The Influence of Reinforced Concrete Columns Thermal Protection Qualities in Buildings With Ventilated Basement in the Conditions of Permafrost

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Abstract: The article shows the results of research during which is carried out numerical analysis using the calculating program for three-dimensional temperature fields of the angle joint fragment of the walls with the basement of the building with ventilated substrata under various layout options of reinforced concrete columns. Specific losses of heat through the overlap are determined taking into account the influence of the column. Calculations have shown that the presence of columns requires a substantial increase in the thickness of thermal insulation in the frame-monolithic buildings with the basement.

1. Introduction

Heat conductive inclusions in the enclosing structures of buildings significantly reduce their heat-shielding properties. The same effect is exerted by the angle joints of the fences. In the corners of the outer fences, the temperature is much lower than on the inner surfaces of the joined structures. Therefore, the calculation of the temperature on the inner surface of the outer corner buildings’ of fences attract some attention [1-5]. The method of calculation of heterogeneous enclosing structures is being improved [6]. In accordance with the instructions of the SP 23-101-2004 it was possible to apply approximate calculation methods, but the SP 50.133300.2012 requires as follows: "The reduced resistance to heat transfer of a fragment of the thermal protection shell of a building ... is calculated in accordance with annex E, using the results of calculating the temperature fields". With different levels of accuracy, record of thermotechnical heterogeneity is carried out in the countries of Northern and Central Europe [7].

In the regions with permafrost, where buildings are designed with cold or ventilated substrata, it is especially important to take into account the heat conductive inclusions in the basement of buildings. Heat conductive inclusions placed directly in the basement have a negative effect on the temperature regime of the floor surface [8]. Angle joints of buildings’ basement with ventilated or cold substrata with external walls not only significantly reduce the temperature of the inner surfaces of the fences [9], but also lead to an increase in heat loss [10]. In previous articles, we considered options for placing thermal insulation, in which the temperature in the corner formed by walls and the basement would be provided within the regulatory limits, i.e. above the dew-temperature [9, 11, 12].
2. Methods

All calculations were made using the calculating program for three-dimensional temperature fields Shaddan 3D [4]. The influence of reinforced concrete columns that pass through the thickness of the thermal insulation layer should be considered in construction of multi-storey buildings with a prefabricated or monolithic frame. In the articles [9 - 12], this factor was not considered; they are suitable for low-rise construction with load-bearing walls. Various options of columns layout are used for erecting frame-monolithic buildings. Various options of columns’ layout relative to the walls from the standpoint of providing the highest temperature in the joint area of the floor and column were searched. To solve this problem and determine the influence of the columns on the reduced resistance to heat transfer of the wall fragment and the basement, numerical calculations were carried out using the program of spatial temperature fields’ calculation [4].

As the first option, layout of columns flush with the edge of the overlap and the outer surface of the masonry made of small concrete blocks is considered (Fig. 1). The thickness of the wall layers: cement-sand solution - 0.02 m; masonry made of small concrete blocks – 0.19; mineral fiber boards made of stone fiber – 0.20m. The construction of wall with a ventilated air gap and the heat transfer coefficient is assumed as equal to 12 W/m²C. Composition of the basement: linoleum – 0.003m; cement-sand screed – 0.08m; expanded polystyrene – 0.30m; reinforced concrete floor – 0.20m. Design temperatures: \( t = 21^\circ C \), \( t = -52^\circ C \). Coefficients of thermal conductivity: mineral wool slabs – 0.042 W/m°C, masonry made of small concrete blocks – 0.80 W/m°C, expanded polystyrene \( \lambda = 0.04 \) W/m°C, reinforced concrete \( \lambda = 1.92 \) W/m°C, cement-sand solution \( \lambda = 0.76 \) W/m°C; linoleum \( \lambda = 0.38 \) W/m°C. On the horizontal axis of the computational grid, the same step is taken \( 0.01 \times 179+0.02 \times 21 \), on the vertical axis it is \( 0.02 \times 100+0.003 \times 1+0.01 \times 58+0.02 \times 30 \).

![Fig.1. The spatial fragment of the fence](image)

1 - reinforced concrete floor; 2 - expanded polystyrene; 3 - cement-sand screed; 4 - wallboard insulation of mineral wool slabs; 5 - masonry made of small concrete blocks; 6 - plaster of cement-sand solution; 7 - reinforced concrete column; 8 - ruberoid.

Cases when columns’ layout with its’ exposed faces are aligned with the inner surfaces of the masonry, and are spaced at a distance of 0.2; 0.4; 0.6; 0.8m from the inner surface of the walls, are considered as well. Figure 2, as an example, shows the option of placing the column at a distance of 0.4 m from the inner surfaces of the walls. A fragment of enclosing structures along the horizontal section along the floor surface is shown, since the structure of the basement remains unchanged. Computer issuing the control lines by the task of operator. The results of numerical calculations using the program for calculating three-dimensional temperature fields are in Table 1. It should be noted that the calculations do not take into account the effect of the connectors for fastening the heater and brackets. To determine the level of influence of the columns’ dimensions on the thermal characteristics of the fence fragment, options of \( 0.4 \times 0.4 \) m and \( 0.5 \times 0.5 \) m sections are considered.
(Table 1). The calculations consider the upper parts of reinforced concrete piles with a height of 0.6 m, placed in ventilated substrata and having similar cross-sectional columns.

![Diagram of fence]

Fig. 2. The spatial fragment of the fence  
1 - monolithic reinforced concrete overlapping; 2 - heater from expanded polystyrene; 3 - cement-sand solution; 4 - thermal insulation of wall from mineral plates; 5 - masonry; 6 - plaster layer; 7 - reinforced concrete column.

3. Results

Minimum temperatures in the joint area of the floor and column $\tau_f^l = -0.77^\circ C$ (-1.38°C) were obtained by placing the column in the masonry. As shown in the calculation results (Table 1), in the construction of carcass-monolithic buildings it is advisable to place the columns at a distance of 0.4 m from the walls. With increasing their step of temperature in the joint of column and floor surface, the resistances to heat transfer practically does not differ. If the distance from the edge of the overlap to the column increasing, the calculated load on the overlap is also increases. The change in temperature in the joint of the floor and the column, depending on its layout, is shown in the graph (Fig. 3). In all the cases, the temperatures noted to be below the dew point ($t_p = 11.62^\circ C$).

![Graph showing temperature change]

Fig. 3. Change in temperature at the junction of the floor and the column, depending on its layout, where 1 is the graph for the column with a cross section of 400 mm., 2 is the graph for the column with a cross section of 500 mm.

Resistance to heat transfer of the overlap without taking into account the influence of the columns is bigger than the required resistance to heat transfer ($R_o = 7.88 > R_{o,tr} = 7.48$ m²°C/W). Calculation of a
A fragment of the basement with a column having a cross-section of 0.4 × 0.4 m and located in the center showed much lower parameter ($R_o=5.54 \text{ m}^2/\text{W}$). The dimensions of the fragment in the plan are assumed to be 3 × 3 m, and the grid spacing along the horizontal axes is selected as 0.02m×50+0.01m×100+0.02m×50.

The decrease in the heat transfer resistance of the overlap within the considered fragment of the basement due to the influence of the column is 29.6% and 37.8% respectively for columns of 0.4 x 0.4m and 0.5 x 0.5m.

Specific components should be established in determination of heat losses through all external enclosing structures [6,7] according to the instructions of "Thermal protection of buildings".

Table 1. Heat-shielding indices of a fragment of enclosing structures, obtained with the application of a calculating program for three-dimensional temperature fields for various layout of the column

| Options of the column layout in the plan: | Column with cross section 0.4×0.4(m) | Column with cross section 0.5×0.5(m) |
|------------------------------------------|--------------------------------------|--------------------------------------|
|                                          | $\tau_o^{(i)}(^\circ\! C)$ | $R_o$ (m$^2$/°C/W) | $\tau_o^{(i)}(^\circ\! C)$ | $R_o$ (m$^2$/°C/W) |
| in masonry                               | -0.77 | 3.22 | -1.38 | 3.12 |
| in the corner from the inner surface of the masonry on distance 0.2m from the wall | 0.12 | 3.17 | -0.40 | 3.06 |
| on distance 0.4m from the wall           | 9.33* | 2.98 | 8.36* | 2.81 |
| on distance 0.6m from the wall           | 9.94* | 2.96 | 8.86* | 2.79 |
| on distance 0.8m from the wall           | 10.01* | 2.96 | 8.99* | 2.79 |
| on distance 0.8m from the wall           | 10.02* | 2.96 | 9.00* | 2.79 |

* The values of minimum temperatures of the floor surface in the joint area of the floor and column are given, and the minimum temperature on the inner surface of the fence fragment is maintained in a spatial angle and varies from 2.8 °C to 2.9 °C, depending on the location of the column.

Heat losses through a node containing local spatial thermotechnical heterogeneity in the form of a column with a cross section of 0.4 × 0.4 m, that determined on the calculation basis of the temperature field, equal to $Q_k = 118.499 \text{ Wt}$. The losses of heat through the basement without taking into account the influence of columns are equal to:

$$Q = (t_v - t_n) F / R_o = (21 - (-52)) \times 9/7.876 = 83.418 \text{ W}.$$  \tag{1}

Additional heat losses through the local spatial thermotechnical heterogeneity are

$$\Delta Q^K_k = Q_k - \bar{Q}_k = 118.499 - 83.418 = 35.081 \text{ W}.$$ \tag{2}

The specific heat losses through the fragment of basement are determined by the formula:

$$\chi_k = \Delta Q^K_k / (t_v - t_n) = 35.081/(21 - (-52)) = 0.48 \text{ W/°C}.$$ \tag{3}
The reduced resistance to heat transfer of the basement at a grid of 6 × 6 m columns is determined without consideration of the influence of extended linear heterogeneity in the form of a joint of walls and overlap

\[ R^{\text{np}}_o = 1/(U + \sum n_k \chi_k) \times (1/7,876+1\times0,48/36) = 7,13 \text{m}^2\text{C/W} < 7,48 \text{m}^2\text{C/W} = R^{\text{np}}_o. \quad (4) \]

4. Discussion

Calculations showed that current frame-monolithic residential buildings in Yakutsk, with a thickness of expanded polystyrene – 300 mm in the basement, do not meet the requirements a) and c) of paragraph 5.1 of the "Thermal protection of buildings" rules. Only if thickness of expanded polystyrene equal to 370 mm design resistance to heat transfer exceeds the required (7,50m\(^2\)C/W > 7.48m\(^2\)C/W), but the temperature at the joint of the floor surface with the column is 11.19 °C, which is below the dew-point. This problem is solved by placing a skirting board from a pine tree with a thickness of 0.01 m along the perimeter of the column. At a skirting board height of 0.04 m, the minimum temperature is obtained above the dew point and is equal to 12.28C. There remains the problem of unacceptably low temperature in the spatial angle, which can be solved by changing the design of the walls [11 - 13]. When the setting of concrete blocks is carried out on reinforced concrete overlaps it leads to the significant heat conductive inclusions along the entire length of the wall. To reduce its influence, an option with local heat conductive inclusions are proposed [11, 12]. Application of reinforced concrete front panels allows complete excluding heat conductive inclusions at the joint of "wall-basement overlap" [13]. The proposed design solutions have patents [14 - 18].

Conclusions

Building designers can use the obtained value of heat losses for individual parameters of the basement. For columns with a large cross-section, the thickness of the thermal insulation must increase. It is advisable to use the program of calculation of three-dimensional temperature fields in determining heat losses and reduced resistance to heat transfer in the design of similar structural solutions of buildings, especially since there are houses with different sections of columns. As noted, the evaluation of the thermal protection properties of the basement was carried out without taking into account the influence of extended linear heterogeneities in the form of a joint between the walls and the overlap. To calculate the heat load on a building's heating system, the calculation should be done using traditional or matrix methods [19-21], taking into account both the noted extended linear heterogeneities and the influence of point imperfection in the form of connectors that fasten heat-insulating slabs to wall panels and brackets of the hing facade.

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