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Investigations of Hydro- and Hygro-sorption Properties of Silicate Masonry Products

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The study deals with the hydro- and hygro-sorption properties in silicate masonry products of multilayer enclosure structure, such as sorption moisture content, capillary water adsorption, water vapour permeability, water absorption and impact of the impregnation of aplite face brick surface by hydrophobic liquid SILRES BS16 on its frost resistance. It was established that moisture content in silicate products may vary from 1.65 % to 12.0 % subject to operation conditions. The investigations showed that upon determination of frost resistance no visible injuries were observed on the wall surface after 50 cycles of freezing.

Keywords: multilayer enclosure, silicate blocks, split face brick, masonry mortar, adhesive, plaster, hydro- and hygro-sorption properties, frost resistance.

INTRODUCTION

One of the most efficient and economical way of the technical design of external walls, with necessery thermal insulation properties is an application of multilayer enclosure constructions [1, 2]. For instance, such an enclosure may consist of a layer of silicate blocks, an external layer of silicate split face bricks and a between-layer of thermal insulation out of mineral wool (Fig. 1).

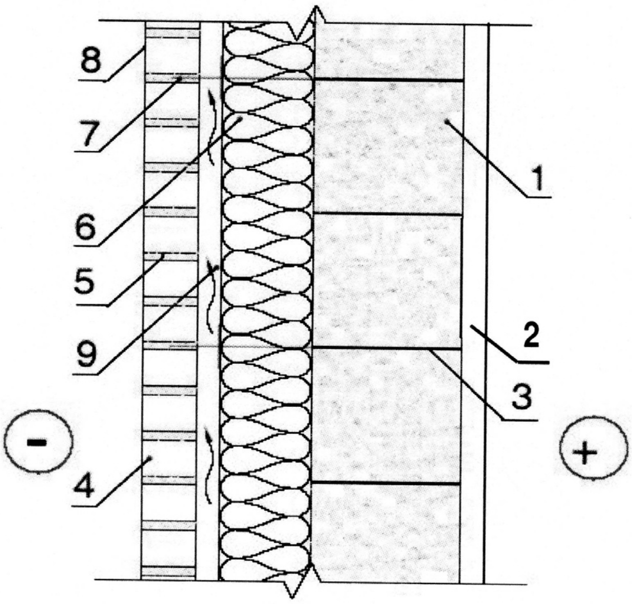

Fig. 1. Multilayer enclosure of silicate elements: 1 – silicate block; 2 – plaster; 3 – adhesive; 4 – split face brick; 5 – hydrophobic masonry mortar; 6 – layer of thermo-insulating material; 7 – flexible bonds; 8 – hydrophobic surface; 9 – air gap [1]

In this case each layer of enclosure performs a different function. The inner bearing masonry work should meet the strength requirements specified for bearing materials, moreover, it should ensure water vapour migration outwards from inside, i. e. the wall should secure the requirements of thermal "breathe" [3, 4]. The middle thermo-insulating layer of enclosure should secure requirements of the thermal resistance specified for construction work [5 – 7]. The external face layer should protect the thermo-insulating material from direct atmospheric exposure, as well as should ensure the aesthetic appearance of construction work and its life to failure [8 – 10].

One of the ways to reduce the water sorption of external layer of enclosure and prolong its life-time is the layer's surface impregnation by special hydrophobic materials, e. g., sodium or potassium siliconates [11 – 13].

The insoluble hydrophobic but pervious to gas and water vapour calcium siliconate film is formed on the surface of products, which have Ca^{2+} ions, after impregnation with water soluble siliconates of alkaline metals [11, 13].

However, as authors state in [12], suitable for every case hydrophobizator should be selected individually. The disorder of a moisture balance in the surface layer of ceramic finish bricks is possible after hydrophobic impregnation and drying. It can make a negative effect to the frost resistance [12].

It is necessary to note that hydrophobization of silicate bricks became actual quite recently, when split and axed finish bricks for the formation of enclosure external layer were started to produce in Lithuania. Although surface hydrophobization of silicate bricks is used in other countries (e. g. in Germany) but there were no publications found for this subject. From literature sources about hydrophobization of products with prevalent amount of SiO_2, publications fall on research of light fillers and dry mixtures for the most part [13, 14].

The bearing wall consists of silicate blocks containing special rebates and recesses, which allow not to fill vertical joining seams by mortar. Horizontal seams are filled by a thin layer (of 3 mm) of masonry mortar (adhesive).

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At first silicate blocks were developed in Germany and in accordance to their standard devided into CS I (CS – calcium silicate, compressive strength is ≥20 N/mm^2) and CS II (compressive strength is ≥ 12 < 20 N/mm^2) classes [15]. At present they are included in general European standard EN 771-2+A1:2005 with other masonry units from calcium silicate and divided into 13 compressive stength classes. The blocks are sucessfully used as masonry elements for enclosure in many European countries [16].

These blocks are a new building material on the Lithuanian market, therefore, it is important to know the content of moisture accumulated during operation, i. e. the hydro- and hygro-sorption properties of enclosure's silicate elements, which have a great effect on thermal resistance, frost resistance, strength etc. of wall.

The performance characteristics of enclosures were an object of research [17 – 19], however, the properties of enclosures out of silicate blocks were investigated not fully. Silicate blocks differ from their foreign analogues, firstly, by nature of raw material (quartz quantity in the sand, it's granulometric composition etc.) and, secondly, by it's technologies peculiarities (compressive load of semifinished product, autoclaving parameters etc.). These differences, of course, affect the physical properties of masonry products.

The aim of this study is to investigate comprehensively some performance characteristics of enclosure out of silicate masonry elements, such as sorption moisture content, water vapour permeability, water absorption, capillary water adsorption, as well as to determine the impact of hydrophobic impregnation on frost resistance of face brick wall.

MATERIALS AND TECHNIQUES OF INVESTIGATION

For investigation the following samples were selected: masonry products – silicate blocks and split face bricks (LST EN 771-2+AI:2005) from JSC "Matuizų plytinė", masonry mortar, adhezive (LST EN 998-1:2004) from JSC "Matuizų dujų silikatas". All masonry mortars were prepared from Portland cement (mortar and adhesive), or from cement-lime sand (plaster) binder with different additives.

The data on physical-mechanical properties of the masonry products used are provided in Table 1.

For the impregnation of façade surface of silicate split bricks, the hydrophobic liquid SILRES BS 16 (an aqueous solution of potassium methyl siliconate, pH = 13, density 1.4 g/cm^3, viscosity 15 mPa · s) was applied.

The compression strength of masonry products was determined by LST EN 772-1:2003, net- and gross densities of dry plasters by LST EN 772-9:2002 and LST EN 772-13:2003, water capillary adsorption by LST EN 772-11+AI:2005 (for silicate blocks) and by LST EN 1015-18:2003 (samples of hardened plaster and masonry mortar), water vapour permeability by LST EN ISO 12572:2002 and LST EN 1015-19:2001, (the standard climatic regime "C" taken as 23 – 50/95 (23 °C – ambient temperature, 50 % – relative air humidity underneath the sample, 95 % – relative air humidity above the sample)). The hygroscopic sorption properties were determined by LST ISO 12571:2000, using the saturated solutions of four salts (K_2CO_3, NaBr, $(NH_4)_2SO_4$ and K_2SO_4), above which at temperature of 23 °C the values of relative air humidity (φ) reached 43 %; 58 %; 81 % and 97 %, respectively, as well as the 16.8 % water solution of H_2SO_4, which ensured the relative humidity of 90 %.

Table 1. The dry density and compression strength of silicate masonry products

Name of product	Dry density, kg/m^3	Average compres-sion strength, N/mm^2	Classificati on by compres-sion strength
"Siliblokas" M-12	1420/1740*	17.62	15
Split face brick**	1870	21.5	20
Hydrophobic masonry mortar	1570	11.74	M10
Adhesive	1590	17	M15
Plaster	1310	1.39	CSI

* The gross dry density of "Siliblokas" M12 is provided in the denominator, while the net one in the numerator.

**The bricks with hydrophobic split surface, made in JSC "Matuizų plytinė" were used in our work.

The moulding and conditioning of samples of masonry mortar, adhesive and plaster was performed according to the requirements of LST EN 1015-11:2003 (the regime of hardening: first five days in moulds under the cover of film, then 2 days stripped under the cover of film (at relative air humidity of 95 % ±5 % and temperature of 20 °C ±2 °C) and finally kept for 21 days at the same temperature and relative air humidity of 65 % ± 5 % (in the open state without any film).

The phobic impregnation of surface of split bricks was carried out by application of hydrophobic liquid SILRES BS 16 with paint-brush on the facade or other surfaces and then leaving the product to dry for 24 h at temperature of 20^{o}C.

Upon determination of effectiveness of hydrophobic treatment for frost resistance of face bricks, two fragments of walls were bricked (0.5 m × 0.5 m) out of hydrophobic masoury mortar. After exposure of 28 days, one fragment was coated from each side by hydrophobic solution and conditioned for 2 days under natural ambient conditions (at temperature of 20 °C). Afterwards both fragments were submerged into water, exposed for 48 h and mounted in the stand of one-side freezing for determination of frost resistance by LST 1413.12 technique. The periodically fluctuating temperature was kept in the chamber 24 h during the freeze from one side by this method. The duration of one fluctuation period – 3 h, over this period specimens were freezed 7 times and partly defrosted 6 times. The temperature in a chamber was – 16 °C at the end of freezing half period, and partly defrosting ~0 °C. The specimen section was disconnected from freezing chamber and turned at a 180° angle after 7th freezing half period than it was joined with a heating-aeration section. The heating stage duration of test cycle – 24 h. Firstly, the decorative surface of test fragment was aerated 3 min with 15 °C temperature water, later fragment was slowly heated 16 h in a hermetic section with relative air humidity ~95 %. The decorative surface of the fragment was aerated 6 h with 15 °C temperature water at the end of heating cycle. The condition of decorative surface of the specimen was estimated inspecting and thumping every 5 cycles. The condition of test surface was continually compared with a primary condition of the specimen surface. Furthermore, for comparison, the frost resistance tests of silicate face bricks were carried out by requirements of LST EN 772-18:2002.

RESULTS AND DISCUSSION

The isothermal curves of sorption for silicate brick samples with hydrophobic and not hydrophobic surface (at temperature of 23 °C ±2 °C) are provided in Fig. 2 (curves 1 and 2).

For the sake of comparison, there is also provided a sorption isotherm for autoclaved aerated concrete (AAC) with density of 500 kg/m^3 (Fig. 2, curve 3) [18].

The results of performed investigations show that the sorption moisture content of hydrophobized silicate brick samples is less (from 30 % to 58 %) than the value of not hydrofobic samples, when the relative air humidity varying from 60 % to 90 % (curves 1 and 2). When φ = 97 %, the sorption moisture content of not impregnated silicate brick sample exceeds the value of aerated concrete even by 0.6 % (curves 2 and 3).

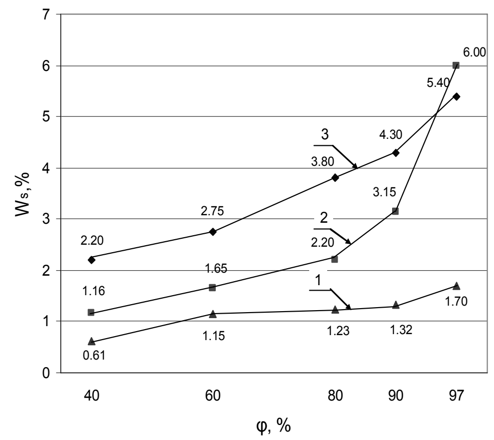


Fig. 2. The influence of relative air humidity (φ) on silicate products sorption (w_S): 1 – brick's sample with hydrophobic surface; 2 – not hydrophobic brick's sample; 3 – AAC [18]

The difference in the micro- and macrostructure of samples accounts for such results. During autoclaving, more numerous calcium hydrosilicates with crystallic state are formed (α-C_2S hydrate, tobermorite of 1.13 nm etc.) in AAC samples, meanwhile in the dense silicate concrete the calcium hydrosilicates in amorphic structure prevail (e. g. CSH I), which at higher relative air humidity distinguish by better water vapour absorption and swelling [18, 20, 21].

The micropore structure (diameter of pores and capillars is up to 200 nm) is characterized for the products of dense silicate concrete (bricks, blocks), while macropore structure is more typical for AAC (diameter of pores is from 0.25 mm to 2 mm) [22 – 24].

The investigations of capillary water adsorption of dense silicate concrete samples show that the silicate products are characterized by rather good capillary sorption (Fig. 3). While comparing the sorption properties of silicate block (ρ = 1740 kg/m^3; curve 1) versus those of not hydrophobized face brick (ρ = 1870 kg/m^3; curve 2), we can see that the values of coefficient of water adsorption due to capillary action of silicate split face bricks samples are less from 30 % to 54 % then silicate blocks samples, subject to duration of impregnation. This may be explained rather by greater approximation of particles in the filling applied on face brick and by greater densing of cementing material than in the sample of silicate block.

The sample of silicate concrete with fully hydrophobized surface has a constant value of coefficient of water adsorption (0.05 kg/(m$^2\cdot$min$^{0.5}$)), irrespective of duration of impregnation of sample (curve 3). This is related to particularities of used hydrophobizator.

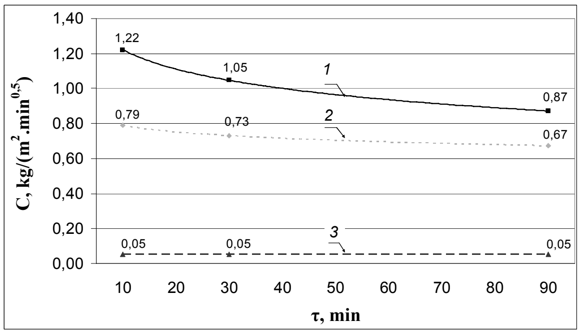


Fig. 3. The impact of time of impregnation on coefficient of water adsorption due to capillary action in the silicate samples: 1 – silicate block (ρ = 1740 kg/m^3); 2,3 – split face brick, ρ = 1870 kg/m^3: 2 – not hydrophobized, 3 – hydrophobized

Figure 4 provides the values of water adsorption coefficient for each silicate element of enclosure after soaking in water for 90 min. We can see that the internal plaster has higher water adsorption (C = 1.08 kg/(m$^2\cdot$min$^{0.5}$), column 1), while the (adhesive (C = 0.05 kg/(m$^2\cdot$min$^{0.5}$), column 3) and the split face brick with fully hydrophobized surface (C = 0.05 kg/(m$^2\cdot$min$^{0.5}$), column 5) least of all.

The results of these investigations show that for operation of multilayer enclosures of silicate elements, it is expedient to hydrophobize the face layer.

The moisture content accumulated in the brick wall removes the quicker, the better is the water vapour conductivity of masonry elements of the wall.

The characteristics of water vapour conductivity of silicate masonry products under investigation are provided in Fig. 5. The obtained data show that such masonry products as silicate block and masonry mortar are not good water vapour conductors and the values of their vapour diffusion coefficient (μ) are rather high: 22.5 and 25.5, respectively (columns 1 and 3). Consequently, for drying of such wall, of importance is as good as possible water vapour conductivity of plasters meant for coating of silicate blocks. The performed investigations confirmed this assumption, e. g. the coefficient of internal plaster

μ = 12.2 (column 2) what means that such a plaster is twice more conductive to water vapour than the dense silicate concrete. For comparison, the value of water vapour diffusion coefficient for earlier investigated AAC is provided (column 4) [18].

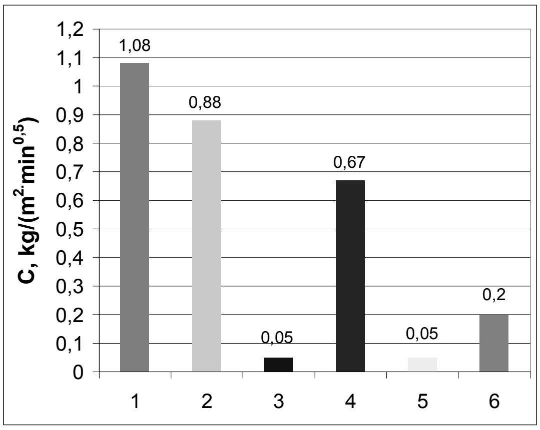


Fig. 4. The values of capillary water adsorption coefficient in silicate masonry products of enclosure after soaking for 90 min: 1 – plaster; 2 – silicate block; 3 – adhesive; 4 – not hydrophobized split face brick; 5 – hydrophobized face brick; 6 – mortar

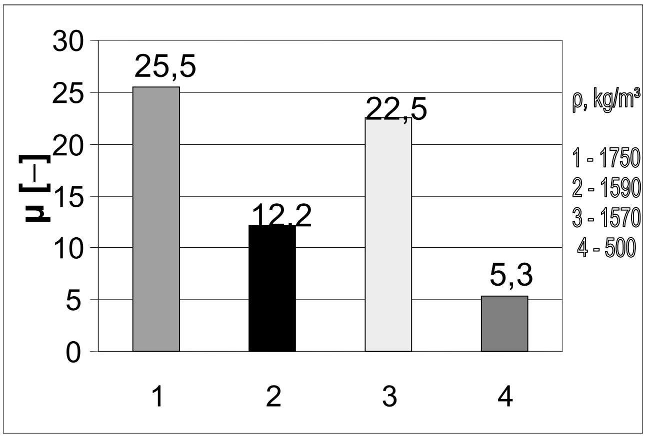


Fig. 5. The values of water vapour diffusion coefficient of silicate samples: 1 – silicate block; 2 – plaster; 3 – adhesive; 4 – AAC [18]

The water vapour migration in the AAC wall proceeds through the AAC blocks themselves because of low value of coefficient μ (5.3), meanwhile in the masonry work out of silicate blocks this process runs otherwise.

The water vapour diffusion coefficient of internal plaster (μ = 12.2) allows for assuming that the majority of water vapour accumulated in the room will migrate through plaster and vertical seams of enclosure not filled by mortar and for attributing an enclosure bricked out of silicate blocks to "breathing" walls.

In the course of investigation of full water absorption of silicate masonry products (Fig. 6), it was observed that the water absorption of silicate blocks and face bricks is practically equal, approximately 12 % (columns 1 and 2), irrespective of the fact that one surface (a facade one) of face brick is hydrophobic.

With the object of determining the impact of water-repelling agent on full water absorption, we performed an additional coating of whole surface of brick by hydrophobic liquid. The water absorption of such bricks decreased by 28.3 % versus that of bricks with only one hydrophobic facade surface (columns 2 and 3). For comparison, we also provide the water absorption of AAC [25], which is approximately 6 times higher than that of dense silicate blocks sample (columns 1 and 4).

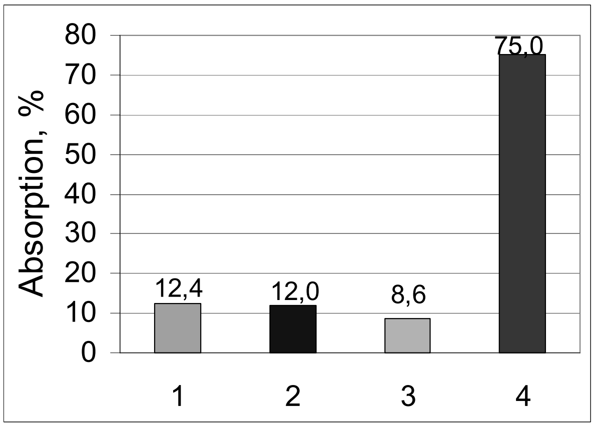
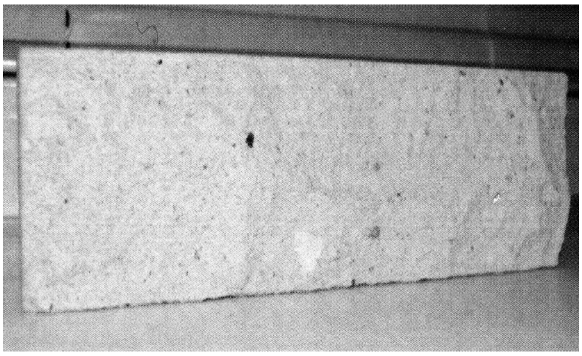


Fig. 6. The water absorption of silicate products (after soaking in water for 48 h): 1 – silicate block; 2, 3 – split face brick: 2 – with hydrophobized facade surface; 3 – with fully hydrophobized surface; 4 – AAC [25]

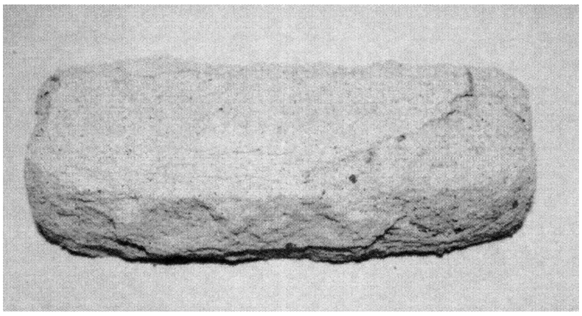
The absorption of product is directly related to its freeze resistance, consequently, the external layer of split face bricks in the multilayer enclosure should have the absorption, as low as possible. The wall of enclosure will be protected from the greater absorption only in case of face bricks with hydrophobic facade surface and hydrophobic masonry mortar. However, the investigation of frost resistance of bricks was based on the requirements of LST EN 772-18:2002, which provide for soaking of silicate brick samples in water for 48 h. In this case the hydrophobization of brick surface in façade finishing has no impact on absorption and thereby on frost resistance, since the remaining 3 sides and end surfaces of soaked bricks are not hydrophobic. The absorption of such bricks equals to that of totally not hydrophobized ones, i.e. ordinary silicate bricks. This was proved by the results of performed investigations, which showed that face bricks with a hydrophobic facade surface withstood 25 freeze-thaw cycles only. The intense disintegration of bricks was observed as early as the 26th freeze-thaw cycle (Fig. 7, a and b).

For the investigation of frost resistance in the face layer of enclosure using the one-sided freeze technique by LST 1413-12, two fragments of wall with external finishing (0.5 m × 0.5 m) were bricked (Fig. 8) out of silicate split face bricks with a hydrophobic fasade surface and out of hydrophobic masonry mortar M 10.

The whole external surface of one wall (all sides) was additionally treated by the hydrophobic liquid, while another wall was bricked without additional hydrophobization. Before freezing, both wall fragments were soaked in water (for 48 h). The data of absorption of fragments are provided in Table 2.



a



b

Fig. 7. The split face bricks with a hydrophobic facade surface: a – before frost resistance test; b – after 26 freeze-thaw cycles

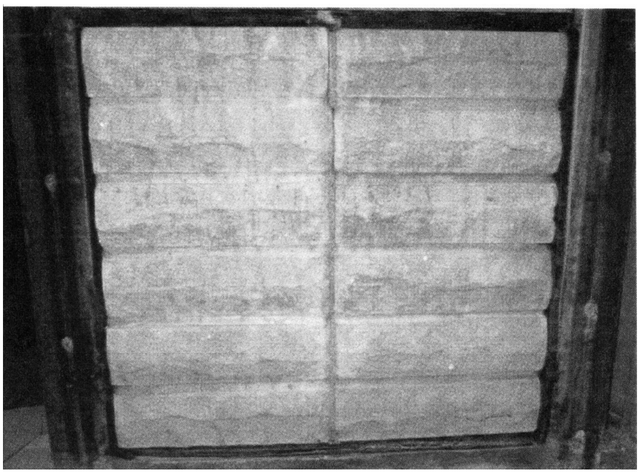


Fig. 8. The wall fragment out of silicate split face bricks

Table 2. The data of absorption in the fragment of silicate face layer of enclosure

Wall fragments	Mass, kg		Absorption, %
	Before soaking	After soaking	
Finishing wall with a hydrophobized only facade surface	39.4	43.8	11.2
Finishing wall with fully hydrophobized external surface	39.8	43.6	9.5

The performed investigations showed that both walls of silicate face bricks withstood 50 freeze-thaw cycles without any visible surface injuries. This fact maintained that the surficial hydrophobization of facade surface of bricks is effective enough, if for that operation the hydrophobic liquid SILRES BS16 and for wall bricking the hydrophobic masonry mortar, which the coefficient of water adsorption due to capillary action is $0.20\ \text{kg}/(\text{m}^2 \cdot \text{min}^{0.5})$, (Fig. 4, Column 6) were used.

CONCLUSIONS

It is established that:

1. The moisture content of not protected silicate products may vary from 1.65 % to 12 %, subject to operation conditions.
2. The values of water vapour diffusion coefficient in the enclosure bricked out of silicate blocks and protected by plaster from the inside are the following: silicate block and masonry mortar 25.5 and 22.5, respectively, and that of 12.2. This allows for assuming that in the enclosure, the water vapour migration proceeds through the layer of plaster and the vertical seam unfilled by masonry mortar.
3. The impregnation of surface of silicate split face bricks by hydrphobic liquid SILRES BS 16 and application of hydrophobic masonry mortar is expedient, since allows for reduction of water sorption in external layer of enclosure, along with the increase of its frost resistance.
4. It is necessery to use one-side freezing method to determine frost resistance of silicate split face bricks with hydrophobic facade surface.

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