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ScienceDirect

Energy Procedia 95 (2016) 119 – 123

Energy Procedia

International Scientific Conference "Environmental and Climate Technologies", CONECT 2015, 14-16 October 2015, Riga, Latvia

Properties of bricks and masonry of historical buildings as a background for safe renovation measures

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Abstract

This article is the first approach of research aimed to recognize historical building materials and their properties, analyzing safe and effective renovation measures to decrease energy consumption for heating of buildings built before 1940. Brick samples taken from historical buildings were tested to assess their compressive strength, soluble salt content and water absorption. In addition the external wall heat transfer coefficient was determined and the moisture level in masonry was set in two different climatic conditions.

Peer-review under responsibility of Riga Technical University, Institute of Energy Systems and Environment.

Keywords: energy efficiency; historical brick buildings; weathering; soluble salt; compressive strength; moisture; energy performance; historical brick properties

1. Introduction

Building stock in Europe is very old. In Latvia alone buildings built before 1940 make up to 38 % of the total existing residential building stock [1]. Hence only by renovating historical buildings can the European Union reach its set goals and noticeably reduce energy consumption. Nonetheless, due to the fact that in most cases due to regulations set on preserving cultural heritage, the facade of historical buildings cannot always be changed, interior insulation is often the only possible post-insulation technique to improve the thermal performance [2]. Applying interior insulation, however, significantly modifies the hydrothermal performance of the wall and, as a consequence, may induce a risk on interstitial condensation, frost damage, mould growth and other damage patterns [3, 4]. The

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Peer-review under responsibility of Riga Technical University, Institute of Energy Systems and Environment.
doi:10.1016/j.egypro.2016.09.032

behaviour of external walls of historical buildings after adding internal insulation depends on the properties of the used materials. There is a need to develop new methods on how to implement energy efficiency measures in these buildings. But first, in order to perform safe renovation, one should obtain knowledge about properties of materials used in historical buildings.

Most remaining historic buildings today are brick buildings especially in the cities of Baltic Sea region [4]. Bricks in unprotected masonry are exposed to moisture and large temperature fluctuations during different seasons. Researchers have proven that the presence of moisture significantly reduces the compressive strength of masonry and modules of elasticity [5, 6]. Strength characteristics of porous materials vary depending on the level of moisture in the material [7]. Because of moisture, thermal conductivity of masonry can increase up to 3 times [18]. Moreover moisture presence in masonry may lead to the presence of soluble salts [9, 10]. The crystallization of soluble salts can cause subflorescence or efflorescence inside the bricks, which eventually cause deterioration of brick and/or mortar. Damage of salt crystallization includes cracks inside the brick, localized crumbling, spalling of the brick faces, and eventually collapse of the individual masonry units or mortar joints.

Research is limited to determination of brick compression strength, water absorption and salt deposits to evaluate the conservation status of bricks. The moisture level in masonry and thermal transmittance of external walls were also measured.

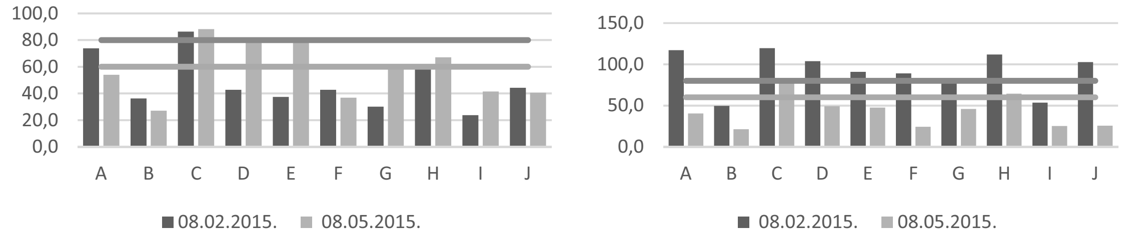
2. Material and experimental methods

All 16 buildings studied in this research are built in the same time period (1890–1940) from clay bricks, and are exposed to the same climate conditions and pollution. The average outside temperature in Riga is 6.2 °C, the average heating season is 203 days long with an average outside temperature 0.0 °C (coldest five-day average air temperature is –20.7 °C) [11], freeze-thaw cycles are very frequent, about 70 cycles per year [12].

Various size brick samples and their parts were used for laboratory measurements. Two different methods were used on the same samples to assess their compressive strength – non-destructive method and destructive method. Water absorption tests were carried out according to standard EN 772-21 [13]. The soluble salts examined were sulphates, chlorides and nitrates, which was conducted by a semi-quantitative method using test strips. Moisture content measurements of masonry were performed two times in different environmental conditions, in February and in May. By means of the microwave technology applied, it was possible to detect distributions of moisture content at a depth up to 300mm from the surface. Thermal transmittance was determined according to standard ISO 9869-1 [14]. Heat flow measurements were stored every 10 minutes for 6 to 7 days.

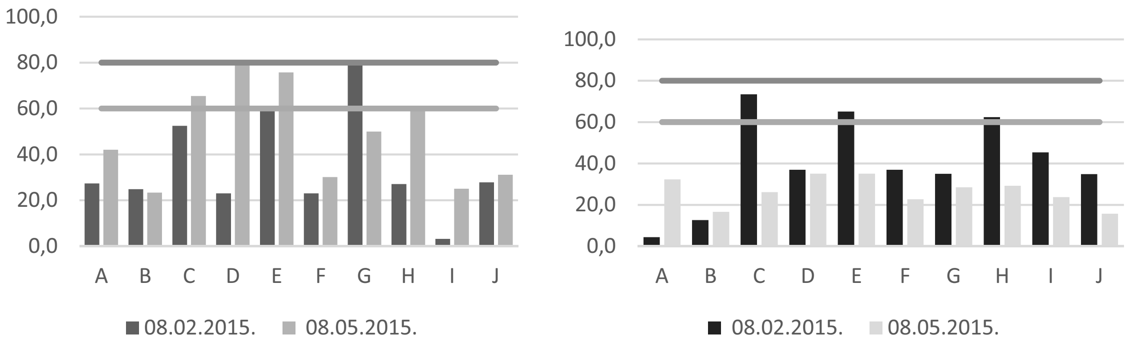
3. Results and discussion

The results of moisture measurements are presented in Fig. 1 and Fig. 2. The measured values are not a qualified moisture measurements, but they can be interpreted as indicators: dry (<40 digits), damp (40–80 digits) and wet (over 80 digits). Analysing the initial measurement data obtained in February, it is seen that the moisture level was higher inside the masonry at a depth of 300 mm. In 70 % of the cases, construction at the foundation level is wet. At a height of 1 m, 30 % of the investigated buildings masonry is wet. The moisture level was lower near the surface of the wall.



(a) (b)

Fig. 1. Moisture level at the foundation: a) at a depth of 300 mm; b) at a depth of 40 mm.



(a) (b)

Fig. 2. Moisture level at the height of 1 m: a) at a depth of 300 mm; b) at a depth of 40 mm.

Measurements taken in May showed that moisture levels decreased inside the masonry both at the foundation level and at the height of 1m, whereas it increased near the wall surface at a depth of 40mm. Therefore results of masonry moisture measurements represent the moisture migration in the masonry from the interior very well. It takes place from the bottom-up through the pores to the exterior.

Despite the fact that all investigated buildings were built in the same time period and the mineralogical composition and firing conditions of used bricks were similar, test results of brick compressive strength show a large range (see Fig. 3). For example, buildings *D* and *E* are both built in 1910 and stand next to each other, but the compressive strength difference is 13.4 MPa. Compressive strength of four samples, all taken from building *I*, varied between 10.4 MPa and 23.4 MPa.

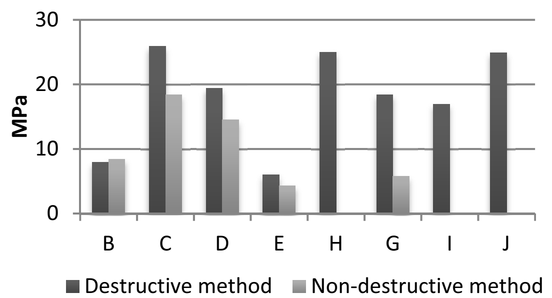


Fig. 3. Compressive strength of taken brick samples.

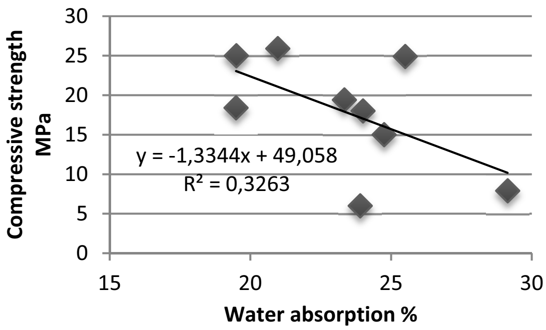


Fig. 4. Correlation between water absorption and compressive strength.

As seen in Fig. 4, the compressive strength of the brick slightly decreases with the increase of water absorption. Average water absorption of nine tested samples from eight buildings is 23.4 %.

Three soluble salts were detected in seven brick samples – nitrates, chlorides and sulphates. Chlorides were detected only in three samples, nitrates in six samples and sulphates in all seven samples (see Table 1).

Table 1. Results of soluble salt content.

Samples	Nitrates		Chlorides		Sulphates	
taken from	mg/l	%	mg/l	%	mg/l	%
B	10	0,12	0	0	<200	<0,4
C	50	0,6	500	1	>1600	>3,2
D	500	6	1000	2	>400	>0,8
E	25	0,3	0	0	>400	>0,8
F	0	0	0	0	>400	>0,8
I	500	6	500	1	<200	<0,4
J	500	6	0	0	>1200	>2,4

Fig. 5. Extensive loss of mortar in masonry in building *C*.

The highest level of sulphates was detected in the sample taken from building *C*. Samples from building *C* also showed the presence of nitrates and chlorides. During moisture measurements, the masonry of building *C* showed the highest moisture level in comparison to other buildings (see Fig. 1 and Fig. 2). This research confirms that which was also evident in other research [15] that sulphates usually attack mortar in masonry (see Fig. 5). Any further mortar loss will create the risk of local collapse of the brickwork. Regulation of construction works [16] from the time when the inspected building were built states that, in the first class bricks, the soluble salt content should not exceed 0.04 %. In all samples where soluble salts were detected – the threshold level was exceeded.

The average measured heat transfer coefficient is 0.894 W/m^2. The highest experimentally determined values are in building *D*, at 1.5 W/m^{2}K and in building *A* – 1.13W/m^{2}K. Compared to moisture measurements, it is seen that the buildings masonry of these buildings contains the most moisture in February.

4. Conclusion

The research carried out on the historical brick masonry allowed the collection of data that can represent a start-up for further investigations. Tests of compressive strength proved that historical clay bricks are highly inhomogeneous and anisotropic as the results show very large dispersion. The most common soluble salt present in the tested bricks was nitrates. Chlorides were found in samples that were taken from the buildings situated near streets, which are strewed with salt-sand mixture during the winter time. Moisture measurements represented moisture migration in the masonry from the interior, from the bottom-up through the pores to the exterior. It is proven that moisture movement in external walls influence not only energy consumption but also the building’s durability, mechanical stability, lifetime, as well as the health and safety of its residents.

Acknowledgements

This survey is carried out in the scope of EU financed project “RiBuild – Robust Internal Thermal Insulation of Historic Buildings” (637268-RIBuild-H2020-EE-03-2014).

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