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ИССЛЕДОВАНИЕ ТЕПЛОВОЙ ЭФФЕКТИВНОСТИ ОГРАЖДАЮЩИХ КОНСТРУКЦИЙ ИЗ ДРЕВЕСНО-ЦЕМЕНТНЫХ КОМПОЗИТОВ

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Задача сокращения энергопотребления и затрат на эксплуатацию зданий и сооружений является предпосылкой для разработки энергосберегающих технологий и материалов. Повышение энергоэффективности достигается при уменьшении потерь тепла через ограждающие конструкции. Технология производства древесно-цементных композиционных материалов имеет большое значение с инженерной точки зрения, а также как технология утилизации древесных отходов, имеющая экологическую привлекательность. В ходе исследований определялись удельные потери тепла через ограждающую конструкцию и термическое сопротивление ограждающей конструкции из древесно-цементного композита в виде опилкобетона и арболита, а также влияние на показатели тепловой эффективности наличия в массиве стены изолированных воздушных полостей и включений из экструзионного пенополистирола. Исследование проводилось с применением программного пакета Elcut. Полученные величины удельных потерь теплоты расчетной конструкции составляют от 19,5 до 51 Вт/(м^2 ·°С), величина сопротивления теплопередаче ограждающей конструкции 1,07 до 2,9 (м^2 ·°С)/Вт показатели зависят от условий эксплуатации и варианта исполнения (цельное тело конструкции, воздушные полости либо вставки из экструзионного пенополистирола). Полученные результаты могут быть использованы при проектировании и эксплуатации строительных конструкций.

Ключевые слова: *древесно-цементная композиция, арболит, опилкобетон, удельные потери теплоты, сопротивление теплопередаче, эксперимент, тепловая эффективность.*

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RESEARCH OF THERMAL EFFICIENCY OF ENVELOPE STRUCTURES FROM WOOD-CEMENT COMPOSITES

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The task of reducing energy consumption and operating costs of buildings and structures is a prerequisite for the development of energy-saving technologies and materials. Increased energy efficiency is achieved by reducing heat loss through envelope structures. The technology for the production of wood-cement composite materials is of great importance from an engineering point of view, as well as a technology for the disposal of wood waste, which has environmental attractiveness. In the course of the research, the specific heat losses through the envelope structure and the thermal resistance of the envelope structure made of wood-cement composite in the form of sawdust concrete and arbolite were determined, as well as the influence on the thermal efficiency of the presence of isolated air cavities and inclusions from extruded polystyrene foam in the wall massif. The study was carried out using the Elcut software package. The obtained values of the specific heat losses of the design structure are from 19.5 to 51 W / (m^2 · ° C), the value of the heat transfer resistance of the envelope structure is 1.07 to 2.9 (m^2 · ° C) / W, the indicators depend on the operating conditions and version (one-piece body of the structure, air cavities or inserts from extruded polystyrene foam). The results obtained can be used in the design and operation of building structures.

Keywords: *wood-cement composition, wood concrete, sawdust concrete, specific heat loss, resistance to heat transfer, experiment, thermal efficiency.*

INTRODUCTION

Industrial and civil construction consumes significant amounts of building structural and thermal insulation materials. The growing cost of energy carriers acutely raises the issue of reducing energy consumption for heating of residential and industrial buildings. Rational energy consumption is achieved through the use of modern materials and implementation of highly efficient structural solutions at the stage of design, construction and subsequent operation of buildings and structures [1; 2]. In the conditions of sharply continental climate of Eastern Siberia with extremely low temperatures in winter, the walls of buildings and structures should ensure heat preservation in the building, and in summer time – to insulate rooms from penetration of high temperatures. Providing high thermal insulation values of external walls increases the temperature of their inner surface. This improves the sanitary condition of the object, improves the microclimate. When the indoor temperature is +20 °C, the temperature of the wall surface should be at least +19 °C, and in the corners of the exterior walls – 14–15 °C, so even if the air humidity increases, no condensation will form on the walls. In addition to increasing the comfort of the object and improving its microclimate, there is a real economic efficiency from reducing the cost of electricity and heat required for heating construction objects [3].

The aim of the research is to determine the thermal resistance of the envelope structure made of wood-cement composite (WCC)

To achieve the goal the following tasks should be solved:

– to analyze the methods of determining the thermal resistance of the envelope from wood-cement composite (WCC);

– to determine by methods of simulation modeling the thermal resistance of the envelope of WCC;

– to study the influence of air cavities in the body of the building envelope on the thermal resistance indicators

MATERIALS AND METHODS RESEARCH

The reduced resistance to heat transfer of the external building envelope is the main heat-protective characteristic of the external envelope, the calculation of which is based on the area-averaged density of the heat flux passing through the envelope in the design conditions of operation.

Considering the performance indicators of thermal insulation of walls made of different materials should be based on the requirements of certain regulatory documents. Determination of thermal conductivity of materials is carried out in accordance with GOST 7076–99 [4]. The essence of the method is to create a stationary heat flux passing through a flat sample of a certain thickness and directed perpendicular to the front (largest) edges of the sample, measuring the density of this heat flux and the temperature of the opposite face edges.

Determination of heat transfer resistance of envelope structures is performed according to GOST R 54853–2011 [5]. The standard normalizes the method of determining the heat transfer resistance on the basis of creating conditions of stationary heat exchange in the envelope and measuring the temperatures of indoor and outdoor air, the temperature of the surfaces of the envelope, as well as the density of the heat flux passing through it.

These methods have certain inconveniences and limitations, such as the need for an expensive heat chamber, the duration of the observation process, the need to install and mount the structure, block or masonry to be tested, the difficulty of obtaining a steady-state heat flux in real conditions, influence of local inhomogeneities, limited number of measuring sensors.

To determine the thermal efficiency indicators in the research process, the Elcut software product was used, the principle of which is based on the finite element method.

The object of the study was to determine the thermal efficiency of the envelope structure of two variants of wood-cement composites. The first variant was sawdust concrete, the second – arbolite, made on the basis of wood chips – crushed wood. Calculation of the reduced resistance to heat transfer is based on the representation of a fragment of the thermal envelope as a set of independent elements, each of which affects the heat losses through the fragment. Specific heat losses due to each element are based on a comparison of the heat flow through the node containing the element and through the same node without the element under study.

The normative document [6] describes a method of determining the reduced heat transfer resistance of the building envelope based on the calculation of temperature fields using computer programs.

Calculation of specific heat losses through the elements of the envelope contains the following parts:

– element scheme;

– temperature field;

– outdoor and indoor air temperatures assumed in the calculation of the temperature field;

– minimum temperature of the internal surface of the structure and heat flow through the node.

The heat transfer coefficient of the homogeneous *i*-th part of the fragment of the building envelope (specific heat loss through the *i*-th flat element), *Ui*, is determined by the formula

$$U_i = \frac{1}{R_i^{\text{усл}}}, \quad \text{Вт}/\left(\text{м}^2 \cdot C^0\right), \tag{1}$$

where $R_i^{\text{усл}}$ is the conditional resistance to heat transfer of the *i*-th element, $(\text{m}^2 \cdot {}^\circ\text{C}) / \text{W}$. It is determined by the formula

$$R_i^{\text{усл}} = \frac{1}{\alpha_{si}} + \sum R_s + \frac{1}{\alpha_{se}}, \ \left(\text{м}^2 \cdot C^0\right)/\text{Вт}, \tag{2}$$

where *Rs* is the thermal resistance of the homogeneous part of the fragment, $(\text{m}^2 \cdot {}^\circ\text{C}) / \text{W}$; α_{si} is the heat transfer coefficient of the inner surface of the envelope, $\text{W} / (\text{m}^2 \cdot {}^\circ\text{C})$; α_{se} is the heat transfer coefficient of the outer surface of the envelope, $\text{W}/(\text{m}^2 \cdot {}^\circ\text{C})$,

$$R_s = \frac{\delta_s}{\lambda_s}, \tag{3}$$

where λ_s is the heat conductivity coefficient of the material, $\text{W}/(\text{m}^2 \cdot {}^\circ\text{C})$; δ_s is the thickness of the material layer, m.

Then it is necessary to check the fulfillment of the condition

$$R_s \geq R_{\text{норм}}, \tag{4}$$

where $R_{\text{норм}}$ is the standardized value of the reduced heat transfer resistance of the envelope, $(\text{m}^2 \cdot {}^\circ\text{C}) / \text{W}$.

To determine the thermal protection indicators, a thermal calculation was performed according to the requirements of SP 50.13330.2012. The value of the reduced resistance to heat transfer was estimated. The envelope structure made of WCC was modeled in the Elcut system. Then the structure was divided into a finite element mesh and the steady-state heat flow through the envelope was calculated.

The program determined the heat flow through a certain cross-section using thermal fields [7]. Mathematical modeling of the envelope and its thermal regime was based on certain boundary conditions, which were:

– Indoor air temperature with walls made of WCC according to GOST 30494-2011, t_{int} = 20 °C [8].

– Outdoor air temperature according to SP 50.13330.2012, t_{ext} = –35 °C [6].

– Heat transfer coefficient of the wall surface (internal) according to SP 50.13330.2012, α_{si} = 8.7 W/(m^2·°C) [6].

– Heat transfer coefficient of the wall surface (external) according to SP 50.13330.2012, α_{se} = 23 W/(m^2·°C) [6].

The object of modeling was a fragment of the envelope structure, the dimensions of which are shown in Fig. 1. The heat flow was directed normal to the surface and crossed a 40 cm thick layer of material.

In the first variant it is a full-body construction. Wood-cement composite in two variants (sawdust concrete and arbolite) was taken as a design material. Indicators of density, thermal conductivity of materials determined in the course of previous works are presented in Table 1. Operating conditions of envelope structures for the Krasnoyarsk region can be taken as A or B depending on the humidity regime of the rooms and moisture zones of the construction area.

The thermal resistance of the insulated air layer with dimensions of 10×30 cm can be assumed to be R = 0.16 m^2 ºC/W. The calculated coefficient of thermal conductivity is 0.26 W/(m ºC) [9]. In the second variant, insulated air cavities of a certain size are made in the body of the structure. In the third variant these cavities are filled with an effective heat insulator (extrusion polystyrene foam), R = 0,033 m^2 ºC/W [10]. The thermal conductivity values of wood-cement composites have been determined previously [11].

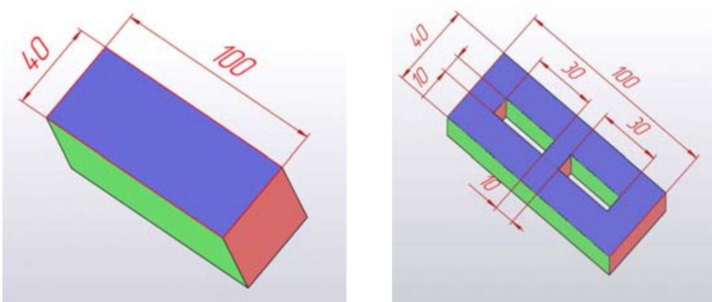

Fig. 1. Geometric dimensions of the wood-cement composite envelope structure

Table 1
Thermal conductivity coefficient

Material	Density kg/m^3	Thermal conductivity coefficient W/(m ºC)		
		In dry condition	Operating conditions	
			A	B
WCC sawdust concrete	880	0,25	0,41	0,63
WCC arbolite	670	0,18	0,33	0,53
Extrusion polystyrene foam	40	–	0,033	–

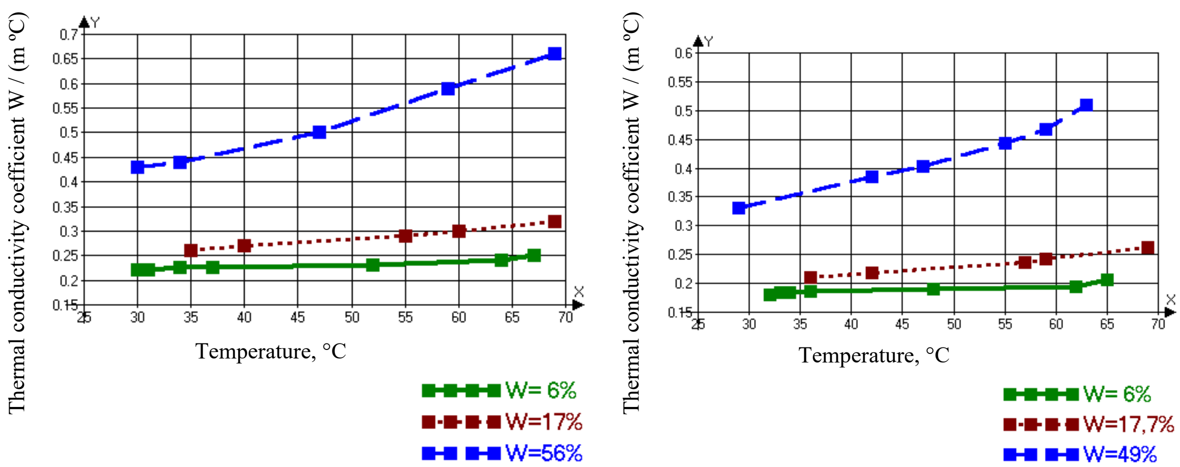

Fig. 2. Value of thermal conductivity coefficient of WCC (sawdust concrete on the left, arbolite on the right)

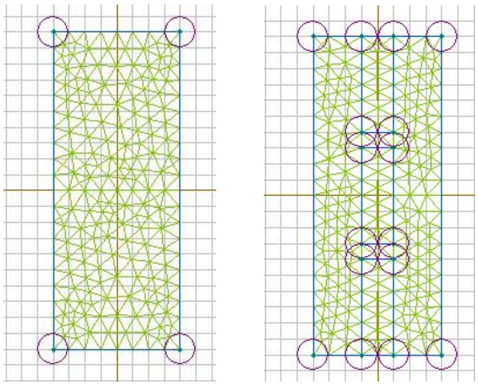

Fig. 3. Base reference points and nodes, finite element mesh partitioning of the design body in the Elcut program

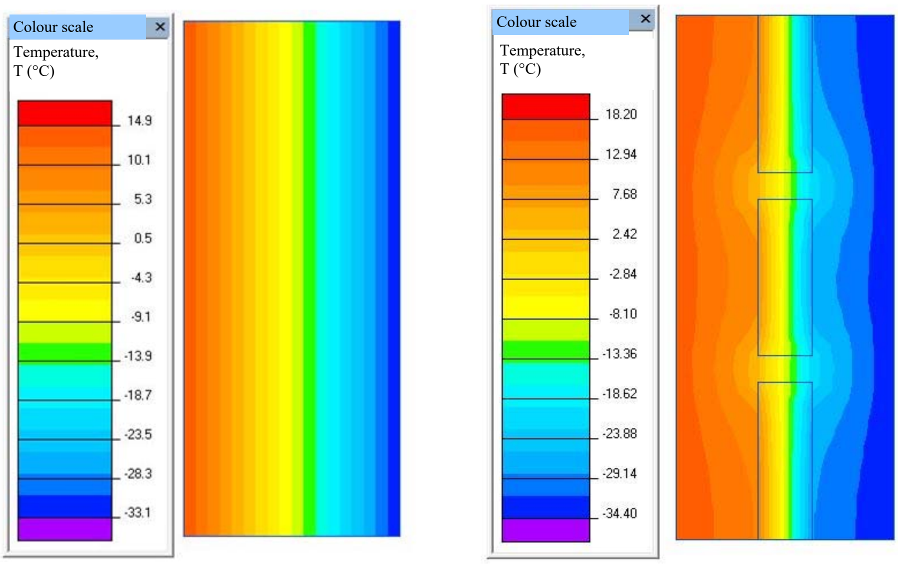

Fig. 4. Thermal fields and temperatures of the design body in the Elcut program
(solid WCC body on the left, filled cavities with extrusion polystyrene foam on the right)

RESULTS AND DISCUSSION

Table 2 shows the calculations of specific heat losses and the obtained values of heat transfer resistance for different operating modes of the structure.

The obtained values of specific heat losses of the design structure are from 19.5 to 51 W / (m^2 · °C), the value of heat transfer resistance of the envelope structure is 1.07 to 2.9 (m^2 · °C) / W, the values depend on the operating conditions and the version of execution (solid body of the structure, air cavities or inserts from XPS foam).

The normative value of heat transfer resistance of the envelope for the climatic conditions of Krasnoyarsk according to the requirements [6] is R = 3.6 (m^2 · °C) / W. Thus, it turns out that even the wall of wood-cement composite in the form of arbolite with a density of 670 kg/m^3 400 mm thick with inserts of extruded polystyrene foam, which has in the most favorable conditions (dry state) R = 2.9 (m^2 · °C) / W, does not meet the requirements of the normative document. That is, to meet the existing regulatory requirements requires a multi-layer construction with high-performance insulation. The real experience of individual builders shows a somewhat different picture. Usually, the thickness of the building envelope is assumed to be equal to double the cross-section of the most common masonry block with the size of 0.4×0.2×0.2 m. In the best case we have a massive wall with a thickness of 40 cm. The experience of living and the value of heating costs of houses with walls made of wood-cement composite, even in the absence of thermo-efficient inserts or insulated air cavities in the wall construction, shows that such a construction has the right to exist and heating costs do not exceed critical values [12; 13].

High thermal efficiency indicators (with an energy saving coefficient value of 3 or more) inevitably require comprehensive justification because of the need to use expensive effective thermal insulation of sufficient thickness. In this case, it is important to fulfill the condition according to which the service life of effective insulation materials will exceed their payback period. Consequently, there are prerequisites to consider the normative values of thermal efficiency coefficients somewhat overestimated, which is in good agreement with the research data [14].

CONCLUSION

1. Methods of determining the thermal resistance of the envelope structure from wood-cement composite, provided by the requirements of GOST 7076–99, GOST R 54853–2011 are very labor-intensive and have significant drawbacks.

2. Modern methods of simulation modeling and finite element method allows us to analytically determine the

thermal resistance values of the envelope structure made of wood-cement composite. The obtained values of specific heat losses of the design structure are: (for average operating conditions) 36.3 W / (m^2 · °C) for WCC arbolite, 44.37 W / (m^2 · °C) for WCC sawdust concrete, the value of resistance to heat transfer of the envelope structure for WCC arbolite is 1.52 (m^2 · °C) / W, for WCC sawdust concrete it is 1.25 (m^2 · °C) / W.

3. When placing in the body of the building envelope insulated air cavities indicators of thermal resistance of the building envelope increases: (for average operating conditions) 34.1 W / (m^2 · ° C) for WCC arbolite, 38.8 W / (m^2 · °C) for WCC sawdust concrete, the value of heat transfer resistance of the building envelope for WCC arbolite is 1.61 (m^2 · °C) / W, for WCC sawdust concrete it is 1.41 (m^2 · °C) / W. Under the condition of replacing the volume of these cavities with high-performance thermal insulator in the form of extrusion polystyrene foam thermal resistance indicators increase significantly to the levels of 19.5 W / (m^2 · °C) for WCC arbolite, 20.35 W / (m^2 · °C) for WCC sawdust concrete, the value of heat transfer resistance of the building envelope in this case for WCC arbolite is 2.82 (m^2 · °C)/W, 2.7 (m^2 · °C) / W for WCC sawdust concrete.

The increase in the thermal efficiency of the structure with the introduction of XPS foam inserts into its array is: for arbolite 167 %, for sawdust concrete 192 %. Wall structures made of sawdust concrete, which has a higher density than arbolite, it is advisable to equip with inserts made of highly efficient thermal insulation material – extrusion polystyrene foam.

Table 2
Calculation results

Type of wood-cement composite	Density kg/m^3	Specific heat losses Q, W / (m^2 · °C)			Calculated value of the heat transfer resistance of the envelope structure R, (m^2 ·°C) / W		
		In dry condition	Operating conditions		In dry condition	Operating conditions	
			A	B		A	Б
Sawdust concrete	880	42,1	44,37	51,3	1,31	1,25	1,07
Sawdust concrete with air cavities		36,4	38,8	43,25	1,52	1,41	1,27
Sawdust concrete with XPS foam inserts		20,21	20,35	22,4	2,72	2,7	2,45
Arbolite	670	34,23	36,3	38,8	1,61	1,52	1,41
Arbolite with air cavities		31,12	34,1	39,6	1,77	1,61	1,37
Arbolite with XPS foam inserts		18,67	19,5	20,1	2,9	2,82	2,73

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