MODELLING RADIATION EXPOSURE IN HOMES FROM SIPOREX BLOCKS BY USING EXHALATION RATES OF RADON

by

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Building materials are the second major source of indoor radon, after soil. The contribution of building materials to indoor radon amount depends upon the radium content and exhalation rates,which can be used as a primary index for radon levels in the dwellings. This paper presents the results of using the experimentally determined exhalation rates of siporex blocks and concrete plates, to assess the radiation exposure in dwellings built of siporex blocks. The annual doses in rooms have been estimated depending on the established modes of ventilation. Realistic scenario was created to predict an annual effective dose for an old person, a housewife, a student, and an employed tenant, who live in the same apartment, spending different periods of time in it. The results indicate the crucial importance of good ventilation of the living space.

Key words: radon, exhalation rate, radiation exposure, siporex, concrete, modelling

INTRODUCTION

Radon (^{222}Rn) and its progeny are present in all dwellings, because radium is present in building materials as well as in the soil. It is important to understand the generation and migration process of radon from building materials, which contributes to 55% of total radiation dose received by the population from the environment [1]. A research, dealing with the radiation exposure induced by radon decay products in homes, has shown that the cause of increased radiation may as well be the construction material of the building. When estimating an average annual radiation exposure, one should also take into account life at home, because the level of radiation can be higher within homes than outside, bearing in mind that the walls themselves can contain and emit radionuclides. Depending on the type of the construction material and ventilation efficiency [2, 3], radiation indoors can be many times higher than outdoor, and as such, it represents a serious health hazard. The average annual dose in Europe from radon and its progeny, in homes and workplaces, is estimated to be 1.6 mSv.

In order to determine activity concentration of radon in siporex blocks and concrete, exhalation measurements were performed by a closed chamber method [4, 5] and then used to calculate annual doses in dwellings made out of siporex blocks. Impact of radon concentration activity from the construction material, on annual doses, depending on the established ventilation mode, has been analyzed. Since the main source of radon and its progeny is soil, this simulation should consider only apartments on higher floors in a modern residential building [6, 7].

Depending on the established mode of ventilation, the radon activity concentrations and the annual effective doses in rooms, have been estimated. Four scenarios for different types of tenants were created to predict the dose received by an old person, a housewife, a student, and an employed tenant, who live in the same apartment.

BASIC DATA NECESSARY FOR THE DOSE ASSESSMENT IN HOMES

Siporex and concrete exhalation rates

Radon gas is formed inside building materials by decay of the parent nuclide ^{226}Ra. However, it is not possible to determine the radon exhalation rate simply from the activity concentration of ^{226}Ra. Instead, one must measure radon exhalation rates directly at the surface of the material, as shown by many studies in the literature [4, 8-12]. There are various methods for measuring the radon exhalation rate of building materials,

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such as the accumulation method, which involves open and closed chamber method, the charcoal method, and the solid state nuclear track detector method, [4, 8, 9]. The closed chamber method, essentially a kind of accumulation method, which takes into account the leakage of the accumulation chamber and the back diffusion rate, is widely used in the measurement of the radon exhalation rate of building materials [10-12]. On the other hand, for application of this method, it is necessary to conduct active, continuous monitoring of radon concentration inside the chamber [5, 12, 13].

The radon exhalation rate E (Bqm^{-2}h^{-1}) is defined as the quantity of radon activity liberated from the surface area of building materials per unit of time. Using this value and the area of the indoor surface, radon emanated per unit of time could easily be calculated and applied to estimate the radon concentration in the indoor environment. Radon exhalation rates of siporex and concrete were determined by already developed closed chamber method with active continuous radon measurement technique [5]. Measurements were performed by means of certified Safety Siren radon detectors (Family Safety Products Inc.). As previously stated, the closed chamber method takes into consideration two main factors that could influence the exhalation rates. By checking both of the factors, it was found that back diffusion can be neglected and the chamber leakage λ, which can be described by the rate of chamber's ventilation, was obtained to be λ = 0.0028 h. This value agrees well with the previously published data for closed chambers, with volumes of up to 1.5 m^3 [13, 14].

In order to eliminate moisture content, the siporex and concrete samples were dried in an oven at 110 ºC and then put into compartments until saturation time occurred (5-7 days). Using a technique, previously developed to measure the radon exhalation rates of granites, with an accepteble level of confidence [5, 15], the exhalation rates for siporex and concrete were determined to be E_s = 0.212 0.03 Bqm^{-2}h^{-1} and E_c = 0.210 0.03 Bqm^{-2}h^{-1}, respectively.These data are in good agreement with the mean values of the exhalation rates obtained by measurements performed with an online radon measuring device, for 104 samples of concrete and 14 samples of siporex (aerated concrete) [16].

Building materials and dwelling model

In fig. 1, we present a simplified model of a home with the basis of 48 m^2, whose walls are built of

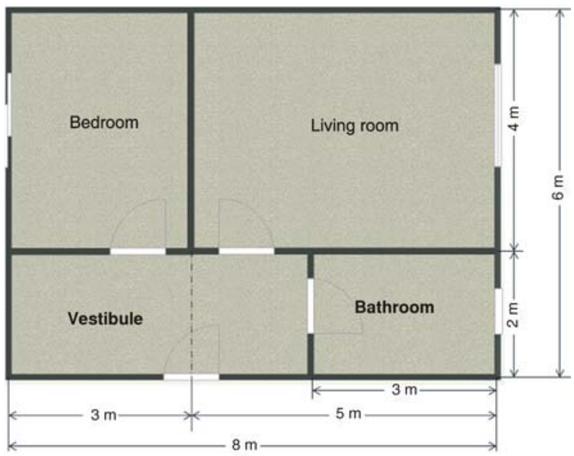

Figure 1. Floor plan with dimensions of residential premises

siporex blocks 0.25 m thick and 0.6 g/cm^3 dense, while floors and ceilings are made of a 2.3 g/cm^3 dense concrete.

The assumption is that the home consists of four rooms: bedroom, living room, vestibule, and bathroom and the height of the apartment is 2.2 m. In the center of each room, there is a recipient (tenant) who spends some required time in it. Table 1 shows room dimensions as well as total walls surface and volumes of the rooms.

Radon activity concentration

Radon activity concentration C_{Rn} originating from siporex and concrete can be calculated directly as [1, 13]

$$C_{\text{Rn}} \quad \frac{EA}{V\lambda_v} \qquad (1)$$

where E is the radon exhalation rate for siporex or concrete, A – the total surface of siporex wall in the rooms, or the surface of ceilings and floors made of concrete, V – the volume of the room, and λ_v – the room ventilation rate.

In this way, radon activity concentration was calculated for each room by using experimentally obtained values of the radon exhalation rate E for siporex and concrete, and the total activity concentration for a room is determined as the sum of the concentrations originating from siporex blocks and concrete, separately. For each room, radon activity concentrations are obtained by changing air ventilation rate λ_v (fig. 2).

Table 1. Dimensions of the rooms

Room type	Room dimensions [m]	Total windows and doors surface [m^2]	Total walls surface made of siporex [m^2]	Total floor and ceiling surface made of concrete [m^2]	Room volume [m^3]
Living room	4 5	4.39	35.21	40	44
Bedroom	4 3	4.92	25.88	24	26.4
Vestibule	2 5	5.54	25.26	20	22
Bathroom	2 3	2.37	19.63	12	13.2

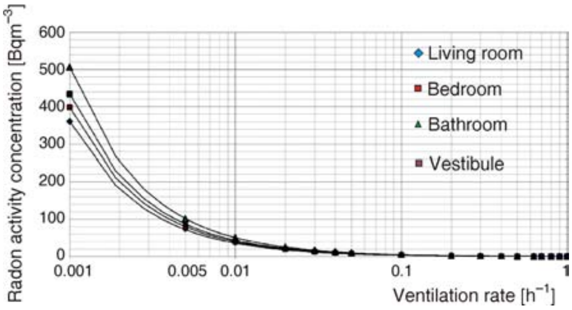

Figure 2. Dependence of the radon activity concentration on ventilation rate

In the literature, the air ventilation rates range from 0. 2 per h to 2 per h, while the average value is 0.63 per h [13]. In this paper,for estimation of exposure to exhaling radon, 17 room ventilation rates were used in the range from 0.001 per h to 1 per h.

DOSE ASSESSMENT

Calculation of the annual effective dose

The annual effective dose *H*, received by tenants, due to inhalation of radon originating from building material, has been calculated by the following expression [1, 14]

$$H \quad C_{\mathrm{Rn}} \quad \mathrm{F} \quad \mathrm{O} \quad DCF \qquad (2)$$

where F is the radon equilibrium factor (0.4), O – the occupancy factor expressed as the total number of hours which the inhabitant spends in the room in one year, and *DCF* – the dose conversion factor (9 nSv/Bqm^3 for radon).

For each room, the annual effective dose *H* is determined by changing the air ventilation mode, wherein for each mode of ventilation, three different periods of time, spent by tenants in a specific room, were assumed. The obtained results for annual equivalent dose, in each room, are presented in fig. 3(a-d).

Furthermore,the annual effective dose in rooms, for the two residence times (2 h and 10 h) and for the minimum (λ_v = 0.001 h), average (λ_v = 0.63 h), and maximum (λ_v =1 h) ventilation modes, is calculated and presented in tab. 2.

It is evident from tab. 2 that the mode of ventilation has the biggest impact on the annual effective dose received by a tenant. Thus, at the minimum ventilation (λ_v = 0.001 h) and for a modest time period of two hours a day, spent in the room, the annual dose exceeds permissible level of 1 mSv per year in every room, except for the living room where it is at the edge of the permitted level (0.948 mSv). The annual effective dose proportionally increases with prolonged stay in a room. However, even with the medium intensity of ventilation (λ_v = 0.63 h), the annual dose received by a tenant becomes negligible regardless of the time spent in any room.

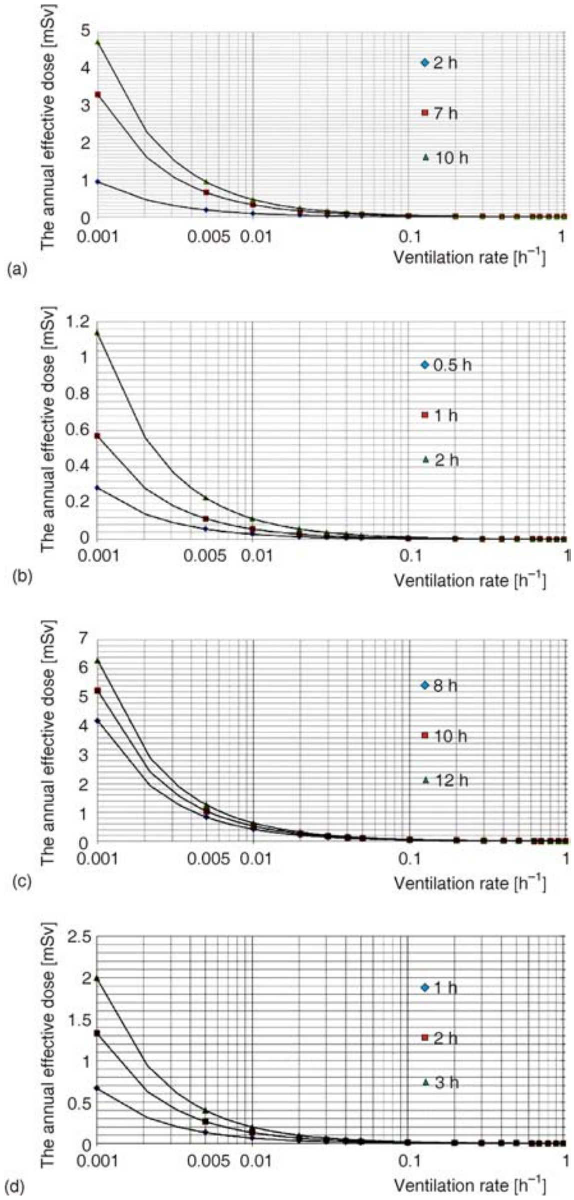

Figure 3. Total annual radiation exposure of a recipient in the living room (a), vestibule (b), bedroom (c), and bathroom (d), depending on the airflow mode

Calculation of dose depending on the four tenant scenarios in apartment

In tab. 3, the four scenarios for different types of tenants are presented, assuming that each of them spends an appropriate period of time in every room of the apartment and a part of the day outside of home. On this basis, the minimum, average, and maximum annual doses received by tenants during their stay in the apartment are calculated corresponding to the maximum, average, and minimum air ventilation.

We can see, from tab. 3, that the highest dose will be received by an old person, who spends 22 hours in the apartment and 2 hours outside, followed by a housewife who spends only 3 hours outside the apart-

Table 2. Annual effective dose (in mSv) for tenants, which spend 2 hours or 10 hours per day in different rooms, with three modes of ventilation

Time [h]	Mode of ventilation, λ_v [h^{-1}]	Living room	Vestibule	Bedroom	Bathroom
2	0.001	0.948	1.14	1.05	1.33
	0.63	0.002	0.002	0.002	0.002
	1	0.001	0.001	0.001	0.001
10	0.001	4.74	5.71	5.24	6.65
	0.63	0.008	0.009	0.008	0.011
	1	0.005	0.006	0.005	0.007

Table 3. Scenario and doses for tenants in apartment

Tenant		Old person	Student	Housewife	Employed person
Living room		10 h	6 h	8 h	3 h
Vestibule		1 h	1 h	2 h	1 h
Bathroom		1 h	2 h	3 h	1 h
Bedroom		10 h	9 h	8 h	9 h
Period outside		2 h	6 h	3 h	10 h
Annual effective dose [mSv]	Minimum	0.011	0.009	0.011	0.009
	Average	0.01	0.01	0.01	0.01
	Maximum	11.21	9.45	11.11	8.03

ment. The lowest annual effective doses in both modes of ventilation will be received by an employed person and a student, in agreement with the maximum number of hours spent outside home. In addition, it is confirmed that in the hypothetical situation of the apartment without ventilation, the annual doses significantly exceed the permissible level of 1 mSv, while in case of good ventilation the doses can be ignored.

CONCLUSION

The annual effective dose received by a tenant living in residential premises built from siporex blocks is in the acceptable limit if the moderate ventilation is provided. The results have pointed out the necessity of a regular ventilation of apartments, by means of air exchange with the environment, in order to reduce the annual effective dose and so the threat to the health of the tenants.

AUTHORS' CONTRIBUTIONS

The experiments and calculations were carried out by M. D. Nikolić and manuscript was written by M. D. Nikolić and D. R. Simović. All authors analyzed results and participated in preparation of the final version of the manuscript.

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МОДЕЛОВАЊЕ ИЗЛАГАЊА ЗРАЧЕЊУ У СТАНОВИМА ОД СИПОРЕКСА ПОМОЋУ ЈАЧИНЕ ЕКСХАЛАЦИЈЕ РАДОНА

Грађевински материјали представљају после земљишта други најважнији извор радона у затвореним просторијама. Допринос грађевинских материјала количини радона у просторијама зависи од садржаја радијума у њима и јачине ексхалације, те су они примарни чиниоци који доприносе нивоу радона у становима. У овом раду приказани су резултати коришћења експериментално одређених јачина ексхалације сипорекс блокова и бетонских плоча ради процене изложености зрачењу у становима изграђеним од сипорекс блокова. Одређене су годишње дозе у просторијама у зависности од оствареног начина вентилације. На основу претпостављеног реалистичног сценарија боравка процењене су годишње ефективне дозе за стару особу, домаћицу, ученика и запосленог укућана, који живе у истом стану проводећи у њему различито време. Резултати указују на суштински значај доброг проветравања стамбеног простора.

Кључне речи: радон, јачина ексхалације, излагање зрачењу, сипорекс, бетон, моделовање