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## Radon barrier: Method of testing airtightness - 2. Edition

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### Abstract

The test method NBI 167/02 *Radon membrane: Test of airtightness* can be used for determining the airtightness of a radon barrier as a system solution. The test determines the air infiltration through the radon barrier for a number of levels of air pressure differences. The airflow through versus the difference in air pressure over the barrier is measured. The air pressure difference is kept constant, at a number of manually controlled levels. At each pressure level, the difference is measured in a single point close to the point where the suction for lowering the air pressure is located. Improvements to the test method were suggested. A digital stirring and control system, and a method for determining the mean air pressure difference, as well as a method for testing barriers with a very low air infiltration, were provided. The digital stirring and control system ensured automatic control and measuring of coherent values of the airflow and the difference in air pressure. The method determining the mean air pressure difference was based on measurements from 5 units placed at specific locations. The method for testing barriers with a very low air infiltration introduced the need to provide air to the side of the barrier with the low air pressure, through a well-defined opening, as a modification of the test method in general. Results, obtained using the improved test method, are shown for a number of radon barriers tested.

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*Keywords:* Radon Barrier, Airtightness, Test Method

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### 1. Introduction

Radon-222 develops from the radioactive decay of radium-226 and has a half-life of 3.8 days. This gas seeps through soil into buildings, and if not evacuated, there can be much higher exposure levels indoors than outdoors [1], which is where human exposure occurs [2]. In this way, radon affects occupants through the indoor climate.

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The World Health Organization recommends states to introduce requirements for the maximum concentration of radiation from natural sources in the indoor air. These new recommendations are the result of the World Health Organization's evaluation of radon as being responsible for 3-14% of lung cancer incidents, depending on the average radon exposure in different countries [3]. Results show radon to be the second-largest cause of lung cancer (tobacco smoking is still the primary cause). Therefore, it is crucial to prevent radon from infiltrating into buildings.

Since 2010, Danish homes must be constructed so as that they ensure that indoor radon levels stay below 100 Bq/m<sup>3</sup> [4].

One way to prevent radon from infiltrating into buildings is to establish a radon barrier facing the ground, as infiltration of air from the ground underneath a building is the main source of radon to the indoor air [5]. As an air barrier can prevent radon from infiltrating into buildings, it is important to determine the airtightness of such a barrier when used as a radon barrier. Moreover, the barrier itself needs to be sufficiently airtight, and it is also necessary to provide sufficiently airtight joints at e.g. corners, across changed floor levels as well as around barrier penetrating pipes and against floor drains.

The test method NBI 167/02 [6] is used to determine the airtightness of a radon barrier as a system solution. The test method was improved and provided with a digital stirring and control system. The digital stirring and control system ensures automatic control and measuring of coherent values of the airflow and the air pressure difference, measured as the difference in air pressure between the front of and the back of the barrier. By using the test method, it became clear that a more advanced method was needed for determining the overall mean air pressure difference. A method for determining the overall air pressure difference with 5 units measuring the air pressure is shown, as well as the needed provided air, through a well-defined opening, when determining the airtightness of a radon barrier, especially at a very low infiltration.

The paper describes how to implement the suggested improvements to the test method. Results obtained using the improved test method are shown.

## 2. Test

The test determines the air infiltration through a material tested for suitability as a radon barrier. The test evaluates how well a barrier is able to perform to prevent radon infiltration. The barrier was mounted inside a mock-up providing a stable basis, with penetrating pipes, an elevation, and narrow angled – as well as wide-angled corners. The shown test method is an upgrade of the test method NBI 167/02, [6]. The airtightness of a barrier is determined as the air infiltration through the barrier itself and its joints for a difference in air pressure over the barrier of 30 Pa, denoted  $q_{30}$ .  $q_{30}$  is given in litre/minute. The difference in air pressure over the barrier is the difference in air pressure between the air inside the volume of a mock-up, designed as a box, and the air in the surrounding test laboratory.

### 2.1. Measurement set up

The test is carried out by mounting the test material inside a mock-up. After moulding the test material, the mock-up is filled with pressure-firm thermal insulation of mineral wool. On top of the firm insulation, a layer of the test material is mounted to seal the volume of the mock-up that holds the firm insulation enveloped by the test material. The constant airflow drawn from the sealed volume of the mock-up is measured. The airflow provides a constant air pressure difference, between the air inside the mock-up and the air outside, in the surrounding test laboratory where the test is carried out.

### 2.2. Equipment

The barrier was mounted in a mock-up made of laminated wooden boards 3.0 m in length, 3.0 m in width and 0.3 m high with a notch of 1.0 by 1.0 m, with changed floor levels, penetrating pipes and floor drains, as shown in Figure 1a. Air is sucked out of the volume, consisting of the pressure-firm thermal insulation material enveloped by the test material, by a fan. Measurements of coherent values of the airflow and the difference in air pressure between the air inside the volume of the mock-up and the air in the surrounding test laboratory is measured.

### 2.3. Improvements

Air was sucked out of the volume, consisting of the pressure-tight thermal insulation material enveloped within the test material, by a fan. A PC controls the fan. Measurements of coherent values of the airflow and the difference in air pressure between the air inside the volume of the mock-up and the air in the surrounding test laboratory was logged systematically. Data were logged using a PC by connecting the PC to a unit measuring the pressure difference and the fan. The PC program used was TECLOC3 for BlowerDoor GmbH. The fan used was a Minneapolis Micro Leakage Meter, type FD E51-767 that was able to measure airflow in the range between 0.09 - 79 m<sup>3</sup>/h. The fan was mounted on a disc with a circular hole to be able to measure the airflow. Individual discs were mounted and had a circular hole of 3.8, 8.0, 20 and 45 mm, respectively. A PC controls the fan in order to suck air out of the volume of the mock-up introducing a predetermined difference in air pressure between the volume within the mock-up and the air in the surrounding test laboratory. The airflow was measured for a number of predetermined differences in the air pressure between the volume within the mock-up and the air in the surrounding test laboratory.

As the air pressure within the mock-up was seen not to be homogeneously distributed, 5 air pressure difference measurement units were mounted on the top layer of the test material. A mean value of the pressure difference between the volume within the mock-up and the air in the surrounding test laboratory was determined from the 5 units and used to calibrate the pressure for the airflow measurements.

To measure the airtightness of barriers with a low airflow and in the lower ranges of the capacity of the used Micro Leakage Meter, it was necessary to add air infiltration through well-defined openings. The well-defined opening located at CD1 was added using discs with a diameter of 7, 10, 14 and 20 mm respectively. The airflow through the well-defined opening was subtracted from the measured airflow. The location where the air was sucked out of the volume, the location of the well-defined opening and the location of the 5 air pressure difference measurement units, denoted P1 to P5, are shown in Figure 1b.

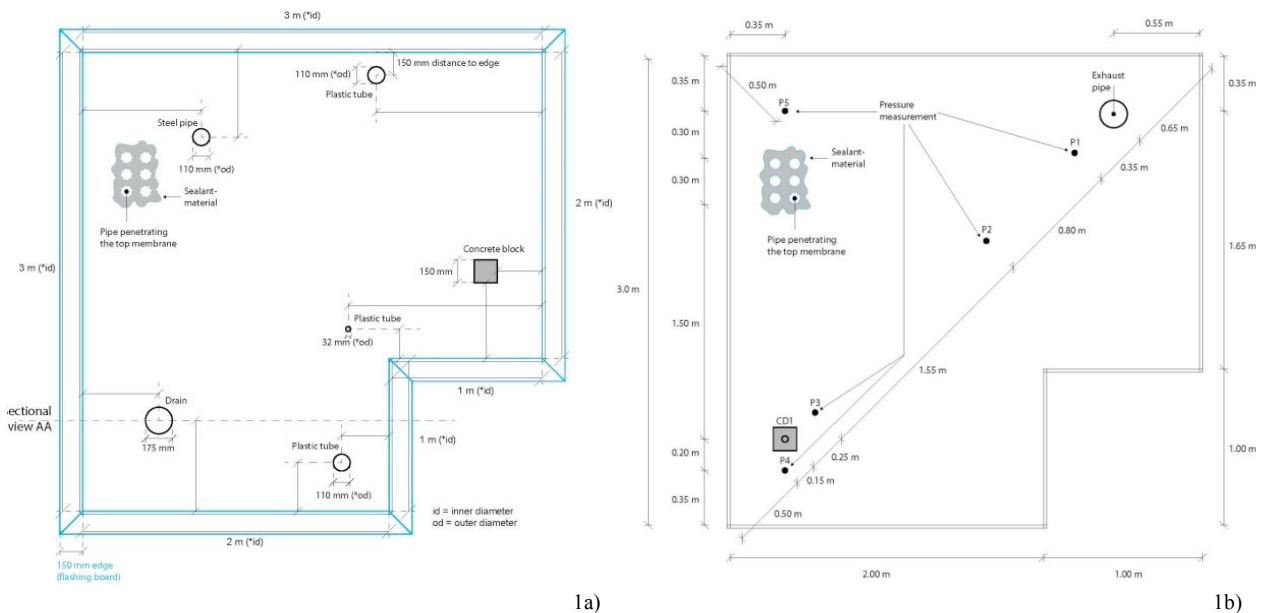


Fig. 1a). Mock-up used for measuring the airtightness, measured as the air infiltration. A barrier is used as a radon protection layer shown in a vertical and horizontal section. The location of changed floor levels, penetrating pipes and floor drains are shown. Fig. 1b). Location where the air is sucked out of the volume, where the well-defined opening is placed and the location of the 5 air pressure difference measurement units.

### 2.4. Barriers tested

Four types of barriers were tested, including an bitumen-based radon blocker, a wet room membrane, a reinforced fix mortar paste and a mortar KC50/50/700.

The barriers were used as delivered and carried out by the manufacturer. The test can start 40 hours after mounting the barrier to ensure a stress-free barrier and joints. The test sets no specific requirements to the indoor climate at the laboratory used for testing; however, the indoor climate should be a dry tempered room. A dry tempered laboratory will typically have a temperature ranging between 17 and 25 degrees Celsius and have a relative humidity ranging between 15% and 65%, with shorter periods with a temperature and relative humidity outside these intervals.

### 3. Results

#### 3.1. Processing results

Mounted over the barrier, the airflow was measured at 4 different air pressure levels of 30, 50, 70 and 90 Pa, respectively, controlled by the air pressure measuring equipment located at P1, see Figure 1b. At each pressure level, 4 measurements were carried out using 4 different openings in the well-defined opening denoted CD1. For all 16 measurements, the area of the well-defined opening  $A$  in  $\text{mm}^2$ , together with the individual air pressure difference in locations P1 to P5 in Pa, and the airflow through the suction point,  $q$ , in  $\text{l/min}$ , was measured.

The area of the well-defined opening  $A$  at CD1 is

$$A = \sum A_i \quad (1)$$

Where

$$A_i = \pi/4 d_i^2, d_i = 7, 10, 14, 20 \text{ mm} \quad (2)$$

The pressure difference along the edge,  $P_R$  in the mock-up is

$$P_R = 1/3(P_3 + P_4 + P_5) \quad (3)$$

The mean pressure difference,  $P_M$  over the barrier is

$$P_M = 1/9 (P_1 + 3P_2 + 5P_R) \quad (4)$$

The relative airflow  $q/\sqrt{P_M}$  is linear and proportional with the opening  $A$

$$\frac{q}{\sqrt{P_M}} = cA + b \quad (5)$$

Where,  $c$  is the airflow resistance in the mock-up and  $b$  is the relative airflow through the barrier.

The relative airflow measured was plotted versus the area of the well-defined openings for the 4 mean pressure difference levels tested. The relative airflow through the barrier,  $b$ , was then found as the airflow for  $A = 0$  by using linear regression for each of the 4 mean pressure difference levels tested.

By plotting, the 4 values for  $b$  versus the 4 mean pressure difference levels tested, an expression for the pressure-related value  $b$  can be found by using linear regression, as

$$b = \alpha P_M + b_0 \quad (6)$$

where,  $b_0$  is the relative airflow through the barrier for no pressure difference over the barrier.

Testing barriers that are very airtight, the statistical test uncertainty can result in a negative value for  $b_0$ . In this case, a new linear regression must be made using the equation,

$$b = \alpha P_M \quad (7)$$

The result of the test is given as the airflow in litre per minute [ $\text{l/min}$ ] for a 30 Pa mean pressure difference over the barrier, determined as:

$$q_{30} = b\sqrt{30} = (\alpha 30 + b_0) \sqrt{30} \quad (8)$$

Figure 2a shows the relative airflow versus the area of the well-defined opening for 4 different air pressure levels mounted over the barrier. An air pressure difference of 30, 50, 70 and 90 Pa, respectively for a barrier of fibre-reinforced fix mortar paste was used. The well-defined openings were known, a diameter of 14 mm, 20 mm and a combination of them both. For an air pressure difference of approximately 50 Pa controlled by the air pressure measuring equipment located at P1 and an area of a well-defined opening of  $157 \text{ mm}^2$  at CD1, the air pressure in P1 to P5 was measured to be 49.2, 44.8, 44.0, 44.6 and 45.5 Pa, respectively.

Figure 2b. shows the relative airflow through the barrier of fibre-reinforced fix mortar paste from where the airflow, as a function of the air pressure, was found by using linear regression. The pressure difference was calibrated to the mean air pressure difference.

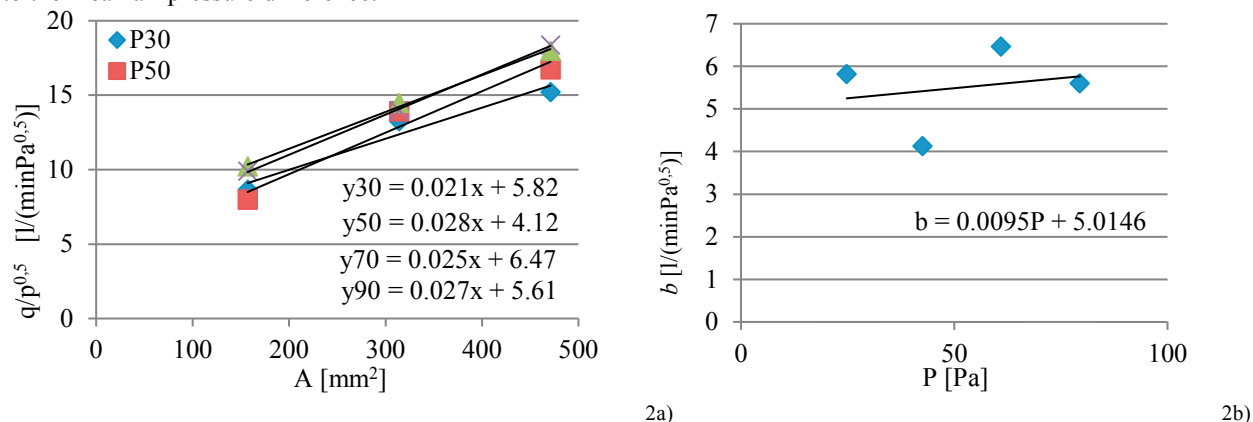


Fig. 2a). Relative airflow versus the area of the 4 well-defined openings for 4 different air pressure difference levels mounted at P1 over the barrier of approximately 30, 50, 70 and 90 Pa. Fig. 2b). Relative airflow through fibre-reinforced fix mortar paste.

#### 4. Results

Table 1 shows the determined air infiltration  $q_{30}$  for the four types of barriers tested.

Type of barrier	$q_{30}$
bitumen-based radon blocker	4.5
wet room membrane	10.0
reinforced fix mortar paste	30.0
mortar KC50/50/700	43.0

#### 5. Discussion

The ground is the primary source of radon in most countries including Denmark [7]. Therefore, the geological composition of the ground, on which a building is situated, sets the level for how high the indoor radon concentration can become. Radon seeps into a building by air infiltrating from the ground through cracks or other unforeseen openings in the ground construction [8]. Therefore, it is of great importance to ensure an airtight building envelope towards the ground or to avoid infiltration of air from the ground by other means. Radon is without colour, smell, taste or sound and can therefore only be detected through measurements [9]. Ensuring a good quality of the indoor air includes a focus on radon, and hence measurements of the radon concentration in the indoor air. An efficient way to avoid radon infiltrating into a building and to control the concentration of radon in the indoor air is to combine three design criteria, described by Rasmussen [5]: 1) A radon barrier, either as a) an airtight construction towards the ground or as b) a radon barrier placed in the ground underneath the building, and 2) lowering the air pressure at the capillary barrier at the lower zone of the slab facing the ground, and 3) Effective dilution of the indoor air with outdoor air. In this way, the radon concentration in the indoor air of a building can be controlled and kept at an acceptable level.

The presented improved test method helps choosing the most suitable barrier as the radon barrier. The most suitable radon barrier depends on the building physics of the individual building. The infiltration requirements to the radon barrier can be defined depending on the radon level in the ground and the need of radon reduction. In some cases a diffusion-tight and airtight radon barrier can be used and in other cases a less airtight, but diffusion-open, barrier is preferred. The choice of barrier depends of the moisture level in the foundations of the building. It is important to choose a barrier that is sufficiently airtight so that it may constitute as the needed radon barrier and at the same time contribute to the building physics for the building.

The test method was found to be useful for determining air infiltration for different materials with different degrees of air infiltration. The improved test method shows the necessary processing of results handling the fact that the air pressure within the mock-up is not homogeneously distributed, which is why 5 air pressure difference measurement units are introduced. Allowing airflow measurements to be calibrated to the mean overall air pressure difference, between the air pressure within the mock-up and the air pressure in the surrounding test laboratory. The improved test method enables the measurement of the airtightness of barriers with a very low air infiltration. The test method meets the lower range of the capacity of the used fan and control system by allowing air infiltration added through well-defined openings and after subtracting the added air from the measured airflow in the processing of results.

## 6. Conclusion

A test method for determining the airtightness of a radon barrier as a system solution was improved and demonstrated. The test method is an improvement of an earlier used method, named NBI 167/02 [6] developed by the Norwegian Building Research Institute. The test method was improved and provided with a digital stirring and control system. The system ensures automatic control and measuring of coherent values of the airflow, air infiltration, and the air pressure difference over the barrier mounted the mock-up, between the air pressure outside and the air pressure inside the mock-up. The improvements added to the test method allow controlled suction of the air out of the mock-up, enveloped by the test material, using a fan. A PC controls the fan. Additionally, the PC was connected to 5 units measuring and logging the air pressure difference at different locations in the mock-up and logging airflow data. The fan used was able to measure and control airflows in the range between 0.09 - 79 m<sup>3</sup>/h. The test method was used for a number of different materials that allowed a wide range of air infiltration. The improved test method take into account that the air pressure within the mock-up is not homogeneously distributed and introduced 5 air pressure difference measurement units that were mounted on the top layer of the test material. Allowing airflow measurements to be calibrated to the mean overall air pressure difference between the air pressure within the mock-up and the air pressure in the surrounding test laboratory. Furthermore, the improved test method enables measuring the airtightness, air infiltration, of barriers with a very low air infiltration. By allowing infiltration of air added through well-defined openings and after subtracting the added air from the measured airflow in the processing of results, air infiltration can be determined for all barriers.

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