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Preliminary Study for 3D Radon Distribution Modelling in the Room

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1. Introduction

There are lots of hazardous materials in indoor air such as Formaldehyde, CO or dusts, and radon (referred as ^{222}Rn in this paper) is one of the hazardous material which is natural radioactive nuclide in indoor air. Radon exists in the form of noble gas, which comes from decay of ^{238}U, becoming stable ^{206}Pb going through 4 alpha and 4 beta decays. If this process occurred in human body after inhalation, lung could be damaged by interaction with these radiations causing lung cancer.

Most radon in indoor air comes from soil (85 – 97%) through crack of the wall but it also came from wall (2 – 5%) itself in home. Therefore, radon concentration is generally lower at high stories than ground, but some cases of which walls were made by radon rich materials show high radon concentration. Due to its hazardous and unpredictable characteristic, radon became one of the concerning nuclides in indoor air. Hence, the number of survey and research about radon has been increased.

Although accurate radon measurement is important to evaluate health risk, it is hard to actually achieve because radon is affected by many conditions, where its concentration can vary easily. Moreover, radon concentration can vary according to the height because of density of radon in the spatial aspect. Therefore, measured value in one rooms could be different. To find radon concentration in the room exactly, how radon in the room is distributed has to be investigated. In this study, fundamental 3D radon distribution modelling in the room is focused.

2. Methodological analysis

In this section some of the techniques used to model the 3D radon distribution are described. The modelling was progressed as sequence of basic parameter, room grid Aerodynamic modelling, thoron modelling, representative values, and other considerable conditions.

2.1 basic parameter

To start modelling radon distribution, ideal room definition was needed. The room was assumed perfect square and there are nothing in the room for simplification. Size of room was assumed 5 · 5 · 5 m, so volume of room was 625 m^3. Air in the room was assumed as ideal gas.

Radon came from walls, floors and ceiling which were radon concentration was generally maximum at this point. 5 scenarios was assumed as the number of radon rich walls, and 15 scenarios was assumed as whether floor and ceiling were radon rich or not.

Radon rich wall generated radon continuously, and the rate of radon generation could be defined G (Bq/m^2). Then, average radon concentration gradient in the room is followed equation (1).

$$\frac{dC}{dt} = \frac{GA}{V} - C_n(\lambda_{Rn} + \lambda_v) \quad (1)$$

Where C is radon concentration (Bq/m^3), G is radon generation rate (Bq/m^2/s), A is radon rich wall area (m^2), V is volume of the room (m^2), λ_{Rn} is radon decay constant(s^{-1}) and λ_v is air change rate in room (s^{-1}).

2.2 Room grid

For calculating fluid dynamics, the room was divided as small square grid structure as seen in figure 1. Smaller the size of a grid was more detailed radon distribution would be. At the edge of the wall, boundary condition for radon generation and air change was given. Each cell was calculated independently for its fluid transfer and affects to near cells.

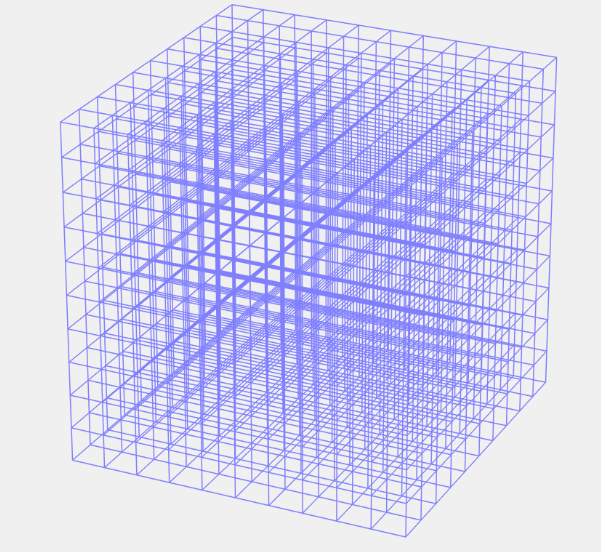

Fig. 1. Grid as 10 · 10 · 10 at ideal rooms

2.3 Aerodynamic transportation modelling

Radon acts as if it is fluid in indoor air, so its movement based on the Transport equation which is conservations of mass, momentum and energy.

The conservation of mass for radon is simply described as the following Eulerian type differential equation 2 [1].

$$\frac{\partial \mathrm{C}}{\partial \mathrm{t}} + \nabla uC = \nabla[(\mathrm{D_M} + \mathrm{D_T})\nabla \mathrm{C}] + \frac{\mathrm{E}}{x}t - (\lambda_v + \lambda_j + \lambda_{dj})C \quad (2)$$

Where C is mass concentration, u is velocity vector, D_M is diffusion coefficient by molecular motion, D_T is the diffusion coefficient by airflow turbulence, E is exhalation rate, λ_v is the ventilation rate, λ_j is the decay constant and λ_{dj} is the deposition rate.

The conservation of momentum is described in equation 3 for x, equation 4 for y coordinate, and equation 5 for coordinate [2].

$$\nabla(\rho uV) = \frac{\partial}{\partial x}\left(\mu\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right) + \frac{\partial}{\partial z}\left(\mu\frac{\partial u}{\partial z}\right) - \frac{\partial p}{\partial x} \quad (3)$$

$$\nabla(\rho vV) = \frac{\partial}{\partial x}\left(\mu\frac{\partial v}{\partial x}\right) + \frac{\partial}{\partial y}\left(\mu\frac{\partial v}{\partial y}\right) + \frac{\partial}{\partial z}\left(\mu\frac{\partial v}{\partial z}\right) - \frac{\partial p}{\partial y} \quad (4)$$

$$\nabla(\rho wV) = \frac{\partial}{\partial x}\left(\mu\frac{\partial w}{\partial x}\right) + \frac{\partial}{\partial y}\left(\mu\frac{\partial w}{\partial y}\right) + \frac{\partial}{\partial z}\left(\mu\frac{\partial w}{\partial z}\right) - \frac{\partial p}{\partial x} + pg \quad (5)$$

Where ρ is density of indoor air, u, v, w is velocity component in x, y, z coordinates, V is flow velocity vector, p is pressure and μ is viscosity of indoor air.

Solving these differential equation for each cells, 3D radon distribution mapping for the room is possible.

The general form of the conservation of energy in indoor air is described in equation 6.

$$\frac{\partial(\rho C_p T)}{\partial t} + \nabla(\rho C_p TV) = \nabla(k\nabla T) + S \quad (6)$$

Where C_p is specific heat capacity of the air, k is the thermal conductivity, T is temperature and S is energy source. At equilibrium, the conservation of energy reduce to equation 7[3].

$$\nabla(\rho C_p TV) = \nabla(k\nabla T) \quad (7)$$

2.4 Thoron modelling

Thoron, which is known as ^{220}Rn is one of radionuclide of radon, it is decayed from thoron. Thoron also comes from walls, but its half-life is smaller than that of radon as 55s. Decay chain and Human Respiratory Tract Model (HRTM) of thoron are different with ^{222}Rn, so hazard of thoron was evaluated separating ^{222}Rn. Distribution of thoron in indoor air at the room was shown different figure because of sources and half-life difference.

2.5 Representative values

Concentrations of radon is based on many variable, so it is variable in indoor air as the position in the room. Therefore, it is needed to set representative values for radon concentrations to evaluate health risks. Average of radon in the room in one of possible candidates for it, but it is not appropriate to use it to evaluate health risks.

Radon is heavier than atmosphere, so it generally more abundant near floor, so the height of the place which has average radon concentration is close to floor and fixed. However, most radon are affected to human as inhalation, so height of human nose is critical values and it depends on ages, and behavior at the rooms, such as office works, sleeping, having a meal. Thus, representative values had to be variable as dwelling scenarios in the rooms.

As research from Korean Agency for Technology and Standards, height from feet to eyes of 20~24 ages was 156.4 cm, and height from feet to eyes of 20~24 ages with sitting was 81.3 cm[4]. Assuming height of eyes is same as nose, it is applicable 156.4 cm to representative value for rooms which field work mainly carried out, and 81.3 cm for rooms which office works mainly carried out.

2.6 Other conditions

There are some conditions for radon modelling for modelling detail. Concentration of radon became lower because of natural or artificial ventilation at the windows, doors, and fans. There are occupy specific area in the wall, and air exchange occurred, so ventilation had to be considered at cells in that area.

Most radon came from soil through the crack, specifying soil concentration and crack at wall modelling also important issue for radon distribution modelling. Soils below the rooms and radon inflow through cracks had to be considered for radon distribution modelling.

3. Conclusions

3D distribution modelling in the room of radon with aerodynamic features and sources variations was carried out to find average and maximum radon concentration. Each cell acts were analyzed from conservation of mass, momentum and energy for the room of square grid. 3D radon distribution in the room would be find through this computational analysis and it is thought to be possible to correct measured radon concentration with spatial variation to fit the height of nose where inhalation occur. The methodological concept for 3D modelling was set up to solve transport equation for radon behavior by using computational fluid dynamics (CFD) software such as FLUENT.

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