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Selection criteria of space planning and structural solutions of low-rise buildings

Критерии выбора объемно-планировочных и конструктивных решений малоэтажных зданий

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Ключевые слова: оптимальный выбор; энергоэффективность; комфорт; безопасность; эффективность капитальных вложений; объемно-планировочные и конструктивные решения; малоэтажное строительство

Abstract. The present study is devoted to development of methodology used for optimal selection of space-planning and structural solutions of low-rise buildings. Objective of the study is developing the system of criteria influencing the optimal selection of space-planning and structural solutions of low-rise buildings and structures aimed at enhancing the efficiency of capital investments, energy and resource saving, creating comfortable conditions for the population considering climatic zoning of the construction site. Developments of the project can be applied while implementing investment-construction projects of low-rise housing at different kinds of territories based on the local building materials. The system of criteria influencing the optimal selection of space-planning and structural solutions of low-rise buildings has been developed. Methodological basis has been also elaborated to assess optimal selection of space-planning and structural solutions of low-rise buildings satisfying the requirements of energy-efficiency, comfort and safety, and economical efficiency. Elaborated methodology enables to intensify the processes of low-rise construction development for different types of territories taking into account climatic zoning of the construction site. Development of low-rise construction processes should be based on the system of approaches which are scientifically justified; thus it allows enhancing energy efficiency, comfort, safety and economical effectiveness of low-rise buildings.

Аннотация. Проведено исследование по разработке методики оптимального выбора объемно-планировочных и конструктивных решений малоэтажных зданий. Целью исследования является разработка системы критериев, влияющих на оптимальность выбора объемно-планировочных и конструктивных решений малоэтажных зданий и сооружений, направленных на повышение эффективности капиталовложений, энерго- и ресурсосбережение, создание комфортных условий для населения с учётом климатического районирования местности строительства. Данные разработки могут быть применены при реализации инвестиционно-строительных проектов малоэтажной застройки различного типа территорий на основе местной базы строительных материалов. Разработана система критериев, влияющих на оптимальность выбора объемно-планировочных и конструктивных решений малоэтажных зданий. Разработаны методические основы оценки оптимальности выбора объемно-планировочных и конструктивных решений малоэтажных зданий, отвечающих требованиям энергоэффективности, комфорта и безопасности, экономической эффективности. Разработанная методика позволяет интенсифицировать процессы развития малоэтажного строительства для различного типа территорий с учетом климатического районирования местности строительства. Развитие процессов малоэтажного строительства должно основываться на системе научно-обоснованных подходов, что позволяет повысить энергоэффективность, комфорт, безопасность и экономическую эффективность малоэтажных зданий.

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Introduction

Strategic goal of state housing policy is defined as formation of affordable housing market, meaning economy-class buildings with integration of energy sources, energy-saving technologies, modern materials, and provided with comfortable living conditions for the citizens. In this regards a number of federal programs has been approved; the programs are aimed at integrated land use planning and management, increasing the performance of housing construction development enabling to create comfortable living conditions [1–2].

Special place in this process should be taken by low-rise multiple-flats construction, as this type of construction is considered to be one of the most optimal formats of new territories development where there are no problems with free land plots and these territories are marked with high provision of natural energy producing materials (hydrocarbons, biofuel, etc.).

Increase in growth rates of comprehensive low-rise housing development, expansion of social and transport infrastructure (stimulating social and economic processes) requires development of optimal space-planning and structural solutions of buildings at the design stage depending on its geographical location.

It should be noted that Russia has a great potential in the field of energy efficiency and use of renewable energy sources. However low efficiency of applying energy-saving technologies in construction is a reason of high costs of housing and public utilities during buildings operation. Such a situation testifies on the necessity of rational use of independent heat supply sources in the projects of low-rise housing taking into account climatic zoning.

Integrated approach for optimal selection of space-planning and structural solutions will contribute to increasing the volume of construction of economy-class houses, reduction of its costs, corresponding to the requirements of comfort, safety and energy efficiency of buildings, increasing the amount of citizens being able to improve their living conditions on their own. This will enable to solve the problem of generating capacity deficit on one side and save significant amount of money of owners of houses on the other side [3].

Foreign construction experience is mainly based on environmental protection, i.e. introduction of efficient and profitable measures to reduce greenhouse gas emissions [4]. Housing construction in most countries is considered as a unique system enabling to provide enhancement of new projects. The main directions of system approach are as follows: 1) heating and cooling, 2) hot water, 3) household appliances, 4) lighting, 5) fridges and deep-freezers [5]. More and more countries pass on to renewable energy sources from oil and gas; preliminary calculations show that it allows reduction of energy consumption of building by 60–80% [6]. Within the project CEPHEUS (Cost Efficient Passive Houses as European Standards) five European countries built houses according to the Passivhaus standard from scientific point of view. In order to reduce energy for heating the following measures have been performed: appropriate heat isolation, passive use of solar energy, extra glazing, and active ventilation [7].

Some authors suggest improving the optimal shape of low-rise buildings and defining the optimal building structure that could provide the required capacity of wind power generator [8]. Other authors offer two-stage design optimization approach resulting in high indicators of energy-efficiency. Apart from that, they investigate single-sided ventilation and cross-ventilation models under varied thermal load requirements to compare the preferable design solutions for each scenario [9].

Low-rise construction in Russia is currently one of the most significant reserves of construction complex development that enables to increase the construction growth rate in a down economy. However it needs not only the governmental assistance, but also the strict requirements of legal framework.

Quite large number of research papers are devoted to the issues of standard setting, increasing of requirements to thermal protection of buildings and energy efficiency [10–13]. Authors consider the development history of regulatory requirements to thermal protection, the problems of energy efficiency in construction, requirements of buildings energy efficiency. The mentioned studies are aimed at regulation of irrational consumption of energy sources and maintaining the definite parameters of internal environment inside the building. Conducted research on development of low-rise construction in Russia, they concluded the general projected growth of low-rise construction, including: energy efficiency, economical efficiency and ecological development of low-rise housing

[14]. The most complete typology of low-rise buildings and problems of low-rise housing development on the territory of Russia [15]. Described the principles of formation of space-planning solutions for low-rise buildings and comfortable living [16–17]. The typology of buildings upon the level of their energy efficiency can be found in [18]. The methodology to evaluate the effectiveness of applying energy-efficient measures in buildings [19]. In monograph [20] conducts a complete consideration of energy consumption and primary energy and resource consumption, however, the issues of maintenance costs has not been solved.

The whole complex of studies in energy-efficient buildings and their structures is based on a substantive knowledge basis [21–24]. However, though many studies have been conducted in the field of energy efficiency and energy saving in construction, still they are characterized by fragmentary mature and are not completely systematized upon the special features of regional conditions. Regulatory documents in energy efficiency mostly present results of studies devoted to separate regions [25].

Special attention should be paid to development of new space-planning solutions, search of optimal structural solutions giving a special accent on local materials use, meeting the requirements of energy efficiency, effectiveness of capital investments, comfort and safety and the use of renewable energy sources for engineering systems during the whole life cycle of a building.

Materials and methods

Results of systematization of the objects of low-rise construction necessary for development of classification framework enable to define the criteria for optimal selection of space-planning and structural solutions of low-rise buildings. These criteria can be defined as follows:

1. Safety.
2. Comfort of living.
3. Energy efficiency.
4. Economic efficiency.

Based on the suggested classification and criteria framework the indicators forming methodological environment for selection of optimal space-planning and structural solutions for low-rise buildings have been defined (Fig.1).

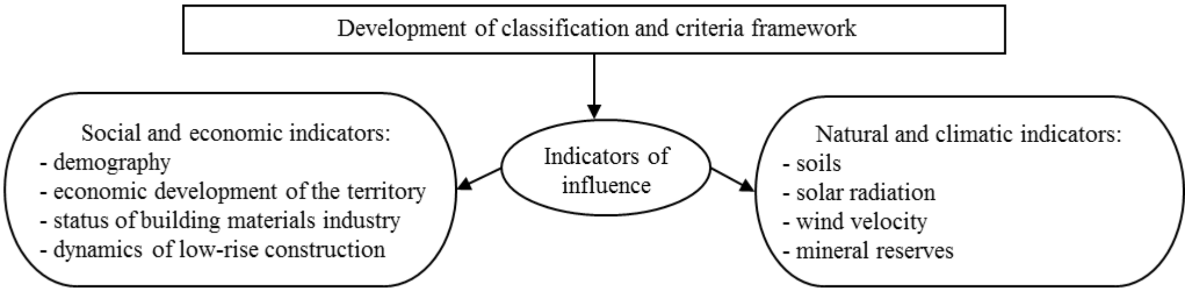

Figure 1. Indicators for defining optimal space-planning and structural solutions of low-rise buildings

Suggested methodology allows moving beyond the traditional schemes of selection of space-planning and structural solutions of low-rise buildings and gives a chance to make an optimal choice using the defined criteria. The resulting matrix is given in Table 1.

The first criterion is defined as safety of living. For that purpose wall materials are typologized by the following features: the degree of fire resistance, structural design of building, thickness of walls, wear degree (for old buildings). Thus we can define the external shell of a building at the initial stage.

The next criterion is defined as comfort of living. The given criterion is classified by the type of territory of living: urban, suburban, rural, remote. Depending on the territory type typological criterion is appropriate to be classified by the ratio of land plot area to the total area of the building. Low-rise buildings of economy class are required to have the definite land plot area. Total area of house land plots depends on the territory of living. The number of floors is typologized up to three floors.

The next criterion is building typology according to energy efficiency. It includes energy efficiency of structural elements of low-rise building and type of energy supply. In order to assess heat protective properties of building envelopes we need to define the climatic conditions of the construction site. Construction-based climatic zones are defined to find optimal design and space-planning solutions of urban low-rise housing construction for each of the zones.

All residential units referring to the group of economy-class housing should correspond to the requirements influencing the energy efficiency of buildings; the energy consumption is checked with respect to accordance to the established standards. Energy efficiency classes are established in accordance with the acting regulatory documents.

Apart from building envelopes being the main reserve of energy saving one also needs reasonable interlinked arrangement of energy sources and energy consumers (electricity, heating, gas), reducing expenses for transportation. Selection and justification of applying centralized, locally-centralized and local systems of engineering equipment depends on the type of living territory. Selection of independent energy sources and non-renewable energy sources depends on the opportunity to provide engineering specifications for connection to urban network.

The final stage is the criterion of capital investments. It is formed from the construction cost, cost for engineering systems of a building, total expenses for operation of building during the whole lifecycle.

Total expenses for construction and building operation will enable to define the effectiveness of capital investments per square meter by comparative method with traditional systems. Resulting from calculation we get construction cost of low-rise building and cost per square meter during the whole life cycle of a building.

Results and Discussion

Foreign experience of many countries shows the need to improve the requirements for ensuring the required energy efficiency in buildings [26]. One of the important tasks for today is to determine the optimal typology of buildings depending on climatic conditions. Recently, the building typology is being developed and enhanced all over the world. In EU countries, in the USA, and in China they use the project on building typology named TABULA. The number of building types differs in different countries, e.g. there are 14 types in the USA, 72 in Spain [27].

Consideration of these recommendations in the practice of modern housing construction can serve the basis for establishing novel advanced tendencies in architecture of comprehensive low-rise housing construction both in space-planning as well as in structural solution of low-rise houses meeting the requirements of energy-efficiency.

This section will be devoted to building of energy efficient low-rise house and its justification applicable to the chosen type of space-planning and structural solutions, contributing to increase of energy-efficiency, safety, comfort of living and economic effectiveness.

The area under study is presented by territory of continental climate of temperate zone, where low-rise houses are in higher demand from the point of social and economic development of newly developed territories.

The suggested methodology considers low-rise house of block-type. Low-rise multi-apartment residential building (block) is given as a two-storey building with the sizes in outer axles 9.6 m x 8.0 m, with a built-in garage (Fig.2). The number of blocks depends on the social necessity and the amount of money allocated from the budget. Space-planning solution provides standard insolation of all the premises for long-term presence of people.

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Table 1. Typology of low-rise buildings while optimal selection of space-planning and structural solutions by the criteria of safety, comfort of living, economical effectiveness of capital investments

Typology of low-rise buildings by energy efficiency criterion

typological feature, boundary / calculated value			Given condition – climatic areas of construction: IA, IB, IC, ID, IIA, IIB, IIC, IID, IIIA, IIIB, IIIC, IIID, IVA, IVB, IVC, IVD
Structural elements	Exterior walls	One-layered	
		Two-layered	
		Multi-layered	
	Insulant	Organic base	
		Inorganic base	
		Mixed type	
		Reflecting type	
	Façade finishing	Selection is additional	
	Translucent structures	Selection is additional	
	Foundation	Mat	
		Strip	
		Detached	
	Roof	Sloped	
		Flat	
Energy efficiency class of a building	A++		
	A+		
	A		
	B+		
	B		
	C+		
	C		
	C-		
	D		
	E		
By energy supply type	Centralized		
	Locally-centralized		
	Local		

Typology of low-rise buildings by safety criterion

typological feature, boundary / calculated value		Given condition – wall material: Wall material (brick, wood, light concrete, foam concrete)
By fire resistance	I	
	II	
	III	
	IV	
By structural solution	Frame	
	Frameless	
	Volume-block-type	
Service life by groups of solidity	I	
	II	
	III	
	IV	
	V	
Wear %	Up to 30	
	30–60	
	More than 60	

Typology of low-rise buildings by comfort of living criterion

typological feature, boundary / calculated value		Given condition – type of territory for living: Urban	Suburban	Rural	Remote
Ration of land S to total S of a building, m^2/m^2	2/1				
	4/1				
	6/1				
Number of floors	1				
	2				
	3				
The level of capital improvement, %	50%				
	75%				
	100%				
Level of lightning, lx	up to 50				
	50–100				
	100-150				
Level of noise in residential buildings, dBA	up to 30				
	30–45				
	no more than 55				

Typology of low-rise buildings by the criterion of economic effectiveness of capital investments

typological feature, boundary / calculated value		Given condition – type of building: Detached	Block-type	Blocks of flats
Cost 1 m^2	up to 3 minimum monthly wage			
	from 3 to 5 minimum monthly wage			
	from 5 to 7 minimum monthly wage			
	more than 7 minimum monthly wage			
Operation costs 1 m^2 per month	up to 0.2% of the average wage in region			
	up to 0.2–0.6% of the average wage in region			
	up to 0.6–1% of the average wage in region			
	higher than 1% of the average wage in region			

While designing foundations we considered the most peculiar soils of the selected region, as well as the existing experience of design, construction and maintenance of buildings in similar engineering-geological and hydro-geological conditions. For block-type low-rise houses built in temperate zone of continental climate it is reasonable to apply two variants of foundation:

1. Slightly in-ground foundations (belt-type monolithic).

2. Helical metal or bored piles.

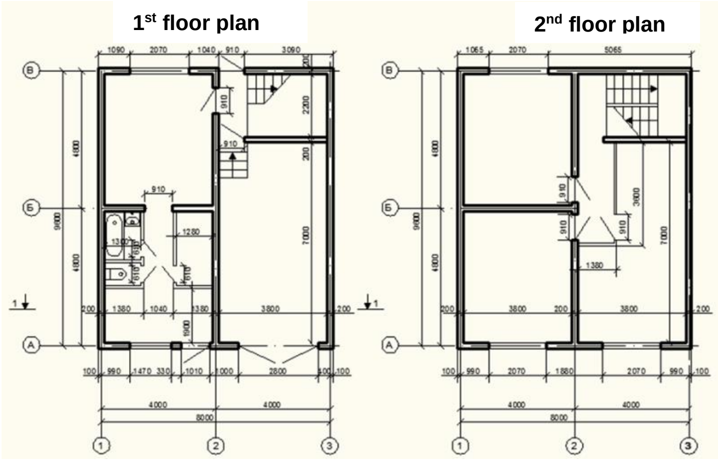

Figure 2. Space-planning solutions of low-rise block-type residential building

Thermal design of exterior building envelope is made in accordance with Russian Construction Codes: “Thermal protection of buildings. Revised edition of Construction Rules and Regulations 23-02-2003” and Construction Codes 131.13330.2012 “Construction Climatology”. Outer shell is calculated as a plane wall separating air environment with different temperature and humidity, constrained by parallel surfaces and transverse to heat flow. Nominal value of reduced total thermal resistance of building envelope satisfying the requirements of sanitary-and-hygiene and comfort is calculated by Construction Codes 50.13330.2012 “Thermal protection of buildings. Revised edition of Construction Rules and Regulations 23-02-2003”. As a load-bearing layer of the exterior wall the following options have been considered: ceramic brick, gas-concrete block, timber (pine-tree), wall panel from expanded clay concrete [28].

Two types of roofing can be used in the designed building: inclined and flat. Corresponding calculations have been conducted. Building materials under study are reliable and durable, correspond to the climate conditions. Variability of choice is conditioned by minimum cost of material.

Optimal technical solutions with reduced energy consumption have been justified by the method of multiple-choice design of energy-saving equipment for low-rise buildings. Comprehensive use of energy-saving building envelopes and renewable energy sources allows solving completely the problem of energy supply considering the requirements of energy efficiency, economical feasibility and comfort of living during building maintenance. In particular the schemes of energy supply have been justified, such as centralized, local and new developed locally-centralized.

Heat balance of building, heat losses for heating of infiltrating air has been defined by means of calculations. Calculation of heat losses through building envelopes has also been conducted. We defined hot water and heat expenses. Resulting from the calculations it was decided to use the combined heat supply system. The basic system is heat pump; solar collectors provide the necessary covering of expenses for hot water supply. Wind power generators cannot be used at the chosen territory of residential buildings due to restrictions of noise exposure.

Taking into account the condition of maximum energy-saving for low-rise buildings of block-type we accept horizontal heating system with placement of heat pump in the technical room. In the periods of peak loads corresponding to the periods of long-lasting low outside temperatures the conditions of comfort in the rooms do not worsen due to using diesel generator, placed in each garage of the flats. Hot water supply per one block-section requires settlement of 13 solar collectors with total surface of 26 square meters.

Ventilation system is natural. Data recording on energy resource consumption is performed automatically by means of dispatcher system.

While designing low-rise building special attention has been paid not only to financial effectiveness of construction but also to the operation effectiveness. Thus, effectiveness indicator is multi-component, as the present project considers effectiveness during construction and during further building operation. Economy during construction has been reached by means of integration of optimal design solutions enabling to increase thermal protection of building envelopes and by means of equipment (in case of absence of such equipment for heating of low-rise building we would have to build a boiler-house thus leading to additional expenses). Operation effect has been obtained by means of economy on communal public services, heating and hot water supply in particular [29].

While calculating the effectiveness of capital investments of low-rise buildings of block type per accounting period we consider costs of building materials, construction and installation works, costs of replacement or repair, service life, cost per one year of operation. Calculations of further results and expenses within one accounting period (time horizon) accepted as 30 years have been conducted. Calculation step has been accepted as a one year [30].

Results of thermotechnical calculation of building envelope, glazing and doors, roofing and flooring have been taken as a basis. Energy systems: heating system, hot water supply for domestic needs, water disposal system. Comparative results of initial capital expenses and annual expenses for building structures are given in Table 2.

Table 2. Comparison of costs of building materials of low-rise building

Material of building envelope	**Capital expenditures for building structures, rub per square meter**	
	Total cost of the building	Cost per one year of operation considering replacement or repair
1. Brick	15487	310
2. Aerated concrete	19624	392
3. Beam	13929	279
4. Expanded clay concrete	20189	404

Comparative analysis has been held for centralized, locally-centralized and local heating systems of low-rise block-type house. Comparison of cost of heat energy from different sources is given in Table 3.

Table 3. Comparison of cost of heat energy from different sources

Indicators	**Value**
Cost per 1 kW of electric energy, rubles	3.1
Cost per 1 kW of heat energy obtained from heat pump, rubles	0.4
Cost per 1 kW of heat energy obtained from gas-fired boiler, rubles	0.5
Cost per 1 kW of heat energy according to tariff of company TGC-11 (Tomsk, Russia), rubles	3.24

Tariff that is used by Public limited company TGC-11 for selling of heat is 8.1 times higher than cost for heat from heat pump and 6.48 times higher than cost from gas-fired boiler. Thus it can be seen that using heat pumps is more profitable from the point of communal expenses. Using locally-centralized system of heat supply allows reduction of heating expenses due to economy of unit of heat energy.

Utility payments have been calculated depending on the type of energy supply (Table 4).

Table 4. Comparison of utility payments by different type of energy supply per year

Indicators, rubles	Type of energy supply		
	Centralized	Locally-centralized	Local
Annual expenses for heating, rubles	548	58	72.5
Annual expenses for hot water supply, rubles	267.47	Considered in heating	37.9
Operation costs per year, rubles	20	Not required	Not required
Maintenance and seasonal operations per year, rubles	0	0	33
Total, rubles	835.47	58	143.4

Calculation results have shown that cost per one square meter of heating while using centralized heat supply is 14.4 times higher than of locally-centralized heat supply with the use of heat pumps and 5.8 times higher than while using gas-fired boiler.

Resulting from calculations of economical efficiency of block-type low-rise building the least expenses for building structures are provided by beam house. Capital expenditures for components of building structures made from wood considering replacement or repair comprise 13929 rub/m^2 per one block-section. Cost of building per one year of operation makes 279 rub/m^2 per one block-section.

Total annual economic effect is reached by using locally-centralized type of energy supply in comparison with centralized and local type in calculation per one block-section. Cost of utility services (hot water supply + heat supply) by locally-centralized type of energy supply per year makes 58 rub/m^2.

Conclusions

The system of criteria influencing the optimal selection of space-planning and structural solutions of low-rise buildings satisfying the requirements of energy-efficiency, comfort and safety, economical effectiveness has been developed. Resulting from the suggested methodology we decided to accept the option of block-type. By means of increasing thermal protection of building envelopes we get economy of energy sources during building operation.

Optimal technical solutions of energy provision of low-rise buildings of block-type have been justified. During comprehensive development of low-rise buildings of block-type at the newly developed territories which do not have access to heat network, the optimal solution is use of local type of energy supply. Increasing the level of applied technical solutions leads to increased value of capital expenditures for construction, however the effect is reached by means of economy of fuel and energy resources and social protection of the population.

Methodology of effectiveness of capital investments of block-type low-rise buildings enabled to define the operation costs per one square meter in a year. Resulting from calculations of further expenses and results within the limit of accounting year the most economically feasible is the option of residential building of block-type made from wood. Calculations demonstrate that due to heat economy, increase of lump-sum costs will pay off within 5 years.

The objectives solved within the project allowed justifying the technical capability and economical feasibility of building low-rise energy-efficient buildings of economy class. The maximum energy-saving effect can be reached during comprehensive consideration of space-planning and structural solutions and using renewable energy sources during constriction of engineering systems.

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