Thermal imaging method for quantitative and qualitative assessment of the acceptable heat losses in configurations of structures in the diagnosis of buildings

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Abstract. The article discusses the possibility of using a hardware thermometric diagnostic method based on a thermal imaging device in energy-intensive low-rise industries. The proposed optoelectronic device, a thermal imager, can operate in real time, store and process information, and transmit the received data to the consumer. The solution, the creation of a model - an algorithm with software, can be used for the purpose of obtaining numerical values of heat losses and the accompanying characteristics of differentiated temperature states with the surface heat transfer coefficient.

1. Introduction
Modern building technologies, implying airtight and vapor-tight enclosing structures, now more and more need to diagnose the temperature state of premises [1, 2]. Today, in construction technologies, the hardware thermometric diagnostic method based on a thermal imaging device is objectively and subjectively in demand. Such an optoelectronic device as a thermal imager can operate in real time with the ability to save information recording and transfer the received data, and taking into account new developments (engineering and circuit solutions), it is possible to obtain numerical estimates of heat loss, infiltration, stratification and humidity, that is, to obtain the main parameters of comfortable room microclimate.

Thermal costs can be significantly reduced thanks to thermal imaging, using computed tomography and obtaining a picture of the temperature spectrum [3].

Various colors, obtained for convenience on the thermogram, show the change in the intensity of infrared rays - an approximate idea of the supercooled parts of the structure. As a result, we have on hand a reliable thermographic report with a picture of the problems identified in color, namely: to see the picture of construction defects, defects in windows, joints, ceilings, to diagnose the presence of "cold bridges".

2. Body
As a kind of spectrum of electromagnetic waves, thermal or infrared radiation (IR radiation) occurs in solids, liquids and gases due to vibrations of atoms in a crystal lattice or rotational-vibrational motion of molecules [4]. The range of this spectrum (IR) 0.75 μm to 1000 μm lies between visible light and radio waves. When radiation falls on a body, the following picture takes place, shown in Figure 1: interaction of radiation with heat: 1) absorption (coefficient); 2) reflection (coefficient); 3) transmission (coefficient).
The output electrical signal of the IR thermal imager is proportional to the total absorbed flux. It is used in modern thermal imagers to determine true temperatures.

Physical radiation receivers generate an electrical signal proportional to the power of optical radiation absorbed by their sensitive areas [5, 6]. The principle of operation of thermal detectors is based on the bolometric effect, i.e. on the change in the electrical resistance of the sensitive element when heated by absorbed IR radiation. A thermal imager registers thermal radiation from objects using the bolometer sensor. The signal from it is converted by the processor into a thermogram - taking heat from the object, i.e. the picture that we see on the monitor. The warmest places are red, and the coldest places are blue.

3. Methodical part

Our proposed solution is the creation of an electronic - digital model - an algorithm with software for obtaining numerical values of heat losses.

To obtain a quantitative assessment of these heat losses, the existing thermal imaging survey, taking into account some thermograms, is generally not enough. We know that heat loss from the surface of a building to the environment is determined by the formula:

\[ Q = \alpha \cdot (t_c - t_a) \cdot S, \]  

where:
- \( \alpha \) - surface heat transfer coefficient, W/m\(^2\)°C;
- \( t_c \) - average surface temperature, °C;
- \( t_a \) - ambient temperature, °C;
- \( S \) - surface area, m\(^2\).

Determination of the numerical or percentage value of heat loss is associated with the determination of all quantities included in the equation and is performed during the operating mode, including both thermal imaging and, if necessary, contact measurements. As an example, we use a thermometer (TH90 from AMTAST) with the function of measuring the temperature and humidity of the ambient air, integrated with the thermal imager system (Fig. 2).
Figure 2. Thermometer (TH 90) with the function of measuring the temperature and humidity of the ambient air

Thermometer type TH 90 - Specifications:
- Indoor temperature measurement range: from -50 °C to +70 °C.
- Indoor relative humidity measurement range from 10% to 99%.

For a comprehensive determination of indicators, additional functions of the thermal imager model are used: a method of stocking images (hard disk, SD memory card, USB, flash card), a method of image processing.

The implementation of the diagnostic algorithm (approach) is most successful and economically feasible with an optoelectronic device - a thermal imager with the following parameters. The UTi 160B model, which has a temperature measurement range from -20 °C to 300 °C, with a resolution of 160 × 120 pixels, with video output to an NTSC and PAL television system, has a USB serial port. (made in China).

Consider the possibility of determining the type of defect using the matrix sensitive area of the UTi160B thermal imager. The thermal imaging image on the screen is a temperature matrix, which creates advanced software so that the user can use the extensive capabilities of digital data processing in order to obtain geometric dimensions - an area $S$ (defect). Consider an example of fixing a defect (area) with a thermal camera (Fig. 3) in a thermal enclosure in the form of a flat figure, digitally represented in the form of a matrix $K$, whose elements $k_{i,j}$ represent line by line the coordinates of the centers of gravity of the points of the defect image in the coordinate system $XOY$. 
Figure 3. A flat figure representing a defect fixed by a heat chamber

There were 123 points with two coordinates in total. In addition, let, programmatically define a function that describes the contour of a flat figure of a defect $L(x, y) = 0$, which can be represented in any form. In the simplest case, it can be presented in tabular form.

$$L_{xy} = \begin{bmatrix}
6 & 7 & 8 & 9 \\
7 & 5 & 10 & 0 \\
8 & 5 & 11 & 0 \\
9 & 4 & 12 & 0 \\
10 & 4 & 12 & 0 \\
11 & 5 & 13 & 0 \\
12 & 5 & 13 & 0 \\
13 & 5 & 13 & 0 \\
14 & 5 & 14 & 0 \\
15 & 5 & 14 & 0 \\
16 & 6 & 14 & 0 \\
17 & 6 & 14 & 0 \\
18 & 7 & 14 & 0 \\
19 & 8 & 13 & 0 \\
20 & 9 & 13 & 0 \\
21 & 11 & 13 & 0 \\
22 & 12 & 12 & 0
\end{bmatrix}$$

Next, we determine the position of the center of gravity of this figure, using (Fig. 3) and the matrix $K$ and taking the areas of the points of the figure as a unit. As a result, we get: the area of the figure is 123 units, the coordinates of the center of gravity $X_C = 13.341; Y_C = 9.187$.

$$\bar{S} = \sum_{i=1}^{123} \Delta S_i = 123$$

$$X_C = \frac{1}{\bar{S}} \cdot \sum_{i=1}^{123} (\Delta S_i \cdot A_{i,2}) = 13.341$$

(3)

(4)
\[ Y_c = \frac{1}{S} \sum_{i=1}^{123} (\Delta S_i \cdot A_i) = 9.187 \]  

We connect a new coordinate system \( X'CY' \) with the center of gravity of a plane figure and calculate the axial and centrifugal moments of inertia relative to the new axes, taking \( \delta_S = 1 \). As a result, we get:

\[ J_{CY'} = \delta_S \cdot \sum_{i=1}^{123} (C_i) = 2.08 \times 10^3 \]  
\[ J_{CX'} = \delta_S \cdot \sum_{i=1}^{123} (C_i) = 860.699 \]  
\[ J_{CYXY} = \delta_S \cdot \sum_{i=1}^{123} (C_i) = 580.146 \]  

Using the obtained expressions, we find the parameters of the ellipse of inertia: the direction of the main axes of inertia and the value of the main central moments of inertia.

\[ J_{CXY} = \frac{1}{2} \sqrt{(J_{CX} - J_{CY})^2 + 4 \cdot (J_{CYX})^2} \]  
\[ J_{CX} \]  
\[ J_{CYX} \]  

From here we find the equations of the main central axes of the ellipse of inertia:

\[ y_{max} = \text{equation of the major axis of the ellipse of inertia;} \]  
\[ y_{min} = \text{equation of the minor axis of the ellipse of inertia.} \]  

Solving these equations, together with the function \( L(x, y) = 0 \), we obtain the values of the coordinates of the points of intersection of the axes of the ellipse with the contour line of the flat figure characterizing the defect of the thermal enclosure, from which we find the dimensions of this figure - length -17.6; width - 8.9 units. Thus, the problem of determining the dimensions of the defect figure is solved.

In general, the work shows the possibility of determining the geometric parameters and the simplest types of defects in thermal fencing of buildings and structures. As a result, in order to obtain a quantitative assessment of any section of heat loss by thermal imaging, taking into account the obtained area of the defect \( \delta \), temperature \( t_a \) and \( t_s \), the tabular heat transfer coefficient \( \alpha \), we determine the amount of heat loss taking into account all quantities included in the equation.

4. Conclusions

Thermal imaging control in building structures has become widespread, especially at the stage of operation during the acceptance of buildings [7]. Modern diagnostic thermal imagers with extended functionality provide an opportunity to obtain in the control mode the temperature range using thermograms and then diagnostic characteristics in numerical or percentage form, comparing them with the existing standards. Such widespread use of thermal imaging, low-energy laser and other optoelectronic systems, closed on a computer, makes it possible to evaluate the image of an object with a certain logic of calculus, where the analysis of an optical image of the surface state of an object serves as the basis for characterizing its qualities.

References

[1] Smirnov N V, Dudin - Barkovsky I V 1965 Course in Probability Theory and Mathematical Statistics for Technical Applications (Moscow: Nauka) p 501
[2] Fritsch V 1984 Application of microprocessors in control systems (Moscow: Mir) p 464
[3] Larioshina I A, Vavilov V P 2012 Thermal imaging as a tool for energy audit Energetic, No 8, pp 38 - 39
[4] Cowden D 1961 Statistical Methods of Quality Control (Moscow: Fizmatgiz)
[5] Daniel W B, James V A 2001 Polarization sensitive QWIP thermal imager Infrared Physics & Technology, 42, pp 323 - 328
[6] Peric D, Livada B, Peric M, Vujic S 2019 Thermal Imager Range: Predictions, Expectations, and Reality Sensors, No 15, p 3313
[7] Nikolsky E K, Eriskina T O, Belyakova M S 2014 Remote Methods of Monitoring of fires and their consequences Geoinformation Sciences and Environmental Development: New Approaches, Methods, Technologies. Collection of articles of the II International conference. Southern Scientific Centre of RAS, pp 7-14