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# Applicability of various insulating materials for radon barriers

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## Abstract

The effectiveness of various insulating materials for limiting radon entry into houses has been investigated under laboratory conditions. Results for the radon diffusion coefficient measurements in more than 80 insulating materials are summarized. We have discovered that great differences exist in diffusion properties, because the diffusion coefficient varies within four orders from $10^{-13}$ $m^2/s$ to $10^{-10}$ $m^2/s$. A methodological approach is proposed in order to identify the minimal thickness of radon-proof membranes, depending on building and soil characteristics. General guidelines for the selection of radon-proof insulation are presented. © 2001 Elsevier Science B.V. All rights reserved.

*Keywords:* Radon; $^{222}Rn$; Diffusion; Radon mitigation; Membranes

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## 1. Introduction

Damp-proof or waterproof insulation placed over the entire surface of the floors and basement walls in contact with the soil can prevent radon from entering buildings from the soil. Our experience confirms that some kinds of the above mentioned insulation can be considered as one of the most effective radon reduction systems for new houses (Jiránek, 1996). However, due to the lack of information, the correct selection of radon-proof insulation from the total amount of materials is very difficult.

## 2. Experimental methods

To provide an answer to the question of what kind of insulation can be considered radon-proof, we have studied the most important mechanical and physical properties of insulating materials as

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well as their diffusion properties by means of the radon diffusion coefficient. Determination of radon diffusion coefficients was based on the measurement of the radon flux through the tested material placed between two cylindrical containers. A detailed description of the measuring method has been presented by Hůlka and Jiránek, 1996.

## 3. Results

### 3.1. Mechanical and physical properties of insulating materials

Insulating materials must function effectively over their required service time. From this point of view, preference should be given to insulating materials with longer durability and a higher resistance to aging, i.e. suitable materials include PVC or PE foils and membranes based on plastomeric (APP modification) or elastomeric (SBS modification) bitumen. On the other hand, membranes based on oxidized bitumen should not be applied, because their resistance to soil corrosion as well as to weathering is very low. For reinforcing fabrics, only membranes with moisture resisting fabrics made of mineral, glass or synthetic fibers should be used. Concerning application aspects, bonded sheets (fully adhered to the substrate) represent a higher degree of protection compared to unbonded sheets, which rely on perfect joints to a far greater extent than bonded membranes, because radon can travel in the air gap beneath the unbonded membranes to the loose places in the insulation.

### 3.2. Radon diffusion coefficients

The results of the radon diffusion coefficient *D* measurement, realized by the Faculty of Civil Engineering of the Czech Technical University in Prague and by the National Radiation Protection Institute in more than 80 insulating materials available throughout Europe, are summarized in Fig. 1. Generalizing results obtained up to now, we have found out that for the most often used insulation, the diffusion coefficient varies between $10^{-13}$ m$^2$/s and $10^{-10}$ m$^2$/s.

The lowest values of the radon diffusion coefficient *D* were obtained for polypropylene foils. In HDPE foils with dimples, the coefficient varies

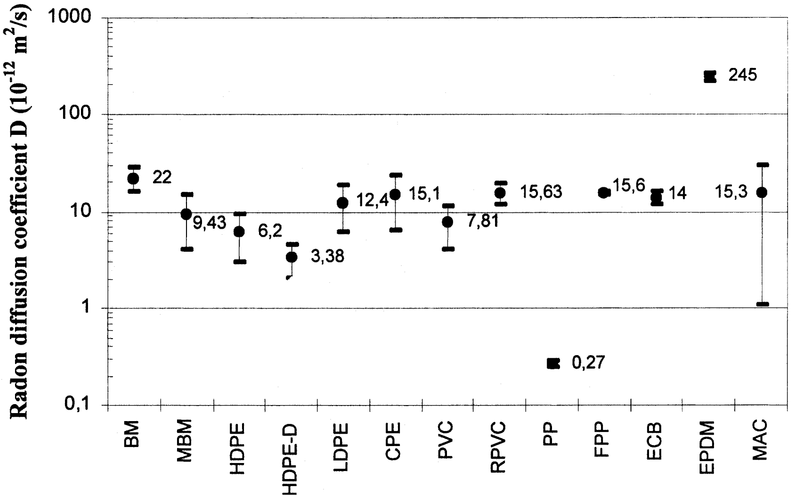

Fig. 1. Radon diffusion coefficients. BM — bitumen membranes made of oxidated asphalt; MBM — BM made of modified asphalt; HDPE — high density polyethylene foils; HDPE - D-HDPE foils with dimples; LDPE — low density polyethylene foils; CPE — chlorinated polyethylene; PVC — flexible polyvinylchloride foils; RPVC — foils made from recycled PVC; PP — polypropylene foils; FPP — flexible PP; ECB — ethylene copolymer bitumen; EPDM — ethylene propylene diene monomer; MAC — modified asphalt coating.

in the range $1 \times 10^{-12}$ and $5 \times 10^{-12}$ $m^2/s$. Radon diffusion coefficients for HDPE and PVC foils and plastomeric or elastomeric bitumen membranes were measured between the orders of $5 \times 10^{-12}$ and $10 \times 10^{-12}$ $m^2/s$. In the range $1 \times 10^{-11}$ to $2.5 \times 10^{-11}$ $m^2/s$, the coefficients for bitumen membranes made of oxidized asphalt, recycled PVC and LDPE or ECB membranes were found. The highest values of $D$ were discovered for rubber foils made of EPDM, where the coefficient $D$ increases up to the order of $10^{-10}$ $m^2/s$.

### 3.3. The dimensions of radon-proof insulation

The minimal thickness of the radon-proof insulation can be derived from the fact that the insulation must minimize the radon supply rate $J_s$ (Bq/h) from the soil into the interior. Under steady-state conditions the maximum value for $J_s$ can be found from Eq. (1) ensuring that the indoor radon concentration will be below the limit value $C_{\mathrm{lim}}$:

$$J_S \leq C_{\mathrm{lim}} \cdot V \cdot n \quad (\mathrm{Bq/h}) \tag{1}$$

where $V$ is the interior air volume ($m^3$) and $n$ is the air exchange rate ($h^{-1}$).

In practice, both convection and diffusion contribute to the radon supply rate. Since the radon transport through cracks, loose joints and pipe penetrations is usually much greater than the diffusion through unfaulted insulation, a significant reduction in the interior radon concentration can only be achieved by a significant reduction of the radon penetration through leaky places and defects. Under the condition that all joints between sheets are airtight and any penetration of utility entries through the insulation is properly sealed, we can consider the convective transport of radon to be negligible. Therefore, it is possible to assume that the radon supply rate into the house with continuous tanking is created only by diffusion through the insulation. Based on this simplification, the condition for the highest permissible radon exhalation rate from the insulation $E_{\mathrm{lim}}$ can be derived, from Eq. (1), where $C_{\mathrm{lim}}$ was replaced by $C_{\mathrm{dif}} = 10\%\ C_{\mathrm{lim}}$. The value of $C_{\mathrm{dif}}$ means that the importance of the diffusion was reduced to the estimated 10% and the remaining 90% of $C_{\mathrm{lim}}$ is reserved for the accidentally occurring convection. Our estimate of $C_{\mathrm{dif}}$ is consistent with the range 4–50% presented by Holub and Killoran (1994), in which the upper limit of 50% for the diffusion component was found for a substructure without insulation. The highest permissible radon exhalation rate can thus be calculated for each house from Eq. (2):

$$E_{\mathrm{lim}} = \frac{C_{\mathrm{dif}} \cdot V \cdot n}{A_f + A_w} \quad (Bq/m^2h) \tag{2}$$

where $V$ is the interior air volume ($m^3$), $n$ is the air exchange rate ($h^{-1}$), $A_f$ and $A_w$ are the floor and the basement wall areas in direct contact with the soil ($m^2$) and $C_{\mathrm{dif}}$ is 10% of the highest permissible radon concentration indoors (in the Czech Republic 20 $Bq/m^3$ for new buildings and 40 $Bq/m^3$ for existing buildings).

Detailed design of radon-proof insulation is dependent on real geological and building characteristics, based on the condition that the radon exhalation rate $E$ from the real insulation in a real house must be less or equal to the highest permissible radon exhalation rate $E_{\mathrm{lim}}$ calculated for that house.

$$E \leq E_{\mathrm{lim}} \tag{3}$$

$$E = \alpha_1 \cdot l \cdot \lambda \cdot C_S \frac{1}{\sinh(d/l)} \quad (Bq/m^2h) \tag{4}$$

where $C_S$ is the radon concentration in the soil gas ($Bq/m^3$); $\lambda$ is the radon decay constant ($0.00756\ h^{-1}$); $d$ is the thickness of the radon-proof insulation (m); $l$ is the radon diffusion length in the insulation $l = (D/\lambda)^{1/2}$ (m); $D$ is the radon diffusion coefficient in the insulation ($m^2/h$) and $\alpha_1$ is the safety factor, that should eliminate the inaccuracies arising during the soil gas radon concentration measurements. Values of $\alpha_1$ have been estimated according to the soil permeability (for highly permeable soils $\alpha_1 = 10$, for soils with medium permeability $\alpha_1 = 4.3$ and for low permeable soils $\alpha_1 = 3$).

On the assumption that the insulation is homogeneous, its minimal thickness can be calculated from Eq. (5) obtained after the replacement of $E$ in Eq. (4) by $E_{\lim}$ from Eq. (2):

$$d \geq l \cdot \operatorname{arcsinh} \frac{\alpha_1 \cdot l \cdot \lambda \cdot C_S}{E_{\lim}} \quad (m) \tag{5}$$

## 4. Discussion

The principle of designing according to the above mentioned method, which is also incorporated into the Czech Standard ČSN 730601 'Protection of buildings against radon from the soil', can be identified from Fig. 2 in which the thickness of the insulation with $D = 1 \times 10^{-11}$ m$^2$/s is plotted against the soil gas radon concentration and soil permeability. It can be seen that the thickness increases proportionally to the radon concentration in the soil and soil permeability.

The thickness of the insulation in dependence on the radon diffusion coefficient $D$, soil permeability and the house type is plotted in Fig. 3. It is clear that the thickness of the insulation with $D$ of the order of $10^{-12}$ m$^2$/s can be only several tenths of 1 mm, even in the areas with high radon concentration in the soil. Such a small thickness is not practical and would also be sensitive to puncturing and, thus, in practice a, thicker insulation must be used.

On the other hand, the applicability of the insulation with $D$ of the order of $10^{-10}$ m$^2$/s will be very strongly dependent on building characteristics and the radon concentration in the soil. Since radon barriers made of such insulation must be thicker (several millimetres), the insulation must be placed in two or three layers. It can be seen that rubber foils made of EPDM with $D$ of approximately $2.45 \times 10^{-10}$ m$^2$/s are too permeable to be used for radon-proof insulation.

This clearly leads to the conclusion that the optimal value of $D$ lies in the interval $5 \times 10^{-12}$ to $1 \times 10^{-11}$ m$^2$/s (Jiránek, 1997). This interval corresponds with the production thickness of the

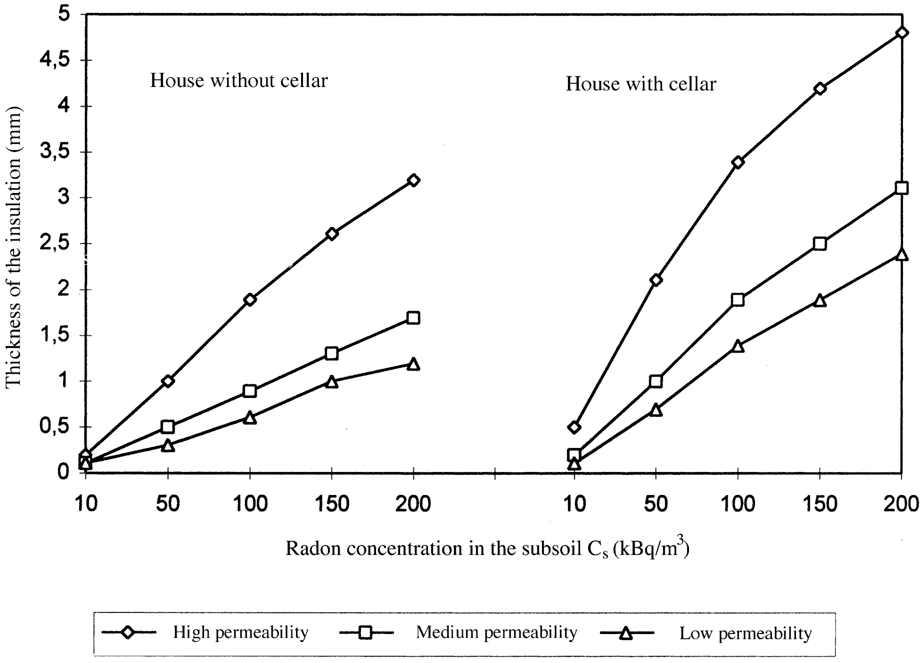

Fig. 2. The thickness of the insulation with $D = 1 \times 10^{-11}$ m$^2$/s plotted against the soil gas radon concentration, soil permeability and the type of house.

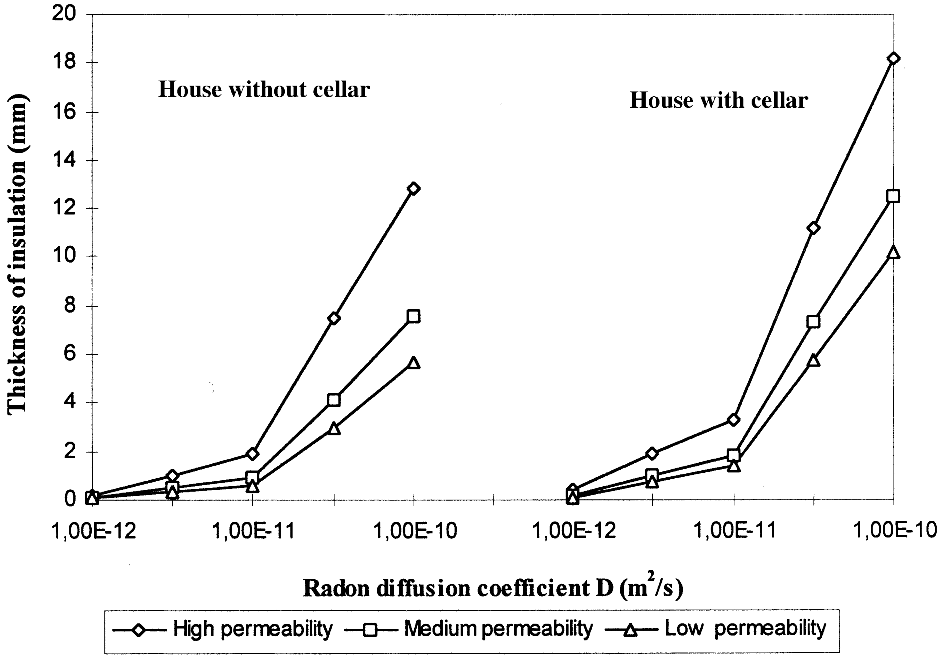

Fig. 3. The thickness of the insulation in dependence on the radon diffusion coefficient $D$, soil permeability and the house type (for $C_s = 100$ kBq/m$^3$).

most frequently used insulating materials, which is 1 or 2 mm for plastic foils and 3 or 4 mm for bitumen membranes (which, in addition, can be applied in two or three layers).

## 5. Conclusion

Experiments show that radon-proof insulation can create an effective barrier against radon, preferably in new buildings. A method has been developed for the evaluation of the minimal thickness of radon-proof membranes, depending on the building and soil characteristics and the radon diffusion coefficient in the insulation. The results indicate that the method can be useful in examining the effectiveness of the insulation and in optimizing its design. The general guidelines for the selection of insulating materials have been expressed into the following aspects:

1. The durability of the insulation must be equal to the expected lifetime of the building, because future maintenance and repair works are hardly feasible and are always complicated and very costly.
2. The insulation must be resistant to soil corrosion caused primarily by microbiological agents and chemical compounds occurring in the soil.
3. The insulation must be capable of withstanding (without being punctured) permissible movements of the building substructure to which it is applied. Materials with higher elongation are less sensitive to puncturing. On the other hand, placing the insulation between two sheets of geotextile matting can reduce transfer of tensile forces from the substructure to the insulation.
4. Complete insulating systems should be preferred to pure and simple insulating materials. Complete systems with extra components for external and internal corners, edges and pipe entries ensure higher quality and air-tightness of details.
5. Particular attention should be given to the

various sites. Some insulation must not be applied at temperatures below 5°C, some materials are difficult to seal, etc.

6. The insulation must eliminate the convective flow of soil gas containing radon and minimize radon transport by diffusion. Optimal values for the radon diffusion coefficient should be within the range $5 \times 10^{-12}$ $m^2/s$ to $1 \times 10^{-11}$ $m^2/s$.

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