Energy-efficient construction materials in capital repair of apartment buildings (on the example of Rostov-on-Don)

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Abstract. This paper assesses the need to improve the energy efficiency of multi-apartment residential buildings in Rostov-on-Don, built in the period of industrial house building for the use of energy-efficient building materials. The paper analyses the existing housing stock, identifies the series of apartment buildings, determines the dynamics of construction by year, and the structural schemes of each series. Also, the heat transfer resistance of the building envelopes of all building series was calculated and high-performance insulation materials were selected according to the green materials assessment criteria.

1 Introduction

This century is characterised by the development of scientific and technological progress and increased intensity of life. This is particularly clearly reflected in construction. Thus, building materials are a category of goods of constant high demand, which has a calculated level of quality requirements. In connection with the high growth of progress, new, modern, technological approaches are introduced, environmentally friendly and durable materials are used, the quality of technology production, the comfort of buildings, facilitating the processes of work.

Modern building materials used in the construction of civil buildings should combine high energy efficiency, simplicity and cheapness of production along with high strength, reliability and durability. An important indicator of modern building materials is their environmental friendliness, which consists in the possibility of organising the processing and use of building material as secondary raw materials; minimising the impact on the environment; the use of renewable natural resources in the manufacture of building materials and rational supply of production [1].

Nowadays, the issue of efficient, rational and economical consumption of energy resources is acute. The policy of many countries in the field of construction is aimed at increasing the level of energy efficiency, established in regulations and depending on the energy consumption per unit area or volume. Modern housing construction should combine, among other things, the reduction of energy costs for the production of building materials while simultaneously improving the quality of products [2, 3].

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The practice of using energy-efficient building materials is based on the introduction of multilayer building envelopes, the use of which with the same heat transfer resistance allows to reduce the thickness of walls and, as a consequence, to increase the square footage of rooms, or, on the contrary, to increase the heat protection qualities with an unchanged area. Reduction of energy losses of buildings is organised by organising water drainage from the surface of external enclosing and underground building structures; choosing energy-efficient thermal insulation materials with the lowest thermal conductivity; cutting off "cold bridges" with inserts made of thermal insulation materials; organising reliable sealing of joints and seams of external walls and their elements; arranging insulated vestibules at building entrances; increasing the performance of engineering equipment systems; using multilayer glasses.

It is important to note that 25% of all heat losses occur in the building envelope, 30% through windows, 5% through the floor and ceiling. The remaining 40% of heat energy is used to heat the infiltrated outside air.

The ecological component of modern building materials must fulfil environmental requirements, which are becoming stricter over time. The material should not have a negative impact on the environment, ecosystem and have toxic vapours that significantly increase the risk of diseases in users of the product. The production of sustainable building materials should be accompanied by the use of renewable energy sources (solar, wind and others), thereby reducing the impact on the ecosystem. An important requirement for sustainable building materials is their use as secondary raw materials, allowing to reduce the impact of waste on the environment thereby saving resources and disposal costs [4].

Modern building material should also meet the requirements of durability, which increases the life expectancy of a building or structure, reducing, slowing down physical deterioration.

2 Methods and Materials

At the moment in Russia there is a problem of irrational use of energy resources. This is also observed in energy saving and energy efficiency of residential buildings. In most cases, this problem was particularly pronounced in industrial buildings in the period from 1956 to 1999. In the subsequent period, this problem became less pronounced due to the mass introduction of multilayer building envelopes incorporating highly efficient heat-insulating building materials, as well as due to the introduction of regulatory requirements for the energy efficiency of modern buildings.

However, despite the rapid increase in the construction of new housing stock, in Russia, most of it still consists of apartment buildings from the industrial period, which were designed according to the old normative documents with maximum resource saving and taking into account the heat loss of structures, which does not meet modern requirements. Also, with the increase in heating prices by an average of 4% per year, the problem of energy saving in such apartment buildings becomes more acute, because it is because of heat losses that residents of panel and block houses overpay tens of thousands of rubles per year on heating receipts [5].

Thus, it is safe to say that most of the housing stock in Russia needs major repairs with a focus on reducing energy consumption and improving energy efficiency.

The scope of the research work was to investigate the use of energy efficient materials in the modernisation of old apartment buildings in the city of Rostov-on-Don.
3 Results

The study analysed the housing stock in all districts of the city. Mass construction with apartment buildings of the industrial period is present in Voroshilovsky, Sovetsky, Proletarsky, and Zheleznodorozhny districts [6]. Based on the information received, a graph with the number of houses by year of construction was drawn up (Fig. 1).

**Fig. 1.** Graph of dynamics of apartment buildings construction in Rostov-on-Don by years.

In addition, based on the information obtained as a result of analysing the housing stock, a graph of the areas of built houses in Rostov-on-Don by year was constructed. (Fig. 2).

**Fig. 2.** Graph of areas of built apartment buildings in Rostov-on-Don by year.
At the next stage, a table was formed indicating the house series, type of wall construction, wall thickness and material. Also, for each series of houses according to the requirements of the Russian Code of Regulations SP 50.13330.2012 "Thermal Protection of Buildings" the calculation of the heat transfer resistance of the enclosing structures was made. The calculation is given in Table 1.

Table 1. Calculation of heat transfer resistance of enclosing structures of apartment buildings of industrial period erected in Rostov-on-Don.

<table>
<thead>
<tr>
<th>Apartment series</th>
<th>Wall construction type</th>
<th>Envelope material</th>
<th>Envelope thickness, mm</th>
<th>Design heat transfer resistance of envelope structures, m²·°C/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-447</td>
<td>brick</td>
<td>White sand-lime bricks</td>
<td>510</td>
<td>0.73</td>
</tr>
<tr>
<td>1-447c-47</td>
<td>brick</td>
<td>White sand-lime bricks</td>
<td>510</td>
<td>0.73</td>
</tr>
<tr>
<td>1-464A-17</td>
<td>prefabricated (panelled)</td>
<td>LECA</td>
<td>300</td>
<td>0.71</td>
</tr>
<tr>
<td>1-528</td>
<td>brick</td>
<td>White sand-lime bricks</td>
<td>510</td>
<td>0.73</td>
</tr>
<tr>
<td>111-83</td>
<td>prefabricated (panelled)</td>
<td>LECA</td>
<td>300</td>
<td>0.71</td>
</tr>
<tr>
<td>111-90</td>
<td>prefabricated (panelled)</td>
<td>LECA; 1 layer - LECA; 2 layer - reinforced concrete</td>
<td>300</td>
<td>0.90</td>
</tr>
<tr>
<td>114-86</td>
<td>brick</td>
<td>White sand-lime bricks</td>
<td>510</td>
<td>0.73</td>
</tr>
<tr>
<td>II-49</td>
<td>prefabricated (panelled)</td>
<td>LECA</td>
<td>340</td>
<td>1.10</td>
</tr>
<tr>
<td>1-419</td>
<td>lightweight concrete blocks</td>
<td>Slag concrete</td>
<td>500</td>
<td>1.51</td>
</tr>
<tr>
<td>1-515/9sh</td>
<td>prefabricated (panelled)</td>
<td>LECA</td>
<td>400</td>
<td>1.27</td>
</tr>
<tr>
<td>111-96</td>
<td>prefabricated (panelled)</td>
<td>LECA</td>
<td>350</td>
<td>1.13</td>
</tr>
<tr>
<td>111-121</td>
<td>prefabricated (panelled)</td>
<td>LECA</td>
<td>350</td>
<td>1.13</td>
</tr>
<tr>
<td>P-44</td>
<td>prefabricated (panelled)</td>
<td>1 layer - reinforced concrete; 2 layer - foam; 3 layer - reinforced concrete</td>
<td>300</td>
<td>1.94</td>
</tr>
</tbody>
</table>

According to the results of the calculation it becomes obvious that the absolute majority of apartment buildings of the period of industrial housing construction do not meet modern requirements for thermal protection, because according to SP 50.13330.2012 "Thermal Protection of Buildings" the basic value of element-by-element requirements of the resistance to heat transfer of walls should be not less than 2.63 m²·°C/W for residential premises. At this value and above, the envelope will fulfil the thermal protection norms regardless of other requirements [7].
Thus, such housing stock needs the introduction of energy-efficient building materials, which would allow to reduce heat energy consumption and costs for the tenants many times over.

4 Discussion

Considering the use of modern energy-efficient materials in the insulation of buildings of the industrial period it should be noted that individual residents of apartment buildings apply the practice of apartment insulation using high-performance lightweight insulation materials with subsequent plastering, but this has a negative impact on the appearance of the facade. Also, the boundaries of such insulation of an individual flat run along the floor slabs. In these places, the dew point sharply shifts from the insulation to the inside of the wall, which leads to condensation and the risk of mould, and the fungus can appear both in the insulated flat (at the junction of the wall with the ceiling and floor) and in neighbouring flats. The temperature difference of the facade wall in neighbouring areas is also not in favour of the house. As a result, we can talk not only about the problem of increased humidity, but also about the gradual destruction of the capital wall [8]. Another problem is the constant wetting of the upper end of the thermal insulation. Despite the insulation, constant exposure to moisture and snow accumulation gradually destroys the adhesive fixing of the thermal insulation and opens access to water. It is difficult to create a continuous contour of thermal insulation, so the complete tightness of the insulation area is almost impossible.

Therefore, in Rostov-on-Don it is necessary for the municipality to take the initiative to implement a programme of insulation of houses from the industrial building period. Organising facade insulation in conjunction with modernisation of heating systems and individual heat meters will have a positive impact on reducing energy consumption.

Studying the possibility and cost-effectiveness of using energy-efficient materials in the insulation of apartment buildings of the industrial period it is necessary to consider the advantages, disadvantages and the possibility of their implementation [9-11].

In the framework of the study, polystyrene foam, foam glass, and mineral wool were selected for the evaluation of energy efficient materials. The evaluation was carried out according to the following criteria for evaluating green materials: thermal conductivity; logistics of production in terms of the remoteness of the receiving point from the manufacturer; environmental impact; durability; price per volume of material; use of secondary raw materials, recyclability. The results of the evaluation of materials by criteria are reflected in Table 2.

<table>
<thead>
<tr>
<th>Evaluation criteria</th>
<th>foam polystyrene</th>
<th>foam glass</th>
<th>mineral wool</th>
</tr>
</thead>
<tbody>
<tr>
<td>thermal conductivity</td>
<td>0.028-0.044 W/(m·℃)</td>
<td>0.030-0.080 W/(m·℃)</td>
<td>0.032-0.048 W/(m·℃)</td>
</tr>
<tr>
<td>production logistics</td>
<td>254 km</td>
<td>287 km</td>
<td>503 km</td>
</tr>
<tr>
<td>environmental impact</td>
<td>toxic vapours</td>
<td>-</td>
<td>dust</td>
</tr>
<tr>
<td></td>
<td>40-60 years</td>
<td>100 years and longer</td>
<td>30-50 years</td>
</tr>
<tr>
<td>----------------</td>
<td>-------------</td>
<td>----------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>durability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>price per m³ of material</td>
<td>5200-8300 roubles</td>
<td>13400-32000 roubles</td>
<td>3700-6000 roubles</td>
</tr>
<tr>
<td>recycling</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>recyclability</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

Assessing the advantages and disadvantages of each of the materials it is necessary to study their characteristics in detail.

The materials under consideration have similar thermal conductivity characteristics, so the selection of the best option to be used as a high-performance thermal insulator in major renovation of houses will be carried out according to the remaining six evaluation criteria [12].

The use of building materials that are produced within 800 kilometres of its application site can reduce air pollution from vehicles and boost the local economy. The production logistics of all the materials considered are at an acceptable level and do not exceed 800 kilometres [13].

Environmental impacts are present in polystyrene foam and mineral wool boards. Release of the toxic substance styrene occurs during the melting of polystyrene foam; the material itself is flammable. Also, small doses of styrene can be released even at a temperature of +35°C. In the southern climate of Rostov-on-Don, under the influence of open sunlight on the ventilated facade boards, this temperature can be reached in some cases in the air cavity, which will lead to the release of styrene, albeit in small quantities. Mineral wool is not subject to burning, smouldering, but this material emits a moderate amount of fine dust, which is levelled by insulation of the insulation behind the facing layer. Foam glass is a completely inert material, without foaming additives. Unlike polymer compositions, this insulation does not burn, does not emit toxic gases and compounds that poison the environment. Over time, foam glass does not degrade and does not produce decay products [14-16].

Foam glass has the greatest durability among the considered high-performance insulators. It does not lose positive properties, does not shrink over time, is not subject to destruction by pests, humidity and temperature extremes. The operation of the material can be affected by strong physical impact due to the fragility of the material. Polystyrene foam also has high indicators of durability. Its structure does not allow it to absorb moisture, but the large thickness of polystyrene boards can cause deformation and shrinkage during temperature fluctuations. The service life and thermal insulation properties of mineral wool are significantly affected by the impact of water, but this can be avoided by treatment with water-repellent compositions or competent insulation [17].

In the price category, mineral wool is the leader. Foam glass is the most expensive due to the severity of technological tasks in its production using expensive high-tech equipment.

Production of expanded polystyrene does not involve the use of secondary raw materials. In the production of foam glass slabs, window glass, bottle glass can be used as secondary raw materials, thereby helping to reduce the volume of solid domestic waste. The process of mineral wool production can also include the use of blast furnace slag as a raw material [18].

All assessed materials have the potential for recycling. Considering the recycling of polystyrene foam, we note the fact that at the moment the most popular method is its
shredding for further use in the production of polystyrene concrete or primary polystyrene. Also polystyrene can be used for technological purposes for heating. High-temperature combustion of this material in modern pyrolysis boilers with the release of water molecules and carbon dioxide into the flue gases. The polymer chains and aromatic compounds are destroyed. Foam glass when processed into foam glass rubble can be used in the production of new foam glass slabs. Recycling equipment is actively used for mineral wool.

5 Conclusions

Thus, according to the assessment, to improve the energy efficiency of apartment buildings of the industrial period of Rostov-on-Don, the most suitable high-performance insulation material, taking into account the price, positive and negative characteristics, and cost-effectiveness of application, is mineral wool. At a small price per cubic metre, it is not inferior to polystyrene foam in terms of thermal conductivity and durability, and also has a low environmental impact compared to it. In addition, in the production of mineral wool, it is possible to use secondary raw materials.

Despite the best characteristics, the use of foam glass slabs will be the most cost-effective when insulating houses with no more than five floors and no more than two entrances.

References

2. K. Petrov, I. Novoselova, S. Bunescu, E3S Web of Conferences 431, 06022 (2023)
4. E. Agakhanov, G. Kravchenko, E. Trufanova, M. Agakhanov, E3S Web of Conferences 381, 02012 (2023)
5. I. Zilberova, I. Novoselova, K. Petrov, E. Mikhaylov, E3S Web of Conferences 431, 06021 (2023)
7. A. Boyarinov, I. Plastinina, N. Dukmasova, E3S Web of Conferences 6, 03009 (2016)
10. I. Zilberova, V. Mailyan, R. Zilberov, E3S Web of Conferences 376, 03022 (2023)
11. S. Sheina, E. Vinogradova, I. Chernyavsky, Lecture Notes in Networks and Systems 575, 2936-2944 (2023)
17. A. Bahaudin, E. Elias, A. Saifudin, E3S Web of Conferences 3, 01015 (2014)