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Experimental Assessment of Thermal Conductivity of a Brick Block with Internal Cavities Using a Semi-scale Experiment

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Abstract The thermal conductivity of a brick block with internal cavities is studied using a steady-state experiment in semi-scale conditions. A system of two climatic chambers separated by a connecting tunnel for sample positioning is applied in the measurements. The brick block is provided with necessary temperature- and heat flux sensors, thermally insulated and placed in the tunnel between the climatic chambers, where different temperatures are set. After achieving steady-state heat fluxes on both surfaces of the brick block, the calculation of the thermal conductivity is done using the measured data. The obtained results represent valuable information for the practical application of the studied brick block in building practice.

Keywords Brick block · Climatic chamber system · Internal cavities · Semi-scale testing · Thermal conductivity

1 Introduction

The thermal conductivity λ $(\mathrm{W \cdot m^{-1} \cdot K^{-1}})$ of solid materials can be determined by various methods. The most straightforward way presents a direct application of Fourier's law:

$$q = -\lambda \ \mathrm{grad} T, \tag{1}$$

where $q(\mathrm{W \cdot m^{-2}})$ is the heat flux and T (K) is the temperature. However, also indirect methods based on the determination of the thermal diffusivity and specific

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heat-capacity are frequently employed. We will give just a short overview of both direct and indirect methods for thermal-conductivity determination in what follows.

For the application of Eq. 1 to the measurement of thermal conductivity, steady-state methods are the most convenient. Steady-state methods for determination of the thermal conductivity are considered standard reference methods [1,2]. As for the practical experimental setups, the guarded hot-plate arrangement is the most frequently used [3,4]. The standardized versions of the guarded hot-plate method are included, for instance, in ISO 8302 [5] and ASTM C 177 [6].

As achieving steady-state conditions within the thermal conductivity measurement is a time consuming and relative expensive procedure, application of the transient methods of thermal conductivity measurement is also popular [7]. Among them, the hot-wire method is the most frequently applied technique [8–10]. In materials research, there are also applied devices working on a dynamic measurement principle. Here, the measurement is based on the analysis of the temperature response of the analyzed material to heat flow impulses. The heat flow is induced by electrical heating using a resistor heater having direct thermal contact with the surface of the sample [11,12]. Also, the indirect methods based, for example, on measurement of the laser-flash diffusivity find use in materials research [13,14].

A number of advanced apparatuses for thermal-conductivity measurement is available on the current market, which are based on the above principles. Most of them are designed for the investigation of specimens with relatively small dimensions or for a plate configuration with a small specimen thickness. This makes possible measurement of homogeneous materials with no large-scale discontinuities.

Current brick blocks produced by the building industry in Europe are, however, far from homogeneous. They are more or less complex systems of internal cavities which increase their thermal resistance and make possible their application in building envelopes without any additional thermal insulation. Therefore, contrary to the traditional bricks where the thermal conductivity can easily be measured by the standard guarded hot-plate, hot-wire, or flash methods, the complex geometry of new brick blocks makes application of common methods impossible, and alternative treatments are being sought to determine their effective (or equivalent) thermal conductivity. Vivancos et al. [15] in an experimental study, aimed at the identification of the effective thermal conductivity, developed a model for thermal characterization of hollow bricks based on the application of the guarded hot-plate method. Al-Hadhrami and Ahmad [16] applied a modified guarded hot-plate technique to accommodate hollow-brick test samples of larger thickness. Sala et al. [17] used a large-scale guarded hot-box device to measure the thermal resistance of a wall consisting of extruded polystyrene, hollow brick and gypsum, and identified the equivalent thermal conductivity of the hollow brick layer.

In this article, a steady-state experiment in semi-scale conditions for the determination of the effective thermal conductivity of a brick block with internal cavities is designed, and its application for a brick block produced in Czech Republic is presented.

2 Experimental Details

2.1 Studied Material

A brick block with internal cavities produced by Heluz Brick Industry, Czech Republic, was analyzed in the article. The brick was designed for application in thermal insulation masonry having a width of 500 mm. The basic physical properties of the brick body are given in Table 1.

2.2 Semi-scale Experiment

For realization of the semi-scale experiment, the climatic chamber system described in [18,19] was used, which enabled simulation of difference thermal conditions in the studied brick block sample of real dimensions. The testing device consisted of two commercial climatic chambers for simulation of the relative humidity and temperature and a specially developed connecting tunnel for placing the studied samples (Fig. 1). The tunnel was vapor proof and thermally insulated from the environment. The investigated brick block was placed into the connecting tunnel, and then provided with sensors and with the additional thermal insulation consisting of polystyrene boards and polyurethane foam. Finally, the climatic chamber system was closed, and required temperature and relative humidity values were set. In this way, one-dimensional heat transfer across the brick block was simulated.

In the tested sample, continuous monitoring of temperature and relative humidity fields was performed. For monitoring the relative humidity and temperature, commercially produced combined mini-sensors by Ahlborn, Germany were employed. The accuracy was as follows: the capacitive relative humidity sensors were applicable in the 5 % to 98 % relative humidity range with a 2 % uncertainty, the resistance thermometers had an uncertainty of 0.4 °C in the temperature range from −20 °C to 0 °C, and 0.1 °C in the temperature range from 0 °C to 70 °C. The heat flux through the studied brick was monitored by the heat flux plate sensors (Ahlborn FQA020C) of a cylindrical shape having a diameter of 33 mm, which were fixed on both front sides of the brick block. The uncertainty of these sensors was 5 % of the measured value. In both climatic chambers were additional control sensors for temperature and relative humidity monitoring. During the experiment, a constant temperature was maintained in both climatic chambers, (30 ± 0.4) °C and (15 ± 0.3) °C. The relative humidity was also constant, (30 ± 1) % in both chambers. Hence, no significant effect of moisture on heat transport was assumed in the experiment. The sensor placing is shown in Fig. 2. The experiment was running for 25 days to ensure steady conditions in the brick block.

Table 1 Basic physical properties of the brick body

Total open porosity (% $m^3 \cdot m^{-3}$)	Matrix density ($kg \cdot m^{-3}$)	Bulk density ($kg \cdot m^{-3}$)
1389 ± 14	2830 ± 28	50.9 ± 1.0

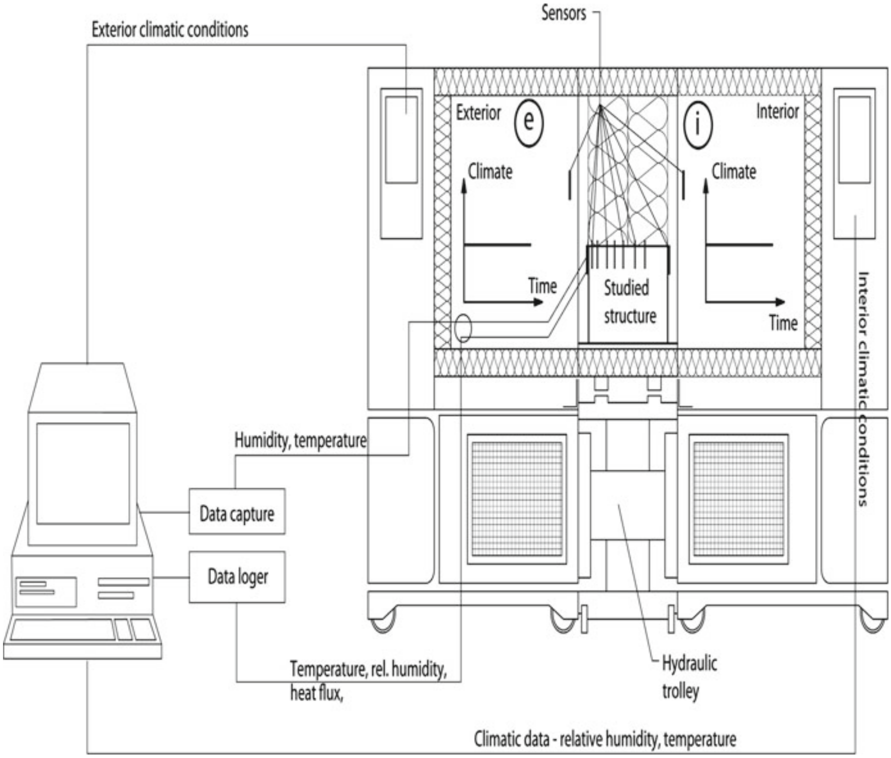

Fig. 1 Schematic diagram of the measuring system

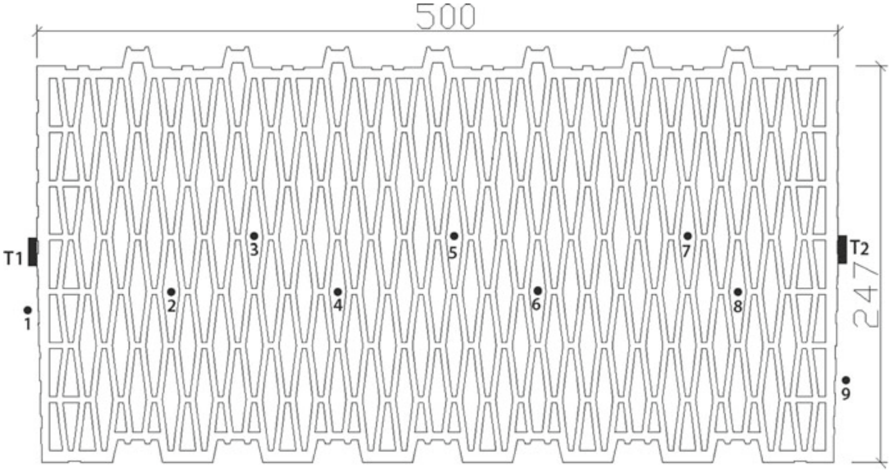

Fig. 2 Location of sensors

2.3 Evaluation of the Effective Thermal Conductivity

The effective thermal conductivity of the brick block was calculated according to Eq. 1, using the heat fluxes and temperatures obtained after the achievement of steady-state conditions in the climatically loaded sample.

3 Results and Discussion

Figures 3 and 4 present the results of temperature and relative humidity monitoring in both climatic chambers, respectively. Apparently, the temperature steady-state conditions were maintained well during all the course of the experiment; only small fluctuations could be observed. The variations of relative humidity were also relatively low, based on the particular chamber performance. Therefore, the basic conditions for proper evaluation of the performed experiment were met.

The temperature profiles given in Fig. 5 demonstrate the achievement of steady-state conditions within the studied specimen; only very low-temperature variations could be observed during a relatively long period of time. The heat fluxes measured for both brick block surfaces were averaged over a time interval of several days and then used for calculation of the effective thermal conductivity.

The effective thermal conductivity calculated separately for the heat fluxes on both surfaces of the brick is presented in Table 2. Apparently, the differences were very low, quite negligible from an engineering point of view. The uncertainty in the determination of the effective thermal conductivity was derived from the uncertainties in the measurement of heat fluxes on the brick surfaces, surface temperatures, and brick

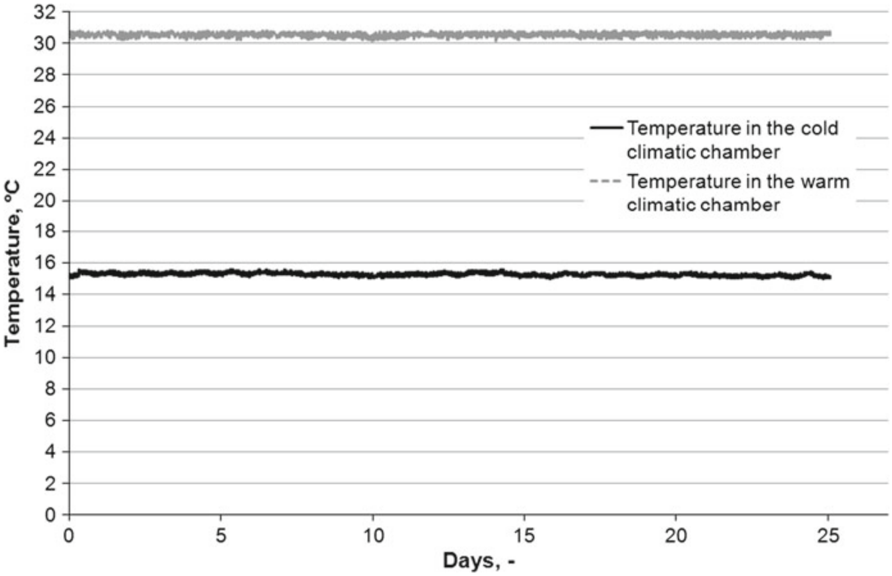

Fig. 3 Temperature course in the cold and warm climatic chambers

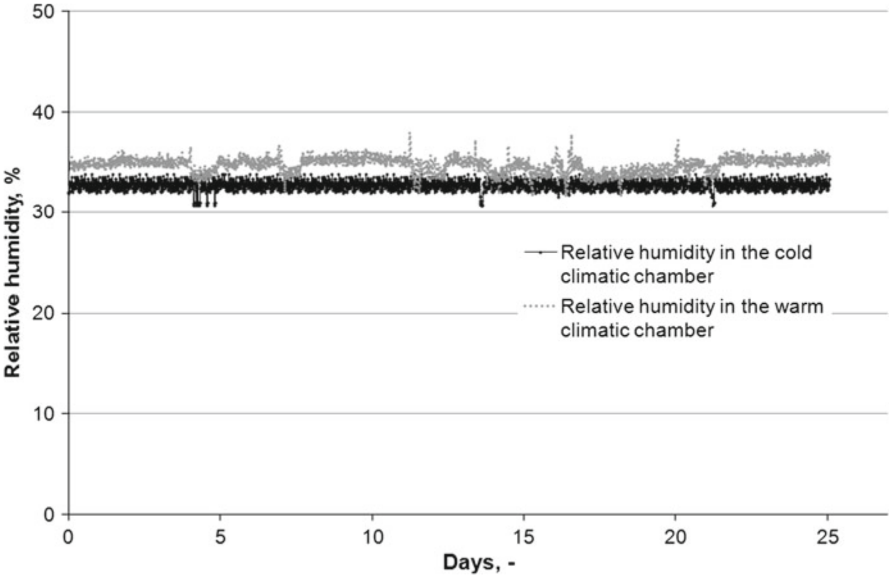

Fig. 4 Relative humidity course in the cold and warm climatic chambers

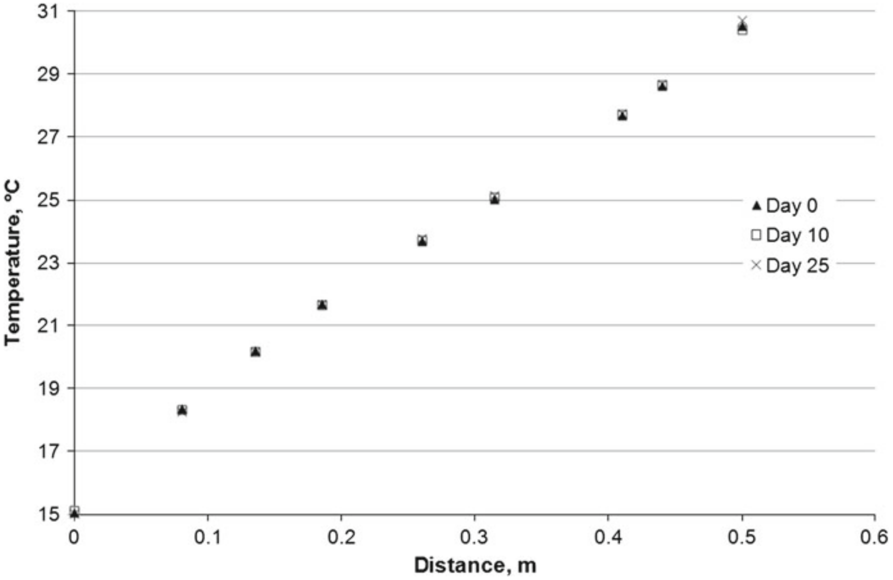

Fig. 5 Temperature profiles in the studied brick block

length. The uncertainty of measuring the temperature was 0.1 °C, for the length it was 0.5 mm, and for the heat flux 5 %. Therefore, the relative standard uncertainty of the effective thermal conductivity could be estimated as 5 %.

Table 2 Effective thermal conductivity of the brick block

Heat flux sensor	Heat flux ($W \cdot m^{-2}$)	Effective thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)
T1	3.82	0.125 ± 0.006
T2	−3.75	0.123 ± 0.006

4 Conclusions

A steady-state experiment in semi-scale conditions for determination of the effective thermal conductivity of a brick block with internal cavities was designed. The result of the experiment presents valuable information for the building practice, where the measured thermal conductivity can find use in the hygrothermal design of brick masonry. In future study, the designed experiment can be used for the determination of the thermal conductivity of other types of building materials with large-scale inhomogeneities, as well as for testing the thermal performance of critical segments of building structures.

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