

## THE IMPORTANCE OF MODERN INSULATION MATERIALS IN INCREASING THE ENERGY EFFICIENCY OF ROOF STRUCTURES

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**Introduction.** At present, one of the most critical global challenges facing humanity is the conservation of energy resources and their rational use. Population growth, the rapid pace of urbanization, and the demands of modern living have led to a continuous increase in energy consumption. In this context, improving the energy efficiency of residential buildings is of paramount importance not only from an economic perspective, but also from environmental and social viewpoints. Energy-inefficient buildings require excessive amounts of energy for heating and cooling, which increases household expenses and causes significant environmental impacts.

According to the data of the International Energy Agency (IEA), approximately 40% of the total global energy consumption is attributed to buildings. Furthermore, more than 30% of global carbon dioxide emissions are associated with heating, cooling, and lighting processes in buildings. Therefore, many countries have developed and are actively implementing national programs aimed at enhancing energy efficiency in the building sector [1].

In the Republic of Uzbekistan, significant legal and regulatory frameworks have been established in recent years to promote the application of energy-efficient technologies in the construction sector, strengthen thermal insulation requirements, and align national building codes with international standards. In particular, in regions with cold climatic conditions, such as the Republic of Karakalpakstan, including the city of Nukus, improving the thermal performance of multi-storey residential buildings is considered one of the key factors in ensuring comfortable living conditions for the population [2].

Roof structures play a crucial role in the thermal protection of buildings. According to statistical data, approximately 10–15% of heat losses in multi-storey residential buildings occur through the roof [3]. This leads to increased heating costs during the winter period and higher cooling energy demand in summer. Therefore, the use of efficient thermal insulation materials in roof structures is a critical factor in enhancing the overall energy efficiency of buildings.

At present, modern thermal insulation materials widely used in the construction industry—such as mineral wool, polyurethane foam, extruded polystyrene, ecowool, and other advanced technologies—demonstrate high efficiency in reducing heat losses. International experience indicates that the application of such materials can reduce energy consumption in buildings by up to 40–60% [4]. At the same time, environmental safety, service life, and economic efficiency of thermal insulation materials are also important criteria in the selection process.

Thus, this thesis analyzes the role of modern thermal insulation materials in improving the energy efficiency of roof structures, including their types, properties, and practical effectiveness. The main objective of the study is to present the theoretical and practical foundations for enhancing energy efficiency through the insulation of roof structures under the climatic conditions of Uzbekistan, particularly in the cold climate of the city of Nukus.

**Modern Thermal Insulation Materials.** At present, a wide range of modern thermal insulation materials is available in the construction industry, each possessing specific properties and performance characteristics. The main materials that are widely used in practice are described below.

Mineral wool (basalt wool). This material is produced from natural stone, typically basalt, and is distinguished by its environmental safety and high thermal insulation performance. It is fire-resistant, exhibits good moisture retention properties, and does not emit harmful substances into the indoor air. The thermal conductivity coefficient of mineral wool ranges from 0.035 to 0.045 W/(m·K) [5].

Polyurethane foam (PUR, PIR). This material is considered one of the most efficient thermal insulation materials currently available. It is lightweight, dense, and has a uniform surface structure, providing a high level of insulation even at minimal thickness. Polyurethane foam is mainly applied in spray form. Its thermal conductivity varies between 0.022 and 0.028 W/(m·K).

Extruded polystyrene (XPS). This material is characterized by high density and excellent moisture resistance, making it particularly suitable for roof structures, especially in areas exposed to significant moisture. In addition, it demonstrates high resistance to compression and mechanical loads. The thermal conductivity of extruded polystyrene ranges from 0.029 to 0.035 W/(m·K).

Ecowool. Ecowool is a cellulose-based insulation material that is environmentally friendly but has a relatively high moisture absorption capacity. It is primarily used in wooden roof structures and lightweight construction systems [6].

**Application and Practical Effectiveness of Insulation Materials.** The proper selection and efficient application of thermal insulation materials in roof structures significantly enhance the energy performance of buildings. Practical studies and international experience demonstrate that the implementation of thermal insulation measures can reduce energy consumption by up to 40–60%.

For example, in Germany, buildings constructed according to the “Passive House” concept are characterized by insulation thicknesses of at least 25–30 cm, enabling a reduction in annual heating energy demand to as low as 15 kWh/m<sup>2</sup> [7].

Under the climatic conditions of Uzbekistan, particularly in the cold climate of the city of Nukus in the Republic of Karakalpakstan, the adaptation of such practices can yield substantial benefits. Reducing heat losses through roof structures during the cold season contributes to the optimization of energy consumption and significantly improves indoor comfort conditions for residents.

**Key Factors in the Selection of Insulation Materials.** When selecting insulation materials for roof structures, the following factors should be carefully considered:

**Thermal conductivity coefficient:** The lower the value, the better the insulation performance of the material.

**Moisture resistance:** Roof structures are more frequently exposed to moisture and precipitation.

**Fire performance:** This is a critical factor from the perspective of building safety.

**Environmental safety:** Insulation materials should not emit harmful substances into the indoor air.

**Service life:** Materials with longer durability and stable performance are preferable.

Taking these factors into account and making design-based selections significantly contributes to improving the overall energy efficiency of buildings.

**Conclusion.** The conducted analysis demonstrates that heat losses through roof structures have a direct impact on the overall energy efficiency of multi-storey residential buildings. The use of modern insulation materials not only improves the thermal protection of buildings but also ensures long-term economic and environmental benefits. Therefore, thermal insulation has become a strategically important issue in contemporary construction practice.

First, scientific research and practical experience confirm that the application of thermal insulation materials can reduce energy consumption by 40–60%. On the one hand, this significantly decreases household utility expenses, while on the other hand, it contributes to the conservation of national energy resources. The “Passive House” concept, widely implemented in Germany and other developed countries, clearly

demonstrates the critical role of roof insulation in enhancing building energy efficiency.

Second, when selecting insulation materials, particular attention should be paid to factors such as thermal conductivity, moisture resistance, fire performance, environmental safety, and service life. Properly selected materials ensure long-term durability, reduce building operation and maintenance costs, and improve indoor living conditions.

Third, under the climatic conditions of Uzbekistan—especially in the city of Nukus and other regions of the Republic of Karakalpakstan, where cold winter seasons prevail—the effective insulation of roof structures represents one of the most pressing challenges. Reducing heat losses during the cold season not only enhances indoor comfort for residents but also supports energy conservation at the national level.

Fourth, the use of modern insulation materials plays a significant role in ensuring environmental sustainability. Increased energy consumption by conventional heating systems leads to higher emissions of carbon dioxide and other harmful gases, which negatively affect global climate change. From this perspective, improving energy efficiency through thermal insulation is one of the most effective approaches to ensuring environmental safety.

In conclusion, the widespread application of modern thermal insulation materials in roof structures to improve energy efficiency is one of the most urgent tasks in contemporary construction. This approach provides economic and environmental benefits, enhances the quality of life of the population, promotes rational use of resources, and supports the development of sustainable construction practices. Therefore, it is essential to implement comprehensive measures within national programs and scientific research initiatives aimed at promoting the use of modern insulation materials in the construction sector of Uzbekistan.

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