virtue of a 2002 study, the average indoor radon concentration is approx. 22.5 Bq/m^3, as a result of testing more than 10.000 dwellings. Another study sought connection between the population suffering from lung cancer and indoor radon in Shenyang. The average concentration in the surveyed apartments was 89 Bq/m^3. [15] The building methods are most commonly industrialized technologies, concrete and reinforced concrete.

Libya

The measurements effectuated in Libya, led by A. F. Saad [16] used the volume of the given room, the degree of ventilation and the level of emission to calculate the annual effective dose.

The results were then grouped by building materials. The method to measure radon exhalation in building materials was the ‘sealed-can’ technique, which consists of an alpha-detector in a container that is sealed airtightly to the examined material.

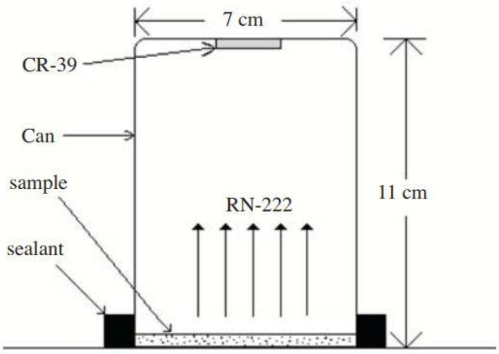

Figure 3: Sealed-can technique used in the measurements of A. F. Saad [16]

4. EVALUATION OF RESULTS

Hungary

According to the investigation of Nikl [9], the average indoor radon concentration in the surveyed buildings was 126 Bq/m^3, with 16% of them having higher levels than 200 Bq/m^3, and 1.5% exceeding 600 Bq/m^3. The test results of Tóth [10] showed an average level of 133 Bq/m^3, with 1.6% of dwellings exceeding 400 Bq/m^3 in smaller settlements, 1% in middle-sized towns and 0.5% in cities and capitals. The highest level measured was 5800 Bq/m^3, the lowest was only 10 Bq/m^3. Another significant result of the research of Tóth was the estimation of the place and percentage of Hungarian territories exceeding 200 Bq/m^3 by their geological attributes, divided to regions. Based on these geological properties, the area of Hungary has been divided to 21 sections. According to this, the most outstanding radon concentrations were found in the volcanic ranges of the Northern hills of Hungary (Északi-középhegység) and in smaller parts of the Lowlands (Alföld). [17]

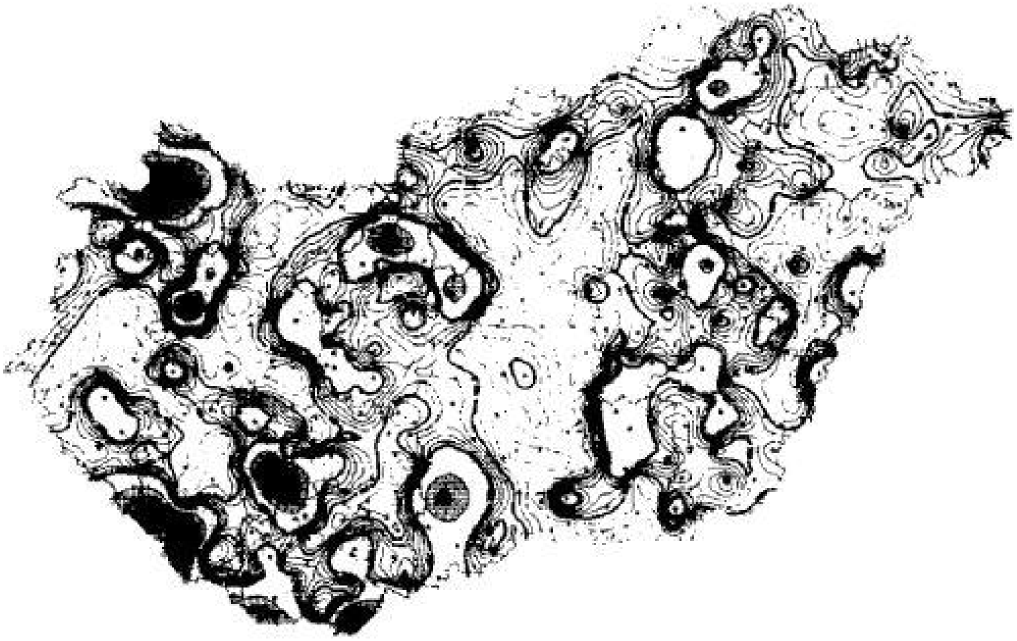

Figure 4: The radon map of Hungary made by István Nikl [9]

United Kingdom

In the UK, the Radon Affected Areas are territories of which more than 1% predictably outstrips 200 Bq/m^3. Fortunately, only an estimated 0.4% of dwellings top the Action Level of 200 Bq/m^3 across the UK. [2]

Sweden

Based on the test results, the average indoor radon level of Sweden does not seem much, however, this value is an average level; according to the estimations, 450.000 residences are above the Action Level of 200 Bq/m^3. This equals to the 8.5% of total housing in Sweden, with 3% exceeding 400 Bq/m^3, too. [18] Sweden has managed to reduce its average indoor radon concentration by 23 in only 18 years.

United States of America

The differing units of measurement of course requires conversions. With a national average of 48 Bq/m^3 (1.3 pCi/l), 4 pCi/l is the Action Level (148 Bq/m^3), which is the maximum allowed value. Between 2 and 4 pCi/l it is recommended to utilize radon mitigation.

China

The radon map made of China is, unfortunately, insufficient to provide evident information. Based on the appromaxitive measurement methods (e.g. grab-sampling technique), a clear conclusion cannot be made. [19]

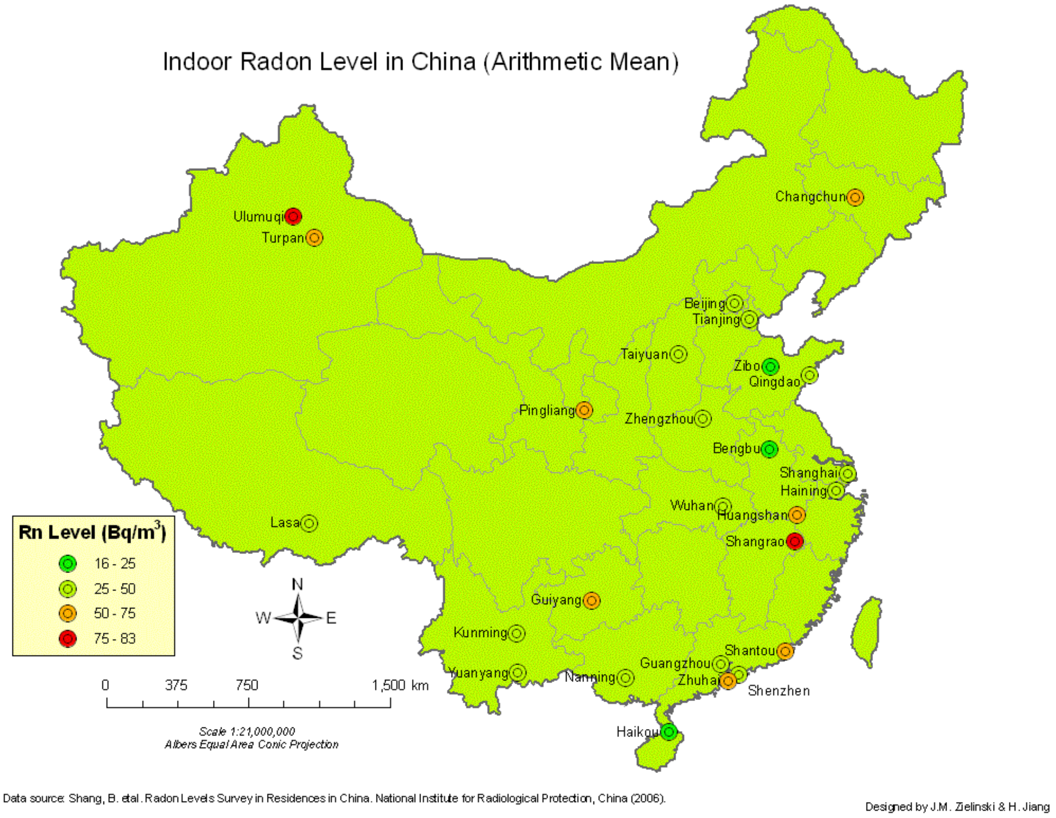

Figure 5: Radon map of China [20]

Libya

The outcome of the test results eventuated an average radon concentration of 172 ± 5.8 Bq/m^3 for brick walls, 145.1 ± 4.9 Bq/m^3 for ceramic floor tiles, and 174.5 ± 5.8 Bq/m^3 for marble ledges. The most radon emission was generated by marble, while the least was by ceramics. As for marble, the highest measured radon level was 298.7 ± 10.0 Bq/m^3, near the Action Level of most countries, hence marble requires increased precaution – however it can be established that marble is rarely used in large quantities. [16]

6. SUMMARY OF MEASUREMENTS

According to the test results, I review the previously declared values.

Results of the national radon survey made by István Nikl:

Material of masonry	Soil connection	Radon concentration with standard deviation [Bq/m3]
Traditional bricks	ground floor	145 ± 194
	upper floor	93 ± 136
Loam	ground floor	148 ± 153
Prefabricated concrete	upper floor	64 ± 54

Table 1: Radioactivity of dwellings, groupped by building material and connection to the soil [9]

Annual effective dose [mSv/year]	Radon emission quotient on sample surface [Bq/m^{2}h]	Radon concentration [Bq/m^3]	Building material
17.2 ± 0.6	0.146 ± 0.005	192.8 ± 6.5	brick masonry
10.6 ± 0.4	0.090 ± 0.003	119.5 ± 4.0	
24.8 ± 0.8	0.210 ± 0.007	277.9 ± 9.3	
10.5 ± 0.4	0.089 ± 0.003	118.2 ± 4.0	ceramic sheathing
7.8 ± 0.2	0.066 ± 0.002	87.0 ± 2.9	
11.3 ± 0.4	0.096 ± 0.003	127.3 ± 4.3	
20.6 ± 0.7	0.175 ± 0.006	231.8 ± 7.8	marble sheathing
14.9 ± 0.5	0.126 ± 0.004	166.2 ± 5.6	
24.9 ± 0.8	0.211 ± 0.007	279.2 ± 9.3	

Table 2: Radon concentration of brick-, ceramic- and marble products [16]

Libya has shown a significant radon level in marbles.

The results of measurements made in Iraq, by L. Najam et al.:

Sample	Surface exhalation rate (E_a) [Bq/m^{2}h]	Mass exhalation rate (E_m) [Bq/kgh]	Radon concentration [Bq/m^3]	Country of origin
Cement	1,24	0,35	205,05	Iraq
Common brick	1,01	0,28	166,55	Iraq
Ceramics	1,05	0,3	174,12	Syria
Porcelain	1,63	0,46	270,04	Turkey
Black marble	1,26	0,36	290,04	Turkey
White marble	1,21	0,34	200,27	Turkey
Red granite	2,3	0,65	383,3	Turkey

Table 3: Measurement results of various building materials made by L. Najam et al. [21]

7. SUMMARY

Granite has the most potential of all of our building materials to emit radon, along with andesite and rhyolite. Additionally, sandstone, concrete, bricks, marble and gypsum are potential radon risk sources. [22] The radiation emission of these building materials depends on the extent of usage inside of the building. Basically, when used in greater quantities, pyroclastic (volcanic clastic) rocks are to be utilized with precaution, as blocks of these may contain radon in ranges up to 200-400 Bq/m^3. Test results of cement showed low, under 100 Bq/m^3 level of radiation in types of cement CEM I, II, III and V, only CEM IV (pozzolan cement) has revealed radiation levels more than 100 Bq/m^3. [23] Pozzolan, being volcanic ash, carries higher risk of radioactivity. Furnace ash is also radiologically potent, which has been frequently used in concrete in the previous decades. [24] Fly ash is also considered to be a threat of radiation; nonetheless, fly ash cement still does not reach the Action Level set by the European Commission. [25] Ceramic-based bricks have higher radon emission than concrete. This is mainly because of the higher porosity of bricks, which eventuates the escape of more radon from between the granules. Test results show a radon concentration of 63-185 Bq/kg of perlite. Based on the connection of radon and porosity, I conclude that the increased air volume of expanded perlite results in the higher diffusion of radon. Thus, the testing of heat insulation and light concrete that contains expanded perlite is suggested.

In conclusion, the aforementioned measurements and their results make it clear that building materials are possible radon hazards and thus, indicate further measurements and experiments to be executed in the topic. As for Hungary, new, extensive indoor and soil radon measurements are essential in order to mitigate the dwellings with high radon concentration and help the residents be safe from radon induced lung cancer.

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