TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
CIVIL ENGINEERING | BUDOWNICTWO

2-B/2016

DOI: 10.4467/2353737XCT.16.158.5769

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CHANGE OF THERMAL PARAMETERS OF CERAMIC AND SILICATE BRICKS AS A RESULT OF CAPILLARY EXPANDING FLOW

ZMIANA PARAMATRÓW CIEPLNYCH CEGŁY CERAMICZNEJ I SILIKATOWEJ W WYNIKU ROZPRZESTRZENIAJĄCEGO SIĘ ZAWILGOCENIA KAPILARNEGO

A b s t r a c t

This paper provides an assessment on how capillary flow affects the thermal parameters of the two popular materials for the construction of walls – ceramic and silicate bricks. In order to tackle this problem, it was necessary to conduct capillary water rise tests, consisting in recording changes in the mass of the materials in question, having them put in touch with liquid water. The dependence of the mass variation in time, measured for the individual samples, was used for the determination of particular sorption coefficients. During the course of capillary action, the basic thermal parameters, i.e. the thermal conductivity coefficient and the volumetric heat capacity coefficient were measured. A 28-day simulation period was adopted. For both materials, different diversifications of the thermal parameters were identified throughout the partition thickness, with a scale changing along the duration of the capillary flow.

Keywords: capillarity, sorption coefficient, thermal conductivity coefficient, volumetric heat capacity coefficient,ceramic brick, silicate brick

S t r e s z c z e n i e

W artykule przedstawiono ocenę stopnia oddziaływania zawilgocenia kapilarnego na parametry cieplne dwóch popularnych materiałów ściennych – cegły ceramicznej i silikatowej. Realizacja tego zadania wymagała przeprowadzenia badań podciągania kapilarnego, które polegały na rejestracji zmieniającej się masy próbek testowanych materiałów, wprowadzonych w kontakt z ciekłą wodą. Odtworzona w odniesieniu do poszczególnych próbek zależność zmiany masy w czasie posłużyła do wyznaczenia składowych współczynników sorpcji. W trakcie procesu podciągania kapilarnego prowadzono równoczesne pomiary podstawowych parametrów cieplnych, tj. współczynnika przewodzenia ciepła i objętościowej pojemności cieplnej. Przyjęty okres symulacji wynosił 28 dni. W przypadku obydwu materiałów stwierdzono odmienne zróżnicowanie wartości parametrów cieplnych po grubości przegrody o skali zmieniającej się wraz z czasem trwania procesu podciągania kapilarnego.

Słowa kluczowe: kapilarność, współczynnik sorpcji, współczynnik przewodzenia ciepła, objętościowe ciepło właściwe, cegła ceramiczna, cegła silikatowa

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1. Introduction

Undoubtedly, dampness has a negative effect on structural partitions. Water, which is inhibited in the material, deteriorates its thermal-insulation parameters [1], thus contributing to increased consumption of energy for heating, which, furthermore, entails an increased emission of CO_2.

Increased dampness in the partitions affects the comfort of using the rooms. Growth of fungi and mould, which takes place on strongly dampened surfaces [2, 3], brings about diseases of the respiratory tracts, cancer and allergic reactions.

Corrosion of the building units due to multiple freezing/thawing cycles [4] and microbiologic corrosion [5] lead to accelerated aging of the materials [6] and deterioration of their mechanical properties [4, 7, 8]. In a long-term perspective, appearance of dampness in structural partitions entails huge financial expenditures to be made on their renovation. It is stated in [9] that „approximately 1% of the annual return in the building sector goes to repair of moisture-related damages, which equals 9 billion euros per year in the EU".

One of the most significant reasons for dampening of external walls is the capillary flow of water [10–13]. Most building materials are porous, where the role of the classical hair-thin tubes is played by pores and capillaries of strongly diversified geometry [14]. Capillary action occurs where the porous spaces available for water are of relatively small sizes.

Capillary tracts, which are present in porous materials, can raise water, bringing it inside those materials in cases when: ground moisture penetrates the walls of buildings without correct horizontal or vertical insulation; there are rainfalls, especially those coming askew, making the external wall go wet deeply or even totally, or when diffusing water vapour condensates inside the wall.

In practice, we also find cases of extreme dampness resulting from defects in utility systems, as well as natural disasters, including highly pressurised flood waters.

The thermal parameters are strongly dependent on the moisture content. Along with a growth of dampness, the thermal conductivity coefficient and volumetric thermal capacity of porous material increase considerably. These tests were conducted in order to diagnose which intensity of such changes must be expected during a one-month-long expansion of capillary dampness in walls built of ceramic and silicate bricks.

2. Course of tests on capillary flow

The performed tests on capillary action consisted in systematic measurements of the changing mass of individual samples which had been put in contact with water. It was decided that the measurements would be performed with the gravimetric method, widely described in [4,1 5, 16].

The experiment was composed of two stages: preparation of the samples and a testing station, and then observation of the sample mass growth resulting from the capillary rise.

Both the ceramic brick (CB), and the silicate brick (SB) were tested in their natural condition, without drying them earlier. Directly after purchasing, the bricks were transported to laboratory where they were stored at a temperature of 20°C and relative humidity of approx. 40%. After one month, the capillary research was started. The samples used in the tests had sizes as follows: the ceramic brick – 25×12×6.5 cm, the silicate brick – 24×12×8 cm. For all the samples, their initial mass, actual volume and initial volumetric capacity were determined. Having taken inventory of the materials, the samples were put one by one in trays with distilled water. The samples were positioned vertically on open-work pads, providing only some pointed support from the bottom. The trays were filled with water in such a way that its level reached 2 mm above the sample bottom. The water was re-filled regularly in order to keep its level unchanged. Temperature in the room where the tests were performed was 20°C. The tests commenced upon bringing the sample in touch with water. The regular weighing enabled to determine the increases in the mass of each sample, comparing to its initial mass. In the first three hours, the samples were weighed every 30 minutes, then every hour, two hours, twelve hours, twenty-four hours, forty-eight hours and seventy-two hours. The tests lasted 28 days.

3. Course of the tests on thermal parameters

Tests of the thermal parameters were performed using the non-stationary method, with ISOMET, model 2104 as measuring apparatus. This device works based on the non-stationary heat transport method, co-operating with clip-on temperature sensors with their measurement range appropriately selected.

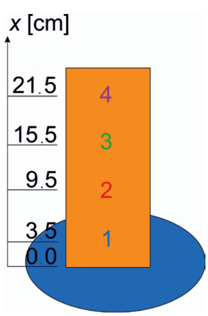
The surfaces, on which the measuring probes were put, had been polished in order to have the probes adhere to the material surface properly.

Then, four measurement points were marked on the polished surface to make sure all the following measurements were taken in the same places.

Each sample was put in touch with water which, by spreading on its height, brought about its gradual dampening, resulting in changes in the thermal parameters in question, i.e. heat conductivity coefficient λ and volumetric thermal capacity c_ρ.

Figure 1 presents a diagram illustrating the measurement concept and location of the measurement points.

a)



b)

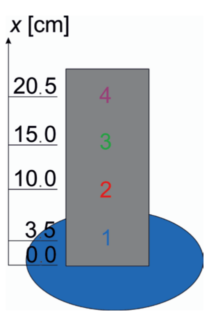


Fig. 1. Schematic diagram of location of the measurement points on the samples: a) ceramic brick, b) silicate brick

The purpose of this research was to determine the influence of expanding capillary moisture on the basic thermal parameters of the tested building materials. For that reason, each time before measuring them with Isomet, the samples were weighed with laboratory scales, with the precision of 0.01 g in order to diagnose their gaining of moisture in the course of the process.

The research on thermal conductivity coefficient λ and volumetric thermal capacity c_ρ lasted 28 days, too. On the first day, the measurements were taken every two hours on average. On the following days, the time spans were elongated, initially to twelve, then to twenty-four, forty-eight and seventy-two hours.

4. Results of tests on capillary suction

Figure 2 presents the results obtained directly in the experiment on capillary action for the both materials in question. On the axis of ordinates, the rate of capillarity raised water mass to the sucking surface is marked as $\Delta m_t/F$, while the axis of abscissa shows the root of time of the process duration $\sqrt{t}$. This function takes into account the linear dependence between the mass of absorbed water Δm_t, and the time root $\sqrt{t}$.

In reference to the time span, when the mass changes were proportional to the time root, a capillary sorption coefficient A was determined for each individual sample. The formula given in PN-EN ISO 9346 standard [17] was used:

$$m_s = \frac{\Delta m_t}{F} = A \cdot \sqrt{t} \, . \tag{1}$$

Where: m_s represents the mass of absorbed water, referred to the area of sample surface remaining in touch with water ($\Delta m_t/F$), while t is the process duration.

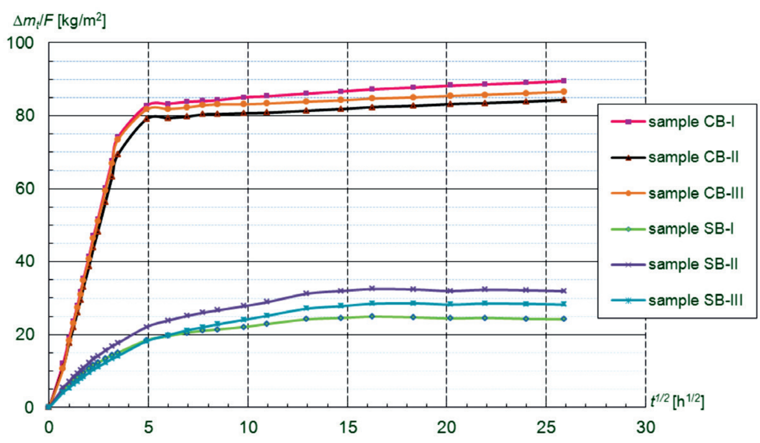


Fig. 2. Dependence $\Delta m_t/F = f(\sqrt{t})$ obtained in the tests on ceramic and silicate bricks

Basing on results obtained for individual samples, the mean values of coefficients A [kg/(m^{2}h$^{1/2}$)] were calculated. For the ceramic brick, on average A = 22.0 [kg/(m^{2}h$^{1/2}$)], while for silicate brick A = 4.6 [kg/(m^{2}h$^{1/2}$)]. The determined values are comparable to those published in the literature. For example, in the work [18] the values of A = 22 [kg/(m^{2}h$^{1/2}$)] for ceramic brick and A = 4 [kg/(m^{2}h$^{1/2}$)] for silicate brick were given.

After the capillary tests, the samples were fully submerged in water where they remained until reaching the state of saturation. Then, the mass-related moisture capacity of the tested materials was also determined and it amounted to w_m = 13.25% for ceramic brick and w_m = 11.50% for silicate brick.

5. Results of tests on the thermal parameters

During the tests on capillary action, the main thermal parameters, i.e. heat conductivity coefficient λ [W/mK] and volumetric thermal capacity c_ρ [J/m^{3}K], were simultaneously determined for the materials in question.

Figure 3 presents graphs depicting variability of the heat conductivity coefficient λ in function of time t, for all measurement points on the ceramic and silicate brick samples as presented schematically in Fig. 1.

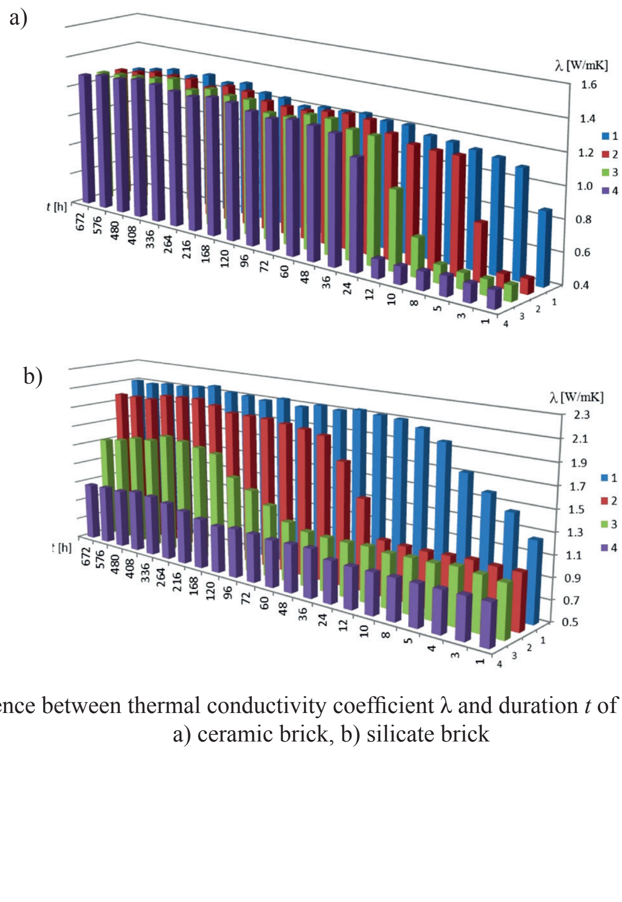
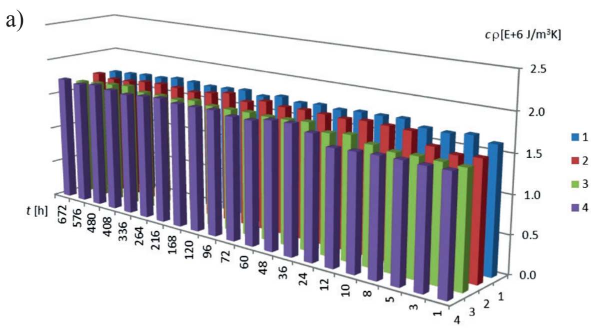


Fig. 3. Dependence between thermal conductivity coefficient λ and duration t of the capillary action: a) ceramic brick, b) silicate brick

In Figures 3a) and 3b), the axes represent: axis of ordinates – thermal conductivity coefficient λ, axis of abscissa – the process duration t, axis of depth – subsequent measurement points (point 1, point 2, point 3, point 4).

Figure 4 presents graphs depicting dependence of volumetric thermal capacity c_ρ in function of time t, for all measurement points on the ceramic and silicate brick samples as presented schematically in Fig. 1. In this case, the axes are as follows: the axis of ordinates – volumetric thermal capacity c_ρ, the axis of abscissae – the process duration t, the axis of depth – the measurement points (point 1, point 2, point 3, point 4).



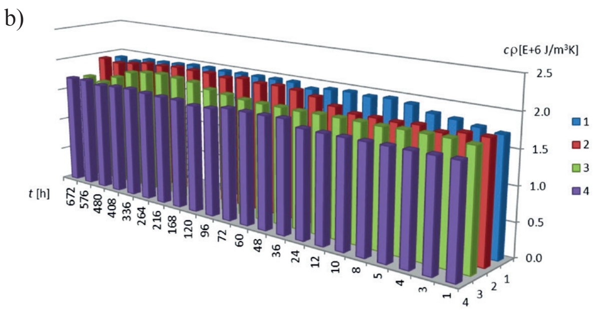


Fig. 4. Dependence of volumetric thermal capacity c_ρ on the capillary action process duration t: a) ceramic brick, b) silicate brick

6. Conclusions

In reference to the both materials in question, the research conducted on capillary action and the accompanying measurements of the thermal parameters changing during the process, permit for the following conclusions:

– for the ceramic brick samples, a linear dependence $\Delta m_t = f(\sqrt{t})$ within a relatively short and easy to define time span could be observed, while for the silicate brick samples, the assumption of linear dependence $\Delta m_t = f(\sqrt{t})$, being the basis for formula (1), is fulfilled within a span of time which is much narrower and more difficult for clear determination,
– by tracing the tangent of the inclination angle of the straight-line sections of experimentally reconstructed functions $\Delta m_t = f(\sqrt{t})$, it is possible to determine, for the both materials,

using formula (1), the values of the capillary sorption coefficient A value; however, with better accuracy for the ceramic brick samples than for the silicate ones,
- the thermal conductivity coefficients λ determined in the research show a tendency to significant increases in their values along with the development of dampness being the result of capillary suction,
- an increase in the volumetric thermal capacity c_ρ was observed in the tested materials, following the growing dampness,
- the growing tendency manifested itself most quickly and intensively in the measurement points located the lowest on the tested samples.

Comparing the results obtained for the both tested materials, a differentiation in the qualitative and quantitative course of capillary action, and, as a result, in the sorption coefficient and thermal parameters values is clearly seen. And thus:
- in comparison with the silicate brick, the ceramic brick absorbs water very quickly and does it in large quantities. For the both materials, qualitative and quantitative differences in the processes can be clearly observed (see Fig. 2). For the ceramic brick, sorption coefficient A_{CB} was 5 times higher than A_{SB} for the silicate brick. This translated to the values of thermal conductivity coefficient λ and volumetric thermal capacity c_ρ, as well as to redistribution of those parameters in time.
- the graphically illustrated results (Fig. 3a) indicate that in the ceramic brick, in measurement point 1, as early as after three hours the value of thermal conductivity coefficient λ got stabilised at a more or less a similar level, around 1.1 – 1.2 [W/mK]. In point 2, that value was achieved after eight hours, in point 3 – after 12 hours, in point 4 – after 24 hours. After 24 hours of keeping the brick in touch with water, it became almost entirely damp affecting the coefficient λ which in all the measurement points had the same values,
- silicate brick raised water quite slowly, which finds its expression in the results illustrated with Fig. 3b). In point 1, λ stabilised after 12 hours, reaching the level of ca. 2.1 [W/mK]. However, at that time, in points 2, 3 and 4, changes of the thermal parameters were still unnoticeable. Along with the increase of dampness in time, thermal conductivity coefficient for those points grew too. Finally, after 28 days, the ratio λ_4/λ_1 was 1.96, which means that the value of λ in point 1 grew almost twice as much as λ in point 4,
- in the silicate brick, the value of thermal conductivity c_ρ also changed in time. Figure 4b) presents a gradual growth of volumetric thermal conductivity c_ρ in points 1, 2 and 3, along with an expansion of the moisture inside the material. Only in point 4, where moisture reached very slowly, it was possible to observe trace changes in c_ρ,
- the ceramic brick behaved, however, differently, which can be clearly seen on the graphically illustrated results presented in Fig. 4a). Contrarily to the silicate brick, here, the increase in the volumetric thermal capacity c_ρ does not proceed gradually. The ceramics raised water very quickly and thus the value of c_ρ changed in all the measurement points quickly, too.

In case there is a direct exposure of a wall to water or when capillary condensation occurs, significant changes of thermal parameters take place. It should be stressed that the parameters reach significantly diversified values throughout the wall thickness. The degree of diversification depends strongly upon the duration of the process and the type of material the wall is built of.

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