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Improvement of organizational and technological design of low–rise residential buildings with consumption of fuel and energy resources

In recent years, there has been an active growth in low-rise housing construction in Russia. This trend is explained by the state policy, which is aimed at developing this sector in order to increase accessibility for the population and provide comfortable housing. In addition, the relevance of low-rise housing construction is evidenced by the need of the population in the natural environment, as well as the possibility of living in separate houses. Along with individual construction, the most popular is low-rise housing development in the form of organized residential settlements ("cottage village") with a developed communal, transport and social infrastructure. The regulations define the requirements to ensure the efficient and rational use of fuel and energy resources. This confirms the need to increase energy savings also in the sector of low-rise housing construction.

The article presents the classification of energy consumption by functional purpose in the construction of low-rise residential buildings, identifies the main groups of energy consumers "machines and mechanisms", "temporary infrastructure of the construction site" for complex low-rise residential buildings and considers an algorithm for calculating the costs of fuel and energy resources for these groups. It is proposed to include forms of documents for calculation, accounting and control of fuel and energy resources in organizational and technological documentation. This approach will allow you to choose energy-efficient construction technologies at the design stage and keep track of energy consumption during the construction of buildings.

Keywords: *low-rise construction, organizational and technological design, energy consumption, energy consumption, fuel and energy resources, machines and mechanisms, construction site*



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INTRODUCTION

One of the key directions in construction industry development in recent years is the increase in the share of low-rise residential buildings. Within the limits of state programs for the development of individual housing construction[1] and the provision of citizens with affordable and comfortable housing [2], a direction for the development of low-rise housing construction has been set. In conditions of dense development of urban areas, the increase in the construction of low-rise residential buildings is focused mainly on the development of suburban and agricultural areas [1–3]. According to the Rosstat data (Fig. 1), from 2016 to 2020, the commissioning of multistorey residential buildings per 1,000 residents in urban areas was 2,615 and 3,033 m^2 in rural areas.

These statistical indicators, as well as a number of scientific sources [4–7], indicate a steady trend in the development of the low-rise construction sector.

The priority task of the state policy for the development of the country's economy is to increase energy efficiency in various sectors of the national economy. The requirements of the Federal Law No. 261-FZ "On energy saving and on increasing energy efficiency ..." [3] provide legal regulation in the field of increasing energy saving, and the adopted Energy Strategy of Russia for the period up to 2035 [3] determines strategic long-term planning in the field of energy sector development, ensuring rational and environmentally friendly responsible use of energy and energy resources.

Compliance with the requirements of these regulations must be ensured in the construction industry. In connection with the increase in the share of low-rise housing construction in the total volume of housing construction, the issue of accounting for the consumption of fuel and energy resources in the documents of organizational and technological design becomes urgent.

MATERIALS AND METHODS

Modern low-rise housing development is characterized by a variety of applied technologies and construction materials, the peculiarities of the application of which are devoted to a significant number of studies, including foreign ones [8–12]. The main ones include: traditional (using small-piece materials such as brick, lightweight concrete blocks, stone, etc.); industrial (lightweight reinforced concrete blocks); frame (panel houses); panel (SIP panels); combined (fixed formwork made of expanded polystyrene blocks, chipboard slabs, etc. with filling the inter-formwork space with a lightweight concrete mixture). The features of the selected design and

1 On the approval of the state program of the Russian Federation "Provision of affordable and comfortable housing and utilities for citizens of the Russian Federation": Resolution of the Government of the Russian Federation of December 30, 2017 No. 1710.

2 On the approval of the state program of the Russian Federation "Provision of affordable and comfortable housing and utilities for citizens of the Russian Federation": Resolution of the Government of the Russian Federation of December 30, 2017 No. 1710.

3 On energy saving and on increasing energy efficiency: Federal Law of November 23, 2009 No. 261-FZ.

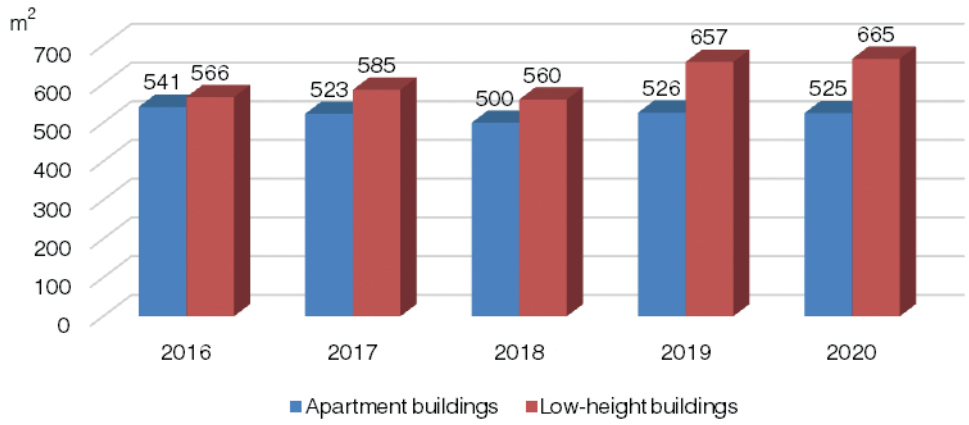


Fig. 1. Commissioning of residential buildings in cities and rural areas (Rosstat data, 2020)

technological solutions form the structure of energy consumption in the performance of work at the construction site.

Analysis of research in the field of energy saving [13–16] showed that the construction stage is quite energy-intensive. Despite the short time period in the general life cycle, the construction stage in terms of average monthly fuel and energy resources is comparable to the operation stage. As a result of the calculations, the obtained quantitative values of the specific energy consumption, presented in Table 1, indicate that the monthly consumption of energy resources during the construction of buildings is more than 3 times higher than the energy consumption during operation.

This is due to the fact that in modern low-rise housing construction, along with the implementation of construction processes using manual labor, preference is given to the comprehensive mechanization of labor using various machines and mechanisms. The execution of mechanized, semi-mechanized and manual mechanized construction processes is carried out using construction equipment, technological equipment and hand tools. In addition, given that the modern nature of the construction of low-rise residential buildings is focused on development in the form of cottage settlements or blocks, additional fuel and energy costs arise associated with the power supply of the temporary infrastructure of the construction site.

As a result of the decomposition of fuel and energy resources, a classification of energy consumption was developed for the construction of a complex of low-rise residential buildings (Fig. 2).

According to the presented classification, all energy consumers of a construction site can be divided into 2 groups:

- related to the production of work (machines and mechanisms);
- related to energy supply (temporary infrastructure of the construction site).

As a result of the conducted studies of energy consumption for various technologies of low-rise construction, it was found that for these groups of consumers, the structure of energy consumption has

Table 1. Comparison of fuel and energy costs in the construction and operation of low-rise residential buildings

Type of energy resources consumed during construction	**The projected cottage quarter in the Moscow region with a total area of 5,730 m²**
Electric heating of temporary household and work premises, electric heating of water for domestic needs	129,267 kWh/7 months
Lighting of the construction site, household and work premises	19,200 kWh/7 months
Electricity consumption by machines, equipment and tools	9,415 kWh/7 months
Diesel fuel consumption by machinery, equipment and tools	6,550 l/7 months
Total consumption of fuel and energy resources	*28,443 kg of fuel equivalent/7 months*
Total unit costs of fuel and energy resources, per month	*0.7 kg of fuel equivalent/m²*
Type of consumed energy resources during operation	**Svetly cottage village in the Pestrechinsky district of the Republic of Tatarstan with the total area of 1,113,788 m²**
Electricity supply for household needs of residential buildings with electric stoves and public buildings	21,262,500 kWh/12 months
Gas supply for heating residential, public buildings and hot water supply	106,161 thousand m³/12 months
Total consumption of fuel and energy resources	*2,678,893 kg of fuel equivalent/12 months*
Total unit costs of fuel and energy resources, per month	*0.2 kg of fuel equivalent/m²*

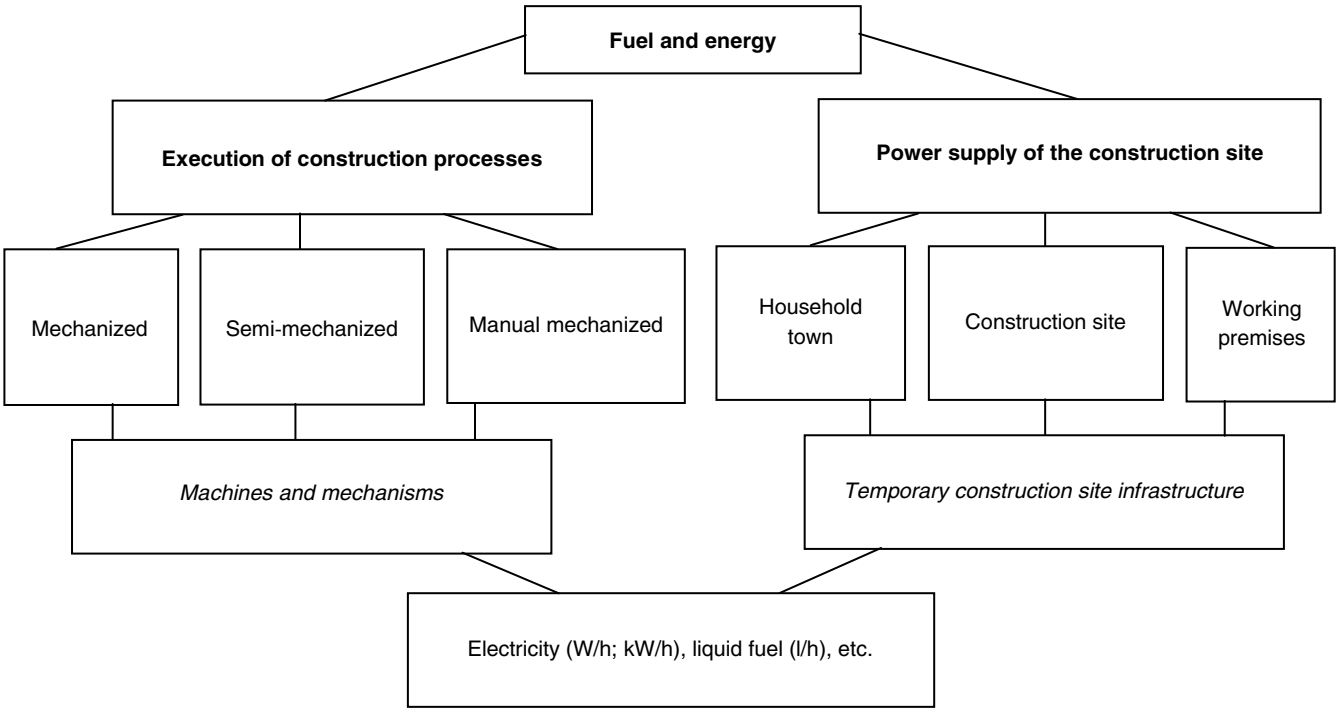


Fig. 2. Classification of fuel and energy costs by functional purpose in the construction of low-rise residential buildings

significant differences (Fig. 3), which should be taken into account in the documents of organizational and technological design.

Calculation and accounting of quantitative values of fuel and energy resources will allow at the stage of development of project documentation to correct and select the most rational options for energy consumption.

The construction of low-rise buildings as part of a complex development is carried out on the basis of organizational and technological decisions that are made in the construction organization project (plan for organization of construction) and the project for the production of works (project for implementation of construction operations). The composition of the plan for organization of construction sections is determined by the Decree of the Government of the Russian Federation No. 87 [4], the project for implementation of construction operations is regulated by SP 48.13330.2019 [5]. So, when developing a plan for organization of construction, the required capacities of energy consumers are calculated in order to connect the construction site to utility networks and ensure their uninterrupted operation during the construction period. In this case, as a rule, the costs of fuel and energy resources are not calculated, and the required capacities are determined with a margin. Given this approach, it is quite difficult to determine the reserves for reducing energy consumption during the construction of the building.

According to the proposed approach for calculating energy costs, the assignment of the composition of energy consumers is carried out in accordance with the selected construction technologies, the adopted organization of work, the climatic characteristics of the area, etc. As a result, the selected brands/models of energy consumers, their purpose (for example, lighting a construction site) and the number for the groups "machines and mechanisms" and "temporary infrastructure of the construction site" are entered in the recommended form presented in Table 2.

Energy consumption is calculated by multiplying the operating time of the consumer by the hourly consumption of fuel and energy resources (l/h, kW/h, etc.), which is determined according to technical data sheets. For comparability of the obtained values in liters, kW, etc. it is advisable to convert all types of energy resources into a commensurate unit, expressed in kilograms of fuel equivalent (kg of fuel equivalent) in accordance with GOST 51750-2001 [6]. As a result, the formula for calculating the costs of fuel and energy resources can be presented in the following form:

$$E_i = Q_i T k, \quad (1)$$

where E_i is the consumption of fuel and energy resources of the i-th consumer, kg of fuel equivalent; T is the duration of work, hour; k is conversion factor into kilograms of fuel equivalent (according to GOST 51750–2001).

To calculate the specific energy consumption (kg standard fuel/m^2), the sum of all the obtained quantitative values of the fuel and energy resources consumption of various consumers is divided by the area of the building being constructed:

$$E_{uc} = \frac{\sum E_i}{S} \quad (2)$$

where E_{uc}. is unit costs of fuel and energy resources, kg of fuel equivalent/m^2; S is the area of the building being erected, m.

4 On the composition of sections of project documentation and requirements for their content : Resolution of the Government of the Russian Federation No. 87 dated February 16, 2008 (as amended on December 21, 2020).

5 Organization of construction. Updated edition of SNiP 12-01-2004: (SP 48.13330.2019) : approved by order of the Ministry of Construction and Housing and Utilities of the Russian Federation of December 24, 2019 No. 861/pr.

6 GOST R 51750-2001. Energy saving. Methodology for determining energy consumption in the production of products and the provision of services in technological energy systems. General provisions: adopted by the Resolution of the State Standard of Russia dated May 21, 2001 No. 211-st.



Fig. 3. The structure of fuel and energy resources during the construction of a complex of low-rise residential waiting areas with walls made of bricks (a), expanded clay concrete blocks (b), fixed formwork (c), SIP-panels (d): — machines and mechanisms; — work premises; — construction site and household town

The described algorithm for determining the costs of fuel and energy resources is made according to the form (Table 3).

As a result, the obtained quantitative values of the fuel and energy resources allow, at the design stage, to correct and select energy-efficient options for the construction of low-rise residential buildings.

To account for energy consumption directly at the construction site, it is recommended to carry out daily monitoring of the fuel and energy resources consumption by entering it into the appropriate form (Table 4).

In order to control energy consumption, at the decision of the customer, a department is appointed by the contractor, developer or design organization, which is located on the territory of the facility under construction. The specified department is equipped with the necessary instrumentation and software. The number of employees of the department is assigned based on the shift of work, the number of objects under construction. The received actual costs of fuel and energy resources are compared with those previously calculated for the project. If the actual costs (E_{fact}) exceed the calculated ones (E_{cal}), the analysis of the actual energy costs is carried out and corrective measures are developed.

CONCLUSION

To achieve rational consumption of energy resources in the limits of the specified requirements of regulatory enactments for energy

Table 2. List of the main energy consumers of the construction site

No.	Name	Brand/ Model	Appointment	Required amount

Table 3. Calculation of the energy consumption of the construction site

№ consumer of fuel and energy resources	Required quantity, pcs.	Hourly consumption of fuel and energy resources	Duration of work, hours	Conversion factor in kg of standard fuel	Fuel and energy resources, kg of standard fuel	Specific costs of fuel and energy resources, kg of fuel equivalent/m^2

Table 4. List of energy consumption of the construction site

Name of consumer	Required amount	Actual expenditures of fuel and energy resources	Conversion factor in kg.	Conversion factor in kg of standard fuel	Fuel and energy costs	Compliance with the calculated values of fuel and energy consumption, $E_{fact} \leq E_{calc}$

saving and increasing the efficiency of the investment and construction process, it is advisable to calculate and take into account energy consumption while preparing organizational and technological documentation at the design stage of low-rise residential buildings.

Improvement of organizational and technological documents in terms of resource provision at the stage of construction planning allows you to analyze and select the most rational technologies from the point of view of energy consumption, design solutions, as well as methods of work at the construction site. An important component of the issue under study is the proposed approach to control the consumption of fuel and energy resources, which makes it possible to keep track of energy consumption at the construction site in the course of work in order to correct and reduce unplanned energy costs.

The developed forms of documents are considered as recommended and can be used by design organizations in the preparation of documentation as part of the plan for organization of construction and project for implementation of construction operations for the construction of low-rise residential buildings of cottage settlements.

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Совершенствование организационно-технологического проектирования малоэтажных жилых зданий с учетом потребления топливно-энергетических ресурсов

В последние годы в России наблюдается активный рост малоэтажного жилищного строительства. Тенденция роста обусловлена государственной политикой, направленной на поддержку развития данного сектора с целью повышения доступности для населения и обеспечения его комфортным жильем. Об актуальности малоэтажного домостроения свидетельствует также потребность населения в природном окружении, возможность проживания в отдельных домах. Наряду с индивидуальным строительством наибольшую популярность приобрела малоэтажная жилищная застройка в виде организованных жилых поселков («коттеджный поселок») с развитой коммунальной, транспортной и социальной инфраструктурой. Принятыми нормативными актами установлены требования по обеспечению эффективного и рационального использования топливных и энергетических ресурсов, что подтверждает необходимость повышения энергосбережения, в том числе и в секторе малоэтажного домостроения.

В статье представлена классификация расходов ТЭР по функциональному назначению при возведении малоэтажных жилых зданий, выделены основные группы энергопотребителей «машины и механизмы», «временная инфраструктура строительной площадки» применительно к комплексной малоэтажной жилой застройке, а также описан алгоритм по подсчету энергозатрат для данных групп. Предлагаются к включению в состав организационно-технологической документации разработанные формы документов для калькуляции, учета и контроля расходов ТЭР. Такой подход позволит выбирать энергорациональные технологии возведения на этапе проектирования, а также вести учет энергопотребления в период возведения зданий.

Ключевые слова: *малоэтажное строительство, организационно-технологическое проектирование, энергопотребление, энергозатраты, топливно-энергетические ресурсы, машины и механизмы, строительная площадка*

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