Laboratory exercise No. 4 – Thermal properties of building materials

According to the physical principles that govern processes, three different ways of heat transfer can be distinguished:

- conduction in substances,
- convection of substances,
- radiation.

The heat transfer by conduction occurs in the continuum. The constituting particles of substances exchange between themselves the kinetic energy of their chaotic thermal movements so that the energy is transported from the places with higher temperatures to place with lower temperatures. Heat conduction takes place in solid, liquid, and gaseous substances.

The heat transport by convection also occurs in the continuum. However, it takes place only in liquids and gases. Spontaneous convection is caused by a decrease in the density due to thermal expansion. If a temperature gradient occurs between the place of heating and the place of cooling in a liquid, the heated part of the liquid rises, pushing away the cooled heavier part. In liquids and especially in gases the heat transport by convection is dominant over that by conduction.

Heat transport by radiation is not limited to substances. Heat is transported by the electromagnetic radiation. In case of the infrared radiation (wave length 760 nm – 1 mm), the heat transport is called heat emission.

In **heat transfer on conduction** the particles of substance with higher kinetic energies give away a part of their energy to the particles with lower energies. The rate of heat transport is expressed by the heat flux that is defined as

$$I_q = \frac{dQ}{d\tau},$$

where Q represents the amount of transported heat and τ the corresponding time of the transport. The surface density of the thermal flux q is defined as

$$q = \frac{dI_q}{dS_n}.$$

The driving force of heat transport is a temperature change expressed by a temperature gradient. In 1811 Fourier found experimentally that a linear relation between the heat flux and the temperature gradient,

$$q = -\lambda \; gradT ,$$

where T is the temperature.

The thermal conductivity coefficient λ ($W.m^{-1}.K^{-1}$) describing a heat transfer process represents the ability of a substance to conduct heat and its numerical value is the heat flux at a temperature gradient 1 $K.m^{-1}$ in a given substance. The thermal conductivity coefficient is not constant for any substance because it depends on the material structure, porosity, temperature, pressure, moisture content, rate of compression, powder density, etc.

A high thermal conductivity is characteristic of metals (e.g., 402 $W.m^{-1}.K^{-1}$ for copper), liquids have lower thermal conductivities (e.g., 0.56 $W.m^{-1}.K^{-1}$ for water), and gases have lowest thermal conductivities (e.g., 0.0258 $W.m^{-1}.K^{-1}$ for dry air).

The thermal diffusivity coefficient a ($m^2.s^{-1}$) is defined as

$$a = \frac{\lambda}{c\rho},$$

where c is heat capacity ($J.kg^{-1}.K^{-1}$) defined as the amount of heat needed to heat 1 kg of a material by 1 K and ρ is the volume density.

Thermal conductivity coefficient of different materials can be measured by stationary or non-stationary methods.

ISOMET 2104 is a portable device for the direct measurement of the thermal conductivity coefficient, specific heat capacity, and thermal diffusivity coefficient. For measurements one can used needle probes (for loose and soft materials) or surface probes with a memory and known calibration constants. ISOMET is controlled by a microprocessor which can optimize the conditions of the measured process. The measurement is based on the analysis of the time dependence of the thermal response of a tested material on the impulses of heat flux. A heat flux is induced by electrical resistance heater in the probe which is in a direct contact with the tested sample. Values of device ranges for the measured parameters are in Table 1.

Table 1 – Device range for measuring parameters

Thermal conductivity coefficient	0.015 – 6 $W.m^{-1}.K^{-1}$
Specific heat capacity	4×10^4 – 4×10^6 $J.m^{-3}.K^{-1}$
Operating temperature	From –20 to 70 °C

Shotherm QTM of the Japanese company Showa-Denko is based on a non-stationary method. It uses a non-stationary thermal regime called the *hot-wire method*. Since a sample is heated only for a short time, it is also possible to measure the thermal conductivity coefficient of wet materials. The device is portable, and no modifications to the measured material are required before the measurement. Various homogenous materials can be measured by the device, but it is not possible to measure isolation and construction materials with air pockets, for example, cored bricks. For loose materials the device has a special probe. The device display shows the sample temperature before and after the measurement (the temperature increase during a measurement is usually about 20 K) and the average temperature of the sample during measurement. Shotherm QTM works reliably in the temperature range from -10 to +200 °C.

Task 1: Using ISOMET, measure thermophysical parameters of given materials and determine their dependence on moisture rise.

Task 2: Determinate the amount of heat which is transferred by the stove surface to the surrounding air during 24 hrs. The stove temperature is 120 °C, the air temperature is 20 °C, and the stove surface is 3 m^2. The heat transfer coefficient for the stove surface depends on the temperature t as $\alpha = A+Bt$, where A = 9.8 $W.m^{-2}.K^{-1}$ and B = 0.07 $W.m^{-2}.K^{-2}$.

Task 3: Determinate how much heat is transferred trough a brick wall (area S = 0.5 m^2, thickness d = 45 cm) during one hour. The temperature of the internal wall surface is

t_1 = your measured value and the external surface t_2 = 5 °C. You may ignore heat losses into the surroundings. The thermal conductivity coefficient of the brick wall is λ = your measured value.