The influence of architectural and construction parameters of residential buildings on energy efficiency in Russian Federation

Aleksey Ivantsov[1][0000-0001-6047-3123] and Artem Petrov[1][0000-0001-6643-9110]

1Kazan State University of Architecture and Engineering, Kazan, Russia
E-mail: ivantsov.arch@mail.ru, ruarty@mail.ru

Abstract. The article discusses the dependence of the energy saving class of a residential multi-apartment building on various architectural and construction parameters. The study was conducted on the example of a building model for 36 cities of the Russian Federation in various climatic conditions. The calculation of the energy saving class was carried out according to the method of Building Code 50.13330.2012 «Thermal insulation of buildings». The analysis of this technique in relation to the architectural and construction components of the building is given. It is shown that the traditional approach to the design of residential buildings without the use of additional energy saving measures allows to achieve an energy saving class at level «B» (above -30 % of the base value) regardless of the height of the building. A significant change in the energy saving of the building with a different glazing-to-wall ratio is shown. It is proved that the additional insulation of the building envelope does not lead to an effective increase in energy saving. The calculation showed that heat recovery using a mechanical ventilation system is an important factor in increasing the energy efficiency of residential buildings.

Keywords: Energy efficiency, residential sector, glazing-to-wall ratio, building energy, building envelope, energy.

1 Introduction

According to various studies [1-3], buildings are the largest consumer of energy resources, accounting for more than one third of final energy consumption worldwide and an equally important source of carbon dioxide. In Russia, the share of energy consumption in buildings reaches 40 % [4]. Therefore, in the design and construction of buildings in Russia, much attention is paid to energy efficiency.

In Russia in the field of construction, the legal framework is regulated by Russian Federation Government Order № 1853-R of 01.09.2016 «Plan («Road map») for energy efficiency in buildings and structures». The plan is aimed at removing technical, regulatory, informational and other barriers to improving energy efficiency and establishing appropriate energy efficiency indicators in the design, construction, operation and overhaul of buildings and structures.

The objectives of the «road map» are:
- rational use of energy resources by using requirements on the energy performance of buildings, structures and facilities
- reducing payments of the population
- increasing buildings, structures, constructions of high energy efficiency in the design and construction.
- improving the system for monitoring compliance with the requirements and parameters of energy efficiency of buildings.
- development of technical regulation and standardization in energy efficiency

According to the Plan, the share of highest energy efficiency residential buildings in the total number of residential buildings should increase: to 10 % in 2018, 20 % in 2020 and 30 % in 2025 from 100 % in 2015.
In the Russian Federation, there are two parameters for a qualitative assessment of the efficiency of energy consumption by residential buildings: the energy efficiency class and the energy saving class. The energy saving class is determined by comparing the energy consumption of heating and ventilation of buildings, reduced to the heated area of the building, with the base value by Building codes 50.13330.2012 “Thermal insulation of buildings”. The energy saving class of an apartment building is formed on a scale from E («low» - more than +50 %) to A ++ («very high» - below -60 %).

The energy efficiency class takes into account, in addition to the energy consumption for heating and ventilation, the energy consumption for hot water supply, as well as for electricity in terms of the consumption of electric energy for common house needs. At the same time, these consumptions are reduced to the useful area of an apartment building by the Order of the Ministry of Construction of the Russian Federation No. 399/pr of 6 June 2016. The gradation of the energy efficiency class of an apartment building is formed on a scale from G («very low» - more than +50 %) to A ++ («the highest» - below -60%). These classes are quite similar and only differ in the methodology for determining energy consumption.

One way or another, regardless of the class by which the efficiency of using energy resources is evaluated, this parameter is an additional means of positioning housing on the real estate market and a means of increasing the capitalization of the property. High energy efficiency class demonstrates to buyers the competitive advantage of a new building.

In addition, when achieving high energy efficiency classes for the building, a certain established economic incentive is provided (tax benefits, etc.). In this regard, the developer often sets the designer the task of improving the energy efficiency class of the designed building. Moreover, the same task is reflected in the Plan of the government.

The principles of energy-efficient design are described in a large number of works [5-18]. In these works, various methods for analyzing the energy consumption of buildings and energy efficiency parameters are given. In [19-27], an analysis of various parameters of buildings on energy efficiency is given, conclusions are made about the rational parameters of the building. For example, in [28, 29] it was shown that a favorable orientation of the building due to heat input from solar radiation can reduce heating costs by up to 30% in the southern regions.

At the same time, achieving a high class of energy efficiency by traditional design methods in the climate of Russia is a difficult task. On the one hand, the economic effect of an additional increase in the heat transfer resistance of the building envelope as the most obvious way to reduce the heat loss of the building is quite small [29, 30]. On the other hand, according to Decree of the Government of the Russian Federation No. 18 dated January 25, 2011 (as amended on May 20, 2017), energy efficiency requirements should provide for a decrease in indicators characterizing the annual specific consumption of energy resources in a building at least once every five years:

a) for newly created buildings, constructions
   from July 1, 2018 - not less than 20 percent to the baseline,
   from January 1, 2023 - not less than 40 percent to the baseline,
   from January 1, 2028 - not less than 50 percent in relation to the baseline;

b) for reconstructed or overhauled (except for dwellings)
   from July 1, 2018 – not less than 20 percent to the baseline.

A gradual decrease in standard indicators should lead to a reduction in the design energy costs of the building to maintain the same energy efficiency class.

In this regard, it is important to assess the possibility of achieving a high class energy efficiency of a residential building in the climate of Russia.

2 Materials and methods

As the main methodology for calculating the specific characteristics of the consumption of thermal energy for heating and ventilation and determining the classes of energy saving and energy efficiency
is the approved methodology in Appendix G of Building code 50.13330.2012 “Thermal insulation of buildings”. Since the methodology for determining the class of energy saving is described in the same standard, we will conduct further comparative analysis on this indicator.

The energy saving class of a building is determined by the deviation of the specific annual consumption of energy resources from the base (normalized) value. The specific characteristic of the consumption of thermal energy for heating and ventilation is determined taking into account the climatic conditions of the construction area, the selected space-planning decisions, the orientation of the building, the heat-shielding properties of the building envelopes, the adopted ventilation system of the building and the use of energy-saving technologies.

According to the above method, the specific characteristic of the consumption of thermal energy for heating and ventilation of a building is determined by the formula:

\[
q_{heat} = k_{tr} + k_{vent} - \beta (k_{dom} + k_{rad})
\]

\(k_{vent}\) - specific ventilation characteristic of the building, \(W/(m^3 \cdot °C)\);  
\(k_{tr}\) - specific heat-shielding characteristic of the building, \(W/(m^3 \cdot °C)\);  
\(k_{dom}\) - specific characteristic of the internal heat input of the building, \(W/(m^3 \cdot °C)\);  
\(k_{rad}\) - specific characteristic of heat input into the building from solar radiation, \(W/(m^3 \cdot °C)\);  
\(\beta\) - the efficiency of heat gain.

It should be noted that \(k_{tr}\) and \(k_{vent}\) determine the heat loss of the building and, accordingly, to increase energy saving these values must be minimized. The values \(k_{dom}\) and \(k_{rad}\) determine the heat input, they must be maximized.

Since the energy efficiency class characterizes the architectural and engineering solution of the building, each of the formula members is directly or indirectly associated with the architectural solution of the multi-unit residential building.

- \(k_{tr}\) characterizes transmission heat loss through the building envelope. To reduce the \(k_{tr}\) value, it is necessary to harmonize the thermal envelope so that the building envelopes, which occupy the largest area in the building, have the maximum resistance to heat transfer. The limitations of this paragraph relate to the architectural design of the building in terms of the glazing-to-wall ratio and the compactness of the building. It should be noted that the dependence of reducing heat loss on increasing resistance to heat transfer is not linear. An increase in the heat transfer resistance of building envelopes above optimal values gives a minimum reduction in heat loss [30, 31].

- \(k_{vent}\) characterizes heat loss through a ventilation system and depends on the volume of supply air into the building through the ventilation system and the air infiltrating through the building envelope. For residential buildings, the amount of supply air is determined depending on the living area of the building and the number of inhabitants. With an increase in the living area of the building and the number of people, the amount of supply air and the value of \(k_{vent}\) increase.

- \(k_{dom}\) characterizes household heat supply of people and equipment and is determined by the living area of the building and the occupancy of the apartments. The less square meters of the total area per inhabitant, the higher the household heat input and the \(k_{dom}\) value.

- \(k_{rad}\) characterizes the heat input from solar radiation through translucent openings during the heating period. This parameter depends on the area and orientation of the windows to the cardinal points. The larger the area of the windows oriented in the direction of the largest heat input from solar radiation, the higher the \(k_{rad}\) value.

- \(\beta\) depends on the average rate of air exchange and the efficiency of regulation of the heat supply in the heating system in accordance with the conditions of the external environment.

3 Building model

An analysis of the components of formula 1 shows that the main architectural and construction elements of a building that determine its energy conservation class are:

- resistance to heat transfer of building envelopes;
- compactness of the building;
- the glazing-to-wall ratio of the building as a parameter that determines the ratio between the building envelopes with various thermal parameters;
- living area of the building.

It is worth noting that a change in these parameters of buildings can simultaneously increase both heat input and heat loss.

An increase in the living area of the building, on the one hand, increases household heat supply and positively affects the heat balance, on the other hand, increases ventilation heat loss. The energy balance of this solution is determined by climatic conditions, depending on the supply air temperature in the room during the heating period.

An increase in the area of windows, on the one hand, increases heat loss due to lower values of the heat transfer resistance of these structures with respect to the walls, on the other hand, increases the heat input from solar radiation. The energy balance of this solution is determined by the physical characteristics of the translucent structure (heat transfer resistance and light transmission coefficient) and the climatic conditions of the construction site.

To determine the optimal value of the above parameters, the energy saving class of a model residential building was calculated for 36 cities in Russia with a degree-days of heating period values from 1 260 (Sochi) to 10 600 (Yakutsk). As a typical building, was considered a single-section residential building with a different number of floors: 5, 10 and 20 floors, an unheated attic and a basement. To compare the indicators, a different glazing-to-wall ratio was taken: 20, 40 and 60 % (Figure 1). Building envelopes are selected in such a way that the complex and element-wise requirement of BC 50.13330.201 is fulfilled. The ventilation of the building is accepted as natural through ventilation exhaust shafts with air flow through aeration valves.

| Parameter of building | Number of storeys |
|-----------------------|-------------------|
| Heated volume, m³     | 5  | 10 | 20 |
| Heated (total) area, m² | 2162 | 4323 | 8 646 |
| Living space, m²      | 862 | 1723 | 3446 |
| Area of enclosing structures, m²: | | | |
| - basement, m²        | 433 | 433 | 433 |
| - attic floor, m²     | 433 | 433 | 433 |
| - walls (80 %), m²    | 1119 | 2243 | 4089 |
| - window (20 %), m²   | 280 | 562 | 1123 |

As a base level for determining the energy saving class of buildings, the values according to BC 50.13330 are accepted, reduced by 20% for 2020 (table 2).

| Number of storeys | Residential buildings |
|-------------------|-----------------------|
| 5                 | 0.359-20 %= 0.287     |
| 10                | 0.301-20 %= 0.241     |
| 20                | 0.290–20 %= 0.232     |

4 Results and discussion
The results of the study are presented in graphs (Figures 1-3).

Figure 1 shows the distribution of energy-saving classes of a model building for 36 cities in various climatic conditions of Russia. The study was conducted for buildings of various storeys with a different glazing-to-wall ratio. An analysis of the results shows that today, without the use of
additional energy saving measures, the energy saving class of a residential building does not rise above B (above -30 %).

For a 5-storey building in regions with a degree-days (DD) up to 10,000 and coefficient of glazing 40 %, the energy saving class is at the level of class B. When the glazing coefficient is increased to 60 %, the class decreases to C+. It is worth noting that a glazing percentage of 60 % is possible only in regions with DD up to 6000.

**Figure 1.** Dependence of building energy saving with different number of floors and glazing-to-wall ratio.

For 10-, 20-storey buildings, achieving class B is possible mainly with 20 % glazing. 40 % glazing for this number of storeys gives class C+. 60 % glazing-to-wall ratio is not achievable by the complex requirement with the demanded heat transfer resistance.

For degree-days values less than 2000, regardless of the glazing coefficient, the energy saving class remains at level B.

Without taking additional energy saving measures by 2023, due to an additional 20 % reduction in the base value of specific energy consumption (table 2), the building's energy saving class drops to class C (from +5 to -5 % of the base value).

In accordance with the current methods for calculating the energy efficiency class of a building (formula 1), the potential for reducing the specific characteristic lies in:

- increase of the heat transfer resistance of building envelopes;
- the use of a mechanical supply and exhaust ventilation system in residential buildings with the mandatory use of waste-heat recovery;
- introduction of renewable sources of thermal energy into the building’s heating system (since 2023 they should be included in the calculation).

![Figure 2](image.png)

**Figure 2.** Change in energy saving of a building with an increase in heat transfer resistance of all building envelopes by 50%.

Figure 2 shows the change in the energy saving class of a building with an increase in the heat transfer resistance (R-value) of all building envelopes by 50% (up to 150% of the base for BC 50.13330.2012). It can be seen that a change of R-value by 50% gives an increase to the total energy saving of 5% and accordingly leaves the class at the same level. Considering that a significant increase in the heat transfer resistance of fences entails significant structural costs [32], this measure is not effective.

Figure 3 shows the change in the energy saving class of a residential building when a mechanical supply and exhaust air ventilation system with a recuperator are introduced into its structure. For clarity, the coefficient of efficiency of the recuperator is taken 0.5. You can see that the use of heat recovery gives a reduction in the total energy consumption of a building up to 20% with a corresponding increase in the energy saving class by at least one step. Of course, the use of mechanical ventilation in residential multi-apartment buildings is an expensive device, but today there are practically no other potentials to increase the energy efficiency of residential buildings without the use of alternative energy sources.

The influence of the orientation of buildings in the climate of Russia practically does not play a significant role in increasing the energy efficiency of a building. This is due to the fact that for a significant part of the territory of the Russian Federation during the heating period, the amount of heat input from solar radiation is from 10 to 20% of the heat loss from ventilation and transmission.
5 Conclusion

According to the Roadmap of the Russian government in the field of energy efficiency, the share of residential buildings with the highest energy efficiency classes should constantly increase to 30% by 2025. However, with the traditional approach to the design of residential buildings, it is impossible to cope with the task. It is necessary to revise the design methods of residential buildings in the field of energy efficiency.

The main areas of such design, in addition to the introduction of energy-efficient equipment, should include:

- reduction of the glazing-to-wall ratio for the northern regions of the country;
- the number of storeys of buildings according to the basic values of energy consumption does not affect the energy saving class;
- without additional energy saving measures, the energy saving class of a residential building cannot be higher than “B” (from -15 to -30% of the base value);
- additional insulation of walling above current requirements does not give a significant increase in energy efficiency;
- to significantly increase the energy saving class in a residential building, it is necessary to reduce heat loss during ventilation by installing a mechanical system with heat recovery.

![Figure 3. Dependence of building energy saving with using heat recovery in a mechanical ventilation system.](image-url)
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