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Potential factors that impact the radon level and the prediction of ambient dose equivalent rates of indoor microenvironments

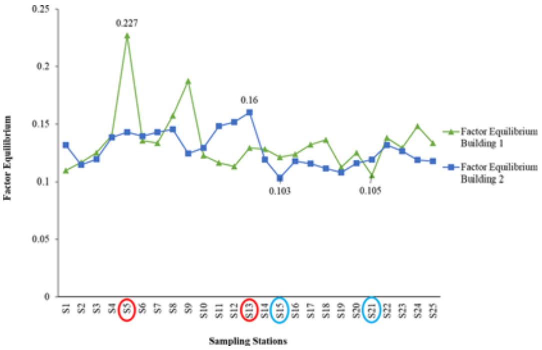
Mohamed Yasreen Mohamed Ali [a], Marlia M. Hanafiah [a,*], Md Firoz Khan [b]

[a] School of Environmental and Natural Resource Sciences, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia
[b] Centre for Tropical Climate Change System, Institute of Climate Change, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

HIGHLIGHTS

- Two ventilated buildings were evaluated for the equilibrium equivalent radon (EECRn) concentration
- The average annual inhalation and effective doses for radon were measured
- Temperature, humidity, ventilation system and distance from the soil surface layer influenced radon emanation

GRAPHICAL ABSTRACT



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ABSTRACT

This study aimed to measure the equilibrium equivalent radon (EEC_{Rn}) concentration in an old building (Building-1) and a new building (Building-2) with mechanical ventilation and a natural ventilation system, respectively. Both buildings were located at the campus of University Kebangsaan Malaysia. The concentration of indoor radon was measured at 25 sampling stations using a radon detector model DOSEman PRO. The sampling was conducted for 8 h to represent daily working hours. A correlation of the radon concentration was made with the annual inhalation dose of the occupants at the indoor stations. The equilibrium factor and the annual effective dose on the lung cancer risks of each occupant were calculated at each sampling station. The average equilibrium equivalent radon measured in Building-1 and Building-2 was 2.33 ± 0.99 and 3.17 ± 1.74 Bqm^{-3}, respectively. The equilibrium factor for Building 1 ranged from 0.1053 to 0.2273, and it ranged from 0.1031 to 0.16 for Building 2. The average annual inhalation doses recorded at Building-1 and Building-2 were 0.014 ± 0.005 mSv y^{-1} and 0.020 ± 0.013 mSv y^{-1}, respectively. The annual effective dose for Building-1 was 0.034 ± 0.012 mSv y^{-1}, and it was 0.048 ± 0.031 mSv y^{-1} for Building-2. The values of equilibrium equivalent radon concentration for both buildings were below the standard recommended by the International Commission on Radiological Protection (ICRP). However, people may have different radon tolerance levels. Therefore, the inhalation of the radon concentration can pose a deleterious health effect for people in an indoor environment.

1. Introduction

In recent years, there has been increasing interest in indoor air pollution studies, which is mainly because indoor air pollution is a major

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* Corresponding author.
E-mail address: mhmarlia@ukm.edu.my (M.M. Hanafiah).

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public-health issue that is linked to detrimental health effects (Sundell, 2004; Zhang and Smith, 2003). One of the most common indoor air pollutants is radon; however, limited studies on radon exposure have been conducted, as most people are completely unaware of the threat of exposure. Radon decay produces radon progeny that emit α (alpha), β (beta) and γ (gamma) emitters. An alpha particle waves that emitted inside the lung can genetically damage lung cells. People spend approximately 80% of their time in indoor environments, thus making them susceptible to hazardous indoor-induced gases and radioactivity gases, including the radiation radon and radon daughter. Radon is a radioactive gas that is colorless and odorless and is formed from the decay of naturally occurring uranium present in the earth's crust (Baskaran, 2016). The half-life of radon is 3.82 days with most radon daughters are short-lived decay products (Harrison et al., 1999).

The human respiratory system has a limited filtration system, which makes it difficult to filter inhalable radon gas and the radon daughters (Kendall and Smith, 2002). Radon is carcinogenic, and long-term exposure to radon leads to adverse effects on human health (El Ghissassi et al., 2009). This is because radon daughters, which are positively charged, bind with particulate matter, enter the human respiratory system, and accumulate in the lungs. Radon daughters then disintegrate and release α particles that interact with the biological tissue in the lungs, leading to DNA damage. A single alpha particle can cause major genetic harm to a cell; therefore, it is possible that radon-related DNA damage can occur at any level of exposure (Organization, 2007). The damaging impact of indoor air pollution, such as sick house syndrome, on human health has become a major social concern, as people spend a large amount of their time in buildings and breathe the air that circulates within the buildings (Matz et al., 2014). People are exposed to outdoor air pollution less often than indoor air pollution. The average time frame for an individual to be exposed to pollutants during the work day is eight hours. People with different health backgrounds are susceptible to lung cancer, and each person has a different tolerance level and sensitivity towards disease (Gibson et al., 2013). The threshold level of exposure to radon concentrations is still unknown for humans (Organization, 2009). Poor ventilation systems may cause menacing effects, as the percentage of pollutants that remain in buildings is high. The estimated concentration of radon measured was limited to office hours rather than 24 h to determine the precise exposure of radon for the workplace. As Sugino et al. (2005) reported, the average radon concentration in offices was about 29 Bq m^{-3} higher than the 17 Bq m^{-3} than has been reported for dwellings. Therefore, it is crucial to determine the specific exposure during the office hours.

Building materials play a crucial role in exposure because radon formation is highly affected by the type of building materials used (Sahoo et al., 2011). Red bricks produce optimum radon emanation because the origin of red bricks is clay. Concrete bricks release less radon in indoor environments (Girault and Perrier, 2012). The ventilation system of a building is crucial as well, as the air that flows within a room affects the concentration of remaining radon and progenies (Awbi, 2003; Yarmoshenko et al., 2016). Mechanically ventilated buildings usually increase exposure to radon and progeny compared with naturally ventilated systems. All buildings experience air penetration during the infiltration process, which brings radon and progeny inside the room through cracks in pipelines and walls (Cao et al., 2014). The height of the building also affects radon concentration because for indoor radon, the diffusion of radon from the subsoil is the second main source of exposure after building materials (Bräuner et al., 2013). The emanation of radon occurs mostly in enclosed spaces, as the distribution of radon in the outdoor environment is too vast to measure (Organization, 2009). Other parameters involved in determining the level of radon concentrations include the humidity and temperature inside the building (Janik et al., 2015). Exposure assessments can be improved by an enhanced understanding of different sources of radon released, such as from red bricks or concrete bricks. Identifying the uncertainties related to ventilation systems is necessary to estimate radon concentration.

In the present study, the measurement of the equilibrium equivalent concentration of radon (EEC_{Rn}) was performed in two different buildings, one with a mechanical ventilated system and one with a natural ventilated system. The concentration of radon during working hours (8 h) was also analyzed to correlate the factors to determine the pattern of radon concentration in the building. The equilibrium factor for radon was calculated for each occupant's room. The total annual inhalation dose and the annual effective doses for each sampling station in each building were estimated based on the measured values of activity concentrations.

2. Materials and methods

2.1. Study area

Building 1 is located at the Faculty of Science and Technology (2°55″ 24.7″N, 101°46″56.5″E), and the Southeast Asia Disaster Prevention Research Institute (SEADPRI) was chosen for Building 2 (2°55′45.1″N 101°47′17.9″E). Both are located at the University Kebangsaan Malaysia at altitudes of up to 48 m above sea level (Fig. 1). Building 1 was built in the 1970s and consisted of a lecturer's room and laboratories at each level of a five-story building, excluding the basement. The building was built using red bricks. Several mold issues within the building indicated a highly humidified building. This building used a mechanically ventilated system, and certain rooms had split air conditioners operating during sampling. The centralized air conditioner did not operate properly in some room with lack of air-suction exhaust inside the room. Building-2 was built in the early 2000s and consisted of a lecturer's room and several meeting rooms on every level of the five-story building. The building was built from concrete bricks next to an unfinished building with stagnant water on the ground floor, which formed a swamp. This explained why the neighboring Building-2 had a high humidity level on the ground floor. The building was naturally ventilated, and each room had split air conditioners. Some sampled rooms were rarely used by the occupants. During sampling, all the windows and doors were closed. A detailed description of the sites was provided by Ali et al. (2017).

Fig. 1(b) shows the schematic design of the sampling site of Building 1. The sampling room had a centralized air conditioner with an air-suction exhaust (not all the sampled rooms had an air suction exhaust). The windows were closed during sampling, and the radon detector was placed a meter away from the wall and a meter above the ground to represent the breathing zone of the occupant. All sampled rooms were covered with carpet. Fig. 1(c) shows the schematic design for the sampled room of Building 2. Building 2 had natural ventilation. The doors and windows were closed during sampling. Each room contained a split air conditioner. The rooms did not have an air suction exhaust, and thus the air circulated inside the room. Similar to the modus operation for Building 1, the radon detector was placed a meter away from the wall and above the ground to represent the average breathing zone of the occupants. The airflows from outdoors into the building are illustrated in the schematic design as A_{og}, A_{o1}, A_{o2}, A_{o3}, and A_{o4}, which shows the airflow from outdoors to the respective floors. The outflow of air from the building to outside are indicated as A_{go}, A_{1o}, A_{2o}, A_{3o}, and A_{4o}, which shows the outflow of air from the building to outdoors. For each level, the sources, such as building materials, released radon, and the radon infiltration through the levels is shown in the schematic design as S_{sg}, A_{g1}, A_{12}, A_{23} and A_{34}.

2.2. Measurement of indoor radon concentration and effective dose

The concentration of indoor radon was measured for 25 sampling stations (five rooms per level) for both buildings during occupied office hours using the Passive Radon Detector model DOSEman-Pro. The