Seasonal and Floor Variations of Indoor Radon Concentration

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Abstract. Radon is a naturally occurring, colourless and odourless radioactive gas, with a half-life of 3.8 days. Dangerous is not radon itself, but its progeny (daughter) products. The radon decay products irradiating of the lung. There is a strong correlation between radon exposure and lung cancer. The indoor radon concentrations in residential buildings are monitored. The study is performed in eight storied blocks of flats and also in family houses. The contributed deals with the radon concentration depending on a year season and floor level. Radon concentrations are varying with the characteristics of the building and its ventilation. Statistical analysis of the results shows that the probability that a weekly measurement represents the yearly radon concentration is significantly higher (twice) in winter and in summer than in summer and autumn. The maximum values of radon concentration is obtained in the first and second-floor rooms might be due to the contribution of radon emanation from the soil, entering into the living spaces from the ground.

1. Introduction
Radon is a health hazard but not by itself. Constructions or other human activities should be a potential factor or increased concentrations of radon. Particular risk is place without adequate air change rate. There are many studies dealing with elevated radon concentrations in the indoor environment due to the small level of air change rate, construction details or concentration of radon bearing underground soil. The concentration of radon can always be reduced by adjustments and interventions by experts [1]. Sufficient air exchange is a determinative factor of the radon concentration in the interior [2]. There are a number of measures to keep low concentrations of radon, which are often inconsistent with energy performance.

Radon decays into radioactive metal ions by alpha radiation. Radon and its radioactive elements are trapped in the respiratory tract and irradiate lung tissue. The effect of these particles may be damage to the lung cell leading to cancer. Long-term research shows that 16% of lung cancer is caused by irradiation with radon or its progeny (formerly daughter) products. Radon is classified as a Class 1 human carcinogen. Approximately 280 of the 2300 lung cancer incidences per year may be linked to radon [3]. Cancer does not erupt immediately. Symptoms may appear in 10 to 30 years.

The current constructions are characterized by the high airtightness of the building envelope. These constructions have well-sealed all structures such as roof, perimeter cladding, windows and ceilings. The higher the airtightness of the building envelope is, the higher indoor radon concentration is. Regular
Ventilation (natural or forced) reduces radon concentrations in high airtightness buildings. Low concentrations of radon are typical for buildings with leaky fillings of holes, which ensures a constant exchange of air. Indoor concentrations of radon are highly variable. The average value of radon in buildings in the Czech Republic is 118 Bq/m³. In the outdoor atmosphere, the radon concentration is approximately 5 Bq/m³. The Czech Republic is among the countries with the highest concentration of radon in apartments in the world.

Figure 1: Radon’s major entry points into a building [4]

Radon penetrates into the interiors of buildings through the foundation structures. Figure 1 shows the radon’s major entry points into a building: A, cracks in concrete slabs; B, spaces behind brick veneer walls that rest on hollow – block foundation; C, pores and cracks in concrete blocks; D, floor–wall joints; E, exposed soil, as in a sump; F, weeping (drain) tile, if drained to popen sump; G, mortar joints; J, building materials, such as some rock; K, water (from some wells) [4].

Radon is dispersed throughout the room due to airflow. Radon concentration in the room varies not only in space but also over time. This is due to the conversion of air volume and the change of radon increase. Radon intake is affected by changes in heat and pressure difference, infiltration, wind force, subsoil permeability, etc. These changes can be short-term (day, night) and long-term (month, year).
The highest concentrations of radon are usually in rooms where contact with the subsoil (ground floor areas of uncovered buildings, underground rooms, etc.) prevails.

The source of higher volumetric activities of radon in the ambient air may be an increased concentration of $^{226}$Ra in building materials. Natural materials are crushed, milling and heat-treated, which can lead to a greater release of radon from the building material into the interior of the building. In the past, various types of waste (cinder or slag) used in building materials have proven problematic. At present, all building materials must have a radon certification.

Radon is a naturally occurring, colourless and odourless radioactive gas, with a half-life of 3.8 days. There are 39 known isotopes of radon from $^{193}$Rn to $^{231}$Rn. The isotopes of $^{222}$Rn, $^{220}$Rn and $^{219}$Rn are basic naturally occurring isotopes of radon. The most common isotope (occurring in 95%) is $^{222}$Rn, which is usually called radon. It is a member of the uranium-radio conversion line. The isotope $^{222}$Rn is the direct descendent of $^{226}$Ra. An isotope $^{220}$Rn known as a thoron with a half-life of 55.6 seconds is a member of the thorium conversion line. The third radon isotope is $^{219}$Rn (actinone), a member of the actinium decay line, with a half-life of 3.92 seconds. All isotopes are radioactive [5-6].

Radon progeny are important in terms of irradiation. The progeny include polonium $^{218}$Po (a half-life of 3.1 minutes), lead $^{214}$Pb (half-life of 27 minutes), bismuth $^{214}$Bi (half-life of 20 minutes) and polonium $^{214}$Po (half-life of 164μs). All of these decay products are metals that settle in the atmosphere on the surface of the dust particles. Most of the activity of radon progeny is associated with particles of the small diameter between 0.006 and 0.2 mm, with the mean diameter of about 0.025 mm. A small fraction of radon progeny, typically 0.1 or less, remains unattached and in dynamic equilibrium with attached particles. Subsequently, they are inhaled and, depending on their size, can be deposited in different parts of the airway or lung lining. Due to the high toxicity of α particles are the most harmful both isotopes of polonium, which disintegrate in this way [5-6].

2. Methods and measurements
All radon-control measures applied in existing buildings require maximum effectiveness, simple realization, minimum impact on environmental comfort, economic effectiveness at realization as well as its realization and minimum maintenance.

The indoor radon concentrations in residential buildings were studied. The study was performed in eight storied blocks of flats and also in family houses. The information about the concentration of radon, in most cases is based on a single short-terms measurement. Because of the temporal variations in indoor radon concentrations, these type of measurements may not accurately represent the value that would have been obtained from measurements made over a longer period. Continuous weekly measurements were made over the period of a year.

On the base of radon program, the indoor radon concentrations in residential buildings were studied. The buildings were different by the building materials, type of windows, by the heating system, and ventilation rate. Also, indoor spaces were different by their distance from the soil. The screening measurements over a period of a year using CR – 39 system were done. The trace detectors which were located in various rooms of dwellings were used. The detectors were fastened on a string hanging about 40 cm from the ceiling and at least 20 cm from the wall opposite to the window. The detectors were hung for a 1-year period. After exposure, the detectors were collected and assessed by Quantimet 520 Analyser.

Radon concentrations were measured using the Radon Progeny Monitor – system RPM-256. The data results were collected, the mean radon concentration and mean standard deviation was estimated.
It is evident that we need to search for factors that dominantly influence indoor radon concentration. The main one is the intensity of air change.

3. Results and discussions

3.1. Indoor radon and seasonal variation

Meteorological and climatic factors cause short-term as well as seasonal variations of volumetric radon activity in the soil and then, consequently in the building. Among these factors ranks for instance air temperature, soil temperature in different depths, precipitation rate and intensity, changes in the atmospheric pressure, direction and velocity of a wind-stream etc. Observations in the Czech Republic and all over the world show that volumetric radon activity rises during spring and autumn months, on the other side it falls in summer and winter. Rain, snow or high atmospheric pressure lower the radon seepage from the soil; strong winds and higher temperatures cause radon activity in soils to increase. The frozen soil on the surface prevents radon to sleep into the atmosphere and causes a significant increase in radon concentration under the frozen layer [1]

Radon, as an inert radioactive gas, easily penetrates through different media. As a result of a difference in indoor-outdoor temperatures and pressures, radon is absorbed from the building underground soil. This phenomenon is called a chimney effect. Warm air in the building has a lower mass than the outdoor air. Warm air rises up so creating the sub-pressure in the basement what causes air, even from outdoors to be absorbed. If all the windows and doors in the basement and ground floor are sealed tightly, sub-pressure forces the soil air to be absorbed through cracks and fissures in the foundations and, in the lower scale through the base masonry.

The study was performed in eight storied blocks of flats, situated in an area with low and middle radon risk. The buildings were made of concrete as well as the foundations. The test spaces had an area of approximately 50 – 90 m². There was no air-conditioning system present in any of the measured rooms. As well, each room was equipped with the central heating system. The gas was used for cooking.

The ventilation rate is during the year different. It is connected also to local meteorological conditions, indoor thermal comfort and various lifestyle of dwellers. In order to test the reliability of short-term measurements for predicting long-term exposure seasonal and annual a lot of measurements were done. Statistical analysis of the results shows that the probability that a weekly measurement represents the yearly radon concentration is significantly higher in winter and in summer than in summer and autumn. Overall the results indicate that short-term radon measurements appear to represent the yearlong average only if the measurements are made during winter and spring. The seasonal variation of the radon concentration is described in Table 1. Figure 2 shows the association mean radon concentration during seasons.

| Season | Mean Radon Concentration [Bq.m⁻³] | Mean Standard Deviation [Bq.m⁻³] | Mean Air Change [ACH] |
|--------|----------------------------------|---------------------------------|-----------------------|
| Winter | 152.8                            | 6.4                             | 0.3 – 0.5             |
| Spring | 146.0                            | 6.5                             | 0.3 – 0.5             |
| Summer | 58.2                             | 4.7                             | 0.7 – 0.9             |
| Autumn | 54.6                             | 3.8                             | 0.7 – 0.9             |

In the indoor building environment design, civil engineer plays an important role. Each building is characterized by its underground soil – geological composition of soil layers implemented construction
materials, building purpose, its exploitation and maintenance. The radon-control measures have to be
designed and solved individually.

In construction planning, it’s important to find out the presence of radon in the soil air by the
geological survey. Basing on the survey, civil engineer chose the convenient building foundation and,
decide if build or not underground floors.

It’s necessary to take into account the “chimney effect” problem that may emerge and may result in
soil air with radon gas seeping into the home. In such case, the underground part has to be tightly
detached from the floors above. The right situation of the staircase is also of great importance.

In foundation and parts of buildings that are in touch with soil, in addition to current insulation, it’s
necessary to implement insulation with high diffusion resistance. The most advantageous seem to be
asphalted girdles with aluminum, cooper or lead film, respectively plastic polyethylene films.

3.2. Indoor radon and different floor level
The effect of the pressure differences between lower and upper floors was watched. The distribution of
\(^{222}\)Rn concentrations in the different levels of the buildings measured in typical eight-floor building over
the year is given in the Table 2.

The maximum values obtained in the first and second-floor rooms might be due to the contribution of
radon emanation from the soil, entering into the living spaces from the ground. The radon concentrations
decrease from the basement to upper floors. Increasing radon concentrations found at the upper levels
were due to well-known chimney effect as well as to reduced air change on these floors see figure 3.

| Table 2. Indoor radon concentrations at different levels. |
| Floor level | Mean Radon Concentration [Bq.m⁻³] | Highest Value Found [Bq.m⁻³] | Mean Air Change [ACH] |
|-------------|----------------------------------|-----------------------------|----------------------|
| 1st Floor   | 114                              | 157                         | 0.54                 |
| 2nd Floor   | 97                               | 143                         | 0.58                 |
| 3rd Floor   | 84                               | 118                         | 0.58                 |
| 4th Floor   | 73                               | 111                         | 0.72                 |
| 5th Floor   | 77                               | 126                         | 0.78                 |
| 6th Floor   | 86                               | 132                         | 0.87                 |
| 7th Floor   | 89                               | 127                         | 0.89                 |
| 8th Floor   | 112                              | 152                         | 0.81                 |

**Figure 3.** Variation of mean radon concentration depending on floor.

3.3. Construction Adjustments

The most often case of existing buildings that requires adaptation from the ionizing microclimate optimization point of view, is the building with the underground floor, where the source of radon is underlying soil and rock. Radon gas seeps through cracks and fissures in foundations. Under pressure in the building, amplified by the chimney effect increase its concentration also at the higher floors. The constructions in touch with soil are mostly made of concrete or masonry insulated with current hydro insulation. If the crack appears, no barrier exists there against radon gas seeping. In such case adaptations are inevitable.

One of these possible solutions is ventilation of an air space created under the floor construction. First of all, the cracks must be sealed properly. Airspace can be created by wooden prisms laid down on a concrete layer in the distance of about 1 meter. Ensuring the ventilation of the space, the prism has holes (with diameter 10 mm). Transversely on the prisms, there are laths that serve as an underlayer for layers of the floor. Such airspace in the floor can be connected to ventilation that draws radon out into the atmosphere.

The next possible radon-control measure is an additional insulation of vertical and horizontal constructions in touch with underground soil. As it was already said, it is necessary to seal all the existing
cracks, too. Insulation cardboard is on a concrete layer and supplementary film with high diffusion resistance is employed (insulation girdles with aluminium, cooper or lead film). The same effectiveness can be attained with plastic polyethylene film, that accomplish hydroinsulation demands, too. Vertical walls have to be covered with hydroinsulation.

The anti-radon paint coating is suitable for new as well as for existing buildings and can be applied to horizontal and vertical constructions (surfaces). The wall coat serves as a protection against soil radon entering and construction materials emissions. The surface must be flat and smooth to ensure high quality and long life-time. The main disadvantage of this unexacting measure is the possibility of mechanical damage and thus, loss of effectiveness.

4. Conclusions
The amount of radon, as well as the amount and form of existence of its decay products in buildings, is strongly dependent on the rate of penetration and release of radon, on the intensity of air change, and on the presence and properties of aerosol pollution. Variance of radon concentration indoors is associated with the heterogeneity of influencing factors. The basic strategy of decreasing radon concentration in buildings is ventilation. Statistical analysis of the results shows that the probability that a weekly measurement represents the yearly radon concentration is significantly higher (twice) in winter and in summer than in summer and autumn. The maximum values of radon concentration are obtained in the first and second-floor rooms might be due to the contribution of radon emanation from the soil, entering into the living spaces from the ground.

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