Calculation of optimal outdoor enclosure in the arctic conditions

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Abstract. Definition of optimal thickness of thermal insulating materials, prevention of frost penetration and overheat and provision of proper thermal efficiency is an important problem in arctic conditions. This article demonstrates the results of thermotechnical calculations of enclosing constructions using SHADDAN software and economic calculations made in RIK software. These results allowed us to perform comparative analysis of two building technologies: «thermal block» and «render system». Both options met regulatory heat transfer requirements. However, regarding cost efficiency, use of «thermal blocks» technology is more effective in arctic conditions.

1. Introduction

Climatic and natural factors affects conditions of the construction in the arctic area due to uncommon climatic, economic conditions and permafrost soil. These factors may play the leading role in designing and organizational decisions, therefore it is necessary to develop projects with proper space-planning and structural solutions, in order to meet all the standards and regulations.

The influence of natural and climatic factors of the arctic area requires use of special multiplying or decreasing coefficients for the improvement of people’s and mechanisms’ efficiency. It should be also noted that these coefficients have to differ depending on the month.

During the development of construction master plans the engineers have to take into account not only climatic conditions but also: increased labour and machine costs and decreased work efficiency.

Nowadays the most popular building technology is monolithic frame construction (about 70% of residential and public buildings), that replaced prefabricated concrete buildings. This popularity was caused with possibility to design broad range of space-planning solutions, high economic efficiency of the construction and with good structural properties that this technology provides. Furthermore, monolithic constructions lack seams at the joints which a great advantage in arctic conditions.

2. Methods

2.1 Thermotechnical calculations

Calculation of optimal thickness of thermal insulating materials, prevention of frost penetration and overheat and provision of proper thermal efficiency can be provided with proper thermotechnical calculation for external walls [3-6]
In this article we performed comparative analysis of two building technologies: «render system» and «thermal block». The first one is widespread in Yakutsk, and the second is one is relatively modern. [3-6]. «Render system» is a thermal insulation system for building’s façade that is made of basalt insulation boards which are mounted on the wall using wall plugs. Then it is covered with facing plaster, glass web, decoration plaster and paint [7,8].

«Thermal block» is a modern building material with precise dimensions (±1 mm), that is made of three layers which are bonded with fiberglass rebars. The first layer is the bearing one which is made of lightweight aggregate concrete (M50, M75, M100 grades). This material allows to greatly reduce block’s weight and improve its thermal insulation and sound proofing properties. The middle layer is made of expanded polystyrene. The face layer is a decorative and shielding one, which is also made of lightweight aggregate concrete with decorative finishing. Seemingly resembling artificial stone, it may be produced with almost any texture. A «thermal block» is usually used for the building of external bearing walls in low-rise housing construction and also is very popular in high-rise monolithic frame construction as a material for external self-bearing walls [9-19].

Thermotechnical calculation was performed in SHADDAN 3D software which is designed for the calculation of temperature distribution among external walls in conditions of continuous heat flux. Thus, the software solves two-dimensional problem. The heating flux, heat transfer resistance and etc. are defined using calculated plane field. The algorithm of the calculation is described below.

First step is the preparation of the initial data for the calculation. In the beginning we have developed the scheme of external constructions. This scheme then is divided onto rectangular calculation net. The grid step may be variable. However, it should not surpass 200mm. This limit is used in order to obtain more precise calculations. It should be also mention that grid steps should go along the division lines between different materials (figure 1).

The second step is the adjustment of the grid. There we have defined grid steps in X, Y, Z planes and the repeat number of the steps. Third step – is the division onto rectangular blocks made of one material and input of the coordinates of the block from the material with determined number. Also there we have input numerical values of materials’ properties: thermal conduction and heat exchange coefficient, air environment temperature. Fourth step – calculation of the heat flow density. The line may look like a right line or like continuous polyline, made of section which are parallel to the axis. Regarding the filling of the calculation line table, as a line we mean sections that are aligned with grid lines.

Calculation results from the software are presented on the figures 2-4 and in the table 1.
Figure 2. Temperature distribution isolines of the «thermal block»

Figure 3. Temperature distribution isolines of the «render system»
2.2 Study subject

This article is based on the study of nine-storied monolithic frame building with the following dimensions: 33x18m. The construction is located at the 53rd quarter of Yakutsk city, the capital of Sakha republic. The climate is subarctic and permafrost soil is typical for this area. Average January temperature is ~40...~45°C, with average low up to -55°C. Average July temperature +19°C, with records up to +38°C.

The building has a rectangular form in the plan with an attached stairs block. The height of the first floor is 3.6m, 2-9 floors – 3.3 m.

The structural scheme of the building is monolithic frame with column grid 6x6m, external and indoor walls are made of small concrete blocks.

Foundations – precast reinforced concrete piles SM10-40
Basement slab – monolithic reinforced concrete slabs mounted on monolithic reinforced concrete beams and foundation frame
Columns – made of monolithic reinforced concrete with profile dimensions 400x400 mm
Slabs – monolithic reinforced concrete slabs, without beams, thickness – 200mm.
Stair flights and wells – monolithic made of reinforced concrete.
Lintels – precast reinforced concrete
The building is equipped with two cargo-passenger elevators.
Basement slab thermal insulation – expanded polystyrene 250mm thick.
Roof thermal insulation – expanded polystyrene 200mm thick.
External walls thermal insulation – render system with basalt insulation boards 200 mm thick.
External walls – masonry made of small concrete stones, 200mm thick
Dividing walls – masonry made of small concrete blocks, 100mm thick
Roof - flat built-up roof with three layer Ruberoid roofing felt
Doors – blocks made of PVC profiles
Windows – PVC profiles with triple-pane glass
Perimeter walk – 1200mm width made of B7.5 concrete F100, 80mm thick, mounted on the ground base.

3. Results

| Property              | Description                                                                 | Technology «Thermal block» | Technology «Render system» |
|-----------------------|-----------------------------------------------------------------------------|----------------------------|----------------------------|
| Q                     | Heat flux of the enclosure (simple average value of the heat fluxes of the external and internal planes of the enclosure), W; | 1.313                      | 0.969                      |
| q                     | Heat flow density on the computational length, W/(m*mm);                     | 16.407                     | 12.115                     |
| T min.internal        | Minimal temperature of the enclosure’s internal plane, deg;                | 18.114                     | 18.607                     |
| T max.external        | Maximal temperature of the enclosure’s internal plane, deg;                | -51.286                    | -51.162                    |
| Rk                    | Reduced thermal impedance of the construction, (m*mm) *deg/W;              | 4.230                      | 5.785                      |
| Ro                    | Thermal resistance, (m*mm) *deg/W;                                        | 4.388                      | 5.943                      |

Figure 4. Study subject
The results meet the following requirement: \( R_0 > R_{\text{regulatory}} \).

Regulated value of reduced thermal impedance of enclosing construction was calculated using the following formula:

\[ R_{\text{0 regulatory}} = R_{\text{0 needed}} \cdot m_p \]  
\( m_p \) – coefficient used in order to adjust the value in accordance with the regional climatic features;  
\( R_{\text{0 needed}} \) – basic value of the needed thermal impedance of enclosing construction \([(m*m) *\text{deg/W}]\), should be taken in accordance with heating degree-day, HDD \([\text{deg*day/year}]\);  

Heating degree-day (HDD)

\[ \text{HDD} = (t_{\text{int}} - t_{\text{ext}}) \cdot z_{\text{heat}} \]

Where \( t_{\text{ext}} = -20.9 \) – average external air temperature, °C;  
\( z_{\text{heat}} = 252 \) – period of heating, day/year, when the average external air temperature is below 8°C.  
\( t_{\text{int}} = 19°C \) – calculated internal air temperature °C, that is taken up using table 3, regarding minimal values of optimal temperature for the relevant type of the building (in the interval of 19-21 °C).

\[ \text{HDD} = (19+20.9) \cdot 252 = 10051.8 \] \([\text{deg*day/year}]\).

\( R_{\text{0 needed}} \) value was calculated using the following formula:

\[ R_{\text{0 needed}} = a \cdot \text{HDD} + b \]

Where \( a = 0.0003; b = 1.2 \) for public, administrative, household and industrial premises;  
\( R_{\text{0 needed}} = 0.0003 \cdot 10051.8 + 1.2 = 4.22 \) \([(m*m) *\text{deg/W}]\);  
\( R_{\text{0 needed}} = 4.22 \cdot 1 = 4.22 \) \([(m*m) *\text{deg/W}]\).

### 3.1 Economic efficiency calculation

In order to define economic efficiency, the following cost estimates were calculated: general construction works local cost estimate, detailed estimate of construction costs and summary calculation of construction’s cost. «RIK» software was used for the mentioned above calculations.

Regulations for incidental expenses and estimated profit were taken up in accordance with. Calculation results were aggregated into table 2 and 3.

### Table 2. Regulation for incidental expenses and estimated profit

| Types of building and installation works | Regulations in % of salary budget of the workers | Incidental expenses | Estimated profit |
|-----------------------------------------|-----------------------------------------------|--------------------|-----------------|
| Earthwork operations:                   |                                               |                    |                 |
| Manual                                  | 88                                            | 45                 |                 |
| Mechanized                              | 105                                           | 50                 |                 |
| Pile works (foundations)                | 150                                           | 80                 |                 |
| Metal structures                         | 99                                            | 85                 |                 |
| Monolithic concrete and reinforced concrete constructions | 177                                           | 100                |                 |
| Woodwork construction                   | 130                                           | 63                 |                 |
| Masonry                                 | 134                                           | 80                 |                 |
| Floors                                  | 135                                           | 75                 |                 |
| Roofing                                 | 132                                           | 65                 |                 |
| Finishing work                          | 116                                           | 55                 |                 |
| Thermal insulation                      | 110                                           | 70                 |                 |

### Table 3. Technical and economic indexes

| №  | Index                  | Units     | «Thermal block» | «Render system» |
|----|------------------------|-----------|-----------------|-----------------|
| 1  | Cost estimate          | thous.rub.| 284 446,943     | 296 147,021     |
| 2  | Which includes:        |           |                 |                 |
| 3  | Construction works     | thous.rub.| 225 974,717     | 235 269,672     |
| 4  | Installation works     | thous.rub.| 12 521,769      | 13 036,823      |
| 5  | Miscellaneous expenditures | thous.rub. | 21 608,757     | 22 497,585      |
| 6  | Building volume        | m³        | 17 820          | 17 820          |
| 7  | Total area             | m²        | 4 745,25        | 4 745,25        |
| 8  | Cost 1m³               | rub.      | 15 962,23       | 16 618,80       |
| 9  | Cost 1m²               | rub.      | 59 943,51       | 62 409,15       |
4. Discussion
Comparative analysis of the studied technologies allows us to make the following conclusions:
1. Regarding heating performance, specifically of thermal impedance, external walls made with «render system» technology is better than the other one that is made of «thermal block»;
2. Regarding economic efficiency, building with «thermal block» technology is more effective
Thus, both technologies meet the regulatory requirements of heat transfer. Nevertheless, use of «thermal blocks» can reduce construction costs and this technology is more suitable for arctic area.

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