Investigation the building walling influence on the radon concentration distribution in the soil

IOP Conf. Series: Materials Science and Engineering 463 (2018) 022027 doi:10.1088/1757-899X/463/2/022027

Investigation the building walling influence on the radon concentration distribution in the soil

N V Bakaeva[1], A V Kalaydo[2]

[1]Southwest State University, Kursk, Russia
[2]Russian Academy of Architecture and Building Science Research Institute of Building Physics, Moscow, Russia

E-mail: kalaydo18@mail.ru

Abstract. Radon and its progeny in the indoor air form more than 70 % of the annual individual radiation dose for a modern human; they are the second leading cause of lung cancer after smoking. Under such conditions ensuring of the buildings radon safety is an extremely important scientific and practical problem, which is especially relevant for projected constructions. In this case mathematical simulation is the only way to predict radon levels in the future. Soil under the building is the main source of radon entry in indoor air, therefore radon safety of building project is determined by the construction and condition of its underground walling. The article deals with the influence of the building structural features on the amount of radon load on underground walling as one of the main factors of the formation of the radon conditions in the building. Two-dimensional stationary model of diffusion radon transport in the system «soil-atmosphere-building» is used for the calculation of radon concentration fields in the soil air of the base of the building. The obtained fields of radon concentration in the soil air give an opportunity to estimate the changes in the radon field in the neighbourhood of the building.

1. Introduction

Nowadays a human spends more than 7,000 hours per year in apartments and only about 2,000 hours in the outdoor. As a result, indoor radon-222 exposure plays the leading role in the formation of population individual annual dose from ionizing radiation sources not only in the Russian Federation [1; 2], but also in the European and North American countries [3-5]. At the same time the main danger are the short-lived radon-222 progeny (Figure 1, a): ^{218}Po (RaA), ^{214}Pb (RaB) and ^{214}Bi (RaC), incoming the lungs during the respiration and decaying there because of a small half-life. Another isotope radon-220 or thoron *Tn* (Figure 1, b) is a decay product of Thorium. It has a much shorter half-life (54 s), so it doesn't have a time to migrate significantly from the formation source, which is why it is not as dangerous as the main isotope radon-222.

Radon and its decay products exposition in dwellings is the reason from 10 to 14% of population lung cancer cases [6]. Now the radon and its progeny radiation in dwellings is officially recognized as the second most serious (after smoking) cause of lung cancer death and radon is assigned to the first group carcinogens. The quantitative characteristic of the radon concentration in indoor air is the equivalent equilibrium radon concentration (EERC) of radon-222 and radon-220 (thoron) isotopes

$$EERC = EERC_{Rn} + 4.6 \cdot EERC_{Tn}, \tag{1}$$

where the equivalent equilibrium radon isotopes concentrations are

IOP Conf. Series: Materials Science and Engineering 463 (2018) 022027 doi:10.1088/1757-899X/463/2/022027

$$EERC_{Rn} = 0{,}105 \cdot RaA + 0{,}515 \cdot RaB + 0{,}380 \cdot RaC, \tag{2}$$

$$EERC_{Tn} = 0{,}913 \cdot ThB + 0{,}087 \cdot ThC. \tag{3}$$

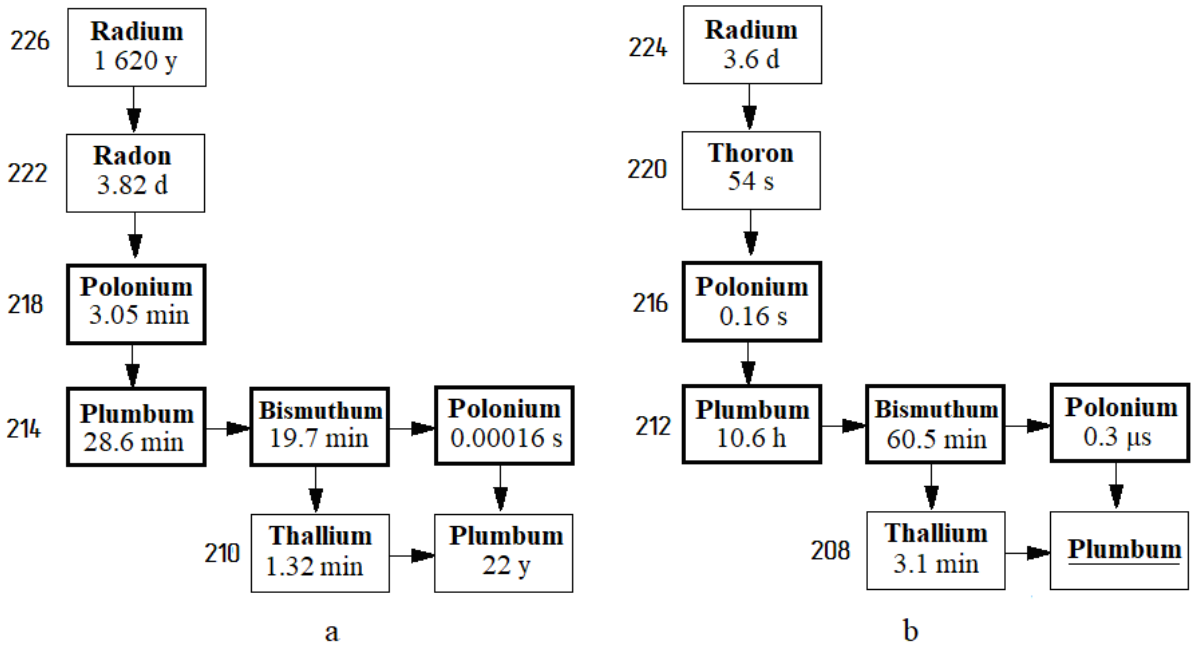

Figure 1. Radon-222 (a) and thoron (b) progeny

The requirements for the radon exposure limitation in buildings are contained in the Russian Radiation Safety Standards, which set the following control levels of EERC: 200 Bq·m^{-3} for the exploited buildings and 100 Bq·m^{-3} for new and reconstructed buildings. However, indoor radon levels that are considered to be reasonably low today may not of the same level in near future. Therefore, it is necessary to have an ability to calculate the radon situation in the building, taking into account its determining factors, but it should be borne in mind that the prediction of radon levels in buildings is quite a difficult task due to the multifactor process of radon situation formation.

The soil under the building is the main radon source in the indoor air [8-10], its contribution to the indoor radon concentration amounts to more than 90%. Secondary processes are the radon exhalation from the walling materials and its infiltration entry with atmospheric air. The radon entry with water and natural gas are so low that they do not need to be accounted at the radon situation simulation [20].

The intensity of radon entry from the soil can vary widely by constructive means and depends on a number of different nature factors with a simultaneously action. Nazaroff, Wang et al. think that the building basement geometry play the leading role in radon transport from soil into the lower floor indoor air [8-9, 16]; Revzan, Fisk, Andersen, et al. consider the soil air entry through the leaks in the building shell under the temperature-induced pressure difference action [7, 11, 14-15]. Kohl, Nielson et al. [12, 19] consider the diffusion and convective radon transport through the underground walling. They determine the dominant transport mechanism depending on the soil base permeability. Jelle also accounts the role of walling materials air permeability with the soil permeability [13], the influence of building ventilation modes was made in [18].

The considerable discrepancy between the results of model studies and the levels of radon observed in full-scale experiments is typical for the majority of the known models and can be explained by the uncertainty of the dominant mechanism of radon transfer through underground enclosing structures and the exclusion from consideration of the mass radon flow from the ground into the atmosphere [17]. In addition, all the models discussed above distinguish the determining factor associated with the

IOP Conf. Series: Materials Science and Engineering 463 (2018) 022027 doi:10.1088/1757-899X/463/2/022027

physical characteristics of the soil, the structure of the building or the environment [7]. At the same time, subsystems "ground", "atmosphere" and "building" interact with each other, and therefore the process of the radon situation forming must be considered within a single system of environments.

2. Materials and methods

In the open area radon moves freely to the surface and emerges into the atmosphere in the open areas, and in the upper homogeneous soil layers forms a one-dimensional field of radon concentration. In this case, the radon concentration isolines in soil air are parallel to the daily surface and the maximum radon concentration established at a depth, which exceed the radon diffusion length in the soil. This radon concentration in undisturbed soil is called the soil radon potential P_{Rn}

$$P_{Rn} = A_{Ra}\rho f \tag{4}$$

where A_{Ra} is the mass activity of radium Ra^{226} in the soil, Bq·kg^{-1}; ρ is the soil density, kg·m^{-3}; f is the soil radon emanation coefficient.

The building on the soil is an obstacle to the free radon discharge into the atmosphere. As a result, a three-dimensional radon field is formed in the soil block around the building underground walling. As it was shown above, the radon situation in the building determined by the radon flux density through the horizontal walling on 90%

$$q_n = \Delta A/R \tag{5}$$

where ΔA is the radon concentration difference between the soil air and indoor air, Bq·m^{-3}; R is the walling radon resistance, s·m^{-1}.

Radon concentration in the soil air is at least two orders of magnitude higher than the indoor radon concentration and concentration difference ΔA can be assumed equal to the radon concentration in the soil air at the outer boundary of the horizontal underground walling. To determine the rate of radon entry from the soil into the building it is necessary to know the magnitude and distribution character of radon concentration in the soil air under the building basement. The two-dimensional stationary model of diffusion radon transport in the media system "soil-atmosphere-building" was developed for the estimate the radon concentration distribution in the building soil foundation (Figure 2).

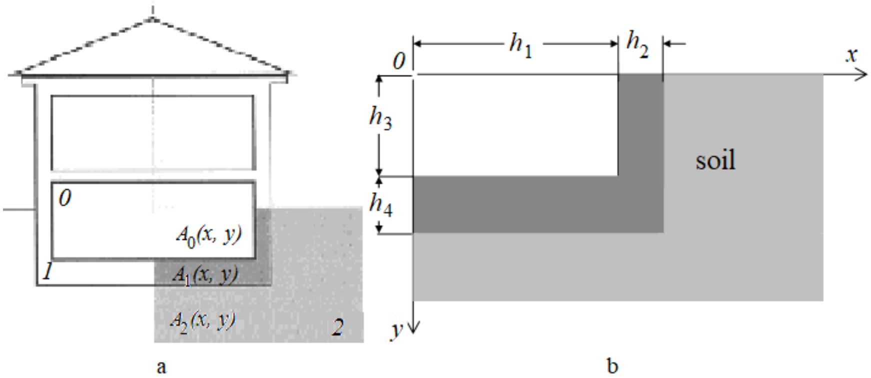

Figure 2. Situational scheme (a) and the scheme of the system elements binding to the coordinate axes (b)

The following assumptions were used during the model constructing:
- the radon sources are the soil under the building, the walling materials and incoming outside air;
- diffusion is the only mechanism of radon transport in the soil and walling materials;
- indoor radon is instantly and evenly distributed over the room volume;
- there is no horizontal radon transport from the soil through vertical underground walling;
- the building width is much less than its length, and the building is symmetrical, which allows us to consider half its length.

The model is a system of linear equations

$$D_i(\partial^2 A_i/\partial x^2 + \partial^2 A_i/\partial y^2) - \lambda A_i(x, y) + W_i = 0,\ i = 1, 2 \tag{6}$$

where D_1 and D_2 are the radon diffusion coefficients in the walling material and in the soil, respectively, m^2·s^{-1}; A_1 and A_2 are the radon concentrations in the walling material and in the soil air, respectively, $Bq \cdot m^{-3}$; W_1 and W_2 are the radon generation rate in the walling material and in soil, respectively, $Bq \cdot m^{-3} \cdot s^{-1}$; $\lambda = 2{,}1 \cdot 10^{-6}$ is the decay constant of radon-222, s^{-1}.

The boundary conditions have the next form:

- gas exchange condition at the "soil-atmosphere" boundary

$$D_2(\partial A_2/\partial y) = \alpha A_2 \text{ if } y = 0, x \geq h_1 + h_2 \quad (7)$$

- fluxes and activities equality at the "walling - soil" media boundary

$$D_1(\partial A_1/\partial x) = D_2(\partial A_2/\partial x), A_1 = A_2 \text{ if } x = h_1 + h_2, 0 \leq y \leq h_3 + h_4, \quad (8)$$

$$D_1(\partial A_1/\partial y) = D_2(\partial A_2/\partial y), A_1 = A_2 \text{ if } y = h_3 + h_4, 0 \leq x \leq h_1 + h_2, \quad (9)$$

- radon flux absence at the outer boundaries of the calculation region

$$D_2(\partial A_2/\partial x) = 0 \text{ if } x = 0, y \geq h_3 + h_4, \quad (10)$$

$$D_1(\partial A_1/\partial x) = 0 \text{ if } x = 0, h_3 \leq y \leq h_3 + h_4, \quad (11)$$

$$D_1(\partial A_1/\partial y) = 0 \text{ if } y = 0, h_1 \leq x \leq h_1 + h_2, \quad (12)$$

- air exchange conditions at the "walling - indoor air" media boundary

$$D_1(\partial A_2/\partial y) = \alpha A_1 \text{ if } y = h_3, 0 \leq x \leq h_1, \quad (13)$$

$$D_1(\partial A_2/\partial x) = \alpha A_1 \text{ if } x = h_1, 0 \leq x \leq h_3, \quad (14)$$

where h_1, h_2, h_3 and h_4 are the linear dimensions (Figure 2, b), m; α = 0,1 is the gas exchange coefficient between the walling surface and the indoor air.

3. Results

The radon concentrations field in the soil for the building depths from 0.5 to 10 m was found by means of using the described mathematical model. Figure 3 shows the modeling results of the radon concentration field in the soil basement at two building foundation depths (3 and 6 m). determined for the In the calculations the radon diffusion coefficient was taken $D_2 = 5 \cdot 10^{-8}$ $m^2 \cdot s^{-1}$. The lower isoline is the soil radon potential, in this case its value is 45,000 $Bq \cdot m^{-3}$, the next lines values of the decreasing to the soil surface in increments of 1,000 $Bq \cdot m^{-3}$. The building presence changes the natural distribution of radon concentration in soil significantly, in undisturbed soil the isolines are parallel to the daily surface.

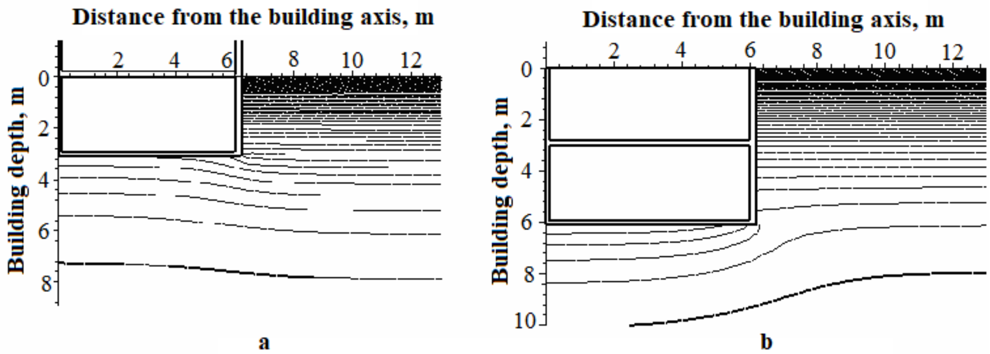

Figure 3. The radon concentration in the soil for the building depth 3 m (a) and 6 m (b)

The developed mathematical model was also used to study the significance and direction of the factors determining the radon situation in the building. The radon load N (the average radon concentration in the contact plane between the building basement and the soil) is the most important parameter of the indoor radon situation formation. In numerical experiment was studied its relation with the soil radon potential and the building foundation depth (Figure 4).

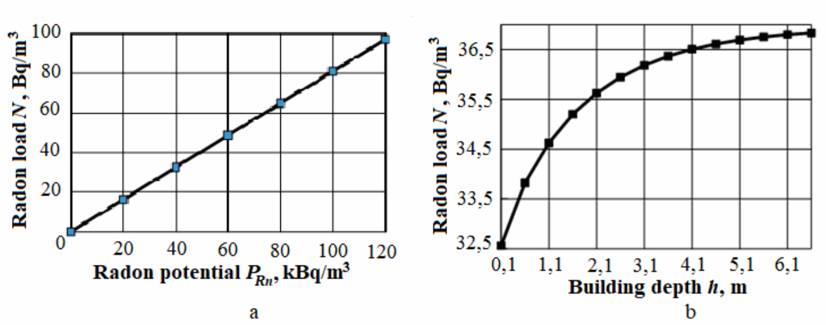

Figure 4. Radon load dependence on the soil radon potential P_{Rn} (a) and the building depth h (b)

Figure 4 shows that the radon load increases non-linearly with the increase in the building depth and approaches asymptotically to the soil radon potential. The radon load on the underground horizontal walling is slightly less than the soil radon potential and the closer to it with the soil air permeability decreasing and increasing the radon resistance of underground horizontal walling.

4. Conclusions

Three conclusions can be drawn from this study:

1. The soil under the building is the main source of indoor radon in the lower floor apartments; therefore the buildings' radon-protective properties must be laid at the design stage and provided the underground walling.
2. The calculation of radon entry from the soil into the indoor air is possible on the basis of diffusive radon transport model due to the use in modern construction of the underground walling with the high radon resistance.
3. The radon concentration fields in the soil under the building were obtained basing on the model. It showed much higher soil radon concentrations at the external border of underground horizontal walling than a few meters outside the building in the undisturbed soil. At the same time, the distortion rate of the radon concentration field increases with the increase in the building basement depth.

References

[1] Yarmoshenko I, Onishchenko A and Zhukovsky M 2013 *Establishing a regional reference indoor radon level on the basis of radon survey data* (J. Radiol. Prot.) 33 pp 329-338

[2] Vasilyev A and Zhukovsky M 2013 *Determination of mechanisms and parameters which affect radon entry into a room* (J. Environ Radioact.) 124 pp 185-190

[3] Mehra R, Jakhu R, Bangotra P, Kaur K and Mittal H 2016 *Assessment of inhalation dose from the indoor ^{222}Rn and ^{220}Rn using RAD7 and pinhole cup dosimeters* (Radiat. Prot. Dosimetry) 171 (2) pp 208–211

[4] Abd El-Zaher M 2011 *Seasonal variation of indoor radon concentration in dwellings of Alexandria city, Egypt* (Radiat. Prot. Dosimetry) 143 (1) pp 56-62

[5] *United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and Effects of Ionizing Radiation. UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes*. Vol 1 (New York: United Nations) p 102

[6] *Health Effect of Exposure to Radon 1999 Committee on Health Risks of Exposure to Radon (BEIR IV)*. (Washington: National Academy Press)

[7] Revzan K and Fisk W 1992 *Modeling Radon Entry into Houses with Basements: The Influence of Structural Factors* (Indoor Air) 2 pp 40-48

[8] Nazaroff W W, Moed B A and Sextro R G 1988 *Soil as a source of indoor radon: generation, migration and entry*. (In: Nazaroff W W and Nero Jr A V, editors.) Radon and its decay products in indoor air (New York: John Wiley & Sons) p 615.

[9] Fan Wang and Ian C Ward 2000 *The development of a radon entry model for a house with a cellar* (Building and Environment) 35 pp 615–631

IOP Conf. Series: Materials Science and Engineering 463 (2018) 022027 doi:10.1088/1757-899X/463/2/022027

[10] Nero AV and Nazaroff W W 1984 *Characterizing the source of radon indoors (R*adiat. Prot. Dosimetry) 7 pp 23-29

[11] Andersen C E 1992 *Entry of Soil Gas and Radon into Houses, Riso Nat. Lab.,* Roskilde, Riso-R-623

[12] Kohl T, Medici F and Rybach L 1994 *Numerical simulation of radon transport from subsurface to buildings* (J. of Appl. Geophysics) 31 pp 145-152

[13] Jelle B P 2012 *Development of a model for radon concentration in indoor air* (Science of the Total Environment) 416 pp 343-350

[14] Gadgil A J 1992 *Models of radon entry (R*adiat. Prot. Dosimetry) 45 (1-4) pp. 373-380

[15] Andersen C E, Spgaard-Hansen J and Majbom-Rise B 1994 *Soil gas and radon entry into a simple test structure: comparison of experimental and modelling results (R*adiat. Prot. Dosimetry) 36 (1-4) pp 151- 155

[16] Fan Wang and Ian C Ward 2002 *Radon entry, migration and reduction in houses with cellars* (Building and Environment) 37 pp 1153-65

[17] Diallo T, Collignan B and Allard F 2015 *2D Semi-empirical models for predicting the entry of soil gas pollutants into buildings* (Building and Environment) 85 pp 1-16

[18] Fan Wang and Ian C. Ward 1997 *Modelling Multiple Radon Entry and Transport in a Domestic Dwelling* (Building and Environment*)* 32 (4) pp 341-350

[19] Rogers V C and Nielson K K. 1988 *Radon emanation and transport in porous media.* In: Osborne, M.; Harrison, J. (cochairs). Proceedings of the 1988 EPA Symp. on Radon and Radon Reduction Methods, Vol. I, Oral Papers. (U.S Environmental Protection Agency publication EPA/600/9-891006a).

[20] Scott A G 1993 Modeling radon sources and ingress *The 1993 International Radon Conference*, *September 20-22, Denver, Colorado* Vol. IV pp 66-74