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Laboratory verification of water vapour permeability of plaster compositions

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Abstract

There are many significant historic buildings of our national heritage in the Czech Republic that worth protecting. These astonishing buildings are most frequently damaged by water, precisely speaking by moisture. The moisture can come from several sources, for example from a flood. That is the reason we should know about the materials and their behaviour from the point of view of the moisture in the vapour form as much as possible. This paper summarizes properties important for material water vapour permeability represented by water vapour resistance factor. There are stated and tested three compositions of materials, commonly used in the praxis, in the paper. The compositions are: basic adhesive diffusion mortar with no finishing; basic adhesive diffusion mortar + silica penetration; basic adhesive diffusion mortar + silica penetration + silicate plaster. Not only diffusion parameters but also the border condition and their impact on the material behaviour have been tested and determined. We should know how to treat these buildings during a flood well. After previous floods that damaged many valuable buildings it seems to be a very priceless familiarity. Moreover the tested values help to find out if there is going to be condensation of water vapour on the surface of the tested material inside a building.

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Keywords: Diffusion; water vapour resistance factor; border conditions; temperature; relative humidity, barometric air pressure; mortar; water vapour permeability; plaster; moisture

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1. Introduction

The Klokner Institute is a research institute that, beside other things, has been dealing with tests of diffusion properties of various building materials, because these properties are ones of the basic characteristics of building materials. The characteristics help in instance when drying of buildings after floods in case of selecting a way of a building rehabilitation. This paper compares three compositions of building materials. These compositions are often used in praxis. The materials differ from each other mainly in their diffusion parameters. The mentioned compositions are: basic adhesive diffusion mortar without finishing; composition with extra penetration; and composition with extra penetration and silicate plaster. Nevertheless it is necessary to deal not only with the values themselves, but the impact of the standard used for the calculation should be also taken into consideration.

2. Material and methods

The experiments of many compositions of building materials have been performed in the accredited laboratory of the Klokner Institute, CTU in Prague. Three chosen compositions commonly used in the praxis were used for a comparison. The compositions were intentionally chosen this way to have rather different diffusion properties and be able to demonstrate an influence of border conditions on diffusion different compositions. Relative humidity, temperature and barometric air pressure belong among the examined border conditions having the influence on the value of water vapour resistance factor and other diffusion properties. Also the standard, according to the value is calculated, is equally important for the value of water vapour resistance factor.

The following compositions were tested:

- Composition 1 (LSHD): Basic adhesive diffusion mortar with no finishing
- Composition 2 (LSHD + PS): Basic adhesive diffusion mortar + silica penetration
- Composition 3 (LSHD + PS + SZO3): Basic adhesive diffusion mortar + silica penetration + silicate plaster with maximal grain 3 mm

The required diameter of the discs is stated in the both standards [1,2]. So the discs were made according them. Then three approximately 117 mm diameter discs from each composition were tested. Also the measuring was performed according to the standard ČSN EN ISO 7783 [1,2] focused on paints and varnishes as well as the determination of their water vapour permeability. Basic properties of the tested compositions (weight, thickness and their average values) are stated in the following tables (Tab. 1 – 3).

These mentioned properties were determined before the tests of diffusion properties. Sample diameters should range around required value 117 mm, imprecisions were solved by silicon sealant. It has two roles. First is to ensure an impermeability of water vapours around a sample, second is to enable permeability only through a tested sample. Sample thickness is taken into consideration in the calculation of the diffusion properties themselves.

Table 1. Composition 1 - Dimensions.

Sample mark	Sample number	Sample weight (*g*)	Ø (*mm*)		Average (*mm*)	Sample thickness (*mm*)		Average (*mm*)
LSHD	A	30.7	117.3	118.0	117.7	1.8	2.0	1.9
	B	30.9	117.7	117.7	117.7	1.9	1.9	1.9
	C	34.2	117.2	117.6	117.4	2.4	2.3	2.4

Table 2. Composition 2 - Dimensions.

Sample mark	Sample number	Sample weight (*g*)	Ø (*mm*)		Average (*mm*)	Sample thickness (*mm*)		Average (*mm*)
LSHD+PS	A	38.4	117.6	117.7	117.7	2.0	2.0	2.0
	B	37.6	117.3	117.3	117.3	2.5	2.3	2.4
	C	39.9	117.3	117.2	117.3	2.6	2.5	2.6

Table 3. Composition 3 - Dimensions.

Sample mark	Sample number	Sample weight (*g*)	Ø (*mm*)		Average (*mm*)	Sample thickness (*mm*)		Average (*mm*)
LSHD+PS	A	78.7	117.0	116.9	117.0	5.5	5.5	5.5
+SZO3	B	76.9	116.9	117.0	117.0	5.6	5.5	5.6
	C	80.6	117.0	117.0	117.0	5.5	5.6	5.6

3. Results and discussion

Three samples from each composition were chosen. For determining water vapour permeability, samples were weighted on scales in accordance with the standards ČSN EN ISO 7783 [1,2]. These three samples of the particular composition were simultaneously tested in one measuring interval. The duration of the interval ranged around 14 days. It was the period necessary for the steading of the values of temperature and relative humidity inside of the chamber required by the standard.

Required border conditions were ensured by an impermeable aquarium connected to a ventilation system. It managed temperature and relative humidity inside it. All quantities, relative humidity and temperature inside and outside of the aquarium, were continually measured using a measuring probe. Weight losses on scales were also continually measured and monitored identically. The data from the scales were monitored on a connected device every minute.

The results summarizing main diffusion characteristics, it means the results of water vapour rate, water vapour permeability and water vapour resistance factor from the measuring of the particular compositions are stated in the tables (Tables 4 – 6).

Table 4. Composition 1 - Water vapour permeability and water vapour resistance factor - relative humidity 52%, temperature 24°C.

Sample mark	Sample number	Water vapour rate ($\times 10^{-8}$ *kg/s*)	Water vapour permeability (*kg/(m²·s·Pa)*)	Water vapour resistance factor (-)
LSHD	A	3.44	1.24E-08	8.57
	B	3.52	1.33E-08	7.96
	C	3.49	1.29E-08	6.59
Average		3.48	1.29E-08	7.7

Table 5. Composition 2 - Water vapour permeability and water vapour resistance factor - relative humidity 52%, temperature 23°C.

Sample mark	Sample number	Water vapour rate ($\times 10^{-8}$ *kg/s*)	Water vapour permeability (*kg/(m²·s·Pa)*)	Water vapour resistance factor (-)
	A	2.57	6.02E-09	17.0
LSHD+PS	B	2.49	6.57E-09	12.9
	C	2.57	5.14E-09	15.3
Average		2.54	5.91E-09	15.1

Table 6. Composition 3 - Water vapour permeability and water vapour resistance factor - relative humidity 52%, temperature 23°C.

Sample mark	Sample number	Water vapour rate ($\times 10^{-8}$ *kg/s*)	Water vapour permeability (*kg/(m^2.s.Pa)*)	Water vapour resistance factor (-)
LSHD+PS +SZO3	A	8.92	1.29E-09	28.3
	B	9.27	1.35E-09	26.7
	C	9.03	1.39E-09	27.3
Average		9.07	1.34E-09	27.4

Detailed results of average values (decisive for some quantities for the particular measuring day of the balanced state required by the standard): sample diameter, sample thickness, dependence factor, sample specific area, density of water vapour flow rate, water vapour resistance, diffusion resistance, diffusion conductivity factor, atmospheric pressure factor, water vapour resistance factor, equivalent diffusion thickness, are possible to see in the tables (Tables 7 – 9).

Table 7. Composition 1 - Results of diffusion parameters - relative humidity 52%, temperature 24 °C.

Quantity	Quantity name	Unit	LSHD A	LSHD B	LSHD C
D	Sample diameter	(*m*)	0.1	0.1	0.1
d	Sample thickness	(*m*)	0.0019	0.0019	0.0024
G	Dependence factor	(*kg/s*)	3.44E-08	3.52E-08	3.49E-08
A	Sample specific area	(*m^2*)	0.007850	0.007850	0.007850
g	Density of water vapour flow rate	(*kg/(m^2.s)*)	4.38E-06	4.49E-06	4.44E-06
W_c	Water vapour resistance	(*kg/(m^2.s.Pa)*)	1.24E-08	1.33E-08	1.29E-08
Z	Diffusion resistance	(*m^2.s.Pa/kg*)	8.08E+07	7.50E+07	7.75E+07
δ	Diffusion conductivity factor	(*kg/(m.s.Pa)*)	2.38E-11	2.57E-11	3.10E-11
δ_a	Atmospheric pressure factor	(*kg/(m.s.Pa)*)	2.03E-10	2.03E-10	2.03E-10
μ	Water vapour resistance factor	(-)	8.57	7.96	6.59
s_d	Equivalent diffusion thickness	(*m*)	0.02	0.02	0.02

Table 8. Composition 2 - Results of diffusion parameters- relative humidity 52%, temperature 23 °C.

Quantity	Quantity name	Unit	LSHD+PS A	LSHD+PS B	LSHD+PS C
D	Sample diameter	(*m*)	0.1	0.1	0.1
d	Sample thickness	(*m*)	0.0020	0.0024	0.0026
G	Dependence factor	(*kg/s*)	2.57E-08	2.49E-08	2.57E-08
A	Sample specific area	(m^2)	0.007850	0.007850	0.007850
g	Density of water vapour flow rate	($kg/(m^2.s)$)	3.28E-06	3.17E-06	3.28E-06
W_c	Water vapour resistance	($kg/(m^2.s.Pa)$)	6.02E-09	6.57E-09	5.14E-09
Z	Diffusion resistance	($m^2.s.Pa/kg$)	1.66E+08	1.52E+08	1.95E+08
δ	Diffusion conductivity factor	(*kg/(m.s.Pa)*)	1.20E-11	1.56E-11	1.32E-11
δ_a	Atmospheric pressure factor	(*kg/(m.s.Pa)*)	2.03E-10	2.03E-10	2.03E-10
μ	Water vapour resistance factor	(-)	17.0	12.9	15.3
s_d	Equivalent diffusion thickness	(*m*)	0.03	0.03	0.04

Table 9. Composition 3 - Results of diffusion parameters - relative humidity 52%, temperature 23 °C.

Quantity	Quantity name	Unit	LSHD+PS +SZO3 A	LSHD+PS +SZO3 B	LSHD+PS +SZO3 C
D	Sample diameter	(*m*)	0.1	0.1	0.1
d	Sample thickness	(*m*)	0.0055	0.0056	0.0056
G	Dependence factor	(*kg/s*)	8.92E-09	9.27E-09	9.03E-09
A	Sample specific area	(m^2)	0.007850	0.007850	0.007850
g	Density of water vapour flow rate	($kg/(m^2.s)$)	1.14-06	1.18E-06	1.15E-06
W_c	Water vapour resistance	($kg/(m^2.s.Pa)$)	1.29E-09	1.35E-09	1.39E-09
Z	Diffusion resistance	($m^2.s.Pa/kg$)	7.76E+08	7.41E+08	7.64E+08
δ	Diffusion conductivity factor	(*kg/(m.s.Pa)*)	7.12E-12	7.53E-12	7.36E-12
δ_a	Atmospheric pressure factor	(*kg/(m.s.Pa)*)	2.03E-10	2.03E-10	2.03E-10
μ	Water vapour resistance factor	(-)	28.3	26.7	27.3
s_d	Equivalent diffusion thickness	(*m*)	0.16	0.15	0.15

3.1. Dependence of diffusion on relative humidity

Relative humidity has an important impact on water vapour resistance factor. Only A samples were included into the comparison. Their characteristics are shown in the previous tables (Tab. 1–9). The comparison was aimed at the demonstration of the impact of relative humidity on water vapour resistance factor of the different kinds of compositions. During the achieving of the steady humidity required by the standard was managed to achieve relative humidity 52% and 43% for all compositions so it was possible to draw the comparison. In following Table 10 it is possible to see how water vapour resistance factor is affected by relative humidity.

The changes of the values of water vapour resistance factor are shown in Table10. Composition 1 has changed about 1.2 down. The water vapour resistance factor of the second composition with silica penetration has changed its value about 0.6 up. There was the change of 0.3 up in the third composition with silica penetration and silicate plaster.

Table 10. Dependence of water vapour resistance factor on relative humidity.

Property	Basic adhesive diffusion mortar	Basic adhesive diffusion mortar + silica penetration	Basic adhesive diffusion mortar + silica penetration + silicate plaster
Thickness (*mm*)	1.9	2.4	5.5
Relative humidity (*%*)	52	52	52
Temperature (*°C*)	24.1	23.1	23.1
Air pressure (*hPa*)	979	998	994
Dependence factor (*kg/s*)	0.0000000344033	0.0000000249	0.00000000891823
Water vapour resistance factor at relative humidity 52 % (-)	8.6	12.9	28.3
Relative humidity (*%*)	43	43	43
Temperature (*°C*)	24.1	22	24
Air pressure (*hPa*)	977	992	992
Dependence factor (*kg/s*)	0.0000000448	0.0000000276	0.000000011003
Water vapour resistance factor at relative humidity 43 % (-)	7.4	13.5	28.5

3.2. Dependence on other conditions

As it was mentioned before, water vapour resistance factor is affected by many other parameters and border conditions. Thickness and diameter of a sample count among the parameters having an impact on water vapour resistance factor, too. These quantities are constant during the whole measuring and they are stated in the previous tables (Table 1 – 3). Temperature and barometric air pressure are the variable quantities having an impact on water vapour resistance factor. It was mentioned above that temperature together with relative humidity are measured and monitored on a PC device during the whole experiment. Values of barometric air pressure for every hour are also measured and it is possible to download them from a meteorologist station, too.

The paper "The Influence of Incoming Parameters on Accuracy of Determination Water Vapour Resistance Factor of Lime and Modified Mortars" [3] discusses parameters having an impact on water vapour resistance factor. It is obvious from the paper, that not only the border conditions can have the significant impact on the water vapour resistance factor but also the standard according to a sample is tested and evaluated, because each standard requires different testing conditions (required relative humidity and distance between a saturated solution and a tested sample). Besides, the value of water vapour resistance factor is influenced by: an inaccuracy of the determination of particular quantities; an inaccuracy of the measuring; changes of surroundings (temperature, humidity, pressure); other impacts (a sample manufacture technology, duration of achieving of a steady state); errors of a reading and an incorporation of data into the calculation.

Among main parameters influencing the result calculations belong: the choice of values and a subtraction of a weight change, the determination of an exposed area and thickness of a tested sample, the determination of thickness of an air layer between a sample and a level of a salt solution, the setting and a maintenance of temperature of a surrounding, barometric pressure and its changes during the tests, the values of air relative humidity.

The main issue still remains: How much is the value of water vapour resistance factor influenced by the mentioned parameters. It is possible to see in Table 10 that composition 1 was the most influenced by the change of relative humidity. Composition 1 has the smallest water vapour resistance factor. But factor of this composition was changed down unlike the other compositions. Composition 2 has smaller water vapour resistance factor than composition 3 as well as it had bigger change of the factor.

It is obvious the knowledge suffers from the lack of data. There are not many papers on this topic, but it is possible to find some [7,8]. The paper Diffusion Parameters of Basic Diffusion Adhesive Mortars with Silicate or Acrylic Plaster [4] has dealt with the comparison of three different compositions, too.
The compositions were following:

- Composition 1 (LSHD): Basic adhesive diffusion mortar without any finishing
- Composition 2 (LSHD + PS + SZO3): Basic adhesive diffusion mortar + silicate penetration + silicate plaster - maximal grain 3 mm
- Composition 3 (LSHD + PAS + AZO3): Basic adhesive diffusion mortar + acrylic-silicon penetration + acrylic plaster - maximal grain 3 mm.

The kinds of compositions are not so important as their water vapour resistance factors and the influences of relative humidity. The first composition is known composition 1 that has water vapour resistance factor 8.6 at 52% relative humidity (7.4 at 43% relative humidity), the second composition 2 had 28.3 (28.5) an the third had 91.1 (105.8). The accurate values are not the decisive.

Decisive is that the course is the same. When you have a composition with really small water vapour resistance factor (8) it seems to be influenced by decreasing relative humidity down. If you have a composition with bigger one, the decreasing relative humidity causes the change of water vapour resistance factor up. The bigger water vapour resistance factor the bigger change of it.

Of course it is necessary to examine more kinds of compositions as well as examine the other border conditions and their extent of the impact on the value of water vapour resistance factor.

4. Conclusions

The paper has dealt with three compositions commonly used for wall finishing. The main characteristics of the compositions were determined. The main diffusion properties were determined, too.

The values of water resistant factor were compared to each other from the point of view of relative humidity values. This comparison was made at 52% and 43% relative humidity. The input parameters and the border conditions having an impact on the determination of the value of water vapour resistance factor were summarized in the end. The parameters having according to researches the most significant influence on the values of water vapour resistance factor were set aside.

The results of the compositions were compared with the other compositions that had been examined before. The course of the change of water vapour resistance factor is the same.

Nonetheless the definition of the most influencing parameter is not so simple and it differs for the particular compositions in dependence on their values of water vapour resistance factor. Relative humidity can be decisive for some values, barometric pressure is decisive for some values and for the others it is not really easy to find the direct relation of them. For a further research it is necessary to pay a detailed attention to the extent of the impact of the particular parameters on the determination of water vapour resistance factor for various types of compositions with different values of water vapour resistance factors. All the results of the determination of the values of water vapour resistance factors serve as a base for an annual assessment of water vapour condensation and am evaporation balance. The construction assessment can be performed according to the classic method stated in ČSN 73 0540 [5] or according to the modern one stated in ČSN EN ISO 13 788 [6]. The tested values help to find out if there is going to be condensation of water vapour on the surface of the tested material inside a building.

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