GREEN ROOFS: SUSTAINABLE BUILDING SOLUTIONS

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Abstract: *Green technologies are in the trend of modern architecture. An advantage of green technologies is the creation of conditions for a healthy lifestyle, primarily by absorbing dust, reducing noise levels and protecting structures that cover buildings from atmospheric influences. Due to the use of environmentally friendly construction technologies, a high effect is obtained by reducing heat loss through the outer envelope of the building, which reduces the amount of heat consumed.*

Keywords: Green roofs, thermal protection, Air permeability

1. Introduction

Green roofs help mitigate the urban heat island effect thru shading, evaporative cooling, and thermal insulation. The use of green roofs flattens the heat island effect by leveling surface temperatures and can significantly reduce the average temperature of an entire city.

However, until recently, the design issues of green roofs were not regulated, which prevented the full utilization of the high energy, ecological, and economic potential of green roofs in different humidity and climate zones. Thus, two Codes of Practice for green buildings and neighborhoods have recently been developed in the Republic of Moldova, which contain some regulations in this regard. These regulatory documents will undoubtedly be useful to the broader professional community: architects, designers, engineers, developers, and urban planners. Generally, it is expected to stimulate the construction of green roof buildings. Implementing the recommendations of the Codes of Practice developed in the Republic of Moldova will make it possible to utilize the advantages of green roofs more fully in construction. Also, in the Russian Federation this year, GOST R 58875–2020 "Arrangement and Maintenance of Green Roofs of Buildings and Structures" came into effect. Technical and environmental requirements." This standard, for the first time, establishes the typological characteristics of green roofs.

2. Methodology

The specific features of the construction solution for green roofs are: A green roof is a complex building envelope. It includes several layers of materials that perform different functions (Figure 1).

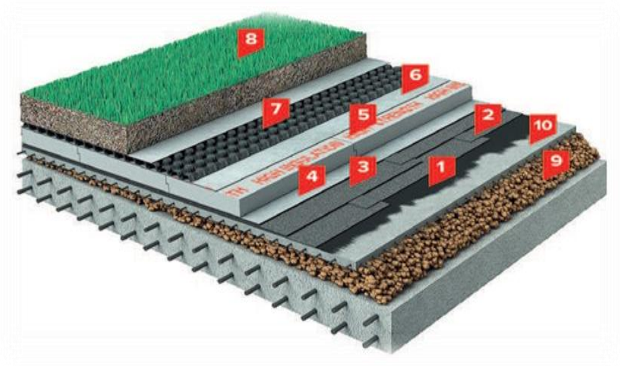

Figure 1. *Green roof construction*

1 - adhesive layer; 2 - the main waterproofing layer; 3 - an additional layer of waterproofing; 4 - lower separation layer; 5 - thermal insulation; 6 - upper separating layer; 7 - drainage layer; 8 - substrate with green spaces; 9 - slope formation layer; 10 - cement-sand reinforced screed

Thus, the structural layer meets the mechanical safety requirements of buildings. The thermal insulation layer is designed to reduce heat loss and passively regulate the microclimate within the building. The waterproofing layer is used to protect spaces from moisture. The upper surface of the roof is represented by the vegetation layer, which consists of plants planted in a special substrate. The roof also includes special layers: drainage, water retention, filtration, and aeration. During operation, roofs are exposed to a wide range of climatic influences. The operating conditions of the spaces also affect the thermal and humidity conditions of the roofs.

Green roofs are designed to provide high-quality indoor air and environment. These require the use of special methods for calculating thermal characteristics, air insulation, and moisture resistance. However, there are no rules for designing thermal protection for green roofs in the developed Codes of Practice, nor in GOST R 58875–2020. This complicates the work of an engineer and slows down the introduction of new design solutions into the practice of building biopositive buildings.

3. Results and discussion

Problems in the design of thermal protection for green roofs and green roof heating technology involve: In building design, it is necessary to ensure the required thermal technical characteristics of the enclosing structures. These characteristics include low heat transfer resistance, sanitary and hygienic parameters, and heat resistance. There are no methods for calculating these characteristics in relation to green roofs in SP 50.13330.2012 either. It is not clear how the heat transfer resistance of structures for the cold season should be determined. How to consider the influence of non-homogeneous sections of enclosure structures? In GOST R 58875–2020, green roof structures can include various types of thermal inhomogeneities: water intake funnels, wall bonding nodes, expansion joints. Thermal inhomogeneities lead to the formation of complex two-dimensional and three-dimensional temperature fields within the structure. Tabular data on specific heat losses caused by thermotechnical inhomogeneities in the thermal structure of green roofs are lacking. This complicates the calculation of the reported heat transfer resistance of enclosure structures and does not allow for a basic assessment of the thermal protection of green roofs.

According to sanitary and hygienic requirements, the temperature on the interior surfaces of the enclosing structures should not be lower than the minimum permissible values. This temperature for all non-homogeneous thermal zones can be determined from the results of the temperature field calculation. However, such a calculation method is not found in SP 50.13330.2012.

To perform a thermal calculation, it is necessary to know the calculated thermophysical properties of building materials and products under different operating conditions of the enclosing structures. The absence of these characteristics in regulatory documents makes it difficult to calculate the thickness of the thermal insulation layer for green roofs in different humidity and climatic zones of the respective climatic territory.

To analyze the thermal impact of a structure on the environment, calculations of the thermal resistance of green roofs are necessary. The most accurate thermal characteristics of green roofs can be determined from the results of numerical modeling of the unsteady heat transfer process, including the calculation of three-dimensional temperature fields within the structures. Performing such calculations is extremely necessary at the current stage in order to formulate new design solutions for biopositive buildings and their elements.

Air permeability of green roofs. Air filtration is possible in the wet material. This process is clearly expressed in capillary-porous building materials with a large volume of open pores and voids, for example, in the substrate layer. In air filtration, the moisture flux density is considered to be proportional to the air pressure gradient.

During the operation of green roofs, it is necessary to limit air filtration. The air permeability of enclosure structures is closely related to their thermal regime. The air permeability of the flat structural element and its joints primarily affects the temperature drop on their inner surfaces during the cold season.

From an air regime perspective, the green roof construction can be conditionally divided into two parts - the lower and the upper. The lower part of the structure, made of dense materials (reinforced concrete, extruded polystyrene foam), is practically airtight, which excludes air flow into the enclosure thru the filtration mechanism. The upper part of the structure consists of porous materials, so during operation, humid air is filtered thru individual sections of the enclosing layer. Air circulation within the plant layer is necessary to deliver oxygen to the plant roots. Due to the alternation in the construction of dense and air-permeable layers, transverse air filtration is most likely to occur. Air infiltration into the substrate layer during the cold season can lead to a decrease in the structure's thermal resistance, additional heat losses thru the enclosure element, and a reduction in the overall energy efficiency of the building. The penetration of internal humid air into the structure due to exfiltration is also dangerous in terms of air-borne moisture transfer, structural damping, and a decrease in its thermal protection properties in this regard. There is no regulatory data on the air permeability of materials and products as part of green roofs, which makes it difficult to quantify air permeability and its effect on the thermal regime of the structure. It is necessary to develop a methodology for calculating the thermal regime of green roofs, taking into account humid air filtration.

Moisture protection for green roofs. Green roofs must provide reliable protection against moisture for the spaces below. The construction solutions for green roofs should create the necessary conditions for drainage from the roof surface, exclude the appearance of materials with atmospheric and operational moisture, and also, due to the diffusion of water vapor from the room, ensure the waterproofing of the roof. At the same time, a favorable environment for plant life must be created within the structure.

"Moisture in the building envelope is a mysterious guest." These words, spoken by Academician V.N. Bogoslovsky, a prominent scientist in the field of building thermal physics, are largely fully applicable to green roof structures.

Wet material in building structures is an open heterogeneous system. This system consists of several components: the solid part of the material (the matrix), air, and moisture (Figure 2). Moisture in the material's pores can exist in several phases: water vapor, liquid, surface films, ice. The components and phases of the wet material interact with each other, and heat and mass transfer occur between them.

Currently, more than 20 moisture transfer mechanisms are known in wet material. But neither of them allows for a complete description of moisture circulation. Let's examine the main mechanisms of moisture circulation in green roof structures.

Due to the humidity and the absorption of building materials, the movement of vaporous moisture occurs thru the mechanism of water vapor diffusion under the influence of the partial vapor pressure gradient within the material's pores. Thru calculation, we can determine the amount of moisture condensation within the structure, assuming that the liquid moisture is tightly bound to the material and remains stationary.

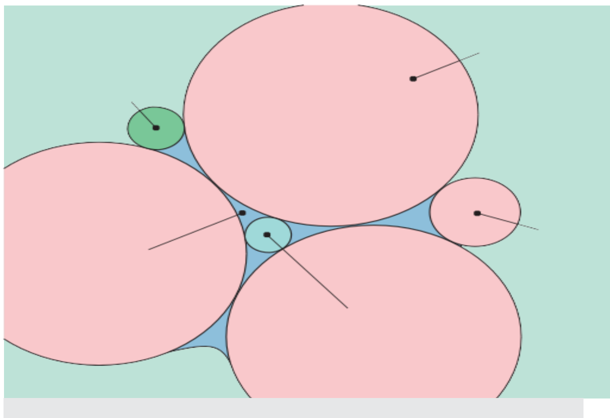

Figure: 2. Structure of the wet material (diagram):

1 - matrix; 2 - water vapor in the air; 3 - film and joint moisture; 4 - capillary moisture; 5 – ice

A large volume of liquid moisture can be introduced into the structure thru atmospheric precipitation, as well as thru watering plants. Some of this moisture evaporates, which causes the evaporative cooling effect on the surface of the structure. Together with the green layer, this effect flattens the roof's temperature regime when exposed to intense solar radiation.

Some of the moisture is absorbed by the substrate and the moisture accumulation layer. The moisture accumulation layer is designed to accumulate moisture during a rainy season and return it to the plant roots during a dry season. The viability of plants depends heavily on this layer. Some of the moisture drains thru the filter and drainage layers and is removed from the roof by gravity. In these cases, it is necessary to consider capillary moisture transfer under the influence of the moisture content gradient, as well as moisture filtration with a total fluid pressure gradient. At negative temperatures, some of the moisture freezes and forms a cryophase in the pores of the building material, which should be reflected in the moisture transfer model.

Under non-isothermal conditions, it is necessary to consider the moisture flux caused by the temperature gradient - the thermal conductivity of moisture.

Considering all moisture transfer mechanisms in a wet material is an extremely difficult task; Therefore, in practice, various generalizations of moisture transfer theory are often used. The final generalization is V.N. Bogoslovsky's creation of the theory and method for calculating moisture transfer based on the total non-isothermal thermodynamic potential of moisture.

This potential, based on the equilibrium moisture content of the reference body, makes it possible to consider almost all moisture transfer mechanisms in exterior enclosure materials. The moisture flux density within the material is proportional to the moisture potential gradient. V. N. Bogoslovsky's moisture potential allows for a simple notation of the moisture distribution condition at the junction of different materials, assuming that the moisture potential values of both materials are the same. This potential allows for a relatively simple description of the complex mathematical process of unstable moisture transfer in multilayer structures across the entire moisture range.

4. Conclusion

Heat and moisture transfer processes are interconnected, therefore, the thermal technical assessment of green roofs should be carried out as a general calculation of the thermal and moisture protection properties of a building's external enclosures..

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