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Case study

Case study of water vapour transmission properties of EPDM façade membranes

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Abstract: This research aimed to investigate the water vapour transmission properties of chosen EPDM membranes applied in façade and window systems under laboratory tests. The applied procedure included in national and international standards utilized for the laboratory tests of water vapour transmission properties of EPDM membrane is described. Two main types (outside and inside types) of EPDM membranes are laboratory tested. The authors indicated that the EPDM membranes should differ in surface factures. Nevertheless, some manufacturers mark EPDM membranes on each roll (on the package only) without different permanent denotations on the EPDM membranes surfaces. This form of denotations can cause using problems – using the wrong types of the EPDM aprons in building partitions, because when the package is removed there is impossible to visually identify the type of EPDM membrane (outside or inside type) from the texture of the membrane surface. The experimental results of laboratory tests indicated using the wrong type of EPDM membrane in the inside aprons in building partitions in the investigated façade window system. The designed proportion of the s_d values (the resistance to movement of water vapour) of inside and out-side EPDM façade membranes should be designed equally to about 3.0 (recommended value 4) to provide proper diffusion properties of partitions around windows in façade systems. The paper can provide scientists, engineers, and designers an experimental basis in the field of the EPDM membranes water vapour transmission properties applied to façades and windows systems.

Keywords: façade systems, EPDM, water vapour transmission, moisture resistance factor, s_d value

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1. Introduction

Polymeric and plastic building materials are used often in modern building construction which are sometimes also as replacements for traditional materials see e.g. [1]. Plastic materials may be formed into different and complex shapes, are durable and low maintenance, and have a wide spectrum of properties, e.g. do not suffer from metallic corrosion or microbial attack, resistant to heat transfer and moisture diffusion, etc. Building partitions must not only ensure adequate load-bearing capacity but also meet the building's physical engineering requirements. Building partitions assembly require sometimes a proper air barrier and a vapour barrier to meet the design requirements. The vapour barriers control diffusion and are used only when needed placed near the warm side only while the air barrier control airflow [38].

The limitation of water vapour condensation in a building partition is an important aspect that always requires a detailed analysis. For wetness and moisture concentration analysis different approaches and methods of measuring are used. New approaches and methods in building's physical engineering are still developed, tested and investigated by engineers, researchers and scientists. Hens [18] performed a test method for measuring the water vapour diffusion resistance of composite layers of building partitions. Sonderegger and Niemz [41] investigated the water vapour resistance factor of the wood-based materials and concluded that increases with rising density and decreases with increasing moisture content. Choi et al. [11] used long-term field measurements to quantify the indoor humidity generation rates of households vulnerable to condensation and described appear problems. Brzyski [8] presented issues associated with moisture presence in the lime-hemp composite wall partitions. Miszczuk et al. [32] indicate that the types and thickness of individual materials used in the wall affect the possibility of condensation of water vapour inside the building envelope. Nawalany et al. [35] showed that the temperature and humidity of the indoor air periodically exceeded the accepted values of thermal comfort for historic wooden buildings. Bogdanovic and Milanovic [7] indicated that the significance of the water vapour characteristics of the external render of the façade thermal insulation systems influences the occurrence of the condensation in some of the wall layers, and at the systems with the rock wool, in the wool itself. Wójcik and Kosiński [46] used an innovative method of local reheating thermal bridge areas with halogen radiators using various infrared radiation bands. Lee et al. [27] analysed the thermal environment around the built-in furniture during summer and winter through field measurements at apartment buildings. Torres-Ramo [42] showed the different missions that the air-tightness products and the breathable membranes fulfil and what is their arrangement within the construction typology. Slanina and Šilarová [40] formulated an analytical equation that describes water vapour diffusion flux through perforated vapour retarders. Bademlïoğlu et al. [6] indicated that in constant indoor-outdoor conditions in general, as the water vapour diffusion resistance factor increases, the risk of condensation inside the wall first decreases and then increases. Diyaroglu et al. [12] presented a novel wetness and moisture concentration analysis approach that utilized a finite element method for the solution technique mainly using thermal and surface effect elements. Liu et al. [30] presented a method to solve condensation problems by using the computational fluid dynamic method. Rymarczy et al. [39] described an innovative solution for the evaluation study of the dampness level of walls and historical buildings. Klemm et al. [22] investigated a potential application of laser radiation for the detection of phase transition processes in low temperatures occurring on the surface layers of cementitious materials. Litavcova et al. [29] derived a mathematical model that describes liquid water and vapour diffusion as two separate processes. Kreiger and Srubar [25] given critically review characterization methods and models for moisture buffering. Caulk et al. [9] described a pore-scale numerical method dedicated to the simulation of heat transfer and associated thermo–hydro-mechanical couplings. Arendt and Krzaczek [4] proposed a co-simulation strategy of transient CFD and heat transfer in the thermal envelope. The literature concerning building's physical engineering is very extensive, the paper shows its review in a compact form.

In window and façade systems, the high-performance EPDM (ethylene propylene diene monomer) rubber membrane is also applied for permanently sealing around building penetration points (e.g. around in windows, see Fig. 1). In the case of glass curtain wall systems, the usage of a galvanized sheet steel pan in the spandrel area is performed for vapour diffusion control and air leakage control. The sheet steel is sealed at the perimeter of the frame spandrel and is impermeable to moisture and it is positioned on the warm side of the insulated assembly. Each façade and window systems are limited and have some advantages and disadvantages which influence the costs of façade system implementation, see e.g.: [3, 28, 33, 44]. Nevertheless, the physical properties of partitions have to be detailed studied and analysed. EPDM materials have many applications in different fields of industry. EPDM is a naturally elastic material, with over 300% elongation, even at extremes of temperature. The applications of the EPDM are wide and used also to develop new composite materials, see e.g. [10, 17, 19, 21, 45] and others applica-

Fig. 1. Outside apron EPDM membrane in a window façade system fastened to reinforced concrete wall

tions, see e.g. [16, 24, 26, 34, 47]. The EPDM membrane used in civil and building engineering applications as rubber vapour control layers and rubber damp proof courses in the European Economic Area (EEA) must hold the CE marking in accordance with standard EN 13984 [13] and EN14909 [14]. Different types and sorts of synthetic rubber membrane strips are available and used in civil and building engineering for permanently sealing (with sealant adhesives) around building penetration points to seal gaps in façade and window systems. Generally, two types of EPDM membrane: inside and outside types are designed to control moisture concentration water vapour in building partitions. The inside type of EPDM membrane is applied indoor to prevents the penetration of water vapour into the partition from indoor. The outside type of EPDM membrane is destined for outdoor use only provides vapour control as to open to water vapour diffusion, permitting trapped moisture to dry out. There are used also dual types of EPDM membranes for indoor and outdoor use to provide vapour control in building penetration (e.g. in windows systems). Some manufactured EPDM membranes have different surface factures, which facilitate the recognition of a given type of membrane (inside type or outside type, see Fig. 2). On the other hand, there is a large group of EPDM membranes in the market where it is impossible to visually identify the type of EPDM membrane (outside or inside) from the texture of the membrane surface. These types of EPDM membranes differ only in their chemical constitution and physical properties. Without a proper additional permanent type designation of EPDM (OUT/IN) after cutting from the new batch, subsequent identification is visually impossible. In these cases, there is possible to make a mistake on building sites or in assembly plants.

Fig. 2. Two types (outside and inside) EPDM membranes – visible different surface factures on the backside

Diffusion properties of thin products (e.g. EPDM membranes, vapour retarders, waterproof membranes, etc.) are most commonly described with the help of the water vapour diffusion-equivalent air layer thickness s_d (m). The water vapour diffusion-equivalent air layer thickness s_d is defined by the following relation [37]:

$$s_d = \mu \cdot d \tag{1.1}$$

where: μ the water vapour resistance factor of material (–) and d is the thickness material in (m).

On the other hand, the desiccant method of ASTM E 96 [5] is used to determine a material's ability to restrict the amount of moisture that passes through it, which determines its vapour retarder (barrier) class: Class I is a vapour barrier (impermeable vapour barriers): 0.1 perm or less; Class II is a vapour retarder (semi-impermeable vapour barrier): $0.1 < \text{perm} < 1.0$ perm; Class III is a vapour retarder (semi-permeable): $1.0 < \text{perm} < 10$ perms; Class IV is a permeable or breathable: more than 10 perms. The unit knows as "perms" or permeability ($\text{ng}/(\text{Pa} \cdot \text{s} \cdot \text{m}^2)$) measures the ability of a material to retard the diffusion of water vapour ($1 \text{ perm} = 57.2 \text{ ng}/(\text{Pa} \cdot \text{s} \cdot \text{m}^2)$).

Façade systems practice of design and construction with building site supervision provides many interesting engineering experiences and makes it possible to recognize new technologies and applications of new materials. One of the authors performed construction site supervision (as construction site inspector) on the building site where the window façade system is applied. In investigated window façade system a chosen types of EPDM rubber membranes (inside type and outside type) are applied for the sealing of façades around windows (vapour control layer) and as through-wall flashing (damp proof course layer). EPDM membranes used and delivered to the building site are marked on each roll in accordance with standard EN 13984 [13] and EN14909 [14] on the package only without permanent denotations on the EPDM membrane surfaces. When the package is removed from the EPDM membranes there is impossible to visually identify the type of EPDM membrane (outside or inside type) from the texture of the membrane surface. This form of the denotation of EPDM membranes (on the package only) can cause using problems – using the wrong types of the EPDM aprons in building partitions in the façade window system. Changing types and properties of EPDM aprons negatively affect water vapour transmission in designed building partitions. To confirm used on building site types and properties of the EPDM inside aprons it is decided to take EPDM samples for laboratory tests to a determination of the moisture resistance factor. The investigation contributes an expert opinion on the chosen EPDM façade membrane water vapour transmission properties and verification of building partition in the range of possibilities to appear wet and rise moisture concentration. The paper provides scientists, engineers, and designers with a practical and experimental assessment of investigated EPDM façade membrane water vapour transmission properties.

2. Materials and methods

The EPDM membrane specimens were taken from different chosen locations. Firstly, the specimens named OUT and IN types were cut-out from the new batch of outside and inside EPDM membranes, originally packed (brand-new) and delivered to the building site. The based properties of the investigated EPDM membranes declared by the manufacturer are collected in Table 1. Both OUT and IN EPDM membranes have the same surface factures. The differences in the moisture resistance factor result from the chemical compositions of EPDM membranes [31]. Secondly, the specimens named N.N. were cut-outed from the EPDM aprons mounted to the window profiles from the inside in the window façade system on the building site.

Determination of water vapour transmission properties of the EPDM membranes under laboratory tests was performed according to the method B guidelines in the PN-EN 1931 [37] standard. This method is dedicated for plastic or rubber sheets for determination of the water

Table 1. Based EPDM properties declared by manufacturer

Properties	OUT	IN
Moisture resistance factor μ (–)	33,200	99,800
Thickness	0.75 mm	
Tensile strength	≥ 6.5 MPa	
Tear strength	≥ 25 N	
Elongation at break	≥ 300%	

vapour transmission properties and for the calculation of the density of water vapour flow rate and the water vapour resistance factor. The applied dry cup (desiccant) method assembly measures weight gain due to water vapour from the test chamber transmitting through the EPDM specimens due to the desiccant absorbing any moisture from the EPDM sample and the humidity from the test chamber that is being absorbed by the material.

Four square samples (about 200 mm by 200 mm) each EPDM type, to allow the required three test samples and one reference specimen to prepare, were cut off and were delivered for laboratory tests. The EPDM samples were stored for at least 24 h at about 20°C before the test pieces were cut according to EN 13416 [36] standard requirements. Before test specimens were cut, which were adjusted to the dimensions of the cup about 90 mm, the test pieces were visually inspected to ensure that the test pieces were free of any visible defects. After the EPDM test specimens were mounted and sealed on the cup (with layer of desiccant on the bottom of the cup), weight the assembly and then store in the test chamber were carried out.

3. Laboratory test results and discussion

3.1. Thickness and surface density

Each EPDM membrane samples were measured thickness and surface density. The thickness measurements were performed in several places on the sample. The results of the measurements are collected in Table 2. It can be shown that the mean thickness of all investigated EPDM membrane specimens is equal to 0.76 ± 0.01 mm. The result of the mean value is presented as the sum of mean values and standard error of the mean of the specified range. The EPDM membranes OUT and IN types had a near equal mean surface density (see Table 2), while

Table 2. Measurement results of thickness and surface density

Type of EPDM	Thickness [m]	Surface Density [kg/m^2]
OUT	0.00076 ± 0.00001	72.4 ± 2.4
IN	0.00076 ± 0.00001	72.6 ± 2.6
N.N.	0.00076 ± 0.00001	70.0 ± 3.0

the N.N. EPDM membrane type had a slightly lower density, equal to 70.0 ± 3.0 kg/m^2. The lower surface density of the EPDM membrane N.N. may be influenced on the water vapour transmission properties.

3.2. Water vapour transmission properties

The three specimens for each type of EPDM membrane are sealed to the open flange of a test cup containing a desiccant and one as a reference specimen. Circular test specimens are adjusted to the dimension of the cup. The assembly is placed in an atmosphere with a controlled temperature (23 ± 1°C) and humidity (75 ± 2% R.H. (relative humidity)). The starting time ($t_0 = 0$ s) is the time when the mass change with time started to be linear. When mass take-up was linear over a period of time, the assembly is weighed periodically on times $t_1 = 1824400$ s, $t_2 = 3628800$ s, and $t_3 = 5443200$ s (see Tables 3, 4, and 5) to determine the density of moisture flow rate through the test specimen into the desiccant. In laboratory tests, method B according to PN-EN 1931 [37] standard is applied.

Table 3. Changes of weight (g) over time (s) – OUT specimens

Time (s)	0	1,824,400	3,628,800	5,443,200	Reference Assembly
OUT_s1	0	0.0762	0.1524	0.2286	–0.149
OUT_s2	0	0.0853	0.1706	0.2558	
OUT_s3	0	0.0726	0.1452	0.2177	

Table 4. Changes of weight (g) over time (s) – IN specimens

Time (s)	0	1,824,400	3,628,800	5,443,200	Reference Assembly
IN_s1	0	0.0127	0.0254	0.0381	–0.107
IN_s2	0	0.0154	0.0308	0.0463	
IN_s3	0	0.0145	0.0290	0.0435	

Table 5. Changes of weight (g) over time (s) – N.N. specimens

Time (s)	0	1,824,400	3,628,800	5,443,200	Reference Assembly
N.N._s1	0	0.0998	0.1996	0.2994	–0.148
N.N._s2	0	0.1052	0.2105	0.3157	
N.N._s3	0	0.0907	0.1814	0.2722	

Firstly, the mass of water vapour transmitted through a unit area of the sheet of specified thickness in a unit time under specified conditions of temperature and humidity is determined and is defined as the density of water vapour flow rate g [kg/(m^{2}s)].

The density of water vapour flow rate g for every test EPDM membrane specimen is calculated by the following equation [37]:

$$g = \frac{\Delta m}{A \cdot \Delta t} \tag{3.1}$$

where: Δm is the rate of mass change determined from the endpoints of the straight line, A is the exposed area of the test specimen, Δt is the time interval between two corresponding weightings of the test assembly in second.

The mass of water vapour transmitted through a unit area of the sheet of specified thickness in a unit time under specified conditions of temperature and humidity for the investigated EPDM membrane types are determined and collected in Table 6. The mean value of the density of water vapour flow rate g is equal to 1.735E–8 kg/m^2·s, 5.470E–9 kg/m^2·s, and 1.626E–8 kg/m2·s for OUT, IN and N.N. type of EPDM membranes, respectively. The samples of the OUT EPDM membranes exhibit the largest mean value of the density of water vapour flow rate.

Table 6. Density of water vapour flow rate g (kg/m^2·s)

EPDM Type	1	2	3	Mean
OUT	1.380E–8	1.480E–8	2.3441E–8	1.735E–8 ± 0.306E–8
IN	5.304E–9	5.604E–9	5.501E–9	5.470E–9 ± 0.088E–9
N.N.	1.639E–8	1.699E–8	1.540E–8	1.626E–8 ± 0.046E–8

Following, the water vapour resistance factor μ is calculated according to the following equation [37]:

$$\mu = \frac{4.1668 \cdot 10^{-4}}{p \cdot g \cdot d} \tag{3.2}$$

where: p is the mean barometric pressure.

The water vapour permeability of air with respect to partial vapour pressure equal to $1.97762 \cdot 10^{-10}$ kg/(m·s·Pa) is adopted in the calculations. The determined mean values of water vapour resistance factors μ for investigated EPDM membrane types are collected in Table 7.

Table 7. Determined values of vapour resistance factors μ

EPDM Type	Mean (–)
OUT	39.119
IN	100.164
N.N.	33.691

The obtained laboratory test results confirm that the quality of the OUT and IN EPDM membrane types are sufficiently high. The determined vapour resistance factors μ for EPDM membrane OUT and IN types are greater than declared by the manufacturer, see Table 1. For OUT type about 18% and for IN type about 0.4% greater than declared by the manufacturer values of vapour resistance factor. N.N. type of EPDM membrane should be classified as an outside type with water vapour resistance factor μ equal to 33,691 and couldn't use in inside building partition as apron EPDM membranes in a supervised building site where window façade system is applied. The laboratory tests confirmed using the wrong type of EPDM membrane in the inside aprons in building partitions (see Fig. 3) in the supervised façade window system.

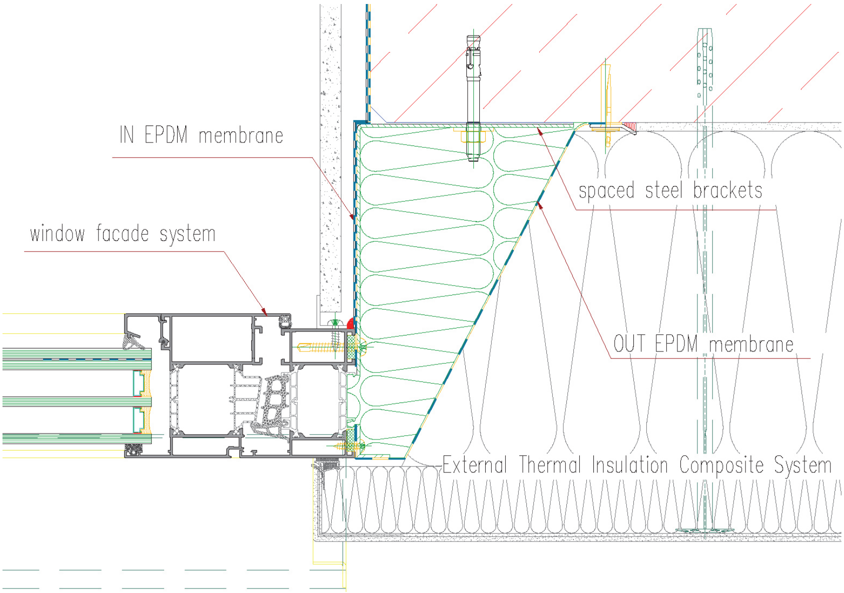

Fig. 3. Horizontal cross-section of EPDM membranes configuration in investigated window façade system

The designed s_d value for OUT and IN type of applied EPDM membranes in investigated façade window system used at the building site are:

$$\begin{aligned} s_d^{\mathrm{OUT}} &= \mu^{\mathrm{OUT}} \cdot d^{\mathrm{OUT}} = 33200 \cdot 0.0075 = 249 \text{ m} \\ s_d^{\mathrm{IN}} &= \mu^{\mathrm{IN}} \cdot d^{\mathrm{IN}} = 99800 \cdot 0.0075 = 748.5 \text{ m} \end{aligned} \tag{3.3}$$

where: μ and d are taken according to Table 1.

The designed proportion of the $s_d^{\mathrm{OUT}}/s_d^{\mathrm{IN}}$ is about 3.0, and it is a minimum value (recommended value 4) to proper diffusion properties of partitions around windows in investigated façade window systems. In the case of the recommended value of proportion $s_d^{\mathrm{OUT}}/s_d^{\mathrm{IN}}$ equal to about 4 the inside EPDM should have the thickness equal to 1.0 mm instead of 0.75 mm. In the investigated building site, the EPDM membranes with similar s_d value is used to make internal and external aprons. In such a case, there is a high possibility of water vapour accumulation in the building partition. The N.N. type of EPDM membrane is destined for outdoor use only provides vapour control as to open to water vapour diffusion (permitting trapped moisture to dry out). The inside EPDM membrane should prevent the penetration of water vapour into the partition from indoor and must have a greater resistance to water vapour diffusion than outdoor.

In order to properly perform the works and fulfill physical requirements of building partitions, the method of repairing improperly made internal EPDM membrane aprons by add from inside an additional layer of EPDM membrane for inside application (IN EPDM membrane type).

4. Conclusions

The experimental results of laboratory tests indicated using the improper type of EPDM membrane in the inside aprons in building partitions in the investigated façade window system. Performed and described laboratory tests allowed avoiding problems and defects during exploitation of façade windows system. Sometimes the problems, defects, and construction problems are disclosed on different stages of "live" of façade systems (see e.g. [20, 43]) where additional laboratory tests have to be performed (see e.g. [2, 15, 23]). In the period of over 3-month laboratory tests on the construction building site, there is significant progress in the execution works. Improving or repairing façade elements that are incorrectly made is always associated with additional costs and material and financial outlays that may disturb the planned work schedule and handing over the building for use. In this case, the repair consisted of making (gluing) an additional EPDM apron to the existing one. Leaving the wrong apron and sticking an additional EPDM layer had a positive effect on the improvement of the physical properties of the partition. Proper tight connection (gluing) of the membranes and the absence of any mechanical damage (perforation) ensure the proper properties of the building partition. A significant decrease in s_d value with increased perforation percentage is observed. The decrease in the water vapour diffusion-equivalent air layer thickness value is greater for materials with a higher value of water vapour resistance factor, see e.g. [40].

The paper may be considered a possible base for new investigations. The obtained results encourage authors to continue the research, based on EPDM façade membranes water vapour transmission properties to confirm proper building physical properties chose of partitions in façades systems. Future research will be also supplemented with numerical analysis of the water vapour transmission of building partitions. The authors hope that the described laboratory tests spark a vital interest in the community of civil engineers and scientists to take into consideration the subject of the EPDM membranes water vapour transmission properties applied to façades systems.

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Właściwości dyfuzyjne fasadowych membran EPDM

Słowa kluczowe: systemy fasadowe, EPDM, przepuszczalność pary wodnej, współczynnik odporności na wilgoć, wartość s_d

Streszczenie:

Celem badań było określenie właściwości przepuszczalności pary wodnej wybranych membran elewacyjnych EPDM stosowanych w systemach fasadowych i okiennych w ramach testów laboratoryjnych. Omówiono zastosowaną procedurę zawartą w normach krajowych i międzynarodowych stosowanych do badań laboratoryjnych właściwości przepuszczalności pary wodnej membrany EPDM. Dwa główne typy (zewnętrzne i wewnętrzne) membran EPDM zostały poddane badaniom laboratoryjnym. Proces określania właściwości przepuszczalności pary wodnej dla membran EPDM jest długotrwałym badaniem laboratoryjnym. Projektowana proporcja wartości sd (oporu na ruch pary wodnej) wewnętrznych i zewnętrznych membran elewacyjnych EPDM powinna być równa około 3,0 (zalecana wartość 4), aby zapewnić odpowiednie właściwości dyfuzyjne przegród wokół okien w systemach elewacyjnych. Eksperymentalne wyniki badań laboratoryjnych wskazały na zastosowanie niewłaściwego rodzaju membrany EPDM w fartuchach wewnętrznych przegród budowlanych w badanym systemie okien fasadowych. Autorzy mają nadzieję, że opisane testy laboratoryjne wzbudzą żywe zainteresowanie środowiska inżynierów i naukowców, aby uwzględnić tematykę właściwości przepuszczalności pary wodnej membran EPDM stosowanych w systemach elewacjach i okiennych.

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