Energy efficient building for arctic regions

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Abstract. The relevance of this topic is stipulated by the sharp changes in climate in the Arctic region, characterized by such factors as increased winds and blizzards, the impact of the stone particles from the quarries near industrial centers, low temperatures, temperature rise, decrease in the area and thickness of ice, melting of the Greenland ice sheet. In 2007-2008, satellite observations showed that its area reached the minimum for 30 years of observations, the next minimum was registered in 2012. In many existing Northern cities and towns, a serious problem with the functioning of housing and communal services is beginning to emerge: emergency and dilapidated housing exceeds the average for Russia. A significant number of standard projects, not adapted to the extremely harsh Northern conditions, requires frequent repairs, excessive heat and energy, which leads to a huge expenditure of funds. These factors determine the need to design new types of buildings in high-latitude regions.

1. Introduction

A significant part of the territory is attributed to poorly studied areas, the values of wind speeds for which are not presented. The use of a single value of the reliability coefficient of the wind load in the transition from the standard to their calculated values does not allow taking into account the spread of variable values of the coefficients of variations of annual maxima, which ultimately leads to unequal reliability of the designed structures [1]. Based on the above, there is a need to find technical solutions for rational energy-efficient buildings.

Analyzing the strategy of development of the Arctic zone of the Russian Federation, it is necessary to take into account the spread of various activities localized not in cities, but in small settlements. In general, the following typology of settlements is possible on the functional basis: transport base, emergency rescue base of the Ministry of Emergency Situations, military base, base of fuel and energy complex (FEC), industrial production working settlement, scientific base, and tourist base [2].

The earth's climate is getting warmer every year, and the Arctic’s warming is two to three times faster than the rest of the planet.

As the main reason, scientists call the sharp temperature jumps caused by climate change in the Northern hemisphere, as well as the influence of warm winds. As a rule, the sea off the Northern coast of Greenland freezes so much that until recently it was called the "last ice region", which was supposed to be a deterrent to global warming.

According to the latest data, the Arctic ice cover in the Spitsbergen region at the end of August was 40% lower than the average for this time of year since 1981. A record low was reached in July 2018.
According to experts, at some stage between 2030 and 2050, ice in the Arctic Ocean may completely disappear in summer [3].

Abnormal temperatures in February and August 2018 led to the ice retreating from the coast at a record distance. "Almost all the ice to the North of Greenland is significantly destroyed and damaged, and therefore more mobile. Open water off the Northern coast of the island is an unusual phenomenon," emphasizes Ruth Mottram of the Danish Meteorological Institute [4].

The extreme North can be attributed to a kind of world in which you can select certain difficulties for design, such as:

- The severity of the climate, namely: permafrost, long winters, hurricanes and blizzards;
- Weather contrast: changes in air temperature from minus 60 degrees in winter to plus 40 degrees in summer;
- The rapid transition from long winters to short summers;
- Vastness: a quarter of the earth's land, where forty-seven percent of the territory of Russia with the most valuable raw materials and energy resources are swamped, snow-covered and frozen;
- Lack of roads and deserted areas;
- Shift and expeditionary nature of work, which generate the psychology of a temporary worker.

The main difficulty in solving the problem of forming a comfortable settlement environment in the extreme conditions of the North is that it is difficult to determine the boundary between the temporary and permanent character [5].

Significant flows of workers, affecting the quantity of population, structural and temporal features of extractive industries should also be taken into account.

In the opinion of the architect Yu. F. Ysov [6], the features of the northern dwelling architecture include the following factors:

1. Compactness - a property of the capacity of a spatial form, which is determined by the ratio of volume to the surface;
2. Orientation is a property of flexibility of the spatial form, its ability to reflect the conditions of the outside world. If the compactness of the shape stems from the need of isolation of the dwelling from the external environment, the orientation of the shape, on the contrary, is caused by the necessity of its connection with the external environment;
3. Integrity is a property of the spatial form that characterizes the organic unity of all its parts and details. If compactness is a special measure of volume, if the orientation establishes a connection of this volume with its environment, then the integrity of the spatial form expresses the unity of internal spatial organization.

The scale of structures, requiring enormous material, technical and labor resources, set the task of finding rational design schemes while maintaining the uniqueness and aesthetics of the architectural appearance [7]. In addition to this, the above complicating factors for construction in the Northern regions are to be superimposed.

The proposed residential building is intended for realization in the Far North. The building can be used as a permanent home, and for the seasonal stay of people (scientific expeditions, tourism, mining, etc.). According to the authors, for the Arctic in terms of energy conservation, proper circulation of air inside, the most rational buildings are the ones in the form of combinations of dome forms: biconvex lenses, spheres, Reuleaux cone and others, at the base of which are the foundations of the platform type.

The main reason for the energy efficiency of the dome is its shape. Due to the geometry of the sphere, the properties of some types of energy in the dome structure are optimal for their economy [8-10].
They are subject to the following requirements: fast construction; maximum factory readiness of structures and components; all-season and easy installation; lack of "wet" processes; uniformity of the main load-bearing structures, allowing to significantly reduce the cost of construction; spatiality and compatibility of elements and structures to improve mechanical safety during operation; ensuring modern quality of life through the use of innovative technologies.

The main elements of the dome with a diameter of 30 meters and a height of 12.8 meters (three floors) are designed from wood. The ratio of the boom to the span of the dome is 1:2.5. The useful area of the building is 1842.2 m², the volume of internal space is 718 m³. The frame is formed by sixteen glued boarded meridional ribs (the semi arch length is 19.87 m). The connection of meridional ribs in the upper ends of the dome is constructed using a metal ring with a diameter of 2 m of the box section with a wall thickness of 12 and 10 mm, respectively.

On the ground floor there are 6 two-room apartments with an area of 78.3 m² each and one three-room area of 118.4 m². On the ground floor there are also 2 vestibules and a technical room. On the second floor there are 8 two-room apartments with a total area of 533.6 m², on the third floor there is an open-plan space of 475.2 m². The layout of the first floor is shown in Figure 1.

Elements of the staircase are made of wooden columns, pivotally supported on a base platform, loosened between themselves by wooden ties. The connection of the columns with the crossbar is carried out with the help of a metal lining. In the inter-storey ceilings in the center of the building there is a hole with a diameter of 2 m, around which a spiral staircase is made. For the support of the intermediate landing there are additional racks. Fire safety is ensured by combining constructive and chemical methods. They are device of fire walls or fireproof sections and floor coverings, a division of hollow fireproof coatings, diaphragms, device of safe cutting of flues and furnaces, plastering of the ceilings, the increase in cross section of timber elements.

![Figure 1. Layout at 0.000.](image)
Floor decks are collected from glued veneered plates of trapezoidal shape with a width of 1.5 meters, laid on beams, which are located radially under semiarches. Walls and partitions have a frame structure. Wood consumption for the supporting frame of the building is 96.4 m³. The section of the dome building is shown in Figure 2.

![Section of the dome building.](image)

The sandwich panels of trapezoidal shape, with a height of 3 m (Figure 3) are used as walling to make the frame rigid longitudinal ribs are connected by glue to with transverse ribs provided at the ends of the plate. For the device of the longitudinal joint, edges of the plates have special piles of trapezoidal bars.

Based on the conditions of global warming, it is proposed to design buildings and settlements at a considerable height above ground level, which can become a water surface in the foreseeable future [11].

The foundation is a spatial platform having dimensions in the extreme axes of 33x33 m in the upper zone and a height of 1.5 m. The selected type of the foundation has the following advantages [12]:

Let us make a comparative calculation for a domed house with a covered area of the circle radius \( R = 15 \) m and a rectangular house with dimensions \( a = 24 \) m and \( b=30 \) m.

| Comparative characteristic | Domed house | The house is rectangular in shape | Conclusions |
|----------------------------|-------------|----------------------------------|-------------|
| Living area (on 1st floor) | 706.5 m²    | 720 m²                           |             |
| Building height            | 12.8 m      | 10 m                             |             |
| A) complete                | 1,413 m²    | 1,800 m²                         | 21.5% less than the total surface area |
| B) roofing                 | 471 m²      | 720 m²                           | 34.6% less than the area of the roof |
| C) wall                    | 942 m²      | 1,080 m²                         | 12.8% less than the area of the side |
| Volume                     | 2,826 m³    | 7,200 m³                         |             |
As can be seen from the comparison, with the same covered area there is a significant difference in the surface area of buildings. Therefore, the first energy-efficient advantage of the dome construction is the reduction of heat loss due to the smaller surface area. The shape of the dome is made almost seamless, which means that heat loss through the seams is also minimal [13].

Snowdrifts as a result of snow shifts in a period of strong winds, depend upon wind velocity: when the speed exceeds 4-5 m/sec, a drifting snow usually starts – a ground snow-storm, moving the previously fallen snow; at speeds more than 10-15 m/sec removal of packed snow begins, and at a speed over 20 km/h - the ice crust of compacted snow is destroyed. The aerodynamic properties of the dome reduce wind resistance, resulting in the absence of drafts and weathering of heat [14,15]. If less heat goes through the surface area, then less heat enters the building from the outside, and in winter it will be warm in the dome house. So there is a significant cost savings for additional heating and cooling of the building.

Due to the natural curvature of the dome, there is a natural air circulation: warm air from the floor rises up, cold air falls down, and thus air exchange takes place [16].

Energy efficiency of dome structures can be increased by improving the natural performance, such as: competent placement of double-glazed windows to increase the flow of natural light. The output is a transparent sealed hole at the top of the dome [17].

The unique thermal characteristic of the spherical house is provided by a positive area-to-volume ratio. Heat losses are directly related to the surface area, neither the thickness of the walls, nor the number of insulation used, nor the thickness of the window frames play a special role. Indoor heat loss is also affected by aerodynamic drag. Due to the streamlined shape of the dome and the absence of front walls, wind flows freely slide on the surface and blow the hemisphere with less resistance [18].

One cannot but note one more advantage of the dome building – acoustic properties.

The original form stands out from the same faceless mass of similar buildings, attracts attention, and fits perfectly into the surrounding landscape [19].

2. Conclusions
The obtained results should be applied by economic entities engaged in foreign economic activity, one of the elements of which is export operations. In the Russian Arctic, when designing a human habitat, it is possible to apply universal principles of habitat formation in extreme conditions [20].

The proposed building is designed before the albums stage of working drawings. The dome is competitive in comparison with the known solutions due to less heat loss, due to the smaller surface area, improved aerodynamic properties.

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