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COMPUTER MODELING OF ENERGY-EFFICIENT JOINTS OF WOOD COMPOSITE PANELS

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Abstract: High air permeability and the presence of thermal bridges at the junctions of wooden frame wall panels have a significant impact on the thermal balance of the building and its operational characteristics. The importance of improving the energy efficiency of nodal interfaces of panels with a wooden frame is undeniable.
To date, there is no single generally accepted method for calculating heat losses through nodal interfaces of panels with a wooden frame. Based on the analysis carried out, it is necessary to carry out calculations and measurements that allow creating this calculation methodology. To carry out numerical studies, a list of characteristics and parameters affecting their conduct is formulated: the influence of the thickness of a li-ear-discrete inclusion on the heat-protective properties of the panel docking unit; the thermal conductivity characteristics of the material used to fill linear-discrete inclusions affecting the heat flux density of the node interface; consideration of the influence of the outdoor temperature of air depending on different climatic zones on the density of heat flow. The dependences of the heat flux density on the "inner" surface of the experimental samples on the thermal conductivity coefficient of the material of the insulating insert, the width of the insulating insert and the outside air temperature were revealed and the nature of the temperature distribution on the "inner" surface of the prototypes was established. By calculating two-dimensional temperature fields in the cross section of the node, isofields of temperature distribution inside the structure, isofields of heat flux density and its direction, lines of temperature distribution and heat flux density along the inner and outer surfaces are obtained. It was found that the heat flux density in the ribs with heat-insulating inclusions is lower in comparison with solid wood parts by an amount from 13% to 52%.

Keywords: thermal engineering calculation, wooden panels, nodal interfaces, thermal conductivity, energy efficiency, thermal insulation dissections, specific losses, temperature, air permeability, thermal bridge, thermophysical parameters, temperature fields

КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ ЭНЕРГОЭФФЕКТИВНЫХ СТЫКОВ ДЕРЕВОКОМПОЗИТНЫХ ПАНЕЛЕЙ

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Abstract: Высокая воздухопроницаемость и наличие тепловых мостов в местах соединений деревянных каркасных стеновых панелей оказывает значительное влияние на тепловой баланс здания и его эксплуатационные характеристики. Важность повышения энергоэффективности узловых сопряжений панелей с деревянным каркасом неоспорима. На сегодняшний день единой общепринятой методики расчета тепловых потерь через узловые сопряжения панелей с деревянным каркасом не существует. Исходя из проведенного анализа, необходимо провести расчеты и измерения, позволяющие создать данную методику расчета. Для проведения численных исследований сформулирован перечень характеристик и параметров, влияющих на их проведение: влияние толщины линейно-дискретного включения на теплозащитные свойства узла стыковки панелей; характеристики теплопроводности материала, применяемого для заполнения линейно-дискретных включений, влияющих на плотность теплового потока узлового сопряжения; учет влияния температуры наружного воздуха в зависимости

различных климатических зон на плотность теплового потока. Выявлены зависимости плотности теплового потока на «внутренней» поверхности опытных образцов от коэффициента теплопроводности материала теплоизолирующей вставки, ширины теплоизолирующей вставки и температуры наружного воздуха и установить характер распределения температуры на «внутренней» поверхности опытных образцов. Путём расчёта двухмерных температурных полей в поперечном сечении узла получены изополя распределения температуры внутри конструкции, изополя плотности теплового потока и его направленности, линии распределения температуры и плотности теплового потока по внутренней и наружной поверхностям. Установлено, что плотность теплового потока в рёбрах с теплоизолирующими включениями меньше по сравнению с цельнодеревянными деталями на величину от 13% до 52%.

Ключевые слова: теплотехнический расчет, деревянные панели, узловые сопряжения, теплопроводность, энергоэффективность, теплоизолирующие рассечки, удельные потери, температура, воздухопроницаемость, тепловой мост, теплофизические параметры, температурные поля

INTRODUCTION

Wood, as a structural material, has unsurpassed properties, being a natural renewable resource. The processability of processing, accessibility, high physical and mechanical properties, environmental friendliness make it possible to effectively use wood in various areas of the construction industry.

The issues of static modeling of heat transfer for thermal bridges of buildings are considered in [1-3], it is concluded that the proposed approach demonstrates a significant improvement over traditional modeling results. The dynamic calculation of heat fluxes considered in [4, 5] is analyzed over time to determine the step and for given boundary conditions: a sinusoidal change in internal temperature and a sharp or more realistic change in external temperature. Numerical characteristics of bridges are shown in [6], in particular, the method of infrared thermography, which is used to visualize thermal bridges, is presented for the first time, as well as a genuine additional experimental method that allows us to determine the quantitative aspects of heat loss through the shell. The authors of the article [7] model thermal bridges in three different approaches. Energy efficiency and thermal characteristics were studied in [8, 9], they proved that an accurate assessment of the availability and energy efficiency of buildings depends on the degree of use of the main components. Various methods of reducing the influence of thermal bridges are given in [10-12]. Heat transmission through the wall enclosure is considered in [13, 14] the heat transfer coefficient (U-value) of three LSF walls with different configurations is established, which is investigated on the basis of four different approaches: experimental laboratory measurements based on the thermal flowmeter method (HFM); 3D modeling by the finite element method (FEM) using the ANSYS software CFX ® ; 2D modeling based on FEM modeling using THERM software; analytical estimates based on the ISO 6946 procedure for constructing components with heterogeneous layers. The effect of connectors on the thermal characteristics of walls was considered in [15, 16], it was found that the increased distance and reduced length of connectors led to an improvement in thermal characteristics, which additionally indicated the need to study the effect of connectors on thermal characteristics. The life cycle assessment and thermal characteristics are given in [17, 18], the behavior of the wall plate during bending with various geometric parameters was experimentally investigated and a numerical model was created to study the thermal characteristics of the wall plate. Issues of improving thermal bridges in articles [19, 20], maps of temperature distribution in walls, their components and areas where walls intersect with other building structures were developed. These maps were used as an auxiliary tool for estimating the areas of zones affected by existing thermal bridges and for calculating R-values for these areas. New methods for predicting heat flows over a thermal bridge are discussed in [21, 22], studies show that existing approaches to

implementing the effect of thermal bridges do not correspond to the progress made in thermal insulation requirements, and the corresponding structure should be updated to better support efforts to achieve more rational and accurate results. Laboratory and full-scale non-destructive methods for assessing heat transmission in works [23, 24], in particular, the influence of the location of thermal insulation on its effectiveness in LSF facade walls is evaluated. For this purpose, several types of LSF walls are evaluated, namely cold, warm and hybrid construction. The influence of thermal bridges created by steel studs on the overall thermal characteristics of LSF walls is also evaluated. Calculations are performed using specialized finite element software (THERM). The prediction of heat transmission is given in [25, 26]. Evaluation of the effectiveness of thermal rupture strips in external walls is given in [27] it is proved that it is more effective to increase the thickness of thermal rupture strips (TBS) than their width. The energy characteristics of fire-resistant walls are shown in [28, 29]. A measurement method for quantifying the heat transmission coefficient is presented in [30], a new active method for determining the characteristics of a thermal bridge in situ is proposed. It generalizes the measurement of the thermal resistance of a homogeneous wall.

Numerical studies of composite structures are considered in papers [31…33]. Studies of the work of composite structures in frame wooden buildings were carried out in [34…36]. Engineering calculations of composite structures are considered in works [37…39], properties of composite materials in work 40.

Numerical studies were carried out in the Heat2D program by calculating two-dimensional temperature fields in the cross section of the node. The aim of the numerical studies was to evaluate the thermal properties of the nodal joint depending on the variable parameters. The calculations performed were preceded by a full-scale experiment and were carried out in the volume planned in the combination square.

The study was carried out in order to analyze the theoretical (calculated values) and practical (measured values) analysis of thermal bridges.

From the point of view of thermal conductivity, the paired rack formed by the joint of two panels is a linear heterogeneity of the panel material. When calculating the reduced resistance to heat transfer , it is necessary to take into account the influence of thermal bridges according to the formula:

$$R_0^{red} = \frac{1}{\frac{1}{R_0^{red}} + \sum l_j \psi_j + \sum n_k \chi_k} = \frac{1}{\sum a_i U_i + \sum l_j \psi_j + \sum n_k \chi_k} \quad (1)$$

where, R_0^{red} - is the area-averaged conditional resistance to heat transfer of a fragment of a heat–protective shell of a building or a dedicated enclosing structure, m^2 °S/W;

l_j – is the extent of linear inhomogeneity of the j-th type per 1 m^2 of a fragment of a heat-protective shell of a building, or a dedicated enclosing structure, m/m^2;

ψ_j – specific heat losses due to linear inhomogeneity of the j type, W/(m·oS);

n_k – the number of point inhomogeneities of the k- type per 1 m^2 of a fragment of the heat-shielding shell of a building, or a dedicated enclosing structure, pcs/m^2;

χ_k – specific heat losses due to point heterogeneity of the k type, W/°S;

a_i – the area of a flat structural element of the i – type, per 1 m^2 of a fragment of the heat-shielding shell of a building, or a dedicated enclosing structure, m^2/m^2.

$$a_i = \frac{A_i}{\sum A_i} \quad (2)$$

where A_i - is the area of the i-th part of the fragment, m^2;

U_i - is the heat transfer coefficient of the homogeneous i-th part of the fragment of the heat shield of the building (specific heat loss through a flat element of the i-th type), W /(m · ° C).

$$U_i = \frac{1}{R_{0,i}^{red}} \quad (3)$$

The essence of heat losses is taken into account in EN ISO 14683 "Thermal insulation of buildings" and is calculated by the linear heat transfer coefficient ψ [W/m×K] of the thermal bridge, which is obtained from the numerical determination of the two-dimensional coefficient of thermal coupling L^{2D} (i.e., the total heat flow through the component per linear meter divided by the temperature difference) of the component separating the two media under consideration. The linear thermal coupling of the frame -wall coupling coefficient ψ is obtained from the equation:

$$\psi = L^{2D} - \sum_{j=1}^{j} U_j \cdot I_j, \quad (4)$$

where L^{2D} - is the two-dimensional coefficient of thermal coupling, W/(m*K);
U_j- is the heat transfer coefficient of a one-dimensional element j, W/(m^2*K);
I_j - is the length of a one-dimensional element j, m.
When calculating the energy balance, thermal bridges can be considered standard. Buildings with high thermal protection, taking into account an increase in the heat transfer coefficient by 5%. Buildings with low thermal protection are a 10% increase in the heat transfer coefficient. If we want to calculate the energy demand for heating a building with almost zero energy consumption, it is necessary to specify each cold bridge.
Based on the review of regulatory documentation, it can be concluded that there is no method for calculating energy-efficient nodal interfaces of panels with a wooden frame. In this regard, the development of a method for calculating energy-efficient node interfaces of panels with a wooden frame is relevant.
The purpose of the work is to identify the calculated dependences of the heat flux density and to establish the nature of the temperature distribution on the inner and outer surfaces of the joint of wall panels, depending on variable factors: the thermal conductivity coefficient of the material of the insulating insert, the width of the insulating insert and the outdoor temperature.
The object of the study is the joints of the interface of wall wooden panels.
The subject of the study is the calculation of the energy parameters of the joints of wall panels.

METHODS

The Heat2D program uses a kind of finite-difference method - the control volume method to obtain a discrete analog of a stationary two-dimensional thermal conductivity problem. In this method, the calculated area is represented by the union of disjoint control volumes, each of which contains one nodal (calculated) point. To obtain a discrete analog, the differential equation of thermal conductivity is integrated for each control volume.
The resulting system of linear algebraic equations is solved by the method of exclusion of unknowns (Gauss method). Let's consider the main components of the method.
The process of two - dimensional heat transfer in a solid is described by the differential equation:

$$(\partial^2 t/\partial x^2 + \partial^2 t/\partial y^2) = Q \quad (5)$$

where Q is the source/heat drain, W/m^3.
The studied area of the two-dimensional section of the structure is divided into elementary platforms - rectangles so that each rectangle consists of one material. The center of each rectangle is taken as a node of the thermal grid. Thus, each grid node is surrounded by four neighboring ones, with which it is connected by thermal resistances equal to the resistances between the centers of the corresponding rectangles. The temperature at each node is the average temperature of an elementary rectangle.
So, in general terms, the area under study is replaced by its discrete analog, called a thermal grid, each node of which corresponds to a certain rectangle, and the thermal resistance to the interstitial connection.
Each node must maintain a balance of heat (energy), which is expressed by the

corresponding algebraic equation linking the heat flows coming into and out of the node. This equation can be obtained by integrating (5) over an elementary rectangle. As a result , we obtain the equation:

$$t_0(K_{01} + K_{02} + K_{03} + K_{04}) - t_1K_{01} - t_2K_{02} - t_3K_{03} - t_4K_{04} = q\Delta x\Delta y \quad (6)$$

Heat2D program, a system of linear algebraic equations is solved by an economical method of eliminating unknowns (the Gauss method) using a matrix system of equations with double precision inside the machine representation of numbers.

When calculating an axisymmetric temperature field, which is characterized by the fact that the temperature field does not change when the area under study is rotated around the vertical axis of symmetry OZ, the following differential equation is solved:

$$(\lambda/r)\ \partial(r\,\partial t/\partial r)/\partial r + \lambda\,\partial^2 t/\partial z^2 = 0 \quad (7)$$

where r is the distance from the axis of symmetry OZ.

So, if the axis of symmetry is to the left of a rectangle with a central node 0, then the resistance between points 1 and 0 can be expressed as follows:

$$R_{1-0} = (\ln(r/r1) + \ln(r_0/r))/(\lambda\Delta y) \quad (8)$$

where r_0, r_1 и $r = r_0 + \Delta x/2$ are the distances of the corresponding points to the axis of symmetry.

The scheme of finite-difference sampling of the node connection is shown in Figure 1.

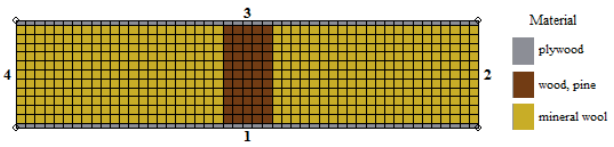


Figure 1. Scheme of finite-difference sampling of a node connection

where $K_{01}, K_{02}, K_{03}, K_{04}$ - are the conductivities of the interstitial connections of the grid.

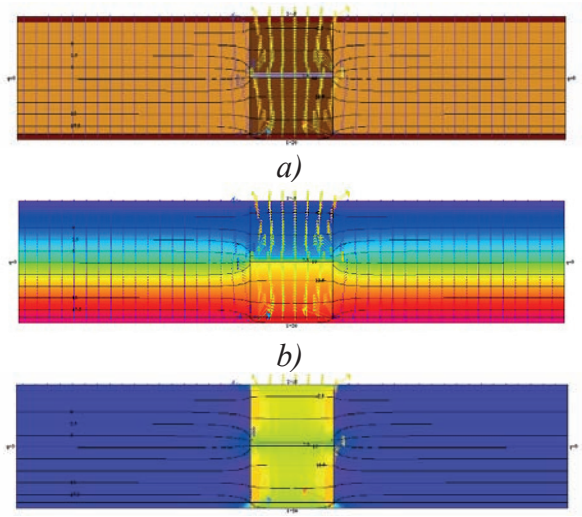
In equation (6), the temperature t_0 of the central node is expressed in terms of the temperatures of neighboring nodes, whose values (if they are not located on the border) are also unknown. To find the temperature at any node, it is necessary to make equations of type (6) for each node and solve the resulting system of equations. In the

When implementing the numerical calculation, 12 types of wall panel joints were investigated [31-34]. The first letter of the marking is the type of joint (D – solid wood joint, T - joint with heat-insulating inclusion); the second digit is the value of negative outdoor temperature (-5, -20, -35 ° C); the third letter is the filling of the heat-insulating insert (V – air; E – extruded polystyrene foam; P – penofol); the last the figure is the width of the thermal insulation insert (5, 15 or 25 mm). An example of decoding the T-35-E-5 joint is a joint with a heat-insulating inclusion; the value of the negative outdoor temperature is 35 ° C; the filling of the thermal insulation insert is E – extruded polystyrene foam; the width of the thermal insulation insert is 5 mm.

RESULTS AND DISCUSSION

According to the results of calculations of thermal fields in the Heat2D program, isofields of temperature distribution inside the structure, isofields of heat flux density and its direction, lines of temperature distribution and heat flux density along the "inner" surface are obtained. The program also calculated the value of specific heat loss through linear thermal heterogeneity (wooden joint ribs), which directly takes into account heat loss in the junction when calculating the reduced heat transfer resistance.

As an example, the results of calculations of the joint of the T-35-E-5 panel in the software package are given. Figure 2 shows a finite element model of the junction of panels and an isofield of temperature distribution and heat flow. Figure 3 shows graphs of temperature and heat flow distribution, and Figure 4 shows 3-D graphs of their distribution.

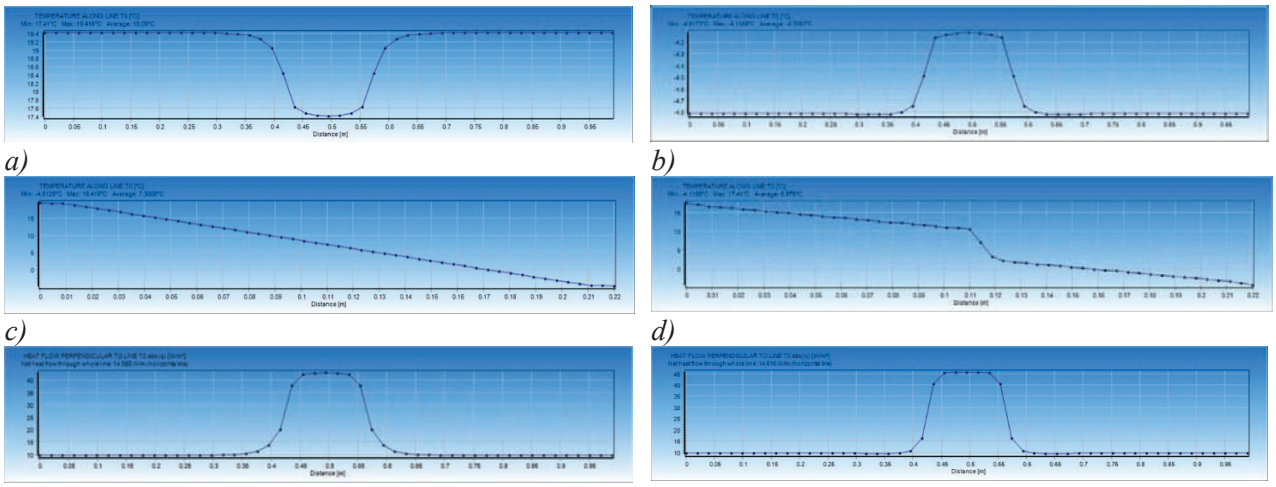


a)

b)

c)

Figure 2. Results of calculation of panel joints in the software package: a) finite element model of panel junction; b) isolines of temperature distribution over the section of the structure; c) isolines of heat flow distribution over the section of the structure

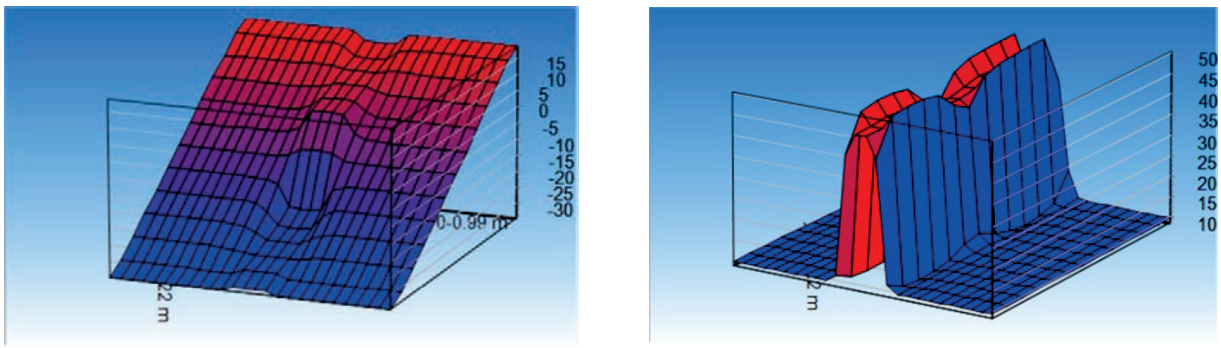


a) *b)*

c) *d)*

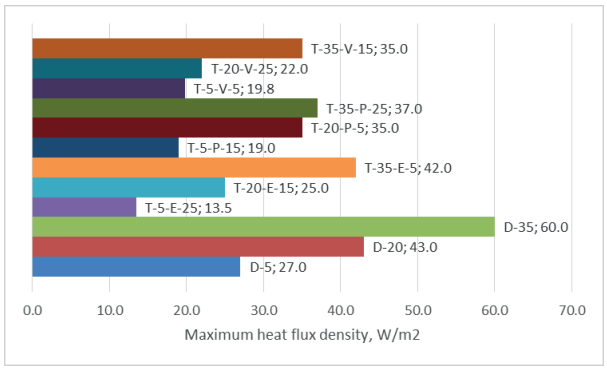
f) *g)*

Figure 3. Distribution charts: a), b) temperatures on the inner surface on the outer surface of the structure; c), d) by the cross section of the panels and by the cross section of the panels in the docking node; f), g) heat flow on the inner surface on the outer surface of the structure

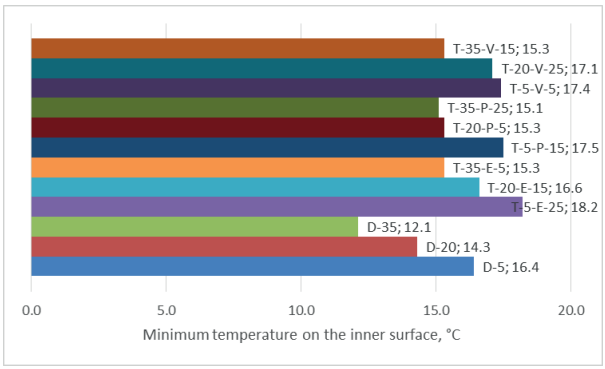


a) *b)*

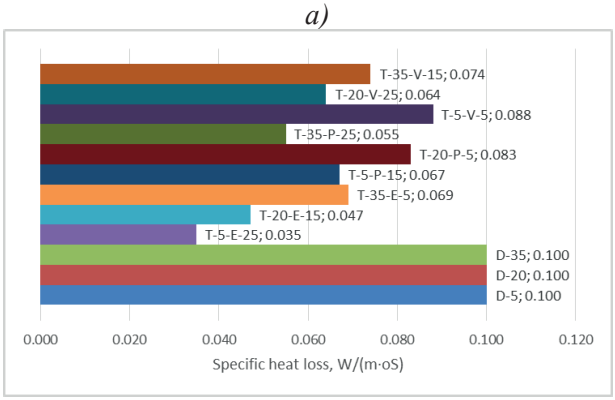
Figure 4. 3-D distribution graphs on the inner surface of the structure: a) temperatures; b) heat flow



a)



b)



c)

Figure 5. Results of numerical research: a) Maximum heat flux density, W/m²; b) Minimum temperature on the inner surface, °C; c) Specific heat loss, W/(m·oS)

The shape of the graphs of the distribution of heat flux density and temperature along the inner face of the junction is the same for all variable parameters and differs only in peak values. The results of the numerical study are shown in the histograms of Figure 5.

Numerical values of the heat flux density, as well as the temperature on the inner surface of the enclosing structure for various combinations of variable parameters are given in Table 1 and 2, respectively.

Table 1. Heat flux density values for various combinations of variable parameters

Thermal conductivity coefficient of the material, W/(m*^{0}C)		Expanded polystyrene			Penofol			Air			Without insertion
Insert thickness, mm		5	15	25	5	15	25	5	15	25	
Outdoor temperature, ^{0}C	-5	19.5	16.0	13.5	22.0	19.0	17.0	19.8	16.1	13.6	27.0
	-20	31.0	25.0	22.0	35.0	31.0	27.0	32.0	25.5	22.0	43.0
	-35	42.0	34.0	29.5	49.5	42.0	37.0	44.0	35.1	30.0	60.0

Table 2. Temperature values on the inner surface of the structure for various combinations of variable parameters

Thermal conductivity coefficient of the material, W/(m*^{0}C)		Expanded polystyrene			Penofol			Air			Without insertion
Insert thickness, mm		5	15	25	5	15	25	5	15	25	
Outdoor temperature, ^{0}C	-5	17.4	17.9	18.2	17.1	17.5	17.8	17.4	18.1	18.2	16.4
	-20	15.7	16.6	17.1	15.3	16.0	16.4	15.8	16.6	17.1	14.3
	-35	15.3	15.4	16.1	13.2	14.4	15.1	14.3	15.3	16.1	12.1

CONCLUSIONS

Thus, based on the results of numerical studies of the energy efficiency of the joints of wall panels with a wooden frame, the following conclusions can be drawn:

1. Numerical calculations of the effect of dissections on the work of the nodal racks of wooden panels are carried out. The possibility of their use in node connection racks has been determined.
2. The dependences of the density of the heat flow passing through the linear thermal heterogeneity on the type of insulation used in the dissection, the width of the dissection and the outdoor temperature are determined.
3. By calculating two-dimensional temperature fields in the cross section of the node, isofields of temperature distribution inside the structure, isofields of heat flux density and its direction, lines of temperature distribution and heat flux density along the inner and outer surfaces are obtained.
4. The value of specific heat loss through linear thermal heterogeneity (wooden joint ribs) is calculated, which directly takes into account heat loss in the junction when calculating the reduced heat transfer resistance.
5. It was found that the heat flux density in the ribs with heat-insulating inclusions is less in comparison with solid wood parts by an amount from 13% to 52%.

GRATITUDE

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