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Additional measures protecting buildings from climatic influences

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Abstract. The Russian territory is characterised by a great variety of different climatic zones with complex weather conditions. There are a large number of people living in these areas. New towns and cities are being built. Ensuring comfortable conditions for people to live and stay in the buildings of various purposes is of great importance for the implementation of social programmes adopted by the Russian government for the near future. Construction practice has developed a certain approach to the materials and structures that protect buildings from the effects of various climatic factors such as extremely high or low temperatures. However, the dramatic climate change that has been taking place on our planet in recent decades has led to additional research and the search for new structural and architectural solutions. This article presents the results of pre-design and construction solutions for public buildings in hot and harsh climates. Different materials for building envelopes are considered and thermal calculations are carried out. The ETFE membrane system is shown to be a versatile material that can be recommended for different climate zones. Particular attention is paid to additional structural measures such as the introduction of special canopies or enclosed spaces in the form of domed structures, which add a certain architectural expression to both the individual building and the group of buildings as a whole.

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1. Introduction

Climatic effects are distinguished by rich variety over the vast territory of the Russian Federation: harsh climate with low temperatures, hot climate with high positive temperatures at high and low humidity, abrupt temperature changes, strong winds, cyclones, hurricanes etc. Today, scientists all over the world are noticing significant changes happening with the planet climate that may become the cause of disturbances in functioning of the planet biological and ecological systems and thus have negative impact on human health and living [1]. In this regard, it becomes of primary significance that comfortable, favorable and safe conditions are created for people to stay and work in various purpose buildings. The issue has become especially relevant since the adoption by the Government of the Russian Federation of the social and economical development programs for the nearest future of the country according to which the development of the Arctic coast, Far East, southern regions will be of special significance.

According to construction norms SP 131.13330.2020 "SNiP 23-01-99 Construction Climatology, the territory of Russia is divided into climatic zones, each one of them having different temperature and humidity characteristics''.

The territories with hot climate include vast lands in the Lower Volga Region, Caspian Depression, Krasnodar Krai, Stavropol Krai, and Crimea. These regions are characterized both with humid and dry hot climate.

Certain principles and approaches to design, construction, and operation of buildings were formed in the said climatic conditions. They are stated in such documents as SanPiN 2.2.1-2.1.1.1076-01 Hygienic Requirements for Insolation and Solar Protection of Residential and Public Buildings and Territories, SP 50.13330.2012 ''SNiP 23-02-2003 Heat Protection of Buildings'' (2018 version with changes No. 1,2), SP 25.13330.2012 ''SNiP 2.02.04-88 Bases and Foundations on Permafrost Soils, SP 370.1325800.2017 Solar Protection Devices for Buildings'', etc.

The developed and tested architectural, structural and planning solutions are widely presented in various literature. Thus, in works [2–4], the issues of adaptation to climate, the peculiarities of the influence of a hot climate on construction sites in various southern countries, for example in Iran, are considered. Evaluation of the effectiveness of various constructive measures to protect buildings from a hot climate is presented in [5–7]. The issues of energy saving in the southern regions are reflected in the works [8–9]. The peculiarities of the influence of low temperatures on the building in the northern regions are presented in [10–13]. At the same time, special attention is currently paid by specialists to the constructive solutions of facade systems [14–15]. The complex of existing structural solutions and climate studies for a building can be conditionally divided into the following groups: urban planning measures, a complex of space-planning solutions and constructive measures that ensure optimal conditions for people to stay in buildings. Implementation of all practices provides for the required level of comfort in buildings and creates the required conditions for emergency-free operation of construction facilities. Here it should be mentioned that specific operational difficulties usually occur in public buildings of significant size inside which large numbers of people can stay and move around simultaneously in order to perform some functions. The examples of such public buildings are shopping malls, transportation buildings, exhibition pavilions, etc. The effects that climatic factors have on such objects becomes quite significant. This especially noticeable nowadays due to global climate change on the planet. Events that took place in 2021 in Texas, USA, may be used as an example of climatic anomalies. A significant snowfall and abrupt temperature drop happened in this state while this territory has always been distinguished by dry and hot climate. In this regard, a need arises to arrange for further studies and to develop additional architectural layout, and structural practices, structures including not only the new construction materials for coverage or guarding structures but also development of special structural solutions protecting the construction facilities from negative climatic effects. Different studies are being made in this sphere, and new structures are being searched for both in Russia and abroad. All of the aforesaid confirms the relevance and necessity of such questions to be asked.

It is known that solar protection devices (SPDs) of various types are used in hot climate regions in order maintain comfortable conditions inside. Stationary SPDs became widely used in Russia and they are used not only for protective purposes but also to form the architectural composition of buildings. Solar protection devices can be installed on the windows: outdoors in the window opening and indoors. Domestic and foreign materials, technologies, solutions allowing for implementation of a rich variety of solar protection devices became widely used on the Russian construction market.

Installation of additional solar protection devices onto cooling structures being protected from overheating became widely spread in Arabic architecture. This solution has influenced the design of architectural facades of buildings where the guarding structures are built as floral elements of Arabic pattern [16–17]. The structures are shaping the facade architectural space and simultaneously protecting it from overheating. The set objective is achieved by means of using a cover on top of the facade made of golden “umbrella modules” which are opened and closed depending on illumination and are automatically controlled from a single center.

Original design of the building facade was developed in Doha, Qatar. The 231 meter tall building has a metallic mesh facade which is used as a sun screen (the temperature in the city rises up to plus 50 °C in hot time of the year) and is also a certain additional decoration to architectural image of the building.

Such additional elements can also be built as wide-span structures that provide additional shading to the construction facility, facilitate air circulation, and protect the building from possible precipitation. An example of such structures is the solution built as a tent covering the Göbekli Tepe temple complex archaeological site in Turkey from climatic effects and not only protecting the artifacts within but also creating favorable and comfortable conditions for visitors of the historical object as well.

Equally complicated conditions are experienced by people in buildings located in northern regions. Living there shall be arranged so that such factors as low temperatures, snowstorms, strong wind currents, and indoor insolation only in particular hours are taken into account. All these have significant impact on people’s physical and moral state. As of today, a large number of space-planning, structural solutions have been developed using modern technologies. One of such solutions is the use of dome space where all

conditions are created for living. The enclosed space allows for comfortable staying inside, prevents winds and snow from getting into the internal space. Special unified modules [14] have been developed for rotation camps. They provide protection and also may broaden the architectural layout options when building residential areas in northern regions.

Analysis of modern tendencies in development of architectural forms, special construction solutions for buildings of various purpose in regions with complicated climatic conditions shows that they are quite diverse. Still, not all the tendencies are efficient, low-cost, technologically simple, or could be implemented both in hot and severe northern climate.

Many protective structures are mostly used in foreign construction practice and not adapted on the Russian market. In this regard, the objective of these studies is too further study and look for structural, architectural layout solutions in harsh conditions of the climatic zones specific to the Russian Federation.

The objects of the study are public buildings, as which the buildings of the exhibition complex, shopping center, transport buildings are considered.

The tasks of the study were as follows:

- development of additional structural suggestions and selection of materials which improve protection from low or high temperatures for some public buildings;
- performance of front-end engineering design;
- performance of thermophysical and strength calculation studies for
- justification of the suggested structures;
- evaluation of the feasibility of suggested solutions to be used in construction practice.

2. Materials and Methods

Architectural and numerical simulation methods were used to fulfill the set tasks.

At the first stage of the study, the issues of additional protection for various purpose public buildings in regions with hot dry climate under the influence of high positive temperatures were reviewed. At this stage, the study was performed using the architectural simulation methods.

A building for various exhibitions was chosen as the study object. The building is located in the driest region in the European part of Russia, Kalmykia. Absence of significant number of water bodies at the taken territory has severe impact on air dryness in this region.

The architectural layout solution covers all the necessary premises for exhibitions, a set of service and utility premises, etc. A version of the general layout and the building facade are given in Fig. 1. A version of a dome structure providing the guarding and solar protective functions was suggested as the solar protection device during the building engineering. In order to ensure protection of the structure from solar rays, several versions of guarding structures were studied, for example, single glazing, triple-pane windows, and ETFE film applied in 3 rows. Considering the architectural layout solution of the building being designed and the peculiarities of its erection in especially hot weather conditions, the ETFE membrane material was selected as the final solution as the desired curvilinear shape and dramatic architectural facade could be achieved using the film.

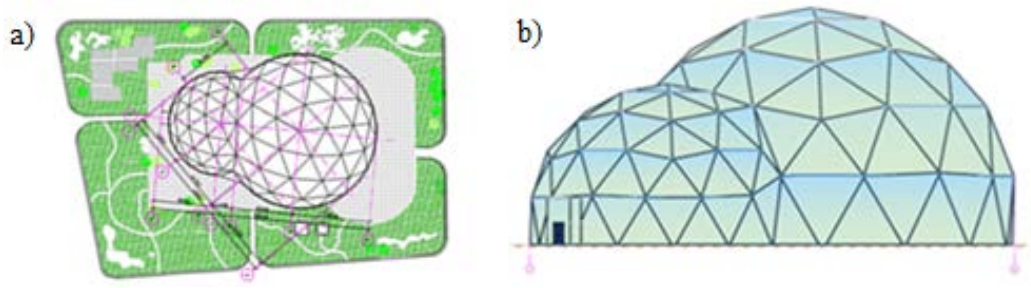

Figure 1. Exhibition Complex Building Under Design in Hot Climate Region of Kalmykia: a – general layout version; b – facade in within axes 1–4.

Membrane technology [18–20] is becoming more and more spread in regions not only with hot climate but also in the Far North, Far East, and Siberia due to its high process and operational qualities such as wide operational range of outdoor temperatures, high strength, low weight, fire safety, resistance to UV radiation, high energy-efficiency, and other.

In order to evaluate the feasibility of using the mentioned technology in Kalmykia conditions, the authors performed structural calculations of the dome structure to assess ingress of solar radiation hear through the coverage considering the rated national recommendations.

The structural solution of the coverage was calculated in SCAD software complex. The calculation diagram in shown in Fig. 2.

Numerical simulation methods were used at this stage of the study.

At the next stage of the study, a shopping mall building in hot climate of the city of Astrakhan was reviewed. The building is of rectangular shape, approximately 13 meters tall, three-story with a basement. Service premises as well as some utility and auxiliary premises are located on the floors of the buildings. During the study, main attention was paid to the building coverage as this zone is mostly affected by overheating. Applying the architectural simulation methods, the authors designed the coverage structure as a system of beams made of metal pipes 300 mm in diameter (Fig. 3). The beams are mounted in crosswise pattern forming a diamond shaped space between them. The beam resting joints are made as hinges. Metal elements are interconnected using bolted joints. The space between the beams is filled with ETFE membranes spanned in three layers just like in the previous version of the exhibition pavilion. The shopping mall facades are design fully glazed. Figure 4 shows the calculation diagram of the object being studied. The calculation studies were performed using the numerical simulation methods based on the finite-element method. The calculations were made in SCAD software complex.

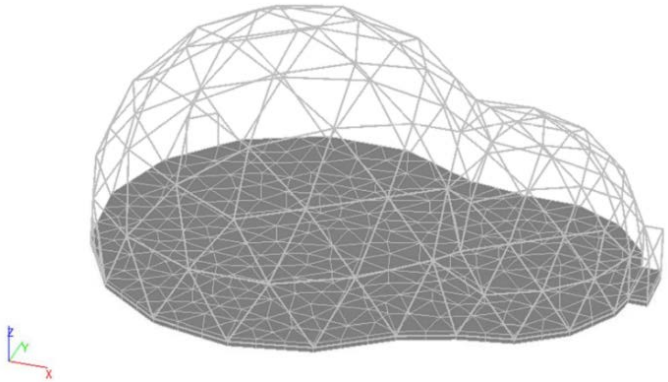

Figure 2. Calculation Diagram of Exhibition Pavilion Coverage.

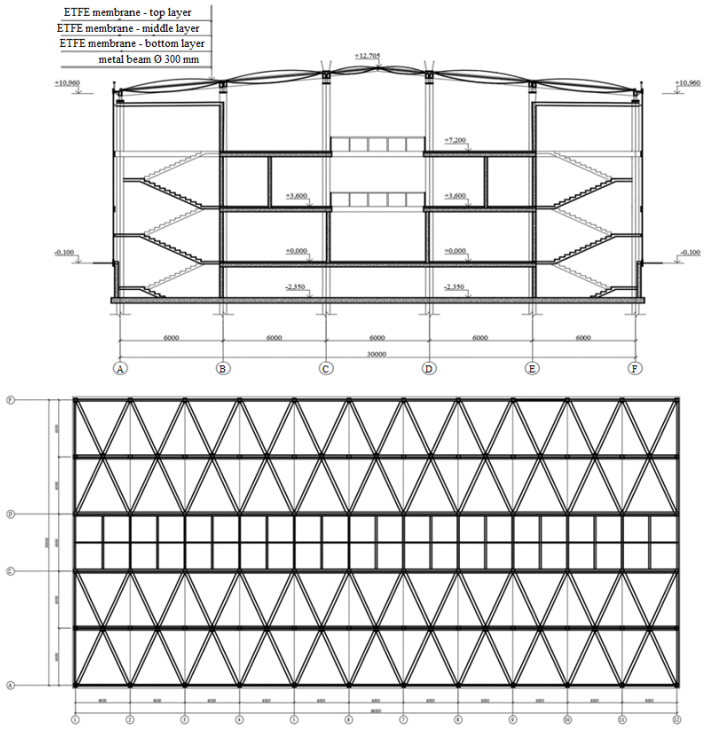

Figure 3. Shopping Mall Building Under Design in Astrakhan:
a – lateral section of the building under design;
b – metal framework of the coverage structure (top view).

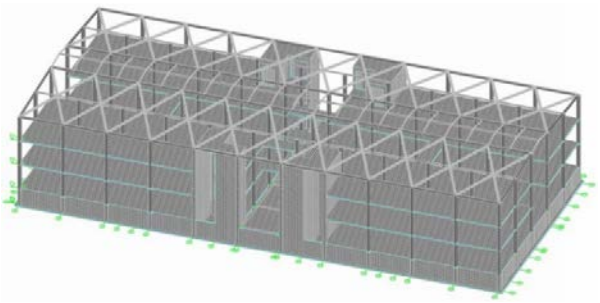

Figure 4. General View of Calculation Diagram.

Additionally to public buildings, the study covered railway stations where significant crowding of people moving in different directions occurs. Premises in such buildings are large and long. The description of space-planning and structural solution for the building reviewed is given in the work by the authors [21]. The main idea of additional protection of the building from overheating consisted in creation of a metal shed (or "umbrella") filled with solar protection glass with soft coverage (Fig. 5). Within the study, heat from solar radiation was evaluated and calculations were made for a shed designed of metal tubular elements. Regions with low temperatures were also reviewed additionally to the hot climate zones in this study.

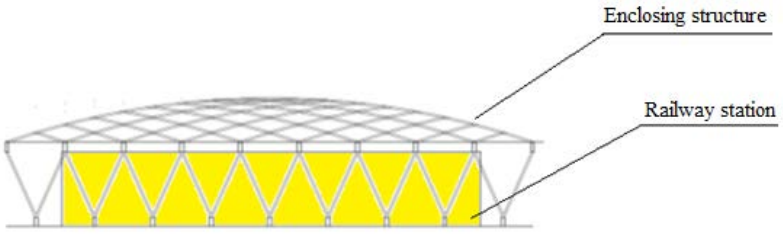

Figure 5. General View of Metal Shed.

The authors developed different versions of protection for transportation facilities from harsh climatic conditions in the Northern climatic zone. Thus, a design solution was developed for a railway station in Salekhard using, for example, a geodetic dome. Among its peculiarities in terms of the designed solution, one should note lightness of its structure, coverage of larger area, stream-line form which prevent ingress of wind and snow into the inner space of the station (Fig. 6).

Besides, a city building layout diagram was developed for rotation camps located along the Arctic coast. The specialty of this diagram lies in the centering core with passages running to it from the residential modules which provides for comfortable moving around the settlement. The centering core incorporates shopping, entertainment, sport, office and other premises. The core is also covered with a geodetic dome.

All calculation studies were performed using the numerical simulation methods. The calculations were divided into 2 stages. At the first stage, the entire complex of thermotechnical calculations was performed. At the second stage, structural calculations were made with the aim of checking the strength and resistance of the taken structural elements in terms of protection from climatic effects: either from high positive or from low temperatures.

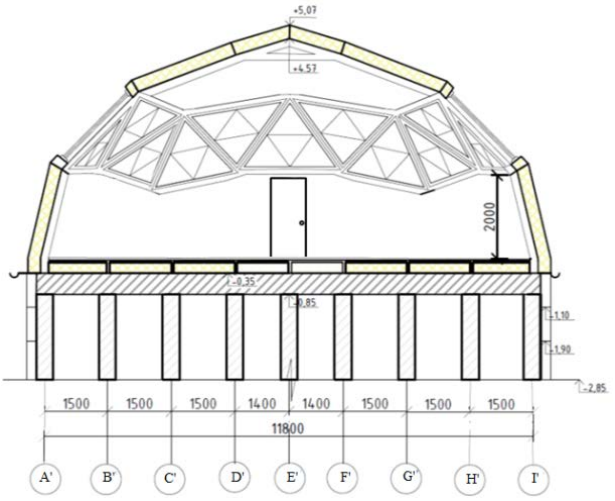

Figure 6. Example of Railway Station Space Coverage with a Geodetic Dome.

Well-known methods given, for example, in SP 50.13330.2012 (2018 version with changes No. 1,2), were used for thermotechnical calculations, and according to them, the heat protection coverage of the building shall comply with certain requirements as follows:

a) element-wise requirements (reduced resistance to heat transfer of individual structures shall not be less than nominal values);

b) complex requirements (specific heat protection characteristic of the building shall not exceed the nominal value);

c) sanitary and hygienic requirements (temperature on the inner surfaces of the guarding structures shall be not lower than the minimum allowable values).

Table 1 contains characteristics of materials used, for example, in study involving the exhibition pavilion in Kalmykia.

Table 1. Characteristics of materials used in study involving the exhibition pavilion in Kalmykia.

Structural element	Thickness, m	Thermal conductivity, W/m·°C	Thermal resistance to heat transfer m^2·°C/W
Dual-pane window SunGuard High Performance Silver 35-16	0.024	–	0.7
Triple-pane window EKA SOFTLINE 70	0.042	–	0.76
ETFE film (3 rows of film)	0.003	0.17	0.0176

Similarly the characteristics of guarding structures were set for other solutions made at the pre-design studies stage. For example, wall structures made of aerated concrete, bricks, sandwich panels, etc. were studied as guarding structures of the railway station. The temperature values were taken in accordance with the climatic norm temperature values. Beside the thermotechnical ones, some calculations were made for air- and vapor-permeability and an evaluation was made of the solar radiation heat coming through the wall structures and the coverage.

As all the suggested structural solutions are spatial structures, strength calculations using numerical simulation methods in SCAD software complex were made for all suggested design solutions additionally to the thermophysical calculations. In this regard, initially calculation diagrams were built for each object in the form of finite-element spatial models. Herewith, the following allowance were made:

- the calculations were made at the elastic stage;
- interaction with the soil base was implemented as per the “rigid platform” hypothesis.

The calculation procedure included the following:

1. Collection of loads;
2. Strength and deformation calculations;
3. Evaluation of internal forces occurring in the additional protection structures of the building under the set loads.

The results of the calculations are deformation diagrams, moment diagrams for longitudinal and transverse forces.

3. Results and Discussion

Evaluation of the results of thermophysical calculations showed that the taken versions of guarding structures comply with the thermotechnical requirements and the air- and vapor-permeability requirements. Herewith, a multi-layer structure made of aerated concrete with spun glass insulation was taken for the final version of guarding structures of the railway station because such structure is preferable for hot climate. As for the exhibition building, all the suggested versions also comply with all necessary thermotechnical requirements. Still, considering the possibility of temperature differential and extremely high temperatures, the ETFE membrane systems were selected as they have unique physical and chemical properties with one important advantage additionally to the ones mentioned above – adaptivity to snow and shower rain loads characteristic of climatic zone III.

Aggregated estimation of heat losses for the railway station building in northern regions showed that use of the dome shape caused reduction of heat losses by 1.5 as compared to rectangular shape.

Some of the results of structural calculations made by the authors are shown in Fig. 7–9.

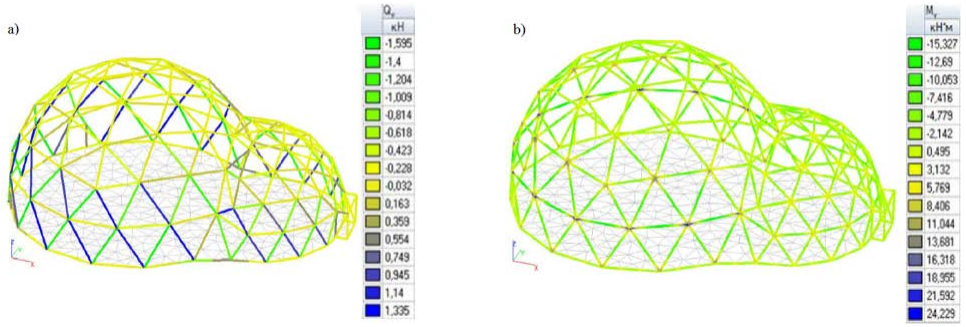

Figure 7. Structural Calculation Results for Exhibition Complex: a – isofields in elements created by transverse forces; b – isofields in elements created by force moments.

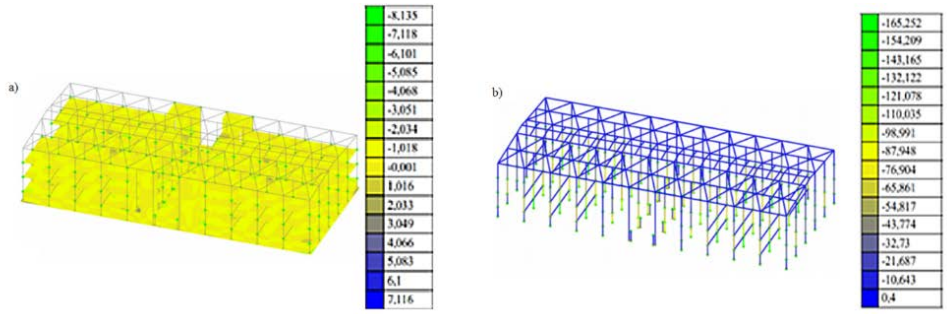

Figure 8. Structural Calculation Results for Shopping Mall: a – isofields of stresses M_{xy}; b – values of forces N in shafts of the diagram.

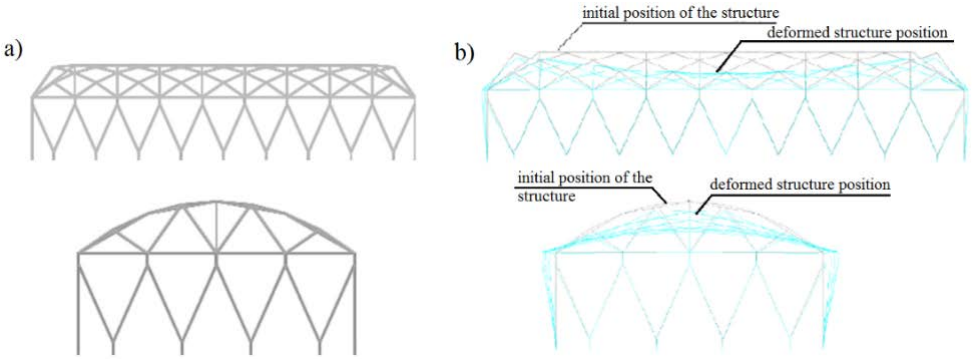

Figure 9. Calculated Theoretical Study of Guarding Structure for Railway Station: a – calculation diagrams; b – structural deformations.

The figures show changes in the stress-strain state in the structures under consideration. The stress values are represented on the plots of moments, transverse and longitudinal forces. In tabular form, in the form of a color scale, changes in effort from minimum to maximum values are shown. Thus, the analysis of these values for the exhibition complex shows that the maximum values for the longitudinal compressive forces plot are 121 kN, and stretching is 175 kN. For the diagram of transverse forces, the maximum value for compression was 15.3 kN, stretching 24.2 kN. Taking into account the calculations performed, the sections of the elements were selected. For the exhibition complex, the dome structure consists of pipes of circular cross-section 100×3 mm. The calculations performed showed the stability of this structure to the loads acting on it. The received values of forces and displacements are in acceptable values.

The performed structural calculations and design studies for additional devices protecting from temperature impacts are simple and reliable solutions that can be used in construction. Their main advantage is simplicity of erection, low cost, repairability, and high degree of protection from various climatic factors.

The performed complex of pre-design studies of the types of buildings reviewed as well as the estimation of obtained thermophysical parameters of guarding structures indicate that well-known solutions and materials as well as new technologies such as the ETFE membrane systems can be used in the climatic conditions in questions. Moreover, studies have shown that this system can be used both in hot and harsh

climate which makes it quite universal and broadens the area of its use. The study has confirmed that when solving the tasks related to building protection from climatic factors, the task of the highest importance is to select the material for guarding wall structures and for coverage structures as well. Herewith, the protection material shall be not only efficient in terms of thermophysical properties, readily available, repairable, low-cost and so on, but it also shall make the building facade architecturally expressive while blending seamlessly into urban environment.

The idea of making protective spaces as domes or any other additional structural solutions allows creating certain microclimate indoors which is especially important for public buildings. Heat losses are significantly reduced indoors when such solutions are used. It shall be noted, the closed spaces are the most reasonable solution, especially on the Arctic coast.

The performed studies were compared with the results presented in [22–25]. Comparison of the results showed that the considered additional structures provide the necessary level of protection in terms of thermal and physical parameters for the specified climatic areas of construction and meets the requirements of strength and stability, taking into account the loads acting on them.

4. Conclusion

Based on the performed studies, the following conclusions may be made:

1. Significant climate change on the planet that has been happening in recent years indicates that a serious approach shall be applied when designing buildings and structures in different climate regions of the Russian Federation.

2. Versions have been suggested and justified for use of additional structural elements in the form of dome roofs, sheds, membrane coverages, etc. to provide protection from different temperature effects.

3. Based on the performed calculated theoretical studies, it has been determined that the suggested additional architectural structural elements provide protection both from low negative and high positive temperatures.

4. Feasibility of implementation of the architectural structural elements has been shown by the example of some public and industrial buildings such as shopping malls, exhibition and transportation complexes.

5. It has been confirmed that the use of ETFE-type membrane system is the most preferable in different climatic zones for efficient protection from climatic effects.

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