A method of apportioning indoor radon concentration to the constituent building components

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ABSTRACT

Indoor radon concentrations in high-rise buildings are found to be affected by two major factors, namely the ventilation rate and the radon production rate of building materials. In this paper we present a method to apportion the indoor concentrations to their individual emission sources. The method consists of two parts: one part is to determine the overall radon production rate in a sealed room space, and the other part is to determine the radon production rate from a particular component. The methods are based upon mass balance models. The radon concentration profile was typically measured over a period of not less than 3 days. In order to quantify the whole room radon production rate, the room was sealed during the measurement. In the apportionment test, a radon chamber was established on site to measure the emanation rates of the covering materials directly. Covering materials including wallpaper, wooden floor covering and windowsill counter-top granite were involved in the apportionment chamber test. It was found that the wooden floor covering greatly reduced radon emission from the bare concrete slab, while concrete walls and ceilings with a covering of wallpaper were the dominant emission sources. The granite windowsill, which had no covering material, was in between the wallpaper and wooden floor covering. The chamber test is an effective way to identify potential radon contributors in an existing building. Following the sealed room or apportionment method, the radon production rate of the building material can be obtained.

INDEX TERMS

Radon production rate; Emanation rate; Apportionment; Building materials

INTRODUCTION

Radon is a natural radioactive gas. If the gas and its decay products are inhaled into the respiratory system, they attach to the lung tissue and increase the risk of lung cancer. The Hong Kong Environmental Protection Department (HK-EPD) reported that there were around 5% and 10% of residential and non-residential premises with radon levels exceeding the Indoor Air Quality Guidelines proposed level (Pang and Pun 1994). The proposed annual average level was set at 200 Bq m^{-3} by HK-EPD (Pang 1994). Concrete is commonly used in building construction. It is one of the essential radon contributors indoors. Tso and her colleagues studied the radon emanation rates of the local building materials (Tso *et al*. 1994). They found that the emanation rate of granite (34×10^{-6} Bq kg^{-1} s^{-1}) was just followed by concrete block (21×10^{-6} Bq kg^{-1} s^{-1}). Yu studied the radon 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 ranged from 9.7×10^{-3} to 11.3×10^{-3} Bq m^{-2} s^{-1} and 9.22×10^{-3} to 10.6×10^{-3} Bq m^{-2} s^{-1}, respectively (Yu 1994). Since each covering material may have its own shielding ability against radon emission from a concrete surface, different coatings or covering materials applied on concrete surface can be resulted in different emanation rates. Due to the selected materials and the application of coverings varying from place to place, different radon production rates are expected from room to room. Lembrechts and his colleagues reported that the radon production rate of materials could vary over a wide range (Lembrechts *et al.* 2001) when they studied radon transport and ventilation in Dutch homes. In our current study, the new apportioning method is used to identify the radon production rate of each component. The effective radon production rate of the room is quantified too.

METHODS

Two solid-state real time radon detectors, RAD7 Detector-I and Detector-II, were used to measure the indoor and outdoor radon concentrations of the sampled room, respectively. The room was sealed using adhesive tape in order to obtain the radon growth curve for analysis. Each measurement was conducted for not less than 72 h, and the default logging rate was 30 minutes per data. The effective radon production of the sealed room, Ω_{Room}, is given by Eqn (1).

$$\Omega_{\mathrm{Room}} = \left[\left(\frac{M_{\mathrm{s}}}{(C_{\infty} - C_{\mathrm{i}})} \right) (C_{\infty} - \langle C_{\mathrm{o}} \rangle) + \langle C_{\mathrm{o}} \rangle \lambda \right] V, \qquad (1)$$

where M_{s}, C_{∞}, and C_{i}, are the initial slope, equilibrium radon concentration and the initial concentration of the growth curve, respectively. The radon decay constant, mean outdoor radon concentration and the volume of room are represented by λ, $\langle C_{\mathrm{o}} \rangle$ and V, respectively. Alternatively, the effective radon production rate of the room can be obtained by the apportioning chamber test through on site measurements on each covering individually. The effective radon production rate of the room obtained by the apportioning method is defined as Ω_{Apport}, given by Eqn (2). Theoretically, Ω_{Apport} is identical to Ω_{Room}. That is,

$$\Omega_{\mathrm{Apport}} = \Omega_{\mathrm{w}} + \Omega_{\mathrm{g}} + \Omega_{\mathrm{f}} = \Omega_{\mathrm{Room}}, \qquad (2)$$

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where Ω_w, Ω_g and Ω_f are the radon production rates of the papered wall and ceiling (w), granite windowsill (g) and wood floor (f), respectively. In the apportionment chamber test, the sampled air was re-circulated back to the chamber. Ω_j of covering j of the sampled room is given by Eqn (3). Here, the subscript j can be w, g and f.

$$\Omega_j = \left[\left(\frac{(M_{\text{chamb}})_j}{[(C_{\text{chamb}})_\infty - (C_{\text{chamb}})_i)}\right)[(C_{\text{chamb}})_\infty - <C_{\text{indoor}}>] + <C_{\text{indoor}}>\lambda\right] 0.063 \times \frac{A_j}{0.25}, \quad (3)$$

where $(M_{\text{chamb}})_j$, $(C_{\text{chamb}})_\infty$ and $(C_{\text{chamb}})_i$ are the initial slope, equilibrium concentration and initial radon concentration of the radon chamber growth curve of covering j, respectively. The mean indoor radon concentration is $<C_{\text{indoor}}>$. The testing area of covering j is 0.25 m^2 and the chamber volume is 0.063 m^3. The area of covering j used in the sampled room is A_j. Since the radon emanation rate of the covering is defined as its production rate per unit exposing area, the radon emanation rate of covering j, E_j, can be obtained using Eqn (4).

$$E_j = \Omega_j / A_j. \quad (4)$$

RESULTS

The radon growth curve obtained by the sealed room method is presented in Figure 1. From the sealed room growth curve, the initial radon concentration was found to be 30 Bq m^{-3} and the equilibrium concentration was 750 Bq m^{-3}. The initial slope of the curve is 30.38 Bq m^{-3} h^{-1}. By Eqn (1), Ω_{Room} is found to be 360.0 Bq h^{-1}. The radon growth curves of wood floor, papered wall and granite windowsill, which were obtained from radon chamber tests, are presented in Figure 2. The initial slopes of the curves, applied areas, the radon apportioning production rates and emanation rates are summarized in Table 1. Using Eqns (2) and (3), Ω_{Apport} is found to be 341.8 Bq h^{-1}, which is 5.1% deviated from the result of the sealed room method.

Figure 1 Radon growth curve in sealed room measurement.

Figure 2 The measurement and theoretical profiles of three coverings in apportionment tests.

Table 1 The radon production and emanation rates of coverings in apportioning tests[a]

Coverings	Initial slope (Bq m^{-3} h^{-1})	Initial Rn conc. (Bq m^{-3})	Equilibrium Rn conc. (Bq m^{-3})	Mean indoor Rn conc. (Bq m^{-3})	Covering exposure area (m^2)	Covering Rn production rate (Bq h^{-1})	Covering Rn emanation rate (Bq m^{-2} h^{-1})
Papered wall and ceiling	50.88	95	660	25.8	23.38	337.6	14.44
Granite	17.31	5.5	850	20.41	0.4	1.7	4.32
Wood floor	1.53	87	238	27.5	4.08	2.4	0.59

[a]Remark: Volume of the radon chamber is $0.063m^3$ and the area of the tested materials is $0.25m^2$.

DISCUSSION

From Table 1, it can be found that the wood floor has the smallest radon production rate, papered wall has the largest rate and granite lies in between them. The wood floor, with the smallest radon emanation, is expected to have a proportional shielding ability as a covering material. The shielding ability can be characterized by the permeability, porosity, thickness and radon affinity of the covering. The wood floor is composed of three layers. The first layer is a PVC sheet, which is a poor-permeability material. It is directly put on the surface of bare concrete. The second layer is a plywood layer that is on the PVC sheet. The thickness of the layer is around 6 mm. The third layer is a wooden layer. It is made of wood slabs that are systematically nailed on the plywood layer. After nailing, the wooden floor is polished in order to get it flat and level. Waxing is the last step in the wooden floor processing. Waxing makes the floor shinier and seals the gaps between the slabs. Floor waxing may help inhibit radon emission. As a result, the wood floor has the low radon emanation rate. The papered walls and ceiling have the largest radon production rate among the coverings. It is believed that radon gas emitted from the bare concrete can diffuse through this fibre-based wallpaper. The radon shielding ability of the fibre-based wallpaper is not as great as the wood floor. The large exposure area of wallpaper is also a significant factor in the radon production rate. The radon production rate of granite is believed to be contributed by itself and not the underlying bare concrete material, since granite can act as a barrier to block radon emission from bare concrete. From the outcome of apportioning tests, indoor radon concentrations contributed by the papered wall and ceiling, granite and wood floor are 98.8, 0.5 and 0.7%, respectively.

CONCLUSION AND IMPLICATIONS

The current study concerns the radon production and emanation rates of building materials that are used in a room. The production rate of each component is proportional to the product of its emanation rate and the exposure area. Papered walls (walls and ceiling) are identified as the major indoor radon contributor because of their strong emanation rate and the largest exposure area. Wood floors are identified as minor radon contributors because of their complex structure and good workmanship. The apportionment method can be used to identify the major radon contributors of a building. However, the radon production rate of the room can be effectively obtained by the sealed room method. Based on the known effective radon production rate, the occupant can adjust the ventilation of his or her living space to reduce indoor radon down to the accepted level. The models are valid if the leakage rates of the sampled volumes are maintained less than 0.1 h^{-1}.

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