Increasing the energy efficiency of wooden house construction

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Abstract. Individual housing construction in the Krasnoyarsk Territory is actively developing. Rising housing prices in multi-storey buildings, increasing building density, and socio-demographic factors are increasing the popularity of individual construction. Technologies for such construction imply the widespread use of available local building materials, in particular wood. During the study, the designs of private houses in the settlement - the regional center of the Krasnoyarsk Territory - were analyzed. It was found that 90% of the sample examined were houses built from timber. Using simulation modeling methods, the actual thermal resistance of the enclosing structure made of timber with a cross-section of 0.15 x 0.15 m was determined. The calculated value was compared with the standard resistance indicator of the enclosing structure, taking into account energy saving standards. The Elcut solid modeling system was used in the work. The required heat flow power to maintain stationary heat transfer conditions was determined. It has been established that the design enclosing structure does not provide the required thermal resistance taking into account energy saving standards. It is necessary to consider a multilayer enclosing structure and increase the design resistance by insulating the outer surface of the wall with heat-insulating materials.

1 Introduction

Individual housing construction is a form of providing citizens with housing through the construction of houses on the right of personal ownership, carried out with the direct participation of citizens or at their expense. Wood is a traditional building material that combines such qualities as high thermal insulation performance, accessibility, a wide range of sizes and sections, and the presence of specialist builders who have well mastered the technology of wooden house construction. Despite the spread of stone building materials,
clay bricks, foam and aerated blocks, wooden housing construction remains a serious competitor, since it combines high performance indicators and comparative availability and low cost. A wooden house successfully provides all the basic needs of the resident for warmth, safety, durability, practicality and convenience - these are the qualities that a modern home provides [1,2].

A residential property is either an apartment in an apartment building or a private house. Individual housing construction projects allow homeowners to design and implement ideas for building a house in accordance with individual requests, ideas, imagination and financial capabilities. The study [3] determined that housing is one of the main material conditions for human existence, therefore, without comfortable living conditions, a person will not be able to achieve success in his activities.

The importance and prospects of wooden house construction are largely due to the availability and accessibility of wood in almost all regions of the Russian Federation. According to data [4], the forest area in Russia is 776 million hectares, i.e. 46.4% of the territory is covered with forest vegetation. In this regard, wooden house construction is important in terms of the development of the country. Wood is a natural material, which is famous for its environmental friendliness and durability, which helps create a comfortable microclimate in rooms made of wood. In addition, the presidential decree updated the attention to the construction of wooden low-rise buildings of domestic production using ready-made prefabricated house kits (Pr-562, clause 1b). Over the past 10...15 years, individual housing construction has been developing at a high pace in the Russian Federation (Figure 1). For example, during the period from 2010 to 2023 the increase was at least 20% (ROSSTAT).

![Dynamics of residential building commissioning](image)

**Fig. 1.** Dynamics of commissioning of residential buildings.

According to ROSSTAT statistics, over the past 10 years the volume of housing area has increased from 8,400 thousand m² to 24,000 thousand m², i.e. almost three times. Figure 2 clearly shows a graph of the volumes of housing commissioned, in particular made of wood.

![The total area of residential buildings based on wall materials in the Russian Federation](image)

**Fig. 2.** Entering the total area of residential buildings based on wall materials in the Russian Federation.
For the conditions of megacities or large populated areas, industrial multi-storey development technologies with industrial construction technologies are of undoubted interest. However, the Russian Federation is not only cities with millions of people. A significant part of the population lives in rural and township settlements. According to Rosstat, as of January 1, 2023, the urban population is 75.1%, rural - 25.26%. Based on a population of 147 million people, at least 37 million people live in rural areas. In addition, a significant number of the nominally “urban” population lives in the suburbs in individual residential buildings. Private housing construction, especially in rural remote areas, needs accessible and inexpensive building materials from local raw materials. Of course, one should not rely on centuries-old technologies, when the ultimate dream was a tiny wooden frame, collected with moss and covered with shingles. A qualitatively new stage in increasing the technical level of construction of objects is modern low-rise housing construction. It allows you to quickly complete the task of improving housing. The materials used in housing construction must meet high operational and environmental requirements and are manufactured using low-energy, cost-effective technology using local raw materials [5-7].

2 Purpose and objectives of the study

In the context of increasing construction rates and the emergence of new building materials and technologies, it is reasonable to question the choice of the most energy-efficient and at the same time relatively inexpensive technology for the construction of individual housing. Taking into account the above, we formulate the purpose of the study: to justify the feasibility of carrying out measures aimed at increasing the energy efficiency of wooden housing construction objects, taking into account their resistance to heat transfer of the enclosing structure and regulatory indicators.

Research objectives:
- Identify potential wooden housing facilities, using the example of a rural settlement, that are subject to insulation;
- Conduct an analysis of foreign experience in the field of thermal efficiency of housing construction projects and ways to increase it;
- To substantiate by means of solid-state modeling the indicators and characteristics of the material necessary to ensure compliance of residential buildings with energy saving requirements.

3 Objects and methods of research

The object of the study is the effect of insulation on the thermal efficiency of the enclosing structure of a wooden housing construction project. Research methods are based on qualitative and quantitative data analysis of available research results, forecasting methods. The research used freely available sources, observational methods, modeling and experiment. The ELCUT solid modeling package was used [8].

4 Results and discussion

To describe the most typical types of individual houses in the village. We inspected and recorded the area and material of the walls of the building in Bolshaya Murta, Krasnoyarsk Territory. 213 objects were inspected, of which 92% were wooden (timber and log) houses, 3% were buildings made of wood-mineral composites and 4% were houses built from gas blocks. Analyzing the inspected individual housing construction objects, we can conclude that wooden houses predominate. It must be said that the territory of the Krasnoyarsk
Territory is Eastern Siberia, which is characterized by very harsh climatic conditions. In the conditions of a sharply continental climate, which includes Eastern Siberia, according to SNiP 23-01-99, the average temperature of a cold day is -41°C, and the air temperature of the coldest five-day period is -39°C. It is obvious that when constructing housing, a developer, and especially an individual developer, not burdened with a staff of design engineers and economists, faces many problems, the main thing being heat and energy saving. One of the priority indicators characterizing the heat and energy saving of enclosing structures is the thermal conductivity of building materials. Using empirical dependencies, we determine the thermal resistance of a building envelope consisting of 0.15 m of pine timber:

Let us determine the thermal resistance of the enclosing structure \( R \), \((m^2 \cdot ^\circ C)/W\), according to the formula:

\[
R = \frac{\delta}{\lambda},
\]

where \( \delta \) – layer thickness, m; \( \lambda \) – thermal conductivity coefficient of the layer material, \( W / (m^2 \cdot ^\circ C) \)

For pine and spruce across the fibers (GOST 8486-86, GOST 9463-88) the thermal conductivity is equal for operating conditions \( A = 0.14 \, W / (m^2 \cdot ^\circ C) \), \( B = 0.18 \, W / (m^2 \cdot ^\circ C) \).

The layer thickness is assumed to be 0.15 m.

\[ R = 0.15/0.14 = 1.07 \, ((m^2 \cdot ^\circ C))/W, \]
\[ R = 0.15/0.18 = 0.83 \, ((m^2 \cdot ^\circ C))/W. \]

According to building codes and regulations, there are uniform requirements for thermal protection of buildings and structures. The calculated resistance index of the building envelope, taking into account energy saving standards, is an indicator that must be taken into account when constructing a building. Since its value affects the heat and energy efficiency of the building in a straightforward manner, i.e. if the resistance of the enclosing structure is lower than the resistance of the enclosing structure taking into account energy saving standards, then the enclosing structure will be ineffective in terms of heat conservation, i.e. the wall will be cold. This indicator is determined using building codes and regulations, which take into account the degree of day of the heating period and the average temperature of the heating period. For the conditions of the Krasnoyarsk Territory, the required resistance of the enclosing structure, taking into account energy saving standards, will be equal to \( R_{0}^{en} = 3.64 \). Up to 90% of the wooden house-building objects we examined in the village of Bolshaya Murta were built from timber with a cross-section of 0.15×0.15 m. Only 37% of the objects were insulated in some way. As a rule, insulation comes down to the construction of a ventilated facade and covering with vinyl siding or clapboard. At the same time, such “insulation”, at best, is a barrier against the wind, but does not fundamentally increase the thermal insulation qualities of the object. Based on this, the resistance of the enclosing structure made of timber with a cross-section of 0.15×0.15 m does not meet the requirements of energy saving standards.

Calculations have shown that in order to fulfill the requirement for energy saving, it is necessary to construct an enclosing structure from timber 0.5096 m thick, which is practically impossible or very expensive. Consequently, there is a need to justify the effectiveness, payback period and technology of measures to increase the thermal efficiency of wooden houses. After all, these houses, even if they are built with violations and do not comply with the principles of energy efficiency, are housing for thousands of people.

Foreign experience [9,10] shows that a systematic approach to optimizing the thickness of the insulating material, based on an analysis of life cycle costs, allows saving up to $21/m² when insulating with mineral wool and establishing a payback period of 1 to 1.7 years, depending on the type wall structures. In Spain, potential heating system energy savings have been achieved by implementing various retrofit measures, such as installing a heat recovery ventilation system, improving the insulation of opaque structural elements, replacing existing windows with windows with high thermal performance, reducing air infiltration rates,
requirements developed by Passivhays standards imply a reduction in energy costs for the heating system from 57% to 81% [11]. In Turkey, thermal losses of new and existing buildings are the main sources of energy waste, so the optimal insulation thicknesses, economic feasibility and payback periods were calculated and it turned out that the optimal thermal insulation thickness varies from 2 to 17 cm, and energy savings from 22% to 79%, the payback period ranges from 1.3 to 4.5 years [12]. The presented interest in thermal energy losses is of economic interest.

The CAE product of the ELCUT system was used to model and calculate the heat flow power. This is a software product developed for engineering modeling of electromagnetic, thermal and mechanical problems using the finite element method. To create the model under study, the program has a model editor, which allows you to quickly create, edit and use an object for modeling. Moreover, 3D models from third-party graphic editors such as Compass 3D, AutoCAD, etc. can be imported into the Elcut software package. The results of the software product can be presented in the form of graphs, tables, color maps, etc. Previously, we successfully used this package to solve problems of substantiating the performance of enclosing structures made of wood composite materials [13-15].

We will consider the rationale for the feasibility of increasing the resistance of the enclosing structure on a fragment of the enclosing structure made of timber with a cross-section of 0.15x0.15 m. The fragment of the enclosing structure was designed in the Compass 3D software package (Figure 3).

![Fig. 3. 3D model of the enclosing structure: 1 – timber, 2 – tow, 3 – inner layer of plaster.](image)

After this, the building envelope fragment was imported into Elcut. The parameters of the stationary heat transfer problem were specified in the software package, after which calculations of the stationary heat flow through the building envelope were performed. To the outer surface, the external air temperature was applied according to SP 50.13330.2012 \( t_{\text{ext}} = -35^\circ\text{C} \), heat transfer coefficient \( a_{\text{ew}} = 23 \text{ W/(m}^2\cdot^\circ\text{C)} \), and to the inner surface temperature \( t_{\text{in}} = 25 \) and heat transfer coefficient \( a_{\text{si}} = 8.7 \text{ W/(m}^2\cdot^\circ\text{C)} \).

We determined the thermal conductivity indicators earlier and used them for loading into the Elcut system [16].

The result of the Elcut package is shown in Figures 4, 5.
Thus, in the Elcut system, the power of the heat flow, carried out under the conditions of stationary heat transfer, was determined for a fragment of the enclosing structure with an area of $S = 0.305 \, \text{m}^2$ and a heat flow value of 12.8 W, then in terms of $1 \, \text{m}^2 = 41.3 \, \text{W/m}^2$. Then, when operating a building with an area of 100 $\text{m}^2$, it is necessary to expend thermal power equal to 4196 W constantly, i.e. 24 hours a day. A reasonable question would be about a way to reduce the consumed power under the same operating conditions and parameters of the tested object. There are many ways to increase the resistance of a building envelope, such as insulating the outside of the building envelope with heat-insulating materials. Thermal insulation materials are materials that have low thermal conductivity and low density.
Designed to increase the resistance to heat flow through the building envelope. Thermal insulation materials have many parameters, such as thermal conductivity, density, and vapor permeability. Vapor permeability is the ability of a material to pass partial pressure differences to water molecules at the same atmospheric pressure. In addition, vapor permeability in wooden housing construction is important when carrying out measures aimed at increasing the resistance of enclosing structures, namely insulating the outer side of the wall. According to the author’s research [17], wood, in particular pine, is a moisture-conducting material that can conduct 1.9–3.2 times more in the radial direction than in the tangential direction. Therefore, it is necessary to take into account the insulation material in order to avoid the loss of free steam on the outer surface of the enclosing structure. Let's consider the insulation material in the form of mineral wool with a thickness of 50 mm (Figures 6, 7) and 100 mm (Figures 8, 9).

![Fig. 6. Geometric model of a building envelope made of timber and 50 mm insulation in the Elcut application package.](image)

![Fig. 7. Thermal fields of the enclosing structure in the form of timber and 50 mm mineral wool insulation.](image)
The results of calculations of the heat flow power with increasing resistance of the enclosing structure with 50 mm thick mineral wool are equal to 6.3 W, i.e. for 100 m² is 2065 W.

Fig. 8. Geometric model of a building envelope made of timber and 100 mm insulation in the Elcut application package.

When insulated with 100 mm mineral wool. The heat flow power is 13.7 W/1m² for 100 m², respectively 1377 W. Next, calculations were carried out at thicknesses of 25, 50, 75, 100, 125, 150, 175, 200 mm to draw up a graph of changes in the magnitude of the heat flow from the thickness of the insulation material. The graph is shown in Figure 10.
Fig. 10. Dependence of the heat flow on the thickness of the insulation material.

Thus, a change in the thickness of the insulation material affects the amount of heat flow power non-linearly and has a certain meaning in justifying the optimal thickness of insulation by the payback period of the materials used.

Fig. 11. Dependence of changes in payback period on the thickness of the insulation material.

The graph of the change in payback period depending on the thickness of the insulation material (Figure 11) in combination with the graph of the change in the magnitude of the heat flow on the thickness of the insulation material allows us to specify the optimal thickness of the heat-insulating material [18].

5 Conclusion

A characteristic feature of individual housing construction projects in the regional center of Bolshaya Murta is the widespread distribution of wooden timber houses. It has been established that 92% of the objects examined are wooden houses (including 90% are timber houses). Basically, these are enclosing structures made of timber with a cross-section of 0.15×0.15 m. Such walls do not meet the heat and energy saving requirements for the regulatory regimes of the Krasnoyarsk Territory.
Foreign experience in the field of thermal efficiency of housing construction projects shows the relevance of measures aimed at increasing the resistance of the building envelope by insulating it and creating multilayer structures.

A solid modeling program based on the finite element method allows you to analytically calculate actual thermal efficiency indicators. The magnitude of the heat flow power for the enclosing structure without insulation material and with insulation materials ranged from 41.3 to 13.77 W/1 m². Thus, increasing the thermal resistance of the enclosing structure has a significant impact on the amount of heat flow power. For design conditions, it is possible to recommend insulating timber structures from the outside with a layer of mineral wool 100 mm thick.

References

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