Determination of Specific Heat of a Building Material

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Abstract: - Specific heat is important property of building materials which is used for thermal evaluation of building constructions. The paper presents method for determination of this property for samples of chip-wood boards. The determination of physical properties of the boards was a task of a research project focussed on the energy evaluation of low-energy housing. The specific heat capacity was determined on the basis of experimental measurements of selected samples of chip-wood boards.

Key-Words: - Building materials, thermal properties, specific heat, thermal mass, chip-wood boards, building constructions, low-energy houses.

1 Introduction

Thermal properties of building materials serve as input data for thermal evaluation of building constructions and energy balance of buildings. One of important properties is specific heat of materials [1]-[5]. This property very interesting mainly in the context of newly designed and constructed building. New buildings use modern light weight materials and constructions. It is correct with the contemporary trend oriented on lightweight technologies. On the other hand lack of thermal mass materials causes problems with overheating and thermal discomfort in these buildings. Design of building materials should be optimized with respect to their thermal mass and specific heat properties.

The paper is focused on description of the method used for the specific heat chip-wood boards. The boards (made of 85% wood chips and 15% of cement mixture) are used in the building industry for many purposes. The main application is as the hidden forming for monolithic concrete technology. The slabs have also found wide application in low-energy houses.

The determination of physical properties of the boards was included as one of particular tasks of a research project focussed on the energy evaluation of low-energy housing. The specific heat was determined on experimental thermal measurements on selected samples of chip-wood boards. On the basis measurements the mean value of specific heat was determined which is in a good agreement with similar materials on wood base [6].

2 Description of the method

The specific heat capacity was determined on the basis of input data of measurement of temperature rise of water inside of in the thermally insulated bottle with the sample chip-wood board to the steady state thermal condition. The difference between steady state and initial temperature served for the specific heat calculations. The specific heat was calculated on the basis of these considerations:

$$Q_v(\tau_k) + Q_H(\tau_k) = Q_v(\tau_0) + Q_H(\tau_0) \quad (1)$$

$$t_v(\tau_0) > t_H(\tau_0) \quad (2)$$

$$t_v(\tau_k) = t_H(\tau_k) = t_k, \qquad t_H(\tau_0) = t_0 \quad (3)$$

where

Q_v is heat in the sample of the chip-wood board [J],
Q_H is heat in the water in the insulated bottle [J],
τ_k is final time of measurement (steady state thermal condition) [s],
τ_0 is initial time of measurement [s].
$t_v(\tau_0)$ is initial temperature of the sample [°C]
$t_H(\tau_0)$ is initial temperature of water in the bottle[°C]

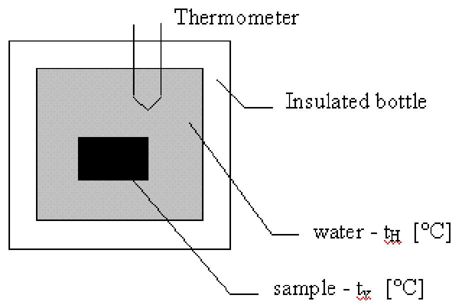

Fig. 1 Scheme of the thermally insulated bottle with the sample of chip-wood board

Tempered samples of chip-wood board of initial temperature $t_v(\tau_0)$ are inserted into the water in the insulated bottle with the initial temperature $t_H(\tau_0)$. Temperature time profile was measured to the steady state conditions. The steady thermal state in the insulated bottle is influenced by initial temperatures of water and board samples, see Fig. 2.

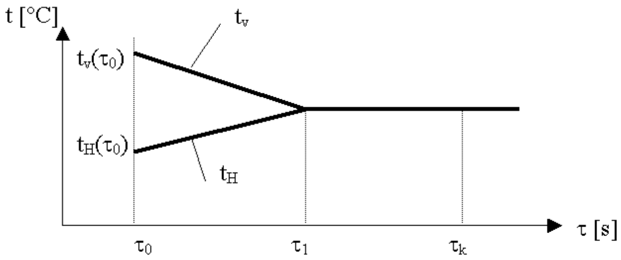

Fig. 2 Temperature time development into the steady state condition

Heat of the water in the bottle Q_H [J] is determined on the basis of the following assumptions:

$$Q_H = A_e - Q_z \quad (4)$$

where

A_e is electric energy given to the water in the bottle from an electric spiral [Ws = J]

$$A_e = \int_{\tau_0}^{\tau_1} U(\tau)I(\tau)d\tau \quad (5)$$

where

τ_0 (τ_1) is initial (final-steady state) time [s]

$U(\tau)$ is electric voltage [V]

$I(\tau)$ is electric current [A], $I(\tau) = U(\tau)/R$

R is electric resistance of the spiral Ω]

If $I(\tau)$ and $U(\tau)$ are constants, then $I(\tau)=I$, $U(\tau)=U$

$$A_e = U.I.(\tau_1 - \tau_0) \quad (6)$$

Q_z is heat loss of the bottle [J],

if Q_z = 0-insulated bottle, then $Q_H = A_e$ (7)

$$A_e = Q_H = m_H c_H(t_{H,k} - t_H(t_0)) \quad (8)$$

where

m_H is weight of water in the bottle [kg]

c_H is specific heat of water in the bottle [$J.kg^{-1}K^{-1}$]

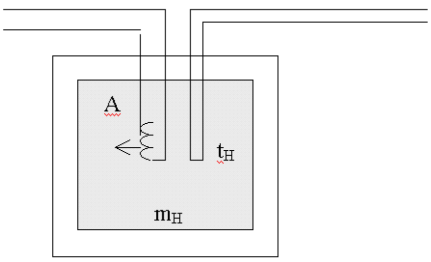

Fig. 3 Scheme of the thermally insulated bottle with the electric spiral

The calculation specific heat of the water in the insulated bottle c_H [$J.kg^{-1}K^{-1}$] is derived from the equation (4) into the following formula

$$c_H = \frac{UI(\tau_1 - \tau_0)}{m_H(t_{H,k} - t_{H,k} - t_H(\tau_0))} \quad (9)$$

Specific heat of the chip-wood sample is determined on the basis of energy balance of the insulated bottle for any temperature t_x between initial temperature a the temperature in steady state conditions

$$m_v c_v(t_k - t_x) + m_H c_H(t_k - t_x) = m_v c_v(t_x - t_v(\tau_0)) + m_H c_H(t_x - t_0) \quad (10)$$

where

m_v is weight of the chip-wood board sample [kg]

c_v is specific heat of the sample [$J.kg^{-1}K^{-1}$]

This equation can be simplified for the energy balance of heat in the thermally insulated bottle

$$m_v c_v(t_v(\tau_0) - t_k) + m_H c_H(t_k - t_o) = 0 \quad (11)$$

The equation for the calculation of specific heat of the sample of the chip-wood board c_v [$J.kg^{-1}K^{-1}$] is derived from equation (11)

$$c_v = \frac{m_H(t_k - t_0).c_H}{m_v(t_v(\tau_0) - t_k)} \quad (12)$$

3 Results from measurements

The determination of the specific heat was based on experimental investigation of six samples of chip-wood boards. The material of the boards was pressed and then formed into six small cylinders with determined dimensions and weight – table 1.

Table 1: Dimensions and weight of samples

Sample no	Weight [g]	Diameter [mm]	Height [mm]
1	79.90	55	23
2	77.43	55	21.5
3	76.67	55	21
4	67,73	55	18
5	73.32	55	20
6	73.43	55	20

The prepared samples were dried in the drying chamber KCW 100 and tempered for the required temperature for 2 hours. Then the samples were put into the insulated bottle with water (water content had the determined temperature and weight). The bottle was closed and a thermal sensor monitored temperature rise to the steady state conditions after the insertion of tempered samples. The calculation of the specific heat capacity of the samples required the determination of the water constant-specific heat of the water inside of the bottle. It was evaluated from measured temperature rise in the insulated bottle with water but without samples at the presence of electric voltage. The measuring equipment was: thermally insulated bottle, water, heating spiral, source of electric voltage. Input values for the water constant calculation are presented in Table 2.

Table 2 Measured input values for calculations

Quantity	Value
Weight of water in the bottle	499.58 g
Electric voltage	5.113 V
Heating spiral – weight	3.28 g
Heating spiral – electric resistance	5.33 Ω
Total time of measurement	600 s
Initial temperature of the water	18.85°C
Temperature in the steady state	20.3°C
Electric energy A_e=U.I.($\tau_1 - \tau_0$)	2942.9 J

Specific heat of the water in the thermally insulated bottle c_H = 4062.586 [$Jkg^{-1}K^{-1}$].

Results from the measurement of the temperature rise to the steady state conditions in the thermally insulated bottle are presented in Fig. 4.

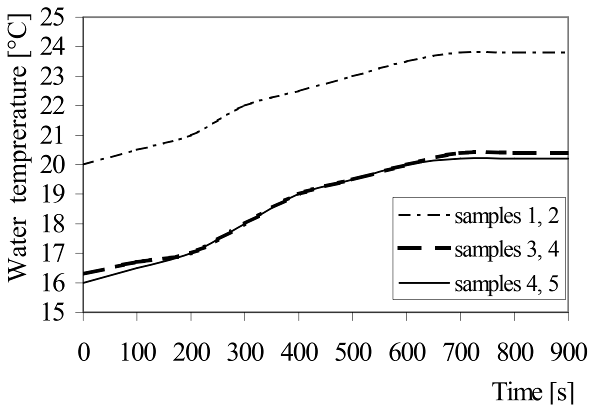

Fig. 4 Temperature rise of the water in the insulated bottle with the board samples

Input values used for the calculation of specific heat c_v [$J.kg^{-1}K^{-1}$] are summarized in Table 3.

Table 3 Input values for calculations

Samples **1, 2**	Samples **3, 4**	Samples **5, 6**
t_o = 20.0°C	t_o = 16.3°C	t_o = 16.0°C
$t_v(\tau_0)$ = 55.3°C	$t_v(\tau_0)$ = 53.9°C	$t_v(\tau_0)$ = 55.6°C
t_k = 23.8°C	t_k = 20.4°C	t_k = 20.2°C
m_H = 0.4998 kg	m_H = 0.49957 kg	m_H = 0.4999 kg
m_v = 0.15733kg	m_v = 0.1444 kg	m_v = 0.14675kg

m_H ... weight of water, m_v ... weight of the sample

Specific heat of the chip-wood boards is calculated according to the equation (12) from measured data. The mean value of the calculated results is determined as

$\bar{c}_v = \frac{1}{n}\sum_{i=1}^{n} c_v$, where n = 3, $\bar{c}_v$ = 1639.72 $Jkg^{-1}K^{-1}$.

4 Conclusion

The samples of the investigated chip-wood boards were tested for the determination of the specific heat capacity. This parameter is one of important characteristics which serve for the thermal evaluation of building constructions and for the determination of energy balance of buildings. The specific heat of the investigated material is 1640 $Jkg^{-1}K^{-1}$. This value is in a good compliance with values of specific heat of similar wood base building materials. The chip-wood boards can be used for monolithic concrete technology with hidden forming or without the concrete core for internal partitions in building interiors.

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References:

[1] Schrefle, B.A. et al. Multiphase Model for Concrete. *WSEAS Transactions on Heat and Mass Transfer*. Issue 6, Vol. 1, 2006.

[2] Incropera F.P., Witt D.P., *Fundamentals of Heat and Mass Transfer*, Willey, New York 1996.

[3] Hewit G.F.: *Heat Exchanger Design Handbook*-Part 5: Physical properties, Begel House, New York 2002.

[4] Beaton C.F., Hewit G.F. *Physical property data for the design engineer*, Taylor & Francis, New York 1998.

[5] Garbai, L., Mehes, S. New Analytical Solutions to Determine the Temperature Field in Unsteady Heat Conduction. *WSEAS Transactions on Heat and Mass Transfer*. Issue 7, Vol. 1, 2006.

[6] ČSN 730540:2005 Thermal protection of buildings.