# Calculation of energy consumption in the construction of low-rise buildings

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**Abstract.** Low-rise housing construction is a promising segment of the development of the housing construction industry. One of the priority tasks of state policy in advanced countries is to increase energy efficiency in various sectors of the national economy. In the general life cycle, the stage of construction of buildings, despite a relatively short period of time, is a large consumer of energy resources, so the issue of energy saving during the construction of buildings becomes especially relevant. The predominance of manual labor, as well as the use of low-power construction equipment, significantly affects the reduction of energy consumption at the stage of construction of low-rise residential buildings. However, the widespread use of various technologies for low-rise construction and, as a consequence, differences in design and technological solutions affect the specifics of the use of construction machines and mechanisms. From the standpoint of rational energy consumption, it is advisable to take into account the costs of fuel and energy resources at the construction planning stage. The article proposes tools for calculating the consumption of fuel and energy resources during work on a construction site, identifies the most energy-intensive technology for low-rise housing construction.

**Key words:** energy consumption, low-rise construction, fuel and energy resources, machinery and mechanisms, mechanized work, construction site.

## 1 Introduction

Low-rise housing construction is a promising direction for the development of the construction industry, as evidenced by a number of scientific publications addressing the development of low-rise housing construction [1-3]. At the same time, one of the priority tasks of state policy for the development of the national economy of any country is to increase energy efficiency and energy saving in all sectors of the national economy and production.

The analysis of scientific works on the problem of energy saving [4-6] showed that construction production is a fairly energy-intensive consumer of resources. An increase in the share of low-rise residential buildings in the total volume of housing construction

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determines the need to conduct a comparative assessment of the consumption of fuel and energy resources at the stage of building construction. A review and analysis of studies assessing the development [7-9] and effectiveness [10-12] of programs to reduce energy consumption showed that issues of energy saving during the construction of buildings have not been sufficiently studied.

Currently, various materials and technologies are used in low-rise housing construction: small-piece (brick, stone, lightweight concrete blocks), wooden (cobblestones, frame), as well as energy-efficient construction technologies - panel technology using SIP panels [13-15] and combined technology construction of load-bearing walls of a building from blocks of permanent polystyrene foam formwork [16-17], the advantages of which have been the subject of a sufficient number of foreign studies. As a result of the application of the selected construction technology, the cost structure of fuel and energy resources consumed by energy consumers directly at the construction site is formed.

According to the classification given in the article [18], the main consumers of energy resources during the construction of buildings include:

– construction machines, equipment and tools;

– infrastructure of on-site facilities (construction site and utility camp);

– equipment to ensure the quality of technological processes (heating of concrete, brickwork, etc.).

Since the modern sector of low-rise buildings, by the nature of construction, is characterized by both individually built residential buildings and complexes of buildings in the form of cottage villages [19], the number and structure of energy consumers can differ significantly. Thus, in individual housing construction there is no need to organize a community camp, which affects the reduction of energy consumption during the construction of buildings. In this regard, construction machines, equipment and tools in individual housing construction are the main consumers of fuel and energy resources in the construction of buildings.

Modern construction production should be considered as a comprehensively mechanized process of performing construction work, which is carried out using various machines and mechanisms. Any technological construction processes, both complex and simple, can be classified according to the degree of their mechanization:

– mechanized: performed using construction machines;

– semi-mechanized: performed using both machines and manual labor;

– manual: performed using mechanized tools.

In this case, energy consumption is characterized by power parameters and the number of machines and mechanisms necessary for construction work, which set the vector of energy consumption in low-rise housing construction.

The construction of low-rise residential buildings, as a rule, is associated with the predominance of manual labor and construction equipment with low energy consumption, however, the consumption of fuel and energy resources can be significantly higher when work is carried out using low-rise housing construction technologies using industrial products or high intensification of construction processes. Moreover, the increase in energy consumption depends on the selected geographical location of the construction area and its climatic features, as well as the time of year (seasonality). These factors should also be taken into account at the construction planning stage. As a result, the features of the selected technologies for the construction of low-rise residential buildings form the structure of energy consumption during mechanized work on the construction site.

## 2 Materials and Methods

To conduct the study, the technologies most often used in the practice of low-rise housing construction were adopted:

1) construction of a brick building (option No. 1);

2) construction of a building from expanded clay concrete blocks (option No. 2);

3) erection of a building from polystyrene foam blocks of permanent formwork with filling of the space between the formworks with a lightweight concrete mixture (option No. 3);

4) construction of buildings from SIP panels (option No. 4).

The project of a low-rise residential building with a total area of 190 $m^2$ was chosen as the object of study. The rectangular shape of the selected building allows the use of the technologies in question for its construction.

At the initial stage of the study, the main structural elements of the building were systematized in relation to the low-rise housing construction technologies under consideration, which are shown in Table 1.

**Table 1.** Constructive solutions for building construction using low-rise construction technologies

| **Structural part of the building** | **Technologies** | | | |
|---|---|---|---|---|
| | **Option No. 1** | **Option No. 2** | **Option No. 3** | **Option No. 4** |
| | **Constructive decisions** | | | |
| Foundation | Prefabricated belt made of foundation blocks | Shallow belt prefabricated foundation blocks | Shallow belt prefabricated foundation blocks | Pile |
| Walls | Brick | Made from expanded clay concrete blocks | Made from permanent formwork blocks with the inter-form space filled with lightweight concrete mixture | Made from SIP panels |
| Floors | Reinforced concrete slabs | Lightweight reinforced concrete slabs | Lightweight reinforced concrete slabs | Floor slabs made from SIP panels |
| Roof | Gable rafter system covered with metal tiles | Gable rafter system covered with metal tiles | Gable rafter system covered with metal tiles | Gable made of SIP panels covered with profiled flooring |
| Facade finishing | Facing brick | Facing brick | Decorative plaster mixture | Decorative facade panels |
| Finishing facilities | Plastering walls and ceilings (pre-finishing) | Plastering walls and ceilings (pre-finishing) | Plastering walls and ceilings (pre-finishing) | Textured finishing of walls and ceilings (finishing) |

Based on the adopted design decisions and specified construction parameters for each construction technology, the main organizational and technological parameters were

determined: composition of workers and shifts, labor intensity and duration of work. For each technology under consideration, the composition of energy consumers was determined: machines, equipment and power tools.

The structure of energy consumption varies depending on the type and number of machines and mechanisms used, their power indicators, as well as the duration of mechanized work. Moreover, each of them differs in its type of energy resource consumption (electricity, liquid fuel). In this regard, to bring energy costs to a comparable unit of measurement, it is advisable to measure them in kilograms of standard fuel - kg standard fuel. The conversion of electricity and liquid fuel to conditional was carried out on the basis of the following ratios:

1 kg of standard fuel = 29.3 MJ = 7000 kcal;
1 kWh = 3.6 MJ = 0.12 kg of standard fuel;
1 kg of diesel fuel = 1.45 kg of standard fuel;
1 kg of gasoline = 1.52 kg of standard fuel.

The calculation of fuel and energy resources costs was carried out based on formula (1) proposed earlier in the study [19]:

$$Wuser = Q_{hour} \cdot k_i \cdot T_{day} \cdot T_{work}, \quad (1)$$

where Wconsumer – consumption of fuel and energy resources by consumer i;

$Q_{hour}$ – hourly consumption of various types of fuel and energy resources (energy consumption per hour);

$T_{day}$ – duration of the working day;

$k_i$ – coefficients of conversion of fuel and energy resources into standard fuel according to GOST R 51750-2001;

$T_{Work}$ – duration of work.

Information on fuel and energy resources consumption is determined from the relevant technical data sheets for the selected brands of machines and mechanisms.

## 3 Results and Discussion

As a result, calculations were made for the consumption of fuel and energy resources during mechanized work for the considered low-rise construction technologies. The results of energy consumption calculations are presented in Table 2.

**Table 2.** Consumption of fuel and energy resources in the production of mechanized work for low-rise construction technologies

| Technology | Machinery and mechanisms | Fuel and energy resources consumption, kg standard fuel |
|---|---|---|
| **Option No. 1** | **Excavation works:** | |
| | Bulldozer | 24,0 |
| | Excavator | 18,0 |
| | Mobile compressor with pneumatic rammer | 9,0 |
| | **Concrete works:** | |
| | Concrete | 2,0 |
| | mixer Surface vibrator | 1,0 |
| | **Masonry works:** | |
| | Concrete mixer | 4,0 |

| | | |
|---|---|---|
| | **Installation works:** | |
| | Crawler crane | 153,0 |
| | **Roofing:** | |
| | Saw with carburetor engine | 1,5 |
| | **Finishing works and installation of windows and doors:** | |
| | Mortar mixer | 2,0 |
| | Mortar pump | 12,0 |
| | Hammer | 0,5 |
| | | ∑=227 |
| **Option No. 2** | **Excavation works:** | |
| | Bulldozer | 24,0 |
| | Excavator | 9,0 |
| | Mobile compressor with pneumatic rammer | 7,0 |
| | **Concrete works**: | |
| | Concrete mixer | 0,5 |
| | Surface vibrator | 0,8 |
| | **Masonry works:** | |
| | Concrete mixer | 3,5 |
| | **Installation works:** | |
| | Crawler crane | 99,0 |
| | **Roofing:** | |
| | Saw with carburetor engine | 1,5 |
| | **Finishing works and installation of windows and doors:** | |
| | Mortar mixer | 2,0 |
| | Mortar pump | 12,0 |
| | Hammer | 0,5 |
| | | ∑=160 |
| **Option No. 3** | **Excavation works:** | |
| | Bulldozer | 24,0 |
| | Excavator | 9,0 |
| | Mobile compressor with pneumatic rammer | 5,0 |
| | **Concrete works:** | |
| | Truck concrete pump | 175,0 |
| | Deep vibrator | 9,0 |
| | Concrete mixer | 1,3 |
| | Surface vibrator | 0,5 |
| | **Reinforcement works:** | |
| | Pumping station with reinforcement press | 6,0 |
| | **Installation works:** | |
| | Crawler crane | 136,0 |
| | **Roofing:** | |
| | Saw with carburetor engine | 1,5 |
| | **Finishing works and installation of windows and doors:** | |
| | Mortar mixer | 2,0 |
| | Mortar pump | 14,5 |
| | Compressor with sandblaster | 4,0 |

| | | |
|---|---|---|
| | Hammer | 0,5<br><br>∑=388 |
| **Option No. 4** | **Excavation works:** | |
| | Bulldozer | 24,0 |
| | **Piling works:** | |
| | Mini piling rig | 15,0 |
| | Welding unit | 7,0 |
| | Welding inverter | 10,5 |
| | **Concrete works:** | |
| | Deep vibrator | 0,5 |
| | **Installation works:** | |
| | Automotive crane | 261 |
| | **Roofing:** | |
| | Saw with carburetor engine | 1,5 |
| | **Finishing works and installation of windows and doors**: | |
| | Mortar mixer | 0,5 |
| | Mobile compressor with painting unit Paint | 13,0 |
| | grater | 0,3 |
| | Hammer | 0,5 |
| | | ∑=334 |

The data obtained characterize various quantitative indicators of energy consumption during mechanized work using low-rise housing construction technologies. Figure 1 shows the comparative consumption of fuel and energy resources by machines and mechanisms for the considered technologies for the construction of a low-rise residential building.

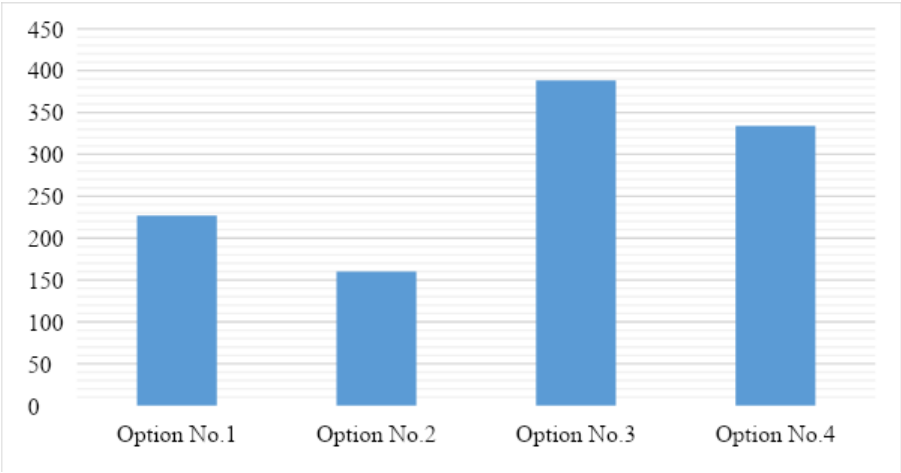


**Fig.1.** Comparative energy consumption in the production of mechanized work on low-rise construction technologies

Based on the presented calculations, the least energy-intensive technologies are those using small-piece materials: expanded clay concrete blocks (option No. 1) and brick (option No. 2). Construction technologies using permanent formwork blocks (option No. 3) and SIP panels (option No. 4) are the most energy-intensive among the low-rise housing construction technologies under consideration. This is explained by the use of technological

machines (concrete mixer truck) and lifting equipment (crawler crane). At the same time, the consumption of fuel and energy resources during mechanized work on the construction of a building made of SIP panels, expanded clay concrete blocks and bricks is respectively lower by 11%, 42% and 59% in comparison with the construction of a building in permanent formwork.

Thus, the consumption of fuel and energy resources will be largely determined by the specifics of mechanization of work in relation to the selected structural and technological solutions of buildings.

## 4 Conclusions

A distinctive feature of low-rise construction with mechanization of work is the possibility of using small-sized and low-power construction equipment, which significantly affects the reduction of fuel and energy resources consumption during the construction of buildings. However, differences in the technologies used for the construction of low-rise residential buildings affect the specific use of construction machines, equipment and power tools and their corresponding energy consumption.

The methodological approaches in the study correspond to the author's approaches devoted to the problem of assessing energy consumption on a construction site during the construction of buildings for various purposes. The selected tools for determining the consumption of fuel and energy resources by machines and mechanisms made it possible to perform a decomposition of construction work with reference to the corresponding construction equipment and mechanized tools. As a result of the calculations, the results obtained make it possible to integrate them into a general data bank on the specific energy costs of constructing buildings using various construction technologies.

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