Research of permafrost soil thawing under the foundation platform of structural type

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Abstract: The expediency of using spatial foundation platforms on permafrost soils is justified in this paper. The stress-strain state of the spatial foundation platform under the building of a lens-shaped structure at different heights of the ventilated space is investigated. The structural solution of the spatial foundation platform is made in the form of a plate-and-rod structure. The calculation is carried out using the SCAD software package. The parameters of the rods and nodal joints of the spatial foundation platform are determined. With the help of the COMSOL Multiphysics software package, temperatures are investigated throughout the year in the central part of the platform under the its lower belt.

1. Introduction

The modern policy of the Russian Federation is aimed at the development of the Arctic regions. The cryolithozone (the upper layer of the earth's crust, characterized by negative temperatures of rocks and soils and the presence or possibility of existence of underground ice) stores huge reserves of hydroelectric resources. Construction in permafrost constantly requires improvement, energy and construction efficiency, reduction of the construction time due to the short summer period. Taking into account cryogenic permafrost processes and predicted global warming, it is important to develop foundation structures that ensure the stability of the building during the degradation of permafrost [1].

The use of reinforced concrete foundations has its significant disadvantages due to the underdeveloped logistics of high-latitude construction and seasonality of installation works. Precast concrete is difficult to transport, and monolithic reinforced concrete significantly slows down the construction process. With all the known advantages, metal structures contribute to undesirable heat transfer to the thickness of the ground base.

Timber possesses a small coefficient of thermal conductivity, which significantly increases the energy efficiency of the structure as a whole. Such material can reduce heat transfer from the structure to the base, which is important in the operation of the building on permafrost soils, built on the first principle. Timber structures increase logistics due to their transportability. In addition, due to the assembly of timber structures the speed of construction increases.

On the whole, the construction of timber buildings and structures in the Northern latitudes is a promising direction due to the technical, aesthetic and geometric characteristics of the structure and requires the development of special foundations [2, 3, 4].

According to the authors, it is worth considering the feasibility of using a spatial foundation platform [5, 6, 7, 8]. Platforms can have solutions in the form of cross beams, structural plates, plate-rod structures, as well as shells and folds. Regardless of the design solution, the spatial foundation platform is prefabricated.

The use of spatial foundation platforms is promising for a number of reasons:

- Reduction of engineering-geological surveys;
- The structure does not require a large amount of excavation, which in the case of frozen soils is quite time-consuming;
- The spatial foundation platform is less sensitive to the deformation of the footing soil due to the solid work of the structure; it is advisable to build it in seismic areas, on weak and structurally unstable soils, including permafrost soils;
- The possibility of the structuren of a spatial foundation platform to be adjustable, for example, by means of jack devices;
- Availability of repair and reinforcement of the foundation structure;
- The platform prefabrication solves the issues of transportation and increases logistics when applying foundations in the Northern latitudes;
- All-season construction;
- Reduction of construction time;
- Due to the thermal properties of timber, the energy efficiency of the construction built on such foundations in the Arctic regions is increased;
- The upper belt of construction elements can serve as floor;
- The use of a spatial foundation platform allows to implement the principle of building closure, which increases the energy efficiency of the first floor;
- Use of ventilated space for technical needs;
- Due to the low coefficient of thermal conductivity of timber and the ability of the spatial foundation platform to be ventilated, the risk of thawing of the base is significantly reduced, which is effective when building the foundation on a degraded permafrost soil.

Prefabrication and versatility of the spatial foundation platform allows it to be used for various buildings and structures (figure 1, 2).

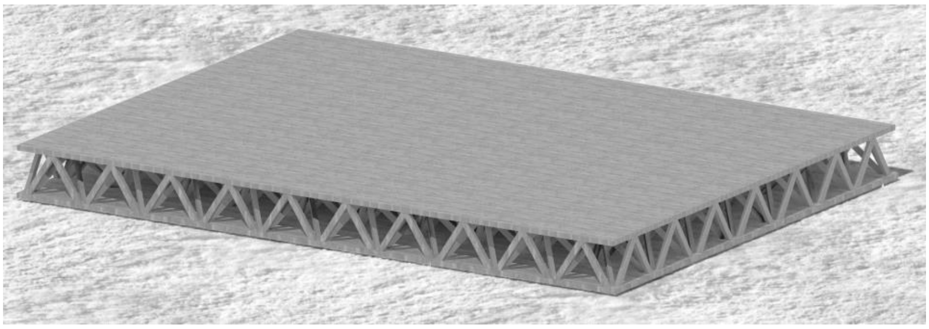


Figure 1. Spatial foundation platform of plate-and-rod structure for a rectangular building.

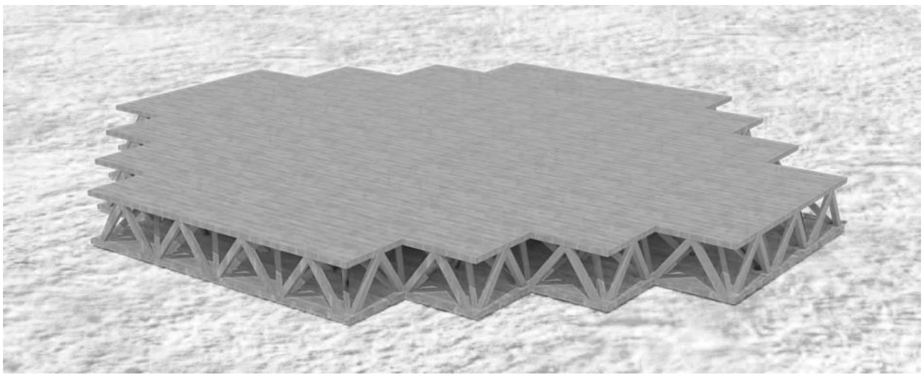


Figure 2. Spatial foundation platform of a plate-rod structure with a rounded shape for aerodynamic building forms.

2. Numerical research

The authors have calculated the spatial foundation platform made of timber elements for the building of a lens-shaped form (figure 3). The structural solution of the spatial foundation platform is made in the form of a plate-and-rod structure.

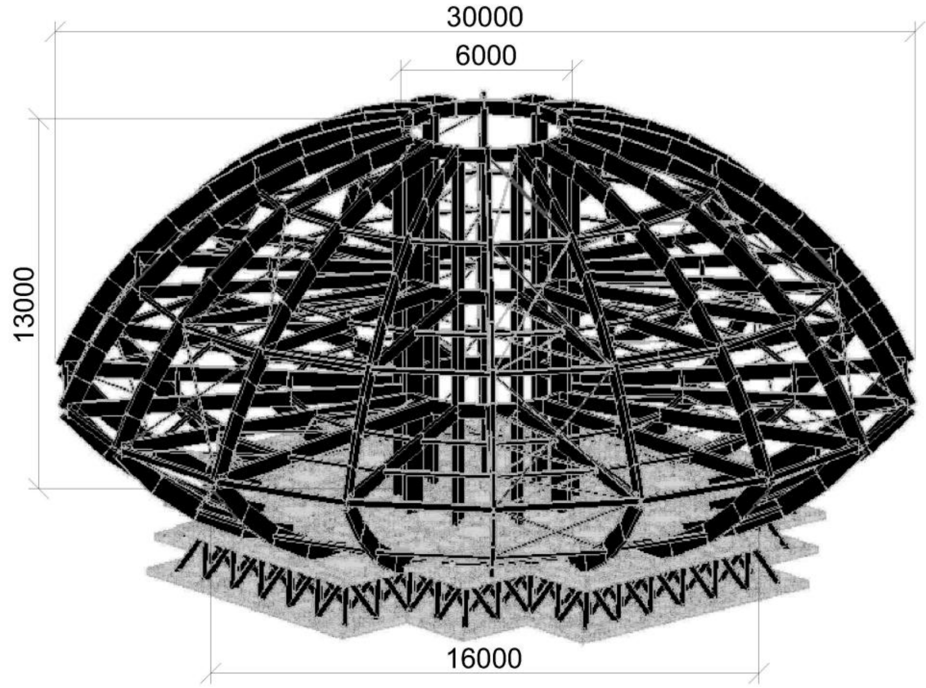


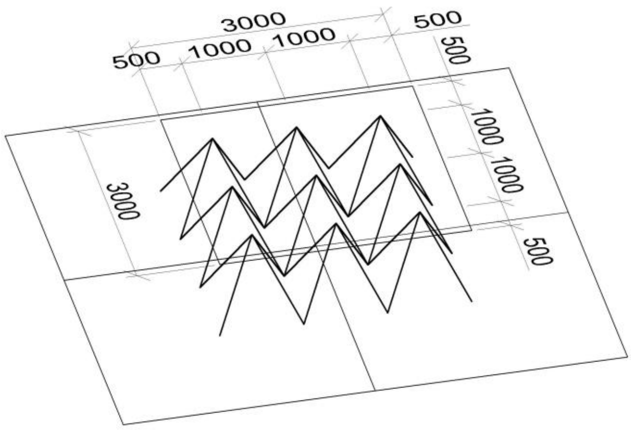
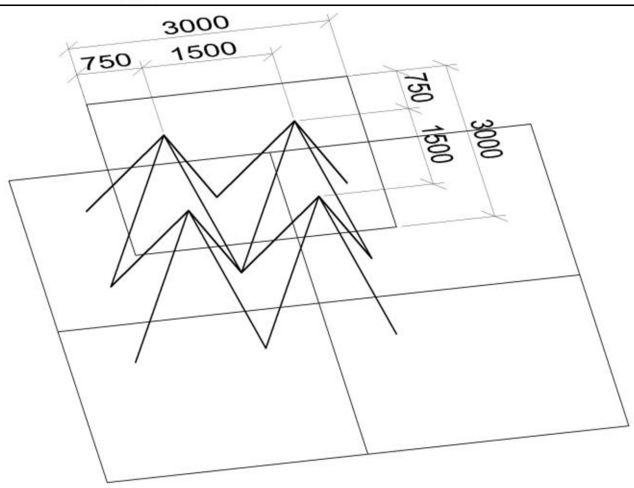
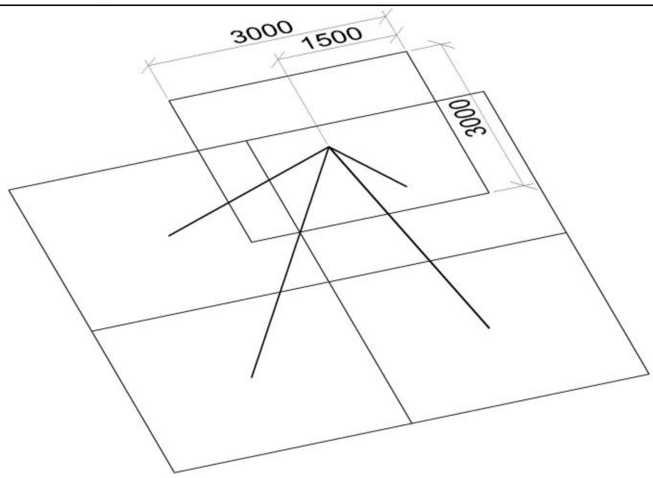
Figure 3. Design scheme.

The frame of the building of the lenticular type is formed by sixteen half-arches in an amount of 16 pieces with a cross section of 160×693 mm in increments of 5.209 m in the 30 m largest diameter of the building. The diameter of the lens base is 16 m. The height of the building is 13 meters. From the greatest diameter of the building the semi arches are located down to the footing and up to the key ring that unites the 6m columns. The 235×660 mm section columns are around the circumference in the number of 9 pieces. The supporting structures are made of the second grade glued timber (pine).

The spatial foundation platform in the form of the plate-and-rod structure is designed from timber plates with 3×3 m dimensions, made of cross-glued layers of lamellas (CLT), forming the upper and lower construction belts [9]. Timber elements are made of the second grade larch. The plates in the belts are connected to each other by a hinge. The thickness of the CLT plates of the upper and lower belt is 231 mm. The lattice rods, forming a spatial structure, are made of bars and are inclined. As a result, the spatial operation of the platform is provided, and favorable conditions for the transfer of impacts to the footing are created.

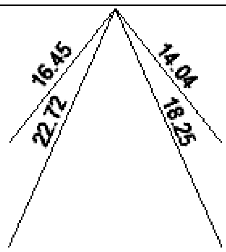
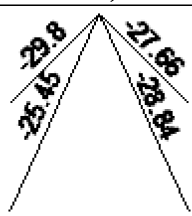
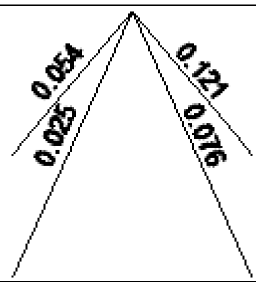
The authors have performed numerical studies of the stress-strain state (SSS) of the spatial foundation platform under varied values of height: 1; 1.5 and 2 m. the Calculation was performed with the SCAD software package. The structure was modeled on an elastic base with unfavorable characteristics. In calculation the elastic base deformation modulus is taken 350 MPa, the layer thickness - 10 meters, the Poisson ratio - 0.35. To prevent the negative impact of frozen soil and water on the design of the base, preparation in the form of bedding of gravel or crushed stone with a thickness of 100-200 mm is provided. At different heights of the ventilated space, design features of the spatial foundation platform are being changed (table 1). The plates of the upper belt are displaced relative to the lower belt by a different value. Depending on the height of the ventilated space, the number of nodal connections per plate and the angle of inclination of the rods are changed.

Table 1. Schemes of spatial foundation platform with different heights of the ventilated space.

Ventilated space height, m	Scheme	Rod inclination, rad (°)	Number of nodal connections per one plate, (pieces)
1		0.96 (55)	9
1.5		0.96 (55)	4
2		0.75 (43)	1

As a result of calculations, the maximum longitudinal forces in the rods and the maximum values of moments in the upper zone [10] are established (table 2).

Table 2. Maximum longitudinal forces in the rods and the maximum values of moments in the upper zone.

<table>
<tr><th>Ventilated space height, m</th><th>"Bunch" of rods with N maximum tensile stress, kN</th><th>"Bunch" of rods with N maximum compression stress, kN</th><th>M maximum meaning, kN·m</th></tr>
<tr><td>1</td><td>
</td><td>
</td><td>
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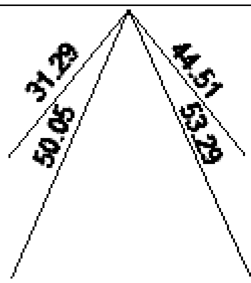
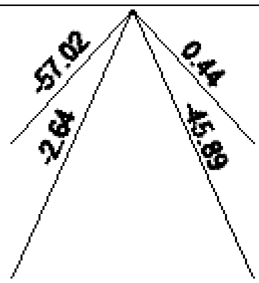
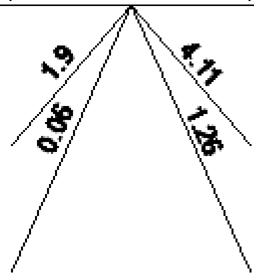
<tr><td>1.5</td><td>
</td><td>
</td><td>
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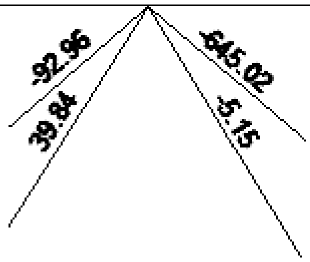
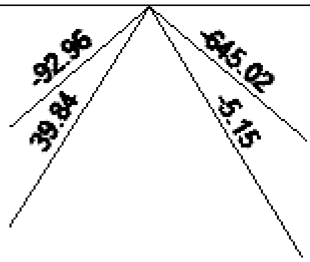
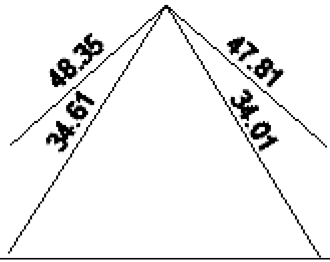
<tr><td>2</td><td>
</td><td>
</td><td>
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Comparative analysis of consumption (table 3) of the main materials has shown that the economical benefit increases with decreasing platform height (of the ventilated space).

Table 3. Consumption of the main materials.

Platform height, m	Timber consumption for the lattice, m^3	Cost of assembly (prices for 2018), thousand roubles
1.0	8.00	148
1.5	10.88	201,5
2.0	21.57	400

However, to ensure the reliability of operation and for reasons of possible repair and maintenance of the foundation structures and communications, the height of the ventilated space is advisable at least 1.5 meters [11].

In figure 4 the connection node of the upper belt and the rods of the lattice of the spatial foundation platform with the 1.5 m height of the ventilated space is given. [12, 13]. The connection is designed with a support steel platform of the square 250×250×15 mm profile. For fastening the bars of the lattice, 6 mm thick gussets, welded to the specified plate of 8 mm thick and 100 mm wide are provided, which in turn are based on the support platform. The gussets are attached to the timber brace with the help of steel 16 mm diameter pin bolts. The plate is reinforced by a stiffener.

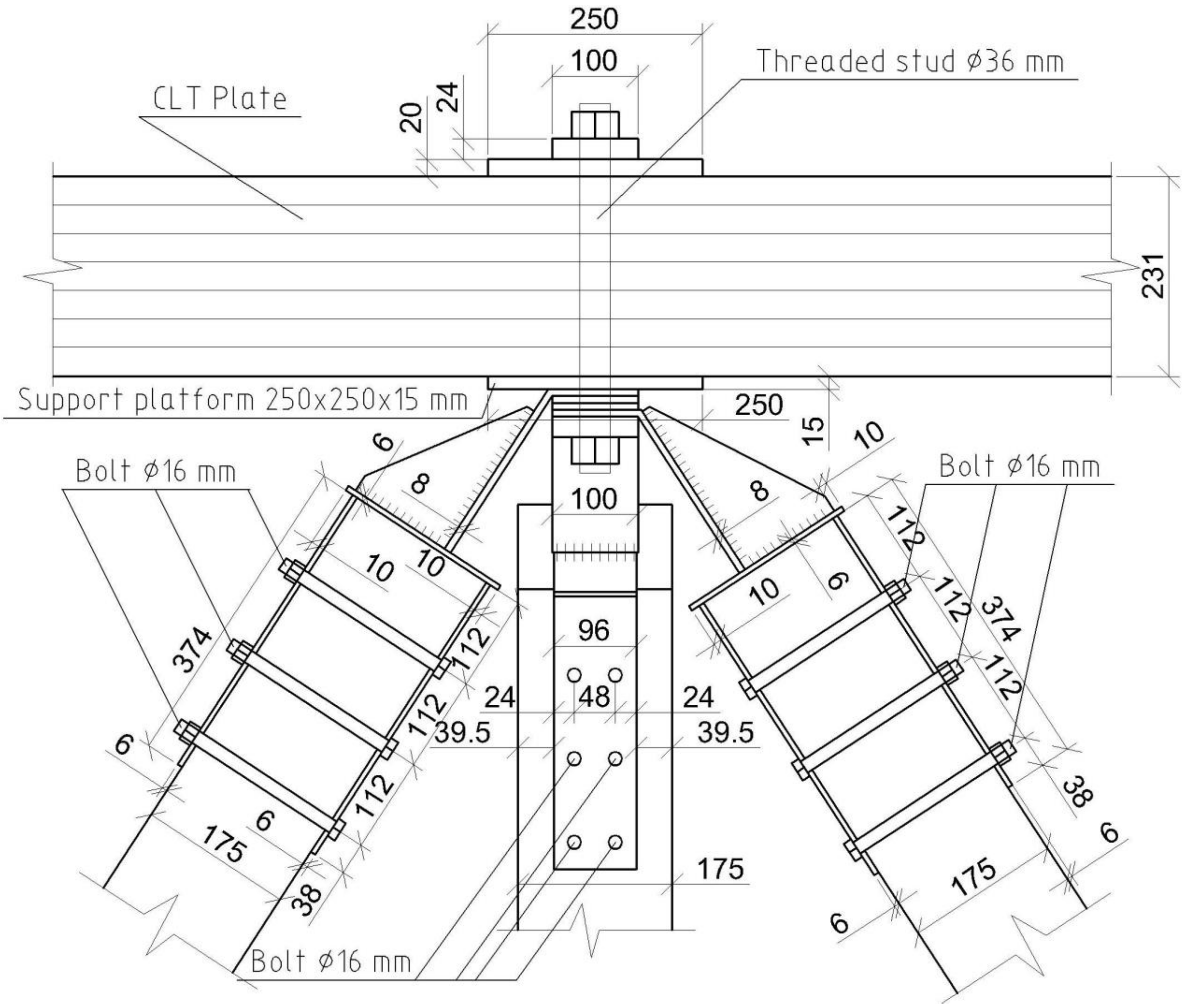

Figure 4. The node connection of the plate and the rods of the structure of the spatial foundation platform.

The further investigated spatial foundation platform was calculated with the COMSOL Multiphysics software package with the aim of determining the parameters of the thawing of the soil under the lower belt. The cross section with the largest amount of heat-conducting material (metal) was chosen for the calculation model (figure 5). The calculation was performed without taking into account convection and flowability of the ventilated space of the foundation platform. The spatial foundation platform rested directly on the ground without filling. The problem was solved with boundary conditions of the third kind. When calculating the heat transfer coefficient was taken to be constant and equal to 23 $W/m^2 \cdot °C$ in accordance with [14]. The surface temperature was taken to be equal to the average monthly outdoor air temperatures for the city of Norilsk [15] (table 4). At the lower boundary of the design area, at a depth of 10 meters, on the basis of the literature and the calculated data, the heat flux of 2.72 W/m^2 was set. On the upper belt of the platform heat insulation with 150 mm thickness was provided, made of mineral wool. The temperature on the surface of the heater was taken 20 °C, heat transfer coefficient equal to 8.7 $W/m^2 \cdot °C$

Table 4. The average monthly outdoor air temperatures for the city of Norilsk.

Month	January	February	March	April	May	June	July	August	September	October	November	December
Soil temperature T, K (ºC)	245,85 (-27.3)	247,95 (-25.2)	252,95 (-20.2)	258,45 (-14.7)	267,95 (-5.2)	278,35 (5,2)	287,55 (14.4)	283,85 (10.7)	274,95 (1.8)	261,95 (-11.2)	251,35 (-21.8)	247,15 (-26)

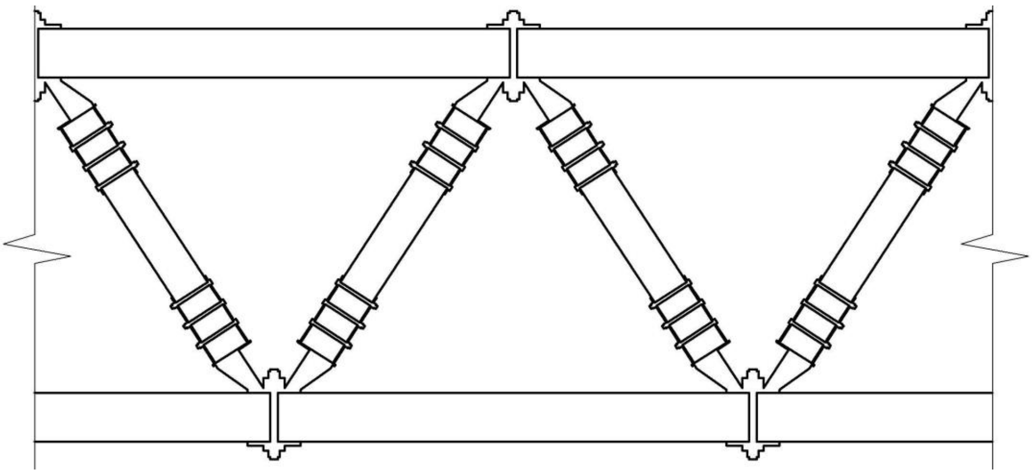

Figure 5. A model for determining the thermal impact on the soil by the spatial foundation platform.

In the course of the calculation for 4 years, the soil temperatures were determined under the foundation platform of the structural type. It was found that in the hottest month of the year the temperature in the central part of the platform under the lower belt was negative (figure 6). This indicates the possibility of optimizing the design from the position of minimizing the thermal impact on the ground base.

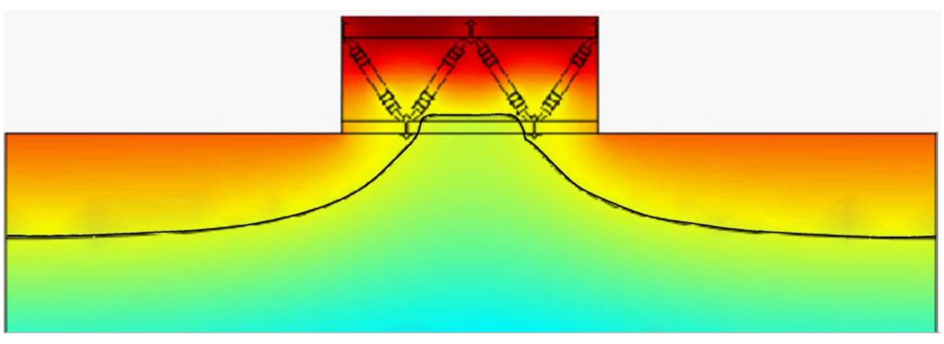

Figure 6. Isoline of the temperature equal to 273.15 K (0 °C) in the hottest month of the year.

3. Conclusions

- It is revealed that the minimum height of the ventilated space of the foundation platform is 1.5 meters in terms of the requirements;
- It was found that the Foundation platform with the height of 1.5 meters provides negative soil temperature under the lower belt in the hottest month;
- The numerical experiment has proved that the suggested design reduces the risk of soil warming.

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