HEALTH HAZARDS DUE TO THE EXPOSURE TO RADON IN SCHOOLS OF THE CAPPADOCIA REGION

by

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This study presents the results of a survey of radon concentrations in schools (kindergartens, primary schools, secondary schools, high schools, colleges, and one faculty) located in the province of Nevsehir which is the center of the Cappadocia region. Radon measurements covered two consecutive 6-month periods in the ground floor classrooms inside the school buildings and they were performed using a continuous active radon detector (AlphaGUARD PQ2000 PRO). Data distribution is well fitted by a log-normal curve. The arithmetic average value of the radon concentrations measured in summer and winter was found as 75 12 Bqm^{-3} and 67 10 Bqm^{-3}, respectively. From the measured results, the effective doses from radon exposures in summer and winter were estimated as 0.27 and 0.40 mSv and 0.24 and 0.36 mSv for students and teachers, respectively. The results showed that radon concentration measured in schools does not pose significant health hazards for students and teachers.

Key words: indoor radon, active technique, AlphaGUARD, annual effective dose, school

INTRODUCTION

Radon (^{222}Rn) is naturally occurring radioactive noble gas that emanates from rocks and soils and tends to concentrate in enclosed spaces like houses [1]. Soil gas under the house infiltration is recognized as the most important source of residential radon. Radon and its decay products (^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po) are the most important sources of natural ionizing radiation for the human exposure [2]. Epidemiological studies have provided convincing evidence of an association between the indoor radon exposure and the lung cancer, even at the relatively low radon levels commonly found in residential buildings [1]. A national reference level for radon represents the maximum accepted radon concentration in a residential dwelling. The World Health Organization (WHO) recommends a reference level of 100 Bqm^{-3} to minimize the health hazards caused by an indoor radon exposure [1]. In Turkey, the reference level for indoor radon exposure in future constructions was set as 200 Bqm^{-3} under the prevailing country-specific conditions [3], while recommended value for remediation of indoor radon exposure in existing building is 400 Bqm^{-3} [4].

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The monitoring of indoor radon levels in school buildings as well as houses and offices is very important for an adequate radiological risk assessment for students and staff. In the past decade, several systematic radon surveys were carried out in school buildings all over the world [5-16] but few data are available regarding the presence of radon in schools in Turkey [17-19]. In general, the radon survey in schools was performed using the passive track etching with solid state nuclear detectors type CR-39 and LR-115. However, the indoor radon survey in schools located in Nevsehir province is not available in the literature. To our knowledge, this is the first study on indoor radon levels in schools. The aim of the present study is the determination of radon concentrations in a sample of schools (23 schools and one faculty) located mainly in the province of Nevsehir using the active method with AlphaGUARD PQ 2000PRO radon monitor.

MATERIAL AND METHOD

Schools surveyed for radon

Nevsehir province is located in the center of the Cappadocia region of Turkey. According to the 2013 census, the population of Nevsehir province is

285.460 of which 126.307 live in the city of Nevsehir. There are 62 schools (5 kindergartens, 15 primary and secondary schools, 13 primary schools, 12 secondary schools, 3 colleges, and 14 high schools) one university (7 faculties) in Nevsehir province. The number of students in these schools is 28.805. In the present study, indoor radon measurements were completed in the ground floor classrooms of 23 schools (three kindergartens, seven primary schools, three secondary schools, seven high schools, and three colleges) and one faculty located in Nevsehir province (fig. 1). The number of the schools surveyed for radon is 46 % of the total number of students.

Measurement equipment

Short-term measurements of the indoor radon concentrations in the ground floor classrooms in the schools were performed using a professional radon monitor AlphaGUARD PQ2000 PRO. AlphaGUARD is a portable measuring system for the continuous determination of the radon- and radon progeny concentration in air, water and soil as well as the relevant climatic parameters. It incorporates a pulse-counting ionization chamber with a high detection efficiency, a wide measuring range, a fast response to concentration gradients and a permanent, maintenance-free operation. The cylindrical ionization chamber of the AlphaGUARD has the active volume of 0.56 dm^3. AlphaGUARD has a measurement range of 2-2 000 000 Bqm^{-3} ^{222}Rn. The indoor air samples were taken in closed classrooms of the schools. Total measuring time for radon concentrations in the schools lasted about 2 years. Measurement conditions of the schools surveyed for radon are given in tab. 1.

RESULTS AND DISCUSSION

Radon concentrations

The indoor concentrations of ^{222}Rn measured in the ground floor classrooms of 24 schools are presented in tab. 2. The statistical data obtained from the indoor radon survey in the schools and a summary of the results are given in tab. 3. From tabs. 2 and 3, the average values of the concentrations of ^{222}Rn measured in summer and winter varied from 20 2 to 217 12 Bqm^{-3} with an arithmetic and geometric average value of 75 and 58 Bqm^{-3} and 17 2 to 219 13 Bqm^{-3} with an arithmetic and geometric average value of 67 and 54 Bqm^{-3}, respectively. Figure 2 shows that in 50 % of measured schools, radon concentrations in summer are higher than those measured in winter.

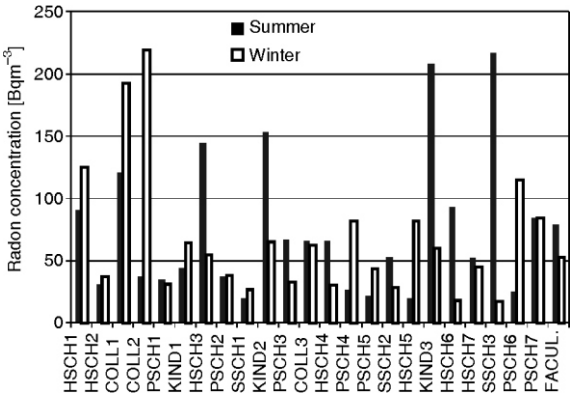

Figure 2. Comparison of radon measured in summer and winter

The comparison of the average values of concentration of ^{222}Rn measured in the schools with Turkish action levels of 200 and 400 Bqm^{-3} for future and existing buildings, respectively, and with the reference level of 100 Bqm^{-3} recommended by WHO is given in tab. 3. The 79 % of schools (for summer) and 83 % of schools (for winter) had radon levels below 100 Bqm^{-3}, while in 8 % of schools (for summer) and 4 % of school's radon values are higher than 200 Bqm^{-3}. From tab. 3, the positive value of the skewness coefficient shows an asymmetric distribution of radon average concentrations with the right tail longer than the left. In addition to the positive kurtosis coefficient implies that the distribution is higher and narrow than the normal [20]. The fre-

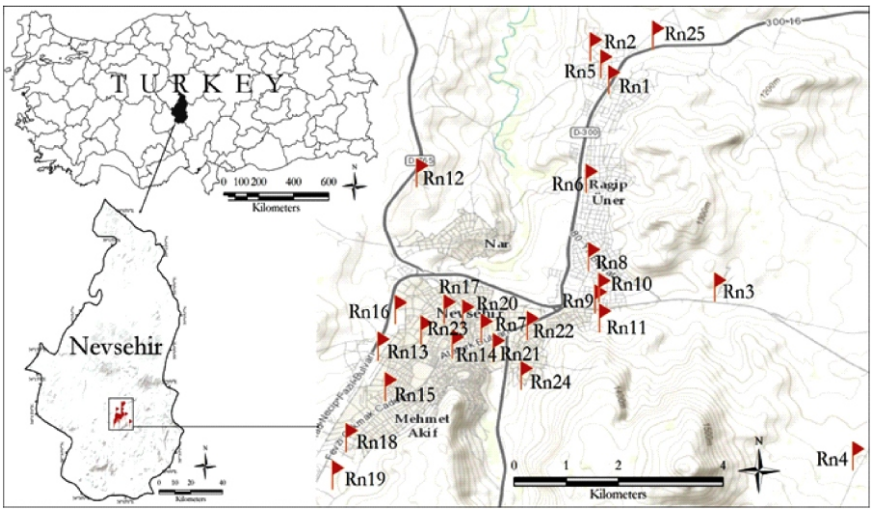

Figure 1. Map of Nevsehir province with locations of schools surveyed for radon

Table 1. Measuring conditions determined in the school surveyed for radon

School code	Winter			Summer		
	Temperature [°C]	Humidity [%]	Pressure [mbar]	Temperature [°C]	Humidity [%]	Pressure [mbar]
HSCH1	15	43	878	23	40	882
HSCH2	21	32	882	25	38	884
COLL1	18	41	865	25	47	874
COLL2	18	38	859	24	50	864
PSCH1	23	29	887	26	40	886
KIND1	15	47	887	27	36	883
HSCH3	19	32	886	25	42	877
PSCH2	22	28	880	24	50	864
SSCH1	15	30	887	27	36	879
KIND2	21	24	877	27	39	879
PSCH3	24	21	875	26	32	877
COLL3	16	29	887	24	32	882
HSCH4	18	29	882	26	31	874
PSCH4	16	31	879	27	31	878
PSCH5	24	46	881	25	31	880
SSCH2	18	24	884	27	27	877
HSCH5	25	23	873	23	33	869
KIND3	20	28	877	23	64	869
HSCH6	23	25	885	23	41	880
HSCH7	17	20	884	27	31	881
SSCH3	19	24	888	25	41	880
PSCH6	20	30	878	24	36	879
PSCH7	23	28	877	27	37	875
FACULTY	24	26	887	25	35	885

Table 2. Radon concentrations measured in summer (July-August) and winter (January-March) in 24 schools and 1 building in Nevsehir province

School code	School name	Radon concentration [Bqm^{-3}]					
		Summer			Winter		
		Min	Max	Average	Min	Max	Average
HSCH1	2000 houses Anatolian high school	15 1	207 10	90 110	33 2	231 7	125 7
HSCH2	TOKI vocational school for girls	13 1	89 6	31 3	17 1	73 3	37 3
COLL1	Altinyildiz college	46 2	191 7	121 7	45 2	404 14	192 14
COLL2	Kardelen college	2 1	123 6	37 3	101 4	374 12	219 13
PSCH1	19 Mayis primary school	6 1	141 6	35 6	8 1	77 4	31 3
KIND1	50. yil kindergarten	19 1	91 4	44 4	29 1	163 8	64 8
HSCH3	Nevsehir high school	33 2	268 11	144 11	9 1	106 4	55 4
PSCH2	Turgut akdeveli primary school	2 1	123 6	37 6	14 1	65 2	38 3
SSCH1	Damat Ibrahim secondary school	2 1	124 6	20 2	2 1	54 2	27 2
KIND2	Vilayetler kindergarten	30 2	340 14	153 14	26 1	117 3	65 3
PSCH3	Yeni cesme primary school	31 2	147 5	67 5	10 1	105 4	33 3
COLL3	Lara college	20 1	131 6	66 6	27 1	126 5	63 5
HSCH4	Anatolian tecaher high school	20 1	131 6	66 6	4 1	64 2	30 2
PSCH4	100. yil pimary school	6 1	61 4	27 4	32 2	173 4	82 4
PSCH5	Ornekevler pimary school	4 1	52 3	22 3	16 1	107 3	43 3
SSCH2	Pamukcu secondary school	11 1	113 7	53 7	8 1	75 2	29 2
HSCH5	Science high school	3 1	80 5	20 5	25 1	164 5	82 5
KIND3	TOKI rainbow kindergarten	31 1	316 12	208 12	20 1	148 4	60 4
HSCH6	Anatolian high school	35 2	191 8	93 8	2 1	66 3	18 3
HSCH7	Hotel management and tourism vocational high school	22 1	113 5	52 5	11 1	143 3	45 3
SSCH3	Mihriban secondary school	67 3	330 13	217 12	2 1	43 2	17 2
PSCH6	Ataturk primary school	6 1	162 5	25 3	45 2	217 6	115 6
PSCH7	Ersular primary school	27 1	180 4	84 4	43 2	149 8	84 8
FACULTY	Faculty of science and letters	12 1	221 8	79 8	15 1	102 7	53 5

Table 3. Statistical data for indoor radon concentrations in 24 schools

Parameter	Indoor radon [Bqm^{-3}]	
	Summer	Winter
Min	20	17
Max	217	219
Arithmetic average	75	67
Standard error	12	10
Standard deviation	57	51
Median	60	54
Geometric average	58	54
Skewness	1	2
Kurtosis	1	3
<100 Bqm^{-3}	79 %	83 %
100-200 Bqm^{-3}	13 %	13 %
>200 Bqm^{-3}	8 %	4 %
No. schools surveyed	24	
No. kindergarten	3	
No. primary schools	7	
No. secondary schools	3	
No. high schools	7	
No. colleges	3	
No. faculty	1	

Table 4. Annual effective doses from inhalation of radon in the school surveyed

School code	Annual effective dose [mSv]			
	Summer		Winter	
	Student	Teacher	Student	Teacher
HSCH1	0.32	0.49	0.45	0.68
HSCH2	0.11	0.17	0.13	0.20
COLL1	0.44	0.65	0.69	1.04
COLL2	0.13	0.20	0.79	1.18
PSCH1	0.13	0.19	0.11	0.17
KIND1	0.16	0.24	0.23	0.35
HSCH3	0.52	0.78	0.20	0.30
PSCH2	0.13	0.20	0.14	0.21
SSCH1	0.07	0.11	0.10	0.15
KIND2	0.55	0.83	0.23	0.35
PSCH3	0.24	0.36	0.12	0.18
COLL3	0.24	0.36	0.23	0.34
HSCH4	0.24	0.36	0.11	0.16
PSCH4	0.10	0.15	0.30	0.44
PSCH5	0.08	0.12	0.15	0.23
SSCH2	0.19	0.29	0.10	0.16
HSCH5	0.07	0.11	0.30	0.44
KIND3	0.75	1.12	0.22	0.32
HSCH6	0.33	0.50	0.06	0.10
HSCH7	0.19	0.28	0.16	0.24
SSCH3	0.78	1.17	0.06	0.09
PSCH6	0.09	0.14	0.41	0.62
PSCH7	0.30	0.45	0.30	0.45
FACULTY	0.28	0.43	0.19	0.29

quency distribution of radon average concentrations in summer and winter can be well described by lognormal distributions as shown in fig. 3.

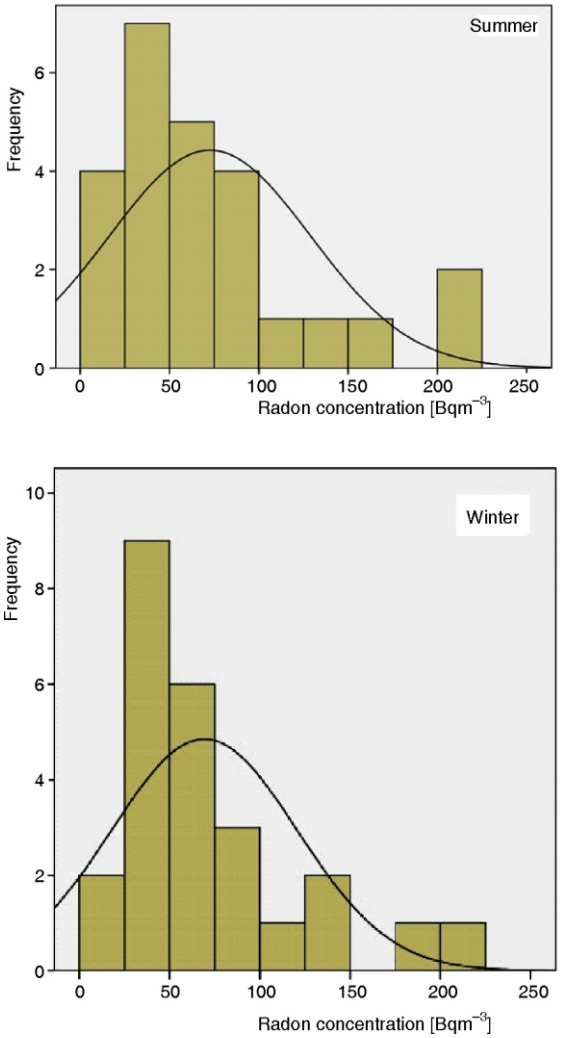

Figure 3. Frequency distributions of indoor radon concentrations measured at ground floor in schools

Dose estimation

The average effective doses (AED in mSv) received by the students and teachers due to the indoor radon measured in the schools were estimated using the following formula [2]

$$\mathrm{AED} \quad C_{\mathrm{Rn}}\, F\, D_{\mathrm{CF}}\, T\, 10^{-6} \tag{1}$$

where C_{Rn} [Bqm^{-3}] is the average indoor radon concentration, F – the equilibrium factor between radon and its progeny (0.4), D_{CF} [9 nSvh^{-1}/ Bqm^{-3}] – the dose conversion factor, and T – the time spent annually inside the schools (1000 h for students and 1500 h for teachers). The results of the AED estimated for students and teachers are given in tab. 4. The average values of the AED for students and teachers in summer and winter varied from 0.07 to 0.78 mSv and 0.11 to 1.17 mSv and 0.06 to 0.79 mSv and 0.09 and 1.18 mSv, respectively. All average values of AED are lower than the limit of the range of the recommended action level (3-10 mSv) [21].

CONCLUSIONS

The short-term indoor radon measurements in the ground floor classrooms of 24 schools located in Nevsehir province have shown that the average radon concentrations are below the Turkish action level (400 Bqm^{-3}) for existing buildings. Most (80 %) of the average radon concentrations are lower than the reference level (100 Bqm^{-3}) recommended by WHO. The distributions of radon concentrations obtained in summer and winter were well described by lognormal distributions. The average annual effective doses from radon exposure during the education process for students and teachers are lower than the recommended action level. Consequently, the results of radon survey show that the schools may be safe from radon health threats.

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AUTHORS' CONTRIBUTIONS

The idea for research of indoor radon in schools was suggested by S. Turhan. Measurements were performed by S. Akyurek and M. Erdogan and analysis and discussion was carried out by S. Turhan, A. Kurnaz, and A. Altikulac. The manuscript was prepared by S. Turhan.

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ЗДРАВСТВЕНИ РИЗИК УСЛЕД ИЗЛАГАЊА РАДОНУ У ШКОЛАМА ОБЛАСТИ КАПАДОКИЈЕ

Приказани су резултати испитивања концентрације радона у обдаништима, школама (основним, средњим и вишим) и једном факултету, који се налази у провинцији Невшехир у центру облати Кападокије. Мерења радона обављена су у учионицама у приземљима школских зграда употребом континуалних активних детектора радона (AlphaGURD PQ2000 PRO), у два узастопна шестомесечна периода. Расподела података добро је описана лог-нормалном кривом. Аритметичка средња вредност концентрација радона током лета и зиме износила је 75 12 Bqm^{-3} и 67 10 Bqm^{-3}, респективно. На основу измерених резултата процењене су ефективне дозе услед излагања радону током лета и зиме на 0.27 mSv и 0.40 mSv за ученике, и 0.24 mSv и 0.36 mSv за наставнике. Резултати показују да измерене концентрације радона не представљају значајан ризик по здравље ученика и наставника.

Кључне речи: радон у затвореној средини, активна техника, AlphaGUARD, годишња ефективна доза, школа