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SOME DEEP FREEZE STORAGE HEAT TRANSFER PROBLEMS

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Abstract

The paper discusses the specific problems that occur with deep freeze storages, from the aspect of building physics. A special review is given of the phenomenon of soil stability, i.e. soil bearing capacity, in the context of soil freezing, deformations of the floor structure, and functional disorders in the interior of deep freeze stores.

A case from practice was presented, in which serious problems occurred in the process of exploitation, which led to the fact that the existing floor structure with all layers had to be completely demolished, a new one constructed with newly designed layers, as well as to improve the connection with existing facade construction.

An analysis of the causes and a proposal for a solution for that building are presented. The focus of the work is on the design concept of the relevant wall and floor structures, the calculation of the temperature in the ground under the building, considering conditions of operation that are specific and include a very low interior temperature of -27°C, a low winter design temperature of the external air -15°C, with an emphasis on the necessity of application of an adequate heat system of under-slab structure. The paper provides recommendations that engineers can use in similar cases.

Key words: *Deep freeze storage, Heat transfer, Soil freezing, Under slab heating*

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1. INTRODUCTION

Building physics of high-rise buildings is an area that we apply in our daily work and which is regulated by domestic and foreign regulations. It can be said that there are no major unknowns, because the projects are such that they mostly resemble each other:

- In winter, there is a need to heat the interior, because the internal design air temperature is higher than the external design air temperature;
- In summer, the situation is reversed, and it is necessary to cool the interior, because the external design air temperature is higher than the internal design air temperature.

However, with buildings that have different needs in terms of maintaining the interior temperature, things become more complicated.

In deep freeze storages it is necessary to maintain a constant temperature both in the winter and in the summer, which must not depend on fluctuations in the outside temperature.

The internal design temperatures in the deep freeze storages depend on the technological process, that is, the level of freezing that should be achieved on the product (material) stored in the interior. The lower the temperature that needs to be achieved and maintained, the greater the temperature difference that HVAC systems need to compensate for, and the building's thermal envelope needs to overcome.

Deep freeze storages/warehouses are buildings that are not studied in architecture studies (in Belgrade), and this text aims to publish some experiences from practice, in order to help designers in overcoming perceived problems.

2. METHODOLOGY

This paper discusses an existing deep freeze storage, relatively recently constructed, which operates in deep freezing mode at Ti= -27°C. Building is constantly lying on the ground. The location is flat, with pronounced gusts of wind and the external design temperature in winter is Te= -15°C.

In the interior, racks were designed and built for storing goods. The racks can be moved electrically via a rail system built into the floor structure.

2.1. Problem

During operation, it was observed that the racks could not be moved, because the floor structure had been deformed in certain areas of the building (the floor is no longer completely horizontal), therefore the rail system for movement was deformed.

The investigation revealed that there are multiple reasons for this:

- There was a significant penetration of atmospheric water from the roof, whose flooding of the underfloor and foundation structure was not planned;
- The heaters in the floor structure had an unexpectedly long interruption in operation;
- The architectural-construction details of the connection between the floor and wall structures in the foundation area are not designed and executed well enough.

These problems resulted in the freezing of the ground in critical zones, which consequently led to the expansion (lifting) of the floor structure due to the force created by the action of the ice.

What is quite specific for buildings of this type is the need to keep the soil temperature above the freezing point, despite the influence of the external air temperature (which is -15°C), and especially the influence of the design temperature in the interior (which is -27°C).

Therefore, the boundary conditions for the design of the structure, i.e. architectural construction details, are very unusual.

The conditions of structural stability cannot be met without the additional heating energy of the layers that are oriented towards the ground, in order to reduce the effect of cooling that takes place in the interior, as well as in the exterior.

In this sense, the system for heating the subfloor structure must be designed and implemented in order to achieve the desired energy balance between cooling and heating. In the existing state, the pipe distribution of floor heating was carried out, with projected temperatures of the heating fluid ranging from +12°C to +30°C. A problem of discontinuity in the operation of that system was observed, due to a failure, and since there was no backup system, the period of time in which the system did not function contributed to the freezing of the ground under parts of the floor structure, which led to the deformation of the structure.

2.2. The task

The task of reconstruction in relation to the observed problems consisted of the following:

- To solve the problem of draining atmospheric water, so that it does not flood the subfloor and foundation structure;
- Design the heating system of the subfloor structure so that there is a backup system. Change the system, so that instead of pipe distribution and heating fluid, electric heaters are provided. The potential price difference was not a consideration in the decision-making process, as the existing fluid distribution pipeline proved unreliable;
- Design the architectural construction details of the joint of the floor and wall structures in such a way that calculations from the aspect of building physics prove that considering the defined conditions of use, the ground does not freeze in the area under the building.

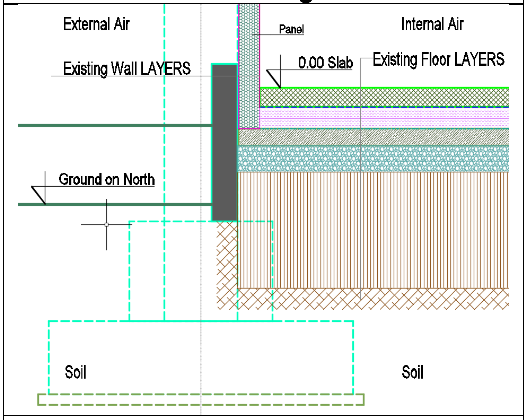
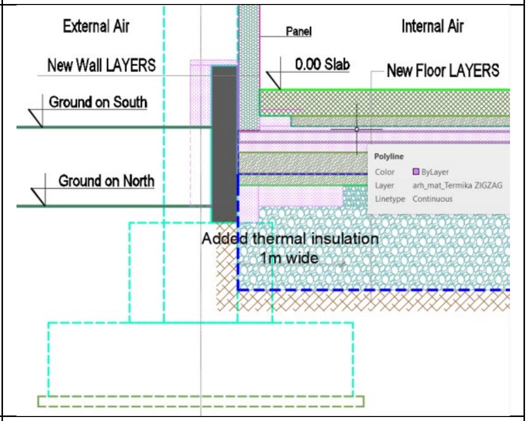
2.3 Architectural detail – concept

Existing structure and designed structure for intervention are shown in the following table.

Considering problems on the site, it was decided to demolish the complete floor and subfloor structures, including RFC slab, all layers, up to soil, and to form a completely new floor structure.

Regading the adequte wall structure (insulated industrial panels), the focus was on the RFC foundation component (plinth wall), which was not insulated at all, and to add some thermal insulation on the external face of this position, which has a contact with the external air.

Table 1 – Architectural details of floor-wall connection (existing and intervention)

Existing	Intervention
	
Floor layers:	Floor layers:
Top / RFC slab Hydroinsulation Thermal insulation, XPS 20cm Foil Concrete / heat system Aggregate, 1 layer Soil	Top / RFC slab, acocording calculation Concrete, anchors Foil Thermal insulation, XPS 25cm Concrete / heat system Hydroinsulation Concrete Aggregate, 2 layers Soil
Wall layers:	Wall layers:
Inside Panel (industrial, 20cm) RFC (foundation wall/beam) Outside	Inside Panel (industrial, 20cm) RFC (foundation wall/beam) Added facade thermal insulation, 20cm External covering

The assumption was that it is necessary to add a layer of perimeter thermal insulation in a width of 1m under the first concrete slab, in a contact with the RFC construction of the plinth wall (an element of the foundation construction).

3. RESULTS AND DISCUSSION

The following general parameters applies in the calculations:

- Design temperatures in the deep freeze Ti= -27°C
- External design temperature Te= -15°C
- The thermal conductivity of the material is in accordance with the data from the Rulebook on Energy Efficiency of Buildings [6].
- Heating of the floor slab is planned with electric heaters, which are placed with distance of 40 cm. The external temperature of the heater is adopted at +20°C.

The goal of this analysis is to establish what the temperatures are at the control nodes, which are at intervals of 1 m in the base and 1 m vertically. They cover the depth from the ground level to 4m below the ground level. Basically, they are arranged from the foundation wall, up to 2m into the building field.

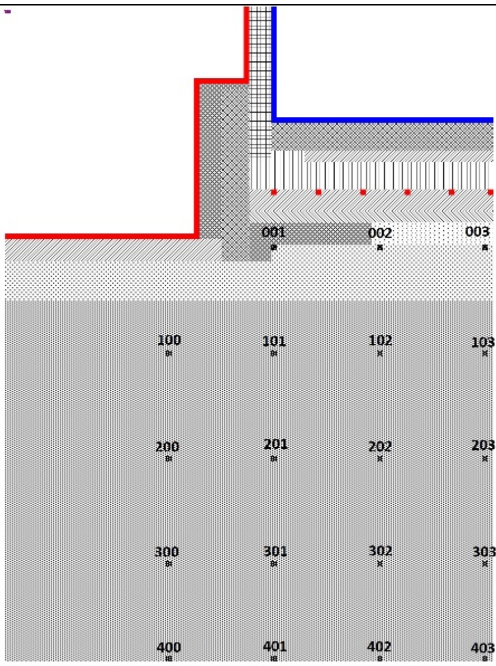
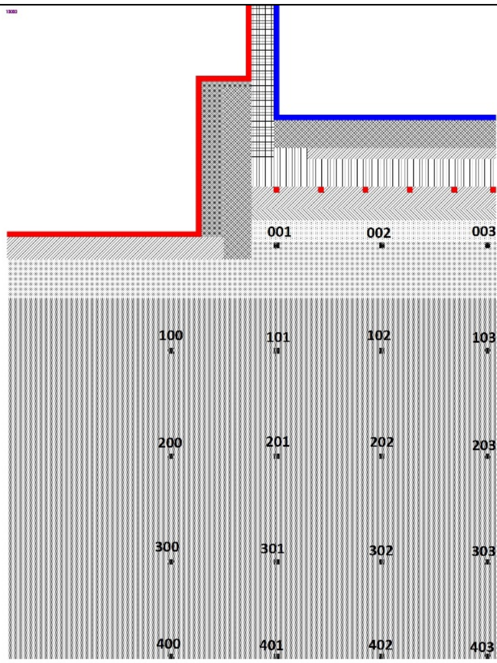
<table>
<tr><th>With added under slab perimeter insulation – detail D1</th><th>Without added under slab perimeter insulation – detail D2</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Figure 1 – Illustration [2] of 2D model of intervention, source: Author

Ideally, the analyzed temperatures below the contour of the object should be positive, in order to reduce the risk of freezing and consequent destruction.

The following details were analyzed:

- D1, detail with higher plinth and perimeter insulation under the slab;
- D2, detail with a higher plinth without perimeter insulation under the slab.

The calculation was carried out in accordance with EN ISO 10211-1 [5], using T-Studio software [7].

Graphic illustration of temperature fields, and numeric results of temperatures in soil nodes are shown in Figure 2 and Table 2 (for Detail D1), and in Figure 3 and Table 3 (for Detail D2).

[2] External air is given with the red line, and internal air is given with the blue line, and those colors does not correspond with the following temperature scale graduation.

Table 2 – Calculated temperatures in the nodes in the soil for detail D1

D1, Te = -15°C (very low temperature of external air in winter)							
Node	Temp [°C]	Node	Temp [°C]	Node	Temp [°C]	Node	Temp [°C]
		001	1.2	002	9.0	003	11.1
100	-5.8	101	-0.7	102	3.8	103	5.7
200	-3.7	201	-1.0	202	1.4	203	2.4
300	-2.7	301	-1.1	302	0.3	303	1.0
400	-2.5	401	-1.1	402	0	403	0.6

D1 Temperature field

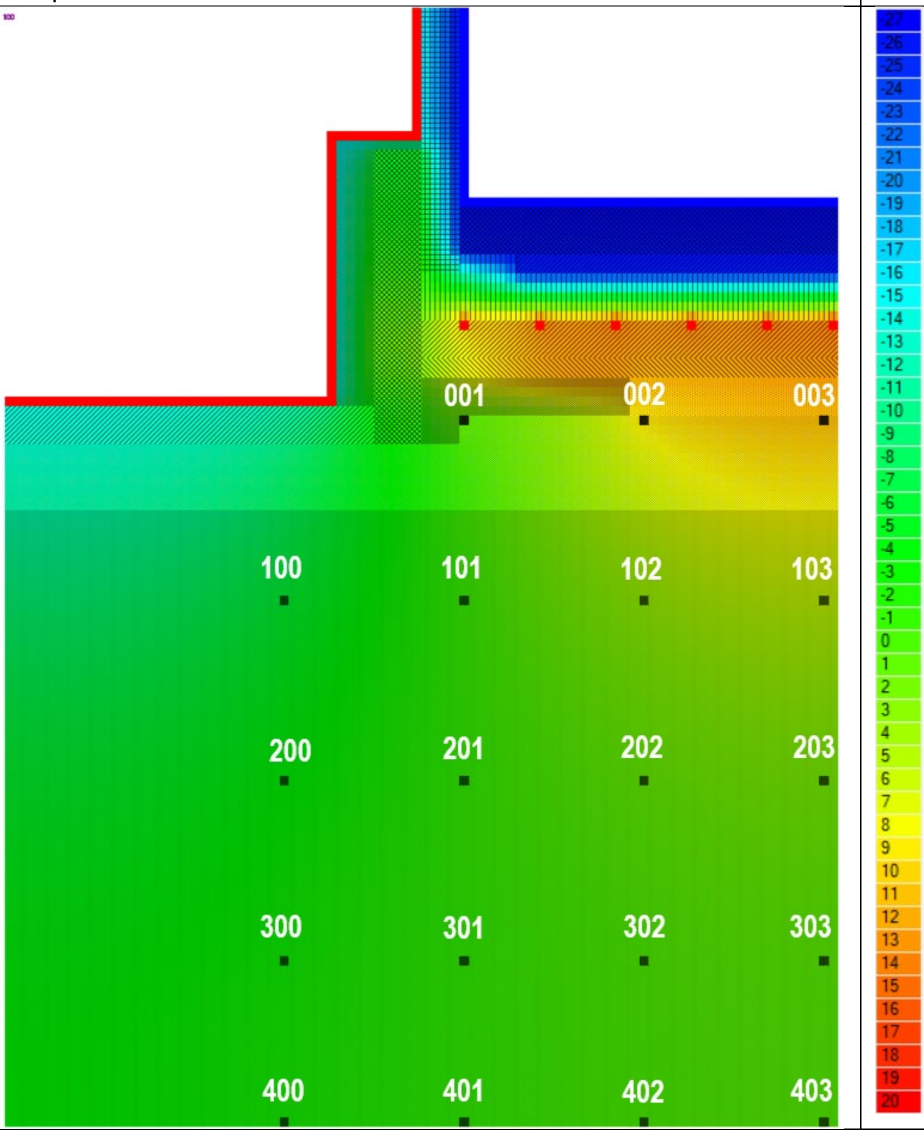


Figure 2 – Illustration of the temperature field for detail D1, source: Author

Table 3 - Calculated temperatures in the nodes in the soil for detail D2

D2, Te = -15°C (very low temperature of external air in winter)							
Node	Temp [°C]	Node	Temp [°C]	Node	Temp [°C]	Node	Temp [°C]
		001	3.7	002	9.7	003	11.4
100	-5.1	101	0.6	102	4.9	103	6.3
200	-3.1	201	-0.3	202	2.0	203	3.0
300	-2.3	301	-0.7	302	0.8	303	1.4
400	-2.1	401	-0.7	402	0.5	403	1.0

D2 Temperature field

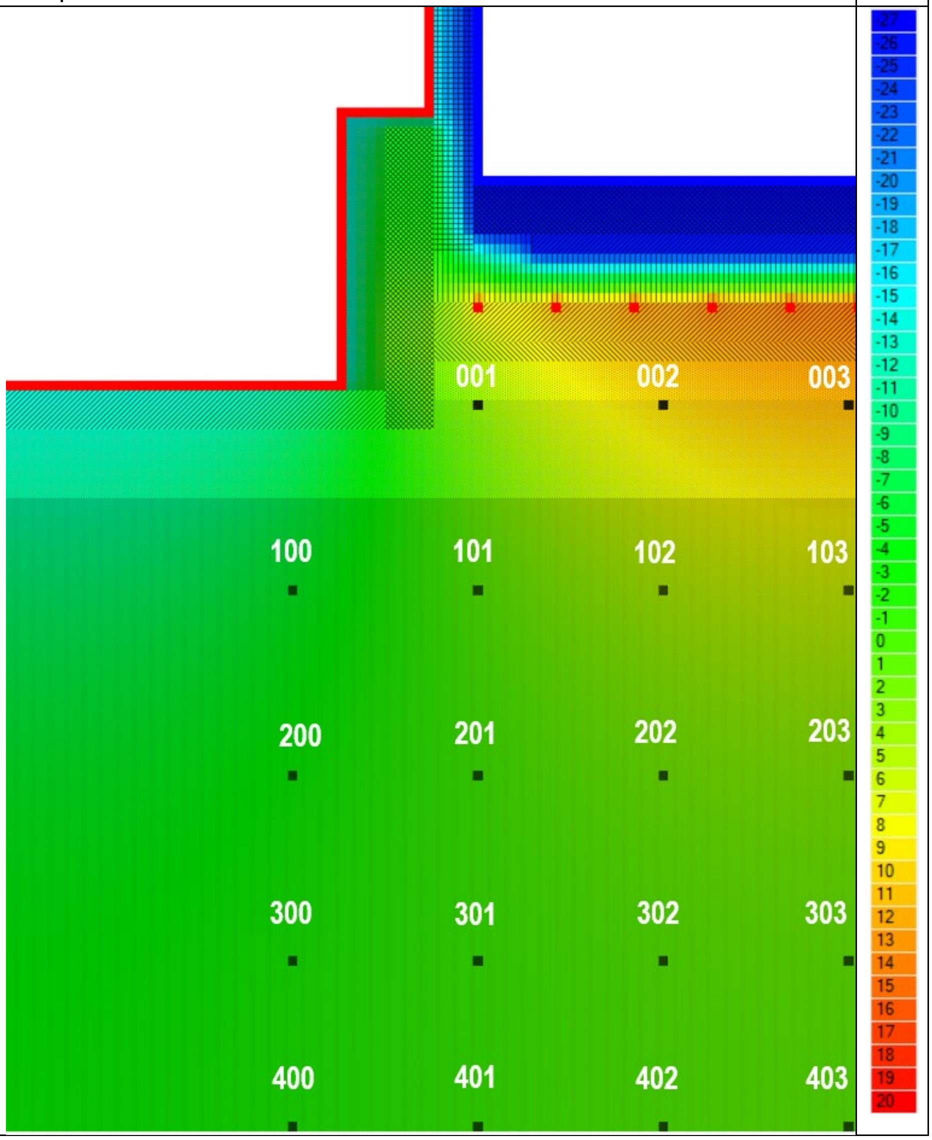


Figure 3 - Illustration of the temperature field for detail D2, source: Author

Variations

Several variations for external air temperatures were conducted, in order to calculate temperatures in relevant nodes in the soil. In the Figure 4, an illustrations of temperature fields are shown, for the temperatures of -10°C, -5°C, and 0°C, and in Table 4, results of temperatures in the soil nodes are presented, all for details D1 and D2.

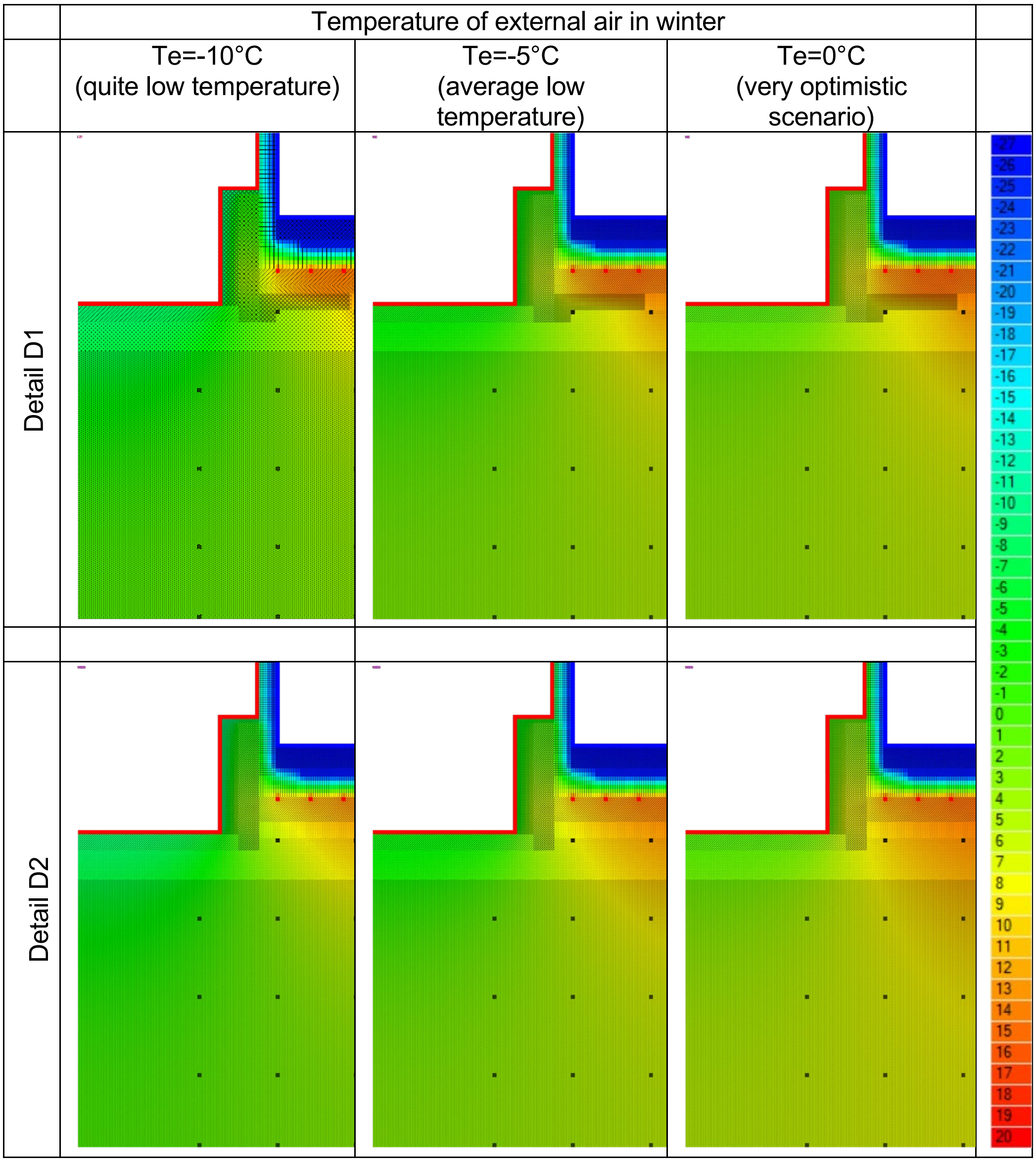


Figure 4 - Ilustration of temperature fields for variated external air tempertures, source: Author

Table 4 - Calculated temperatures in the nodes in the soil for varied exter. temperatures

Detail	Air temper. Te [°C]	Node	Temp [°C]	Node	Temp [°C]	Node	Temp [°C]	Node	Temp [°C]
Detail D1	**-10°C** (quite low air temperature in winter)			001	4.0	002	10.6	003	12.4
		100	-2.0	101	2.5	102	6.3	103	7.9
		200	0.1	201	2.4	202	4.4	203	5.3
		300	1.1	301	2.5	302	3.7	303	4.2
		400	1.3	401	2.5	402	3.5	403	3.9
	-5°C (average air temperature in winter)			001	6.1	002	11.5	003	13.1
		100	1.2	101	4.7	102	7.8	103	9.2
		200	2.6	201	4.4	202	6.1	203	6.8
		300	3.2	301	4.3	302	5.3	303	5.7
		400	3.4	401	4.3	402	5.1	403	5.5
	0°C (very optimistic scenario)			001	7.9	002	12.3	003	13.6
		100	3.9	101	6.5	102	8.9	103	10.0
		200	4.5	201	5.8	202	7.1	203	7.6
		300	4.6	301	5.4	302	6.2	303	6.5
		400	4.6	401	5.3	402	5.9	403	6.2
Detail D2	**-10°C** (quite low air temperature in winter)			001	5.8	002	10.9	003	12.4
		100	-1.6	101	3.3	102	6.9	103	8.1
		200	0.1	201	2.5	202	4.5	203	5.3
		300	0.8	301	2.2	302	3.5	303	4.0
		400	1.0	401	2.2	402	3.2	403	3.6
	-5°C (average air temperature in winter)			001	7.8	002	12.1	003	13.4
		100	1.8	101	5.8	102	8.7	103	9.8
		200	3.2	201	5.1	202	6.8	203	7.4
		300	3.7	301	4.9	302	5.9	303	6.3
		400	3.8	401	4.8	402	5.6	403	6.0
	0°C (very optimistic scenario)			001	9.8	002	13.2	003	14.2
		100	4.9	101	8.0	102	10.3	103	11.1
		200	5.7	201	7.2	202	8.5	203	9.0
		300	6.0	301	6.9	302	7.7	303	8.0
		400	6.0	401	6.8	402	7.4	403	7.7

From the previous shown data, it can be concluded, that in all analyzed cases, the temperature in the soil nodes is above 0°C, so there is no risk of soil freezing. Note that the temperatures which are below 0°C is in nodes which are outside building boundary. In practice, it can be expected that the real results relate to external air temperature between -10°C and -5°C.

4. CONCLUSION:

General conclusions:

- It is necessary to design continuous layers of thermal insulation in the floor construction, above the layer where the heaters are located. The required thickness of this thermal insulation is significantly greater than the thicknesses used in buildings with other, common functions, so a thickness of over 20cm is recommended (in this project it is 25cm). In this case, XPS

(eXtruded PolyStyrene) was used, because of its low thermal conductivity (λ=0.035 W/mK), resistance to moisture as well to mechanical pressure (compressive strength for 10% compressibility ≥700 kPa and permissible compressive load for 2% compressibility ≥250 kPa;
- The plinth on the facade, which is not covered with a thermal panel, must be thermally insulated in order to reduce the thermal bridge (in this project 20 cm XPS is used).

Particular conclusions:
- Comparison of the results between the analyzed details D1 and D2 (with or without added perimeter thermal insulation under the slab) indicates a very small difference. It is observed that the temperature values of the soil in the zone (nodes) directly under the slab (nodes 101, 102 and 103) are more favorable with detail D2 (without added perimeter insulation under the slab). This can be explained by the fact that the heat flow from the downward direction of the heater does not encounter the thermal resistance that the edge insulation does. In this sense, it can be concluded that the added perimeter insulation can be omitted. In the analyzed details D1 and D2, there are few negative temperatures in the soil nodes, only in the area that coincide with the inner line of the facade (101, 201, 301, 401), as well as at all nodes on the outside of the facade line (100, 200, 300, 400);
- The temperature of the nodes immediately below the floor structure (points 001, 002 and 003) is positive in all cases;
- In reality, the external design temperature Te= -15°C occurs in an interval of only a few days (usually in mid of January), so for a wider time frame of observation, and taking into account the thermal inertia of the soil, all relevant results should be positive;
- All the mentioned results may vary in relation to the calculated values of soil characteristics (natural soil, replaced soil, embankment, etc.).

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