ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 10, No. 1. 2004

Moisture Behaviour of Masonry Wall at Rain and Strong Wind Effect

V. Paukštys*, R. Samajauskas, R. Bliūdžius

Laboratory of Thermal Building Physics, Institute of Architecture and Construction,
Tunelio 60, LT-3035 Kaunas, Lithuania

Received 09 October 2003; accepted 20 November 2003

To estimate the effect of wind pressure on the moisture penetration, split surface silicate bricks, samples of concrete-lime mortar and a small dimension mortared wall were chosen as the material for investigation. The choice of the materials was determined by the fact that significant part of exterior surfaces in Lithuanian houses are namely of silicate bricks. Silicate bricks of split surfaces absorb moisture well, therefore, are suitable as the object of the study.

To study the impact of rain with wind over the moisture content in walls, a special stand was used. The speed of the wind (m/s) was simulated respectively by pressure (Pa) to facilitate the experiment. The stand was attached to the surfaces of the wall under investigation; increased pressure was formed in addition to rain. The dependence of the saturation rate upon the rain intensity and formed pressure in the entire structure and for separate samples was investigated.

Keywords: wind pressure, external layer, saturation length, surface density of saturated water.

1. INTRODUCTION

Lithuanian climate may be regarded as smooth, since the flow of the solar radiation energy and the character of the atmospheric circulation in the entire territory of the republic do not demonstrate considerable differences. However, differences come into focus when analysing the distribution of other climatic parameters in separate regions as well as the annual alteration of their values [1, 2].

The practice of project making, construction, execution and exploitation demonstrates how important the estimation of the variety of Lithuanian climate is, since in various regions the effect of the numerical values of temperature, precipitation, wind and moisture on the buildings differs considerably. The divergence of climatic effects generates the project, construction and building solutions including the choice of building materials. The speed of the winds dominating in the sea area is higher than in the remaining territory of the country, and it is most obvious in rain periods [3]. The amount of water poured on the external surfaces of the walls depends on the wind speed and its direction during the rain, as well as the duration and intensity of raining.

The slanting rains with strong wind gusts that are so frequent at the seaside damper the exterior layer of the wall, which starts drying when the rain ceases [4, 5]. Both the temperature and humidity of the external layer of the wall often experience alteration. The water in the surface layers of the walls undergoes change in its amount and aggregate state thus causing the decay processes and the disturbance of the entire wall's humidity balance [6, 7].

While the building walls were made of the massive, single-layer, hardly permeable to water constructions, the moisture effect was exclusively regarded as the problem of the durability of the external finishing layer. However, in recent years, with the construction of the multi-layered with thermal insulation walls made of lightweight porous concrete or lightened brick, the probability of over-moistening of the external layer has increased [3, 5].

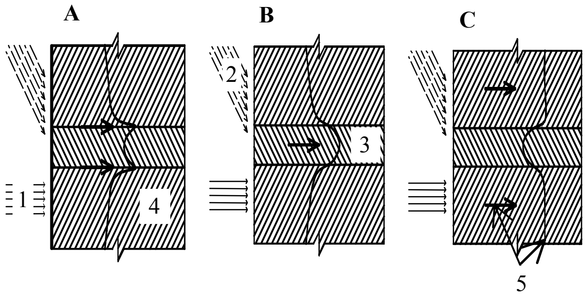

Fig. 1. Main causes of overmoistening: A – brick layer saturates because of an insufficient brick and mortar adhesion; B – brick layer saturates because of the poor mortar quality; C – brick layer saturates because of high moisture permeability of bricks. 1 – wind; 2 – rain; 3 – mortar; 4 – brick; 5 – central areas of moisture movement

Water can migrate throughout the brick wall in the following three cases:

1. When the stiff mortars are used, at the contact points between the brick and the mortar many open large diameter pores are formed through which the rain water penetrates intensively under the wind pressure (Fig. 1, A).
2. When the brick mortar is thick, and the capillaries are fine, the water moves through the seam under the impact of the capillary forces (Fig. 1, B).
3. When the seam is impermeable to water, the rain water moves through a brick (Fig. 1, C) [8, 9].

With respect to heat conservation and strength, it should be more expedient to construct a water impermeable supporting layer from inside and a thin protective layer from outside [10, 11]. Since at present a considerable part of the external wall layers is made of silicate 6 cm thick bricks with a split surface, this

---

[*] Corresponding author. Tel.: +370-37-350799; fax: +370-37-451355.
E-mail address: *silfiz@asi.lt* (V. Paukštys)

particular type of brick has been selected for the present analysis.

Having considered that the former research data regarding the alteration of the climatic conditions as well as the experimental test of the soaking of constructions during heavy rains with strong wind were not sufficiently estimated by the project makers and researchers, the present investigation aims at the solution of the following two problems: whether the construction with thermal insulation behind an external brick layer is possible and whether an air gap used to protect the insulating material from moistening is necessary. The following tasks were solved under the chosen aim:

1. To investigate the dependence of the impact of wind upon rain permeability, moisture accumulation in the wall building materials and their saturation.
2. To determine the dependence of rain penetration through masonry joints on the qualities of the masonry composites.

2. EXPERIMENTAL

The experimental research of the complex climatic impact was carried out with the use of a special stand produced for this particular investigation (Fig. 2).

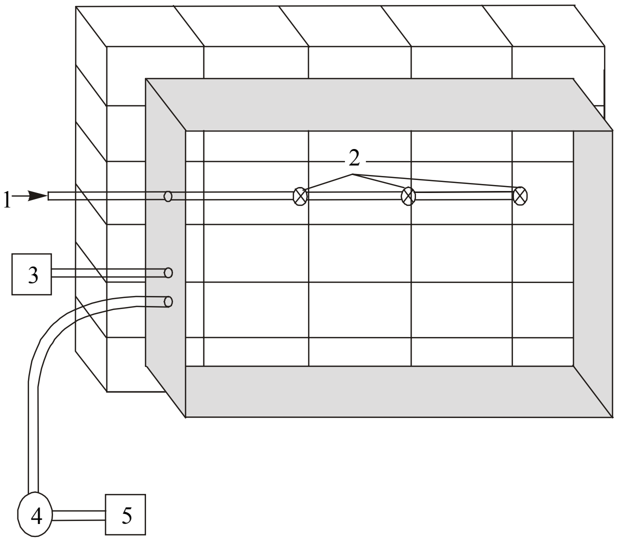

Fig. 2. Scheme of the rain resistance testing equipment: 1 – air meter; 2 – sprinklers; 3 – micro manometer; 4 – water feed; 5 – air-pump

The stand was hermetically attached to the wall fragment. The raised pressure was created with the help of the air-pump and measured with the micro manometer. The water was sprayed on the wall with a special sprayer.

During the analysis of the water absorption in the samples, the choice was made of their hermetical mounting on the wall instead of traditional brick lining. Before the experiment, the samples were dried at 105 °C temperature until their mass became steady and their sides were covered with the mixture impermeable to humidity that was made of colophony and paraffin. In order to evaluate the effect of the capillary forces, the mounted samples were rained on thus producing an entire water pellicle on their surface. The pressure in the stand was not raised. For the estimation of the strength of wind pressure, additional pressure was created.

Dry mortar mixtures produced in Lithuania were used for testing the mortar resistance to climate. The investigation aimed at the creation of the mortar, little permeable to water, by optimizing the granulometric structure of the filling with the help of various additives.

In all the experiments the cement-lime-sand ratio was kept constant: C:K:S = 1:0,5:5.

3. RESULTS AND DISCUSSIONS

3.1. The effect of rain and wind on the saturation of the silicate brick wall

The rain water penetrates into the constructions through the open pores and capillaries that occur in the wall material, and the impact of external pressure (most often, the wind) increases. In the case of fine capillaries that are vertical to the wall surface, the moisture migrates intensively under the impact of the absorbing forces of the capillaries. However, the mechanical influence of the external pressure is inconsiderable.

The smallest amounts of water are absorbed through the wall surface when the pores and capillaries of the applied materials are fine, of unstable direction, and when their surface is covered with resistant to water materials.

Having estimated this central water transfer mechanism, the water migration through the protective finishing wall produced of split-surfaced silicate bricks was examined because this construction, as has been mentioned above, is frequently used and demonstrates a traditional structure.

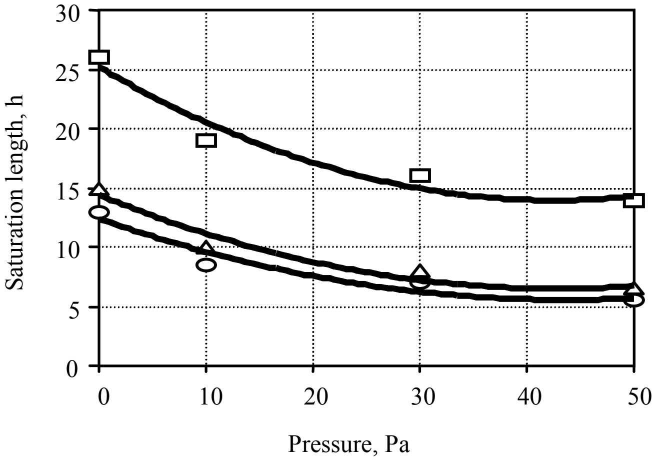

Fig. 3. Dependence of moisture content in silicate brick with split surface on cement-lime mortar due to wind pressure at differents raining intensity: □ – $I_v = 0.003$ mm/min; △ – $I_v = 0.01$ mm/min; ○ – $I_v = 1.0$ mm/min

It is obvious that when the pressure increases from 0 to 50 Pa, independently of the rain intensivity, the period of the wall over-moistening decreases nearly twice (Fig. 3). On the other side of the wall, the damp spots first appear at the seams. Both water and an infiltrated air stream penetrate through the seam cracks and leakings.

3.2. Investigation results of mortar moisture permeability

Since the thickness of the silicate bricks with the split surface varies greatly (around 6 – 7 cm in the thickest part, and in some parts only around 4 – 4.5 cm), moreover, the pores that became open during brick-splitting, are highly permeable to water, the analysis results are show the clear dependence of water absorption and moisture permeability due to the thickness of the sample.

2 – 6 cm thick silicate brick samples with the split surface were taken for the investigation, which was carried out according to the chosen method.

The tests demonstrated that, with the change of the sample thickness from 2 to 6 cm and under the formation of the entire water pellicle on their surface, the process of water absorption might be divided into two periods.

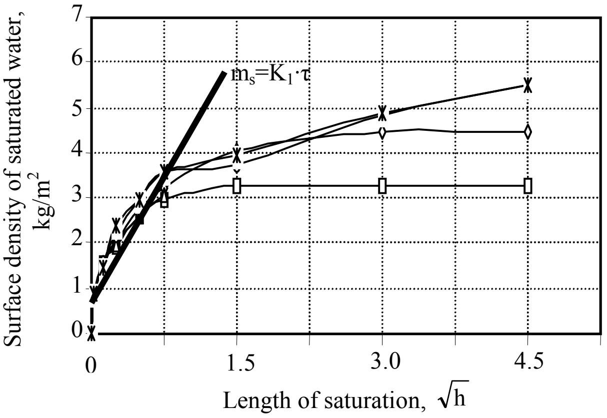

Fig. 4. The dependence of the surface density of saturated water in an external silicate brick layer on the length of saturation when brick thickness makes: □ – 2 cm; ◇ – 3 cm; △ – 4 cm; ○ – 5 cm; ✳ – 6 cm

In the first period (Fig. 4.) the density of absorbed water can be expressed in the following way:

$$m_s = K_1 \cdot \tau \; ; \qquad (1)$$

where τ is the length of saturation, h; m_s is the surface density of saturated water, kg/m^2; K_1 is the proportionality coefficient dependent on a capillary structure of the material, (in the case of silicate bricks $K_1 = 4.7$ kg/(m^2·h)).

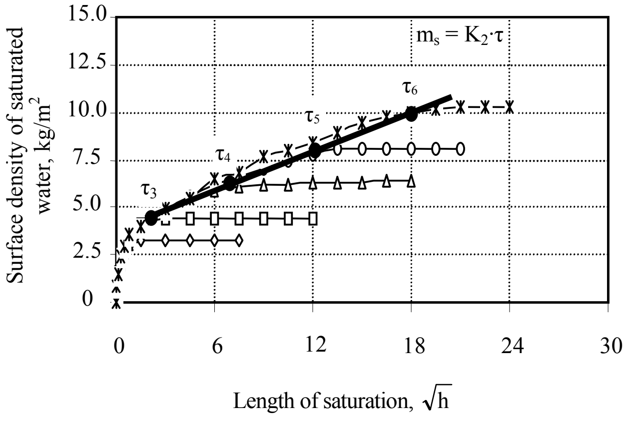

Fig. 5. The dependence of the surface density of saturated water in an exte rnal silicate brick layer on the length of saturation when brick thickness makes: ◇ – 2 cm; □ – 3 cm; △ – 4 cm; ○ – 5 cm; ✳ – 6 cm

When the external layer of the sample is fully saturated with water (1 m^2 silicate bricks surface area, where the bricks' area is 2 cm thick, absorbs about 3 kg water), the rate of change of density of the areal absorbed water considerably decreases.

In the second period the surface density of absorbed water can be expressed in the following way:

$$m_s = K_2 \cdot \tau \; ; \qquad (2)$$

where τ is the length of saturation, h; m_s is the surface density of saturated water, kg/m^2; K_1 is the proportionality coefficient dependent on a capillary structure of the material, (in the case of silicate bricks $K_2 = 0.3$ kg/(m^2·h)).

With such rate water is being absorbed until the sample is fully saturated with water.

Since under the common rain and wind effect, an entire water pellicle does not always form on the surface of the external walls, the further experiment was carried out with the change of the water pouring speed.

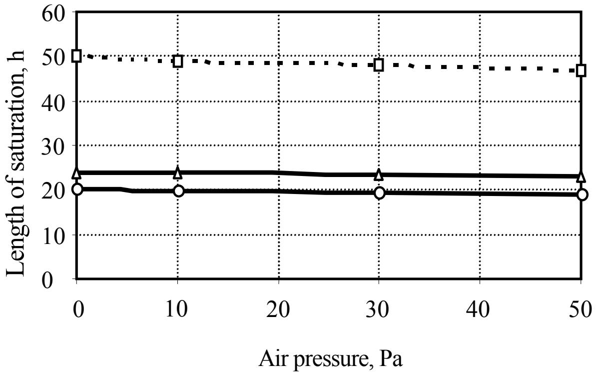

Fig. 6. The dependence of the saturation length in the split surface bricks on the air pressure during different rain intensivity: □ – I_v = 0.003 mm/min; △ – I_v = 0.01 mm/min; ○ – I_v = 1.0 mm/min

The achieved results show that the duration of saturation of the sample of a thick structure (silicate bricks with the split surface) does not considerably depend on the pressure. Thus, the main saturation factors are rain durability and the amount of precipitation falling on a vertical surface. During the rain, when the entire water pellicle does not form on the surface of the sample, the sample's surface absorbs all the rain water.

3.3. The saturation of the brick seams and the materials of which they are made

The most important characteristics of the non-hardened mortar is its plasticity that depends on the mortar's sliding capacity and the degree of water holding. The mortar is slidy and well water-holding, when the porosity of the utilized filling (sand) is the smallest one, i.e. when all the pores of the filling are filled with the paste of the binding material and the filling grains are covered with the paste level of the same thickness [8, 12].

The dry mortar mixtures produced in Lithuania were used for the analysis of the mortar resistance to the climatic effects. In the process, with the help of various additives and by optimizing the granulometric structure of the filling, the investigation aimed at producing the mortar that would be inconsiderably permeable to water.

The surface absorbed water density of the samples produced of the sand transformed in the laboratory are presented in Fig. 7 and Table 1.

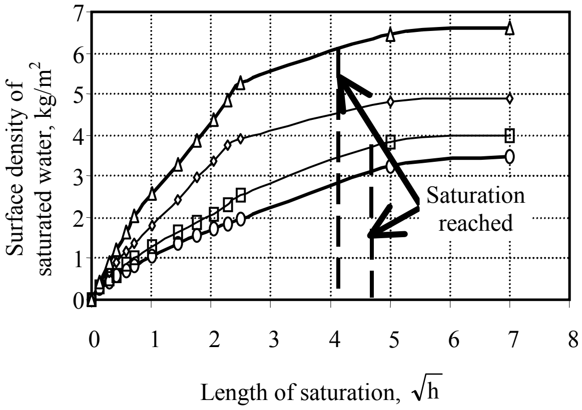

Fig. 7. The dependence of surface density of saturated water on rain duration at different levels of sand porosity: △ – S1; ◇ – S2; □ – S3; ○ – S4

Table 1. The properties of the mortar at different levels of sand porosity

Sample	S1	S2	S3	S4
Sand porosity, %	45	40	37	30
Sample density, kg/m^3	2000	2080	2120	2150
Surface density of saturated water, kg/m^2	6.45	4.81	3.8	3.24

Fig. 7 demonstrates that the durability of the sample's saturation remains more or less similar to the above mentioned cases. However, with the use of the sand transformed in the laboratory, the mortars demonstrate a considerably decreased amount of absorbed water. With the use of the sand with smaller porosity, the mortars with the more dense structure are produced.

In order to prolong the duration of the mortar's non-moistening, various polymeric, surface-activating or increasing water impermeability additives are included into the mortars. The plastics, when put into the mortars, decrease the water amount, improve their quality and at the same time the higher strength and density are reached. At present, super plastics are most often used since they decrease the water amount up to 30 %. With the use of the surface activating plastics, the interphasal energy between the hard phase and the liquid phase decreases (the friction between the particles of the concrete components becomes smaller, and the plasticity increases). For the mortars belonging to the SP1-SP3 group the surface-activating super plastic have been selected. The results are presented in Fig. 8 and Table 2.

A small amount of the additive (a part of one percent) considerably improves the properties both of the mortar mixtures and of a hardened mortar. When the surface-activating additives are used, the mortars need a smaller amount of cement and water, they spread easier on the surface in an even layer, and such mortars possess a denser structure and are less permeable to water. The achieved results show that with an additive that makes 0.5 % of the cement mass put into the mortar, after 24 h the surface density of the absorbed water decreased from 6.5 to 4.7 kg/m^2; with an additive that makes 2 % of the cement mass the surface density of the absorbed water is close to 3 kg/m^2.

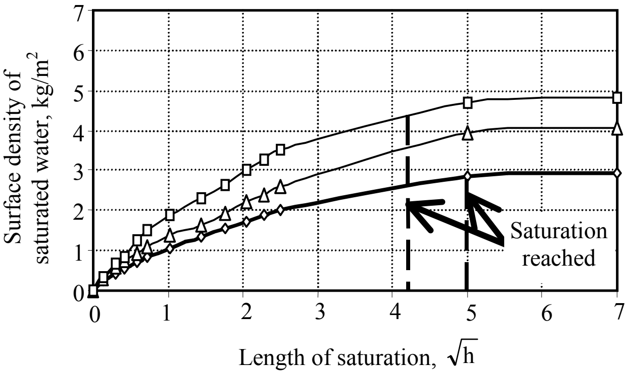

Fig. 8. The dependence of surface density of saturated water on raining duration when different amounts of the surface activating additive are included in the mortar: □ – SP1; △ – SP2; ◇ – SP3

Table 2. The properties of the samples and mortar components when a surface activating additive is used

Sample	SP1	SP2	SP3
Surface activating additive, %	0,5	1,0	2,0
Sample density, kg/m^3	2090	2130	2200
Surface density of saturated water, kg/m^2	4.68	3.92	2.87

However, this surface-activating additive does not protect the mortar from over-moistening. To avoid it, various pore-blocking additives are used.

Open pores and capillaries increase the water absorption in mortars. They are formed during the evaporation of free water. The greater the amount of water poured into the mortar, the greater the amount of unbound water. When this water evaporates, the quantity of the pores increases.

The closed pores are formed by the environmental air drawing which is encouraged by some special additives.

The additive increasing the amount of the closed pores was used for the mortars belonging to the group R1 – R3. The use of this additive produces scum (i.e. a lot of separate air bubbles whose diameter is from 10 to 1000 μm), that leaves the closed pores in the mortar. The closed pores increase the water impermeability in the mortar thus decreasing the strength of water absorption by the open capillaries. However, the quantity of the closed pores should be limited, since in case it is too big it may decrease the strength of the mortar. The research results are presented in Fig. 9 and Table 3.

With the help of experiments it has been determined that with the choice of the sand of lower porosity, the mortars have a denser structure, and their water absorption is smaller.

However, to prolong the durability of their non-over-moistening, the use of certain additives that enlarge the amount of the closed pores is necessary. It has been determined that with the use of a pore amount increasing additive that makes 0.5 % of the cement mass, the duration of the absence of saturation decreases inconsiderably. Meanwhile, the mortars including 1 % of a pore amount increasing additive did not get saturated for a longer period. The first damp spots appeared on the other side of the sample only after 2 days. The mortars including 5 % of a pore amount increasing additive did not get saturated for 5 days. The strength of such a mortar after one day of hardening is twice higher than the strength of the mortars that do not include additives. However, with time, the hardening process is not so dynamic and gets slower. After 28 days their strength is 1.5 – 2 times lower than that of the mortars without additives.

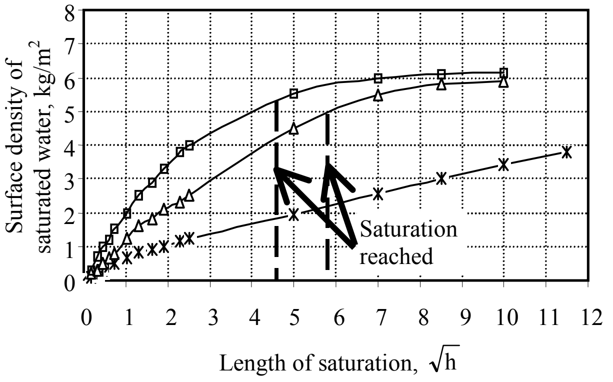

Fig. 9. The dependency of surface density of saturated water on raining duration when an additive increasing the amount of closed pores is used: □ – R1; △ – R2; ∗ – R3

Table 3. The properties of the samples and mortar components when an additive increasing the amount of closed pores is used

Sample	R1	R2	R3
Additive increasing the amount of closed pores, %	0.5	1	5
Sample density, kg/m^3	2030	2030	2050
Surface density of saturated water, kg/m^2	5.5	4.5	1.95

In order to determine the functional interaction of the wind pressure and water absorption, one parameter of saturation durability is not enough. It is necessary to know the speed of the water migration through the seams. The appropriate experiments have been carried out by creating the 50 Pa pressure.

The complex cement and lime mortars of three different slidings have been selected. The samples of two different types of thickness (6 and 25 cm) have been produced for the experiment during which it has been visually observed when the damp spots appeared on the opposite side of the sample. The achieved results are presented in Fig. 10.

Fig. 10 shows that the samples whose sliding according to the depth of the cone embedment was about 8cm, were saturated most slowly. With the use of stiff mortars whose sliding was only 4.5 cm, the samples were saturated most quickly. The mixtures whose sliding was 11 cm were less resistant to saturation.

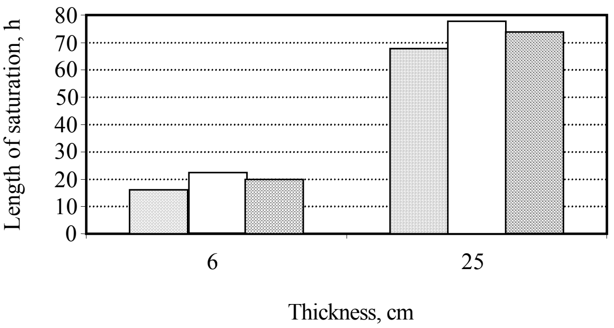

Fig. 10. The dependency of cement and mortar saturation length on the sliding of the mortar: ■ – 4.5 cm; □ – 8 cm; ▧ – 11 cm

For further experimental wall research the mortar with the closed pore amount increasing additive that made 3 % of the cement mass was taken whose sliding was 8 cm. By the alteration of the rain, and pouring intensity and by forming an additional 50 Pa pressure in the stand (Fig. 1), the durability of the wall's saturation was determined. Visually, the focus was on the parts where the first damp spots appeared. The achieved results are presented in Fig. 11.

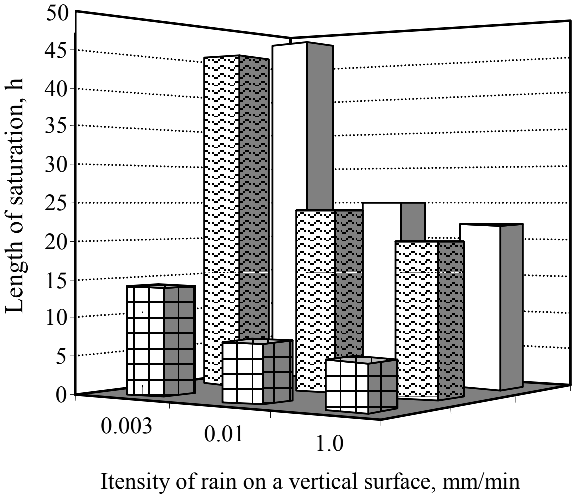

Fig. 11. The dependence of saturation length on rain intensity at 50 Pa pressure: □ – the construction of the split surface silicate bricks when 3% from the cement mass additive increasing the amount of closed pores has been used; the mortar slide making 8 cm according to the depth of cone sinking; ⊞ – silicate bricks with the split surfase; ▧ – the wall of the split surface silikate bricks when the cement-lime mortar is used

The experiment demonstrated that the first damp spots appeared in the bricks. In fact, the saturation of such a wall depends on the density alteration of the surface absorbed water in the silicate bricks with the split surface as well as on the speed of saturation.

CONCLUSIONS

1. It is experimentally established, that wind born pressure has no significant impact on the moisture transfer in materials of dense structure (silicate bricks). The rain duration and amount of precipitation are determining factors.

2. It has been determined that with the choice of the sand of lower porosity, the mortars have a denser structure, and their water absorption is smaller.
3. Moisture permeability rate is decreased at least twice, if special adds forming close pores are applied by ratio of 5 % from cement mass.
4. Seeking to reduce the saturation of brick walls, the mortar of lower sand porosity and additives increasing water impermeability should be used. In order to ensure right mortar adhesion to the bricks, its mobility has to be about 8 cm according to the depth of cone embedment. Moreover, the duration of joint and brick saturation should coincide.

LIST OF SYMBOLS

m_s	surface density of saturated water	kg/m^2
t	duration	h
τ	length of saturation	h
I_v	intensity of rain on a vertical surface	mm/min

REFERENCES

1. Variability of Climate Elements in the Lithuanian Territory. Collective Monograph of Geographical Institute, Vilnius, 1998: 171 p. (in Lithuanian).
2. **RSN 156-94.** Building Climatology. Vilnius, 1995: 136 p. In Force Since 1994 07 01 (in Lithuanian).
3. **Stankevičius, V.** Moisture Behavior and Frost Durability of Building Envelope. Kaunas, 1997: 143 p. *ISBN 9986-13-352-4* (in Lithuanian).
4. **Bomberg, M.** Moisture Flow Through Porous Building Materials *Lund Institute of Technology, Sweden, Report 52,* 1974.
5. **Bradshaw, V.** Building Control Systems. Canada, 1993: 601 p. *ISBN 0-471-57378-7.*
6. **Ujike, I.** A Study on Air and Water Permeability of Concrete Using Aggregate Recycled from Crushed Concrete *Integrated Life-Cycle Design of Materials and Structures. Helsinki,* 2000: pp. 194 – 198 *ISBN 951-758-408-3.*
7. **Schwartz, T. A.** Water in Exterior Building Walls: Problems and Solutions. Philadelphia, 1991: 233 p. *ISBN 0-803-11409-5.*
8. **Künzel, H. M.** Simultaneous Heat and Moisture Transport in Building Components. IRB Verlag, Fraunhofer-Informationszentrum Raum und Bau, 1995: 102 p. *ISBN 3-8167-4103-7.*
9. **Hutcheon, N. B., Handegord, G. O. P.** Building Science for a Cold Climate. Construction Technology Cente Atlantic INC, Canada, 1995: 440 p. *ISBN 0-9694366-0-2.*
10. **Burn, K. N.** Masonry Wall Systems. Exterior Walls: Understanding the Problems *Proceedings Building Science Forum '82. National Research Council of Canada, Institute for Research in Construction*, 1982.
11. **Hansen, K. K, Munch, T. A, Thorsen, P. S, Villumsen, C.** Moisture Movements in Render on Brick Wall *Proceedings of the 2nd International Conference on Building Physics 14 – 18 September 2003, Antwerpen, Belgium*, pp. 471 – 478. *ISBN 90-5809-565-7.*
12. **Vektaris, B.** Fine Grained Constructional Mixtures and Grouts. Kaunas, Lithuania, 1998: 230 p. *ISBN 9986-13-630-X* (in Lithuanian).