Application of porous building materials in low-rise housing construction

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Abstract. The enclosing structure made of porous building materials was considered as the object under study in the work. Let us consider four types of building wall materials (expanded clay concrete, porous ceramics, foam concrete and porous arbolite). Solid-state simulation modeling methods were used in the Elcut and Compass3D software packages. The calculation results showed that the heat flux at the wall made of expanded clay concrete is - 140.38 W/m^2, from a porous ceramic block - 41.66 W/m^2, from porous arbolite - 16.85 W/m^2, foam concrete - 66.96 W/m^2, the data were obtained at an external temperature of - 20°C and an internal temperature of +20°C. For an external temperature of -30°C, the heat flow at the wall made of expanded clay concrete is -175.47 W/m^2, ceramic porous block - 52.1 W/m^2, porous arbolite - 21.1 W/m2, foam concrete - 83.7 W/m^2. The costs of heating the facility built from the materials considered were also determined. Solid fuel generation (coal and firewood) was adopted as a heat source. It turned out that the most expensive to heat a house made of expanded clay concrete, the cheapest was the maintenance of a facility made of porous arbolite.

1 Introduction

Housing construction is an important sector of the country's economy, which is aimed at providing the population with their own housing and jobs. In recent years, individual housing construction (IHC) has been actively developing in Russia. According to the Unified Institute of Housing and Communal Services (UIHS) for the past 2023, the volume of commissioning of IHC facilities amounted to 110.438 million m^2. Also in 2023, 431,515 housing units were built by the population themselves (Figure 1). Figure 1 shows a graph that shows the growth in the volume of individual housing construction in the Russian Federation.

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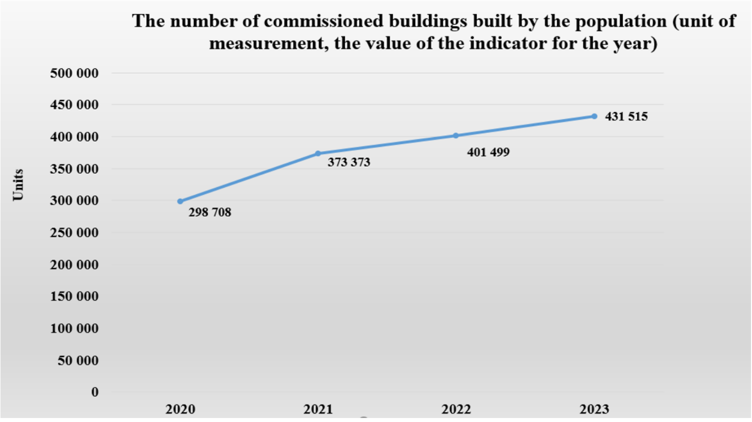

Fig. 1. Volumes of housing built by the population.

The rapid growth of individual housing construction affects the construction materials market, it obliges manufacturers to increase the volumes of production of existing ones, as well as to work on promising construction materials. The choice of wall materials is one of the key stages that determine the durability, cost-effectiveness and energy efficiency of the house. The most relevant wall materials for individual housing construction are: brick, aerated concrete, foam concrete, SIP panels, wood-mineral composites, etc. [1,2].

Therefore, the study of thermal engineering and operational characteristics of porous building materials to improve energy efficiency and environmental friendliness of low-rise housing construction is an urgent scientific problem.

The purpose of the study is to substantiate the relevance of using porous building materials as wall material in individual housing construction. The stated purpose of the work required solving problems.

- To justify the advantages of using porous building materials in individual housing construction;
- To determine thermal conditions of walls made of porous building materials using solid-state simulation modeling methods;
- Calculate heating costs using the following wall materials: expanded clay concrete; porous ceramic block, porous arbolite, foam concrete.

2 Objects and methods of research

The object of the study is the influence of the applied wall materials on the thermal efficiency of the enclosing structure. The research methods are based on a simulation experiment, the use of solid modeling technologies.

Recently, developers have begun to pay much attention to the efficient use of energy resources. This has undoubtedly affected individual housing construction, since the constant growth of tariffs for electricity and heat increases the costs of maintaining individual housing construction. And on a global scale, uncontrolled combustion of hydrocarbons leads to carbon monoxide emissions, which is considered the key cause of global warming and other negative environmental phenomena. Energy-efficient technologies in construction allow not only to reduce heating and electricity costs, but also to increase the level of living comfort. To achieve high energy efficiency indicators, several regulatory documents and standards have been adopted, for example, SP 50.13330.2012. The set of rules will allow you to design buildings that ensure durability, efficient energy consumption, etc.

An important stage of individual housing construction, along with justification of the size and layout of the object, is the choice of materials, especially wall materials. The main factors that the developer pays attention to when purchasing materials are indicators of thermal efficiency, strength, and durability. Energy-efficient wall materials include ceramic porous block, porous brick, porous arbolite, foam concrete, aerated concrete and expanded clay concrete block [3,4].

All the listed materials have a porous structure, which gives the material certain properties:

- High thermal insulation properties;
- Low density of the material (allows construction time and transportation costs);
- Good sound insulation;
- Durability;
- Environmentally friendly.

In addition to their positive qualities, porous building materials have several disadvantages that should be taken into account during construction:

- Increased hygroscopicity and the need for waterproofing (external wall cladding is required to reduce negative factors, this is due to the structure of the material, which can absorb moisture);
- The strength of a porous material is lower than that of a dense one.

The object of study in our work was an enclosing structure made of porous building materials for individual housing construction. Let us consider four design options (Figure 2). The first option is a wall made of expanded clay concrete blocks 190 mm thick, on a cement-sand mortar (CSM) 20 mm thick. The second is a ceramic porous block 250 mm thick, with 10 mm - CSM. The third is porous arbolite 300 mm thick, CSM - 20 mm. The fourth option is foam concrete 200 mm thick, with CSM - 20 mm. The use of cement-sand mortar as a design mortar, on the one hand, clearly reduces the thermal efficiency of the structure. But the widespread practice of individual construction has shown that to reduce costs, walls are erected not on special adhesive compositions, but on cheap and affordable CSM. Individual construction is often carried out in very remote settlements, where suppliers simply do not supply special mixtures, adhesives or foams.

3 Results and discussion

The options for the wall materials used are shown in Figure 2, and the structures under consideration are shown in Figure 3.

Fig. 2. Variants of the wall materials under consideration: a – expanded clay concrete; b – porous ceramic block, c – porous arbolite, d – foam concrete.

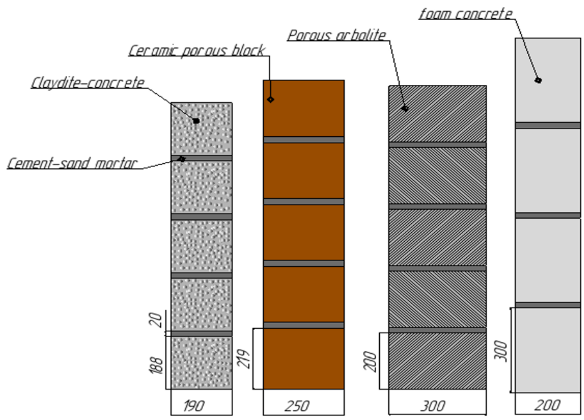

Fig. 3. Variants of the design under consideration.

In the process of work the program "Compass3D" was used, in which models of four variants of the enclosing structure were created and saved in the DFX format, this is necessary for further work in Elcut. Compass3D is a computer-aided design system used for designing three-dimensional models, drawings and documentation. To identify thermal phenomena of the wall, Elcut was used - a program for simulating modeling of processes and calculating heat losses. The model, in the Elcut software package, was given a finite element mesh (Figure 4), this is necessary for further assignment of physical and mechanical properties of the materials under consideration (Table 1). The boundary conditions were an internal temperature of +20 °C, and for a more accurate calculation of thermal indicators of materials at various negative temperatures in regions with a cold climate, external temperatures were selected: -20 °C and -30 °C [5, 6].

Table 1. Physical and mechanical properties of porous materials.

Name	**Thermal conductivity, W/K·m**	**Specific heat capacity, J/kg·K**	**Density, kg/m^3**
Expanded clay concrete	0.66	0.84	1800
Ceramic porous block	0.21	0.88	890
Porized arbolite	0.08	2.3	400
Foam concrete	0.25	0.84	1060
CSM	0.58	0.84	1800

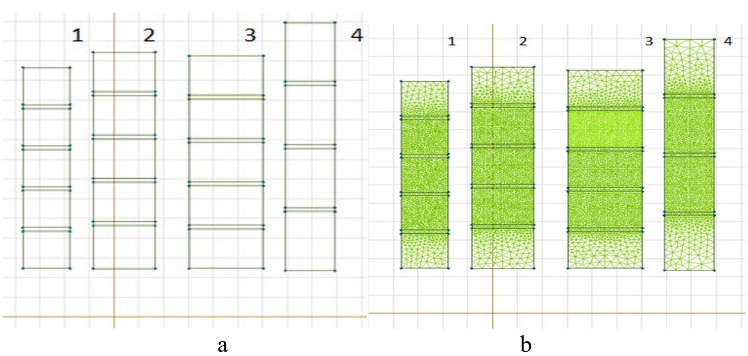

Fig. 4. Assignment of finite element mesh in the Elcut program: a – DFX model, b – finite element mesh, 1 – Wall made of expanded clay concrete; 2 – made of porous ceramic block; 3 – made of porous arbolite; 4 – made of foam concrete.

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The results of calculating the thermal phenomena of the enclosing structure in the Elcut software package for the steady-state thermal conductivity mode are presented in Figure 5, for an external temperature of - 20°C, in Figure 6 at a temperature of - 30°C. The results of the heat flow and the average temperature inside the wall by thickness are also presented in Table 2 [7,8].

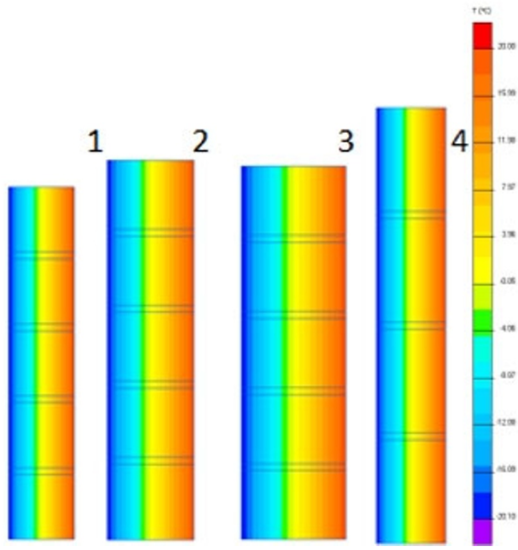

Fig. 5. Results of calculations using the Elcut software package at an external temperature of -20°C: 1 – wall made of expanded clay concrete; 2 – made of porous ceramic block; 3 – made of porous arbolite; 4 – made of foam concrete.

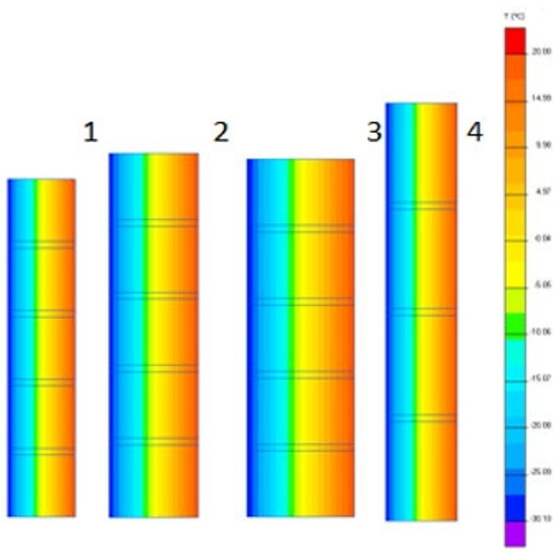

Fig. 6. Results of calculations using the Elcut software package at an external temperature of -30°C: 1 – wall made of expanded clay concrete; 2 – made of porous ceramic block; 3 – made of porous arbolite; 4 – made of foam concrete.

Table 2. Calculation results.

The option under consideration	No.	Temperature - 20°C		Temperature -30°C	
		Heat flow, W/m²	Temperature difference, °C	Heat flow, W/m²	Temperature difference, °C
Expanded clay concrete wall	1	140.38	-2.411	175.47	-1.508
Wall made of ceramic porous block	2	41.662	3.707	52.078	3.9115
Wall made of porous arbolite	3	16.853	-4.406	21.067	-5.3188
Foam concrete wall	4	66.96	1.684	83.7	2.012

To calculate the heating costs of the facility, the following wall materials were selected: 1 – expanded clay concrete; 2 – ceramic porous block, 3 – porous arbolite, 4 – foam concrete. Coal and birch firewood are used as heating materials [8,9].

We take the area of heat radiation of the object as 100 m², to determine the heating costs it is necessary to find the total area of the walls using formula 1:

$$S_{\text{house}} = S_{\text{general}} - S_{\text{doors}} - S_{\text{windows}}, \tag{1}$$

where S_{general} is the total area (we take 100 m²);

S_{doors} – total area of doors (we take 2.27 m²);

S_{windows} – total area of windows (accepts three-wing windows, in the amount of 6 pieces we get 11.388 m²).

$S_{\text{house}} = 100 - 2.27 - 11.388 = 86.342 \text{ m}^2$

Next, we determine the heat losses of the structures under consideration based on the heat flow indicators of the structures (Table 2). We accept the duration of the heating period T = 6 months or 6·30·24 = 4320 hours. We accept the condition according to which 50% of the heating period is at -20°C and 50% is at -30°C. T = 4320/2 = 2160 hours.

$$Q_{\text{losses}} = S \cdot (T \cdot (W1 + W2)), \tag{2}$$

where S is the area of the walls (m²); T is the duration of the heating period; $W1$, $W2$ is the heat flow W/m².

$$Q_{\text{losses1}} = 86.342 \cdot (2160(140 + 175)) = 58747 \text{ W}$$
$$Q_{\text{losses2}} = 86.342 \cdot (2160(42 + 52)) = 17530 \text{ W}$$
$$Q_{\text{losses3}} = 86.342 \cdot (2160(17 + 21)) = 7087 \text{ W}$$
$$Q_{\text{losses4}} = 86.342 \cdot (2160(67 + 84)) = 28161 \text{ W}$$

Calculation of heating costs (for coal and firewood) is made according to formula 3.

$$Sp_{coal} = (Q_{\text{losses}}/(T \cdot E)) \cdot C \tag{3}$$

where, Q_{losses} – heat losses, W;

T – heat of combustion of 1 kg of fuel, kW/h;

E – efficiency coefficient of the heat generation plant;

C – price for 1 kg of fuel (we accept - coal 3.7 rubles, firewood 1.5 rubles).

We take the combustion heat of 1 kg of coal as 5 kW/h, the efficiency of the heat generation unit as 50%, then:

$$Sp_{coal1} = (58747/(5 \cdot 0.5)) \cdot 3.7 = 86945 \text{ rub.}$$
$$Sp_{coal2} = (17530/(5 \cdot 0.5)) \cdot 3.7 = 25944 \text{ rub.}$$
$$Sp_{coal3} = (7087/(5 \cdot 0.5)) \cdot 3.7 = 10488 \text{ rub.}$$
$$Sp_{coal4} = (28161/(5 \cdot 0.5)) \cdot 3.7 = 41678 \text{ rub.}$$

We take the combustion heat of 1 kg of firewood as 3.5 kW/h, the efficiency of the heat generation unit as 50%, then:

$$Sp_{\text{firewood1}} = (58747/(3.5 \cdot 0.5)) \cdot 1.5 = 50354 \text{ rub.}$$
$$Sp_{\text{firewood2}} = (17530/(3.5 \cdot 0.5)) \cdot 1.5 = 15025 \text{ rub.}$$
$$Sp_{\text{firewood3}} = (7087/(3.5 \cdot 0.5)) \cdot 1.5 = 6074 \text{ rub.}$$
$$Sp_{\text{firewood4}} = (28161/(3.5 \cdot 0.5)) \cdot 1.5 = 24138 \text{ rub.}$$

The obtained data are summarized in Table 3.

Table 3. Results of calculation of costs for heating the object.

The option under consideration	No.	Heating with coal, rub	Heating with wood, rub
Expanded clay concrete wall	1	86945	50354
Wall made of ceramic porous block	2	25944	15025
Wall made of porous arbolite	3	10488	6074
Foam concrete wall	4	41678	24138

4 Conclusion

With the growth of individual housing construction and environmental problems in the country, it is important to select energy-efficient building materials. Energy-efficient technologies are solutions in construction that will reduce energy consumption and reduce heating costs, creating favorable conditions inside the house. Wall materials that are distinguished by energy efficiency include: ceramic porous block, porous brick, porous arbolite, foam concrete, aerated concrete and expanded clay concrete block, etc.

The object under study in the work was an enclosing structure made of porous building materials for individual housing construction. Four design options were considered. The first option is a wall made of expanded clay concrete 190 mm thick, with alternating cement-sand mortar of 20 mm. The second is a ceramic porous block 250 mm thick, with 10 mm - CSM. The third is porous arbolite 300 mm thick, with alternating CSM - 20 mm. The fourth option is foam concrete 200 mm thick, with alternating CSM - 20 mm. The Elcut simulation program and the Compass 3D automated design system allow calculating the heat loss of enclosing structures. The calculation results using the Elcut software package showed that the heat flux at the wall made of expanded clay concrete is - 140.38 W/m^2, made of porous ceramic block - 41.662 W/m^2, made of porous arbolite - 16.853 W/m^2, foam concrete - 66.96 W/m^2, the data were obtained at an external temperature of - 20°C and an internal temperature of +20°C. For an external temperature of -30°C, the heat flux at the wall made of expanded clay concrete is - 175.47 W/m^2, ceramic, made of porous block - 52.078 W/m^2, porous arbolite - 21.067 W/m^2, foam concrete - 83.7 W/m^2.

The cheapest way to heat the object under consideration is with firewood. The cost of heating the object with birch firewood per month for expanded clay concrete walls is 50.3 thousand rubles, from a ceramic porous block - 15 thousand rubles, from porous arbolite - 6 thousand rubles, from foam concrete - 24 thousand rubles. The cost of heating with coal for expanded clay concrete walls is 86.9 thousand rubles, from a ceramic porous block - 25.9 thousand rubles, from porous arbolite - 10.5 thousand rubles, from foam concrete - 41.6 thousand rubles.

A wall made of expanded clay concrete has the lowest thermal efficiency, has the highest heat flow, and, accordingly, heating costs. A wall made of porous arbolite has the lowest heat flow and heating costs. The use of porous arbolite in the construction of walls in individual housing construction will reduce heating costs and maintain an internal comfortable temperature longer than walls made of the other materials considered allow.

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