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Determination of Thermal-Physical Properties of Facilities

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Abstract: This study includes a discussion of the importance of experimental research to determine the Termal-Physical Properties (TPP) of the object studied. It was conducted an analytical review of modern methods for determination of the thermal-physical properties of building facilities. There are analyzed the limitations of the methods for determination of the TPP of the object studied, described in this article. Here is given a description of the principle of plant operation, designed to determine the TPP (heat transfer coefficient, heat transfer resistance and specific thermal performance) of the object studied by the non-destructive testing method and its main components. There are presented the necessary formulas for calculating the TPP of the object studied. There are described the basic advantages of the developed plant, in comparison with the well-known analogues.

Key words: Heat transfer, heat transfer coefficient, heat transfer resistance, energy efficiency, method, plant, analysis

INTRODUCTION

One of the most urgent problems concerning an increase in the energy efficiency is the use of simple and reliable ways (methods) to determine the heat loss through the building envelopes of the object to the environment and the analysis of Thermal-Physical Properties (TPP) the heat transfer coefficient, heat transfer resistance and specific thermal performance which significantly affect the heat mode. Currently there are various methods and devices to determine (heat transfer coefficient and heat transfer resistance) the object studied (Kabanov *et al*., 2015a, b; Kreith, 2000; Welty *et al*., 1984; Sukhatme, 2005; Moncef, 2016; Yufeng *et al*., 2016; George, 2015; Paul, 2016; Golovnev and Mozgalev, 2014; Lavrov *et al*., 2006). Based on the Non-Destructive Testing Method (NDTM) we designed a plant to determine the TPP of surfaces of the building envelopes (Vavilov and Grogoryev, 2012). The plant is made in the form of a cube and a heating element is situated inside it. On the thermostat attached to the heating element it is installed a specified air temperature, on the object studied. The measuring sensors of the heat flux density are installed on the building envelope studied. After a set period of time the temperature values and the heat flux density are fixed on both sides of the building envelope studied. According to the data obtained it is defined the TPP under the formulas presented by Vavilov and Grogoryev (2012). A limitation of this method is the low functional ability to control the heat transfer resistance coefficient. This is due to the fact that the dimensions of the device enable to determine the TPP only for the local area of the building envelope. Similarly, it is designed a plant to measure the heat transfer resistance of building envelopes based on the NDTM (Verkhovskiy and Shubin, 2011). The plant creates the established temperature modes on the inner and outer sides of the object studied, controls the heat flow passing through the object under the steady-state conditions. A limitation for the use of this plant is the inability to determine the TPP of the entire object studied as a whole as well as a long duration of time of the object research. To determine the heat transfer resistance of the building structure to the NDTM it is known the method (Pokhodun and Sokolov, 2003). There is installed a heat insulated box with the flat thermostats, thermometer and an adjustable fan as well as a heat flow meter opposite each other on both sides of the building structure. The thermostat keeps in the unchanged state-the ambient temperature, the thermostat in the opposite box keeps the temperature $T_{ambient}$ the internal temperature which is not equal to $T_{ambient}$. After a certain period of time there are determined the temperatures of the surfaces of building structure by the thermometers installed in a thermally insulated box and determined the heat flow density passing through the building structure. By the adjustable fan in the external and internal insulation box, there is measured the intensity of the air flow rate to make a change in the heat transfer of the plant

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Corresponding Author: Panfilov Stepan Aleksandrovich, Ogarev Mordovia State University, Bolshevistskaya St., 68, 430005 Saransk, Republic of Mordovia, Russia studied, according to the conditions described by Pokhodun and Sokolov (2003). After establishing the predetermined heat transfer, the heat transfer resistance is found under the Eq. 1 (Pokhodun and Sokolov, 2003):

$$R = \frac{(T_{internal} - T_{ambient})}{q} \quad (1)$$

A possible limitation in the plant application is a long duration of the research procedure.

MATERIALS AND METHODS

It is known the NDTM of determining the heat transfer resistance through the object studied. The method application algorithm is based on measuring the time interval between the beginning of heating of the inner surface section and the beginning of temperature increase at a given point on the outer (or side) surface of the object studied. Then it is established the dependence of superheat value of outer (or side) surface of the object studied on the time during the experiment. It is determined the dependence of duration of the first heating stage on the superheat value of outer (or side) surface of the object studied. It is calculated the value of heat transfer resistance through the object, for different moments of time. It is determined the values of heat transfer resistance through the object and is calculated its average value. The limitations for the use of this plant include the fact that its dimensions enable to determine the TPP only for the local area of the building envelope as well as long duration of the study. It is developed the measurement device to measure the heat transfer resistance of the building structure (Bogoyavlenskiy, 2013). There is mounted the attached case with the heating element installed in it on the building structure such as the building wall. On the other side of the building, respectively, the attached case is mounted with the becket with a thermoelectric module installed in it. The attached case and becket can be rectangular or circular in shape, while their size is selected to be equal to 3÷5 of the building structure thickness (Sergeyev, 2013). With the heating element, the building structure is heated to a temperature above the ambient temperature by 5-10°C. Simultaneously with heating it is switched on the thermoelectric module which cools the building structure surface to a negative temperature. After some time, it is recorded the heat flow value-q, passing through the building structure and then it is calculated the heat transfer resistance by Eq. 1. The limitations for the use of this plant include the fact that it defines the TPP of the structure only for the local area of the building envelope and therefore it is impossible to define the heat transfer resistance for the entire object as a whole. Based on the NDTM it has been developed the method for measuring the heat transfer resistance and the device for its implementation (Datsyuk and Isakov, 2007). It is made a thermal influence on the outer surface this influence is made by cooling with a moving heat carrier at that it is measured the steady-state value of the inner surface temperature of the object studied in the field of heating; it is measured the steady-state value of the outer surface temperature of the object studied in the field of cooling; it is measured the steady-state value of the moving heat carrier temperature. The device for the implementation of this method comprises the heat source, temperature meter, electronic processing unit and external heat exchanger. The limitations include the long duration of the study, complex installation design and inability to determine the heat transfer resistance of the entire object as a whole.

The NDTM of heat retention properties of the building envelope also includes a method. There are made the in-situ measurements of temperatures and heat flow density at the fixed reference point, in the real climatic conditions of the building operation, in a period of not <2 days. There is calculated the heat transfer resistance at the fixed reference point by processing the results of in-situ measurements with the rejection of individual values of the heat transfer resistance. There is calculated the heat transfer resistance in the arbitrary points by the temperature fields, obtained by thermo graphing and by the calculation results of the heat transfer resistance in the fixed reference point. It is conducted the temperature measurement and registration of the outer and inner air in the room as well as the heat flow temperature and density on the inner and outer surfaces of the building envelope for at least 2 days. The calculation of heat transfer resistance in the fixed reference point is carried out under the results of temperature measurement and heat flow density for each i-th measurement. The limitation of this method is the long duration of the research procedure. It is known the method for determining the thermal-physical performance of the building, multi-layer structures without violating their integrity (Varfolomeyev and Orlova, 1999). The method consists in implementing the active thermal influence on the surface of each outer layer in adiabatic way, from the disk heaters located in the probe cavity bordered with the guarding (heat insulating) rings and in recording the temperature dependence of the surface of the object studied on the time. A determination of the TPP of the structure is carried out using a special approximation and obtained temperature dependences on the time. The limitation of this method is the high methodical error in determining the required TPP. Another important limitation of this method includes the fact that the determination of TPP of the structure outer layers is proposed to be carried out by the contact method which leads to significant error of the time-temperature measurements due to the influence of contact heat resistances, the value of which is random, depends on the state of surface of the contacting bodies, the extent of their pressing against each other, etc. which does not enable to determine the value of heat transfer resistance without making amendments or correction of the measurement results (Chernyshov and Slonova, 2006). It is known the heat NDTM for determining the TPP of the materials which has been developed in Japan. The method consists of the thermal irradiation of the surface of the area studied the data on distribution of temperature field of the object is transmitted for the analysis to the device of thermo graphic control and then to the display device which shows the changes in the temperature field distribution (Budadin and Abramova, 2008). This method enables to determine the structure condition and its TPP but it is not applicable to the study of non-steady-state processes taking place in the real operating conditions of buildings and structures (Panfilov *et al*., 2016).

In the Russian Federation, it is generally used the evaluation method of thermal-physical properties of building envelopes, consisting of measuring the heat flow density passing through the structure studied, temperature measurement on the outer and its inner surfaces, calculating the values of heat transfer resistance to the structure as well as the method for determining the TPP of the objects by analyzing their heat transfer resistance. After a predetermined time interval it is made the heat flow measurement passing through the building structure and the temperature on both surfaces of the building structure according to the Eq. 1. The limitation of this well-known method is that the formula is applicable only for the conditions of steady-state heat transfer process through the object studied. The limitations of this method include the long duration of the study procedure 15 days and the inability to get the TPP of the entire object as a whole.

RESULTS AND DUSCUSSION

The existing methods for determining the heat transfer resistance and heat transfer coefficient establish such coefficients for only a certain area of the surface studied; it will be required a lot of time to determine the TPP data of the entire object as a whole as it is needed 1 day and more to make a single measurement. Such study duration significantly affects the cost of the works conducted. During the research it is necessary to ensure the establishment of special conditions (stable temperature on the inner and outer surfaces of the object studied) during the whole study time that as a result, determines the high energy intensity of the research conducted. The analysis of existing methods for determining the TPP of the object studied has shown that it is possible to develop the plant which will determine the TPP of the object of the NDTM with the use of modern means of control and processing of information in a shorter period of time by the non-steady state method. It is noted in the literature (Ametistov, 2000; Belov *et al*., 1986; Bogoslovskiy, 1982; Vavilov, 1991; Tabunshchikov and Khromets, 1986; Kreith, 2000; Welty *et al*., 1984; Sukhatme, 2005; Moncef, 2016; Yufeng *et al*., 2016) that the non-steady-state methods for determining the TPP are the most promising due to their simplicity and short time of the study. Taking into account the analysis conducted, the researchers developed a plant.

The operating principle of the plant is as follows. Prior to start the object study, it is necessary to set the temperature sensors 3 and 4 on the inner and outer perimeter of the object studied, at equidistant distance from each other. It is necessary to determine the values for further study, namely, the heat supply source power R_{source}, the total area of the object studied S_{total} on the outer perimeter, V-volume of the object studied on the outer perimeter, the time of study t, the study temperature $T_{internal}$ and the study temperature interval $T_{internal}$ as well as the delay time required for the order the temperature could reach the study temperature inside the object. After reaching the temperature $T_{internal}$, a programmable relay 1 fixes the time of active operation of the heat supply source 2 during the whole time of the study. The ambient temperature readings are taken with the temperature sensors 4 during the study after a set time interval for further calculation of the required ratios. At the end of the experiment it is made a calculation of the thermal-physical properties of the object by the following Eq. 2. It is determined the average ambient temperature during the study:

$$\overline{T}_{ambient} = \frac{\sum T_{ambienti}}{n} \tag{2}$$

Where:

$T_{ambienti}$ = Ambient temperature in the ith time of the study
n = Number of readings of $T_{ambienti}$ taken during the study

It is determined the average consumable power to maintain the established temperature for a certain time of maintaining the established temperature of the study (W):

$$P_{consumable} = P_{nominal} \cdot \frac{t_{operative}}{t_{maintenance}} \tag{3}$$

Where:

$P_{nominal}$ = Nominal power of the heat supply source

$t_{operative}$ = Time of active operation of the heat supply source

$t_{maintenance}$ = Specified time for maintaining the established temperature $T_{internal}$

It is determined the heat transfer coefficient of the entire object W/(m^2.°C):

$$k = \frac{P_{consumable}}{S_{total} \cdot (T_{internal} - \overline{T}_{ambient})} \tag{4}$$

It is determined the heat transfer resistance of the entire object (m^2.°C)/W):

$$R = \frac{1}{k} \tag{5}$$

From the literature sources it is known the ration:

$$q_0 V(T_{internal} - T_{ambient}) = P_{consumable} \tag{6}$$

where, q_0 specific thermal performance of the object W/(m^3.°C); it was conducted a study concerning testing of this plant with the predefined action on the object model.

Using the experimental data it has been identified $q_{0experimental}$ = 33.45 W/(m^3.°C) and $k_{experimental}$ = 2.48 W/(m^2.°C). The consumable power expended to maintain the required temperature inside of the object studied is determined by the Eq. 4 and 6 depending on the ambient temperature. The studies have been conducted to measure the TPP (heat transfer coefficient and specific heat performance of the object) at the change of ambient temperature. The experiment was conducted at different ambient temperatures of 6, 7, 8, 9, 11, 10, 12°C. Similarly, it was conducted the calculation of heat transfer resistance and heat transfer coefficient of the object studied. The design heat transfer resistance of the object studied is determined by (m^2.°C)/W):

$$R_{calculated} = \frac{1}{\alpha_B} + \sum \frac{\delta_i}{\lambda_i} + \frac{1}{\alpha_H} \tag{7}$$

Where:

α_B = Heat transfer coefficient of the inner surface of the building envelope

α_H = Heat transfer coefficient of the outer surface of the building envelope

Table 1: The values of heat transfer coefficient and specific heat performance obtained by calculation and experiment

Tambient (°C)	$k_{experimental}$ (m^2·°C)/W	$k_{calculated}$ (m^2·°C)/W	$q_{0calculated}$ W/(m^3·°C)	$q_{0calculated}$ W/(m^3·°C)
6	2.492	2.40	32.43	33.442
7	2.466			33.463
8	2.494			33.445
9	2.468			33.458
10	2.491			33.436
11	2.493			33.461
12	2.469			33.447

λ_i = Thermal conductivity of the i-th layer of the building envelope

δ_i = Thickness of the ith layer of the building envelope

α_B = 7.6 W/(m^2.°C), α_H = 6 W/(m^2·°C), λ_i = 0.12 W/(m·°C), λ_i = 0.0698 W/(m·°C), δ_i = 0.010 m, δ_i = 0.002 m.

$$R_{calculated} = \frac{1}{7.6} + \frac{0.01}{0.12} + \frac{0.002}{0.0698} + \frac{1}{6} = 0.4170\text{W}/(\text{m}^2 \cdot °\text{C})$$

The design heat transfer coefficient is calculated from the Eq. 5:

$$k_{calculated} = \frac{1}{R_{calculated}} = \frac{1}{0.4170} = 2.40\text{W}/(\text{m}^2 \cdot °\text{C})$$

Table 1 includes the values of heat transfer coefficient and specific heat performance. From the data presented it can be seen a spread of values obtained in the experimental way. It has been found that such fluctuations are mainly made by the inaccuracy of temperature sensors used in the studies. The analysis of the results of experiments conducted enables to make a conclusion about the applicability of the proposed portable automated plant to determine the TPP of the objects.

CONCLUSION

Compared to the well-known technical decisions, the proposed one enables to establish the TPP for the object studied as a whole, taking into account all the irregularities of building envelopes as well as to reduce the study duration and to improve the plant mobility.

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