Experimental determination of the resistance to heat transfer of various building envelope constructions

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Abstract. The aim of the current research is to examine instruments for measuring heat flow and temperature, and to present methods for calculating resistance to heat transfer in accordance with regulatory documents. Requirements for constructions chosen as samples, and the conditions for their testing under stationary, quasi-stationary, and non-stationary conditions, are discussed. The study investigates devices for measuring thermal characteristics based on the research conducted by Yaping Cui, Jingchao Xie, Jiaping Liu, Peng Xue. An experiment performed by Chinese scientists to determine heat transfer coefficients using a naphthalene sample is analyzed. The research also presents a field experiment conducted by E.A. Gnezdilova to calculate the design characteristics of heat loss through floor constructions and building envelope constructions in direct contact with the soil. The validity and reliability of applying various methodologies are justified.

1 Introduction

Heat loss in buildings and structures occurs through a number of elements, one of which is the floor and enclosing structures that have contact with the soil. There are several methods for determining heat loss through such structures, but they require constant improvement due to the heterogeneous and complex thermal regime of the soil [1-6]. Researchers in this field are actively working on improving existing norms and rules for calculating thermal properties of these structures. Full-scale experiments are also an essential part of research, as it is necessary to develop a method that can minimize errors in the values of heat loss through the structures that have contact with the soil [7-20].

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2 Devices for measuring heat flow and temperature

Chinese researchers such as Yaping Cui, Jingchao Xie, Jiaping Liu, and Peng Xue conducted research to develop methods for determining heat transfer coefficients in areas with a unique tropical climate on islands. The experiment was based on the sublimation of naphthalene, which allowed for full-scale measurements of convective heat transfer coefficients using a simplified model of calculating the heat transfer coefficient from evaporative systems [5]. The dependence of the convective heat transfer coefficient and wind speed was established [5]. The process of producing the sample is presented in Figure 1.

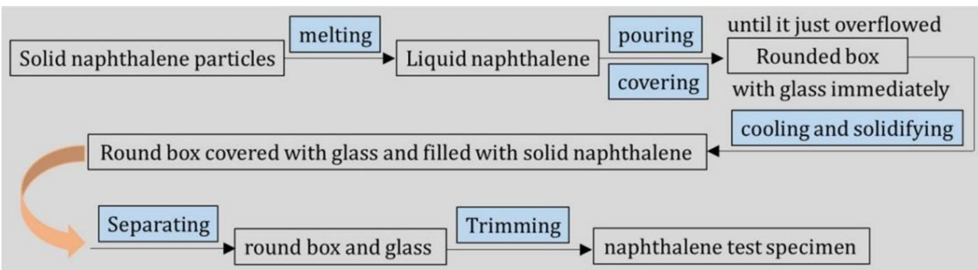

Fig. 1. Production process of the naphthalene specimen according to Yaping Cui, Jingchao Xie, Jiaping Liu, Peng Xue. [5]

A round-shaped aluminum box acted as a container for naphthalene, and the purity of the solid naphthalene particles was 98%, which was necessary to obtain reliable results [5]. Various experimental setups were used to measure the mass loss of the specimen, surface temperature, air temperature, and wind speed. The measurement devices and the specimen used in the experiments are shown in Figure 2 [5].

Fig. 2. Experimental instruments or devices: a) Naphthalene test specimen, b) electronic balance, c) infrared thermometer, d) temperature and humidity recorder, e) hot-wire anemometer, f) homemade bracket according to Yaping Cui, Jingchao Xie, Jiaping Liu, Peng Xue. [5]

Weighing of the naphthalene specimen was performed with a lid to exclude errors during mass determination [5]. Surface temperatures of naphthalene were measured every 10 minutes during the 1-hour experiment [5]. The use of various measuring equipment with low measurement errors allowed obtaining reliable data during the experiment [5].

3 Methods for experimental determination of the resistance to heat transfer of building walls in accordance with regulatory documents

The determination of the resistance to heat transfer in stationary, quasi-stationary and non-stationary full-scale conditions is set up by the regulatory document State Standart R 59939-2021 Buildings and structures “Method for determining the resistance to heat transfer in full-scale conditions.”

The essence of the method for determining the resistance to heat transfer of enclosing structures in full-scale conditions is characterized by measuring the temperature and density of the heat flow on the outer and inner surfaces, calculating the thermal resistance of homogeneous zones, thermal resistance of the enclosing structures, the calculation of the resistance to heat transfer of enclosing structures taking into account heat exchange conditions and measuring the temperature in characteristic zones of the inner surface, which allows conclusions about the compliance of the structure with design standards to be drawn.

According to the State Standart R 59939-2021, the resistance to heat transfer under stationary and quasi-stationary conditions is determined by the formula:

$$R_0 = R_{in} + R_z + R_{out} = (t_{in} - \tau_{in}) / \bar{q} + (\tau_{in} - \tau_{out}) / \bar{q} = (t_{in} - t_{out}) / \bar{q}. \quad (1)$$

where R_{in} – resistance to heat transfer of the internal enclosing structure, $(m^2 \cdot {}^\circ C)/W$; R_{out} – resistance to heat transfer of the outer surface of the building envelope, $(m^2 \cdot {}^\circ C)/W$; R_z - thermal resistance of a homogeneous zone of the building envelope, $(m^2 \cdot {}^\circ C)/W$; t_{in} - average changes in the values of internal air temperatures over the calculation period, ${}^oC$; t_{out} - average values of outdoor air temperatures over the calculation period, ${}^oC$; τ_{in} - average values of temperatures of the inner surface over the calculation period, ${}^oC$; τ_{out} - average values of outer surface temperatures over the calculation period, ${}^oC$; $\bar{q}$ - average actual heat flux density over calculation period, W / m^2.

Objects of measurements are thermally homogeneous zones. At least two similar external building envelope structures, in operation or ready for operation, are selected for testing. There are also several conditions for conducting the measurements: a cold period of the year; the functioning of the heating system is in good condition; the possibility of placing equipment in enclosed test rooms. When obtaining results, measurements of characteristic values of temperature and thermal flux density are analyzed over time during the stationary or quasi-stationary mode. The measurement error should not exceed 15%. State Standart R 59939-2021 also regulates the determination of the resistance to heat transfer of building envelopes under non-stationary natural conditions. In this case, several elements of the envelope structures located in the corner part of the building on the first, middle, and top floors are selected. The thermal resistance of a thermally homogeneous zone i at time j is calculated using the formula:

$$R_{ij} = \frac{\tau_{ij}^{in} - \tau_{ij}^{out}}{q_{ij}}. \quad (2)$$

where τ_{ij}^{in} - internal temperature on the surface of the i-th zone of the structure at time j; τ_{ij}^{out} - external temperature on the surface of the i-th zone of the structure at time j; q_{ij} - the density of the heat flux passing through the i-th zone of the structure at time j.

The actual reduced resistance to heat transfer of the tested construction is found by the formula:

$$R = \frac{1}{\alpha_{in}} + \frac{\sum_{j=1}^{N} R_j}{N} + \frac{1}{\alpha_{out}}. \quad (3)$$

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where α_{in} - heat transfer coefficient of the inner surface of the building envelope, adopted according to the Set of Rules 50.13330.2012; α_{out} - heat transfer coefficient of the outer surface of the building envelope for the conditions of the cold period, adopted according to the Set of Rules 50.13330.2012; N – the number of measurements.
The above-described formulas and requirements for test structures allow for conducting field experiments under various conditions with a low percentage of error.

4 Determination of the resistance to heat transfer of soil

In her research, Gnezdilova E.A. conducted a full-scale experiment to measure the resistance to heat transfer through enclosing structures. The experiment was carried out in a laboratory whose enclosing structures do not have a closed contour of insulation [6]. Information on the materials of the enclosing structures and floor construction to determine the thermal regime was gathered [6]. The main equipment for measuring thermal performance indicators were ITP-MG4.03/X(Y) devices, as shown in Figure 3. The equipment was placed at a distance of more than 3 meters from the sensors, which made it possible to reduce measurement errors [6].

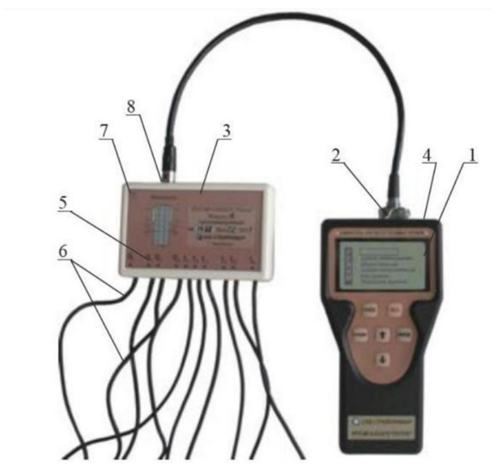

Fig. 3. General view of the ITM-MG4.03/X(Y) meter according to Gnezdilova E.A.: 1 - electronic unit, 2 - connector, 3 - module, 4 - power adapter, 5 - cable marking, 6 - sensors, 7 - LED, 8 - connector for linking the electronic unit [6].

It was found that the absolute uncertainty of heat losses decreases when moving from the outer wall to the center of the room, while the value of heat losses becomes so small that the values of relative uncertainty increase. To solve this problem, high-precision instruments and an increase in the number of measuring points were used. Calculations showed that the experiment is reliable at 95% [6].

The diagram of the sensor installation is presented in Figures 4 and 5.

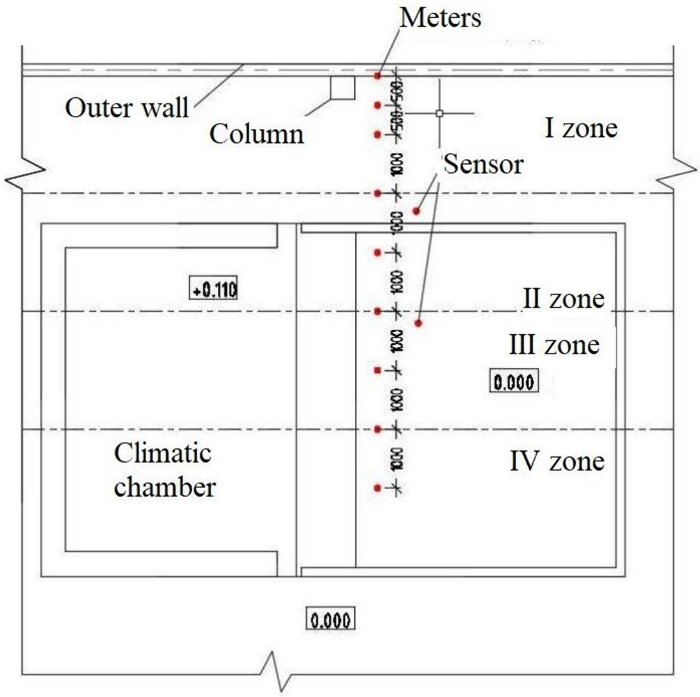

Fig. 4. Fragment of the plan with the scheme of the sensor installation in the laboratory according to Gnezdilova E.A. [6].

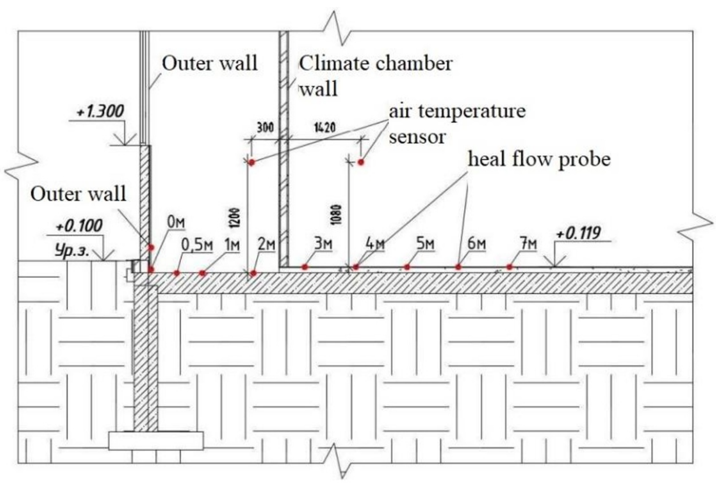

Fig. 5. Sectional view of the premises used for conducting the field experiment with indications of the sensor placement according to Gnezdilova EA [6].

During the experiment, the value of the heat flow was measured. These values were compared with the value of the heat flow passing through the floor and walls through the soil. The values of the internal air temperature in the room and the convective heat transfer coefficient of the surface also played a key role [6].

Sensors for measuring heat flux density and temperature were installed on the surface of the laboratory and at the junction of the wall and floor to control measurements. The surface on which the sensors were placed was treated with heat-conducting paste [6].

The measured values were recorded at an interval of 60 minutes. The experiment was conducted in the period from January to April [6].

The obtained data from the natural experiment have slight deviations from the calculated values, which can be explained by the proximity of the measurement points to the external wall and possible deviation of the actual climatic data of the experimental zone. Thus, it can be concluded that the developed methodology is suitable for further development and application and has a discrepancy between calculated and experimental values of no more than 9.3% [6].

5 Conclusion

In the current paper, various instruments for measuring thermal losses, temperature changes, and other thermal characteristics are discussed. Due to the correct placement of the equipment and low measurement error of the instruments, reliable data during the experiments presented in the article has been obtained.

The study of the Chinese researchers namely Ya. Cui, J. Xie, J. Liu, P. Xue on the sublimation of naphthalene allowed for the development of a methodology for experimental measurement of convective heat transfer coefficients, heat transfer during evaporation, and radiant heat transfer.

Moreover, normative methodologies for calculating resistance to heat transfer under various conditions of conducting field experiments are also presented, along with the necessary requirements and conditions for conducting experiments and selecting designs.
The method developed by Gnizdilova E.A. showed results close to the calculated values, which also indicates the reliability of the experiment. To minimize possible errors and deviations in the results, it is necessary to study the reasons for the deviations in detail and develop measures to eliminate them.

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