Interrelationship of indoor radon concentration and meteorological parameters in Łódź (Central Poland) case study - preliminary results

Agnieszka Podstawczyńska
University of Lodz, Faculty of Geographical Sciences,
Department of Meteorology and Climatology, Lodz, Poland, apodstaw@uni.lodz.pl

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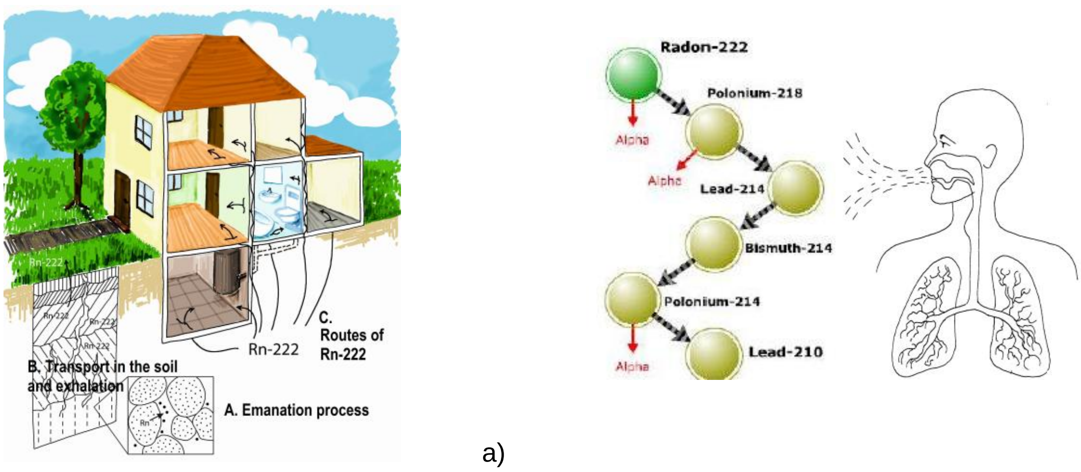
1. Introduction

Radon (Rn-222), a natural radioactive gas, a member of the radioactive decay chain of uranium-238, is produced in all soils and rocks. When Rn-222 released from the ground into atmosphere, it is diluted into low concentrations. The observed worldwide outdoor air concentrations of Rn-222 is 10 Bq·m^{-3} (Bq – becquerel, 1 Bq·m^{-3} means 1 nuclear transformation per 1 second in 1 m^3 of air), whereas in soil air, the concentration of Rn-222 is on average 1,000 times higher than in the atmosphere. Soil radon gas is easily transported into buildings through cracks in the foundations of buildings and slots around the house installations due to the chimney effects, Figure 1a. The radon transport mechanism into building – the chimney effect - occurs when a higher indoor air temperature generates a pressure difference (a few Pa) between inside and outside the building (Nazaroff and Nero 1988). Generally, the ground under buildings is the main source of indoor air Rn-222 concentrations, responsible for 80% of Rn-222 levels (UNSCEAR 2000). According to UNSCEAR (2000) the worldwide indoor air Rn-222 concentration amounts 40 Bq·m^{-3} and maximum values can reach up to thousands of Bq·m^{-3} e.g. 85 000 Bq·m^{-3} in Sweden. Radon indoor air concentration exhibit large spatial and time-scales variations. Many factors related to environment (geological formation, soil air radon concentration, soil permeability and porosity, meteorological parameters) and factors related to buildings (building construction, ventilation system, occupants activities – opened windows and doors etc.) may have influence on the character of the Rn-222 changeability. Number of studies have shown that the weather conditions might have significant impact on fluctuations of indoor radon levels and various, complex indoor air Rn-222 patterns have been presented in houses located in different part of the world (e.g. Marley 2001, Rowe et al. 2002, Riley et al. 1999, Karpińska et al. 2004).



a) b)

Fig. 1a) A. Emanation - process of release of Rn-222 from mineral grains to intergranular space B. Soil profile scheme in which emanation of Rn-222 occurs, Rn-222 transport by diffusion and convection, and Rn-222 exhalation, i.e. release radon from the substrate to the atmosphere; C. Routes of Rn-222 penetrating the building: cracks and fissures in the floor, leaks resulting from the construction of the building such as the walls of the slot to connect to the floor, cracks in the walls, leakage around pipes; Fig. 1b) Rn-222 and its short-lived progenies emits alpha ionizing particles (with kinetic energies between about 4 and 5.5 MeV) as a threat of carcinogenic effect in the respiratory system

Epidemiological studies indicate the long-term exposure to low Rn-222 levels (ca 100 Bq·m^{-3}) in residential buildings as a potential hazards of lung cancer. In respiratory system Rn-222 and its short-lived progenies (Po-218, Pb-214, Bi-214, Po-214) are attached to the lung tissue and deliver ionizing radiation to lung cell, causing biological damage and increase risk of a carcinogenic effects, Figure 1b. Therefore, Rn-222 with its decay products is considered as a significant contaminant of indoor air quality and no levels of Rn-222 concentration in the air are considered safe (WHO, 2009). Inhalation of Rn-222 and its progenies contributes to about 50% to the effective dose of radionuclide from natural sources (UNSCEAR 2000). World Health Organization and American Environmental Protection Agency recommend limits indoor radon action levels of 100 Bq·m^{-3} and 148 Bq·m-^{3}, respectively. In Europe, the new European Basic Safety Standards - Council Directive 2013/59/Euratom of 5 December 2013, laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation, were published in 2014. EU Member States shall establish (by 6 February 2018) a radon national action plan with national reference levels for indoor Rn-222 concentrations in the air not higher than 300 Bq·m^{-3}. Therefore, research on recognition of variation in the concentration of this radionuclide in homes and its determining factors need to be developed. These studies are fundamental to estimate properly the exposure to Rn-222 and to estimate the annual dose from ionization radiation.

Long-term, highly time-resolved (active technic) measurements of indoor air Rn-222 concentration with relation to weather conditions are not popular and well documented in literature. The aim of the study was to investigate as a first approach the variability of hourly Rn-222 concentration in indoor air from May 2014 to May 2015 with reference to weather patterns with special consideration of indoor-outdoor air temperature differences, air pressure, type of atmospheric circulation and rainfall. Particular attention has been given to variability of Rn-222 levels during unoccupied (closed) house.

2. The study area and the data base

1-hour average of indoor air Rn-222 concentrations were monitored through 356 days (from 20 th May 2014 to 10th May 2015) in a detached single-family house. The building was built in 2004 and has two floors without a basement - ground floor and attic. Examined house is located in north-west part of Łódź, in residential area with suburban type of land use (a high proportion of green, address: Kąkolowa Street 66, φ= 51^{o}49' 11''N , λ=19^{o}20'57''E).

The subsoil beneath the house origin from the Quaternary and consists of a thin layer of sand (10-40 cm) at a depth of ca 0.4-0.7 m and sandy clays at a depth of ca. 0.7 m. The level of groundwater occurs shallowly on investigated area – in sand at a depth of 0,4-0,7 m and in the clay at a depth of 1,2 m. Land water conditions are essential for the process of exhalation of Rn-222 into the atmosphere, soil moisture is a significant an inhibiting factor of transport of Rn-222 from the soil into the atmosphere.

Measurements of the indoor air Rn-222 concentration performed on the ground floor (floor area 100m^{2}, 3 m height) using an automatic ionization chamber AlphaGUARD® PQ2000PRO (active method of measurement, diffusion mode), Figure 2a, 2b. The radon monitor was situated at a place remote from the direct impact of external air, Figure 2b. The house was occupied by 1-4 people through the measurement period with the exception of 17 days (from 18th July 2014 is 03rd August 2014).

Long-term, hourly, time series of indoor air Rn-222 concentration used in the study are unique in Poland. The data base also consisted with values of indoor meteorological parameters like air temperature and atmospheric pressure recorded by AlphaGUARD® PQ2000PRO. Outdoor meteorological parameters (air temperature and rainfall) derived from weather station remote 3.3 km from the house to the East.

The daily types of atmospheric circulation were also analyzed in the study. The circulation types were distinguished objectively by the classification based on the circulation indices developed by Jenkinson and Collinson (Piotrowski 2009). This method, modified by Piotrowski (2009), uses two parameters – geostrophic wind and shear vorticity. The daily averages of sea level pressure from NCEP/NCAR reanalysis data were used.

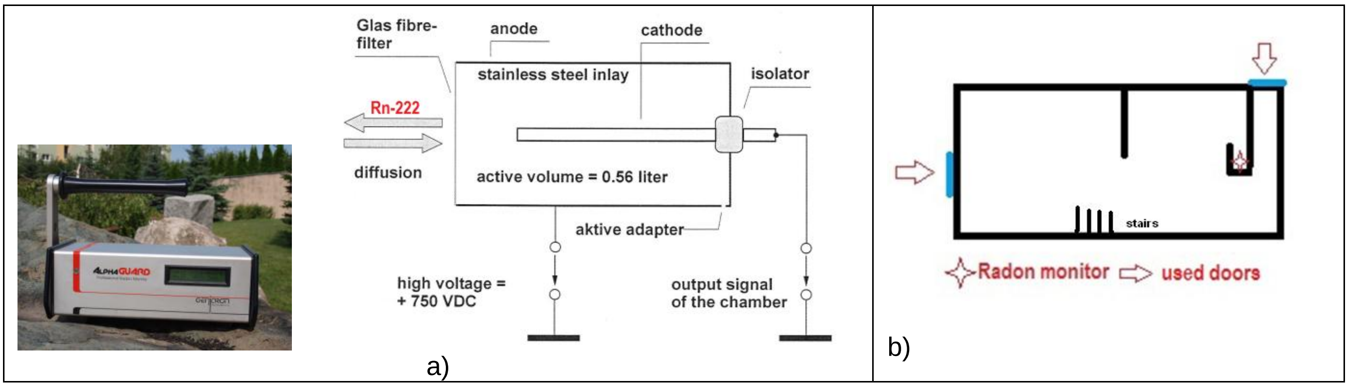


Fig 2 a) Photo and scheme of automatic Rn-222 ionization chamber AlphaGUARD PQ2000Pro (diffusion mode), Saphymo GmbH, www.saphymo.de b) Scheme of ground floor layout (floor area 100m^2, 3 m height) and localization of radon monitor.

3. Results

3.1 One-year series of the daily average of indoor air Rn-222 concentration

The average daily value of indoor air Rn-222 concentration calculated for the period of 356 days (May 2014 - May 2015) was 47 Bq·m^{-3}and it was similar to that of the entire Poland, 49 Bq·m^{-3}and for the Central Poland, 43 Bq·m^{-3} (*Radiation Atlas of Poland 2005*).

In the occupied house, the daily averages of air Rn-222 levels ranged from 8 Bq·m^{-3} (8 th August 2014) to 85 Bq·m^{-3} (3rd October 2014). During unoccupied (closed) house, the averages were higher and varied from 52 Bq·m^{-3}to 125 Bq · m^{-3}, (July 2014), Figure 3.

The fluctuation of 1- hour indoor air Rn-222 concentrations were in the range of 2 Bq·m^{-3}-117 Bq·m^{-3} (occupied house) and 20 Bq·m^{-3}-155 Bq·m^{-3} (closed house). In the course of year of indoor air Rn-222 levels the seasonal variations were observed. Excluding the period of closed house (July 2014), when the Rn-222 levels were 2.5 times higher than the annual average, the increase of the Rn-222 levels occurred in autumn (annual maximum) and winter, while the lowest levels were recorded in the summer, Figure 3, Table 1.

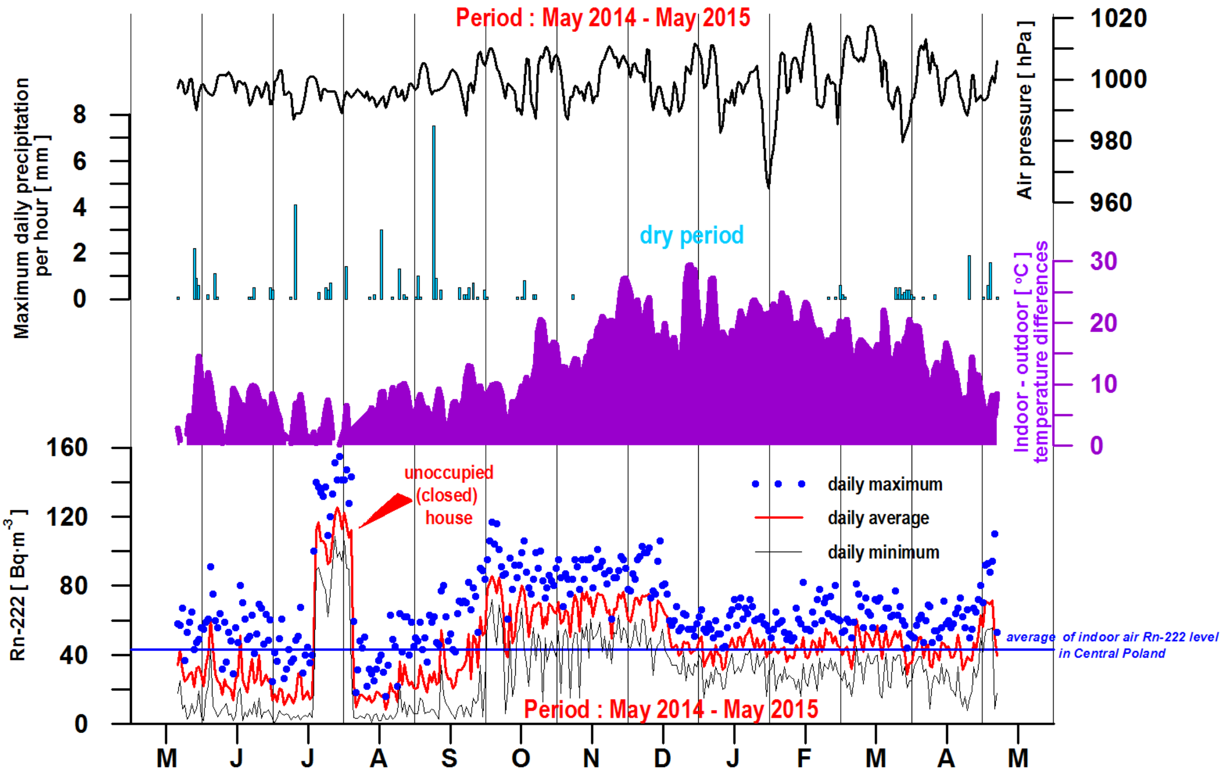


Fig. 3. Indoor radon time series - daily and maximum averages of air Rn-222 concentration with reference to indoor-outdoor air temperature differences, precipitation and air pressure (address: Łódź, Kąkolowa Str. 66)

The average of indoor Rn-222 levels in the summer was about half lower than the other seasons. Autumn is also distinguished by the widest range of daily fluctuations in indoor air Rn-222 concentration. Described annual variability of indoor Rn-222 levels with a maximum in the cold season and a minimum in summer refers to the results presented in the literature concerning homes in northern countries of Europe (e.g. Hubbard et al., 1996). Number of authors emphasized that air temperature differences between the interior and exterior of buildings is a key environmental factors determining seasonal changeability of indoor Rn-222 levels The occupants activity and construction of buildings should be obligatory taken into consideration in the analysis of the factors determining Rn-222 concentration in houses (e.g. Hubbard et al. 1996, Karpińska et al. 2004, Rowe et al. 2002).

The present study generally confirms increase of indoor air Rn-222 concentration during decrease the outdoor air temperature (especially in autumn) excluding winter months (e.g. December 2014) were observed opposite effect, Figure 3, Figure 4. Significant decrease of external air temperature and intensification of the house heating caused intensive air movement and ventilation increased by outdoor air with low radon concentration (outdoor air Rn-222 in Łodź : ca 5 Bq·m^{-3}). In the examined house the occupants used the fireplace as heating system. This influenced on the reduction of indoor air Rn-222 levels in very cold winter days. This effect was described for some Swedish houses by Hubbard et.al (1996).

The present analysis indicated no clear relation between variability of indoor air Rn-222 levels and air pressure, Figure 3, Figure 4. Investigation of type air circulation (cyclonic and anticyclonic) and its effects on daily maximum of indoor air Rn-222 in the house indicated lack of significant difference in the distribution of the Rn-222 levels in two analyzed group of days , Figure 5.

Annual variability of rainfall corresponded to annual fluctuation of indoor Rn-222 levels in the house. Decrease of indoor Rn-222 levels was observed after rainy periods. The connection with the rainfall can be explained by the shallow groundwater levels (ca 0,4-0,7 m below ground level) under the examined house. The groundwater is a factor restrictive the exhalation of Rn-222 from the ground due to so-called “capping effect”. The influence of rainfall on indoor Rn-222 levels in buildings in Southern Italy was documented by Francesco et al. (2010).

Table 1. Average of indoor air Rn-222 concentration in different season in the year (address: Łódź, Kąkolowa Str. 66)

Rn-222 [Bq·m^{-3}]	Summer (JJA)	Autumn (SON)	Winter (DJF)	Spring (MAM)
Average	**22**	**56**	49	46
Average minimum	7	34	34	30
Average maximum	47	80	66	64
Average daily amplitude	40	46	32	35

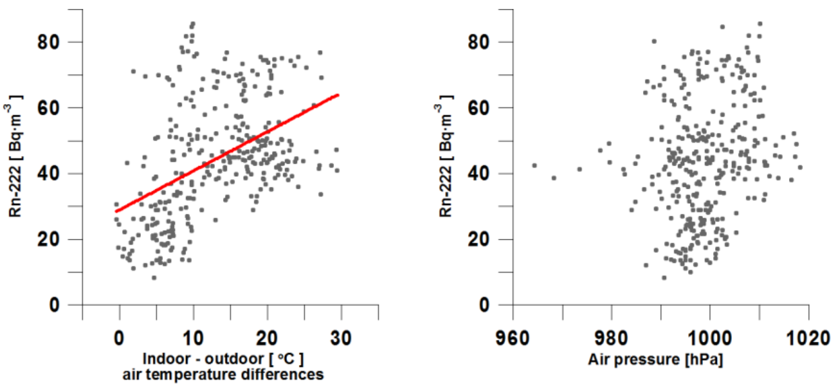


Fig. 4. Indoor air Rn-222 concentration (daily averages) as a function of indoor-outdoor air temperature differences and air pressure (address: Łódź, Kąkolowa Str. 66)

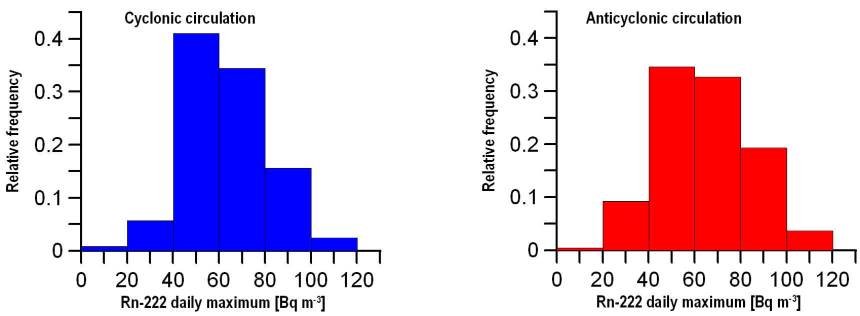


Fig. 5. Distribution of indoor air Rn-222 concentration daily maximum concentration in cyclonic and anticyclonic atmospheric circulation in the period 20th May 2014 - 10th May 2015 (address: Łódź, Kąkolowa Str. 66)

3.2 Variability of 1-hour averages of air Rn-222 concentration in occupied and unoccupied (closed) house

Clear daily pattern with significant increase of Rn-222 levels at night and reduction during the daytime was revealed in an occupied house whereas the daily pattern of indoor Rn-222 concentration disappeared in closed (unocciupied) house, Figure 6, Figure 7. This proved important role of the behavior habits of the occupants (e.g. close windows and doors at night) in daily variability of indoor air Rn-222 levels.

Figures 6 and 7 illustrate that the indoor-outdoor air temperature could be important factor determining transport Rn-222 gas from soil into the building. The closed house in summer (July 2014) caused rapidly increase of indoor Rn-222 levels to 5 times higher values than the average in summer (22 Bq·m^{-3}), Figure 3, Figure 7, Table 1. Analysis of air pressure and circulation type with reference to indoor Rn-222 levels have not given unequivocal results in both periods. During period with unoccupied house the rainfall seems to be a key meteorological factor affecting indoor air Rn-222 levels. Decrease of Rn-222 levels in the house was observed after rainy period, Figure 7.

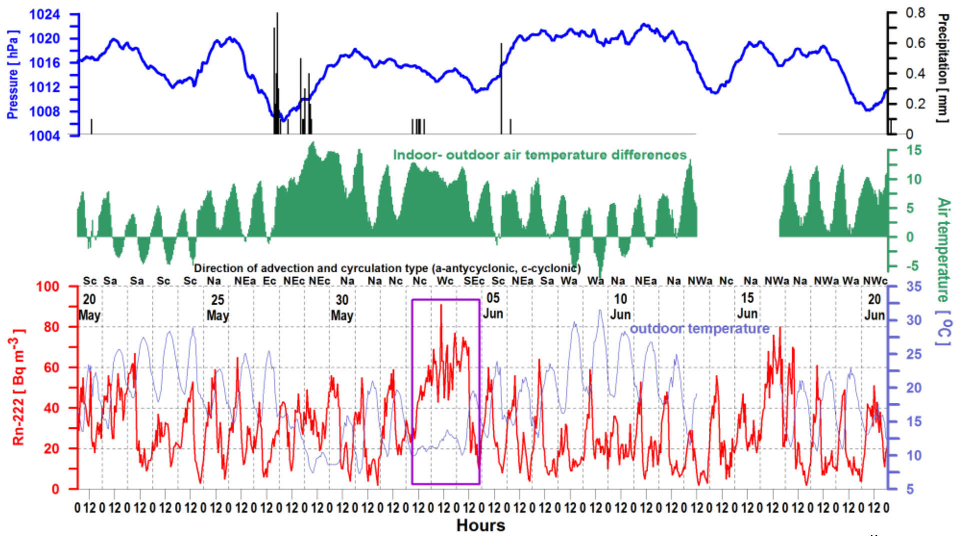


Fig. 6. Variability of hourly indoor air Rn-222 concentration <u>during occupied</u> house (from 20th May 2014 to 20th June 2014 with reference to meteorological elements (address: Łódź, Kąkolowa Str. 66)

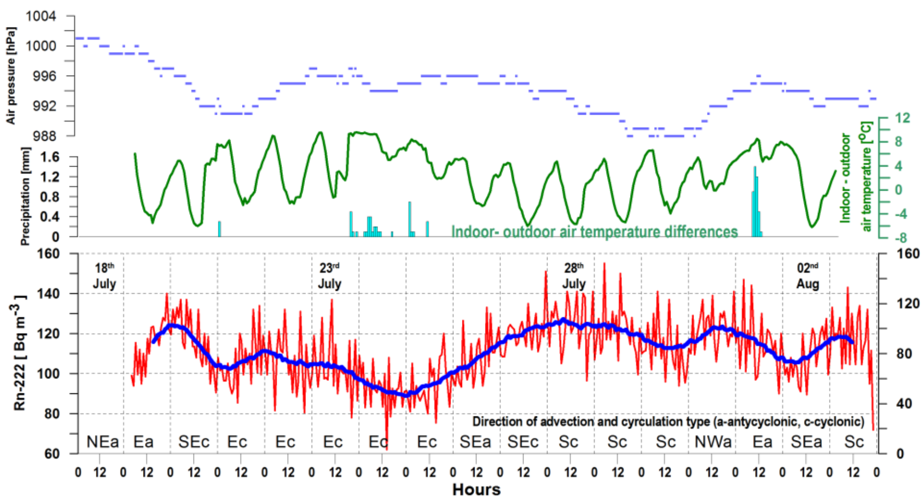


Fig. 7. Variability of hourly indoor air Rn-222 concentration <u>during unoccupied (closed)</u> house (from 18th July 2014 to 03rd August 2014 with reference to meteorological elements (address: Łódź, Kąkolowa Str. 66)

4. Conclusions

- Analysis of one-year measurements of indoor air Rn-222 concentration revealed that the daily averages of radon levels varies over the year with the minimum in summer and maximum in autumn.

- Daily variations of indoor air Rn-222 concentration with maximum at night and minimum during daytime occured in occupied house. The daily pattern disappeared during period with unoccupied (closed) house. The occupants activity (close windows and doors etc.) could determine significant increase of the indoor air Rn-222 at night.

- Limitation of ventilation in the unoccupied (closed) house (in July) caused rapidly increase of indoor air Rn-222 levels up to 5 times higher values than the average level in summer.

- Indoor air Rn-222 concentration was positively correlated with indoor-outdoor air temperature differences, except during winter. Intensive the house heating (by the fireplace) in winter may cause the increase of ventilation and decrease of indoor air Rn-222 concentration.

- Correlation indoor air Rn-222 levels with air pressure and type of air circulation was not confirmed in the study.

- Rainfall can be an important meteorological controlling factor of air Rn-222 levels in the houses located on area with the shallow groundwater.

- Monitoring of temporal variations of radon gas indoors is fundamental to properly estimation of an annual ionizing radiation dose. Further investigations based on continuous long-term Rn-222 air concentration monitoring in the house with reference to meteorological factors are needed to improve predictive model of indoor air Rn-222 concentration.

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References

De Francesco S., Tommasone F.P., Cuoco E., Tedesco D., 2010, Indoor radon seasonal variability at different floors of buildings, *Radiation Measurements* 45, 928-934

Hubbard L.M, Mellander H, Swedjemark A.A.,1996, Studies on temporal variations of radon in Swedish single-family houses, *Environmental International*, Vol.22, Suppl.1, pp. S715-S722

Karpińska M., Mnich Z., Kapała J., Antonowicz K., 2004, Seasonal changeability of indoor radon concentrations in one-family house, *Nukleonika*, 49, 1, s. 33–36.

Marley F., 2001, Investigation of the influences of atmospheric conditions on the variability of radon and radon progeny in buildings, *Atmospheric Environement*, 35, 5347-5360.

Nazaroff W.W., Nero A.V. jr., 1988, *Radon and its decay products in indoor air*, A Wiley-Interscience Publication, New York, 518 s.

Piotrowski P., 2009, An objective method for classification of atmospheric circulation for Poland. Acta Universitatis Lodziensis, Folia Geographica Physica, 10, 216 s. (in polish)

Radiation Atlas of Poland 2005, Central Laboratory for Radiological Protection, Environmental Monitoring Books 2006, pp 64.

Riley W.J., Robinson A.L., Gadgil A.J., Nazaroff W.W., 1999, Effects of variable wind speed and direction on radon transport from soil into buildings: model development and exploratory results, *Atmospheric Environment*, 33, s. 2157–2168.

Rowe J.E., Kelly M., Price L.E., 2002, Weather system scale variation in radon-222 concentration of indoor air, *Science of the Total Environment*, 284, s. 157–166.

UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) 2000, Report - Sources and effects of ionizing radiation, Annex B Exposures from natural radiation sources, s. 84–141, http://www.unscear.org/docs/reports/2008/09-86753

WHO Handbook on Indoor Radon. A Public Health Perspective, 2009, Zeeb H., Shannoun F. (eds.), *World Health Organization Press*, Geneva, 95 s.