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RESEARCH ARTICLE

Indoor radon measurement in buildings of a university campus in central Iran and estimation of its effective dose and health risk assessment

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Abstract

Indoor radon is a serious health concern and contributes about 10% of deaths from lung cancer in the USA and Europe. In this study, radon and thoron levels of 20 multi-floor buildings on the campus of Isfahan University of Medical Sciences were measured in cold and hot seasons of a year. SARAD- RTM1688 radon and thoron monitor was used for measurement. The annual effective dose of radon exposure was also estimated for residences on the campus. The results showed that radon concentration was below the WHO guideline (100 Bq m^{-3}) in most of the buildings. The ranges of radon were from 3 ± 10% to 322 ± 15% Bq m^{-3} in winter and from below the detectable level to 145 ± 8% Bq m^{-3} in summer. Mostly, the radon concentration in the basement or ground floors was higher than upper floors, however, exceptions were observed in some locations. For thoron, no special trends were observed, and in the majority of buildings, its concentration was below the detectable level. However, in a few locations besides radon, thoron was also measured at a high level during both seasons. The average annual effective dose via radon exposure was estimated to be 0.261 ± 0.339 mSv y^{-1}. The mean excess lung cancer risk (ELCR) was estimated to be 0.10%. It was concluded that indoor air ventilation, buildings' flooring and construction materials, along with the geological structure of the ground could be the factors influencing the radon concentration inside the buildings. Thus, some applicable radon prevention and mitigation techniques were suggested.

Keywords Radon concentration · Indoor air · Exposure · Effective dose · Campus · GIS mapping

Introduction

Radon is a radioactive gas that is produced from the natural decomposition of uranium and radium which are present in small quantities in the soil and rocks. It is a colourless and neutral gas with low ability in combination with other elements but high solubility in water. Other sources of radon are oil, natural gas, coal and some industries which are very low compared to the former-mentioned sources [1]. Radon isotopes are produced because of uranium 238, 235 and thorium 232 decay [2]. Radon concentrations in ambient air are very low, but when trapped in buildings and accumulate, its concentration increases [3]. Radon concentrations in ambient air are very low, but when trapped in buildings and accumulate, its concentration increases. About 95% of natural exposure to humans occurs through an indoor environment in which the radon gas and its decay products have the largest contribution [4]. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in 2000, has estimated the effective dose of human exposure from natural sources of radiation by 2.4 mSv y^{-1}, in which about 52% (1.2 mSv/year) is caused by inhaling radon gas [5].

Inside buildings radon accumolates and breaks down into several radioactive elements which are called radon daughters, such as various forms of polonium, lead and bismuth which are solid fine particles. The particles stick on lung tissue by

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inhalation and disintegrated to α, β, and γ-rays. Between them, α-rays emitted from polonium 218 and polonium 214 (radon decomposition products) are dangerous. If α-particles target the inhibitor genes of cancer in the DNA of living cells, the risk of lung cancer increases. Besides, α-particle can ionize the DNA surrounding material and the produced ions can destroy the DNA. Since even a single α-particle can cause major genetic damage to a cell, DNA damage related to radon can likely occur at any level of exposure. Therefore, it is unlikely that there is a threshold concentration below which radon does not have the potential to cause lung cancer. However, given the latest scientific data, the World Health Organization (WHO) proposes a reference level of 100 Bq m^{-3} to minimize health hazards due to indoor radon exposure. Studies conducted by UNSCEAR and other epidemiological research demonstrated an increased risk of lung cancer through the inhalation of radon gas [5–9].

Radon is a serious national health problem in the US. US-EPA has estimated that about 11% of deaths from lung cancer in the United States (15000–22000 cases per year) is attributed to radon exposure. After smoking, radon is the second leading cause of lung cancer in North America [10]. About 9% of deaths from lung cancer in Europe (7,000 cases per year) is due to environmental contact with radon. Studies conducted in different countries such as Canada [11], England [6], Sweden [12] and America [9] have shown that high levels of radon inside buildings are associated with lung cancer. Therefore, awareness of the radon concentration in the workplace and residences is important.

According to UNSCEAR In 1998, the average concentration of radon based on the total amount of the world's population in outdoor and indoor is 10 Bq m^{-3} and 40 Bq m^{-3}, respectively, which increases every day due to incorrect application of building materials [5]. Few studies have been done on the presence of radon gas in Iran's public, commercial and industrial buildings and homes. So, there is no accurate estimate of the resident's exposure to radon. While many buildings constructed on substrates made of granite and shale are rich in uranium. Case studies conducted in some parts of Iran such as Tehran [13], Shiraz [14], Hamadan [15], Raamsar [16] and Neyriz [17] indicated the presence of excessive radon in residential buildings. Also, construction materials, especially travertine, granite, internal and external decorating parts of buildings are used incorrectly in recent years [18]. Some building materials such as concrete made of aluminium gemstones, construction materials made of volcanic clouds and industrial waste can contain high concentrations of radium and release radon gas [19]. Investigation of radon concentration in buildings such as offices, schools, hospitals and faculties due to high population exposure is a higher priority. According to the WHO guideline on indoor air quality, air conditioning systems, seasonal variation, temperature, humidity, outdoor wind and rainfall have a huge influence on concentrations of radon in buildings [3].

Short-term measurement of radon in homes of Valencia in Spain was conducted by Tondeur et al. in 2011 using coal boxes or a diffusion barrier. In this study, the geometric mean value of 24 Bq m^{-3} and the arithmetic mean of 27 Bq m^{-3} for radon has been reported [20]. Radon levels in schools of an Italian city near and far from the geothermal power plants were determined using the Track Etch passive method. Radon levels of 98 Bq m^{-3} for the power plant region and 43 Bq m^{-3} for the region without them were reported. The differences were due to the different geographic specificities of the regions, rather than power plants [21]. In a study in Japan, radon concentrations in indoor workplaces such as offices, schools, hospitals and factories were measured in different seasons of the year and the effective dose from environmental contact with radon was calculated. The annual range of Rn-222 for all sites was achieved 1.4–182 Bq m^{-3}. The average annual concentrations observed for offices, factories, schools and hospitals were 22.6, 10.1, 28.4 and 19.8 Bq m^{-3}, respectively. Also, the average effective dose was estimated at 0.41 mSv y^{-1} for the general public [22]. A study conducted in Winnipeg, Canada in 2009 showed that concentrations of radon in 117 homes were in the range of 20–483 Bq m^{-3} with a geometric mean of 112 ± 2.07 Bq m^{-3}. The radon level in 20% of the homes was above 200 Bq m^{-3} (the preventive level in Canada). In 60% of homes, thoron was lower than the detection limit, but in the rest of the houses, it was in the range of 5-297 Bq m^{-3} with an average geometry of 21 ± 2.53 Bq m^{-3} [23].

The Solid-state nuclear track (active method) and the Prassi portable radon surveyor (passive method) have been applied to measure indoor radon in several cities of northern Iran. The average annual radon concentrations of 163, 240, 160, 55.19, 43.43 and 144 have been reported for Lahijan, Ardebil, Sareein, Aleshtar, Khorramabad and Namin, respectively. The effective doses received annually in Lahijan, Ardabil, Aleshtar and Khorramabad were 3.43, 5.0, 1.39, 1.09 mSv y^{-1}, respectively. In that study, a maximum concentration of radon in winter (in Ardebil) and its minimum concentration in spring (in Lahijan) have been detected. Also, the radon concentration correlated with meteorological parameters and ventilation rate [24]. However, based on a search in the database there was no information on the status of radon and thoron gas concentration and health risk assessment of radon on workers and employees in the university and residential buildings of Isfahan. Thus, in the present study, we aimed to measure the levels of radon and thoron in the different floors of buildings located on the campus of Isfahan University of Medical Sciences and to calculate the annual effective dose proposed by UNSCEAR. Furthermore, the influence of factors related to the structure of the building and meteorological parameters were investigated.

Materials and Methods

Sampling

In this study 20 buildings which are located on the campus of Isfahan University of Medical Sciences (Fig. 1) were selected based on acceptance criteria and available global standards [25]. The categories of the sampled buildings consisted of 8 faculties, 4 office buildings, 3 campus conference halls, a student's dining hall, a campus hospital, a gymnasium and a swimming pool. Sampling and measuring of radon and thoron concentrations inside the selected buildings were carried out in the hot and cold seasons in 2018 using a radon meter, SARAD™ model RTM 1688. In each building, sampling was conducted on the basement (if there was any), first and second floors to evaluate the effect of height in radon concentration. According to the EPA protocol, sampling points were selected 90 cm away from the doors and windows or other potential openings to the outdoors, and about 120 cm from the floor (breathing height in sitting position) and at least 10 cm from other objects. If there were not any doors or windows to the outdoors, the measurement point was within 30 cm of the exterior wall of the building. The samples were collected for at least 3 hours during the working hours and when the location had the highest occupancy rate.

Radon measuring device and its mechanism of detection

An active device, SARAD-RTM 1688 radon meter was used for radon (Rn-222) and thoron (Rn-220) measurement in this study. This devise measures radon gas concentration by the short-living daughter products, generated by the radon decay inside the chamber. Directly after the decay, the remaining Po-218 nuclei become charged positively for a short period, because some shell electrons are scattered away by emitted alpha particles. Those ions are collected by the electrical field forces of a semiconductor detector. The number of collected Po-218 ions is proportional to the radon gas concentration inside the chamber. In the case of thoron, the direct daughter product Po-216 is used to calculate the thoron activity concentration [26].

When the first interval of detection is completed the device displays five different pages. The first page shows the actual

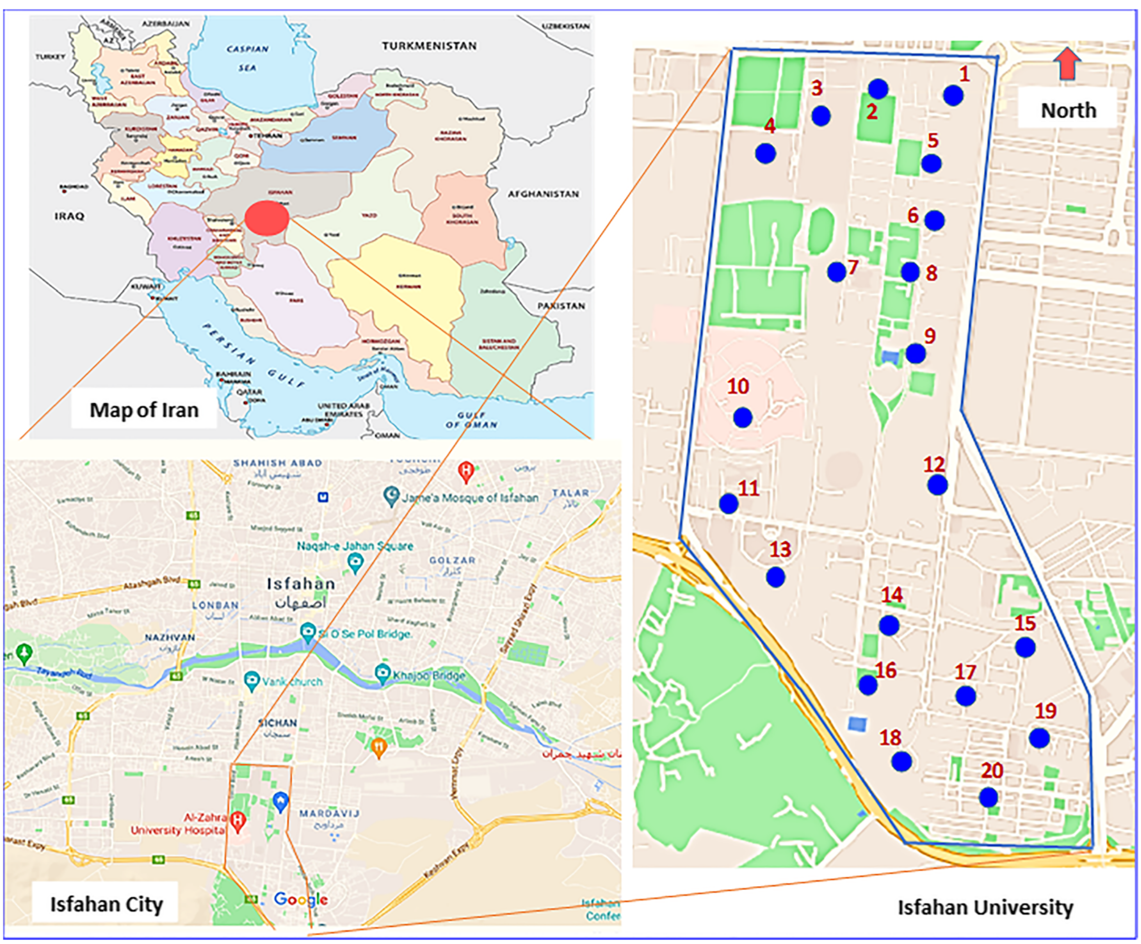

Fig. 1 The map of the study area and sampling locations

radon concentration (calculated for the last sampling interval) in Bq m^{-3} with the statistical error for a 1 Sigma confidence interval. Page two gives the same information for thoron. The readings of the additional sensors are shown on the third page such as ambient temperature, barometric pressure and relative humidity. The next two pages show the average values of the radon and thoron concentration from the beginning of the actual measurement series, and the status information, respectively.

Annual effective dose estimation and risk assessment

The annual effective dose through radon exposure was estimated using the following equation [27]:

$$AED = C_{Rn} \times F \times T \times D_f \quad (1)$$

Where C_{Rn} is the measured indoor radon concentration in Bq m^{-3}, F is the adjustment factor between radon and its progenies (0.4 for indoor measurements), T is the number of hours spends indoor in a year and *Df* is a dose conversion factor (9 nSv per Bq h^{-1} m^{-3}). According to the fact that most of the people in the campus buildings are employees and postgraduate students who spend most of their time inside the buildings, the T was calculated based on 44 hours working day per week and 48 weeks per year [considering two weeks of official holidays and two weeks of employee days off each year] as 44 h × 48 w = 2112 h/year.

The excess lifetime cancer risk (ELCR) of radon was estimated by the following Eq. (2):

$$ELCR = H \times DL \times RF \quad (2)$$

Where H is the mean of effective dose, DL is the average duration of life (70 years), and RF is the fatal cancer risk per Sievert (5.5×10^{-2} Sv^{-1}) suggested by ICRP 103 [28].

Radon concentration zoning

In this study, the Inverse Distance Weighted interpolation model (IDW) was used to map radon concentration by Arc GIS software version 10.1. This method estimates unknown values by using a weighted combination of a set of points with known values. The weight was a function of inverse distance. In this method, the variable decreases with increasing distance from the known points. The intensity of spatial dependence was applied using power. The second inverse power of this model has been repeatedly used by researchers [29]. For this, it is necessary to calculate the weight factor which was calculated based on Kermani et al (2021) study [30].

Statistical analysis

An independent t-test was used to compare the mean values in groups pairwise. Study groups were basement, ground and first floor in summer and winter. The condition for this test is to follow the normal distribution data. Thus, the Kolmogorov-Smirnov test was used to ensure that the data have normal distributions. Also, an independent t-test was applied for the evaluation of the effects of floor types as well as the effect of seasons on the radon concentration on various floors. Excel software was used for the drawing of Charts.

Results and discussion

In this study, radon and thoron levels were measured simultaneously in each selected location of the university buildings. Table 1 represents the measured radon and thoron concentrations in the sampling locations in winter and summer and Fig. 2 compares the averages of radon concentrations between the buildings and the cold and warm seasons. According to the results, apart from two sampling locations, radon concentration was below the standard (100 Bq m^{-3}) suggested by WHO in the rest of the buildings. Results of this study showed noticeable differences in the radon levels between winter (3 ± 10% to 322 ± 15% Bq m^{-3}) and summer seasons (BDL to 145 ± 8% Bq m^{-3}) and almost in all the sampling locations, the radon concentration in winter was higher than in summer which is in agreement with many studies [31, 32]. Commonly, in winter because of tight space inside the buildings as well as low air exchange rate and poor ventilation, radon emission accumulates inside the buildings. Furthermore, in winter there are pressure differences between the indoor and outdoor environments, therefore, radon is drowned from soil and ground to inside and this could be an explanation for a high concentration of radon in winter than in summer [33]. However, some study contradicts to our findings high concentration of radon has belonged to the cold season. For instance, Abdelzaher has investigated the seasonal variation of the radon level in Alexandria, Egypt and found higher concentration in summer than winter [34]. He attributed this finding to the higher temperature inside than outside in winter which replaces with outdoors cold air with a low radon concentration. In the present study, some locations showed very high radon and thoron concentrations in both seasons which could be due to their poor ventilation and weak air circulation, the presence of more furniture, shelves and wardrobes in the indoor environment. Besides, paints and high porosity building materials such as bricks and ceramics used in the buildings can be major sources of radon in the buildings [35].

Generally, thoron in most of the measurements was below the detectable level (BDL) except in a few locations. The highest measured values for thoron in winter and summer were 234 ± 11% and 216 ± 8%, respectively. Also, the high amounts of thoron were measured in buildings with high radon concentrations. In this research, the result did not represent a specific trend for thoron concentration in an indoor environment and thoron levels mostly were under detectable level. However, as shown in Table 1 thoron was found to be high in some locations which are following the study of Shang et al. who reported the thoron levels in traditional Chinese residential dwellings (2005), and Chen J et al. who measured Rn-222 and Rn-220 in Winnipeg, Canada (2009) [23, 36]. These findings may depend on thoron's diffusion length in air, its very short half-life which is only 55 seconds and the air change differences in sampling area [31, 32, 37]. Generally, thoron originates from the ground and walls of a structure and decrease towards the centre of the room. Therefore, to minimize errors the detector was placed at least 20 cm away from the walls. Apart from that, in some locations with high radon concentrations, high thoron levels were also observed.

Table 1 Mean radon and thoron concentration inside the buildings in winter and summer 2018

No	Location	*Winter [Bq/m³±Error %]		*Summer [Bq/m³±Error %]	
		Radon	Thoron	Radon	Thoron
1	Faculty 1- Basement	47±21%	B.D.L	23±10%	B.D.L
2	Faculty 1 - Ground Floor	80±15%	B.D.L	57±14%	73±12%
3	Faculty 1 - First Floor	44±25%	B.D.L	17±21%	B.D.L
4	Faculty 2- Basement	08±22%	B.D.L	B.D.L	B.D.L
5	Faculty 2 -Ground Floor	06±25%	B.D.L	11±30%	B.D.L
6	Faculty 3 - Basement	17±22%	B.D.L	08±25%	B.D.L
7	Faculty 3 - Ground Floor	03±10%	11±22%	03±15%	B.D.L
8	Faculty 4 -Ground Floor	42±26%	9±24%	87±18%	B.D.L
9	Faculty 4 - First Floor	55±23%	14±17%	50±13%	B.D.L
10	Faculty 5 - Basement	06±27%	B.D.L	08±27%	B.D.L
11	Faculty 5- Ground Floor	11±24%	B.D.L	15±22%	B.D.L
12	Faculty 6- Basement	17±22%	B.D.L	11±30%	122±11%
13	Faculty 6 - Ground Floor	03±10%	B.D.L	25±13%	B.D.L
14	Faculty 7 - Ground Floor	22±16%	B.D.L	22±15%	B.D.L
15	Faculty 7- First Floor	28±12%	B.D.L	20±26%	10±25%
16	Faculty 8 - Ground Floor	178±20%	234±11%	113±21%	183±18%
17	Faculty 8 – first floor	08±30%	B.D.L	06±30%	6±10%
18	Office Building 1 - Basement	31±20%	B.D.L	08±28%	B.D.L
19	Office Building 1 - Ground Floor	15±25%	16±26%	13±25%	18±16%
20	Office Building 2 - Basement	33±20%	B.D.L	03±15%	11±22%
21	Office Building 2 - Ground Floor	22±16%	B.D.L	B.D.L	B.D.L
22	Office Building 2- First Floor	14±25%	11±25%	14±25%	11±26%
23	Office Building 3 - Ground Floor	31±20%	B.D.L	60±15%	06±30%
24	Office Building 3 - First Floor	137±16%	122±13%	53±13%	B.D.L
25	Office Building 4- Ground Floor	76±19%	B.D.L	41±17%	B.D.L
26	Office Building 4- First Floor	42±16%	B.D.L	B.D.L	B.D.L
27	Conference hall 1	28±12%	B.D.L	11±30%	B.D.L
28	Conference hall 2	56±12%	B.D.L	25±13%	B.D.L
29	Dining Hall	08±28%	B.D.L	06±31%	B.D.L
30	Hospital - Basement	25±13%	10±31%	11±25%	B.D.L
31	Hospital - Ground Floor	25±13%	B.D.L	06±31%	B.D.L
32	Sports hall - Ground Floor	08±27%	B.D.L	B.D.L	B.D.L
33	Residential home -first Floor	13±20%	18.6±20%	B.D.L	B.D.L
34	Swimming pool	322±15%	205±10%	145±8%	216±8%
35	Dormitory gymnasium	25±13%	11±28%	06±31%	B.D.L

*The results are the averages of 3 hours sampling period

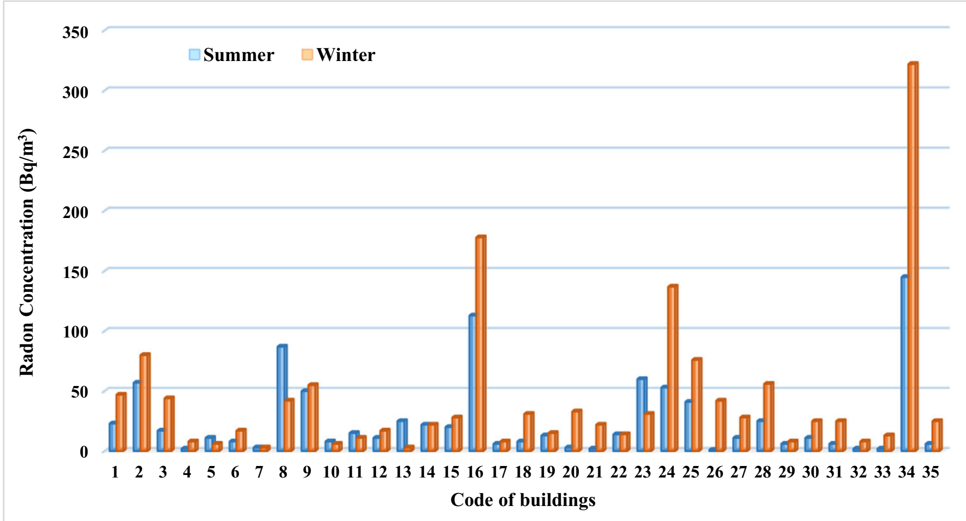

Fig. 2 Comparison of the averages of radon concentration inside the university buildings in the cold and hot season in 2018 (The corresponding name of the codes was given in Table 1)

The results of the Kolmogorov-Smirnov test shown in Table 2 indicated that all obtained data have a P-value greater than 0.05, so, they follow the normal distribution. The results of the independent t-test for assessing the effects of floor types and seasons on the radon concentration are presented in Table 3. Due to the p-values of greater than 0.05, there was no significant difference in the mean values in the different floor types and seasons. Therefore, the increase in height, as well as the temperature did not affect the radon and thoron concentrations in the study area. Statistical data for comparison of radon concentration in different floors in summer and winter are shown in Table 4. The mean concentration of radon in the basement, ground floor and first floor was 9.25 ± 6.04, 35.78 ± 40.35 and 18.89 ± 18.45 Bq m^{-3} in summer, as well as 23 ± 12.89, 52.94 ± 76.89 and 38.78 ± 38.35 in winter, respectively. Although, there was no significant correlation

Table 2 One-Sample Kolmogorov-Smirnov Test for normal distributions

Statistical test	Summer			Winter		
	Basement	Ground floor	First floor	Basement	Ground floor	First floor
Kolmogorov-Smirnov Z	0.765	1.131	0.742	0.476	1.179	0.731
Asymp. Sig. [2-tailed]	0.601	0.155	0.64	0.977	0.124	0.66
a. Test distribution is normal.						

Table 3 Independent Samples Test for Equality of Means

Season	First group	Second group	t	p-value	Equality of Means
Summer	basement	ground	-1.753	0.092	Equal
	basement	first	-1.515	0.167	Equal
	ground	first	0.957	0.348	Equal
Winter	basement	ground	-1.057	0.301	Equal
	basement	first	-1.264	0.227	Equal
	ground	first	0.957	0.348	Equal
Floor		season	t	p-value	Equality of Means
Basement	summer	winter	-1.995	0.063	Equal
Ground f.	summer	winter	-0.831	0.412	Equal
First f.	summer	winter	-1.344	0.200	Equal
All data	summer	winter	-1.472	0.146	Equal

Table 4 Statistical data for comparison of radon concentration in different floors

Season	Floor type	No*	Radon concentration [Bq m^{-3}]				
			Mean±SD *	Min	Max	Median	G.M *
Summer	Basement	8	9.25±6.04	3	23	8	6.35
	Ground floor	18	35.78±40.35	3	145	18.5	16.66
	1st floor	9	18.89±18.45	6	50	14	9.69
Winter	Basement	8	23±12.89	6	47	21	17.96
	Ground floor	18	52.94±76.89	3	322	25	24.07
	1st floor	9	38.78±38.35	8	137	28	24.49

*No = Number of floor types, G.M = Geometrical mean, SD = Standard deviation

between the height of the buildings with radon concentration due to closer values, in most of the multi-floor buildings radon levels in down floors were higher than upper floors in this study. This finding can be attributed to soil gas infiltration which is known as the most significant source of residential radon. It has been reported in some study that mainly higher level of radon from soil gas was detected in basements and ground floors [35]. However, in a few buildings radon concentration in the upper floor was greater than down floor in this study, which can be attributed to the extensive area of sampling location, good and sufficient ventilation in down-floor or basement, and in one case covering materials of room floor and wall surfaces in down-floor was airtight and radon proof. In contrast, the upper floor with a high radon level had tight space with poor ventilation and in direct contact with granite constructional materials [38]. The results of the Kulalı et al. study showed that radon concentration in a university campus building in Turkey ranged from 7 to 177 Bq m^{-3} in which the lowest amounts have belonged to the places with active ventilation [39]. In another study conducted by Al-Ghamdi, similar to our study, radon concentrations in all campus buildings were different and there was no significant dependence between height and radon concentration in the sampling locations [35].

Table 5 represents the effect of season on radon concentrations. The mean concentration of radon in winter (43.53 ± 60.57 Bq m^{-3}) was higher and that in summer (25.79 ± 32.93 Bq m^{-3}). The average indoor temperature in the sampling locations in winter and summer was 23.15 ± 2.37°C and 26.49 ± 1.96°C, respectively, and that of in the adjacent outdoor was 8.81 ± 3.09 and 27.46 ± 1.77 respectively. Indoor relative humidity (%RH) didn't show a specific trend during the study because of the difference in the air conditioning systems of the buildings. However, for outdoor, the seasonal averages of 20.3% in winter and 46.3% in summer were recorded. In some cases, the highest radon and thoron concentrations were measured in buildings when the RH was higher.

Table 5 Statistical data for comparison of radon concentration in different seasons

Season	No*	Radon concentration [Bq m^{-3}]				
		Mean±SD*	Min	Max	Median	G.M*
Winter	35	43.53±60.57	3	322	25	23.59
Summer	35	25.79±32.93	3	145	12	11.76

*No = Number of samples, G.M = Geometrical mean, SD = Standard deviation

The output of the inverse distance weighted interpolation model using ArcGIS software for radon distribution mapping is shown in Fig. 3. This figure shows that the distribution of radon concentration in the health faculty library and swimming pool of the university was higher than in the other places. This may be due to the type of materials used in their floors and walls, and inadequate ventilation in these places. According to Table 6, the annual average of the effective dose received by the workers and employees for all buildings was obtained 0.261 ± 0.339 mSv y^{-1}, assuming an occupancy factor of 2112 h y^{-1} for a worker or employees [40]. Furthermore, assuming that the average duration of life 70 years and the fatal cancer risk per Sievert is equivalent to 5.5 × 10^{-2} Sv^{-1} (recommended by ICRP 103), the mean excess lung cancer risk (ELCR) was estimated to be 0.10% which indicates a low risk of this radon concentration at the sampling points. Also, this estimate does not involve population characteristics such as sex, age, and smoking habits as major factors. In this study, the annual effective dose due to radon exposure in most locations was below the annual effective dose limit of 1 mSv y^{-1} for the public recommended by RCIP 2010 [41]. Similarly, in studies conducted in a university campus in Turkey [38, 39], and dwelling of Khorramabad [42] and Aleshtar [43] in Iran, the annual effective dose of blow the standard level has been reported. Nevertheless, in two sampling locations of this study, it exceeded above the limit value, especially in winter which needs cure actions. Indoor radon concentration depends on the way buildings are designed and how the occupants use and operate them. For buildings with radon concentrations higher than the

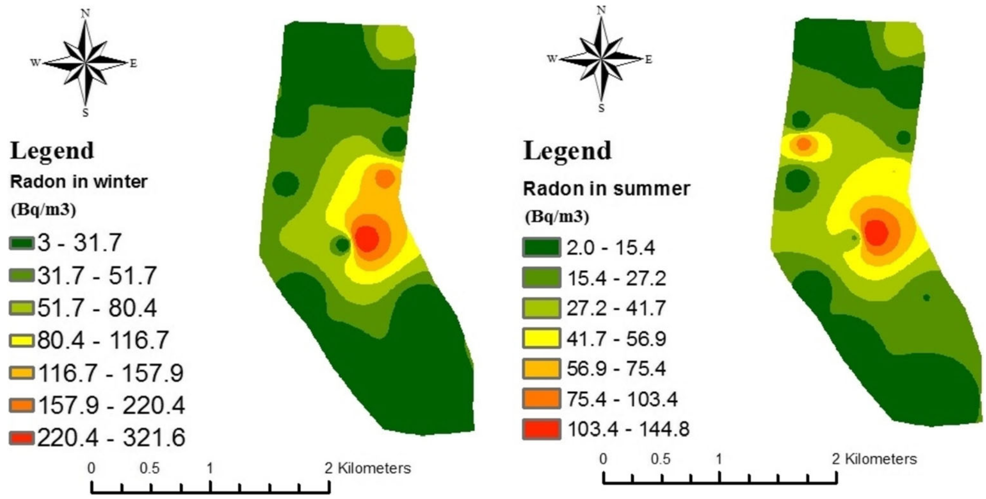

Fig. 3 Radon concentration zoning map in the campus of Isfahan medical science university

suggested limit remedial actions may be needed. There are some strategies for the prevention or even mitigation of indoor radon concentration. Mainly, these strategies focus on the elimination of radon entry routes. However, there are different opinions about this solution as a stand-alone technique but it can be an appropriate mitigation technique by itself. Another effective technique could be depressurization which leads to reverse the air pressure differences between the indoor and outdoor. Active soil depressurization includes actions such as suction of sub-slab soil, the inline fan outside, discharge away from potential exposure and post-mitigation testing. Furthermore, national radon programs should be held in the country to explore the most geographic areas at risk, increasing public awareness about the risk and health effects of indoor radon exposure, training programs for building architects, cooperation with other health programs like indoor air quality, cancer control organizations and preparing radon map for the country especially for high-risk regions [44, 45].

Table 6 Annual effective dose assessment in the campus buildings in summer and winter [mSv y^{-1}]

Sample code	AED	Sample code	AED
1	0.266	19	0.107
2	0.521	20	0.137
3	0.232	21	0.091
4	0.038	22	0.106
5	0.095	23	0.346
6	0.023	24	0.723
7	0.490	25	0.445
8	0.399	26	0.167
9	0.054	27	0.149
10	0.099	28	0.308
11	0.107	29	0.054
12	0.213	30	0.137
13	0.107	31	0.118
14	0.167	32	0.038
15	0.183	33	0.057
16	1.106	34	1.775
17	0.054	35	0.118
18	0.149	Average	0.261±0.339

Conclusion

Although in this study radon concentration in most of the buildings were under the WHO recommended limit, long-term exposure even to low and moderate radon concentrations may lead to lung cancers rather than short-term exposure to high concentrations. Apart from that, other factors such as smoking prevalence in homes and buildings should be taken into account. In this study radon and thoron concentrations nearly in all sampling locations in winter was higher than in summer which may be attributed to ventilation and pressure differences between outdoor and indoor environments. Although, with increasing the height of buildings radon concentration in some sampling locations was decreased, in most buildings upper floors showed higher levels of radon than ground floor or basement. This represents that the height of the building is not necessarily an effective factor in alleviating radon levels. Besides the ventilation, soil and construction materials could play major roles in radon concentration in the indoor air. Also, the average annual effective dose in both cold and hot seasons was lower than the recommended value by ICRP in 2010. The mean excess lung cancer risk (ELCR) was estimated to be 0.10% which indicates a low risk of radon concentration at the sampling points. However, some locations showed higher value than the reference value which requires cure actions and mitigation program. Also, further investigations are needed to clarify sources of emission, the risk of exposure which helps authorities in radon proofing and mitigation strategy planning and taking remedial action in the campus buildings.

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Declarations

Conflict of interest The authors declare that there is no conflict of interest.

References

1. Nakhli A. Radon and the environment. Iran J Nucl Energy. 2017;119:19–20.
2. Ghiyasinejad M, Katozi M. General lessons in radiation protection. Iranian nuclear energy organization. Derbid publication, 2000. (in Persian)
3. WHO. Word health organization guidelines for indoor air quality: selected pollutants. WHO Regional Office for Europe, Copenhagen, Denmark; 2010.
4. Pawel DJ, Puskin JS. The US Environmental Protection Agency's assessment of risks from indoor radon. Health physics. 2004;87(1): 68–74.
5. Charles M. UNSCEAR Report 2000: sources and effects of ionizing radiation. J Radiol Prot. 2001;21(1):83.
6. Darby SC, Whitley E, Silcocks P, Thakrar B, Green M, Lomas P, et al. Risk of lungcancer associated with Residential radon exposure in south-e-west England: acase-control study. Br J Cancer. 1998;78(2):394–408.
7. Laurier D, Valenty M, Tirmarche M. Radon exposure and the risk of leukemia: a review of epidemiological studies. Health Phys. 2001;81:277–88.
8. National Research Council. Health effects of exposure to radon: BEIR VI, 1999. ISBN:0-309-52374-5. http://www.nap.edu/catalog/5499.html
9. Schoenberg JB, Klotz JB, Wilcox HB, Nicholls GP, Gil-del-Real MT, Stemhagen A, Mason TJ. Case-control study of Residential radon and lungcancer among New Jersey Women. Cancer Res. 1990;50:5250–6254.
10. Jean-Christophe L, Favre F, Firmin P, Célestin T, Daniel DW. Residential radon and lung cancer: results form an ecologic study in the Swiss Alps. Cancer Res. 2005;40:440–6.
11. Letourneau EG, Krewski D, Choi NW, Goddard MJ, McGregor RG, Zielinski JM, Du J. Case-control study of Residential radon and lung cancer in Winnipeg, Manitoba, Canada. Am J Epidemiol. 1994;140:310–22.
12. Pershagen G, Akerblom G, Axelson O, Clavensjo B, Damber L, Desai G, Enflo A, Lagarde F, Mellander H, Svartengren M, Swedjemark GA. Residential radon exposure and lung cancer in Sweden. N Engl J Med. 1994;330:159–64.
13. Askari M, Hassanvand MS, Naddafi K, Zarei A, Yousefi M, Alimohammadi M. Assessment of indoor radon concentration in residential homes and public places in south of Tehran. Iran Environ Earth Sci. 2019;78(10):1–10.
14. Yarahmadi M, Shahsavani A, Mahmoudian MH, Shamsedini N, Rastkari N, Kermani M. Estimation of the residential radon levels and the annual effective dose in dwellings of Shiraz, Iran, in 2015. Electron Physician. 2016;8(6):2497.
15. Gillmore G, Jabarivasal N. A reconnaissance study of radon concentrations in Hamadan city. Iran Nat Hazards Earth Syst Sci. 2010;10(4):857–63.
16. Mortazavi SMJ, Ghiassi-Nejad M, Rezaiean M. Cancer risk due to high level of natural radon in the inhabitants of Ramsar. Iran Int Congr Series. 2005;1276:436–7.
17. Shahsavani S, Shamsedini N, Tabatabaei HR, Hoseini M. Indoor radon concentrations in residential houses, processing factories, and mines in Neyriz, Iran. J Environ Health Sci Eng. 2019;17(2):979–87.
18. Bavarnegin E, Fathabadi N, Moghaddam MV, Farahani MV, Moradi M, Babakhni A. Radon exhalation rate and natural radionuclide content in building materials of high background areas of Ramsar, Iran. J Environ Radioact. 2013;117:36–40.
19. Keller G, Hoffmann B, Feigenspan T. Radon permeability and radon exhalation of building materials. Sci Total Environ. 2001;272: 85–9.
20. Tondeur F, Rodenas J, Querol A, Ortiz J, Juste B. Indoor radon measurements in the city of Valencia. Appl Radiat Isot. 2011;69(8): 1131–3.
21. Ciolini R, Mazed D. Indoor radon concentration in geothermal areas of central Italy. J Environ Radioact. 2010;101(9):712–6.
22. Oikawa S, Kanno N, Sanada T, Abukawa J, Higuchi H. A survey of indoor workplace radon concentration in Japan. J Environ Radioact. 2006;87(3):239–45.
23. Chen J, Schroth E, MacKinlay E, Fife I, Sorimachi A, Tokonami S. Simultaneous Rn-222 and Rn-220 measurements in Winnipeg, Canada. Radiat Prot Dosim. 2009;134(2):75–8.
24. Hadad K, Doulatdar R, Mehdizadeh S. Indoor radon monitoring in Northern Iran using passive and active measurements. J Environ Radioact. 2007;95(1):39–52.
25. USEPA. Protocols for radon and radon decay product measurement in homes, Offic of Air and Radiation. United States Environmental Protection Agency Publication 402-R-92-003. 1993.
26. Abd Ali FS, Mahdi KH, Jawad EA. Humidity effect on diffusion and length coefficient of radon in soil and building materials. Energy Procedia. 2019;157:384–92.
27. Annex D, United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and effects of ionizing radiation. Investigation of I. 2000;125.
28. Valentin J. International Commission on Radiological Protection. The 2007 recommendations of the international commission on radiological protection. Annals of the ICRP. ICRP Publication. 2007;103:2–4.
29. Mokhtari M, Jafari N, Mohammadi A, Hajizadeh Y, Ghanbari R, Nemati S, Abdolahnejad A. Temporal and spatial trends of airborne asbestos fiber concentrations in the urban areas of Yazd, Iran. Int J Environ Sci Technol. 2019;16(6):2657–66.
30. Kermani M, Jafari AJ, Gholami M, Arfaeinia H, Yousefi M, Shahsavani A, Fanaei F. Spatio-seasonal variation, distribution, levels, and risk assessment of airborne asbestos concentration in the most industrial city of Iran: effect of meteorological factors. Environ Sci Pollut Res. 2021;28(13):16434–46.
31. Kavasi N, Nemeth C, Kovacs T, Tokonami S, Jobbagy V, Varhegyi A, et al. Radon and thoron parallel measurements in Hungary. Radiat Prot Dosim. 2007;123(2):250–3.
32. Kumar M, Kaushal A, Sarin A, Kumar R, Sharma N. Radon/thoron and progeny levels in dwellings: Regional variations and effect of dwelling characteristics–A case study in Jalandhar district of Punjab, India. Indoor Built Environ. 2018;27(5):706–14.

33. Kurnaz A, Kucukomeroglu B, Cevik U, Celebi N. Radon level and indoor gamma doses in dwellings of Trabzon, Turkey. Appl Radiat Isot. 2011;69(10):1554–9.
34. Abdelzaher M. Seasonal variation of radon level and radon effective doses in the Catacomb of Kom EI-Shuqafa, Alexandria, Egypt. J Phys. 2011;77(4):749–57.
35. Al-Ghamdi S, Khougear G, Baig M. Indoor radon levels and distribution in occupied and unoccupied residential buildings in student's campus at King Saud University, Riyadh, Saudi Arabia. J King Saud Univ Sci. 2007;19:73–81.
36. Shang B, Chen B, Gao Y, Wang Y, Cui H, Li Z. Thoron levels in traditional Chinese residential dwellings. Radiat Environ Biophys. 2005;44(3):193–9.
37. Sathish L, Nagaraja K, Ramanna H, Nagesh V, Sundareshan S. Concentration of radon, thoron and their progeny levels in different types of floorings, walls, rooms and building materials. Int J Radiat Res. 2009;7(1):1.
38. Günay O, Aközcan S, Kulalı F. Measurement of indoor radon concentration and annual effective dose estimation for a university campus in Istanbul. Arab J Geosci. 2019;12(5):171.
39. Kulalı F, Günay O, Aközcan S. Determination of indoor radon levels at campuses of Üsküdar and Okan Universities. Int J Environ Sci Technol. 2019;16(9):5281–4.
40. Loffredo F, Savino F, Amato R, Irollo A, Gargiulo F, Sabatino G, et al. Indoor Radon Concentration and Risk Assessment in 27 Districts of a Public Healthcare Company in Naples, South Italy. Life. 2021;11(3):178.
41. Clement CH, Tirmarche M, Harrison J, Laurier D, Paquet F, Blanchardon E, et al. Lung cancer risk from radon and progeny and statement on radon. Ann ICRP. 2010;40(1):1–64.
42. Hassanvand H, Hassanvand MS, Birjandi M. Indoor radon measurement in dwellings of Khorramabad city, Iran. Iran J Med Phys. 2018;15(1):19–27.
43. Hassanvand H, Birjandi M, Amiri A, Hassanvand M, Kamarehie B. Investigation of indoor radon concentration in dwellings of Aleshtar (western part of Iran) and estimation of the annual effective dose from exposure to radon. Int J Radiat Re. 2019;17(4):659–66.
44. USEPA. Protocols for radon and radon decay product measurements in homes. Washington, DC: US Environmental Protection Agency, Air and Radiation; Publication 402-R-92-003, 1993.
45. Ting DSK. WHO handbook on indoor radon: a public health perspective. Abingdon: Taylor & Francis; 2010;100–102.

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