Thermal efficient panels on a wooden frame for quickly erectable low-rise buildings

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Abstract. The aim of this study is to improve characteristics of thermal efficient panels on a wooden frame with a polystyrene cement insulation for construction of quickly erectable low-rise residential buildings. The construction of quickly erectable low-rise residential buildings erected after the earthquake in Altai, Kosh-Agach village (Russia), is considered. They were built with the use of wall panels on a wooden frame with an effective polystyrene cement insulation. After 15 years of operation, on the basis of defects revealed during the inspection of a residential building, enclosing structures are calculated using the ELCUT 6.3 software, and the floor panels are calculated using the SCAD OFFICE software.

1 Introduction

Natural disasters set the tasks for world and Russian science for quick recovery of damage caused by natural phenomena: fires, earthquakes, tsunamis, floods, landslides and others. In construction, new types of building construction are becoming more and more widespread, including quickly erectable buildings and constructions made of various lightweight materials and structures [1].

Reduction of mass and cost of buildings can be achieved by using effective insulation in cladding, lighter and stronger structural materials, using advanced technological processes in the production of lightweight cladding (Nagruzova L., Laukaitis A.) [2,3].

A characteristic feature of the development of the material and technical base of housing construction is a significant expansion of the use of new types of lightweight structures with effective insulants. The massive introduction of these structures is acquiring an important national economic significance and can give the country a tangible economic effect. Domestic and foreign construction experience convincingly shows the feasibility of using lightweight cladding instead of reinforced concrete walls with lightweight porous aggregates. The weight of a brick house, related to the plan area, is 2.0 t/m^2; panel house - 1.5 t/m^2 in our country, and abroad - 1.0 t/m^2. In some cases, the weight of insulated lightweight wall panels with effective insulation does not exceed 10-12 kg/m, which is 20-25 times lighter than walls made of reinforced concrete on lightweight aggregates.

One of the most important ways to save fuel and energy resources is the reduction of heat loss through the cladding of both operating and erecting buildings and constructions.

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Solving the problem of saving energy resources by improving thermal protection of buildings and construction, developed countries take into account energy costs to obtain this heat insulating structure.

The use of highly efficient heat insulating materials allows not only creating cladding structures that meet the modern requirements of architecture and construction but also reducing operating costs of a building due to reduction of heat loss through cladding in the winter time or reduction of overheating of rooms in the summer time (Nagruzova L.) [2].

Many distinguished domestic and foreign scientists took part in the development and improvement of lightweight cladding, in the studies of technological processes, in the development of technological equipment, studying of bearing capacity of lightweight cladding and fundamental provisions of fire resistance and fire safety. Among them: G.S. Abashidze, A.A. Afanasev, A.Yu. Glazunov, A.B. Gubenko, A.N. Dmitriev, L.M. Kovalchuk, V.I. Zhdanov, A.M. Mushinsky, R.M. Muksinov, D.A. Ukrainchenko, S.A. Sychev, A.S. Chernykh, Rug W., Monsk W., Carroll K., Lockhart C. [1-12].

2 Materials and Methods

Nowadays, the panel technology is widely used in the modern low-rise construction, which ensures the quality and speed of erecting building and constructions. L. Nagruzova [2] developed a modular panel that combines the bearing and enclosing functions, which is important for quickly erectable housing.

Constructive and technological solution for wall and bearing panels on a wooden frame with a polystyrene cement insulation, mounted in accordance with a wall system with a plywood sheathing, is developed.

The nomenclature of modular panels of a low-rise residential building is diverse, includes panels with window and door openings (Fig. 1).

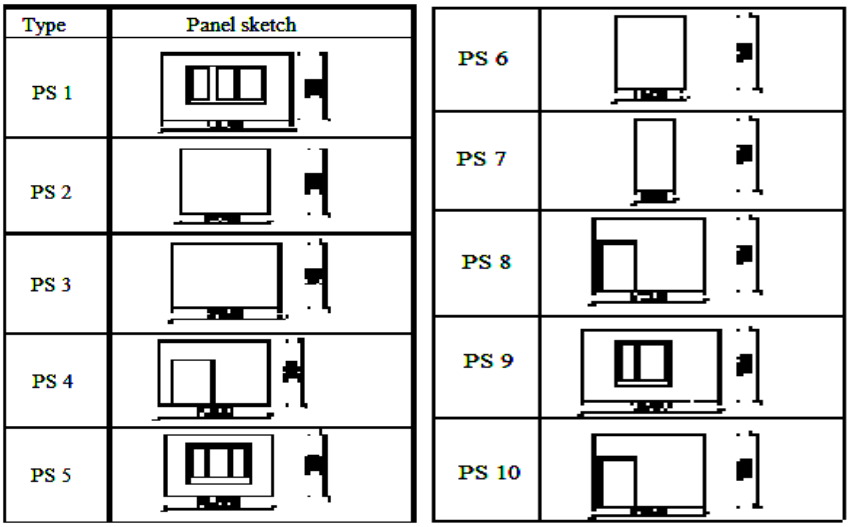


Fig. 1. Modular system of wood frame panels with polystyrene cement insulation for quickly erectable houses.

Wooden panel structures with sheathing rigidly connected to the ribs, for example, with glue, and thus involved in the overall operation of the panel, are a spatial system formed by a thin plate supported by longitudinal and transverse ribs (Figure 2).

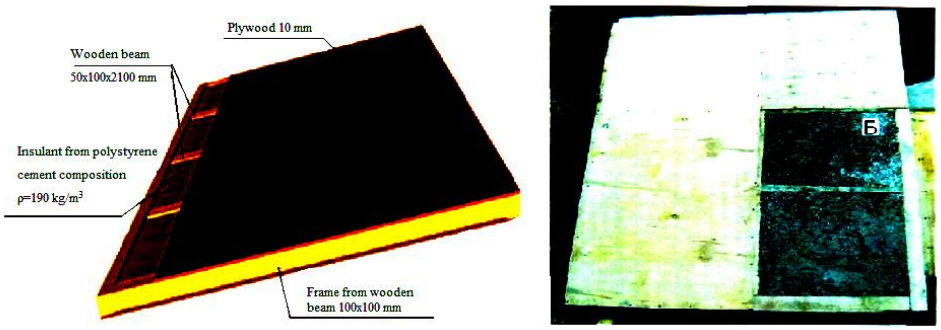


Fig. 2. Panel on a wooden frame with a polystyrene cement composition: a) model of a panel on a wooden frame with dimensions 2300x3000x100 mm; b) photo of manufactured panels for installation of a residential building on a wooden frame.

The following is mainly accepted as an insulation: mineral plates or polyfoam which is combustible material. The author has developed a thermal efficient polystyrene cement composition with a density of 110-190 kg/m^3. Insulation is moldable, completely fills the cavity of the panel, unlike the mineral plate, polyfoam, using which will necessarily create gaps - cold bridges (Table 1).

Table 1. Comparative assessment of the characteristics of insulants.

Parameters of comparison	Styrofoam Cement	Mineral plates
Cost	1	1.15>
Weight	1	3>>
Thermal conductivity	0.062<<	0.75<<
Resistance in transverse bending	1	0.8<
Sound absorption	0.7	0.88<
Resistance to aggressive environment	0.7	0.67<<
Environmental friendliness of production	<<	<<
Fire resistance	1	4.5<<
temperature limits: °C -outside surface -inner surface		 -65…+600˚C -30…+600˚C
Requirements for mounting	No restrictions	Installation in wet weather is prohibited
Restrictions on the use	No restrictions	Food industry

>- higher; >> - significantly higher; < - lower; << - significantly lower.

The analysis of the table predetermined the choice of polystyrene cement as the main insulation in the lightweight cladding. Nagruzova [2] developed and comprehensively studied the compounds of polystyrene cement composition I - with a density of 190 kg/m3; II - density of 150 kg/m3; III - density of 110 kg/m3, which are taken for further study. (Figure 3, Table 3).

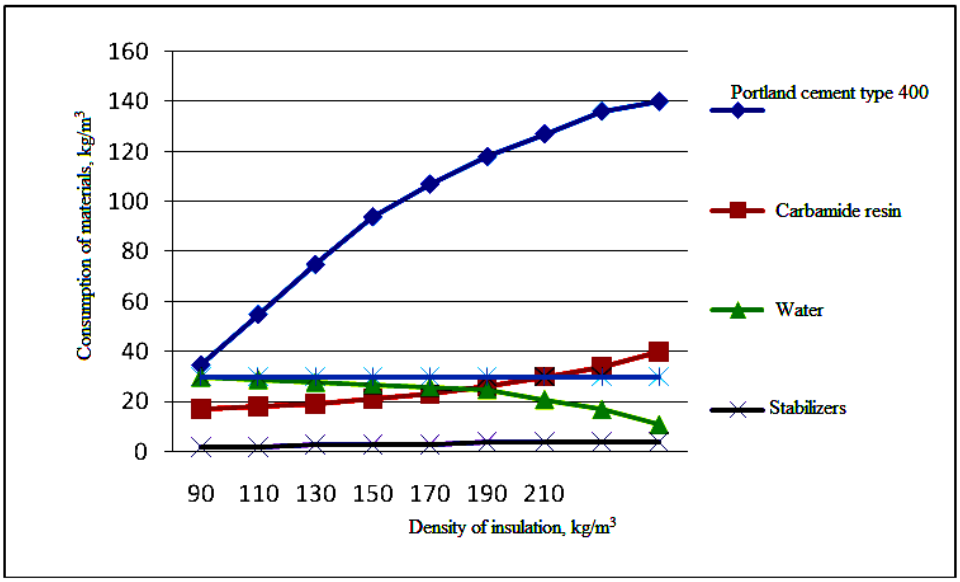


Fig. 3. Consumption of materials depending on the density of insulation.

Table 2. Compounds of polystyrene cement compositions.

Components	Compounds (kg/m³)		
	I	II	III
Foamed granules of polystyrene	30	30	30
Portland cement type 400	140	117	53
Microsilica	–	–	17
Carbamide resin	36	24	17
Stabilizers	4	3	2
Water	12	25	30

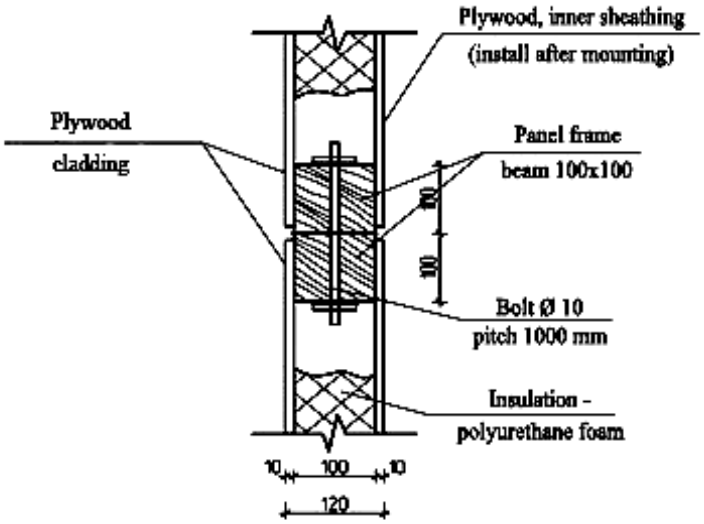
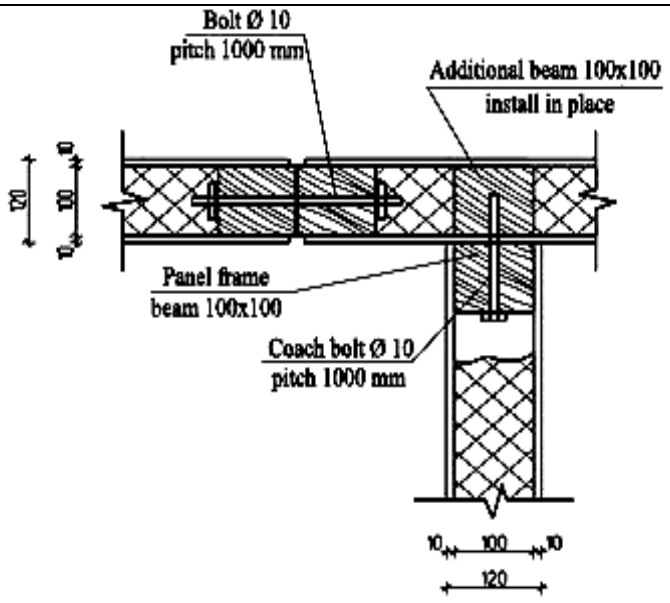
The development of compound I consists in optimizing the number of components to ensure a lower flammability insulation. When developing compound II, the idea of preliminary fire protection (encapsulation) of foamed polystyrene granules was used, which makes it possible to reduce the amount of Portland cement binder. Along with encapsulation, the development of compound III was based on the idea of partial replacement of Portland cement with metallurgical production waste (microsilica) and the use of pre-fractionated polystyrene granules (5-7 mm in size), which ensures tight packing of the granules in the cement matrix. The technical novelty of the obtained polystyrene cement composition is confirmed by copyright certificates No.1616876.

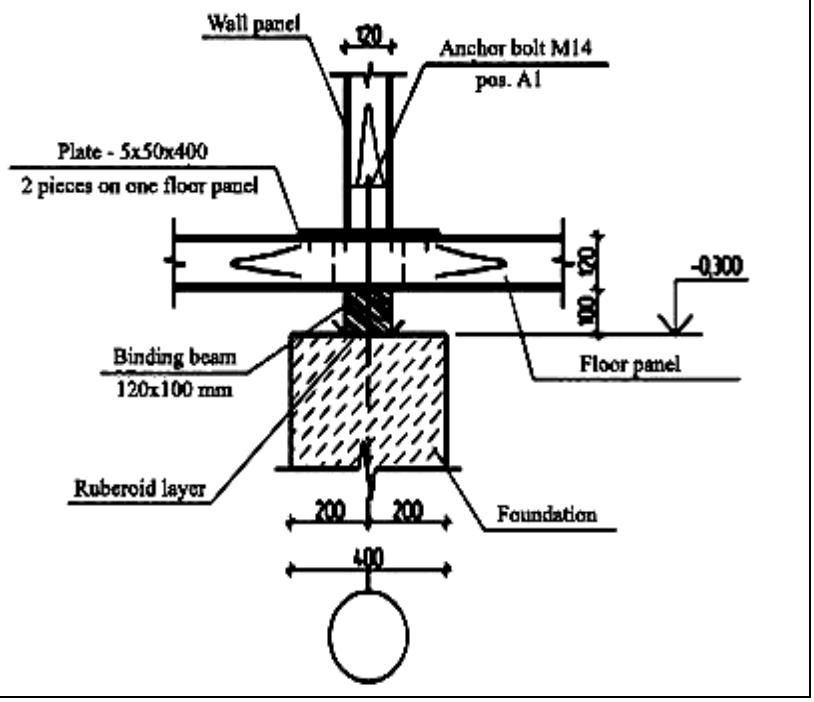
The used effective insulation with a thermal conductivity coefficient of 0.062 W/(m·°C) - at a density of 190 kg/m3, 0.049 W/(m·°C) - at a density of 110 kg/m3 is significant for operational characteristics of lightweight enclosing walls.

According to the thermal engineering calculation, the developed panels made of polystyrene cement composition of a density of 190 kg/m3 have a thickness of 240 mm. It is proposed to additionally treat all external surfaces of the panels with polyurethane foam of 8.8 mm thickness for decorative sheathing (Figure 4, Table 3).

Fig. 4. 3D model of a house, panel structures of a house.

Table 3. Panel joints from Figure 3.

№	Joints from Figure 3
1	
2	

3	

The peculiarities of the quickly erectable house made of panels on a wooden frame include:

- all constructive forms of the studied house are made of the same type of building elements connected by the connections of the same type (bolted);
- partial unloading of the old structure by transferring the load to the frame made of standard elements;
- connection of one panel to another for the purpose of unloading the foundation and basis.

3 Results

In 2003, a 9.0 earthquake occurred at the Altai, the epicenter of which was in the Kosh-Agach village, which was completely destroyed. In 2004, residential houses were built in accordance with the technology of constructive and technological solution from panels on a wooden frame with polystyrene cement insulation with density of 190 kg/m3 of modular system of Table 1. Houses of this type stood for 14-15 years. Constructed houses were erected by builders with deviations from the recommendation in which an additional layer of polyurethane foam 8.8 cm is proposed, since the thickness of the insulation of panels does not correspond to thermal resistance. In this regard, it is necessary to conduct an inspection of a residential house in order to identify defects, to improve the developed panels for the subsequent effective quickly erectable low-rise comfortable housing construction in Russia and, if necessary, abroad.

At the end of January 2018, an on-site inspection of a residential house was carried out: enclosing panels and joints for cold bridges; floor panels for the bearing capacity and other defects. Thermal imaging inspection was performed with a FLIR B200 thermal imager, registration number 41736-09. The certificate of calibration 07300085 issued by the Krasnoyarsk Central Statistical Center.

In this regard, it is necessary to solve following problems:

- identification of defects of enclosing and bearing panels on a wooden frame (insulation and joints between them) with polystyrene cement insulation;
- analysis of the change in the stress-strain state of the studied structural forms depending on the static and geometric parameters, the location of the frame parts in compressed or tension areas of a cross-section with reference to local climatic conditions;
- improvement of constructive solutions of panels on a wooden frame with a polystyrene cement composition, taking into account the identified defects.

The analysis of the inspection showed:

- thermograms show the main disadvantage of the floor panel:
- low temperature at the joints of the panels (Figure 5)

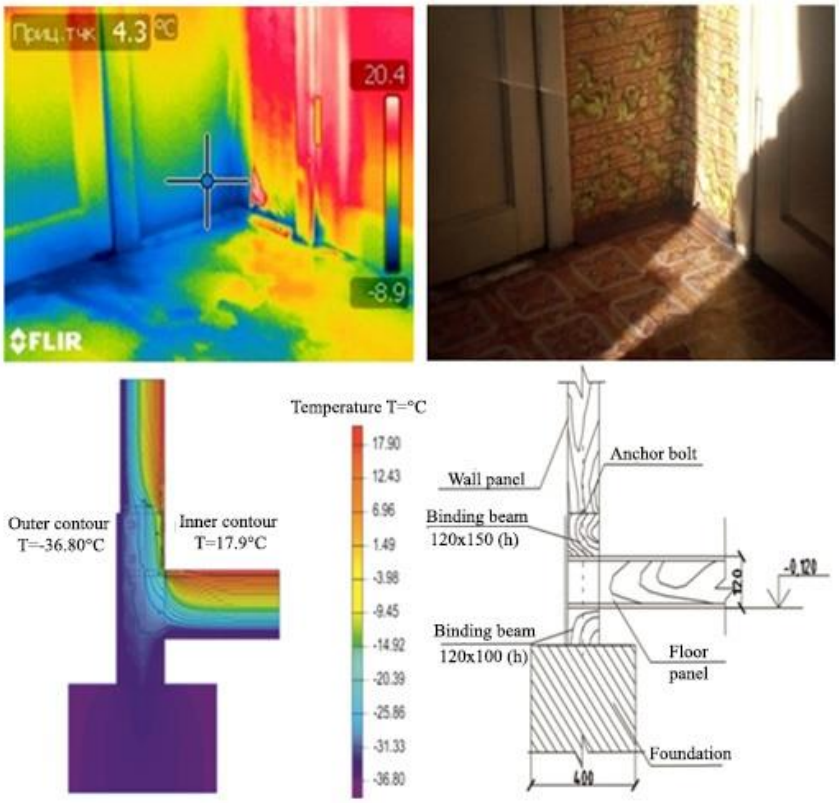


Fig. 5. Low temperature at the joints of the panels: photo; structural joint; thermogram of the joint; heat loss calculation in ELCUT 6.3 software.

Numerical studies have established that defects have been identified at the joints of the structure. If the stability conditions are fulfilled in the panel, then the temperature indicators in the conditions of a sharply continental climate are unstable.

The data on the joints of the wall panel and the ceiling (Figure 6) demonstrate heat loss at the junction of the panels and the corners of the rooms through metal joints that are cold bridges.

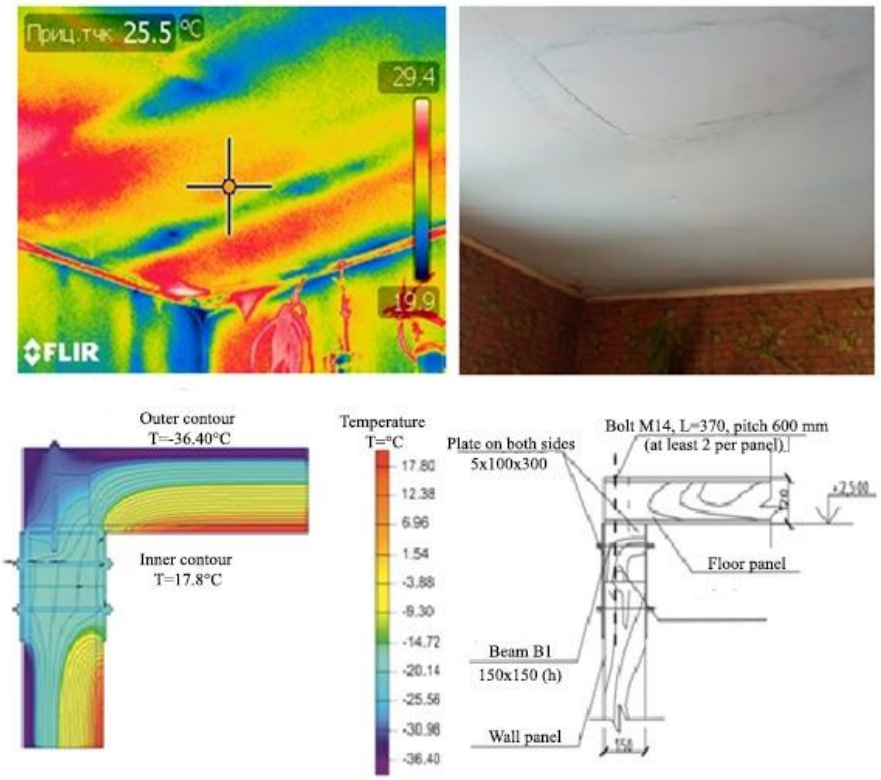


Fig. 6. Joint of the wall panels at the corners: photo of the corner; structural joint; thermogram of the joint; heat loss calculation in ELCUT 6.3 software.

Based on thermal imaging inspection of joints of the panels on a wooden frame with polystyrene cement insulation and a constructive solution taking into account the study of fields in a static (stationary) state, it was determined that heat is retained with the thickness of the insulation 10 cm, but with differences and unevenly.

The analysis of work in the SCAD Office software system showed that the bearing capacity of floor panels (stress-strain state of house floors) and deflection in floor panels are within the normal range (Figure 7).

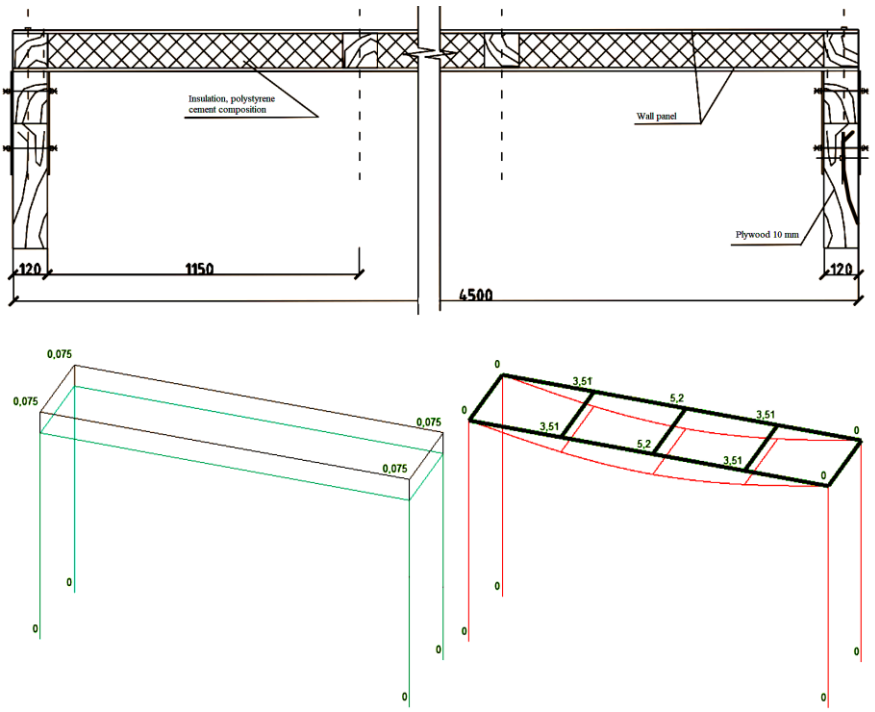


Fig. 7. Indicators of the floor panel 4500x10x1140 mm.

4 Discussion

One of the options to eliminate defects of the structures is to change the width of a panel due to thickness of the used wooden beam and, consequently, thickness of a polystyrene cement insulation.

According to the thermal engineering calculation for a sharply continental climate (Republic of Khakassia), the thickness of an insulation can varies from 18 cm to 24 cm. The thickness of a panel is determined by the density of a polystyrene cement insulation 190 kg/m3.

The use of insulation with the density of 110 kg/m3 increases its cost, but significantly reduces operational costs of a building due to reduction of heat loss through cladding.

Second option for eliminating defects of the structure is more practical – at a panel thickness of 120 mm, use heat-proof liquid vacuum thermal insulation RE-THERM to increase the thermal efficiency of the house (Figure 8) [4].

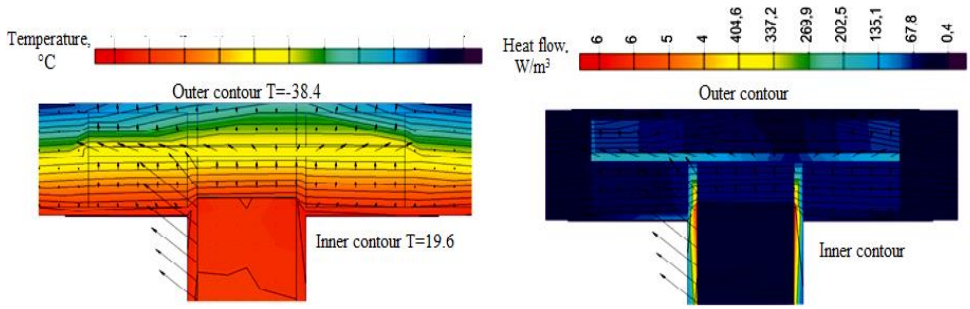


Fig. 8. Calculation of the heat flows of wall panel joint with the use of heat-proof liquid vacuum thermal insulation RE-THERM, using ELCUT 6.3 software.

The analysis of the work in the SCAD Office software system showed that the dimensions of the panel and deformability meet the standards.

5 Conclusions

Numerical methods in the ELCUT 6.3. software based on thermal imaging inspection of enclosing structures have shown that the thickness of the enclosing panel should be 24 cm, which leads to an increase in material costs and the weight of the structure itself. It is proposed to use a polystyrene cement composition with the density of 110 kg/m3. But the use of this insulation doesn't completely solve the problem of cold bridges elimination. At the junctions of the construction ribs, additional warming is necessary (Figure 7) by means of a brush application of heat-proof liquid vacuum thermal insulation RE-THERM of 2 mm thick (Arkhipova A.) [4].

The conducted studies formed the basis for the refinement of recommendations and the design of a low-rise building made of panels on a wooden frame with a polystyrene cement insulation with a density of 190 kg/m3, which allows designing reliable, safe, environmentally friendly, energy-efficient residential buildings with the required fire hazard class during long-term operation, and also with a comfortable living in a quickly erectable low-rise building.

References

1. A.N. Mushinsky, Construction of unique buildings and structures **4(31)**, 182-193 (2015)
2. L.P. Nagruzova, *Design and production of polystyrene cement energy-efficient material in construction* (Comprehensive approach, Abakan, 2013)
3. A. Laukaitis, R. Zuraukas, J. Keriene, Cement & Concrete Composites **27**, 41-47 (2005)
4. L.P. Nagruzova, A.N. Arkhipova, The Eurasian Scientific Journal **6(10)**, 10 (2018) https://esj.today/07SAVN618.html
5. A.S. Chernykh, *Improving the structures and technologies for production of wall panels with a wooden frame. Author's abstract of thesis for the degree of candidate of technical sciences* (Arkhangelsk, 2014)
6. D.A. Ukrainchenko, L.A. Murtazina, K.V. Shmelev, *Collection of scientific papers of the conference* (Orenburg State University, Orenburg, 2015)

7. V.I. Zhdanov, D.A. Ukrainchenko, A.F. Rozhkov, V.E. Afanasev, *Methodological basis for finding rational solutions for wooden panels of the structure, Study guide* ("Universitet" Publishing house, Orenburg, 2016)
8. S.A. Sychev, *Modern technologies for construction and reconstruction of buildings* (BHV – Petersburg Publishing house, SPb, 2013)
9. R.M. Muksinov, V.S. Simonov, R.Sh. Akbaraliev, Bulletin of the Kyrgyz-Russian Slavic University **12-7**, 5 (2012)
10. J. Carroll, C. Lockhart, *The complete Visual Guide to Building a House* (The Taun-ton Press, 2014)
11. W. Rug, W. Monsk, *Holzbau. Bemessung und Konstruction* (Verlag Bauwesen, 2008)
12. D.A. Ukrainchenko, Vestnik of Orenburg State University **4**, 163 – 165 (2011)
13. V.I. Zhadanov, D.I. Ukrainchenko, S.V. Lesov, Collection of scientific works "Modern construction structures of metal and wood" **1(14)**, 93 – 97 (2010)