FACTORS AFFECTING INDOOR RADON VARIATIONS: A CASE STUDY IN SCHOOLS OF EASTERN MACEDONIA

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Received May 13, 2018

Abstract. The subject of this study is the radon concentrations variations, measured with a nuclear track detectors in a total of 58 premises in all 29 primary schools of 4 municipalities in the Eastern part of the Republic of Macedonia. Despite a relatively small territory, the variability of radon concentrations proved to be significant. The geometric means (geometric standard deviations) of radon concentrations in the examined municipalities were in the range from GM = 71 Bq/m^3 (GSD = 2.08) to GM = 162 Bq/m^3 (GSD = 2.69), while for the entire region it was: GM = 96 Bq/m^3 (GSD = 2.47). The influence of the geographical and geological features of the school site as well as the building characteristics on the radon variations were investigated. The analysis showed that type of municipality, building materials, basement and geology have significant effects and respectively describe 6%, 16%, 22%, 39% of the radon total variability.

Key words: geology, building characteristics, radon variations.

1. INTRODUCTION

Radon is a natural radioactive gas present in each indoor environment. Indoor radon concentration (Rn) is subject to large spatial and temporal variations. The main Rn source is radium that is contained in the soil under the building as well as in the building materials. In other words, the amount of radon generated in the terrestrial material depends on the quantity of radium, and how much will exhale from the surface and further accumulate in the indoor atmosphere depends on a series of natural and artificial factors. Apart from the radon geogenic potential and meteorological conditions that affect the radon dynamics, the characteristics of the building and the living habits of its inhabitants are also factors that significantly affect Rn variations.

Many studies have been concerned with the analysis of Rn variations as a function of a given factor, using different manner for their quantification. These are usually expressed by the: *coefficient of variation* (CV)[1, 2] defined as ratio of the Rn standard deviation to the Rn mean value; *geometric standard deviation* (GSD) [3] which describes how spread out are a set of Rn values whose average is presented by the geometric mean; Pearson's correlation coefficient (R), as a measure of the linear relationship between two Rn variables; Spearman's rank correlation coefficient (ρ), as measure of how well the relationship between two Rn variables can be described by a monotonic function [4] or by the correlation ratio (η) [5] which is a measure of the relationship between the Rn dispersion within individual categories and the dispersion across the whole sample.

A recent study of the GSD values of 81 national and regional Rn surveys has revealed that the main factors influencing the Rn variations over a territory are: area of territory, sample size, characteristics of measurements technique, radon geogenic potential, building construction characteristics and living habits [3]. Furthermore, the factors associated with building construction and livings habits have a regional character. In a study carried out in 3 different regions of Bulgaria, is reported that factors effects are in function of geology and geographical position of the measuring location [4].

Motivated by this, we decided to conduct a survey to examine the factors that influence radon variations in a relatively small area with a limited number of measurements. This paper presents the results of that research and compares them with the ones reported in the literature.

2. MATERIALS AND METHODS

The geographical position of study area is shown in Figure 1. It covering: one urban (M3) and three rural municipalities (M1, M2, M4) in Eastern part of Macedonia.

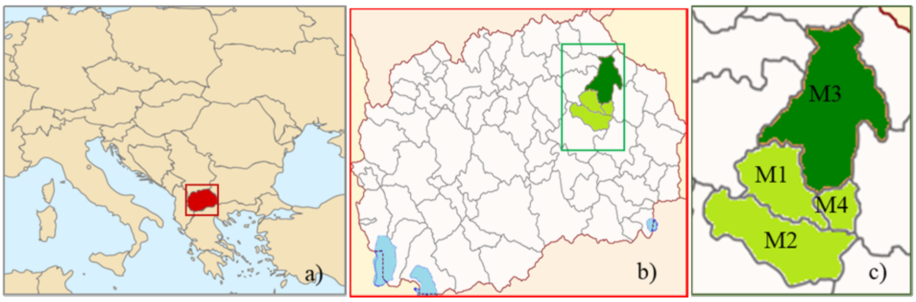

Fig 1 – a) Geographical position of Macedonia in Europe; b) municipalities location in the country; c) Cesinovo-Oblesevo (M1), Karbinci (M2), Kocani (M3), Zrnovci (M4).

According to geology, the area belongs to a Geotectonic zone named the Serbo Macedonian Massif bordering with the Kratovo Zletovska volcanic area to the north and with the Vardar geotectonic zone to the west.

Having in mind that the spatial distribution of primary schools is in function with the population density, we supposed that the Rn in the schools could be representative for the whole region [6]. The survey started at the beginning of the summer semester in January 2016. In each school, two nuclear track detectors for Rn measurements were installed: in a classroom and an assembly hall. The criteria for deployment detectors in the classrooms were their location on the ground floor and that the youngest students (first or second class) stay in them. Generally, the assembly hall in the schools is also located on the ground floor, so out the total 58 monitored premises in 29 schools, only two were on the first floor. At the end of the semester (June 2016), the detectors were collected and sent for analysis.

The Rn concentration was measured by commercial Gamma 1 detectors provided and analyzed by Landauer Company, Sweden. This type of detector has been used in some earlier studies [7–9].

During this field survey, information about the measuring locations was collected. It included: GPS coordinates, altitude, type of municipality. We also considered some characteristics of the buildings such as: presence of basement, total number of the floors, room type and window type. The litho-stratigraphy for the locations were extracted from the detailed geological map of the country [10].

2.1. DATA ANALYSIS

Characteristics of the measuring locations (further named factors) along with the measured Rn were analyzed. The Rn data are well fitted with a log normal function and log transformed values met the criterion for normal distribution. In the cases where the variance of lnRn among certain categorical factors was the same, the parametric ANOVA and Fisher LSD tests were applied to test the differences between the mean values. In addition, when the requirement of homogeneity was not satisfied, the corresponding non-parametric: Kruskal-Wallis and Mann-Whitney tests were applied. As a measure of the level of association between lnRn and categorical factors the squared correlation ratio (η^2) was used, which was calculated as a decimal number in range between 0 and 1 or as a percentage.

3. RESULTS AND DISCUSSION

Descriptive statistics of the measured Rn in schools premises of the entire region and for each municipality separately are given in Table 1.

Table 1

Descriptive statistic of Rn measured in 58 schools premises of the four municipalities

Statistic	Rn				
	All	**M1**	**M2**	**M3**	**M4**
N	58	18	16	20	4
Minimum (Bq/m^3)	10	10	16	15	57
Maximum (Bq/m^3)	508	508	339	201	137
AM (Bq/m^3)	136	223	106	90	104
SD (Bq/m^3)	115	148	84	60	36
GM (Bq/m^3)	96	162	78	71	98
GSD	2.47	2.69	2.41	2.08	1.49

AM: arithmetic mean; SD: standard deviation; GM: geometric mean; GSD: geometric standard deviation.

The GM value for Rn that refers to the whole region was slightly higher than the national value of GM=84Bq/m^3 (GSD = 1.9) [11], but it was lower than the GM = 131Bq/m^3 (GSD = 2.34) published for the Northern and Western neighboring municipalities [12]. Although the chosen region is in a relatively small territory belonging to a geotectonic zone, the Rn variations between municipalities and within them were significant (ANOVA, $p = 0.02$). Rn in the M1 municipality was higher than in M2 and M3 (LSD, $p < 0.05$). The Rn in the M4 municipality did not differ in comparison to the other three municipalities.

The first step in our analysis was to examine the impact of the geographical characteristics of the measuring locations on Rn variations. The correlations between: the longitude, the latitude, the altitude and the Rn were not significant. In addition, Rn were grouped according to the type of municipality. The higher Rn are related to the rural municipalities and the lower to the urban ones (Table 2). In Figure 2, the relatively small value of $\eta^2 = 0.06$, indicated the low degree of association between this factor and Rn. We assumed that its effects are practically related to the type of school buildings that in our case were bigger and newer in urban areas than in rural ones. In other words, this factor itself is not independent and can be overlapping with another factor as has been reported in literature it is sometimes significant [13] and sometimes not [12].

Table 2

Rn measured in rural and urban municipalities

Type of municipality	N[1]	Rn (Bq/m^3)			
		Min[2]	**Max[3]**	**GM[4]**	**GSD[5]**
Rural	38	10	508	113	2.59
Urban	20	15	201	71	2.08

[1]Number of measurements, [2]Minimum, [3]Maximum, [4]Geometric mean, [5]Geometric standard deviation (dimensionless).

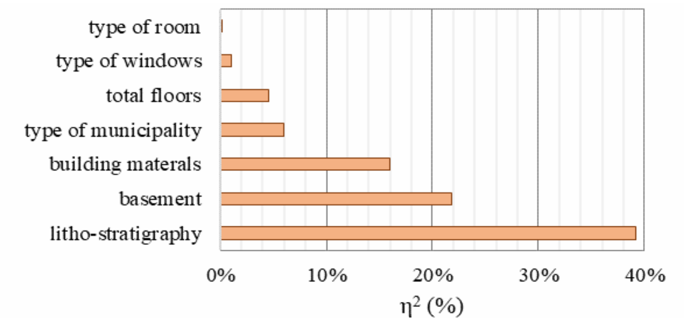

Fig. 2 – η^2 (%) for each categorical factor.

In order to investigate the influence of the geology on the Rn, the measured data were assigned to litho-stratigraphic units. Rn variations between them (Table 3) were significant (KW, $p = 0.014$). The analysis of the multiple pairwise Rn differences between litho-stratigraphic units did not show a strong differentiation in groups. For example, Rn in the andesite-breccia unit was higher only in comparison to units of lower river terrace (MW, $p = 0.02$), proluvial deposits (MW, $p = 0.01$) and schistous granite (MW, $p = 0.04$) while differences with other units were not significant. Similarly, Rn in the schistous granite was significantly lower only in relation to andesitic tuff and andesite-breccia and so on. The highest value of η^2 = 39% in Figure 2 is for the litho-stratigraphic units, indicating the Rn strongest relation with this factor in comparison to all others. This result was expected, bearing in mind that the main source of Rn is radon in the soil gas and that its generation and transport through it are closely related to geology. Different levels of association between Rn and geology, appeared in the literature. For example, regression based on grouping by geological units explains R^2 = 33% of the variation in Switzerland [14] while in research from the Techa River region (Russia), for association between Rn and geological factors the value of $\eta = 0.32$ has been reported [5].

Table 3

Statistic of Rn ascribe to litho-stratigraphic units

Litho-stratigraphic units	**N[1]**	**Rn (Bq/m^3)**			
		Min[2]	**Max[3]**	**GM[4]**	**GSD[5]**
Amphibole-chlorite schist and metadiabase	2	15	66	31	2.85
Andesite-breccia	8	43	508	236	2.40
Andesitic tuff	2	200	201	200	1.00
Deluvial deposits	2	105	177	136	1.45
Lower river terace	20	21	361	99	1.83
Mica-schist and lepttionolite	4	41	101	69	1.55
Proluvial deposits	12	10	243	70	2.60
Schistous granite	2	16	18	17	1.09

[1]Number of measurements, [2]Minimum, [3]Maximum, [4]Geometric mean, [5]Geometric standard deviation (dimensionless).

In our study, stone used as a building material was appeared to be another significant source of Rn. Those buildings made of stone had higher concentrations in comparison to buildings built of bricks (Table 4). A similar trend has been obtained in our previous studies [15]. The value for η^2 presented in Figure 3 shows that construction materials describe 16% of the total Rn variability. Detailed examination of the Rn variability as a function of building characteristics was done in three regions of Bulgaria where building material was significant only in two regions ($\rho^2 \approx 20\%$).

Table 4

Statistic of Rn measurements in buildings grouped by building materials and presence of basement

Factor		**N**[1]	**Rn (Bq/m³)**			
			Min[2]	**Max**[3]	**GM**[4]	**GSD**[5]
Building materials	brick	30	16	236	68	2.02
	stone	28	10	508	139	2.60
Presence of basement in the building	no	44	15	508	122	2.19
	yes	14	10	137	46	2.38

[1]Number of measurements, [2]Minimum, [3]Maximum, [4]Geometric mean, [5]Geometric standard deviation (dimensionless).

The next factor that significantly affected Rn variations was the presence or absence of a basement in the building [16, 17]. From Table 4 it is clearly seen that the buildings with basement have lower concentrations compared to those without basement (LSD, $p = 0.0002$).

It should be noted that the effect of a basement on the Rn in a building is two-fold: although the Rn on a ground floor above a basement can be comparatively low (as the room has no ground contact) the Rn in basements themselves are generally high. Despite the fact that the factor *basement* is well known and confirmed in many studies, the level of its contribution in Rn variability is not everywhere the same. For example in our case, this factor describes 22% of the Rn variability, while in the previously mentioned Bulgarian study in the continental region of volcanic geology the contribution was similar to our $\rho^2 \approx 23\%$, while in continental with sedimentary geology it was about $\rho^2 \approx 6\%$.

The effects of the factors: *window type*, *total number of floors*, *room type* on Rn variations were also investigated. Their influence proved to be not significant, although theoretically it was expected. For example, more building floors reduce the pressure gradient, which further reduces the radon emanation from the soil into indoors, further the new type of windows hermetically sealed the room, making the natural ventilation much lower compared to the rooms with old wooden windows. Yet, it is our assumption that other factors prevail over the impact of these factors. An explanation for the absence of differences between classrooms and assembly hall is assumed due to their similar usage.

4. CONCLUSION

The subject of this study was factors affecting Rn variations in schools premises of 4 municipalities located in Eastern part of Republic of Macedonia.

The geographical position (*longitude*, *latitude*, *altitude*, *type of municipality*), geology of the site (*lithostratigraphic units)* and building characteristics (*building materials*, *presence of basement*, *window type*, *total number of floors*, *room type*) influence on Rn variation was investigated. The analysis has been showed that the factors which appeared to have significant contribution in Rn variations are:

(1) *lithostratigraphic units* which was proved to have the most dominant influence describing 39% of the Rn variability in the examined region;
(2) *basement* affected 22% of Rn variation;
(3) *building materials* allow explanations of 16% Rn variation;
(4) *type of municipality* that explained 6 % of the Rn variability.

In general, comparison of the results obtained in this study with those published in the literature confirms that the factors effects on Rn variations are subject of spatial variability and they should be carefully considered.

Acknowledgements. The authors highly appreciate the collaboration of the mayors and schools directors in Cesinovo-Oblesevo, Karbinci, Kocani, Zrnovci municipalities during this survey. A special acknowledgment to Dr Ilia V. Yarmoshenko and Dr Georgy Malinovski from IIE UB RAS, Ekaterinburg, Russia, for their careful reading of the manuscript and helpful comments.

The Gamma 1 detectors were provided within the Project P- 41028 of the Ministry of Education, Science and Technological Development of the Republic of Serbia.

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Errata with respect to in-print article

This addendum lists the changes applied to the present article that occured after the publication of the printed version of the journal issue.

Jan 20, 2020 Paper co-author (Ajka Šorša) mentioned incorrect own name appearing in the author list. 5^{th} author name changed from “S. Ajka” (as in print version) to “A. Šorša”.