

THE METHOD OF LOCAL AUTOMATIC CONTROL OF THERMOPHYSICAL PARAMETERS OF EXTERNAL WALLS OF BUILDINGS AT THE LOCATIONS OF CONDENSATE LOSS

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Abstract: Today the buildings of the 60-80th of the XX century do not satisfy to modern requirements for energy saving. The low value of the resistance to heat transfer leads overcooling of the wall surface in the cold period of the year and to overheating in the warm period. In addition, over the years of operation building envelopes subjected to numerous of climatic changes that were not envisaged in the design earlier. The lowering of microclimate parameters in the room negatively affects to the comfort and health of a person. As a result, the specific heat consumption for heating increases, the resistance to heat transfer decreases, and the thermal diffusivity increases. Therefore, a new method for calculating the actual value of the resistance to heat transfer is developed. The problem of providing sanitary and hygienic and thermophysical comfort conditions in the premises of the student hostel of the Volga State University of technology is also being solved. This occurs by controlling the temperature of the internal surface of the outer walls with a heating cable. Such a design will not only keep the difference between the wall surface temperature and the internal air temperature within the limits of the norm, but will also help to solve the problem of condensate precipitation by raising the temperature of the inner surface of the wall above the dew-point temperature. The developed technique takes into account the conditions of the heat transfer regime at a particular time, and also makes a correction to the final value of the design resistance. This makes the technique applicable for processing the results of field experiments and determining the actual resistance to heat transfer. Also results of field experimental researches of external walls of buildings are resulted and the scheme of laboratory installation is shown.

Keywords: internal wall insulation, dew point, temperature, humidity, heat flux, heat transfer resistance, the quasi-stationary mode

СПОСОБ ЛОКАЛЬНОГО АВТОМАТИЧЕСКОГО УПРАВЛЕНИЯ ТЕПЛОФИЗИЧЕСКИМИ ПАРАМЕТРАМИ НАРУЖНЫХ СТЕН ЗДАНИЙ В МЕСТАХ ВЫПАДЕНИЯ КОНДЕНСАТА

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Аннотация: В настоящее время здания застройки 60-80-х годов XX века не отвечают современным требованиям по энергосбережению. Низкое значение сопротивления теплопередаче приводит к переохлаждению поверхности стенового ограждения в холодный период года и к перегреву в тёплый период. Кроме этого, за годы эксплуатации ограждающие конструкции зданий испытывают многочисленные климатические изменения, не предусмотренные ранее при проектировании. Снижение параметров микроклимата в помещении негативно воздействует на комфорт и здоровье человека. В результате возрастает удельный расход тепла на отопление, снижается сопротивление теплопередаче, повышается теплопроводность. Поэтому разработана новая методика расчета фактического значения сопротивления теплопередаче. Также решается задача обеспечения санитарно-гигиенических и теплофизических ком-

фортных условий в помещениях студенческого общежития Поволжского государственного технологического университета. Это происходит с помощью регулирования температуры внутренней поверхности наружных стен при помощи нагревательного кабеля. Подобная конструкция позволит не только сохранять перепад между температурой поверхности стены и температурой внутреннего воздуха в пределах нормы, но и будет способствовать решению проблемы выпадения конденсата путем повышения температуры внутренней поверхности стены выше температуры точки росы. Разработанная методика учитывает условия режима теплопередачи в конкретный момент времени, а также вносит поправку в итоговое значение расчетного сопротивления. Это делает методику применимой для обработки результатов натурных экспериментов и определения фактического сопротивления теплопередаче. Также приводятся результаты натурных экспериментальных исследований наружных стен зданий и показана схема лабораторной установки.

Ключевые слова: внутреннее утепление стены, точка росы, температура, влажность, тепловой поток, сопротивление теплопередаче, квазистационарный режим

Currently, the construction of residential buildings in Russia is rising with high speed. As a result, the country's housing stock is being updated. However, a large share in the housing stock still consist of buildings built in the 1960-1980th of the 20th century (up to 45% according to Rosstat). These houses were built by obsolete requirements for today [4]. For such a long period of time, both the external climatic conditions and the operating conditions of the buildings were subject to changes. All these conditions ultimately lead to a significant decrease in the heat-shielding characteristics of the exterior walls of buildings [9,10,11,12]. Under the condition of elevated temperatures and humidity of indoor air in the room, associated with domestic heat generation and insufficient ventilation of air, there are times when the temperature of the internal surface of the wall drops below the dew point temperature, i.e. there is a moment of condensation, which can lead to the formation of mold.

The basis for the development of new methods for determining the actual resistance to heat transfer was the method of V.I. Zuev and co-authors "Method for determining the thermal resistance of a structural element area under non-stationary heat transfer mode" [5], the essence of which is in determining the conditions for the existence of a quasi-stationary heat transfer mode and its criterion θ_{max} . In this method, the negative sides were identified, which were taken into account when developing a new technique.

The aim of this investigation is to develop a new technique that will reduce the calculation of the actual value of the heat transfer resistance to the determination of the minimum measurement time and the correction for thermal resistance ΔR ; development of a local automatic room climate control system using a proportional-integral-differential controller.

Due to the fact that the constancy of the heat flux is an insufficient condition for the stationary heat transfer mode, the criterion for determining the quasi-stationarity of the heat transfer mode is the temperature distribution through the thickness of the fence in a straight line from outside to inside temperature.

In the case of a quasi-stationary heat transfer mode, when determining the actual heat transfer resistance, we distinguish two components: the heat transfer resistance $R^{0,92}$ and the ΔR amendment caused by the quasi-stationary heat transfer mode (1):

$$R_{\text{факт}} = R^{0,92} + \Delta R = \frac{T_{\text{в}}^{0,92} - T_{\text{н}}^{0,92}}{Q^{0,92}} + \Delta R \quad (1)$$

where $R_{\text{факт}}$ is the fact resistance against heat transfer of the wall's part, $\frac{\text{м}^2 \cdot \text{°C}}{\text{Вт}}$; $T_{\text{в}}^{0,92}$ is temperature of internal surface with probability of 0,92(0,98), °C; $T_{\text{н}}^{0,92}$ is temperature of external surface with probability of 0,92(0,98), °C; $Q^{0,92}$ is heat flow with probability of 0,92(0,98), $\frac{\text{Вт}}{\text{м}^2}$;

ΔR is an amendment to heat resistance of the wall's part, $\frac{m^2 \cdot ^\circ C}{B\tau}$.

Taking the heat transfer mode close to stationary, the value $R^{0.92}$ is calculated by the standard formula with the difference that the value of the temperature of the inner and outer surface and heat flux are taken with a probability of 0.92 (0.98). The amendment to the heat transfer resistance takes into account the quasi-stationarity of the heat transfer mode. The criterion of the stationary mode is the linear temperature distribution in the thickness of the outer wall, therefore, the amendment depends on the deviation of the actual temperature distribution from the theoretical (linear) and heat flux passing through the outer wall (2):

$$\Delta R = \sum_{i=1}^6 |R_{cp} - R_i| \quad (2)$$

where

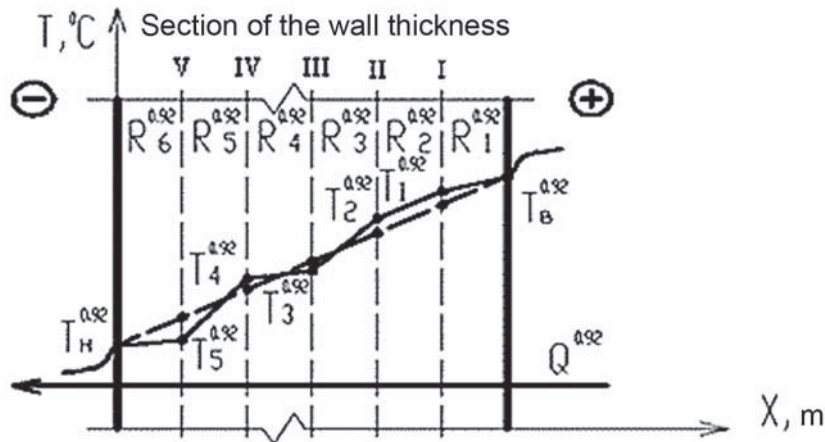


Figure 1. The actual and theoretical temperature distribution in the thickness exterior wall.

In practice, this technique is implemented using software, in which it can be put the selection criteria for the processed time intervals, the value of amendment ΔR in fractions of $R^{0.92}$ or absolute values. Measurements are made during the entire heating period, which allows us to find a set of values with the same criteria for the selection of time intervals. On the basis of the obtained values, the total value is determined with the help of the technique with the required probability, which is recommended to be taken

$R_{cp} = \frac{R^{0.92}}{6}$ is theoretical resistance to heat transfer of i-th layer, calculated for quasi-stationary mode, $\frac{m^2 \cdot ^\circ C}{B\tau}$,

$$R_i = \frac{T_{i-1}^{0.92} - T_i^{0.92}}{Q^{0.92}}$$

calculated in accordance sensor readings, $\frac{m^2 \cdot ^\circ C}{B\tau}$. In Figure 1, the dashed line shows the theoretical temperature distribution in the thickness of the outer wall, the solid one shows the actual temperature distribution in the thickness of the outer wall.

as the actual value of the heat transfer resistance for the heat engineering calculation of the reconstructed buildings.

Using the classical formula to determine the actual resistance to heat transfer without taking into account the amendment ΔR deprives the meaning of the method using this approach for determining $R_{факт}$. In natural conditions it is impossible to create a stationary mode of heat transfer. In some techniques to bring the heat

transfer mode to the stationary it uses the various heating elements, which are located on the inner, outer, or on both surfaces. The use of such heating elements violates the thermal state of the outer wall section, that leads to a large error in the measurement results. Also unknown is there an affecting of these heating elements on the accuracy of data from heat flow and temperature sensors. The only correct solution is to conduct a full-scale experiment without changing the thermal state of the object, taking into account the degree of non-stationarity of the heat transfer mode.

The main conveniently controlled parameter of the stationary mode of heat transfer is the linear distribution of temperatures in the thickness of the outer wall during a time interval not less

than the time of thermal inertia of this outer wall. If the temperature distribution in the thickness of the outer wall differs more significant from the linear one, then the degree of quasi-stationarity of the heat transfer mode is greater.

The developed technique takes into account the conditions of heat transfer at a particular point in time, and also amends the final value $R_{\text{факт}}$. This makes the technique applicable for processing the results of experiments and determining the actual resistance to heat transfer.

The decision of wall insulation becomes the structure, which is a heating element mounted in the inner plaster layer of the wall (Fig. 2) [6].

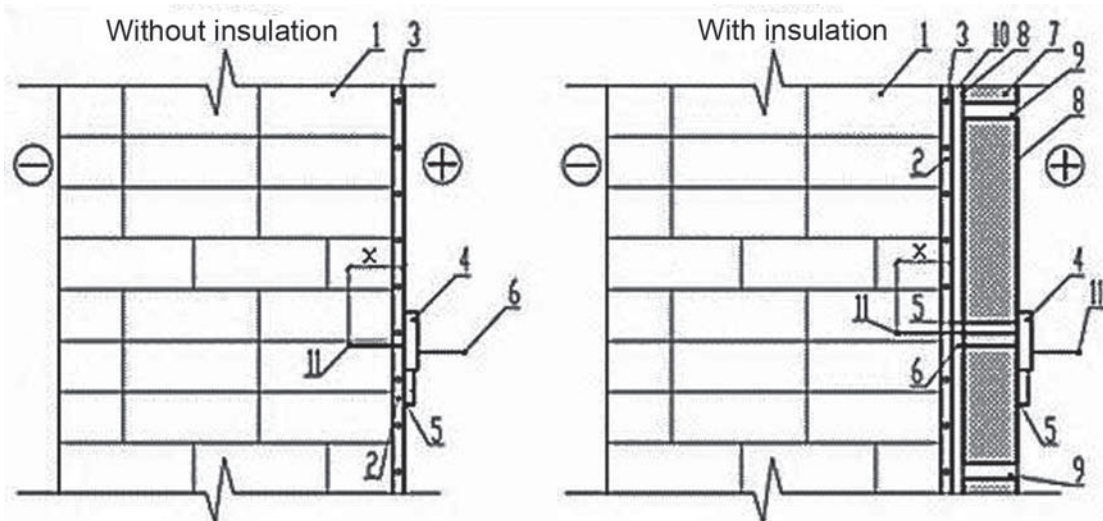


Figure 2. Designed wall fencing with adjustable temperature of the inner surface: 1-outer wall; 2 plastering layer; 3-heating element; 4-thermostat; 5-surface temperature sensor; 6-humidity and air temperature sensors; 7-insulation (mineral wool $\delta = 100$ mm); 8 gypsum plasterboard; 9 products; 10-air gap; 11 temperature sensor.

Such a design not only maintain the difference between the wall surface temperature and the internal air temperature within the normal range (≤ 40 ° C according to [7]), but also help to solve the problem of condensate by increasing the temperature of the internal wall surface above the dew point temperature. In addition, the design variant with insulation (Fig. 2) increases the resistance to heat transfer of the wall enclosure, while the heating element will prevent the

insulation from getting wet by shifting the dew point deep into the wall thickness.

The operation of the thermostat is based on the observance of two parameters: the provision of standardized temperature difference and condensation on the inner surface.

The fulfillment of these tasks will lead to the solution of other important requirements: the prevention of the possibility of mold formation on the inner surface of the walls; exclusion of

the probability of human contact with heated surfaces that are below the level required for a person's comfort; and the obstruction of wetting of the walls and, as a result, the reduction of heat loss through the building envelope.

The mathematical description of the dynamics of the thermal process of heat transfer to building structures are partial differential equations. For the synthesis of algorithms for automatic control of technological processes, when describing the dynamics of processes, the transfer functions of the ratio of the input signal to the output type (3) are used:

$$W(s) = \frac{X(s)}{Y(s)} \quad (3)$$

where $X(s)$, $Y(s)$ are Laplace transformations of input and output signals respectively.

To determine the transfer functions of the masonry, the physical model of the control object is presented in Figure 3, which schematically depicts a heterogeneous masonry with a built-in heating element in the form of a nickel-chrome alloy heating cable, similar to that used in floor heating systems. In the physical model of the control object (Fig. 3), the following descriptions are adopted: Q_0 is a heat flow in the direction from the heating element to the room; Q_1 is a heat flow in the direction from the heating element to the outside of the building; Q_2 is a heat flow in the direction from the room to the outside of the building; Q_3 is a heat flow in the direction outside the building to the room; t_0 is the indoor temperature; t_1 is the temperature of the inner surface of the building wall; t_2 is the temperature of the outer surface of the building wall.

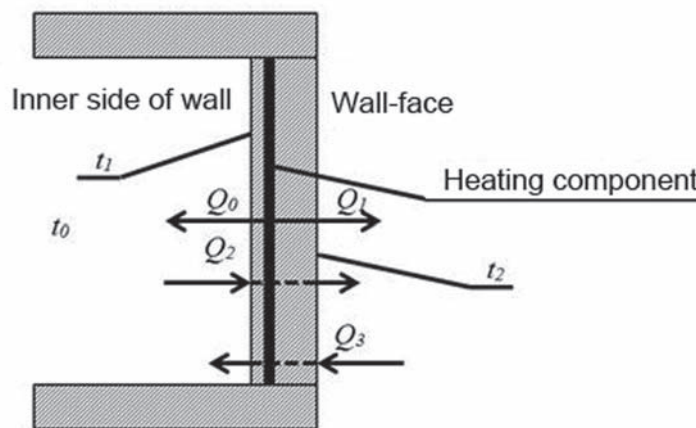


Figure 3. Physical model of the object of control.

V.S. Tkachev, A.V. Kostenko [1,8] proposed to represent the transfer function of heterogeneous masonry in the form of the sum of the transfer functions of its layers, that is, consider the masonry in layers. In this case, in the physical model of a masonry with a heating element, it is possible to distinguish two main layers: 1 is a layer from the heating element into the interior, through which the heat flow Q_0 passes; 2 is layer from the heating element to the outside of the building, through which the heat flux Q_1 passes. Taking into account the small depth of installation of the heating element in the wall relative to

the inner side of the wall (no more than 5 cm), this layer can be considered conventionally homogeneous and describe it as one transfer function of the aperiodic link of the first order of the following form (4):

$$W(s) = \frac{1}{Ts+1} \quad (4)$$

where T is time constant; s is Laplace operator. The purpose of the operation of the automatic control system is to maintain the temperature difference inside the room t_0 and the temperature of the inner surface of the building wall t_1

at a level less or equal to 40 ° C, which ensures the spatial shift of the dew point inside the building wall [2]. This protects the interior surface of the wall with decorative trimming from condensation, the spread of fungus and ensuring a comfortable location of the person inside the room.

In order to control the indoor temperature t_0 and the temperature of the inner surface of the building wall t_1 , it is necessary to install two primary transducers - resistance thermometers. To pre-

vent the possibility of self-oscillations in the automatic control system caused by abrupt changes in the readings of the thermometer of resistance of the internal temperature in the room t_0 , it is necessary to ensure its sufficient inertia by using thermal screens or installing away from the main air flow caused by short-term opening of doors or windows in the room. The block diagram of the automatic control system is shown in Figure 4.

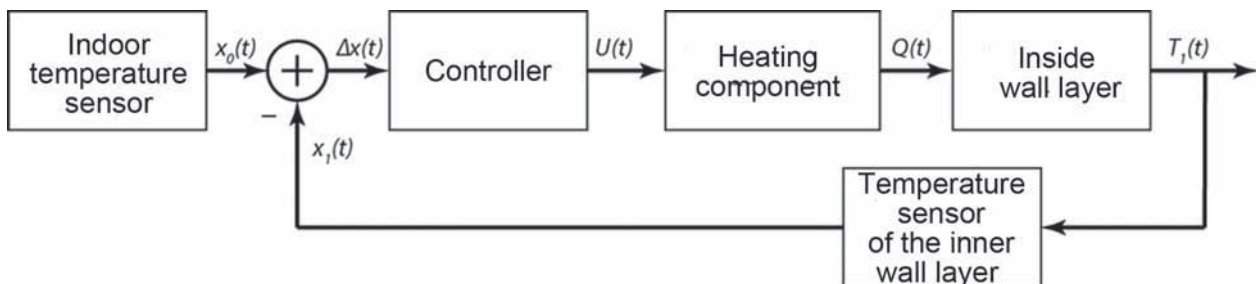


Figure 4. Block diagram of the automatic control system.

The basis of the automatic control system is a controller made according to the scheme of a classical proportional-integral-differential controller (PID controller), the operation of which is described by the expression (5):

$$U(t) = Ke(t) + \frac{1}{T_i} \int e(t) dt + T_d \dot{e}(t) \quad (5)$$

where t is time, K , T_i , T_d are proportionality coefficient, integration constant and differentiation constant respectively.

A signal on the mismatch $\Delta x(t)$ of the measured air temperatures inside the room $x_0(t)$ and the inner layer of the wall $x_1(t)$ is sent to the input of the PID controller. The output control signal $U(t)$ is formed according to expression (5), while the proportional coefficient, the integration constant and the differentiation constant are chosen experimentally from the point of view of minimizing the transition process or the overshoot value. The output control signal $U(t)$ is actually the power control signal of the heating element built into the wall and takes values from 0 to 100 as a percentage of the maximum power of the heating element.

The transient graph obtained during simulation in VisSim is shown in Figure 5 and describes the temperature change t_1 of the inner wall surface with an abrupt change in indoor temperature from 20 ° C to 25 ° C at time $T = 30$ minutes. As can be seen from the graph, the use of the PID controller allows us to significantly reduce the time of the transition process.

For maximum reliability of the results, it is decided to conduct research in natural conditions (Figure 6). A residential dormitory is chosen as an object of study, in the corner rooms of which mold formations are observed.

Characteristics of the dormitory building: year of construction - 1975, number of floors - 9, building volume - 26,708 m³, total area - 6,335.9 m², external walls made of silicate bricks of 640 mm thick, plastered on the inside and outside with a cement-sand mortar 20 mm.

To improve the accuracy of the results, experimental facilities were located in several problem dormitory rooms located on the north-west side on different floors of the building (Fig. 7).

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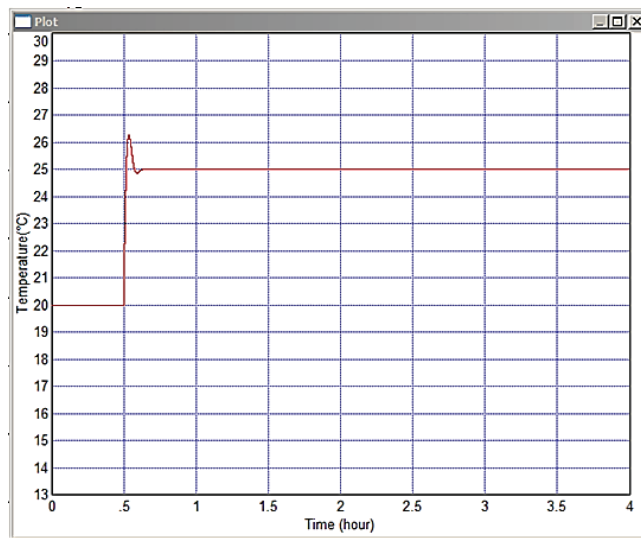


Figure 5. Transient graph of the heating of the inner layer of the wall using the PID controller.



Figure 6. Heating cable on the inner surface of the wall of one of the living rooms of the dormitory.

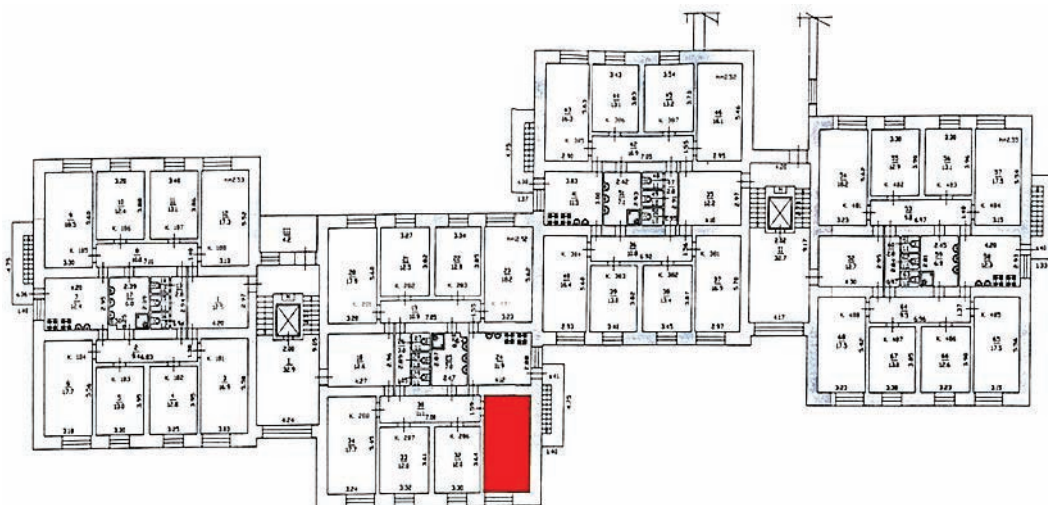


Figure 7. The location of rooms 225, 235, 245, 265 on the floor plan of a typical dormitory (indicated by color).

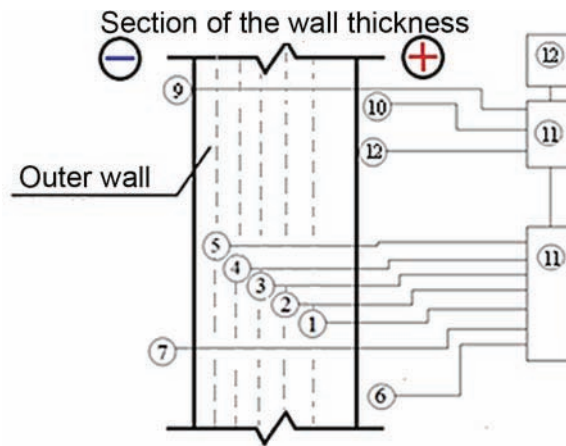


Figure 8. Diagram of the laboratory setup for determining the actual resistance to heat transfer.

The main installation with the control module is located in room number 245 on the fourth floor (Figure 8). The room has two exterior walls, one facing north, the other toward the west, and one window with a PVC profile facing north.

The data obtained from the experimental facilities allow us to track changes in temperature and humidity outside, on the surface and in the thickness of the wall enclosure.

Figure 9 shows a graph of the distribution of temperature fields on the surface and in the thickness of the wall fencing for the heating period of 2014-2015, which has 5 time intervals (I-V), when the difference between the tempera-

tures of the inside air and the inner surface of the wall fencing exceeds the required value of 4°C . The total duration of time when $\Delta t \geq 4^{\circ}\text{C}$ for the heating period 2014-2015 is 68 days, which is about 37% of the total duration of the heating period [3].

The graph (Figure 9) shows that the selected intervals I – V are characterized by a decrease in the values of the outdoor temperature, which indicates a high thermal conductivity of the wall material and a low resistance to heat transfer of the wall enclosure design.

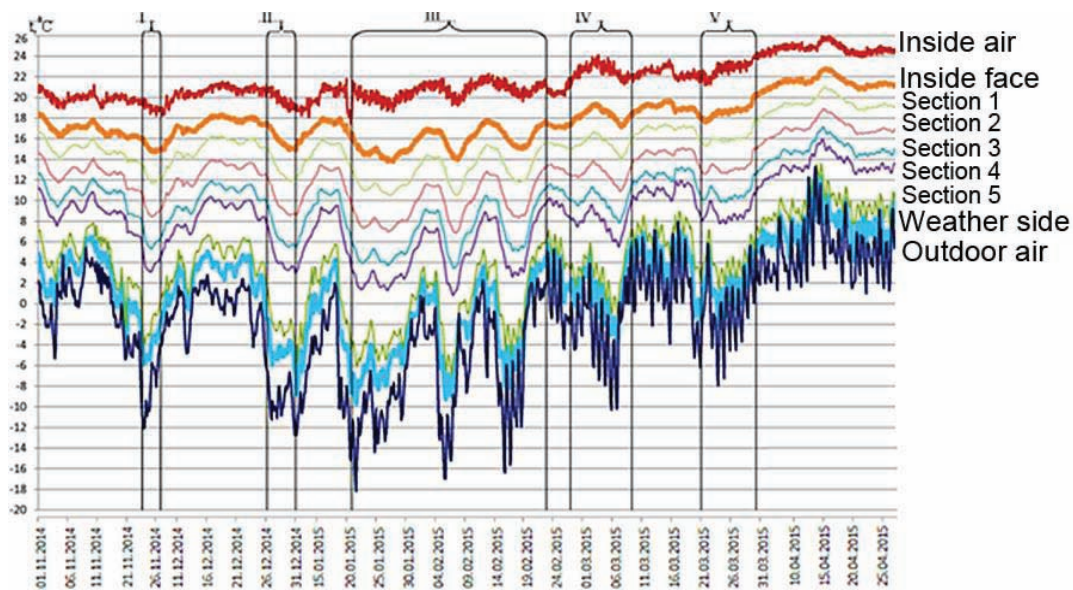


Figure 9. The graph of temperature distribution on the surface and in the thickness of the wall fencing (01.11.14-25.04.15).

Thus, it is visually shown that a low value of heat transfer resistance leads to overcooling of the wall surface in the cold period of the year and to overheating in the warm period, which leads to a person being uncomfortable in the room. The temperature distribution in the section of the wall thickness (Fig. 10) for the point in time when the outdoor temperature assumed the lowest value $t_{\min} = -19.49 \text{ }^{\circ}\text{C}$ (5:00, 01.23.2015) shows that the actual temperature values deviate from the line connecting the temperature of the outer and inner surface, which indicates the non-stationarity of heat transfer.

When analyzing the graph of changes in relative humidity in the thickness of the structure (Fig. 11), it can be seen that the values are not distributed linearly (straight from the inside to the outside of the room), which is clearly shown in Figure 12 at an arbitrary time 02.03.15.

From figures 11 and 12 it can be seen that the relative humidity takes maximum values in 4 sections - at a distance of 1/3 from the outer surface of the wall enclosure.

In one of the time intervals during the measurement period, a moment of condensate was observed on the inner surface of the wall (Fig. 13), when the values of the relative humidity of

the internal air reached values of up to 76%, and the maximum temperature of the internal air is $24 \text{ }^{\circ}\text{C}$, and does not exceed $17 \text{ }^{\circ}\text{C}$, which is lower than the dew point temperature.

Based on the above, it should be noted that the thermal state of the outer wall during the entire heating period is not constant. The thermophysical characteristics of the material of the outer wall change during the entire heating period, which confirms the need for carrying out field studies for a long time.

Analysis of the experimental data shows that the thermal state of the outer wall during the entire heating period is not constant. The thermophysical characteristics of the material of the outer wall vary throughout the heating period.

To reduce labor and time costs, it is proposed to use a computer-aided design (CAD) system for modeling and forecasting heat fluxes in the thickness of a wall fence. CAD will reduce the number of sensors used to two (on the outer and inner surfaces of the wall). In this case, intermediate values will be determined automatically, taking into account probabilistic characteristics, reflecting the deviation of the actual values of temperatures from the theoretical ones.

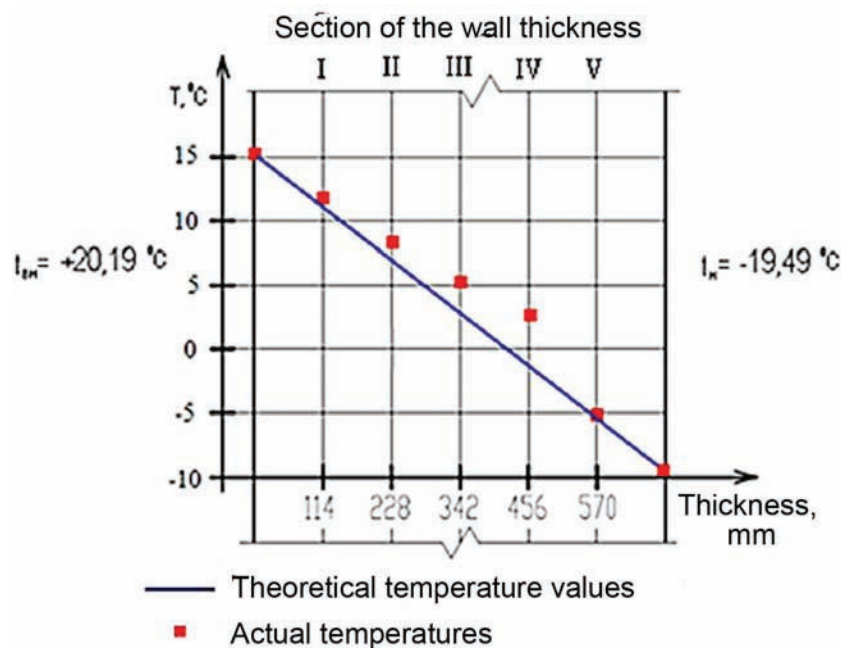


Figure 10. The distribution of temperature values in the thickness of the wall at time 5:00 01.23.2015.

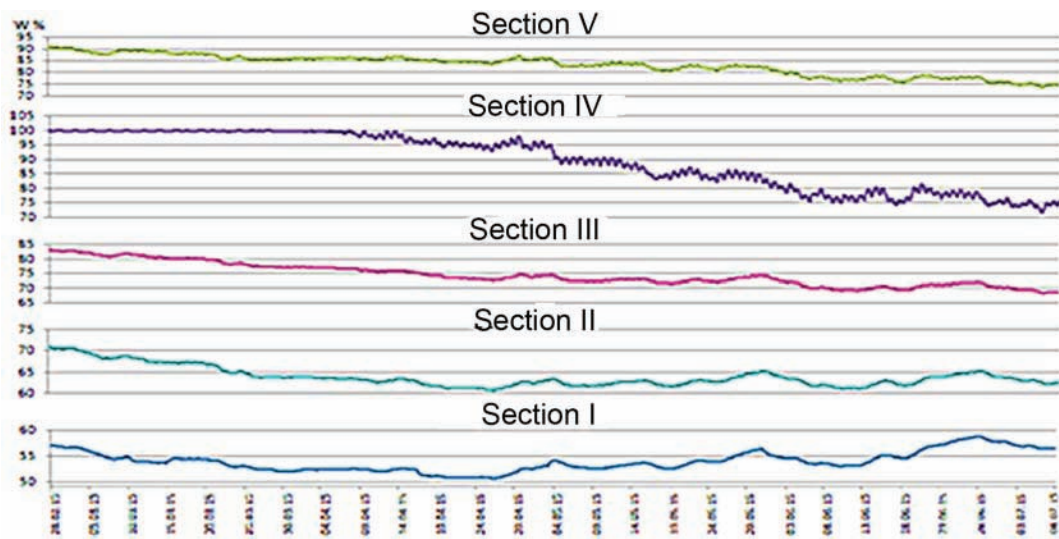


Figure 11. Distribution of the relative humidity values by section of the wall fence.

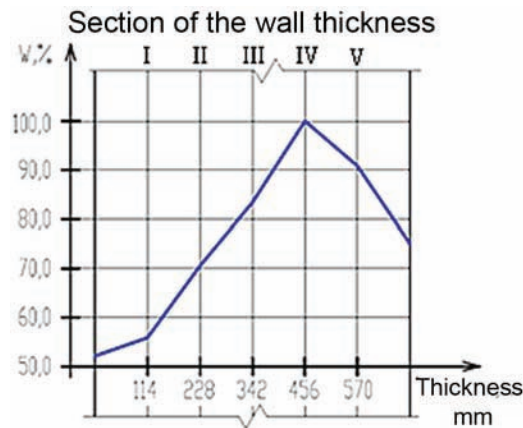


Figure 12. Distribution of values of relative humidity through the thickness of the wall enclosure 02.03.2015.

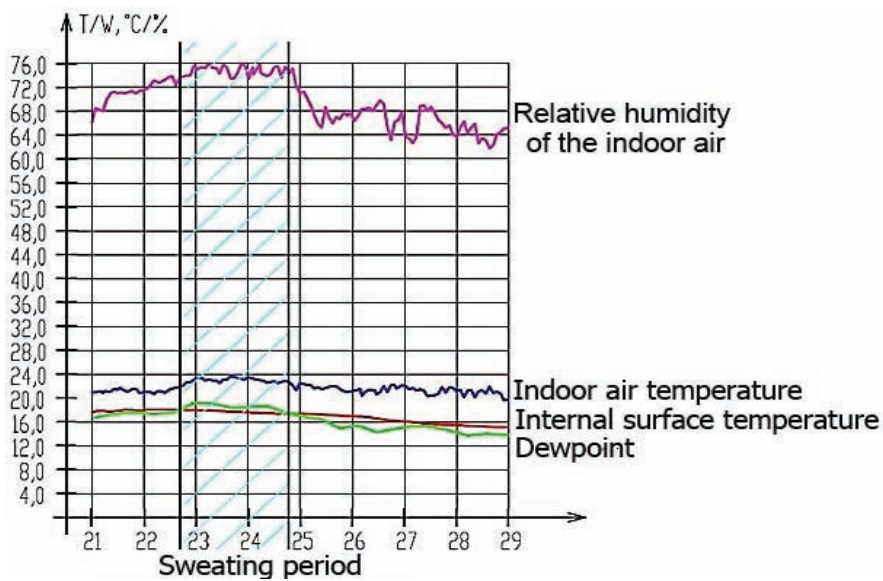


Figure 13. The time interval characterized by condensation on the inner surface of the walls.

Thus, the developed design will allow:

- 1) Prevent condensation on the inner surface of the wall;
- 2) Observe the normalized difference (≤ 4 ° C) between the temperature of the inner surface of the wall and the air temperature in the room.

In the future, it is planned to conduct similar experimental studies on wall fences made of other materials, such as concrete, wood, etc., in order to determine the previously agreed additional coefficients in determining the actual resistance to heat transfer. The need to develop an automated regulator of the heating element with the smallest possible number of unknown parameters and with a more "sensitive" mode of operation has been identified. It is also planned to link the work of the developed design with automated ATP thermal points, which will allow to avoid overheating of the premises and will contribute to energy efficiency.

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