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INDOOR RADON MONITORING IN VARIOUS VENTILATION DEGREE IN SOME SCHOOLS OF DUHOK CITY, IRAQ

by

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Radon is a radioactive noble gas, recognized as a carcinogenic agent, being affected by degree of ventilation. The aim of this preliminary study was to determine the concentration of indoor radon gas in schools, to estimate the main factors affecting their radon concentration levels and to analyze the effective dose received by students in Duhok schools. Therefore, the concentrations of radon were measured in 28 classrooms, from 13 schools located in Duhok city, using both RAD7 and Corentium monitor, from January 15-30, 2021. In all schools indoor radon was measured in four different scenarios of closed, natural and mechanical ventilation then, radon reduction rate between each case was calculated. In addition to that, exposure to annual effective dose of radon, for each different degree of ventilation, was evaluated. Furthermore, effects of building floors were studied. Results showed that maximum radon concentration, 121 Bqm^{-3}, was recorded in closed ventilation, while minimum, 15 Bqm^{-3}, was recorded in mechanical ventilation. Radon reduction rate in a mechanical ventilation is relatively large 81%. Also, results demonstrate that indoor radon levels at first floor, in all schools under study, were considerably greater than those at second and third floor ($p < 0.05$). The annual effective dose of all studied schools at 4 different cases of ventilation were found less than the worldwide average radiation dose of 3-10 mSv. So, it is not required to take any action to minimize the level of radon in schools under study.

Key words: indoor radon, annual effective dose, ventilation, floor effect, school population

INTRODUCTION

Radon is a colorless, odorless, and tasteless, chemically inert radioactive gas belonging to the radioactive chain of ^{238}U. It is produced from the soil and other materials containing ^{226}Ra [1, 2], moves free in nature, has great mobility within the earth's crust, and migrates from the original place, which is the soil, into the atmosphere through pores and cracks in the lithosphere. Furthermore, radon also may be generated, from the construction materials used for buildings, dwellings, schools, *etc*. [3].

Several factors affect the level of indoor radon concentration. The most significant one is the geology of the study area such as the amount of ^{238}U, permeability and porosity of the underlying soil and bedrocks [4]. Furthermore, it depends on the ventilation methods, air tightness of the building, and habits of the occupants, seasonal variation and meteorological parameters such as temperature, humidity, pressure and wind speed [5].

Many studies worldwide have been conducted on this topic in order to determine the level of radon concentrations in dwellings, schools, and workplaces. Most of them found a statistically significant relation between radon exposure and lung cancer risk [5]. It is argued that after tobacco radon is the second leading cause of lung cancer because most cases of radon-produced lung cancer take place among smokers, due to the strong synergic problem of tobacco and radon [6]. Furthermore, radon gas is responsible for the death of many people. For example, in Spain, radon is responsible for about 1500 deaths annually, and in Europe, radon is responsible for 9 % of deaths from lung cancer [4].

The aim of the present study was to measure the concentration of radon in 13 schools in Duhok city, Kurdistan region, Iraq. The effect of different degrees of ventilation in student classrooms was studied and the association between the floor of the monitored classroom and radon concentration in the rooms belonging to various buildings, was investigated. Furthermore, the concentrations of radon were compared to the World Health Organization (WHO) and International Commission on Radiation Protection (ICRP) reference levels to clear whether Duhok schools required taking any action to minimize the level of radon in schools under study.

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METHODS

Survey design

Indoor radon was measured for 13 schools from January 15-30, 2021, in student classrooms located in Duhok city, Kurdistan region, north of Iraq. The schools were chosen taking into account the distribution of the schools in the study region and school population. In each school, one to three classrooms were analyzed depending on the school floors. Each classroom had a door and glass window which could be opened for ventilation on both sides. Data was measured in the classroom, where radon could be analyzed according to the chosen ventilation scenarios.

Radon measurement device

Both a continuous measurement device RAD7, and Corentium monitor were used in all the schools in the same manner to reduce the deviation between the measurement devices. In each classroom, detectors were installed 1 m above the ground and 1.5 m far from the classroom door and windows. The average radon concentration (Bqm^{-3}) was measured. The RAD7 is a true, direct, highly versatile instrument that can form the basis of a comprehensive radon measurement system. It is made in U.S by DURRIDGE Company. In this study RAD7 was connected to dried plastic cylindrical tube filled with calcium sulfate ($CaSO_4$). The dried tube has two holes: one at the top for inlet of the air for measuring the concentration of radon that is present in the study environment and other at the bottom for outlet of dried air. When radon is deposited on the surface of the detector, it radiates alpha particles of special energy immediately into the solid state detector. Electrical signal is created by the detector, and then by electronic circuit this signal is converted to digital form [5]. Corentium monitor, used in this study, is an electronic radon detector, made by a Norway based Technology Company in Norway, Model type; BQM -Digital. To measure the concentration of radon gas, device takes indoor air sample through a passive diffusion chamber, by utilizing alpha spectrometry. Both detectors were used in the study because in some study schools electricity is cut during the night. The RAD 7 was operated by plugging in the electricity unit while the Corentium depended on the batteries for usage, with careful use the batteries can last about two years or more.

Indoor radon measurement

In both natural and mechanical ventilation, the differences in the concentration of radon according to the ventilation types, were measured in 28 classrooms of 13 schools. Natural ventilation was achieved by opening and closing of classroom windows and door leading outside. While the mechanical ventilation measurement was adopted by operating the fan, installed in the classroom.

Before starting the measurement, a survey was achieved in each school to collect information on outdoor environment such as number of occupants, the size and number of classrooms, number of floors, school time, materials, and their conditions concerning floor, walls, to maintain and operate the building and its activities. Based on this survey in each school, four cases were chosen with each case representing a different scenario. In Case 1, indoor radon was measured in closed ventilation from 3 p.m. to 6 a.m. with nobody in the classroom. School time in all the chosen samples start from 8 a.m. to 2 p.m. For that reason, Case 2 was chosen from 8 a.m. to 8.30 a.m., when students were in the classroom, with closed doors and windows. In Case 3, the door and window of the classroom were opened for normal ventilation, indoor radon was measured from 8.45 a.m. to 9.15 a.m. While in Case 4, there were no students in the classroom and forced ventilation was chosen by using mechanical ventilation fan operation. Indoor radon measured from 9.30 a.m. to 10 a.m.. Tables 1 and 2 give information about geographical locations and each case of studied schools, respectively.

Table 1. Geographical, geological, floor numbers and number of classrooms studied in each of the selected schools

School no.	Schools name	Floor no.	No. of classroom	Latitude and longitude location of the sites
1	Mazi 2	3	2	36.7898968, 44.0512718
2	Shalin	1	1	36.88399015, 42.95578963323851
3	Bizhara	2	2	36.8616341, 42.9983706
4	Parlaman	2	3	36.859732, 42.9503786
5	Masiek	2	3	36.8767605, 42.93881464388121
6	Jigar Xwen	1	2	36.8332374, 42.911585
7	Siver	1	2	36.85035255, 43.04534262687393
8	Diryan	1	2	36.845965, 43.0484939
9	Diryan	2	3	36.8513107, 43.05023
10	Tanihe	1	2	36.8610695, 42.896662807731
11	Baroshke	1	1	36.85035255, 43.04534262687393
12	Blind	1	3	36.85035255, 43.04534262687393
13	Hindreen	1	2	36.8332374, 42.911585

Table 2. General information about all four cases in study classrooms

Sample description	Case 1	Case 2	Case 3	Case 4
Indoor radon (C) symbol	$C_{(3\text{ p. m.} - 6\text{ a. m.})}$	C_o	C_N	C_F
Dose symbol	$D_{(3\text{ p. m.} - 6\text{ a.m.})}$	D_o	D_N	D_F
School	13	13	13	13
Classroom door no.	1	1	1	1
Classroom window No. (80 % of the study classrooms have two windows while 20 % have 1)	2 (80 %) 1 (20 %)	2 (80 %) 1 (20 %)	2 (80 %) 1 (20 %)	2 (80 %) 1 (20 %)
Operating time	3 p.m. to 6 a.m.	8 a.m. to 8.30 a.m.	8.45 a.m. to 9.15 a.m.	9.30 a.m. to 10 a.m.
Normal ventilation	Door and windows closed	Door and windows closed	Door and windows opened	Door and windows opened
Fan operating	No	No	No	Yes
Student no.	0	34	<18	0
Teacher no.	0	1	0	0

Radon reduction rate

Radon reduction rates P_r were calculated between all cases according to equations below

$$P_{r1} \quad \frac{C_{(3\text{ p.m.} \quad 6\text{ a.m.})} \quad C_o}{C_{(3\text{ p.m.} \quad 6\text{ a.m.})}} \tag{1}$$

$$P_{r2} \quad \frac{C_o \quad C_N}{C_{(3\text{ p.m.} \quad 6\text{ a.m.})}} \tag{2}$$

$$P_{r3} \quad \frac{C_N \quad C_F}{C_N} \tag{3}$$

where P_{r1}, P_{r2}, and P_{r3} denote radon reduction rate between Cases (1 and 2), (2 and 3), and (3 and 4), respectively.

Dose assessment

To analyze the annual effective dose for students and teachers, radon concentration was converted to dose, using the following equation [7, 8]

$$D_E \quad F\ C\ T\ D\ U \tag{4}$$

where D_E is annual effective dose (mSv), F – the equilibrium factor (0.4) between radon and its progeny [9], C [Bqm^{-3}] – the radon concentration, T [h] – the time spent annually inside the building, in this study T is assumed to be the 1200 h without weekends and holidays (school time). The D [1430 mSv/(Jhm^{-3})] is the dose conversion factor and U (5.56 10^{-9} Jm^{-3}/Bqm^{-3}) – the unit factor.

Statistical analysis

For each school, data were assumed as the average of radon concentration in each monitored classroom at all the floors. In this way, for each observed classroom, a single indoor radon value was acquired. Furthermore, the data analysis is based on the different parameters that may affect the level of indoor radon, mainly: school building age, degree of ventilation and floor level.

The statistical t-test was used to examine if the mean radon concentrations of these study parameters were significantly different from each other. The P-value <0.05 was always considered statistically significant. Excel software program was used for data entry and analysis.

RESULTS AND DISCUSION

The concentrations of radon level in the schools ranged from 15-121 Bqm^{-3}, with geometric mean of 68 Bqm^{-3} and geometric standard deviation of 4. Figure 1 shows the average of radon detections in all of the 13 selected schools, showing the variation of radon concentration in each school. Furthermore, normal and forced ventilation was performed in each school, according to scenarios from Cases 1-4, and the results obtained from the comparison of indoor radon concentrations were presented with the recommended standards of 100 Bqm^{-3} by WHO [10] and 200-300 Bqm^{-3} by ICRP [11]. Average level of measured radon concentrations, in all schools, for Cases 2-4 (school time), were below the global limit recommended by WHO and ICRP. In Case 1, radon levels detected in four schools were higher than the recommendation of WHO, set as 100 Bqm^{-3}. The 100% of the monitored classrooms had a radon concentration below the reference level imposed by ICRP [11]. These outcomes could have been attributed to the fact that the investigated schools were built after 1980. The construction period affects the construction type (*e.g.*, size of window openings, the ground connection and choice of building materials), which may not facilitate the accumulation of radon in confined spaces.

Results demonstrate that the highest radon concentration in each school was recorded in Case 1 where no ventilation was applied to the classroom for roughly 15 hours. The concentration of radon decreased in Cases 2 and 3, when students enter the classroom through the door and using the mechanical ventilation, respectively. Also, one can note that the lowest radon concentration was de-

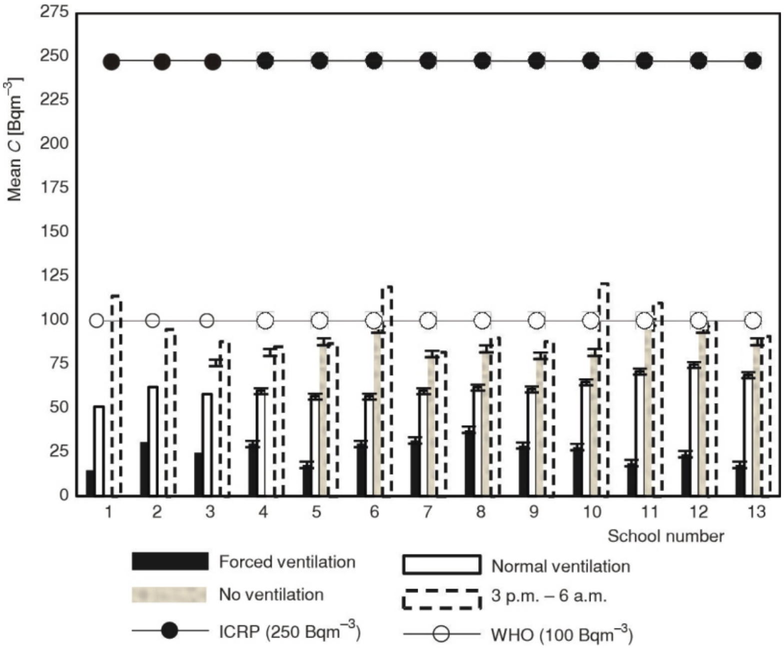

Figure 1. Average radon level detected in 13 selected schools compared with WHO and ICRP

tected in Case 4, when forced ventilation is applied. Radon concentration strongly depends on ventilation conditions as the radon gas can easily move out and does not accumulate inside the building. Furthermore, *t*-tests, that were done between radon concentrations measured at closed ventilation $C_{(3\,\text{p.m.}-6\,\text{a.m.})}$ and the other three cases of ventilation (Cases 2-4), show that indoor radon concentration was statistically significant ($p < 0.05$). The outcomes achieved in this study were consistent with many other studies done on this topic [7, 12, 13].

Radon reduction rates P_r were calculated to identify the indoor radon decrease/increase ratios according to each case. By applying mechanical ventilation, we obtained highest radon reduction rate of approximately 81 %. Radon concentration and radon reduction rate, in each school and in each case, were varied. From the results obtained, one can note that room ventilation has great benefit to decrease any type of indoor pollutants. If choosing soil under the building and for building construction, which are the two main sources of indoor radon, room ventilation can easily control the indoor radon concentration. Table 3 gives information about minimum, maximum and average of radon concentration and radon reduction rate for each case.

The concentrations of indoor radon were known to be varied by a variety of factors including the building materials, floor level, and metrological parameters [5]. To examine the effect of floor level, the observed classrooms were divided into three categories: first floor, second floor, and third floor. Figure 2 depicts the average radon concentrations in all the schools, for each case as a function of floor level.

The statistical study revealed that indoor radon levels on the first floor, in all the study schools were considerably greater than those at the second and the third floor ($p < 0.05$). This result is consistent with the findings of many other researchers [14, 15]. The highest indoor radon concentrations were found on the first floor, which can be related to the fact that radon is primarily produced in the soil [1, 16]. It is expected that the radon concentration accumulates in ground level and decreases at higher floors because it escapes from the ground into the air, where it decays and produces further radioactive particles [17-19].

The differences in the radon concentrations observed in the classrooms lead to differences in the amount of doses. Figure 3 demonstrates the effective dose of all the studied schools for four different cases of ventilation. The annual effective dose in the schools was found to be less than the lower limit of action level (3-10) mSv per year, recommended by ICRP [5, 11]. So, it is not required to take any action to minimize the level of radon in these places in schools under study.

Table 3. Minimum, maximum and average of radon concentration and radon reduction rate in each case

Values	C_F [Bqm^{-3}]	C_N [Bqm^{-3}]	C_o [Bqm^{-3}]	$C_{(3\,\text{p.m.}-6\,\text{a.m.})}$ [Bqm^{-3}]	P_{r1} [%]	P_{r2} [%]	P_{r3} [%]
Minimum	15	51	76	82	1.1	20	55
Maximum	38	75	99	121	32	40	81
Average	25.9 4.2	62.2 6.5	85.6 7.7	97.6 11	12 2	27 3.8	69 9.2

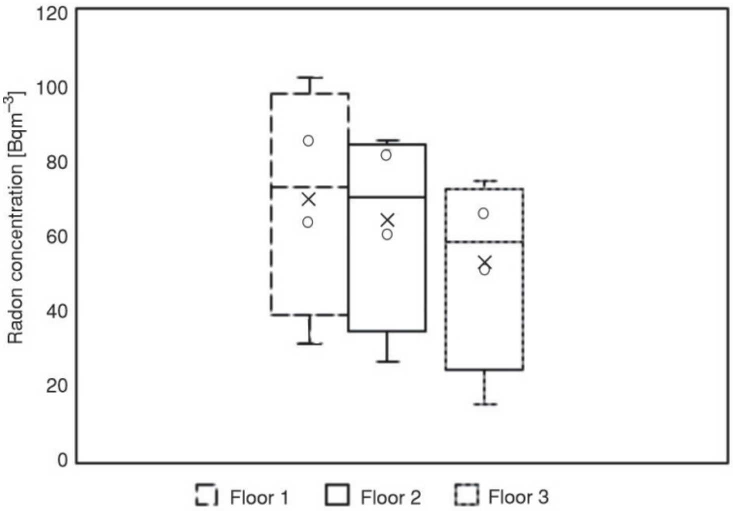

Figure 2. Relationship between radon concentrations and floor of the monitored classroom: the graph reports the average of radon concentration in four different cases of ventilation

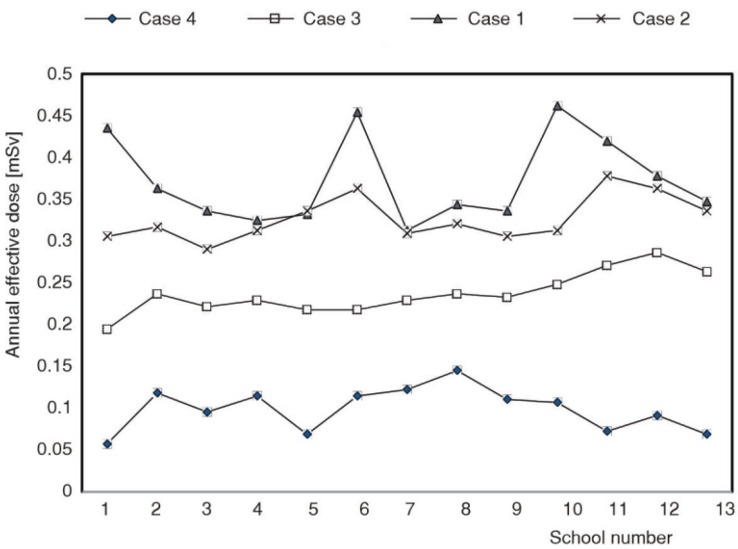

Figure 3. Annual effective dose in 13 schools for four different cases of ventilation

CONCLUSION

Radon was measured in 28 classrooms of 13 schools in the Duhok city. The effect of floors and ventilation was studied by evaluating various ventilation effects of indoor radon under natural and mechanical ventilation conditions. Accordingly, four different ventilation scenarios were chosen. The highest radon reduction rate was found under mechanical ventilation. Furthermore, the results revealed substantial radon concentration variations from floor to floor and from school to school. The change in the concentration of radon with the building floors approved the impact of soil as the main source of indoor radon. Furthermore, the exposure to annual effective dose due to the indoor radon in the studied schools was found to be below the action level presented worldwide.

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МОНИТОРИНГ РАДОНА У ШКОЛАМА ГРАДА ДУХОКА У ИРАКУ, ПРИ РАЗЛИЧИТИМ НИВОИМА ВЕНТИЛАЦИЈЕ

Радон је радиоактивни племенити гас, препознат као канцерогени агенс, на који утиче степен вентилације. Циљ овог прелиминарног истраживања је да се утврди концентрација гаса радона у затвореном простору у школама, да се процене главни фактори који утичу на нивое концентрације радона у њима и да се анализира ефективна доза коју су примили ученици у школама града Духока. Због тога су коришћењем РАД7 и Corentium монитора, од 15. до 30. јануара 2021. године, мерене концентрације радона у 28 учионица из 13 школа које се налазе у граду. У свим школама радон у затвореном простору мерен је при четири сценарија затворене, природне и механичке вентилације, а затим је израчуната стопа редукције радона између сваког случаја. Поред тога, процењена је изложеност годишњој ефективној дози радона за сваки степен вентилације. Надаље, проучавани су ефекти подова зграда. Резултати су показали да је максимална концентрација радона од 121 Bqm^{-3} забележена при затвореној вентилацији, док је минимална од 15 Bqm^{-3}, забележена са механичком вентилацијом. Стопа смањења радона у механичкој вентилацији је релативно висока – 81%. Резултати показују да су у свим истраживаним школама нивои радона у затвореним просторима на првом спрату, били знатно виши од оних на другом и трећем спрату ($p < 0,05$). Годишња ефективна доза у свим проучаваним школама, за четири случаја вентилације, била је мања од светске просечне дозе зрачења од (3-10) mSv, тако да није потребно предузимати никакве додатне радње да се умање нивои радона.

Кључне речи: радон у затвореном простору, годишња ефективна доза, вентилација, ефекат пода, школска популација