# INFLUENCE OF BUILDING TYPE AND YEAR OF CONSTRUCTION ON INDOOR RADON CONCENTRATIONS IN PERNIK CITY, BULGARIA

D. Djunakova*, B. Kunovska, A. Angelova, J. Djounova, K. Ivanova

National Center of Radiobiology and Radiation Protection, 3 Sv. Georgi Sofiyski Str., 1606 Sofia, Bulgaria

## Abstract

*Radon ($^{222}Rn$) is a radioactive gas and formed as a results of the radioactive decay of radium. Radon relieved from ground could accumulate in the building and contribute to human exposure. Radon is recognized as a carcinogenic agent by the World Health Organization and is the second leading cause of lung cancer after tobacco smoke. Radon in buildings is considered to be the most important indoor air pollutant, with harmful effects on the health of the population. The purpose of this survey is to analyze the influence of building type and year of construction on indoor radon concentrations in Pernik city, Bulgaria. The measurements of the indoor radon concentration in buildings located in the town of Pernik (housing, schools and kindergartens) from national database is used. The results for annual radon concentration in 70 dwellings, in 28 public schools and in 34 kindergartens is applied. The nuclear track detectors (CR-39) were used for measurements. The annual radon concentration in schools and kindergartens was evaluated using the seasonal factor for Pernik district. The descriptive statistic is presented according to type of building and year of construction in the article. The arithmetic means of radon concentrations are: for dwellings AM = 133 Bq/m$^3$, for schools AM = 123 Bq/m$^3$ and for kindergartens AM = 136 Bq/m$^3$. The group of buildings built during the period 1950 – 1969 has the highest average value of indoor radon concentration (AM=152 Bq/m$^3$). In order to evaluate the difference between of the radon concentration in the groups separated by type of buildings and year of construction the Kruskal Wallis test was applied. No statistically significant difference was found between the types of buildings, unlike between the groups on years of construction. The influence of year of construction on the radon level was analyzed by applying the discriminative analysis. The results shown that 7.2% of the radon variation could be explain by year of construction of the building.*

**Keywords:** *radon, schools, kindergartens, dwellings, indoor air, Pernik*

## 1. INTRODUCTION

Radon ($^{222}$Rn) is a radioactive gas and formed as a results of the radioactive decay of radium. Radon relieved from ground could accumulate in the building and contribute to human exposure. Exposure to indoor radon and its decay products contributes half of the annual dose received by the public from all natural radioactive sources [1]. Radon is recognized as a carcinogenic agent by the World Health Organization and is the second leading cause of lung cancer after tobacco smoke [2]. Radon in buildings is considered to be the most important indoor air pollutant, with harmful effects on the health of the population.

Various factors control the radon ingress in a building, such as: [1]radon sources—radon potential under the building (related to a radon concentration in soil gas and soil permeability), building materials, water, natural gas; [2]building factors (associated to possibility of radon infiltration and its accumulation); and [3]style of building usage [3]. In compliance with building factors, radon infiltration is occurring driven by radon concentrations in soil gas and air pressure gradients which are existed between the indoor and outdoor surroundings. Furthermore, the radon accumulation is also affected by the air exchange rate which is caused by mechanical ventilation system or by natural convection, creating a repeating cycle that generates wind [1].

The International Committee for Radiological Protection (ICRP) recommendations emphasized the importance of controlling radon exposure in buildings arising from existing exposure situations [4]. The European Union recommended reference level of indoor radon in dwellings, workplace and buildings with public access. The European Directive 2013/59/EURATOM defined the reference level for the annual average radon concentration in air should not higher than 300 Bq/m$^3$ [5] and these have been harmonized into Bulgarian national legislation [6].

Traditionally, radon variations are analyzed by one-dimensional and / or multivariate statistical methods with different sets of input factors, mainly related to the geology and characteristics of the building [7], and sometimes taking into account the temporal variability of radon [8]. The challenge is to study the influence of building characteristics on indoor radon variations.

Kindergartens and schools are more complex buildings than homes. The children spend almost all day in these buildings. For this reason, the investigation of these public buildings is important to ensure air quality control. Children exposed to radon are twice as likely compared to adults to develop lung cancer when exposed to the same concentrations [9]. Children's smaller lungs, faster breathing rates, and lower proximity to the ground results in higher levels of radon exposure and, therefore, a higher risk of developing lung cancer [9].

Bulgaria has a long experience in measuring radon [10], but a systematic survey of radon concentration (CRn) started in 2011 [11], since then, systematic studies of radon level have been conducted throughout the country. In 2016, the National radon survey was completed. Indoor radon concentrations were measured for one year in 2778 dwellings of whole Bulgarian territory. During this study, 51 dwellings in the town of Pernik were measured. In the period 2017-2018, a survey of indoor radon levels was conducted to assess seasonal variations, during which the results of 19 homes in the town of Pernik were analyzed. The total processed results for the surveyed dwellings in the town of Pernik are 70. In 2014, a study was conducted on the concentration of radon in kindergartens located in the municipality of Pernik. During this study, results were obtained for 34 kindergartens located in the town of Pernik. Measurements in kindergartens during the same time were carried in Plovdiv city and it has been found that more than 40% of buildings have radon concentrations above the national reference level [12]. The assessment of radon concentration in schools on the territory of Pernik was completed in 2020, and the results for 28 public schools were analyzed.

This paper presents the results of systematic indoor radon measurements in houses, kindergartens and schools in Pernik city. The analyze of the influence of building type and year of construction on the indoor radon variation have been the crucial idea of this research.

## 2. MATERIALS AND METHODS

### *2.1. Area of study*

Pernik is a town in western Bulgaria (about 20 kilometers south-west of Sofia) with an area 72.289 km$^2$. Pernik is the most populated town (population of 120,880 as of 2019) in western Bulgaria after Sofia. It is the main town of Pernik Province and lies on both banks of the Struma River in the Pernik Valley between the Golo Bardo Mountain, Vitosha Mountain, Lyulin and Viskyar mountains (Fig. 1). Economically Pernik is an industrial town and one of largest in the country with: the Stomana steel complex and production heavy machinery, brown coals, building materials and textiles. Pernik is in moderate-continental climate zone. Climatic conditions are influenced by the relatively high altitude – 750 m, but also by the fact that Pernik is in between mountains, which creates a specific micro-climate. The town of Pernik is administratively divided into 5 neighborhoods: Bela Voda, Kalkas, Iztok, Tsarkva and Pernik. In this territory work 28 public schools and 34 kindergartens. The survey analyzed dwellings (70), kindergartens (34) and public schools (28). To facilitate the design of the survey, according to the project criteria, dwellings of the studied area among those inhabited have been randomly selected. The choice of the surveyed children's institutions is based on their number in the town of Pernik, namely all state schools and kindergartens were measured.

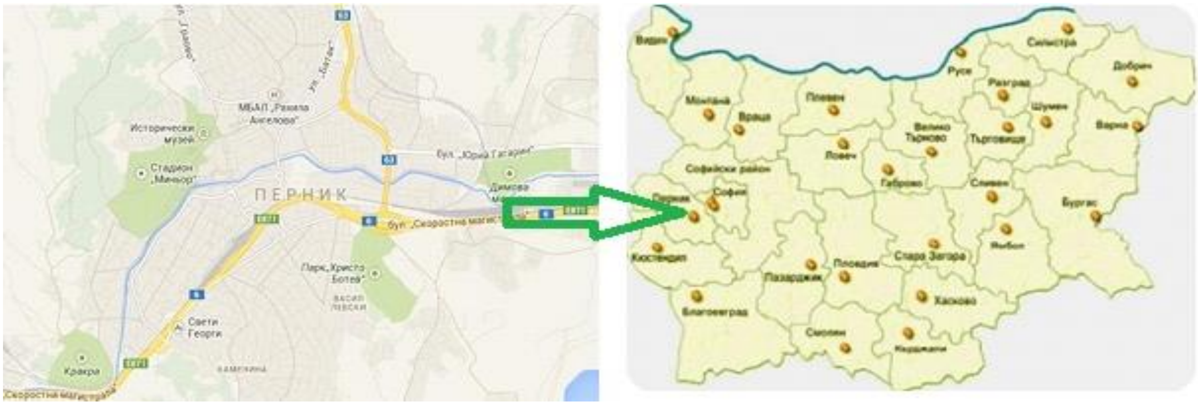


**Fig. 1.** Location of Pernik in Bulgaria and city map

*2.2. Radon Measurements*

The surveys for indoor radon concentration was promoted and coordinated by the National Centre of Radiobiology and Radiation Protection (NCRRP) and carried out in collaboration with Regional Health Inspectorate Pernik. Preliminary preparation is important for the effective performance of the radon test. The first step in the public buildings surveys was collecting the information about the number of the studied premises. Premises closest to the ground surface (ground floor) were inspected, according to the standard laboratory operating procedure. Time integrated radon concentrations were measured using CR-39-based detectors. The second step was to prepare a package with the detectors, instruction forms, brochures and questionnaires. In children's institutions (schools and kindergartens) short-term radon tests were held during the winter months, when radon concentrations are usually highest. In order to compare the annual values of radon in the different types of buildings, each measurement in schools and kindergartens was adjusted using the assessed seasonal variations of radon of Pernik region. Radon measurements in homes were carried out for a period of one year. The detectors were calibrated at the radon chamber of an accredited laboratory and the radon concentrations have been evaluated in accordance with the ISO standard [13]. To ensure the quality control of radon concentration measurements in all surveyed types of buildings, blank and duplicate detectors are distributed. Analysis and processing of the results were performed in the laboratory “Radon” at the NCRRP.

*2.3. Questionnaire*

A detailed questionnaire is filled in for each surveyed building containing relevant parameters for the characterization of the measurement site. The questionnaire included questions about the following topics: type of building construction, year of construction, presence of mechanical ventilation systems, presence of elevators, any energy saving measures, the types of heating, walls, windows, etc. The ID numbers of detectors, the measurement period and the exact location of the detector in the building are completed the questionnaire.

*2.4. Statistical analysis*

IBM SPSS Statistics, v. 23 was used for performing the statistical analysis. To assess the impact on radon, the measurements are grouped as follows: types of buildings in 3 groups (dwellings, schools and kindergartens) and year of construction in 5 groups (to 1949, from 1950 to 1969, from 1970 to 1990, from 1991 to 2016 and "I don't know"). Descriptive analysis, parametric and non-parametric tests are applied for data processing.

## 3. RESULTS AND DISCUSSION

The descriptive statistic of passive measurements of indoor radon concentration in premises on: 34 kindergartens (111 numbers), 28 schools (307 numbers) and 70 dwellings (one measurement in a home) is presented in Table 1. The abbreviation in the Table 1 are as following: N is the numbers of surveyed premises, AM is annual average arithmetic means of radon concentration in Bq/m3, Minimum is the lowest value and Maximum is the highest value of radon levels. The obtained arithmetic mean for kindergartens is have been found to be 136 Bq/$m^3$, for schools is 123 Bq/$m^3$ and 133 Bq/$m^3$ for homes respectively. The maximum value of indoor radon 1030 Bq/$m^3$ was measure a premises in school building in Pernik.

| | **Kindergartens** | **Schools** | **Dwellings** |
|---|---|---|---|
| **N** | 111 | 307 | 70 |
| **AM, Bq/$m^3$** | 136 | 123 | 133 |
| **Minimum, Bq/$m^3$** | 16 | 15 | 19 |
| **Maximum, Bq/$m^3$** | 757 | 1030 | 614 |

**Table 1.** Descriptive statistic of radon concentrations measured in surveyed premises.

The mean arithmetic radon concentration in the 77 schools of Xanthi, Grecce is 231 Bq/$m^3$[14] and is higher compared to the schools in Pernik (AM = 123 Bq/$m^3$).

The arithmetic mean value for the kindergartens in town Pernik (AM = 136 Bq/$m^3$) is lower than the assessed such in Plovdiv city (AM = 278 Bq/$m^3$) [12], but compared to results from the radon study in Hungarian kindergartens (AM = 61 Bq/$m^3$) [15] it is twice as high.

The review of 63 national and regional indoor radon surveys in kindergartens and schools in Europe, Asia, Africa and North America had been found that average radon arithmetic mean for all these surveys were 59 Bq/$m^3$ [16]. This value is lower than assessed arithmetic mean radon concentration in kindergartens and in schools of Pernik town.

A non-parametric statistical test was performed to determine whether the type of buildings (kindergartens, schools and dwellings) had an effect on the variations of the radon. The values of the radon concentration in the premises do not differ significantly between the considered three groups of investigated buildings (KW, p=0.263) (Fig.2).

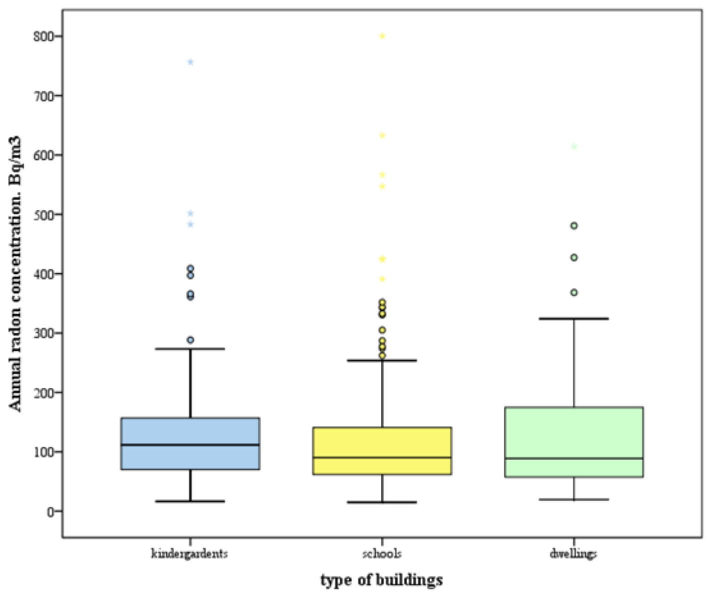


**Fig. 2.** Distribution of radon concentration depending on the type of buildings

The hypothesis whether the year of construction of the investigated buildings influences the variations of radon is considered. The descriptive statistic of radon concentration in premises by groups according to years of construction is presented in Table 2. The highest average value of idoor radon concentration AM=152 Bq/m$^3$ was estimated for the group of buildings „from 1950 to 1969", and the lowest AM=82 Bq/m$^3$ is for a group „from 1991 to 2016". The coefficient of variation (CV, %) of radon concentration was estimated. CV is a standardized measure of dispersion of a probability distribution and is expressed as a percentage. It shows the extent of variability in relation to the mean of radon concentration. Again, the lowest value of the CV = 52% is assessed for the group of buildings „from 1991 to 2016". The most probable reason for this is probably that the buildings construction is a new and have no cracks still on it, where the radon could past inside.

| | **To 1949** | **1950 - 1969** | **1970-1990** | **1991-2016** | **I don't know** |
|---|---|---|---|---|---|
| **N** | 74 | 189 | 157 | 37 | 31 |
| **AM, Bq/m$^3$** | 124 | 152 | 109 | 82 | 135 |
| **STD** | 121 | 141 | 85 | 43 | 84 |
| **Minimum, Bq/m$^3$** | 16 | 35 | 19 | 15 | 24 |
| **Maximum, Bq/m$^3$** | 757 | 1030 | 633 | 187 | 352 |
| **CV, %** | 98 | 93 | 78 | 52 | 62 |

**Table 2.** Descriptive statistic of radon concentrations according to the year of building construction

To test the hypothesis of the influence of the year of construction on radon levels, a statistical test of Kruskal Wallis was applied. The values of indoor radon concentration differ significantly between these groups (KW, p<0.0001). The distribution of median of radon variation by the year of construction groups is presented on Fig.3.

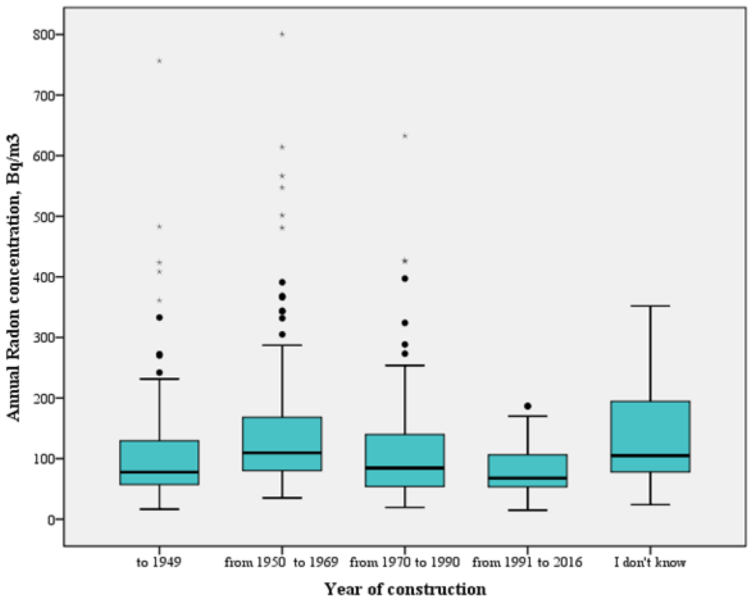


**Fig. 3.** Distribution of radon concentration depending on the year of building construction

Discriminative analysis was applied to the considered groups of results in order to make a model for prediction of the affiliation of the result to the respective group. The first task is to check whether these groups of the dependent variable are statistically significantly different for each of the independent variables using the arithmetic mean for the groups (AM) and analysis of variance (ANOVA). A statistical difference was found between the groups, divided by the year of construction of the buildings ($p<0.0001$). A Box's M test was applied to test the null hypothesis, which is that the covariance matrices are not different between the groups of the dependent variable. The test result is not statistically significant (BM, $p=0.367$) and the prerequisite for the discriminative analysis is confirmed. The following equation was obtained from discriminative analysis:

$$D=-7.178+\ln CRn*1.561$$

where LnCRn - logarithmically transformed values of radon concentration. The discriminative function was found to be statistically significant ($p<0.0001$). The proposed discriminative model can explain 7.2% of the variance in the dependent variable. On the base of the model of original grouped cases the 31.3% could be correctly classified. The Functions at Group Centroids is presented on Table 3.

| **Groups** | **Function** |
|---|---|
| to 1949 | -,093 |
| from 1950 to 1969 | ,308 |
| from 1970 to 1990 | -,205 |
| from 1991 to 2016 | -,514 |

**Table 3.** Functions at Group Centroids

For example if the radon concentration in the buildings is 300 Bq/m$^3$ and it Ln is 5.704, the assessment centroid of the group under the equation is 1.726. The results is positive, which shown that building could be affiliated to group of "from 1950 to 1969".

## 4. CONCLUSIONS

Measurements radon concentrations in indoor air of buildings (homes, schools and kindergartens) in Pernik city were carried out using passive radon detectors. The radon concentration in investigated premises varied in the range of 15 Bq/m$^3$ to 1030 Bq/m$^3$. The arithmetic means of radon concentrations are: for dwellings AM = 133 Bq/m$^3$, for schools AM = 123 Bq/m$^3$ and for kindergartens AM = 136 Bq/m$^3$. The estimated average radon values are below the national reference level on 300 Bq/m$^3$.

In order to evaluate the difference between of the radon concentration in the groups separated by type of buildings and year of construction the statistical test was applied. No statistically significant difference was found between the types of buildings (KW, $p=0.263$), unlike between the groups on years of buildings construction (KW, $p<0.0001$).

Discriminative analysis was applied to the considered groups of results in order to make a model for prediction of the affiliation of the result to the respective group. The proposed discriminative model can explain 7.2% of the variance in the dependent variable, which means that variation of indoor radon concentration depends on other factors. The study shown the variation of radon in the different type of buildings and explain the influence of the years of construction on the radon level and is a basis of future analysis.

## ACKNOWLEDGMENTS

This study presents a part of the research conducted within the national project „Establishment a risk assessment models from radon in buildings with public access for the long-term social implementations" is supported by the Bulgarian National Science Fund, in the framework of Grant No КП-06-Н23/1/07.12.2018.

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