Comparison Of Indoor Radon Concentration At Malaysia Nuclear Agency And Radionuclide Monitoring Station, Cameron Highlands, Pahang

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ABSTRAK

Kajian ini tertumpu kepada kepekatan radon di dua lokasi kajian yang berbeza iaitu Agensi Nuklear Malaysia, Selangor dan Stesen Pemantauan Radionuklid, Pahang, dan anggaran dos tahunan (dos setara dan dos berkesan) kepada pekerja semasa waktu bekerja. Kaedah kajian menggunakan DOSEman Pro untuk melakukan pengukuran dos sewaktu bekerja dan hujung minggu. Julat kepekatan radon adalah dalam 2.2 – 396.3 Bq/m^3. Kepekatan radon adalah tinggi di waktu pagi dan pada hujung minggu berbanding dengan pada waktu petang dan hari bekerja. Hasil kajian menunjukkan julat anggaran dos berkesan dan dos setara tahunan kepada pekerja masing-masing ialah 0.093 – 0.311 mSv and 0.224 – 0.747 mSv. Dos-dos tahunan ini masih rendah dan kurang dari had piawai oleh ICRP, iaitu 10 dan 20 mSv masing-masing untuk dos berkesan dan dos setara.

ABSTRACT

This study focused on the radon concentration at two different study areas which are Malaysia Nuclear Agency, Selangor and Radionuclide Monitoring Station, Pahang, and estimated the annual dose (effective and equivalent dose) to the workers during working hours. Research method used DOSEman Pro to carry out the radon measurement during working hours and weekends. The ranges of radon concentrations were 2.2 – 396.3 Bq/m^3. The radon concentration was higher in the morning and weekends compared to the evening and weekdays. Findings show ranges of estimated annual effective and equivalent dose to the workers were 0.093 – 0.311 mSv and 0.224 – 0.747 mSv, respectively. These annual doses were still low and below the standard limit by ICRP, which are 10 and 20 mSv for effective and equivalent dose, respectively.

Keywords: radon concentration, temperature, effective dose, equivalent dose

INTRODUCTION

Radon is a chemical inert naturally occurring radioactive gas (NORM), which is colourless and odourless radioactive. It is generated by the decay of uranium and thorium that occur naturally from soils, rocks and groundwater throughout the earth's crust (Alofabi et al., 2015). Rn-222 and Rn-220 are the most common isotopes of radon and decay further to its progenies such as Po-218, Bi-210 and Pb-206 (Sulaiman et al., 2020). Radon present either outdoor or indoor atmosphere, but radon can accumulate to harmful levels in the indoor locations compared to outdoor locations. According to UNSCEAR (2000), radon and their decay product have been known as a potential health hazard, which is contributed about 52% of the natural radiation dose received by the public.

Typically, radium is a major source of indoor radon that contained in the soil, directly under the building. Radon plays a very significant role in natural radiation exposure, which moves up through the ground and enters the building air as particle fine through the cracks such as floor, walls and foundation (Kim et al., 2016). Besides that, it also cannot be avoided by the human that entering the human body through the inhalation to the respiratory tract and other tissue; and ingestion processes such as drinking water (Kang et al., 2019). The highly ionizing alpha particles emitted during the decaying process of the radon gas interact the biological tissue in the lung leading to damage of DNA (WHO 2009; Chen &Harley, 2018). Long-term exposure to high levels of radon can cause lung cancer and also considered as a second leading cause of lung cancer among the non-smokers (Krstic, 2017). Table 1 shows the number of radon attributable lung cancer deaths per year.

Table 1 Number of radon-attributable lung cancer deaths per year.

Country	Average of radon, Bq/m^3	Number of deaths	References
Canada	43	847	Peterson et al., 2013
France	89	3337	Catelinois et al., 2006
Germany	49	1896	Menzler et al., 2008
Netherlands	23	150	Leenhouts, & Brugmans, 2001
Portugal	81	2138	Veloso et al., 2012
South Korea	62	40 477	Lee at al., 2015
Sweden	110	420	Leenhouts & Brugmans, 2001
Switzerland	78	231	Menzler et al., 2008
United Kingdom	21	1100	Gray et al., 2009
United States	46	21 800	Cao et al., 2017

In Malaysia, the research of radon and progenies are still new and known as "silent-killer" that quiet lacking as compared to another country. The awareness of radon gas, as a source of energetic alpha radiation has not been extensively highlighted that could contribute to the long-term health problem and also lack of exposure to the public. Even though, there are many research, information and data about radon either indoor or outdoor, but they are lack of representation from many tropical countries, especially on how elevated radioactivity in the soil can affect the radon concentration in the areas. Besides that, the regulations and guidelines of radon are regulated in the mineral industry only but not in the buildings, especially the old buildings and residences (AELB, 2010). Other developed countries such as the United States of America (USA) and Japan, they have a radon safety certification, which will be given to a previously inhabited building and demonstrated that the building is safe to occupied (Yoon et al., 2016; Gordon et al., 2018).

The respective concentration of radon and its progeny are largely depended on the local geology or the ratio of the concentration of U-238 and Th-232 in the soils, rock and also water (Missimer et al., 2019). Therefore, these concentrations are important in predicting radon or thoron activity. According to UNSCEAR (2000), the average global concentration of these radionuclides is 33 Bq/kg for U-238 and 45 Bq/kg for Th-232. However, there are some areas that have an elevated level of radon such as Switzerland, Sweden, Finland, France, Ireland and Italy (WHO, 2009).

Therefore, this study aims to measure the radon concentration during the working hours (8 am – 5 pm) every day in the building of study areas and investigate the factor that influencing the radon concentration. It also calculates and estimates the effective and equivalent dose received by the worker there.

MATERIALS AND METHODS

Study Areas

There were three buildings in the study area selected as the location of sampling for the measurement of radon activity, which focused on two buildings in Malaysia Nuclear Agency, Selangor and one building in the Radionuclide Monitoring Station, Tanah Rata, Pahang. Block 11 (Studio Design and Exhibition Unit) and Block 15 (Asset Section and Public Facilities Offices) were renamed in this study as MN11 and MN15, respectively, at Malaysia Nuclear Agency and selected based on the position of the room that located at the bottom of the building, on the edge of the hillside and closed condition that could contribute to the high radon activity. While Radionuclide Monitoring Station's building renamed as RN42 which located at Cameron Highlands in Pahang was chosen due to its location surrounded by low ambient temperatures and located on a hill. Fig.1. shows the location of study areas in Malaysia Nuclear agency and Radionuclide Monitoring Station.

Measurement of Radon

Radon concentration was measured for three weeks during the study on weekdays and weekends for 9 hours, starting from 8 am to 5 pm. The concentration was measured and analysed by using two instruments, which are the active method performed using continuous radon progeny monitor, which were DOSEman Pro (Sarad, Germany) and Hygrometer Testo.

DOSEman Pro was used to measure the radon concentration in the study areas and recorded in the unit Becquerel per meter cube (Bq/m^3). This equipment is equipped with a semiconductor detector connected to an alpha spectroscopy system capable of discriminating alpha energy peaks emitted by radon and their progeny. The data were analysed by using radon vision software. It also consists of a membrane pump USB interface, filter paper holder, rechargeable battery and high sensitivity, which is 150 cpm or 1000 Bq/m^3 (EEC). While hydrometer Testo 175H1 was used to measure the readings of ambient temperature and humidity in the study areas during the study period. This equipment could measure up to 175 readings of temperature at one time and analysed by using Comfort Testo software.

These instruments were placed on a tripod stand at a height of 1 m above the ground in the study areas. The measurement was conducted about 9 hours a day to obtain a representative average radon concentration during working hours. After 9 hours, the instruments were taken and analysed using the special software.

Data Analysis

There were two software used to analyse the results, radon vision and comfort testo. The results were displayed in the form of graph and they also used to estimate the annual equivalent dose and the annual effective dose received by the workers at the study areas using the following equations (1 & 2).

The annual effective dose is the dose received by the employees or the public within a year (Khalid et al,.. 2013).

$$D_{eff} = C_{Rn} \times F \times O \times T \times D \quad (1)$$

where:

D_{eff} Effective dose, mSv/year.

C_{Rn} Average of radon concentration, Bq/m^3.

F Equivalent factor (0.4).

O Occupancy factor (9 hours/24 hours).

D Exchange unit (9nSv/Bq hour m^{-3}).

T Working hours (2000 hours/year).

The annual equivalent dose is the dose received within a year by the employees or the public on the type of radiation produced by the radon and also involves the human organs and tissues (Khalid et al., 2013).

$$E = D_{eff} \times W_R \times W_T \qquad (2)$$

where:

E Annual equivalent dose, mSv/year.

D_{eff} Effective dose, mSv/year.

W_R Weighting factors for alpha particle, 20.

W_T Weighting factors for lung tissue, 0.12.

RESULTS AND DISCUSSIONS

Measurement of Indoor Radon Concentration

The measurement of indoor radon concentration that has been conducted for three weeks on weekdays and weekends in the study areas and summarized in Table 2. The highest indoor radon concentration on both weekdays and weekends was observed in MN15 that varied from 444.8 Bq/m^3 to 262.2 Bq/m^3 with an average of 115.4 Bq/m^3 and 303.0 Bq/m^3 to 396.3 Bq/m^3 with an average of 341.1 Bq/m^3 respectively. While, the radon concentration in MN11 was quite lower than MN15, at 2.2 Bq/m^3 to 151.1 Bq/m^3 with an average of 35.7 Bq/m^3 for weekdays and 190.7 Bq/m^3 to 301.1 Bq/m^3 with an average of 254.9 Bq/m^3 respectively. Then, the lowest range value of 20.7 Bq/m^3 to 48.5 Bq/m^3 with an average of 34.7 Bq/m^3 in weekdays and 19.3 Bq/m^3 to 34.4 Bq/m^3 with an average of 24.2 Bq/m^3 in weekends were recorded in RN42.

These results were expected due to the location of the building, which is MN11 and MN15 were located at the basement, the edge of the hill and closed place, while RN42 was located at the first floor and top of the mountain (Yousef & Zimami, 2019). Then, these also influenced by the building materials and type of soils used in the older building (Yosef et al., 2015), and contain natural radioactivity and also source of indoor radiation exposure (Khalid et al., 2014; Ismail et al., 2018). The properties of radon are inert and can move freely through the porous media in the building material (Seta & Amente, 2020). The older building was used the red bricks and cement that contained high NORM (Ahmed & Jaafar, 2010). Based on Nuclear Energy Agency Organization reported, that the world average value of radon in building material is 50 Bq/kg (Abdullah et al., 2020). These also affected by worker activity and ventilation factor such as open-closed doors, air-conditioner and fans, could lead to the mixing the indoor and outdoor air of radon, and thus, decrease the radon concentration quickly in the working hours (Al-Khateeb et al., 2017). However, the measured radon concentration is more than world's average of 40 Bq/m^3 and the recommended level average of 100 Bq/m^3 (ICRP, 2010) respectively, but still below than standard range of National Radiological Protection Board (NRPB), United Kingdom and the Economic European Community (EEC) and ICRP, which are 400 Bq/m^3 and 1500 Bq/m^3 respectively.

Table 2 Average and range of radon concentration in the study areas.					
Study areas	Building Material	Average of radon concentration, Bq/m^3		Range of radon concentration, Bq/m^3	
		Weekdays	Weekends	Weekdays	Weekends
MN11	Cement + Stone	35.7	254.9	2.2 - 151.1	190.7 - 301.1
MN15	Cement + Red bricks	115.4	341.1	44.8 - 262.2	303.0 - 396.3
RN42	Cement + Red bricks	34.7	24.2	20.7 - 48.5	19.3 - 34.4
		61.8	206.7	2.2 – 262.2	19.3 – 396.3

Comparison between the indoor radon concentration for weekdays and weekends, MN11 and MN15 had high radon concentration in the weekends than RN42. These might be due to no worker activities and poor ventilation in the building. These enable the radon gas to accumulate and increase the radon concentration in the building. While for radon concentration of RN42 was quite lower than weekdays because of the presence of ventilation and human activity in the building that used as a meeting room to receive the visitors or guests that come to the station during weekends. The measured radon concentrations in this study were higher than the previous study at different locations in Malaysia and summarized in Table 4. Most of the results from the previous study were represented on different types of settlement and building, but the results do not exceed USEPA's action level of 148 Bq/m^3 (Barros et al., 2016).

Table 3 Radon concentration in Malaysia.			
Study area		Radon Concentration (Bq/m^3)	References
Selangor	This study	2.2 – 396.3	This study
	Shah Alam	11.1	Saat et al., 2010
	Ampang	43.66	Saat et al., 2010
Kelantan	UMK	27.01 – 41.81	Khairul Azhar et al., 2017
	Kota Bharu	25.90	Saat et al., 2010
Perak	Kampung Gajah	56.98	Saat et al., 2010
	Lumut	13.69	Saat et al., 2010
Pahang	This study	19.3 – 48.5	This study
Johor	Segamat	2.6 – 69.3	Amira, 2015

Diurnal's Variations of Indoor Radon Concentration

In this study, the diurnal's variations of indoor radon concentrations were conducted and showed a certain pattern supported by the previous study. The radon concentration was high at the night and early morning, but low during the daytime. Figure 2 and Figure 3 show the pattern of radon concentration for 9 hours (8 am to 5 pm) at the study areas (MN11, MN15 and RN42) on both weekdays and weekends. The high radon concentrations were recorded in the morning and began to decrease until the late afternoon, due to the stability of the atmospheric surface layer (Chen et al., 2016).

The earth's surface is in a stable condition at the night until early morning. This is because the surface layer and the atmosphere almost have the same temperature; the radon tends to accumulate near the earth's surface. While, in the daytime, the temperature increases and it create the differential temperature between the earth's surface and atmosphere through the heat transfer process. This process makes the atmospheric surface layer becomes unstable and produces convection. This is made the radon gas upward and spread away from the surface. Then, the atmospheric conditions and radon were gathered again closed to the earth's surface in the evening (Chen et al., 2016; Viet, et al., 2018).

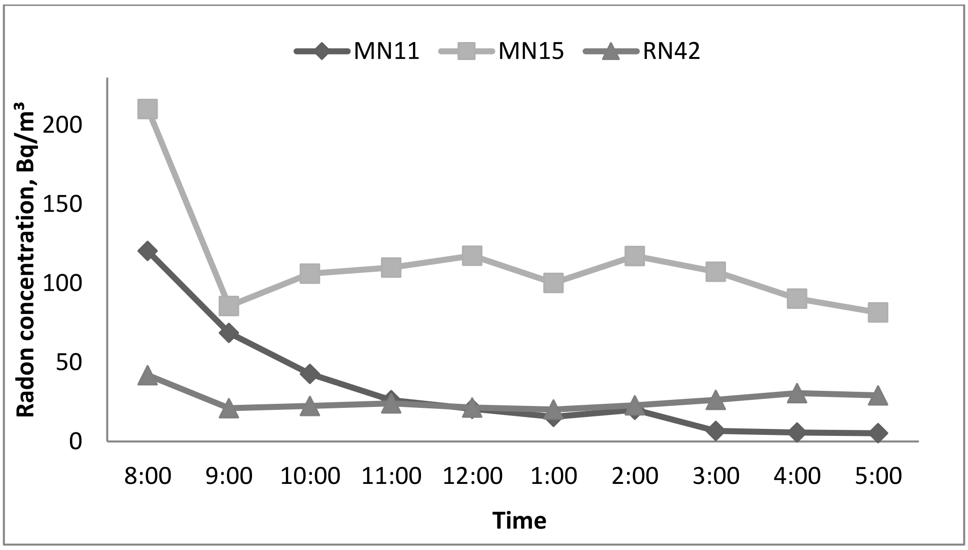

Figure 2. The diurnal variation of radon concentration on weekdays at MN11, MN15 and RN42.

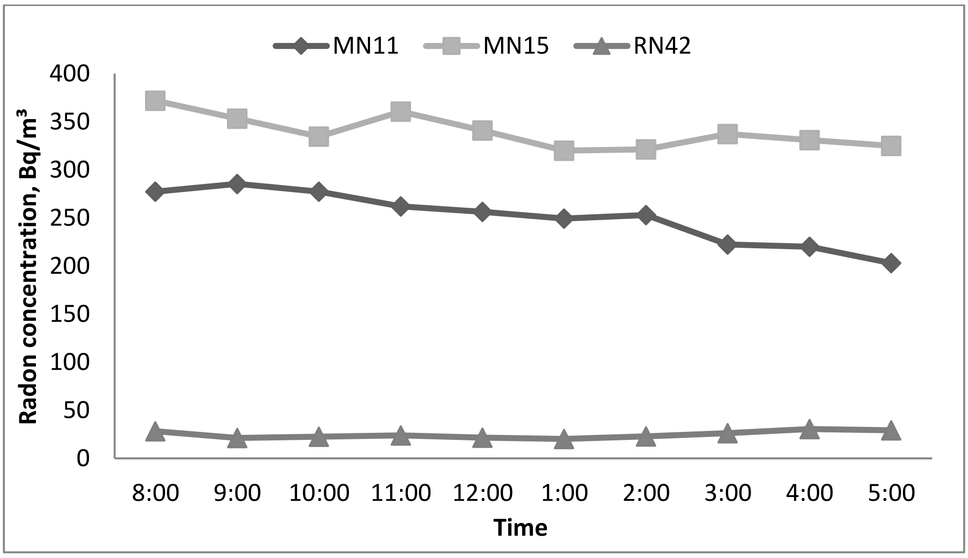

Figure 3. The diurnal variation of radon concentration on weekends at MN11, MN15 and RN42.

Radon Concentration vs Humidity and Temperature.

Indoor radon concentration was also affected by environmental factors, which are humidity and temperature in the building (Khalid et al., 2013). Correlation between radon concentration and humidity is positive with the increment of humidity, the level of radon concentration also increases. While the temperature has a negative correlation with radon concentration. When the temperature rises in the building, so the radon concentration will became inactive and decreases due to their physical property (Khalid et al., 2013; Seta & Amente, 2020).

In this study, the radon concentrations with their environmental factors (temperature and humidity) were displayed into three divisions as shown in Figure 4 - 6. On the 1st days, the radon concentration was high in the morning (Fig.4), due to high humidity and low temperature than the other days. Meanwhile, radon concentration was slightly decreased at the afternoon until the end of working hours on that day, due to decreasing the humidity and slightly increased in temperature as shown in Fig.5 and Fig.6. This result also agreed with the previous studies that stated the level of radon concentration in the building increases, with an increment of humidity but decrease the temperature.

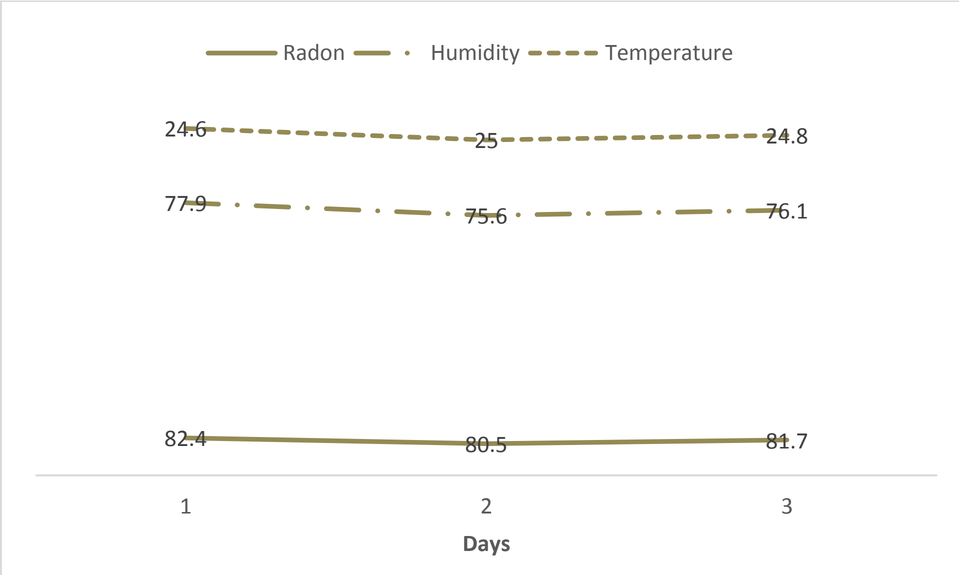

Figure 4. Morning (8am to 11.59am) indoor radon concentration with temperature and humidity.

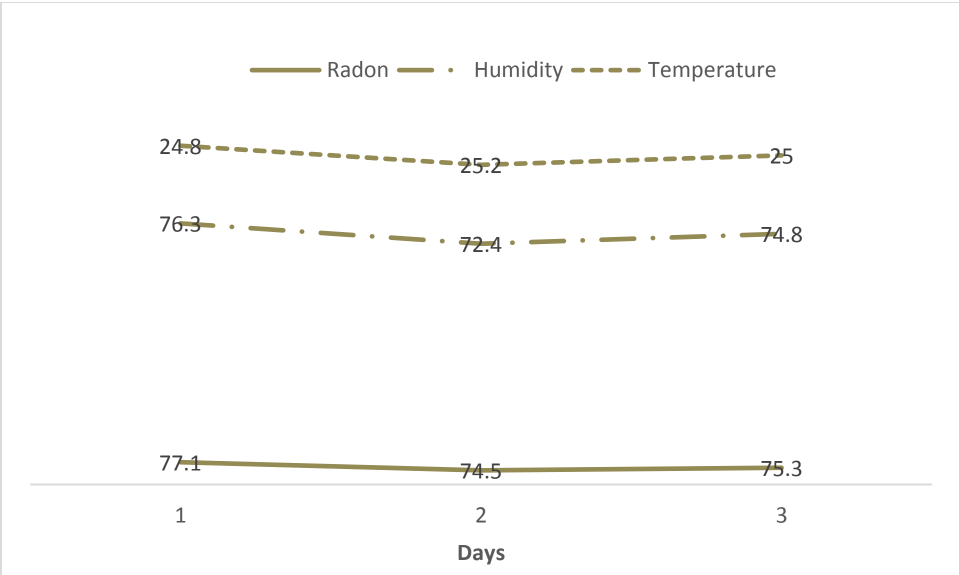

Figure 5. Early afternoon (12pm to 1.59pm) indoor radon concentration with temperature and humidity.

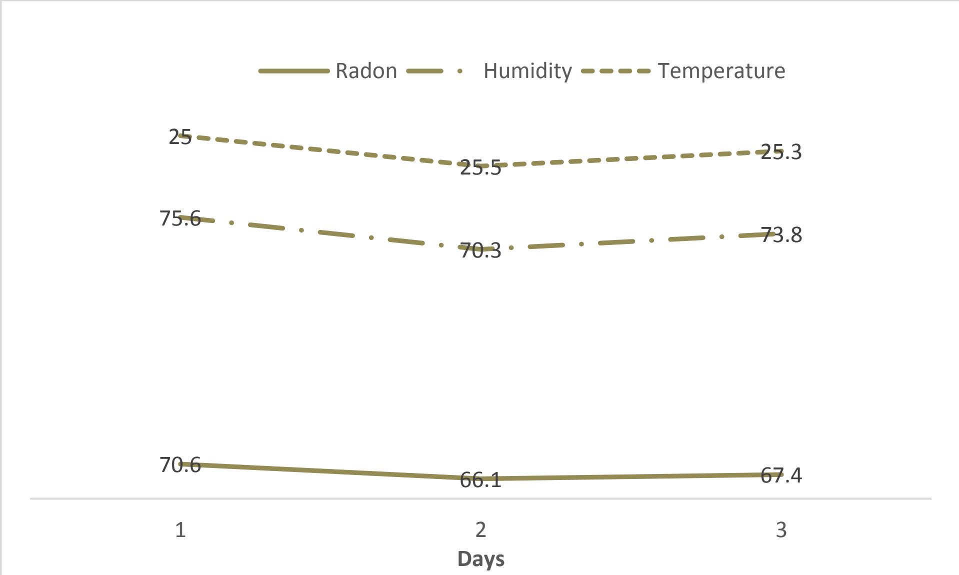

Figure 6. Late afternoon (2pm to 5pm) indoor radon concentration with temperature and humidity.

Effective and Equivalent Dose

The annual effective dose and annual equivalent dose were introduced by the ICRP for the set limits for radiation protection. In this study, they were only focused to calculate the dose received by the workers during their working hours in a year. MN15 had a higher annual effective dose and equivalent dose, which were 0.311 ± 0.098 mSv and 0.747 ± 0.236 mSv respectively, followed by MN11 and RN42. The result of this study also compared with the previous study that is shown in Table 4. According to ICRP (2017) standards for the workers, the present study showed a relatively low annual effective and equivalent dose for all study areas, which are 10 mSv/y and 20 mSv/y respectively.

Table 4 Annual effective and equivalent dose in the study areas.

Study areas	Effective dose, mSv/y	Equivalent dose, mSv/y	Reference
MN11	0.096 ± 0.038	0.231 ± 0.091	This study
MN15	0.311 ± 0.098	0.747 ± 0.236	This study
RN42	0.093 ± 0.022	0.224 ± 0.052	This study
UKM, Bangi	0.008 – 0.072	0.020 – 0.173	Ali et al., 2018
UKM, Bangi	0.160 – 1.060	0.380 – 2.540	Khalid et al., 2013

CONCLUSION

The indoor radon concentration ranged from 2.2 -301.1, 44.8 – 396.3 and 19.3 – 48.5 Bq/m^3 for both weekdays and weekend at MN11, MN15 and RN42 respectively. Radon concentration was high in the morning and then, began to decrease until the late afternoon due to the environmental factors, which are temperature and humidity in the buildings, as well as influenced by a few factors such as ventilation, building materials, location of the building and worker activity. The annual effective and equivalent dose of workers ranged from 0.093 - 0.311 mSv and 0.224 - 0.747 mSv respectively for all study areas. These doses are still low and below the action levels recommended by ICRP.

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DECLARATION OF COMPETING INTEREST

The authors declare that they no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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