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Methodology for determination of radon-222 production rate of residential building and experimental verification

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Abstract

Indoor radon concentration is mainly associated with the radon production rate of building material, ventilation rate, and the outdoor radon concentrations. Radon production rate of a room is defined as the sum of the products of the radon emanation rates and the exposed areas of the materials. Since the selection of the building materials and the exposed areas are different from room to room, it makes the radon production rate of homes fall in a wide range. Here, the radon production rate of a room is suggested to be quantified by a sealing method, in which the systematic radon growth curve is obtained. The radon production rate of the room can be determined from the initial slope of the growth curve. Three rooms at different homes in Hong Kong were selected in the study for verifying the methodology. The uncertainty characterized by data scatter arisen from the coupling effect of the leakage rate and outdoor radon was also included in the discussion. During the measurements, no occupant was allowed into the home. No mechanical ventilation was involved in the measurement. The indoor and outdoor radon concentrations of the sampled homes were monitored simultaneously and lasted for more than three days. The radon production rates and the uncertainties of three rooms at Homes 1, 2, and 3 were found to be 232.8, 46.0, 414.6, and 20.3, 9.4, 59.2 Bq h^{-1}, respectively. The approach is valid when the air leakage rate of the room is controlled below 0.1 h^{-1}.

Keywords: Radon production rate; Building material; Residential building; Ventilation

1. Introduction

Radon is a natural radioactive gas. When the gas and its decay products are inhaled into the respiratory system, they will attach to the lung tissue and increase the risk of lung cancer. Studies on the risk of lung cancer and the exposure of the population to radon have been conducted in China (Wang et al., 2002); Iowa (Field et al., 2001); and Germany (Kreienbrock et al., 2001). Indoor radon can be attributed to different sources, such as earth-based building materials, domestic well water, and soil adjacent to the building, as reported by Nazaroff and Nero (1984) in their study of the entry of radon into residences. Concrete is an earth-based building material, which comprises uranium decay series products. It is widely used in building construction and becomes one of the main contributors indoors. Lambrechts et al. (2001) studied the relationship between ventilation and radon transport in Dutch dwellings. They reported that the building materials and the ventilation of building were the important factors in considering indoor radon levels. However, the scenario in Hong Kong is quite different from the environments of some countries, such as the United States and the United Kingdom. In Hong Kong, high-rise buildings are far more common than detached houses. No well water is provided to buildings. Domestic water mainly comes from reservoirs. The contributions

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of soil and well water indoors become insignificant. The emanation rate of building materials was also studied by Tso et al. (1994) in Hong Kong. They used the local building materials in their study. They found that the emanation rate of granite ($34 \times 10^{-6}\,\mathrm{Bq\,kg^{-1}\,s^{-1}}$) was followed by that of concrete blocks ($21 \times 10^{-6}\,\mathrm{Bq\,kg^{-1}\,s^{-1}}$). Yu (1994) studied the emanation of the local Pulverized Fuel Ash (PFA) and Ordinary Portland Cement (OPC) concrete and reported that the radon emanation rates of PFA and OPC concrete blocks fell in the ranges of 9.7×10^{-3}–11.3×10^{-3} and 9.22×10^{-3}–$10.6 \times 10^{-3}\,\mathrm{Bq\,m^{-2}\,s^{-1}}$, respectively. However, different coatings or covering materials applied on the concrete surface can result in different emanation rates.The inhibition effects of coverings against radon emission on concrete are different. Ma et al. (1995) investigated the effectiveness of finish materials on indoor radon reduction. They made use of wallpaper, tile, plaster, and paint to study indoor radon reduction from concrete wall. They concluded that wallpaper was the most effective radon inhibitor among their tested materials. The radon production rate of the room is directly proportional to the strength of the emanation rates and the size of exposed areas of the covering materials. Since the selected materials and the application of the covering vary from place to place, different radon production rates are expected from room to room. In the current study, an effective method is suggested to quantify the radon production rate of a room. Here, the emanation rates and the coverings applied areas of the room are not needed in detail, while these two parameters are simplified in terms of the radon production rate. The methodology is expected to be helpful to quantify the radon production rates of existing homes and also useful to examine the effectiveness of radon mitigation. In this study we report measurements of radon growth in three rooms of three quite different types of buildings, two houses and one room on the seventh floor of a high-rise building. The data collected were used to test the new theoretical approach presented in this paper.

2. Methodology

2.1. Theoretical approach

The sampled room is maintained as airtight as possible. A systematic radon growth curve can be obtained from the sealed room and expressed by

$$\frac{\mathrm{d}C}{\mathrm{d}t} = \frac{\sum_i E_i A_i}{V} + \frac{q(C_\mathrm{o} - C)}{V} - \lambda C. \tag{1}$$

The first term on the right-hand side of Eq. (1) is a radon generation term. It comes from building materials that are composed of the radioactive element radium. The radon emanation rate of material-i and its exposed area are represented by E_i and A_i, respectively. The effective volume of the sampled room is V. The second term comes from the loss due to air leakage, where q is the infiltration rate of the sampled room. The last term represents the loss due to the process of natural decay of radon gas. The decay constant of radon-222 (Rn-222) has a constant value of $7.55 \times 10^{-3}\,\mathrm{h^{-1}}$. If the initial concentration, C_i, of the sampled room is determined, the general solution of Eq. (1) can be expressed as

$$C = \left(C_\mathrm{i} - \frac{qC_\mathrm{o} + \sum_i E_i A_i}{V\left(\lambda + \frac{q}{V}\right)} \right) \mathrm{e}^{-(\lambda + \frac{q}{V})t} + \left(\frac{qC_\mathrm{o} + \sum_i E_i A_i}{V(\lambda + \frac{q}{V})} \right) \tag{2}$$

or

$$C = (C_\mathrm{i} - C_\infty)\mathrm{e}^{-\beta t} + C_\infty, \tag{3}$$

where

$$\beta = \left(\lambda + \frac{q}{V}\right), \tag{4}$$

$$C_\infty = \left(\frac{qC_\mathrm{o} + \sum_i E_i A_i}{V\left(\lambda + \frac{q}{V}\right)} \right). \tag{5}$$

The equilibrium radon concentration of the sampled room can also be rewritten as follows:

$$C_\infty = \left(\lambda + \frac{q}{V} - \lambda\right)\left(\frac{C_\mathrm{o}}{\beta}\right) + \frac{\sum_i E_i A_i}{V\beta}$$

or

$$C_\infty = (\beta - \lambda)\frac{C_\mathrm{o}}{\beta} + \frac{\sum_i E_i A_i}{V\beta}. \tag{6}$$

The exponential index, β, of Eq. (3) only depends on the air exchange rate of the sampled room, since the decay value λ of Rn-222 is a constant. The effective radon production of the room, Ω_Room, is one of the main parameters that contribute to the indoor concentration of radon. It is the lump sum of the radon production rates of all radium content materials used in the room, and is given by

$$\Omega_\mathrm{Room} = \sum_i E_i A_i. \tag{7}$$

Using Eqs. (6) and (7), the effective radon production rate derived from the sealed-room methodology can be rewritten as

$$\Omega_\mathrm{Room} = [(C_\infty - \langle C_\mathrm{o}\rangle)\beta + \lambda\langle C_\mathrm{o}\rangle]V, \tag{8}$$

where the average value of outdoor radon concentration, $\langle C_\mathrm{o}\rangle$, is used to replace C_o in estimation.

2.2. Determination of β-value

The exponential index, β, can be obtained by taking the differentiation with respect to time, t, on Eq. (3):

$$\frac{\mathrm{d}C}{\mathrm{d}t} = M = -\beta(C_\mathrm{i} - C_\infty)\mathrm{e}^{-\beta t}, \tag{9}$$