Information-Measuring System for Monitoring Thermal Resistance

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Abstract. Thermal resistance is the main informative characteristic when monitoring the quality of insulating materials and the thermal stability of enclosing structures. In particular, the actual values of thermal resistance as a key indicator are important in the assessment of the energy efficiency of the building.

This work describes the information-measuring system for monitoring the thermal resistance of the building enclosure constructions. A scheme for modular construction of the system using various data transmission technologies has been proposed. For the registration of monitoring parameters, specially-designed sensors of heat flux and temperature have been applied. Provided solutions gives possibilities for measuring thermal resistance in 2 ... 40 zones simultaneously and monitoring of enclosing building constructions of complex shape.

An experimental prototype of the system was created and a software module for registration and processing of measurement information was developed.

The combined method for the experimental determination of the buildings enclosure constructions thermal resistance is proposed, and the procedures for carrying out measurements necessary for the qualitative and quantitative analysis of the thermal protection of the building enclosure according to ISO 6781: 2015 and ISO 9869: 2014 are described.

The results of thermal resistance measurements for various types of building constructions are presented.

The reliability of the obtained results is confirmed by tests carried out in the laboratory whose quality control system is certified according to ISO 17025.

Keywords: information-measuring system, thermal resistance, monitoring of enclosing structures, temperature and heat flux sensors, ISO 9869.

1 Introduction

Thermal resistance is the main informative characteristic when monitoring the quality of insulating materials and the thermal stability of enclosing structures. In particular, the actual values of thermal resistance as a key indicator are important in the assessment of the energy efficiency of the building.

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There are several methods for determining the heat loss of buildings and structures. One is based on the principle of heat balance [1], and allows you to determine the total transmission loss through the building enclosure constructions. However, it does not reveal any specific causes of heat losses, nor defective or poorly insulated areas of enclosing structures. In this regard, it is difficult to determine the most effective measures for the thermal modernization of the building.

Another method - regulated in ISO 6781 [2] and EN 13187 [3], is based on remote measurement of the surface temperature of walling using thermal imaging technology. It is the most productive during the examination, allows you to diagnose the building enclosure constructions and identify local defects in thermal insulation by comparing the surface temperature of different sections. However, by giving a high-quality picture, the thermal imaging method itself does not make it possible to determine the numerical values of the thermal resistance of the enclosing structures and the heat losses of the building.

The most accurate results are obtained when heat engineering inspection of buildings, based on contact measurements [4…6] of heat flux through the building enclosure and the temperatures of its both surfaces, as well as air on both sides, with subsequent calculation of the desired values thermal resistance of the enclosing structure as a whole.

The main advantage of the contact method based on ISO 9869 [6] is the ability to determine the numerical thermal resistance values of the enclosing structures. Disadvantages of the method are manifested in the inspection of large objects with large heat exchange surfaces and thermal fields that are non-uniform in space. The disadvantages should also include large labor costs for fixing primary sensors on surfaces of various sections, including hard-to-reach (for example, walls of the upper floors of the building), and reinstalling them to new sections, as well as long (at least 4 days) measurements. When using the contact method, it is difficult to detect local defects.

The development of systems for measuring the thermal characteristics of buildings and structural elements is carried out by such well-known firms as Hukseflux (TRSYS01 High-accuracy building thermal resistance measuring system with two measurement locations) [7]; Green TEG AG (gO Measurement-System for the assessment of U-value, humidity and further parameters) [8]; FluxTeq (FluxTeq R-value measurement System) [9]. The disadvantage of measuring systems from Hukseflux and Green TEG AG is use the heat flux sensors one type and size, which makes it impossible to conduct studies of various elements of the building, in particular windows and window frames. The FluxTeq system provides such an opportunity, but a small number of measuring channels, which limits the number of control zones to 2, does not allow monitoring of complex form building enclosures.

The aim of the work is to create a method and system for monitoring the thermal resistance of the buildings enclosing structures of any configuration.

2 Main Part

Method for determining thermal resistance through the enclosing structure of buildings and structures based on a combination of thermal imaging of the surface temperature of enclosing structures in accordance with ISO 6781 [2], with quantitative contact measurements of surface temperature and heat flux values in accordance with ISO 9869 [6] has been proposed.

At the first stage, a thermal imaging survey of the entire building is carried out. This makes it possible to identify the features of the internal structure and composition of the fragments of the enclosing structure being examined (the presence of areas with unequal technical characteristics, heat-conducting inclusions, assemblies, butt joints, hidden manufacturing defects, etc.) which lead to thermal heterogeneity. Thus, representative areas are defined and areas with anomalous temperature distribution for this type of design.

At the second stage, in representative areas, measurements are carried out with the use of temperature and heat flux sensors. This allows us to obtain a quantitative estimate of local heat losses, as well as to calculate the thermal resistance of the enclosing structures.

For monitoring of the thermal resistance of the building enclosure, the complex must be implemented in the form of an information-measuring system [10], that is, a set of measuring, control, computing and other auxiliary technical means functionally integrated for the measurement information, its transformation, processing, visualization and documentation. A characteristic feature of information and measurement systems is the modular construction principle, which involves the creation of constructively completed modules and the use of standard devices. This principle ensures technical and information-functional interoperability of modules, simplifies maintenance, extends the functionality, as well as improves the accuracy and reliability of the system.

The main requirements for the thermal resistance information-measuring system, are as follows:

theoretical justification: compliance with the requirements of the standards that govern the conduct of the research;

functionality: the ability to determine the thermal resistance of the building enclosing structures of different types and under different conditions;

reliability: ensuring the possibility of conducting measurements during long time in a standalone mode;

profitability: minimizing financial and resource costs when carrying out measurements.

The development of the hardware requires the creation of separate measuring units (modules) to take into account the features of the enclosing structures and ensure the possibility of conducting research on a large number of representative zones.

Registration of temperature and heat flux, transmission, processing and archiving of measurement information is carried out with the help of the hardware-software module system, the structure of which is presented in Fig. 1

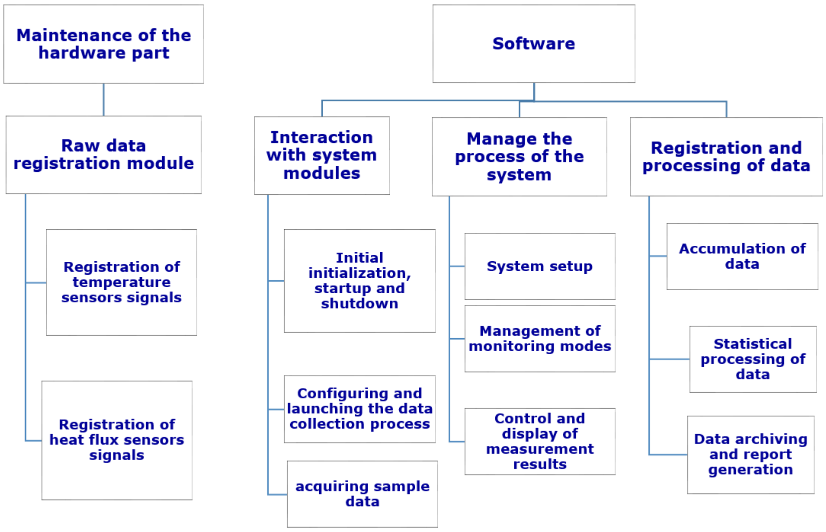

Fig. 1. The structure of hardware-software module system

For implementation of information-measuring system for temperature registration and heat flux sensor signals, modules with the following characteristics are used:

- 8-channel ADC with a bit of 16 bits and a conversion rate of 10 Hz;
- dynamic range setting and calibration;
- support for industrial interface RS-485 and addressing, which makes it possible to create a measuring network.

The unit connects to the system via the RS-485 interface or with the help of the standard radio frequency modules Ys-1100u. Modules Ys-1100u are designed to be used in various small-range systems with two-way data transmission in the unlicensed frequency range of 433 MHz and allow the organization of wireless data transmission at a distance of up to 500 meters (according to the manufacturer) between two devices with interface Rs-485. Thanks to the built-in, pre-programmed NXP microcontroller, the Ys-1100u can transmit data in "transparent" mode on one of 16 frequency channels.

The software package for registration and processing of the measurement information of the monitoring system can be divided into three interrelated levels.

The first level implements the process of analog-to-digital conversion, conversion of data codes and the management of the interface.

At the second level, information is received via the interface and primary processed (conversion to the value of heat flux and temperature), as well as storing information.

The third level of software is specific it performs general system control through the first and second level programs and processing the received data on temperature, heat flux.

3 Results

In fig. 2 presented the implementation of the monitoring system for thermal resistance of the building enclosures. It represents a set of functionally integrated modules, sensors, auxiliary equipment and a personal computer with the corresponding software (not shown in fig.2).

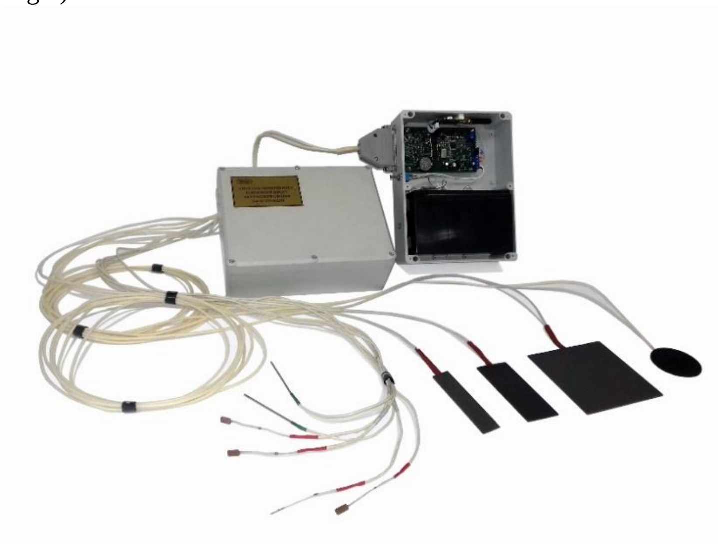

Fig. 2. Measuring modules of the thermal resistance monitoring system

The main technical characteristics of the developed system are shown in the table 1.

Table 1. Technical characteristics

Number of channels	8 … 160
Measuring zones	2 … 40
Type of heat flux sensors	with thermal shunts with thermal correction
Range of heat flux values, W/m²	1 … 2000
Relative error of heat flux measuring, %	depending on the sensor type up ±1,5 to ± 3 %
Temperature sensors	Thermocouples with individual calibration, resistance thermometers Pt100
Range of temperature values, °C	-30 … +100
Absolute error of temperature measurement, K	±0,5 … ± 1
Method of research	ISO 9869

During the measurements of heat flux small with low density, dynamic error makes a significant contribution to the measurement error. This component of the error is caused by the non-stationary of the controlled thermal process. Thus, the dynamic error is proportional to the intrinsic heat capacity of the sensor and the rate of temperature change. To reduce this component of the measurement error in the range of low heat flux characteristic of building elements with high thermal resistance, sensors with a corrective module [11] are provided in the set, which have a time constant (5 ... 10) less than in traditional sensors of the same size and sensitivity.

For experimental studies of the established monitoring system, its comparative tests were carried out using equipment of the laboratory, which certified by ISO 17025.

The experiments were carried out on a construction fragment of three-layer wall panels with insulation of polyurethane foam with indication of homogeneous zones. Figure 3 shows the arrangement of homogeneous zones of fragmentation of the structure.

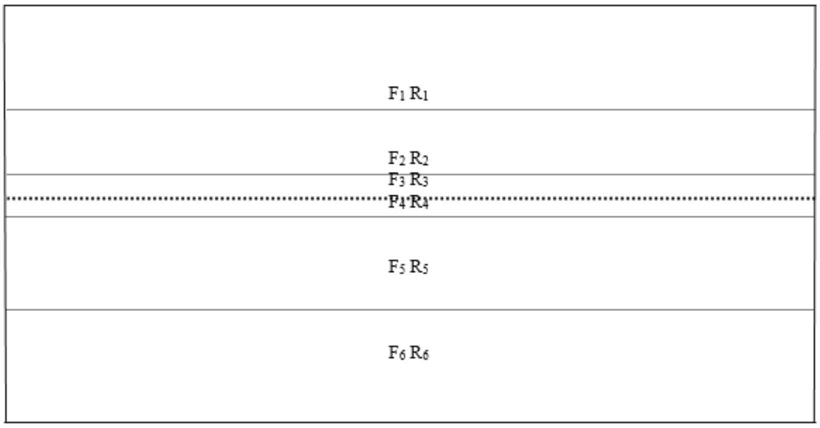

Fig. 3. Arrangement of homogeneous zones of the structure fragmentation

A fragment of the construction was placed in the climatic chamber. The tests were carried out at a distance of 0.15 m from the surface of the sample at air temperature in the cold section of the chamber minus 22.79 ° C ... minus 21.75 ° C, in the warm section of the chamber 22.42 ° C ... 24.21 ° C , the average value of the temperature of the internal air was 23.60 ° C.

Calculations of thermal resistance are carried out according to [12…15]. The obtained results are presented in tables 2 and 3.

According to the data obtained, the difference between the results of the temperature measurement did not exceed ± 0.5 K, the heat flux density ± 0.5 W/m². This indicates the correctness of the determination of the thermal resistance of the enclosing structure with the application of the developed monitoring system.

Testing of the system in natural conditions conducted by monitoring a residential house. The house has six sections of five floors each. The total number of apartments in the house is 120. The total height of the building is 14.6 m, the height of the basement is 2.38 m. The house has one staircase per section.

Table 2. The results obtained on the equipment of a certified laboratory

Name of homogeneous zones	F_1	F_2	F_3	F_4	F_5	F_6
Total area of the sample, **F**, m²	4,84					
Area of measuring homogeneous zones, **F**, m²	1,056	1,056	0,088	0,088	1,276	1,276
The average temperature of the internal surface of homogeneous zones, $\mathbf{t_{вн}}$,°C	21,34	21,68	20,06	19,28	21,37	21,17
The average temperature of the outer surface of homogeneous zones, $\mathbf{t_з}$,°C	-21,96	-21,09	-21,88	-21,74	-21,40	-21,36
The average heat flux of homogeneous zones, **q**, W/m²	8,82	9,28	20,13	20,09	10,49	9,53
Thermal resistance of homogeneous zones, $\mathbf{R_к^{о.з.}}$, m²·K /W	4,91	4,61	2,08	2,04	4,08	4,46

Table 3. Results obtained on the developed monitoring system

Name of homogeneous zones	F_1	F_2	F_3	F_4	F_5	F_6
Total area of the sample, **F**, m²	4,84					
Area of measuring homogeneous zones, **F**, m²	1,056	1,056	0,088	0,088	1,276	1,276
The average temperature of the internal surface of homogeneous zones, $\mathbf{t_{вн}}$,°C	21,01	21,26	20,34	19,43	20,95	21,01
The average temperature of the outer surface of homogeneous zones, $\mathbf{t_з}$,°C	-22,01	-21,30	-21,65	-21,62	-21,65	-21,20
The average heat flux of homogeneous zones, **q**, W/m²	8,60	9,10	19,65	19,71	10,21	9,63
Thermal resistance of homogeneous zones, $\mathbf{R_к^{о.з.}}$, m²·K /W	5,00	4,68	2,14	2,08	4,17	4,38

The structural design of the building is a precast reinforced concrete frame with precast ceilings and a precast base plate. The external walls of the house are made of reinforced concrete 40 mm thick, expanded clay concrete 200 mm thick, and a layer of plaster 50 mm thick. The attic is cold. The technical floor is warm with a dilution of heating and hot water pipelines. The light-transmitting structures (windows, balcony doors) are made of double glazed windows in separate wooden frames.

Figures 4 and 5 show photos and characteristic thermograms of the enclosure of the building, in which the markers with lines and points indicate zones with a higher temperature than the entire wall. These zones are heat loss areas requiring special attention. In addition, a dot marker indicates an area with a normal surface temperature.

On the thermogram shown in Fig. 4, the area indicates the depressurization of the junction of the panels, as well as markers marked areas of high heat loss overlap the last floor of the house.

In fig. 5 dotted markers indicate zones with a higher temperature, which may be caused by a violation of the integrity of the building enclosure.

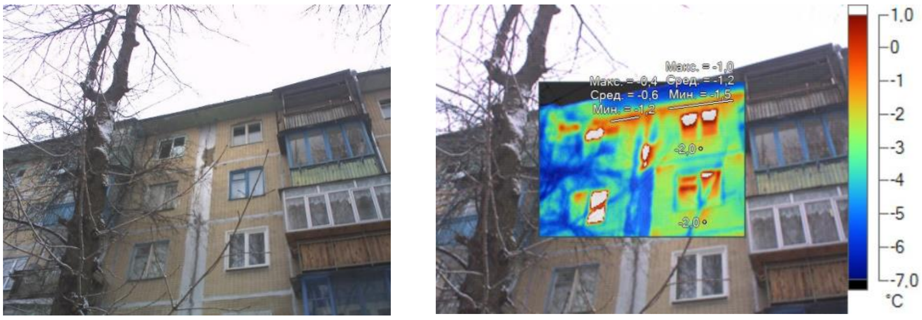

Fig. 4 Photo and thermogram of the depressurization of the joint of the panels of the enclosure constructions

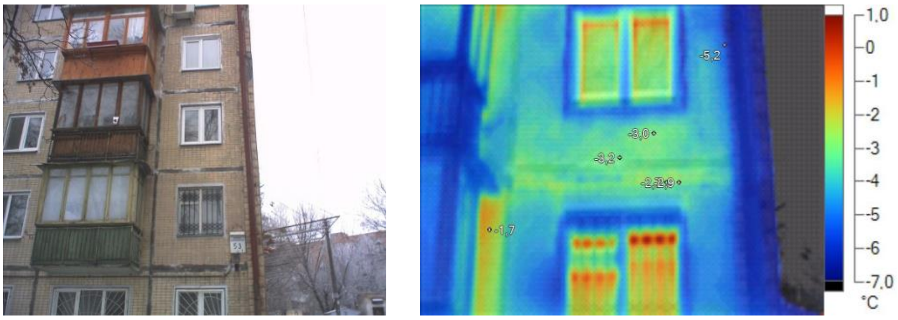

Fig. 5 Photo and thermogram of characteristic zones of the enclosure constructions

The values of thermal resistance of different types of building enclosures are determined during monitoring. The results are shown in table 4.

Table 4. Survey results of structural elements of the building

Construction element	The elements area (***F***), m^2	Thermal resistance (***R***), $m^2 \cdot K/W$
Outside walls	2717	0,81
Windows and balcony doors	806,5	0,3
Docking ceiling	1164	0,8
Basement: – outside walls – ground floor	202 1164 1680	0,81 0,35 4,7

Based on the performed monitoring, it was established that the enclosing constructions of buildings have insufficient values of thermal resistance according to the current standards. In addition, a number of characteristic defects, namely:

- partial destruction of the joints of the wall panels and significant infiltration through them;
- significant thermal heterogeneity of wall panels;
- the presence of poorly isolated construction bridges of the cold;
- insufficient insulation of the attic floor.

4 Conclusions

A system for monitoring the thermal resistance of building envelopes and a software package for registration and processing of measurement information that meets the requirements of ISO 9869: 2014 has been developed.

The results of thermal resistance measurements for various types of building constructions are presented.

The reliability of the obtained results is confirmed by tests carried out in the laboratory whose quality control system is certified according to ISO 17025.

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