Justification of the choice of wall material for low-rise construction

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Abstract. The study analyzed the thermal performance of enclosing structures made of: polystyrene concrete, heat block, arbolite blocks, foam concrete and aerated concrete. The calculation of heat losses was carried out using finite element methods, in the software package "Elcut". The results of the study showed that the enclosing structure in the form of a wall consisting of aerated concrete blocks will be most effective in terms of heat conservation. In order to identify the most affordable and economical material for the construction of a house with an estimated area of 100 m^2, an enlarged calculation was carried out, including determining the cost of building material necessary for the construction of an enclosing structure. According to the calculation results, the most expensive technologies turned out to be construction options from aerated concrete blocks and a heat block. The house made of wood-mineral composites (arbolite) turned out to be the most inexpensive. The materials of the work can be used by developers in the selection and justification of materials for wall structures of low-rise construction.

1 Introduction

It is generally recognized that the construction sector is the driver of the global and regional economy. The analysis of trends in the development of the construction sector allows us to conclude that the patterns of phenomena in the construction sector follow the general trends of the world economy, reflecting migration policy, investment policy, lending, technology development, structures and materials. Construction is an important part of the economy of developed countries. The construction sector and related industries make it possible to provide people with housing, jobs, and form a steadily growing demand and market for building materials [1, 2].

Housing construction is actively developing in the East Siberian part of Russia. According to the statistics of the Russian Federation, one of the leading cities in terms of construction volume are: Novosibirsk, Krasnoyarsk, Irkutsk and Barnaul (Figure 1). The

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volume of housing construction in 2022 in the Russian Federation, according to statistics, amounted to 102.712 million m^2.

Fig. 1. The volume of housing construction for the period from 2020 to 2022 in the Siberian regions.

Abroad, the volume of construction is significantly higher, for example, in 2022 in China - 1.53 billion m^2, in Turkey – 260 million m^2 [3]. For construction in regions with a sharply continental climate, it is important to make an informed choice of building material that will meet the harsh climatic conditions. The climatic conditions of the continental climate are characterized by strong, temperature differences and low temperature values, and strong winds. Therefore, when building houses, it is necessary to select materials of enclosing structures with high strength and thermal efficiency.

Basically, the developer in the Siberian regions is very conservative and builds houses of a simple architectural form, the main building material is: brick, building logs, timber, frame panels, and various building blocks with low thermal conductivity (gas and foam blocks, arbolite). Each material has its advantages and disadvantages, which should be taken into account when choosing a building material. One of the important aspects in the construction of low-rise buildings is strength, durability and thermal insulation. In places with a cold climate, in low-rise construction, it is important to insulate the enclosing structure. The design with properly selected building material and insulation contributes to the long-term preservation of heat in the room. Reducing heat losses helps to reduce heating costs, thereby reducing CO_2 emissions into the atmosphere [4].

In the reach of a modern developer there is a large selection of building materials that differ in thermal, environmental sound insulation and strength characteristics. These include: polystyrene concrete, heat block, arbolite, foam concrete, aerated concrete block, glued beams. Traditional building ceramics in the form of clay bricks in low-rise construction are now unpopular, and modern hollow or porous ceramics are little known in the Siberian Federal District. The use of such building materials has a number of advantages, one of the main ones: such materials have low thermal conductivity, which, in comparison with traditional bricks, allows you to reduce the thickness of the wall, without heat losses. Working with blocks does not require a highly qualified employee. Lighter walls make it possible to dramatically reduce the cost of the foundation, basement, which also pushes clay and silicate bricks into the field of industrial construction and the construction of special facilities.

The purpose of the study is to substantiate the choice of material for the manufacture of walls in the process of individual housing construction. To achieve the research goal, the following tasks should be solved:

1. Using solid-state simulation methods to determine the thermal losses of the enclosing structure depending on the type of building material.
2. To conduct an economic justification of the rational wall material based on the conditions of thermal efficiency, accessibility and ease of construction.
3. To determine the environmental component of the adopted technological solutions and building materials.

2 Materials and methods

An enclosing structure in the form of a solid smooth wall made of various building materials is accepted as the object under study. The choice of building materials was carried out on the basis of accessibility, breadth of distribution and availability of labor resources with skills in working with the material, in relation to the Krasnoyarsk Territory. The following materials were considered: polystyrene concrete, heat block, arbolite, foam concrete, aerated concrete block (Figure 2). These building materials, as a rule, are lightweight concretes with various aggregates (organic – wood pulp or inorganic – polystyrene character). In the case of autoclaved aerated concrete, these are air bubbles located inside a structuring matrix frame made of low–density concrete [5].

Fig. 2. Building materials: 1 - Polystyrene concrete; 2 - Heat block; 3 - Arbolite, 4 - Foam concrete; 5 - Aerated concrete block.

In the process of work, methods of analysis and synthesis, hypotheses, economic calculations, as well as programs "Kompas3D" and "Elcut" were used.

3 Results

In the computer-aided design program "Kompas3D", a drawing of the enclosing structure made of polystyrene concrete, heat block, arbolite, foam concrete, aerated concrete block was created. The block sizes were selected as the most suitable for low-rise construction of houses. Between the blocks and on the inside of the wall there was a layer of cement-sand mortar (CPR), as well as the foundation (Figure 3).

Next, the drawing was saved in the "DXF" format, and loaded into the solid-state modeling system "Elcut" to identify thermal losses of the wall enclosing structure.

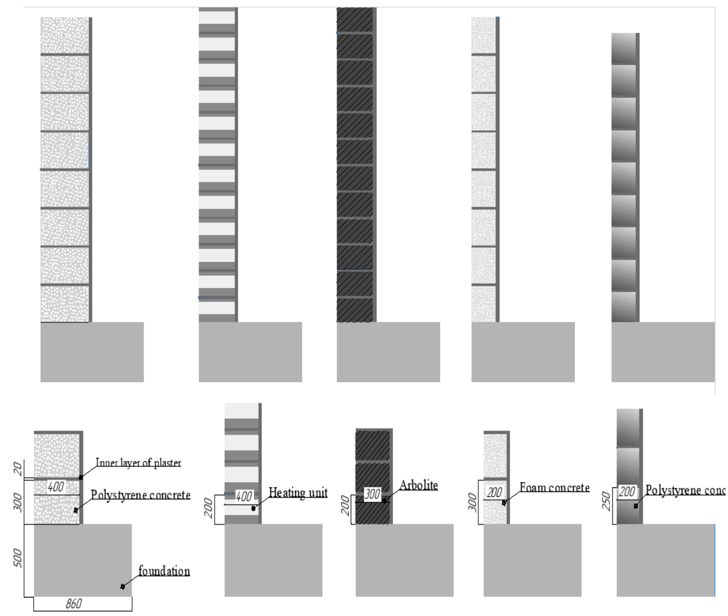


Fig. 3. Options of enclosing structures and their sizes.

The Elcut software package allows solving problems related to thermal engineering calculations, electromagnetic, mechanical, using finite element methods [6].

To calculate the heat losses of various materials of the wall enclosing structure, a grid of finite elements was constructed in Elcut (Figure 4). Next, each component of the wall was given the values of thermal conductivity, specific heat capacity and density necessary for calculations (Table 1) [7].

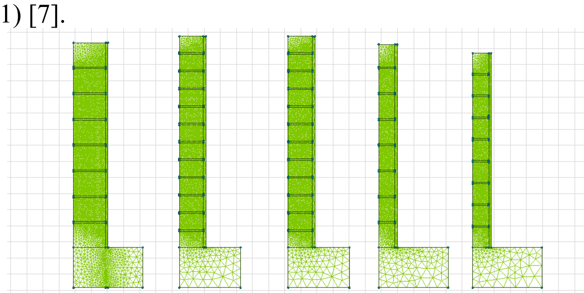


Fig. 4. The finite element grid for the structures under consideration.

The boundary conditions of the wall were: the average temperature in the winter season, and the standard indoor temperature in the Krasnoyarsk Territory. So, the calculated external temperature was t outside = -25 ^{0}C, and the internal temperature according to GOST 30494-2011 is t inside = +20 ^{0}C [8]. For calculations, the material of the interblock joints was adopted - a cement-sand mortar, the foundation is a shallow–buried ribbon, concrete M200.

Table 1. Physical and mechanical properties of materials required for calculations.

Material	Block dimensions, mm	Thermal conductivity, W/K·m	Specific heat, J/kg·K	Density, kg/m^3
Polystyrene concrete	600x400x300	0.14	1.06	400
Heating unit	400x200x400	0.013	0.84	1650
Arbolite	600x200x300	0.33-0.53	2.3	650
Foam concrete blocks	600x300x200	0.14-0.22	0.84	700
Aerated concrete block	625x250x200	0.14	0.84	400
Cement-sand mortar	-	1.2	0.84	1800
Concrete M200	-	1.3	0.84	1800

The calculation of the thermal parameters of the enclosing structure, depending on the material, is shown in Figure 5.

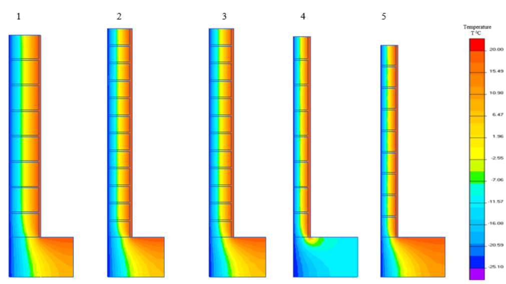
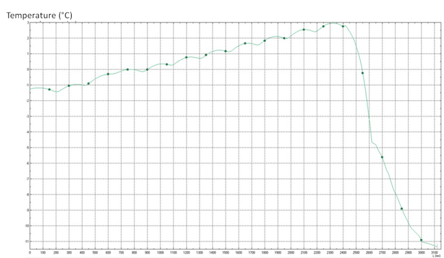


Fig. 5. Thermal fields and temperatures of the enclosing structure in the Elcut program: 1 - Polystyrene concrete; 2 - Heat block; 3 - Arbolite, 4 - Foam concrete; 5 - Aerated concrete block.

Figure 6 shows the temperature distribution of the wall enclosing structure along the cross section from top to bottom, the results are presented in Table 2.



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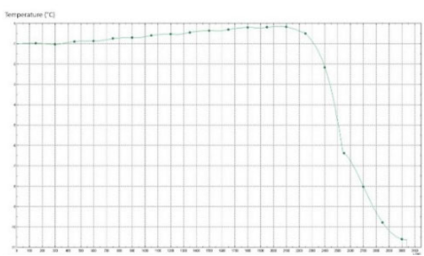

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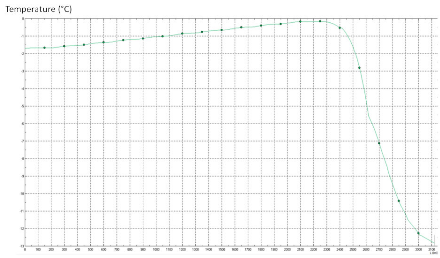

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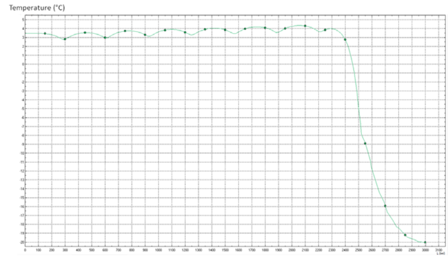

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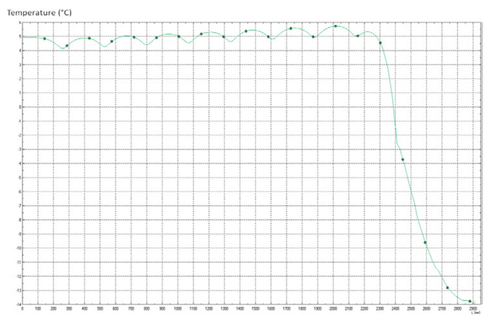

e

Fig. 6. The dynamics of temperature changes along the wall section (top-down): a - Polystyrene concrete; b - Heat block; c – Arbolite; d - Foam concrete; e - Aerated concrete block.

Table 2. Distribution of temperature changes of the wall by section from top to bottom.

Wall Material	**The temperature is ^{0}C along the wall section**
Polystyrene concrete	from -1 to -10.9
Heating unit	from -1 to -10.5
Arbolite	from -3 to -18.0
Foam concrete blocks	from 4 to -20.0
Aerated concrete blocks	from 5 to -13.8

Then an enlarged calculation of the costs required for building materials for the construction of the walls of a single-storey house with an estimated area of 100 m^2 was carried out. The accepted ceiling height is 2.7 m. During the calculation, an assumption was made according to which translucent structures and doors were not taken into account. The cost calculation was carried out for the surface of the wall with the calculated normative resistance to heat transfer of the structure. The standard value of the heat transfer resistance of the enclosing structure for the climatic conditions of the Siberian Federal District (Krasnoyarsk) is R = 3.6 (m^2 * ^{0}C)/W. When calculating the structural elements of the wall made of low-density materials (gas and foam concrete, polystyrene concrete), the costs of mandatory reinforcement were taken into account. For walls made of heatblock and arbolite, the cost of an armature was not taken into account, since the bearing capacity of these materials allows you to build walls without using these structures. The materials are presented in Table 3.

Table 3. The cost of the walls of a residential facility.

Object type	Wall Material	The price of 1 m^3 of material, RUB.	Costs thousand rubles per 100 m^2 of estimated area
One-storey house with an area of 100 m^2	Polystyrene concrete	6800	580 000
	Heating unit	5800	610 000
	Arbolite	5200	397 500
	Foam concrete blocks	4600	469 000
	Aerated concrete blocks	5300	650 000

4 Discussion

An important factor determining the demand and popularity of a building material is its ecological "friendliness", i.e. an indicator characterizing the degree of environmental damage that occurs during its industrial production. In this regard, in many countries, increased attention is paid to lightweight concrete with organic aggregate in the form of agricultural and forestry waste. The production of building materials containing wood chips and waste obtained from wood processing is an urgent task at the moment. In Russia, forests occupy 809 million hectares. Logging operations are underway in most of these territories [9,10].

The main component necessary for the production of the competing materials in question is cement, inert materials and additives. From the point of view of the impact on the environment and carbon monoxide emissions, cement production and consumption is the determining and most important factor.

Today, China is the largest cement producer in the world. In 1982, China overtook Japan and became the world's largest cement producer, and in 2018 it accounted for about 56% of global production (Figure 7) [11].

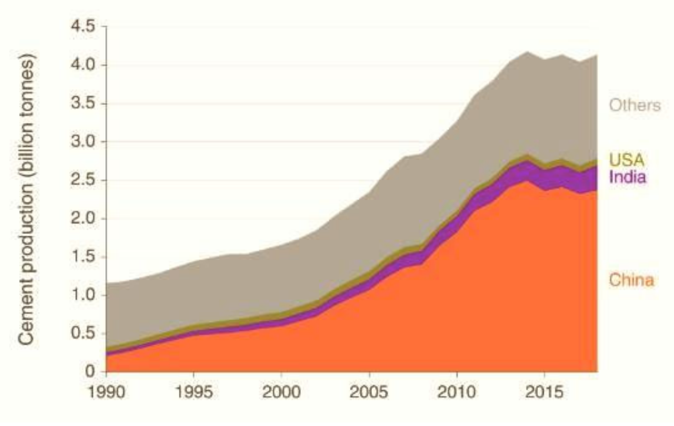

Fig. 7. Cement production by country, 1990-2018.

Global carbon monoxide emissions associated with cement production amounted to more than 1.5 Gt in 2018. This is almost 5% of CO_2 emissions from the burning of all fossil fuels on Earth per year (Figure 8) [11].

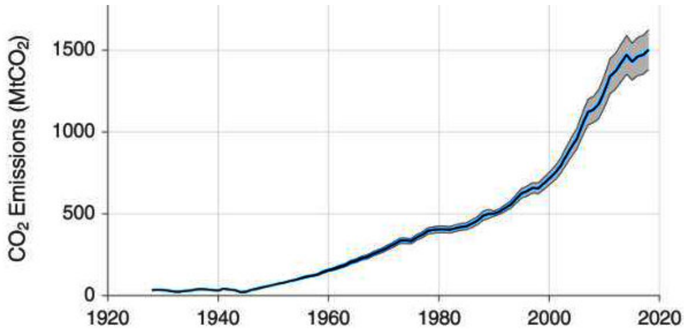

Fig. 8. Global technological emissions from cement production.

The main consumer of cement is the construction industry and specifically the production of building materials, mixtures, blocks and panels. Due to the enormous importance of carbon monoxide emissions, it is important to reduce the specific content of cement in building materials. If possible, replacing it with carbon-neutral materials, for example, organic ones, which is done in a wood-mineral composite – arbolite. Arbolite blocks in their composition per 1 m3 have 300 kg of wood waste (chips), 250... 300 kg of Portland cement, 400 liters of water. For a foam block of the same volume, 300...350 kg of cement, 210 sand, 130 water are required. As a result of comparing the composition of building materials, it can be said that less cement is required for the production of wood-mineral composites. On a global scale, this is millions of tons. Studies [12] have found that during the construction of the port, a 25% reduction in the amount of cement in concrete leads to a decrease in CO_2 emissions by 80,000 tons, and during the construction of the seaport, a decrease in CO_2 emissions by 17,000 tons was noted.

5 Conclusion

Housing construction is actively developing all over the world. Along with the growth of construction, the production of building materials increases. For low-rise construction in regions with a cold climate, it is important to select suitable building materials. Building materials for places with a cold climate must meet a number of specific requirements (low thermal conductivity, high strength, accessibility). As a result, it was found that the lowest heat losses along the wall section (from top to bottom) were in the enclosing structure of the aerated concrete block, and the highest heat losses were in the arbolite block and the heat block. The economic calculation of the cost of building walls for a house with an area of 100 m^2 showed that the most expensive building material turned out to be an aerated concrete block and a heat block. According to calculations, the most economical is a house made of arbolite blocks.

When choosing a building material for low-rise construction, it is important to choose a material with an optimal ratio of strength and thermal insulation characteristics. Heat losses of the enclosing structure lead to an increase in heating costs of the facility, and these are significant financial losses associated with high fuel costs. All other things being equal, if the issues of heat conservation are put at the forefront, then the aerated concrete wall is the most promising. It is worth considering that arbolite blocks conduct heat better than aerated concrete blocks. Heat loss of walls made of arbolite blocks will increase heating costs. On the other hand, arbolite walls are the most affordable and inexpensive. And they are more environmentally friendly in production. Therefore, when deciding on the choice of a particular building wall material for low-rise housing construction, a comprehensive analysis of both thermal efficiency, environmental factors and construction and operation costs is necessary, taking into account availability and tariffs for energy and fuel.

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