

Review of special features of determining resistance to heat transfer under natural conditions and in a climate chamber

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Abstract. The current study aims to review methods of experimental determination of the resistance to heat transfer. In order to study the special features of determining thermal resistance under natural conditions and in a climate chamber, modern patents have been reviewed. Two studies by Mureev P.N. et al. discussed in this article were intended to study the determination of the resistance to heat transfer and the influence of counter heat flows arising in the thickness of the wall enclosure under quasi-stationary conditions in full scale. The authors' experiment has been analyzed, the distinctive feature of which is the introduction of sensors inside the wall enclosure, which makes it possible to more accurately determine the temperature distribution and direction of heat flows inside the enclosure. In his research, Budadin O.N. together with colleagues examined the issues of improving the quality and reliability of determining the thermal resistance of a building envelope when tested in a climate chamber, and succeeded in obtaining a very low error in determining the thermal resistance. A modified climatic chamber presented as a stand with a mobile cassette for installing a sample patented by Verkhovsky A.A. and co-others has also been considered. These methods were justified by the achievement of technical research results.

1 Introduction

There are many diverse scientific directions of construction industry. Building thermal physics is one of such areas of research. The key parameter of building thermal physics is the resistance to heat transfer of building envelopes [1–16].

The resistance to heat transfer can be determined by calculation based on the Fourier and Newton-Richmann laws as well as using an experimental approach. The simplest way is to determine the resistance to heat transfer under stationary conditions of a temperature field. Stationary conditions are achieved when the climatic parameters around the studied building

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envelope do not change over time. The main experiments under stationary temperature conditions are carried out in a climate chamber [1–16].

Another method, which appears to be more complex, is the determination of the resistance to heat transfer under natural conditions. Natural conditions differ as they describe the operating conditions of the fence. The difficulty of experimental determining resistance under these conditions is the presence of a non-stationary temperature field in the structural unit under study, which significantly complicates measurements. Nevertheless, full scale measurement of the resistance to heat transfer plays an important role in controlling the parameters of already constructed and commissioned buildings [1–16].

In modern scientific research in the field of determining the resistance to heat transfer there are 3 main directions [1–16]:

1. Preliminary thermal imaging examination of the structural element under study with subsequent placement of sensors on the building envelope in natural conditions [1–16].
2. Preliminary thermal imaging examination with subsequent placement of sensors on the building envelope in a climate chamber [1–16].
3. Inspection with the placement of sensors in the thickness of the building envelope under natural conditions [1–16].

Despite the already existing approaches to experimental determining the resistance to heat transfer of building envelopes, there are still unresolved issues related to the low accuracy of the experimental determination due to disturbance in the temperature field during operation [1–16].

2 Problem

To review modern experimental methods of determining the resistance to heat transfer of building envelopes in a climate chamber and in natural conditions.

3 Determination of the resistance to heat transfer of brick building walls under natural conditions

Time or time intervals are an important factor for testing. They have a significant impact on the quality and reliability of graphs and thermograms, and subsequently on the assessment of the quality of the building envelope based on its resistance to heat transfer.

Thus, researcher Murec P.N. and his colleagues considered a method of determining the time interval when conducting full-scale thermophysical studies of external walls of buildings made of brick, during which conditions for a quasi-stationary heat transfer regime arise in the thickness of the wall enclosure.

The essence of the method is that the temperature of the internal and external air, the temperature of the internal and external surfaces of the wall enclosure and the temperature in the thickness of the enclosure are measured by placing sensors at 5 points at equal distances [17].

A diagram of sensor placement in the thickness of the wall is presented (Fig. 1).

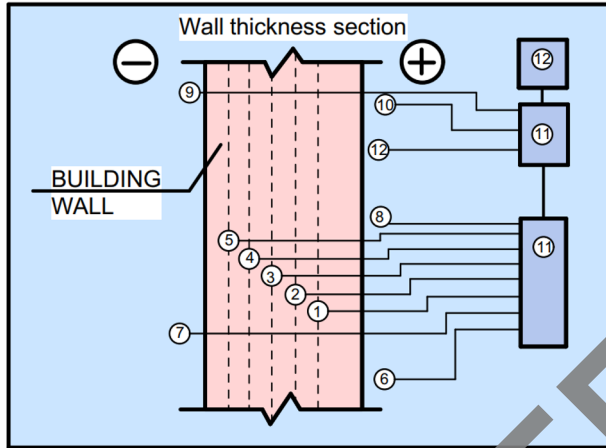


Fig. 1. Scheme of sensor placement in the thickness of the wall, where 1-5 are temperature and humidity sensors of the material located in the thickness of the building envelope every 110 mm; 6 – temperature and humidity sensor in the room; 7 – outside air temperature and humidity sensor; 8 – internal surface temperature sensor; 9 – external surface temperature sensor; 10 – heat flow sensor; 11 – adapters; 12 – control center (thermograph).

It is necessary to select only those intervals where the temperature and heat flow will be constant so that the temperature distribution inside the wall is straight. There might be very few these time intervals or they may not exist at all, so the coefficient Δt is introduced [17]:

$$\Delta t = \text{MAX} \left(\frac{|t_{\pi} - t_{\phi_i}|}{t_{\pi}} \right). \quad (1)$$

where t_{ϕ_i} – actual temperature value in the i -th layer, °C; t_{π} – theoretical temperature value in the i -th layer, i.e. with a linear temperature distribution in the thickness of the wall, °C.

Then the nearest local temperature extreme from the outer to the inner surface of the wall is determined taking into account the case when local extremes are located not at the control points, but between them (Fig. 2).

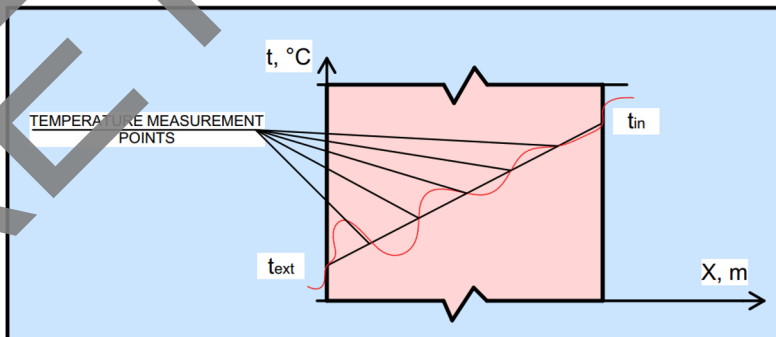


Fig. 2. Scheme of possible actual and theoretical temperature distribution in the thickness of the wall.

Based on the results of the measurements obtained, graphs are drawn up. Using these graphs time intervals that correspond to the conditions specified by the authors are determined. In this way, it is possible to most accurately determine what happens at different points in the section of the wall fence at a specific period of time [17].

4 Taking into account the appearance of counter heat flows due to the influence of the sun on enclosure during a field survey

The simplest way to determine the resistance to heat transfer of an external enclosure under natural conditions is to install temperature and heat flow control sensors directly into the thickness of the enclosure. The disadvantage of the mentioned approach is that during the study the structure under test is destroyed, which is not always possible. For example, it is impossible to conduct such studies in operational residential buildings. However, the main advantage of this approach is high measurement accuracy, since a single-layer brick structure of the building wall is represented as a multilayer enclosure consisting of a series of layers.

The work of P.N. Mureev with co-authors is an example of such research. A method of assessing thermophysical characteristics of building envelopes, the essence of which is that temperature and heat flow sensors are located at several cross-sectional points of the building envelope, has been developed [18].

Counter heat flows caused by solar radiation lead to changes in temperature on the surface and in the thickness of the enclosure, so it is crucial to take into account the nature of fluctuations in heat flows from the outer surface to the inner layers. The most heated layer compared to the surface of the enclosing structure is determined. In the case where the heat flow direction vector is opposite to the temperature gradient vector, heat transfer processes are stationary (Fig. 3). In another case, solar radiation causes a change in the vector of the temperature gradient inside one of the layers, as a result of which a counter heat flow occurs at point 3 (Fig. 4). Thus, a collision between two counter heat flows coming from the outer and inner surfaces of the enclosure occurs [18].

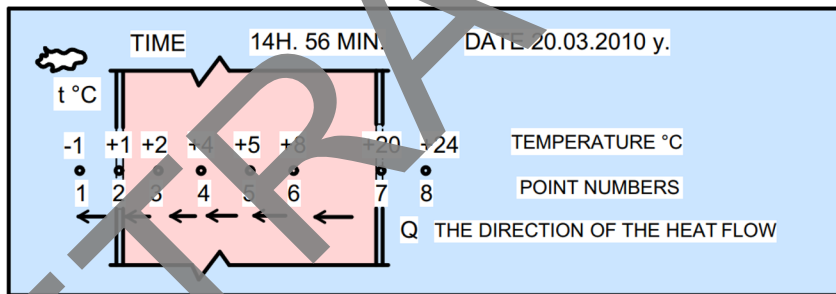


Fig. 3. Diagram of the heat flow distribution during a stationary mode of heat transfer in the thickness of the wall.

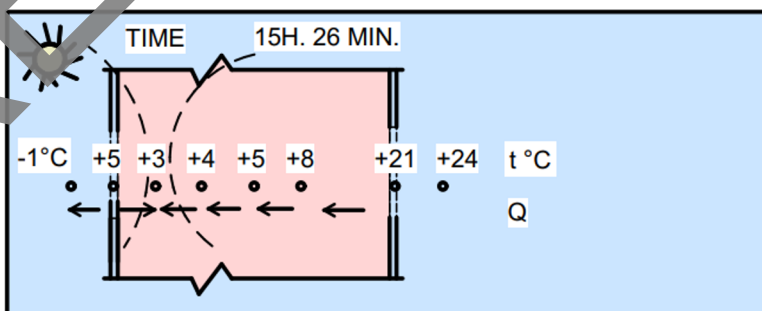


Fig. 4. Scheme of the occurrence of counter heat flow in the thickness of the wall.

Fig. 5 shows the division of the studied enclosure into a series of layers, the temperature gradient of which is equal to [18]:

$$\lim_{\Delta x} \frac{\Delta t}{\Delta x} = \frac{dt}{dx}. \quad (2)$$

where Δx – distance between layers, m; Δt – temperature difference between layers, °C.

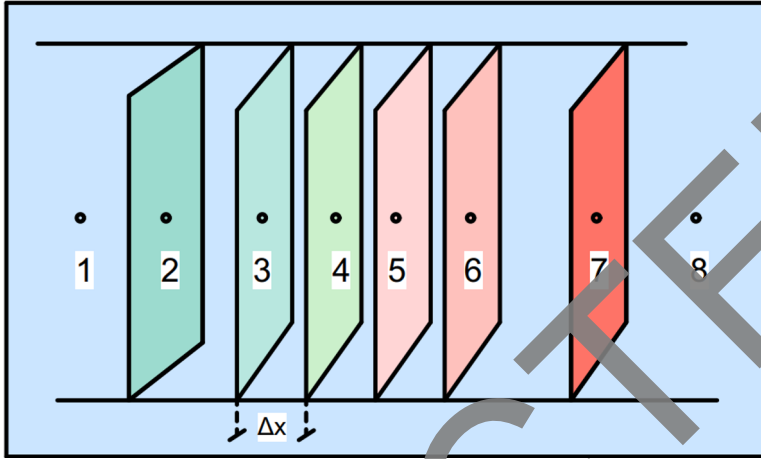


Fig. 5. Diagram of a wall structure section into a series of planes with designation of control points.

Graphs based on the measurements obtained are drawn up. The advantage of this method is that it takes into account the effect of counter heat flows and local temperature extremes [18].

5 Determination of heat transfer resistance in a climate chamber

The climate chamber serves as one of the methods of thermal non-destructive testing of heterogeneous structures.

Researchers, namely Budadin O.N., Slitkov M.N., Abramova E.V., Troitsky-Markov T.E. and Suchkov V.I. developed a method which aims to create a special functional diagram for high-precision determination of the resistance to heat transfer of the enclosure. Sensors for recording temperature and heat flow are installed on the surfaces of the object, and the temperature of the wall surface is recorded using a thermal imaging system. The temperature near the opposite surfaces of the object and the density of the heat flux passed through the enclosing structure on the internal surface are measured. Then the calculated resistance to heat transfer is determined using the formula [19]:

$$R_0 = \frac{T_{in} - T_{surf.in}}{q} + \frac{T_{surf.in} - T_{surf.ext}}{q} + \frac{T_{surf.ext} - T_{ext}}{q}. \quad (3)$$

Based on the received and processed data graphs are drawn up, and the calculated resistance to heat transfer is compared with the received one. The result of testing in a climate chamber is the determination of the quality of the building envelope based on its resistance to heat transfer. The error was less than 0.3 % [19].

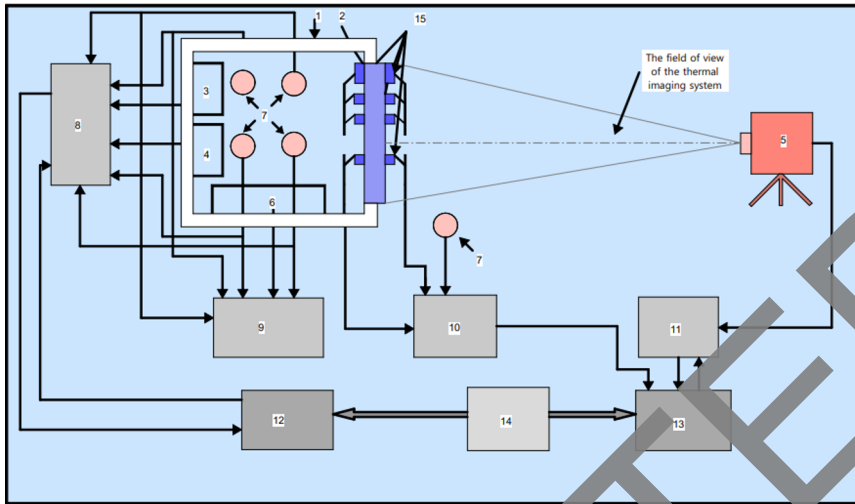


Fig. 6. Functional diagram of experimental research, where 1 – hermetic shell; 2 – test sample; 3, 4 – devices for creating temperature and humidity conditions and air speed; 5 – thermal imager; 6 – system for distributing temperature, humidity conditions and air speed inside the chamber; 7 – a set of sensors for measuring temperature, humidity and air speed inside the chamber; 8 – controller No. 1 – collecting multi-channel information and controlling temperature, humidity conditions and air speed inside the chamber; 9 – controller No. 2 – collecting multi-channel information and controlling the system for regulating the distribution of temperature, humidity conditions and air speed throughout the working volume of the chamber; 10 – controller No. 3 – collection of multi-channel information; 11 – controller No. 4 – collecting information from video images of temperature fields and controlling the thermal imaging system; 12, 13 – microprocessor computing systems; 14 – system and application software for collecting, processing and managing multichannel information; 15 – temperature and heat flow sensors.

6 A climate chamber with a displaceable cassette for sample installation

Verkhovsky A.A. together with other researchers created a stand for measuring the resistance to heat transfer of building envelopes in order to control the quality of the finished product. The stand is a climatic chamber that obtains a number of peculiar features such as: accessibility to the sample from both sides; the possibility of replacing one sample cassette with another to reduce sample installation time; the possibility to move the sample on rails for ease of use. The stand design consists of 3 blocks: cold (low temperature) 2, warm 4 and operator unit 5. Equipment for creating the necessary conditions for testing, collecting and transmitting data is located in the warm block 4, situated on the same mobile chassis with the operator unit 5 for moving on rails. The sample is placed into a mobile replaceable cassette 3, and the required temperature regime is set inside the stand. The temperature of the air and heat flow passes through the object under stationary conditions. The received data is transferred to the operator unit, where further automatic calculation is performed. This stand has been created for the purpose of conducting laboratory tests and quality control of finished products [20].

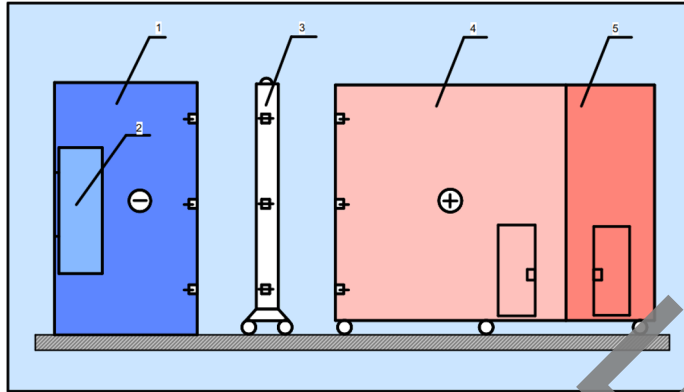


Fig. 7. Stand design, where: 1 – low-temperature (cold) block, 2 – removable cassette, 3 – mobile removable replaceable cassette, 4 – warm block, 5 – operator unit.

7 Conclusion

In the current paper, the features of determining the resistance to heat transfer under natural conditions and in a climate chamber have been considered. First of all, the differences were found in the purpose of the research. Whereas the climatic chamber evaluates the resistance to heat transfer under stationary heat transfer conditions, the field study determines the quality of the actually operated building envelope exposed to unsteady heat transfer conditions.

The study of the new methods of determining the resistance to heat transfer plays an important role in expanding methods of assessing the thermophysical characteristics of building envelopes and improving the quality of the building structure. Research by Budadin O.N. et al. made it possible to determine the quality of the building envelope by its resistance to heat transfer in a climate chamber with an error of only 0.3 %, which is a fairly high indicator of the method reliability. Complementing each other, two studies by Mureev P.N. and co-authors provided an opportunity to conduct a more reliable field study by installing sensors not onto the surface, but into the thickness of the wall enclosure, as well as taking into account the appearance of counter heat flows that affect the throughput capacity of the structure.

Both the climate chamber and the field study of the building envelope are the necessary methods for an integrated approach to the issue of resistance to heat transfer and further improvement of techniques for more high-precision calculations.

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