Temperature and Humidity Regime of Roof Space in Buildings with Glass Roofs

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Abstract. The paper analyzes the temperature and humidity conditions of the roof space of buildings with translucent roofs in the winter period of operation. The work is based on the generalization of data from a number of field observations and monitoring of translucent roofs of atrium buildings in Moscow. It is established that the temperature and humidity regime of the sub-roof space of atrium buildings with translucent roofs in the winter period of operation has a significant impact on the load-bearing capacity and durability of the translucent filling of coatings (insulated glass units), as well as snow loads on translucent roofs. At the same time, an analysis of existing approaches to the design and calculation of translucent roofs atrium buildings has shown that the issue considered in this work is often not taken into account when assigning their design solutions, which further complicates their normal operation. It is established that when performing strength calculations of roof insulated glass units it is necessary to take into account the transitional spring-winter period, which is characterized by low outdoor temperatures and high solar activity. The thermal regime of translucent roofs of atrium buildings also has a significant impact on the formation of snow cover on similar structures, which is manifested in a different nature of the distribution of snow loads on translucent roofs, as well as on the amount of snow loads, which are several times less than the loads on similar deaf insulated roofs.

1. Introduction

Currently, translucent roofs are widely used, primarily in public buildings of the atrium type [1-4]. The design of this type of roof is associated with the need to ensure, at least, the following set of requirements [5]:

- year-round natural lighting of the rooms facing the atrium;
- thermal protection and energy efficiency of the designed building;
- safe operation of the translucent roof (mechanical safety);
- serviceability.

Existing approaches to the design of translucent roofs often do not differ radically from the approaches used for the design of blind insulated roofs (in terms of the purpose of snow loads), as well as translucent facades (in terms of the purpose of technical and operational characteristics of translucent filling) [6].
At the same time, standard temperature and humidity conditions regulated by current regulatory documents are often used as the design operating conditions for translucent roofs [7-9]. However, the extensive experience accumulated over the past 20 years in the operation of translucent roofs in the climatic conditions of the Russian Federation shows the imperfection of this approach.

According to the authors, one of the key factors that is not taken into account when designing this type of roof is the temperature and humidity regime of their roof space. In this work, the authors aim to summarize the experience of using a number of translucent roofs of public buildings of the atrium type and give recommendations for their design, taking into account the influence of the temperature and humidity regime of the sub-roof space on their operation.

2. Functional requirements for translucent roofs of atrium buildings

Translucent roofs when they work as building enclosing elements should perform, in addition to providing protection from precipitation, first of all, two functions—providing year-round natural lighting of rooms facing the atrium and providing thermal protection of buildings. A distinctive feature of winter climatic conditions of operation of translucent roofs (for example, for the Northern countries of Europe) is the accumulation of snow cover on their surface during snowfall, which significantly reduces the light transmission of the roof and, as a result, the natural lighting of rooms facing the atrium.

Snow removal from the surface of a translucent roof is possible using two approaches:
- the use of roof insulated glass units with high values of resistance to heat transfer, providing increased thermal protection of buildings and the use of special technical devices that allow you to remove snow from the roof (electric heating IGU or the supply of heated air to the under-roof space [10], or the use of special mobile running bridges for mechanical snow cleaning);
- use of roof insulated glass units with a reduced value of resistance to heat transfer, which ensures snow melting from the surface of the translucent roof due to the action of heat flow from the under-roof space.

In most cases, natural lighting of atriums with translucent roofs is achieved during the winter period of operation (taking into account the influence of snow cover) by using the first of the approaches described above. At the same time, special running bridges are often used to remove snow, rather than electrically heated insulated glass units.

3. Influence of temperature and humidity conditions on the durability and mechanical strength of roof insulated glass units

Experience in the operation of translucent roofs shows that there are a number of typical problems associated with ensuring the durability of translucent filling (roof insulated glass units).

This is manifested in the violation of the tightness or destruction of insulated glass units under the influence, first of all, repeatedly acting during their operation of climatic loads (atmospheric pressure differences and operational differences in outdoor air temperatures) (see figures 1, 2). In some cases, depressurization of insulated glass units may be accompanied by water accumulation in the inter-glass space due to the suction and condensation of moisture in the internal air of the roof sub-roof space (see figure 3).

Each of these phenomena is a significant defect, leading to violation of the ability of normal use of translucent fill and reduce its mechanical safety by significant reduction of the bearing capacity of glass (glass in insulated glass unit in this case no longer work together when operating loads are applied to it).
Figure 1. Example of depressurization of a roof insulated glass unit.

Figure 2. Example of destruction of internal glass in a roof insulated glass unit.
Figure 3. Example of water accumulation in the interglass space of a roof insulated glass unit.

4. Influence of the temperature and humidity regime of the sub-roof space on the accumulation of snow cover on the surface of translucent roofs

Long-term field observations of translucent roofs of atrium buildings operated in the climatic conditions of Moscow show that due to the relatively low thermal resistance of roof insulated glass units (no more than 0.7 m² °C/W), the heat flow through translucent roofs has a significant effect on the accumulation of snow on its surface [11].

Snow that accumulates during a snowfall on the surface of a translucent roof begins to melt, usually during a snowfall. This is observed both during snowfall, falling at low negative outdoor temperatures (up to -5 °C), and at low outdoor temperatures (below -10 °C). As a result of the formation of a thin layer of water at the "snow-glazing" border, which significantly reduces the adhesion of snow to the glass surface, the snow cover can roll off the surface of the translucent roof even under its own weight. Studies have shown that this phenomenon will be observed even if the angle of inclination of the glazing is more than 15 degrees. Because of this, the distribution of snow cover on translucent roofs differs significantly from similar insulated blind roofs.

In the case of translucent domes, the distribution of snow cover over the surface of the dome will have the following form and character of change. During the initial periods of snowfall, the translucent dome will be evenly covered with snow. This will happen until such a quantity of snow accumulates on its surface that the temperature at the «insulated glass unit-snow» border does not rise to 0 °C and the snow begins to melt. After this point, the nature of snow accumulation on the translucent dome cover begins to change. The snow remains hot on the flat areas (in the upper part of the dome), and the rest of the snow rolls down (see figure 4).
Figure 4. Nature of snow accumulation on translucent domes after a snowfall.

Studies have also shown that at low outdoor temperatures, the water formed when snow melts turns into ice when it flows down. In this case, heat exchange already occurs through the "glazing-ice-snow" system. The duration of snow on the translucent roof increases. Despite this, under any conditions on the surface of a translucent roof with a heated under-roof space, significantly less snow will accumulate than on insulated blind roofs. Long-term field observations have shown that in the climatic conditions of the Moscow state University, the loads on such roofs do not exceed 40 kg/m² (for comparison, on similarly shaped insulated roofs, the value of snow loads during the observation periods exceeded this value several times and were comparable with the standard values).

5. Discussion. Recommendations for the design of translucent roofs
Obviously, the phenomena described above must be taken into account when designing translucent roofs with heated under-roof space:
- when assigning a design solution for roof insulated glass units, it is necessary to take into account both standard design combinations of climatic loads and special combinations caused by the accumulation of warm air in the under-roof space of translucent roofs and negative outdoor temperatures.
- thermal characteristics of roof insulated glass units should be assigned taking into account the technical capabilities of removing snow cover from translucent roofs.

It should be noted that the use of insulated glass units with a low value of heat transfer resistance is not always wrong. Snow melting under the influence of heat flow from the roof space is a positive phenomenon, since it contributes to the performance of such structures at least its main function to provide natural lighting of the roof space. In addition, taking this effect into account when assigning snow loads can significantly reduce the calculated values of snow loads on such roofs [12], and, as a result, helps to reduce the material consumption and cost of their supporting structures.
It should be noted that the accumulation of snow on translucent roofs will also be affected by snow transfer under the influence of wind, as well as changes in the properties of snow when it melts [13-15].

6. Conclusions
Field observations of the temperature and humidity regime of translucent roofs of atrium buildings operated in the climatic conditions of Moscow have shown that it has a significant impact on its safe operation.

1. It was found that for roof insulated glass units the most unfavourable combination of loads observed during the spring period of use, when at the same time there is high solar activity, leading to overheating of roof space and low outside air temperature.

2. Due to the low thermal resistance of roof insulated glass units, there is a significant heat flow through the translucent roofs which leads to the melting of snow accumulating on their surface.

3. Field observations have shown that the nature of the distribution of snow cover and the amount of snow loads on translucent roofs significantly differs from similar insulated roofs. Long-term field observations have shown that for the climatic conditions of Moscow, the value of snow loads on translucent domes does not exceed 40 kg/m², which is significantly less than the standard values that do not take into account snowmelt.

7. References
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