

Effect of natural gas usage on indoor radon levels

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Received: 12 March 2012 / Published online: 9 June 2012
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Abstract Effect of natural gas usage on indoor radon concentrations were investigated in dwellings in four counties of İzmir municipality using LR-115 Type II cellulose nitrate films. The dwellings were separated two groups: natural gas user and non-user. Indoor radon levels were found higher in natural gas using dwellings. Also, indoor radon levels were evaluated in terms of concentrations and annual effective dose. Indoor radon concentrations were found between 22.8 and 707.8 Bq m⁻³ and highest concentrations were determined in kitchen in third floor of Bornova dwellings. Indoor radon concentrations in kitchens were found higher than the living rooms. On the other hand, opposite results obtained for annual effective dose, because of very short occupancy period of the kitchens.

Keywords Indoor radon · Annual effective dose · Natural gas

Introduction

Natural radioactivity may be anywhere in the human environment. These are cosmic and cosmogenic radiation, terrestrial gamma radiation from natural radionuclides in soil and rock, and natural radioactive substances (Fig. 1) [1]. The most important contribution of radiation dose comes from radon and its decay products. Radon (²²²Rn), a decay product of radium (²²⁶Ra) in the uranium decay series, which is a radioactive colorless inert gas [2, 31] and

the radiation dose to human population due to inhalation of radon and its daughters contributes more than 50 % of the total dose from natural sources. Half-lives of radon daughters (²¹⁸Po, ²¹⁴Bi, ²¹⁴Pb) vary from less than a millisecond up to almost 27 min. They are attached dust and water droplets forming radioactive aerosols and when inhaled via breathing enter the human lungs and may lead to serious diseases like lung cancer [3–5]. Recently high levels of ²²²Rn have been reported in dwellings of many countries. It is estimated that indoor ²²²Rn exposure may be responsible for more than 10 % of the US lung cancer incidence. IARC has defined this gas as a human carcinogen due to the fact that when it decays, its progeny emit radioactive alpha particles capable of damaging the pulmonary epithelium and thereby causing lung cancer [6, 7].

Nowadays, as a result of their low carbon dioxide and nitrogen oxides emission [8], natural gas is an important energy source and it's named as a green energy. For these reasons, Turkey and many countries have used natural gas for heating houses and different purposes. In contrast, liquid petroleum gas (LPG) and natural gas are important radon sources [9] and the radon concentrations in houses increase by using these gases. Typically the radon levels in natural gas given as 1,000 Bq m⁻³ [1] and the radon entry rate to building as 0.3 Bq m⁻³ h⁻¹ [10]. An investigation realized in Venezuela showed that the radon content of natural gas contributed of 30 % of total indoor radon level. An additional health hazard of about 0.54 mSv y⁻¹ due to the radon in the gas was found [11]. Generally, radon is transported with natural gas to gas plants, and the raw gas is processed to remove impurities and to recover the less volatile hydrocarbons that separate out naturally in pipelines. Natural gas as supplied usually contains gas from a number of wells and fields and thus can vary over time, depending on the proportions supplied by different sources [1, 12]. Many

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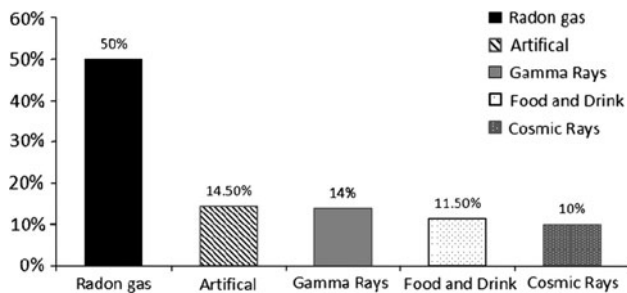


Fig. 1 Source of radiation dose (www.igem.org.uk/Radon.asp)

studies on the distribution of radon gas in gas fields and processing plants, the distribution of ^{222}Rn and its decay products in domestic gas supply, in storage caverns [13, 14] and in LPG rail cars [15] have been carried out [2].

Worldwide indoor radon concentration limits given by international and national organizations such as USEPA, WHO, ICRP, and HPA. USEPA recommends indoor air radon levels less than 148 Bq m^{-3} for house and 400 Bq m^{-3} for workplace [16]. WHO proposes a reference level of 100 Bq m^{-3} to minimize health hazards due to indoor radon exposure. However, if this level cannot be reached under the prevailing country-specific conditions, the chosen reference level should not exceed 300 Bq m^{-3} .

The European Union (EU) accepts the recommended action levels included in the ICRP-65 of between 500 and $1,500 \text{ Bq m}^{-3}$ [17]. The HPA advises that the Action Level should be 200 Bq m^{-3} and that Target Level should be 100 Bq m^{-3} , expressed as the annual average radon concentration in home. In the UK the Health and Safety Executive (HSE) has adopted a radon action level of 400 Bq m^{-3} for workplaces [18]. In Turkey, recommend levels are given by TAEK as 400 Bq m^{-3} for house and $1,000 \text{ Bq m}^{-3}$ for workplace [19].

The use of natural gas industry and the work of city networks in Turkey began with natural gas agreement signed with the USSR in 1984. The residential natural gas was first used in Ankara city in 1988. Then, it was used in İstanbul, Bursa, Eskişehir, and İzmit cities. The amount of natural gas consumed in Turkey annually is expected to reach 55 billion cubic meters in 2010 [20]. The use of natural gas in İzmir City began in Karşıyaka district in 2006 [21]. In this study, we selected buildings in Karşıyaka, Bornova, and Buca counties as study fields. In these counties, natural gas is generally used for cooking and heating contains elevated concentrations of radon, which is released on combustion. Therefore, the present paper describes the indoor radon concentrations in İzmir municipality and effect of natural gas usage on indoor radon concentrations. Radon gas concentration in the indoor air environment due to leaks, venting and other sources were also estimated.

Materials and methods

Study areas

İzmir is the third biggest city of Turkey. The city is also an important industrial and commercial center and a cultural central point. The usage of natural gas in İzmir has rapidly increased in recent years. The most common usage of natural gas in İzmir is Buca, Gaziemir, Karşıyaka, and Bornova counties (Fig. 2). To compare of the indoor radon concentrations, 10–15 years concrete buildings were chosen from each county.

Radon analysis

Indoor radon activity concentrations have been measured in dwellings in the four counties of İzmir. The ^{222}Rn surveys in houses were conducted using the LR-115 type 2 solid state nuclear track detectors. Square pieces ($1.5 \times 1.5 \text{ cm}$) of solid state nuclear track detectors were mounted in special plastic holder. Nuclear track detectors placed 1.5–2 m up to the bottom of kitchens and living rooms [22] and then, 4 weeks later changed with the new ones. The detectors were transported to the laboratory and they were etched in 2.5 N NaOH solutions at $60 \text{ }^\circ\text{C}$ for 120 min [23]. After etching, α -particle track density was measured under an optical microscope at magnification $100\times$. Calibration coefficient was determined by TAEK-ÇNAEM as $0.137 \text{ kBqh m}^{-3}/\text{track cm}^{-2}$.

Annual effective dose calculations

The annual mean effective dose for indoor air was calculated using the formula proposed by UNSCEAR report as:

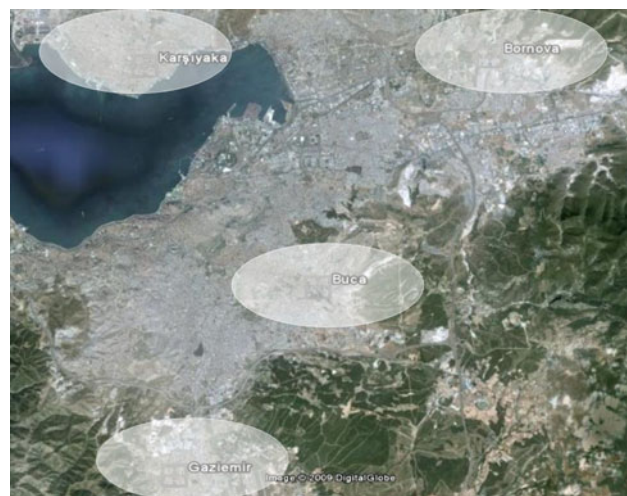


Fig. 2 The digital map of the study areas (Google Earth)

$$H \text{ (mSv y}^{-1}\text{)} = C_{Rn} \times F \times O \times \text{(DCF)}$$

where C_{Rn} is the indoor radon concentration (Bq m^{-3}), F is the equilibrium factor between radon and its decay products (0.4), O is the average indoor occupancy time per person ($7,000 \text{ ha}^{-1}$ for living room) and DCF is the dose conversion factor for radon exposure $9 \text{ nSv h}^{-1} (\text{Bq m}^{-3})^{-1}$. The average indoor occupancy period of kitchens accepted to be $1/3$ of living rooms by the authors. This is the simple guess of the authors so there wasn't any data on this acceptance [10, 24–26].

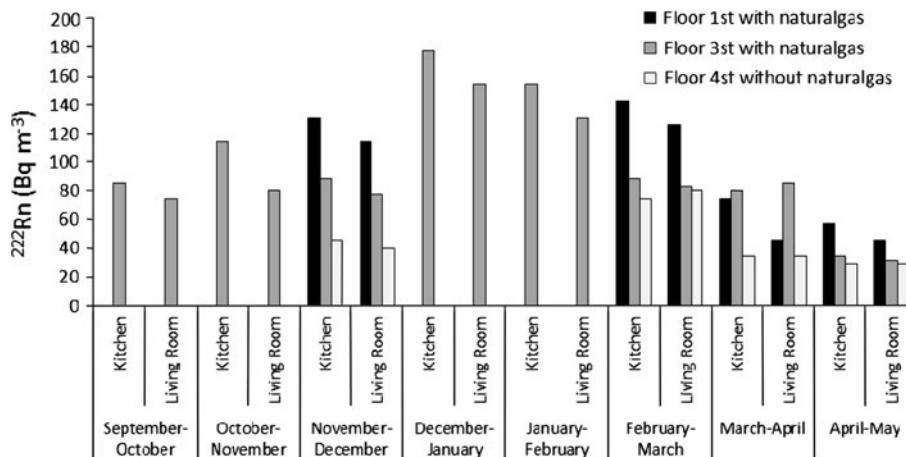
Results

The indoor radon concentrations of buildings (kitchen and living room) were measured consecutively monthly periods (Figs. 3, 4, 5, 6) and summary statistic of indoor radon levels were given in Table 1. Also, the short comparison was given on indoor radon concentrations of kitchen and living room by monthly in Fig. 7. The last one (Fig. 8) shows kitchen and living rooms comparisons in term of annual effective dose levels.

Buca

Indoor radon concentration values in Buca varied from 40.0 to 177.0 Bq m^{-3} and average is 71.8 Bq m^{-3} (Fig. 3). The highest indoor radon concentration is measured in the kitchen during December–January period. The measured radon levels are higher in downstairs and kitchens of the dwellings. Radon levels are higher in winter season because of the ventilation is so less. Mean annual effective dose calculated to be 0.49 and 1.29 mSv y^{-1} for kitchens and living rooms, respectively. The highest annual effective dose calculated for living room of third level dwellings was found as 2.26 mSv y^{-1} .

Fig. 3 Indoor radon concentration (Bq m^{-3}) in Buca apartments



Gaziemir

Indoor radon concentration in Gaziemir was varied from 22.8 to 205.5 Bq m^{-3} and average radon concentration is 85.3 Bq m^{-3} (Fig. 4). The highest indoor radon concentration is measured during January–February period. The indoor radon concentrations of without natural gas dwelling lower than the natural gas user dwelling at same level. Mean annual effective dose calculated to be 0.62 and 1.19 mSv y^{-1} for kitchens and living rooms, respectively. The highest annual effective dose calculated for living room of third level dwellings was found as 1.73 mSv y^{-1} .

Karşıyaka

All apartments are measured indoor radon levels in Karşıyaka uses natural gas for heating and LPG for cooking. Indoor radon levels were decreased with height of the dwellings. In the winter period higher radon concentrations were measured (Fig. 5). Mean annual effective dose calculated to be 0.83 and 2.13 mSv y^{-1} for kitchens and living rooms, respectively. The highest annual effective dose calculated for living room of second level dwellings was found as 3.12 mSv y^{-1} .

Bornova

The highest indoor radon concentrations on this study were measured in the kitchen of third level. This dwelling uses natural gas for heating and cooking. The radon level of this kitchen (707 Bq m^{-3}) is higher than the limits (Fig. 6). Mean annual effective dose calculated to be 1.65 and 2.39 mSv y^{-1} for kitchens and living rooms, respectively. The highest annual effective dose calculated for kitchen of second level dwellings was found as 3.39 mSv y^{-1} .

Fig. 4 Indoor radon concentration (Bq m^{-3}) in Gaziemir

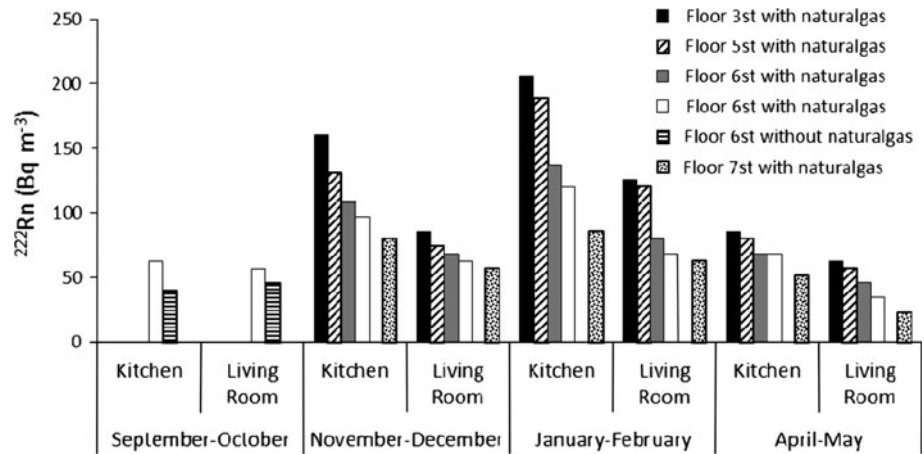


Fig. 5 Indoor radon concentration (Bq m^{-3}) in Karşıyaka

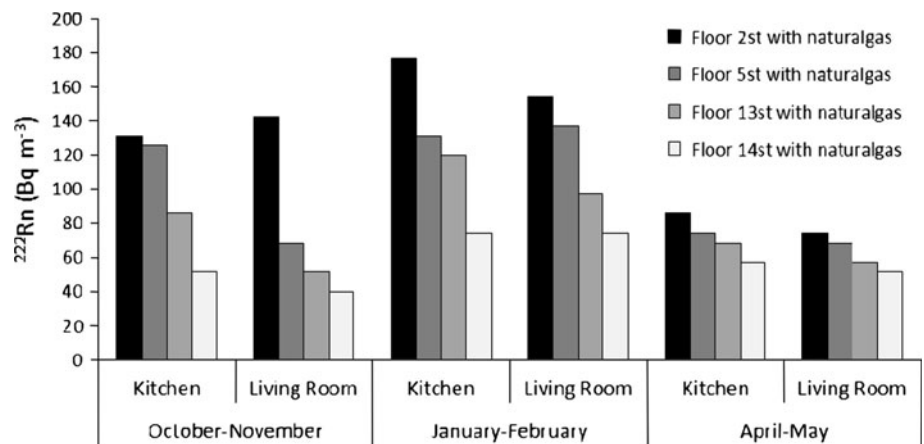
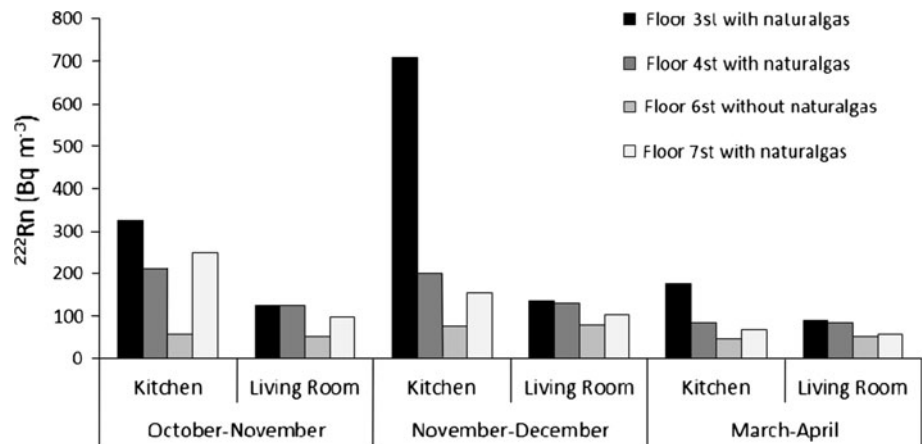


Fig. 6 Indoor radon concentration (Bq m^{-3}) in Bornova



Discussion

Indoor radon concentrations and annual effective dose calculations were made in four counties of İzmir. Indoor radon concentrations ranged from 40.0 to 177.0 Bq m^{-3} , 22.8 to 205.0 Bq m^{-3} , 40 to 177 Bq m^{-3} , and 51.4 to

707.8 Bq m^{-3} in Buca, Gaziemir, Karşıyaka, and Bornova, respectively. The values are in the range of indoor radon levels reported by several authors [27–30] except the value of 707.8 Bq m^{-3} measured in Bornova. Also higher indoor radon concentrations found in Bornova as 199.8 , 211.2 , 251.2 , 325.4 , and 707.8 Bq m^{-3} . The geological

Table 1 Summary statistic of indoor radon levels (Bq m^{-3}) of different floors in four counties of İzmir

County	Floor	Location	AM	Min	Max	GM
Buca	Floor 1st with natural gas	K	101.3	57.1	142.7	94.4
		L	82.8	45.7	127.6	74.0
	Floor 3rd with natural gas	K	102.8	34.3	177.0	93.3
		L	89.6	31.4	154.1	82.1
	Floor 4th without natural gas	K	45.7	28.5	74.2	42.7
		L	45.7	28.5	79.9	42.0
Gaziemir	Floor 3rd with natural gas	K	150.3	85.6	205.5	141.1
		L	91.3	62.8	125.6	87.7
	Floor 5th with natural gas	K	133.2	79.9	188.4	125.5
		L	83.7	57.1	119.9	79.8
	Floor 6th with natural gas	K	94.6	62.8	137.0	90.8
		L	59.5	34.3	79.9	57.6
	Floor 7th with natural gas	K	72.3	51.4	79.9	70.6
		L	47.6	22.8	62.8	43.4
Karşıyaka	Floor 2nd with natural gas	K	131.3	85.6	177.0	125.8
		L	123.7	74.2	154.1	117.7
	Floor 5th with natural gas	K	110.4	74.2	131.3	107.0
		L	91.3	68.5	137.0	86.3
	Floor 13th with natural gas	K	91.3	68.5	119.9	88.9
		L	68.5	51.4	97.0	65.8
Floor 14th with natural gas	K	60.9	51.4	74.2	60.2	
	L	55.2	40.0	74.2	53.4	
Bornova	Floor 3rd with natural gas	K	403.4	177.0	707.8	344.2
		L	118.0	91.3	137.0	116.3
	Floor 4th with natural gas	K	165.5	85.6	211.2	153.4
		L	114.2	85.6	131.3	112.2
	Floor 6th without natural gas	K	59.0	45.7	74.2	57.9
		L	60.9	51.4	79.9	59.5
Floor 7th with natural gas	K	157.9	68.5	251.2	138.4	
	L	85.6	57.1	131.8	82.9	

K Kitchen, L Living room, AM Arithmetic mean, GM Geometric mean

characteristic of that county (uranium and thorium content, soil permeability, soil porosity, radon emanation coefficient) may be the factor that affected the indoor radon concentrations. On the other hand, an important factor as ventilation is so less than the dwellings from the other counties because of the people are working and they have limited time in their home.

The measured radon values in all are higher in kitchens than living rooms. A reason of that may be the differences between kitchens and living rooms volume. In İzmir most of the kitchens are smaller than the living rooms in İzmir. The concentrations measured in winter are higher than other periods. This is because as more natural gas for heating during the winter months can be used. Furthermore, less ventilation is another important factor that also taken into account. Our observations show that the dwellings in the Bornova country are less ventilation than the other counties. Since many of people living in the Bornova are working throughout the day so that their dwellings closed.

Generally, primary factors influenced the indoor radon concentrations are ventilation, season, and height and age of the dwellings. Ventilation, season effect and height of the dwellings were discussed above. Another important factor is age of the dwellings. The old building allows radon escape with their cracked walls and probably the radon concentrations are relatively higher than new buildings. In our study same age buildings (10–15 years) were chosen due to the comparability of concentrations.

In addition, the annual effective doses were calculated and the mean annual effective dose levels changes from 0.49 to 2.39 mSv y^{-1} . The highest annual dose was calculated in the living room of Bornova. Although, the higher concentrations were found in kitchens, because of the less occupancy period the annual effective dose values of living room are higher. However, not all but more concentrations of kitchens were found to be higher than the living rooms (Fig. 7). Mean annual dose calculations of kitchen and living rooms of counties compared in Fig. 8 and this figure clearly show the highest doses both in kitchen and living room of Bornova. The all calculated annual effective dose values are less than the lower limit of recommended action level of ICRP (3–10 mSv y^{-1}). These doses are within the recommended limits of the world organizations [26].

Conclusion

For evaluating the overall long-term indoor radon concentration and natural gas effect on radon concentrations in the dwellings a survey performed in four counties of İzmir. The indoor radon levels of the Buca, Karşıyaka, and Gaziemir counties found to be in international ranges. Radon data obtained from Bornova are higher than the other counties. Parallels to the concentrations, the highest annual effective dose levels are found at kitchen and living rooms of Bornova. Indoor radon concentrations in dwellings that use natural gas have been found to be higher.

At the beginning of the study, same features building were chosen in each county. However, measurement did

Fig. 7 Indoor radon concentrations comparison kitchens and living rooms

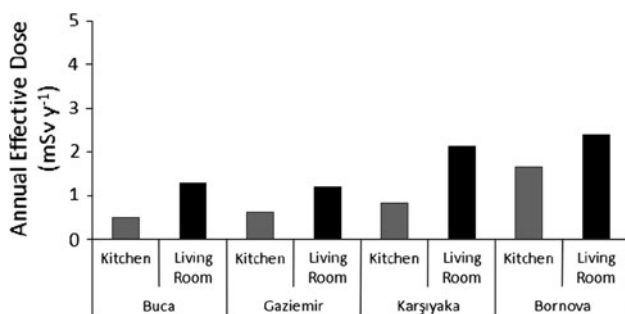
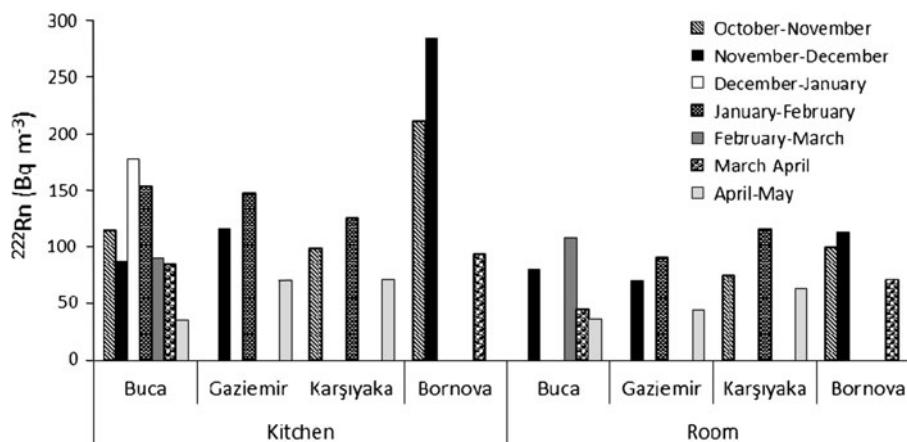


Fig. 8 Annual effective dose comparisons of Counties

not performed in some dwellings. Also some dwellings beginning to use natural gas after the study starts so comparative comparisons do not made. Although some problems prevented the investigation, first data on natural gas and indoor radon levels relationship obtained. A widespread understanding will be formed after the large number of detailed studies completed.

Acknowledgments This research work is supported by the grants from Ege University Scientific Research Project Contract No: 2008/NBE/010.

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