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APPLICATION OF LOCAL THERMAL INSULATION MATERIALS AND DEVELOPMENT OF CONSTRUCTIVE SOLUTIONS IN THE DESIGN OF ENERGY-EFFICIENT BUILDINGS

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Abstract.

This article analyzes the scientific and technical foundations, constructive solutions and practical effectiveness of using local thermal insulation materials in the design of energy-efficient buildings. The study examined the possibilities of reducing heat loss through the external barrier structures of the building, increasing the thermal resistance of wall and roof coverings, and the use of materials such as expanded clay, expanded perlite, basalt fiber mineral wool, vermiculite and lightweight concrete obtained from local raw materials. The normative and legal basis of the work was the QMQ 2.01.04-2018 “Construction Thermal Engineering”, the strategy for transition to a “green economy”, international energy efficiency approaches and the principles of building energy balance. As a result, a constructive model for an energy-efficient building was proposed based on a three-layer wall, a ventilated facade, a composite roof covering, nodes that reduce thermal bridges and local materials.

Keywords: energy-efficient building, local thermal insulation, expanded clay, expanded perlite, basalt fiber material, structural solution, thermal resistance, external barrier construction, "green" construction.

ENTRANCE

Energy-efficient construction has become one of the most important directions in the design, construction and operation of buildings today. The main reason for this is the high amount of energy consumed in heating, cooling, ventilation and lighting systems in residential and public buildings. According to the International Energy Agency, the operational activities of buildings account for about 30% of global final energy consumption and about 26% of energy-related emissions. This indicator indicates the need for thermal and technical improvement of the external envelope of buildings.

In the conditions of Uzbekistan, the issue of designing energy-efficient buildings is even more relevant. The hot and dry summer months in the republic, and the significant cold in some regions in the winter, create high requirements for the thermal protection of the building envelope. Therefore, reducing thermal bridges in elements such as external walls, roofs, foundation perimeters, window installation nodes and balcony slabs directly affects the energy efficiency of the project.

Achieving energy efficiency is not limited to the modernization of engineering equipment alone. It is necessary to consider the building envelope, structural system, material selection, orientation, ventilation mode, and moisture protection measures together. In particular, thermal insulation materials produced on the basis of local raw materials reduce dependence on imports, optimize construction costs, and expand regional industrial potential.

The issue of using local thermal insulation materials is of twofold importance. First, they increase the thermal resistance of the building envelope and reduce operational energy consumption. Second, the use of local resources reduces transportation costs and the environmental burden in the material supply chain. Therefore, the integration of structural solutions with local materials in the design of energy-efficient buildings is a task of scientific and practical importance.

RELEVANCE OF THE TOPIC AND SCIENTIFIC PROBLEM

The republic has set strategic tasks for the implementation of the principles of the "green economy", rational use of energy resources and increasing energy efficiency in construction. The Strategy of the Republic of Uzbekistan for the transition to a "green economy" for the period 2019-2030 emphasizes the need to integrate environmentally sustainable and energy-efficient approaches into economic sectors. The construction sector is one of the main consumers and key areas of modernization in this process.

In practice, many buildings encounter problems such as high heat loss, insufficient substantiation of wall layers by regulatory requirements, the appearance of cold bridges in window and door joints, and incorrect calculation of the vapor-humidity regime in roof structures. Such situations increase the load on heating and cooling systems, reduce the stability of the microclimate in the room, and increase operating costs.

The scientific problem is that the technical properties of local thermal insulation materials, their location in the structural layer and methods of application appropriate to climatic conditions are not sufficiently systematized based on a single design algorithm. For an energy-efficient building, it is necessary to take into account not only the increase in insulation thickness, but also the order of layers, vapor permeability, fire safety, seismic stability, installation technology and economic efficiency .

PURPOSE, OBJECTIVES AND OBJECT OF THE RESEARCH

The purpose of the research is to develop the structural, thermal-technical and technological foundations of the use of local thermal insulation materials in the design of energy-efficient buildings.

To achieve the goal, the following tasks were set:

— determine the role of local thermal insulation materials in energy-efficient construction;

— demonstrate the principles of assessing and calculating heat transfer processes in external barrier structures;

— development of structural solutions for walls, roofs and foundation perimeters;

— justification of project nodes to reduce thermal bridges;

— harmonizing technical, economic and environmental criteria in material selection;

— to propose a conceptual design model for energy-efficient buildings based on local materials.

The object of the study was the external enclosing structures of residential and public buildings. The subject of the study was local thermal insulation materials, their mechanism of operation in layered structures and their impact on energy efficiency.

MATERIALS AND METHODOLOGY

The study used the methods of systematic analysis, regulatory documents analysis, comparative assessment, heat-technical calculation and structural modeling. As local thermal insulation materials, expanded clay and expanded clay concrete, expanded perlite, basalt fiber mineral wool, vermiculite plates, lightweight gypsum concrete and composite plates with local mineral additives were considered.

In thermal engineering calculations, the total thermal resistance of building envelope layers can be estimated using the following expression:

RS = Rsi + S(di / li) + Rse, m²·°C/W

where RΣ is the total thermal resistance of the external barrier structure; Rsi and Rse are the internal and external surface heat exchange resistances; δi is the thickness of the i-th layer, m; λi is the thermal conductivity coefficient of the i-th layer, W/(m °C). The heat flow is determined in the form $q = \Delta T / R\Sigma$. This formula is an important initial criterion for justifying the thickness of insulation in external wall and roof coverings.

Table 1. Comparative description of local thermal insulation materials that can be used in energy-efficient buildings

Material type	Local raw material base	Main constructive application area	Advantage	Precaution
Expanded clay and expanded clay concrete	Clay rocks, mixtures enriched with industrial waste	Three-layer wall, lightweight aggregate concrete, sub-roof layers	Lightweight, fireproof, heat-retaining	Moisture protection and density control are necessary.
Expanded perlite	Perlite volcanic rocks	Thermal insulation mixture, plaster, lightweight block, backfill layer	Low density, high heat and sound insulation	Mechanical strength must be protected by a layer
Basalt fiber mineral wool	Basalt and rocks	Ventilated facade, roof, wall panel	High fire safety, vapor permeable	Protected from moisture and wind by a membrane
Vermiculite	Vermiculite	Roof, interior space, lightweight	Heat preservation	A protective layer against

material	mineral	composite	and fire resistance	compression is required
Lightweight gypsum concrete composite	Gypsum, expanded clay/perlite, polymer additives	Internal partition, dry rooms, frame panels	Can be produced based on local binder	Water resistance and softening coefficient are controlled

DESIGN CRITERIA FOR LOCAL HEAT INSULATION MATERIALS

In energy-efficient buildings, the choice of material is not determined only by the coefficient of thermal conductivity. The density of the material, moisture resistance, vapor permeability, fire resistance, biological stability, service life, ease of installation, recyclability and compatibility with the structural system are also important indicators. Therefore, when introducing local materials into the project, a comprehensive assessment of their physical, mechanical and operational properties is required.

Expanded clay and expanded clay concrete can be used as a heat-insulating and lightweight structural material in multi-layer walls, roofing layers and lightweight concrete blocks. The main advantage of expanded clay is its lightness, fire resistance and the possibility of production based on local clay raw materials. However, moisture saturation can increase thermal conductivity, so it is necessary to properly organize waterproofing and vapor regime in the structure.

Expanded perlite is effectively used in thermal insulation plaster, lightweight concrete, lightweight blocks and under-roof filling layers. The low density of perlite reduces the mass of the building, which is also important for structural safety in seismic areas. However, perlite layers must be protected from mechanical impact, since the material itself is used not as a load-bearing layer, but as a thermal insulation layer.

Basalt fiber mineral wool is one of the most suitable solutions for ventilated facades and flat roofs. It is fire-resistant, vapor-permeable and easy to install. In dry and windy regions of Uzbekistan, such materials must be protected from external moisture and wind pressure using hydro-wind protection membranes.

Composite materials with vermiculite and local mineral additives are particularly promising for roof and interior insulation. Their fire resistance and heat retention properties contribute to energy efficiency. However, it is essential to assess the compressive deformation and service life at the design stage.

CONSTRUCTIVE SOLUTIONS

Structural solutions for an energy-efficient building should ensure a continuous thermal contour of the building envelope. A continuous thermal contour is understood as a thermal protection around the external walls, roof, foundation, window installation nodes and engineering passages without interruption of the insulation layer. Local thermal insulation materials can perform various functions in this contour.

1. Three-layer exterior wall solution

A three-layer wall structure consists of an inner load-bearing layer, a middle heat-insulating layer and an outer protective and decorative layer. Brick, aerated concrete, lightweight concrete or reinforced concrete frame panels can be used as the inner layer. Expanded perlite slabs, basalt fiber mineral wool or expanded clay concrete blocks are used in the middle layer. The outer layer can be facade brick, plaster, ceramic granite, fiber concrete panels or ventilated cladding.

In this solution, the thermal insulation does not carry the load, but rather limits the heat flow. Therefore, the continuity of the insulation layer, the number of mechanical fasteners, moisture protection and the air gap behind the outer cladding are designed separately. The use of local perlite or basalt fiber materials reduces the total mass of the wall and increases its thermal resistance.

2. Ventilated facade solution

The ventilated facade system consists of thermal insulation, air gap and external cladding layers . This system can use basalt fiber mineral wool or high-density perlite boards. The air gap helps to remove external moisture, and the insulation layer reduces the heat loss of the building. Such a solution reduces the heating of the facade in summer and reduces heating energy consumption in winter.

3. Energy-efficient roof covering

Heat loss through the roof structure is a significant factor in many buildings. For flat roofs, the vapor barrier, thermal insulation, slope-forming layer, waterproofing and protective layer are designed as a single system. A lightweight mixture with expanded perlite can be used in the slope layer, basalt fiber boards in the thermal insulation, and expanded clay in the lightweight filling layer. The order of the layers should be arranged from the inside to the outside in accordance with the logic of vapor pressure and moisture movement.

4. Insulation of the foundation and socle

Heat loss in the foundation, socle and first floor floor is often overlooked. Since the socle is exposed to high levels of moisture and mechanical stress, the insulation material must have a water-resistant protective layer. Lightweight expanded clay concrete or moisture-proof mineral plates serve to reduce thermal bridges around the socle. Applying horizontal thermal insulation around the foundation reduces the transfer of cold through the soil.

Table 2. Structural solutions and recommended local materials for an energy-efficient building

Constructive element	The main problem	Recommended material	Constructive solution	Expected efficiency
Exterior wall	Heat loss and cold bridges	Perlite slab, basalt cotton, expanded clay concrete	Three-layer wall or ventilated facade	Thermal resistance increases, wall mass decreases
Roof covering	Heat in summer, heat loss in winter	Perlite mixture, basalt slab, expanded clay	Multi-layer flat roof and correct vapor-moisture	Heating and cooling loads are reduced

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			regime	
Window node	Cold bridge in the assembly seam	Thermal insulation tape, mineral wool	Placing the window frame close to the insulation contour	Condensation and air leakage are reduced
Falcon/foundation	Cold and moisture penetration through the soil	Expanded clay concrete, protected mineral slab	Vertical and horizontal insulation layers	Heat loss through the ground floor is reduced
Interior partition and drywall panels	Mass reduction and sound insulation	Lightweight gypsum concrete, perlite composite	Frame or lightweight block system	Constructive lightness and a comfortable microclimate are provided

TECHNICAL SOLUTIONS TO REDUCE THERMAL BRIDGES

Thermal bridges are a condition where the thermal resistance of an external wall structure is lower than that of the main area. In such areas, heat flow increases, the internal surface temperature decreases, and the risk of condensation and mold increases. Reducing thermal bridges in an energy-efficient building is no less important than increasing the thickness of the insulation.

The main dangerous nodes are the place where the balcony slab protrudes from the wall, the columns and beams of the reinforced concrete frame, the window installation zone, the roof-wall junction, the foundation-plinth section, and the openings through which engineering communications pass. In these nodes, local thermal insulation materials should be used as a continuous layer, and metal fastening elements should be designed with thermal insulation pads.

At the window installation node, it is advisable to place the frame closer to the insulation contour, not to the cold outer part of the wall. The installation joints are made on the principle of three-layer protection: a vapor barrier is placed on the inside, heat and sound insulation in the middle, and a layer that protects against rain and wind, but allows vapor to escape, is placed on the outside.

To reduce thermal losses in balconies and cantilever elements, structural spacers, complete encapsulation with an external insulation layer, or independent support balcony systems can be used. These solutions not only reduce energy consumption, but also reduce the risk of frost damage to concrete surfaces.

RESULTS AND DISCUSSION

The results of the analysis show that the use of local thermal insulation materials in energy-efficient buildings simultaneously provides technical, economic and environmental benefits. Technically, such materials increase the overall thermal resistance of external envelope structures, reduce temperature fluctuations in the room and reduce the load on engineering systems. Economically, the local raw materials and production base serve to stabilize the cost of building materials. Ecologically, the reduction of transport distances and the possibility of using industrial waste reduce the carbon footprint of construction.

Expanded perlite and expanded clay-based materials are suitable for energy-efficient construction in various regions of Uzbekistan, as they are lightweight, fireproof and have heat-retaining properties. Basalt fiber mineral wool is effective in ventilated facade and roof systems, providing a significant advantage in facilities with high fire safety requirements. Lightweight gypsum concrete and perlite composites are promising for internal partitions, dry panels, and additional insulation between floors.

However, when using local materials, it is necessary to ensure quality stability, laboratory testing, determination of the coefficient of thermal conductivity depending on humidity, fire resistance class and strict adherence to installation technology. If the insulation material is incorrectly laid or not protected from moisture, the expected energy efficiency will decrease. Therefore, the design documentation should provide a thermal protection layer, vapor barrier, waterproofing, wind protection and facade fastening system as a single integral system.

In the proposed structural model, the following layers are considered appropriate for the external wall: internal load-bearing layer, vapor control layer, local thermal insulation layer, wind-waterproof membrane, ventilation air gap and external cladding. For the roof, the following sequence of internal finish, vapor barrier, load-bearing coating, thermal insulation, slope layer, waterproofing and protective layer is recommended.

PROPOSED PROJECT ALGORITHM

The following algorithm is proposed for designing energy-efficient buildings based on local thermal insulation materials:

1. determine the climatic zone and the functional purpose of the building;

2. determine the required thermal resistance for external barrier structures;

3. Sort the range of local materials by their λ, density, moisture and fire safety indicators;

4. develop a layered structural scheme for wall, roof, socle and window nodes;

5. preparation of separate nodal drawings for thermal bridges;

6. check the steam-humidity regime and assess the risk of condensate formation;

7. calculate economic efficiency based on material cost, installation cost, and operational energy savings;

8. Coordination of design solutions with the requirements of QMQ 2.01.04-2018, energy efficiency and fire safety.

SCIENTIFIC NOVELTY AND PRACTICAL SIGNIFICANCE

The scientific novelty of the study is to justify the use of local thermal insulation materials in the design of energy-efficient buildings not only as a material choice, but also as a complex structural system, which is associated with external barrier construction, thermal bridges, vapor-moisture regime, and economic efficiency .

The practical significance is that the constructive solutions proposed in the article can be used in the design documentation of residential, educational, administrative buildings and small public facilities. The use of local expanded clay, perlite, basalt fiber materials and lightweight composites optimizes construction costs, reduces dependence on imported materials and serves to reduce energy consumption.

CONCLUSION

1. When designing energy-efficient buildings, the main focus should be on ensuring continuous thermal protection of the building envelope. Disruption of the insulation layer at the junctions of external walls, roofs, socles and windows leads to increased energy loss.

2. Local thermal insulation materials - expanded clay, expanded perlite, basalt fiber mineral wool, vermiculite, and lightweight composites - create a real technical opportunity for energy-efficient construction in the conditions of Uzbekistan.

3. In addition to the thermal conductivity coefficient, constructive solutions must also take into account the material's moisture resistance, vapor permeability, fire safety, installation technology, and service life.

4. Triple-layer walls, ventilated facades, multi-layer roof systems, and nodes that reduce thermal bridges are among the most effective structural solutions for energy-efficient buildings.

5. The design algorithm, which relies on local materials, allows for reduced energy consumption, optimized construction costs, and the implementation of "green" construction principles.

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