Energy-efficient indicators of panel housing mass construction in the climatic conditions of central Russia

Artem Modin 1, Mikhail Lukin 1, Anton Vlasov 1 and Ezzy Hisham 2

1 Vladimir State University named after Alexander and Nikolay Stoletovs, Vladimir, Russian Federation
2 Foster + Partners, Farwaniya, Kuwait

art_modin@mail.ru

Abstract. For the design of energy-efficient buildings, it is only necessary to ensure balanced energy consumption. The definition of energy efficiency is inextricably linked to compliance with requirements and economic costs. The concept of energy efficiency does not only apply to a new building. The new design used all the necessary elements. The use of single-layer prefabricated panels in new construction allows for external insulation taking into account the overlap of all monolithic joints. One of the potentially promising methods of thermal insulation of outdoor structures is the use of liquid-ceramic (thermal insulation) coatings. In the course of the study, it was concluded that the surface temperature of the reinforced concrete panel when using two different insulation options has similar indicators. But the difference in the values of the heat flux is 36.2%, i.e. when using liquid-ceramic insulation, the amount of heat transferred through the wall panel is more by 9.67 W/m². Economic calculation shows that the use of liquid-ceramic insulation has a positive economic effect in comparison with the classical method of wall insulation by 19.56%.

1. Introduction

The issue of energy efficiency of buildings is not new, but remains relevant both in world and domestic practice. During this time, in addition to the term “energy-efficient building”, such as “passive buildings”, “energy-active buildings”, “zero buildings”, “green buildings” and many others have appeared, often changing concepts and confusion about which building in which context in question.

If we turn to foreign experience, the energy efficiency of buildings is considered quite broadly and covers various areas of construction of buildings and structures. For example, tests are being conducted on the impact of climate change for the countries of Southern Europe and the Mediterranean, on the energy efficiency of light steel residential buildings. [1]. Energy is always an important factor in housing developments. Over the years, a number of energy-saving technologies have been developed to reduce primary energy consumption and the use of renewable energy in architectural projects. If we talk about energy efficiency as a set of measures and the interaction of various engineering and commercial structures, then we can say that this is a game process between various stakeholders [2]. If we talk about energy efficiency as a set of measures and the interaction of various engineering and commercial structures, we can say that this is a game process between different stakeholders.
It is worth noting that the concept of energy efficiency applies not only to new buildings, but also should be taken into account when reconstructing existing ones [3]. Existing residential and public buildings that meet the requirements for energy efficiency have imperfect heat protection indicators, which causes a low level of internal thermal microclimate, as well as a significant specific energy consumption per unit area, often these indicators are 2-3 times higher than in Europe and America. Research shows that energy consumption and operating costs of reconstructed residential buildings can be significantly reduced using simple principles of energy conservation. This experience is already actively used, so in the US there are “zero-energy buildings” or “Zero-Energy Buildings” [4]. Zero-energy buildings are buildings that do not require additional energy sources. In the environment, the concept of energy is often used to describe the balance between the energy used by a building and its occupants, as well as the systems and energy produced by its renewable energy systems [5]. The European Directive on buildings with virtually zero energy consumption (NZEB, ED 2010/31 / EU) stipulates that starting from 2021; all new buildings will be considered to have almost zero energy consumption related to primary energy. This new condition has many implications in how buildings are designed, as well as in how cities will perform from an energy point of view. In fact, buildings will need to integrate renewable energy sources to provide the energy they need, they will transform from energy consumers to energy producers. Buildings will be a kind of “threshold” between the city and people where energy is exchanged. This shift in the future will affect not only how buildings are built, but also how the energy system is built [6-7].

The European design experience suggests improving the energy efficiency of buildings by using modern materials that can serve as both enclosing structures and load-bearing ones. For example, ultra-light concrete (ULWC) was recently introduced as a new building material that combines moderate thermal insulation properties and the necessary load-bearing capacity. Its intended use as a monolithic structure opens up new possibilities in building physics, combining the characteristics of both heavy and light types of structures. The unique combination of thermal insulation and structural properties of ULWC allows creating an innovative building concept that meets energy-efficient requirements.

Returning to the issue of reconstruction of existing buildings in order to improve their energy efficiency, it is worth noting the economic component. In this case, it is possible to conduct an experience of evaluating the economic benefits of the reconstruction of apartment buildings as the basis for cost-optimal energy efficiency strategies in Estonia. The results showed that over a 20-year period, there are two options for national energy policy: the quality of life and the cost of assets, caused by a complex reconstruction at a cost of 160 euros/m², or an alternative non-energy-efficient repair in 31 euros/m². The study confirms that investments in energy efficiency are not only important for the environment, but also provide economic benefits at the level of individuals and the state budget. Russian researchers have also proposed a mathematical model to evaluate the discounted payback period for investments, aimed at reducing the energy resources consumed in the building. As a result of the study, it was concluded that factors that positively affect the reduction in the discounted payback period of investments in energy conservation are: a decrease in interest rates on loans; reduction in inflation and risks; increasing the energy-saving potential of the implemented technical solution; decrease in the amount of initial investment [8-9]. Taking into account all the above, we can conclude that the issue of energy efficiency in the world practice occupies a large share in terms of both new construction and existing buildings through their reconstruction. Requirements for the energy performance of buildings are defined in a number of basic standards: EN 15603 and EN 15217. Most residential buildings in use in the Russian Federation do not meet modern standard requirements for thermal insulation of outer shells, which have increased significantly since 2000. For the design of energy-efficient buildings, it is important not only to achieve balanced energy consumption, but also to ensure high quality parameters and thermal comfort in the room, as well as minimize environmental impact. Based on the above, the following definition is proposed: "an energy-efficient building is a structure that meets the regulatory requirements for safety and reliability, the combination of planning, design and engineering solutions that provides the necessary level of consumer comfort at standard or
lower energy costs throughout the entire life cycle". Solving problems related to improving the energy efficiency of buildings has a long-term period. In this case, a comprehensive solution must be provided, which is reflected both in regulatory documents and accompanied by modern materials and production technologies:

- improvement of architectural and construction solutions of buildings and structures;
- use of non-traditional renewable energy sources;
- optimization of systems for ensuring the microclimate of buildings and structures.

Improvement of architectural and construction solutions is one of the main methods of increasing energy efficiency of mass buildings. Large-panel houses made of precast concrete panels have a significant share of the total development in Russia. According to regulatory requirements, it is not allowed to design buildings with energy-saving class "D" and "E". However, most of the operated buildings and structures were built according to the requirements of regulatory documents of previous years and do not meet the more "strict" requirements of the current standard. Therefore, to improve the energy saving class it is necessary to reconstruct such buildings [18], and the construction of new houses made of precast concrete must meet the current requirements.

In new construction, as well as in reconstruction, plaster and curtain systems are used as external wall insulation [19,20]. The use of single-layer prefabricated panels in new construction allows for external insulation, taking into account the overlap of all monolithic seams. One of the potentially promising ways to insulate exterior structures is the use of liquid-ceramic (thermal insulation) coatings [21,22]. Liquid thermal insulation coatings are a suspension of a polymer binder [23]. Manufacturers of such compositions declare a thermal conductivity coefficient of 0.001-0.0015 W/(m·K). These indicators are achieved by the presence of vacuumed microspheres in the binder with a thermal conductivity coefficient of 0.00083 W/(m·K) [24]. Today, the use of liquid-ceramic coatings is skeptical among specialists in the field of heat engineering. This is explained by the insufficient number of studies and practical tests. Despite this, a method for determining the thermal conductivity coefficient of a flat sample with a layer of liquid thermal insulation is proposed in [25]. The study found that an increase in the coating thickness from 1 to 6 mm increases the thermal conductivity from 0.0358 to 0.0739 W/(m·K), respectively. The main characteristics thermal properties heat-insulating coatings is the thermal conductivity and emissivity. The thermal conductivity coefficient is particularly affected by the amount of heat-insulating filler, as well as the coating structure, which depends on the volume concentration of the mixture of pigment and filler [26]. When testing flat sample with an insulating coating by the method of stationary flow allows to determine the coefficient of thermal conductivity depending on the thickness and density of stationary heat flow on the temperature regime of the surface coating with outer and inner sides. Thus, in [27], a heat-insulating paint coating with a thermal conductivity coefficient of 0.0078 W/(m·K) was developed. This composition is intended to increase the thermal insulation of load-bearing and enclosing structures. Based on this, we can make an assumption about the need for research and additional testing of liquid thermal insulation materials for use in civil construction and reconstruction of residential buildings.

2. Methods
Analysis of the structure of heat losses shows that for residential buildings, heat losses through walls make up 20-35% of the total heat losses, conductive heat losses through Windows 25-35%, heat losses due to cold air infiltration are estimated at 15-20%, heat losses through the roof 5-15%, through basement floors and floors 3-7%, heat losses through doors taking into account infiltration reach 2–10% of the total heat loss of buildings [28].

According to the table.2, the main heat loss occurs through walls, Windows, as well as through the exit of warm air through seams, process holes, etc. in order to reduce the share of heat loss, it is recommended to perform a number of design measures:

- insulation of walls from the outside;
- replacement of window and door blocks with energy-saving ones;
- device for thermal insulation of structural seams.
Each method for improving energy-efficient indicators of residential pulp requires the necessary investment of funds, the payback period of which depends on the chosen method. Insulation of walls and structural seams is a long-term investment that pays off, but gives the highest performance.

### Table. 1 Shares of heat losses through the enclosing structures of a panel house

| Building            | Share of heat losses, % |
|---------------------|-------------------------|
|                      | Walls | Infiltration | The attic | Basement | Windows and doors |
| 9-storey panel house | 24.8  | 20.5         | 7.9       | 3.9      | 42.9              |

### Table. 2. Technical and economic indicators of energy saving measures.

|                      | Even | Payback | Efficiency evaluation |
|----------------------|------|---------|-----------------------|
| Replacing window and door blocks with energy-saving one |      | 9-12 years | 23-30%               |
| External wall insulation |      | 7-25 years | 10-27%              |

To perform a technical and economic analysis, a single-layer reinforced concrete panel with a thickness of 160mm with external insulation is considered: a) using mineral wool; b) using a liquid ceramic coating. Heat loss modeling was performed in the Elcut software package. Two stationary calculation schemes are modeled using different types of insulation. A finite element grid is constructed for both schemes. The boundary conditions of the external and internal temperature are set: -28 °C and +22 °C, respectively.

![Figure.1 Design scheme. 1-reinforced concrete wall panel; 2-mineral wool insulation; 3-decorative plaster; 4-liquid ceramic insulation.](image)

### Table. 3 Characteristics of the materials used

| No | Material          | Material density, kg / m³ | Thermal conductivity, W/m-K | Specific heat capacity, kJ / kg °C |
|----|-------------------|---------------------------|----------------------------|-----------------------------------|
| 1  | Reinforced wall panel concrete | 2 500 | 1.69 | 0.84 |
| 2  | Mineral wool insulation | 120 | 0.045 | 0.84 |
| 3  | Decorative plaster | 1 800 | 0.58 | 0.84 |
3. Results and discussion

Based on the results of modeling the map of temperature fields, the main comparative indicators presented in table 4 are obtained. To analyze the distribution of heat losses, the reinforced concrete panel is divided into 4 conventional faces of 40 mm each. The internal temperature of the panel and the value of the heat flow were determined in each face. Analyzing the data obtained, we can conclude that the surface temperature of the reinforced concrete panel when using two different options of insulation has similar indicators. But the difference in the values of the heat flow is 36.2%, i.e. when using liquid ceramic insulation, the amount of heat transferred through the wall panel is 9.67 W/m² more.

| 4 | Liquid-ceramic insulation | 509 | 0.0012 | 1.08 |

**Figure 2.** Calculation model (finite element grid) and distribution of temperature fields for a scheme using mineral wool thermal insulation boards

**Figure 3.** Calculation model (finite element grid) and distribution of temperature fields for a scheme using liquid-ceramic insulation
Table. 4 Temperature field simulation results

| № | Type of insulation | Surface temperature of the conditional face, °C | Heat flow, W/m² |
|---|-------------------|---------------------------------------------|-----------------|
|   |                   | 1   | 2   | 3   | 4   | 1   | 2   | 3   | 4   |
| 1 | Mineral wool insulation | +20 | +19.36 | +18.25 | +17.25 | 17.02 | 17.02 | 17.02 | 17.02 |
| 2 | Liquid-ceramic insulation | +20 | +19.26 | +18.34 | +17.47 | 26.69 | 26.69 | 26.69 | 26.69 |

An economic comparison of the use of two types of insulation per 100m² of reinforced concrete wall panel is presented in table 5.

Table. 5 Economic comparison

| Insulation using mineral wool slabs | Insulation with the use of liquid ceramic material |
|-----------------------------------|-----------------------------------------------|
| Cost name                         | The cost of dollar/m² | Cost name             | The cost of dollar/m² |
| Preparatory and main works        | 20.1                             | Preparatory and main works | 20.76 |
| Materials                         | 13.34                            | Materials             | 6.15  |
| Labor costs                       | 0.021                            | Labor costs           | 0.005 |
| Subtotal:                         | 33.46                            | Subtotal:             | 26.91 |

Economic calculation shows that the use of liquid ceramic insulation has a positive economic effect in comparison with the use of the classical method of wall insulation by 19.56%.

4. Conclusions

Based on the results obtained, we can conclude:

1. The need to improve energy efficiency indicators in new and reconstructed homes remains relevant both in foreign countries and in the territory of the Russian Federation.

2. A method of wall insulation using a liquid-ceramic material as a part of a binder of vacuumed microspheres with a low coefficient of thermal conductivity is considered.

3. A comparative calculation of heat losses for two types of insulation is carried out: with the use of mineral wool insulation and liquid ceramic insulation.

4. We have obtained data showing that the use of liquid ceramic insulation with a layer of 3 mm is an effective method of insulation, and has a positive economic effect in comparison with the insulation of mineral wool slabs with a thickness of 120 mm.

5. The use of liquid-ceramic insulation in civil construction, in particular in the reconstruction of panel buildings is a new direction and requires additional study of the properties of this material and its use in various regions of our country.

In addition, it is worth noting that the study of liquid-ceramic insulation and similar materials with bonded vacuum microspheres is carried out abroad. So in [17] describes the use of “active thermal insulation” of the walls of a building. And in [18-19] the work of nano-bases for thermal insulation of energy-efficient buildings using vacuum insulation panels is described. The article [20] presents the results of the development of a charge composition based on low plastic clay with the addition of unplasticized polyvinyl chloride waste as an additive, which allows increasing the bearing capacity on the foundation during construction and reducing thermal conductivity and, as a result, increasing the
energy efficiency of the material. All of the above speaks of the relevance of the development of new thermal insulation materials that can be used to improve the energy efficiency of buildings and individual structures.

References

[1] Gorshkov A S, Rymkevich P P, Nemova D V and Vatin N I 2017 Method of calculating the payback period of investment for renovation of building facades Constr. Unique Build. Struct.
[2] Gorshkov A, Vatin N, Nemova D, Shabaldin A, Melnikova L and Kirill P 2015 Using life-cycle analysis to assess energy savings delivered by building insulation Procedia Engineering
[3] Nuriev A F, Evstigneeva Y V. and Ibragimov R A 2020 Energy-saving Technologies for Construction in Extreme Climatic Conditions IOP Conference Series: Materials Science and Engineering
[4] Torlova A, Vitkalova I, Pikalov E and Selivanov O 2020 Development of Facade Facing Ceramics with Self-Glazing Effect and Increased Energy Efficiency Advances in Intelligent Systems and Computing
[5] Kolosova A S, Pikalov E S and Selivanov O G 2020 Heat-insulating composite material based on wood and polymer waste Ecol. Ind. Russ.
[6] Chukhlanov V Y, Selivanov O G, Trifonova T A, Ilina M E and Chukhlanova N V. 2017 Thin-layer thermal insulation coatings based on high-filled spheroplastics with polyorganosiloxane binder IOP Conference Series: Earth and Environmental Science
[7] Ramos J S, Delgado Mc G, Dominguez S Á, Félix J L M, de la Flor F J S and Rios J A T 2019 Systematic simplified simulation methodology for deep energy retrofitting towards NZE targets using life cycle energy assessment Energies
[8] Vatin N, Sultanov S and Krupina A 2019 Comparison of Thermal Insulation Characteristics of PIR, Mineral Wool, Carbon Fiber, and Aerogel Advances in Intelligent Systems and Computing
[9] Vitkalova I, Torlova A, Pikalov E and Selivanov O 2019 Energy Efficiency Improving of Construction Ceramics, Applying Polymer Waste Advances in Intelligent Systems and Computing
[10] Shakhova V N, Vitkalova I A, Torlova A S, Pikalov E S and Selivanov O G 2019 Receiving of Ceramic Veneer with the Use of Unsorted Container Glass Breakage Ecol. Ind. Russ.
[11] Vitkalova I, Torlova A, Pikalov E and Selivanov O 2019 The Development of Energy Efficient Facing Composite Material Based on Technogenic Waste Advances in Intelligent Systems and Computing
[12] Korniyenko S V. 2018 Renovation of Residential Buildings of the First Mass Series IOP Conference Series: Materials Science and Engineering
[13] Baranova D, Sovetnikov D and Borodinecs A 2018 The extensive analysis of building energy performance across the Baltic Sea region Sci. Technol. Built Environ.
[14] Encinas F, Marmolejo-Duarte C, Sánchez de la Flor F and Aguirre C 2018 Does energy efficiency matter to real estate-consumers? Survey evidence on willingness to pay from a cost-optimal analysis in the context of a developing country Energy Sustain. Dev.
[15] Tarasova D S and Petritchenko M R 2017 Buildings quasi-stationary thermal behavior Mag. Civ. Eng.
[16] Baranova D, Sovetnikov D, Semashkina D and Borodinecs A 2017 Correlation of energy efficiency and thermal comfort depending on the ventilation strategy Procedia Engineering
[17] Tarasova D, Andreev K and Lakić S 2016 The Feasibility of Energy Efficiency class Improving of a Building from Economic Point MATEC Web of Conferences
[18] Borodinecs A, Žemitis J, Sorokins J, Baranova D V. and Sovetnikov D O 2016 Renovation need for apartment buildings in Latvia Mag. Civ. Eng.
[19] Kalamees T, Lüpšēk A, Sojkovā K, Mārcck O C, Borodinecs A, Almeida M, Rovers R,
Op’Tveld P, Kuusk K and Silva S 2016 What kind of heat loss requirements NZEB and deep renovation sets for building envelope? CESB 2016 - Central Europe Towards Sustainable Building 2016: Innovations for Sustainable Future

[20] Habibi S 2017 The promise of BIM for improving building performance Energy Build.

[21] Roschina S I, Lisyatnikov M S and Koshcheev A A 2019 Technical- and- economic efficiency of reinforced wooden structures IOP Conference Series: Materials Science and Engineering

[22] Romanovich A, Kleshcunov Y and Vlasov A 2019 On potentiality and practicability of installing flooring suspended in geodesic domes by means of cable system IOP Conference Series: Materials Science and Engineering