Thermotechnical calculation of enclosing structures of a standard type residential building

O Gamayunova¹, M Petrichenko¹ and A Mottaeva²,³

¹Peter the Great St. Petersburg Polytechnic University, Polytechnicheskaya, 29, St.Petersburg, 195251, Russia
²Moscow State University of Civil Engineering, 129337, 26, Yaroslavskoe Shosse, Moscow, Russia
³Moscow Region State University, Radio str., 10A, 105005, Moscow, Russia

E-mail: gamayunova@inbox.ru

Abstract. Russia has extensive experience in the design and construction of typical series of residential apartment buildings. When there is a library of standard projects for which additional expertise is not required, this significantly reduces both the price and the construction time of the facilities. Accordingly, the cost per square meter is reduced. Currently, to reduce the cost of construction, some developers use enclosing structures made of materials with high thermal conductivity, thereby reducing the energy efficiency of buildings and structures. In this article, on the example of houses of mass series 1-447, the thermotechnical calculation of enclosing structures was carried out and the option of the optimal position of the insulation was determined. The temperature distribution of the building envelope is presented.

1. Introduction

Typical design decisions - this is the design documentation of the capital construction object, structures, products and units, designed for repeated use in architectural and construction design. In Russia, there are quite a few typical series of residential apartment buildings. Some of them are built only in certain regions, some are built throughout the country.

Advantages of typical series of residential buildings:

- The construction of the same type of building speeds up the process many times, eliminates the need to waste time developing an individual project.
- Simplified construction process. It is already known how much brick, nails, boards and other building materials are needed. The workers who built one building can successfully proceed to the next construction site, having received the necessary experience.
- All standard projects comply with the requirements and standards approved by the state, it is easier to control the construction process.
- Often a typical project is a plan that has already passed the test of time and has proved its effectiveness.
- The main advantage is cheapness, there is no need to spend money on the work of an architect and designer.

Houses of the 1-447 series are present in absolutely all regions of Russia. In terms of prevalence among the brick 5-story buildings of all periods, they occupy the first place. The five-story houses of the 1-447 series are easily recognizable by the unclad external walls, two rows of windows in the end...
sides (mainly without balconies), as well as by the rectangular shape of the hull in the absence of protrusions and corner sections. There are a lot of modifications of this series.

2. Materials and methods

The main thermotechnical characteristics of the external walls of houses of a series 1-447 are given in Table 1.

| Layer number | Material | Layer thickness ($\delta$), m | Thermal conductivity coefficient ($\lambda$), W m$^{-2}$·°C$^{-1}$ | Density ($\rho$), kg/m$^3$ |
|--------------|----------|-------------------------------|-------------------------------------------------|-----------------------------|
| 1            | Double hollow brick (seven-slot), 250x120x138 mm | 0.38                          | 0.57                                          | 1.000 – 1.450               |

Currently, there are requirements for thermal protection of buildings, which are used in the design of thermal protection of buildings under construction or under reconstruction, in which it is necessary to maintain a certain temperature and humidity regime.

Using the above methodology, the thermotechnical characteristics of the material of the wall structure of houses of the 1-447 series, as well as the climatic conditions of St. Petersburg, we will conduct the thermotechnical calculation of the enclosing structures.

Define the thermal resistance of a brick wall (1):

$$ R_0 = R_{int} + R_{ext} + \sum R_i = \frac{1}{23} + \frac{1}{8.7} + \frac{0.38}{0.57} = 0.825 \frac{m^2\cdot{}^\circ{}C}{W}, $$

(1)

where:

- $R_{int}$ is the heat transfer resistance on the inner surface of the wall (2), (m$^2$·°C)/W,
- $R_{ext}$ is heat transfer resistance on the outer surface of the wall (3), (m$^2$·°C)/W,
- $\sum R_i$ is the sum of thermal resistance of all layers of the fence, (m$^2$·°C)/W.

$$ R_{int} = \frac{1}{\alpha_{int}}, $$

(2)

where $\alpha_{int}$ is the heat transfer coefficient of the inner surface of the wall, W/(m$^2$·°C).

$$ R_{ext} = \frac{1}{\alpha_{ext}}, $$

(3)

where $\alpha_{ext}$ is the heat transfer coefficient of the outer surface of the wall, W/(m$^2$·°C).

We define the norm of thermal protection according to the condition of energy conservation (the minimum allowable thermal resistance of the building envelope).

Degree days of the heating period are defined as (4):

$$ D_d = (t_{int} - t_{ht}) z_{ht} = (20 + 1.8) \cdot 220 = 4,796 \ {}^\circ{}C \cdot \text{days} $$

(4)

The normative value of the reduced heat transfer resistance should be taken at least normalized values depending on the degree-days of the construction area (5):

$$ R_{req} = a \cdot D_d + b = 0.00035 \cdot 4,796 + 1.4 = 3.0786 \frac{m^2\cdot{}^\circ{}C}{W}, $$

(5)

where:

- $D_d$ is the degree-day of the heating period in St. Petersburg,
- $a$ and $b$ are the coefficients adopted according to regulatory documents.

The thermal engineering calculation showed that the thermal resistance of the wall is $R_0 = 0.825$ (m$^2$·°C)/W, which is much lower than the required ($R_{req} = 3.08$ (m$^2$·°C)/W). In connection with the revealed discrepancy, it is necessary to additionally insulate the outer walls of the housing project under consideration.

Define the minimum allowable (required) thermal resistance of the insulating material (6):
We will make an adjustment to this value so that the outer layer of the building envelope (insulation) will be plastered. Accordingly, with a cement-sand mortar layer thickness of 0.02 m \((\lambda = 0.93 \text{ W/(m·°C)})\), the minimum allowable (required) thermal resistance of the heat-insulating material will be 2.228 \((\text{m·°C})/\text{W})\).

To date, in the building materials market, there are many options for insulation products from manufacturers such as: Knauf, Isoroc, Isover, Rockwool, Paroc, Ursa, Ecover, Penoplex, Technonikol, Baswool, etc. The thermal resistance of the samples on the market varies from 0.03 up to 0.044 \((\text{W/(m·°C)})\). Using an example of a heater having an average of more than 150 considered insulation options, the value of the coefficient of thermal conductivity \((\lambda = 0.037 \text{ W/(m·°C)})\) we determine the thickness of the insulation that will provide the required thermal resistance of the wall (7):

\[
R_{\text{req}} = \lambda R_{\text{narg}} = 0.037 \cdot 2.228 = 0.082 \text{ m} = 82 \text{ mm}
\]  

Most heaters are available in the form of plates with a thickness of 50 and 100 mm. We determine the thermal resistance of the wall from the condition that the thickness of the insulation will be 100 mm (the thickness as close as possible to the calculated):

\[
R_0 = R_{\text{int}} + R_{\text{ext}} + \sum R_i = \frac{1}{8.7} + \frac{1}{23} + \frac{0.38}{0.57} + \frac{0.1}{0.037} + \frac{0.02}{0.093} = 3.5 \frac{\text{m}^2 \cdot \text{°C}}{\text{W}}
\]  

From the result obtained, it can be seen that \(R_0 = 3.5 \frac{\text{m}^2 \cdot \text{°C}}{\text{W}} > R_{\text{req}} = 3.08 \frac{\text{m}^2 \cdot \text{°C}}{\text{W}}\), which exceeds the minimum permissible standards and ensures a comfortable stay for people.

Let us determine the calculated temperature difference \(\Delta t_0\), °C, between the temperature of the internal air and the temperature of the inner surface of the building envelope (9):

\[
\Delta t_0 = \frac{n (t_{\text{int}} - t_{\text{ext}})}{R_h \cdot \alpha_{\text{int}}} = \frac{1 \cdot (20 - (-26))}{3.5 \cdot 8.7} = 1.5 ^\circ \text{C}
\]

where:
- \(\Delta t_0\) - calculated temperature difference (difference between the temperature of the internal air and the temperature of the inner surface of the wall);
- \(n\) is a coefficient taking into account the dependence of the position of the outer surface of the fence with respect to the outside air \((n = 1)\);
- \(t_{\text{ext}}\) is outdoor temperature in the cold season, °C;
- \(\Delta t_\alpha\) is normalized temperature difference between the temperature of the internal air and the temperature of the inner surface of the building envelope, °C.

We check the condition: \(\Delta t_0 \leq \Delta t_\alpha\). Considering that \(\Delta t_\alpha < 4 ^\circ \text{C}\), the accepted wall design meets the sanitary-hygienic and construction requirements for heat transfer of building envelopes according to the temperature difference.

Define the position of the insulation layer relative to the outer surface of the building envelope. It is selected based on the functional purpose and operation mode of buildings and premises. At the same time, the required thermal stability of the internal environment of the premises should be ensured with a minimum consumption of energy resources for their heating and conditioning.

The correct location of the insulation layer in the enclosing structure determines the durability and reliability of its operation. For this, it is necessary to prevent the possibility of condensation formation and freezing in the hard layers of the building envelope and to ensure their minimum temperature deformation, due to the amplitude of the fluctuation in the outdoor temperature and other climatic parameters that determine the operating conditions of the building throughout the year.

To determine the correct position of the insulation layer, given its previously found thickness. Consider the temperature distribution over the cross section of the building at an outdoor temperature of \(t_{\text{ext}} = -26 ^\circ \text{C}\) for two options:
• the insulation layer is located on the external side and the brickwork (carrier layer) is on the inside;
• the insulation layer is located inside and the brickwork (carrier layer) is located outside of the enclosing structure.

We determine the temperature distribution in the cross section of the structure for two options for the position of the insulation layer.

The temperature at the boundary of the layer \( n \) of the enclosing structure \( \tau_n \) from its “warm” side is defined as (10):

\[
\tau_n = t_{\text{int}} - \frac{t_{\text{int}} - t_{\text{ext}}}{R_0} \cdot r \cdot (R_{\text{int}} + R_1 + ... + R_n)
\]  

(10)

The calculation results are presented in table 2-4 and in figure 1.

**Table 2.** Temperature distribution in the enclosing structure.

| Designation | Temperature at the boundaries of the layers |
|-------------|-------------------------------------------|
|             | insulation outside | insulation inside |
| \( \tau_{\text{int}} \) | 18.5 | 18.5 |
| \( \tau_1 \) | 9.8 | 15.7 |
| \( \tau_2 \) | -22.6 | -16.8 |
| \( \tau_3 \) | -25.4 | -25.4 |
| Average construction temperature | 8.5 | -15.5 |

**Table 3.** Thermophysical characteristics of the enclosing structure (insulation outside).

| Material                  | \( \lambda \) | \( \delta \) | \( R \) | Layer average temperature |
|---------------------------|----------------|---------------|--------|--------------------------|
| Ceramic solid brick       | 0.57           | 0.38          | 0.667  | 14.18                    |
| Insulation                | 0.04           | 0.10          | 2.500  | -6.40                    |
| Cement-sand mortar        | 0.09           | 0.02          | 0.215  | -24.04                   |

**Table 4.** Thermophysical characteristics of the enclosing structure (insulation inside).

| Material                  | \( \lambda \) | \( \delta \) | \( R \) | Layer average temperature |
|---------------------------|----------------|---------------|--------|--------------------------|
| Cement-sand mortar        | 0.09           | 0.02          | 0.22   | 17.11                    |
| Insulation                | 0.04           | 0.10          | 2.50   | -0.53                    |
| Ceramic solid brick       | 0.57           | 0.38          | 0.67   | -21.10                   |
Figure 1. Temperature distribution in the enclosing structure (insulation outside).

Figure 2. Temperature distribution in the enclosing structure (insulation inside).

In the first embodiment (the insulation layer is located outside the masonry), the average temperature of the building envelope is +8.5 °C. Thus, the carrier layer will always be in the region of positive temperatures, and the range of their fluctuations will remain small even with large amplitudes of daily and seasonal fluctuations in the temperature of the outside air. This reduces the size of temperature deformations in the masonry and, consequently, the probability of the formation of deformation stresses and cracks. A gentle slope of the temperature graph shows that when the heating systems are temporarily turned off, a small amount of heat will be released outside, which will ensure thermal stability of the indoor environment. Due to the fact that the masonry (carrier layer) even in extreme cold weather will be in the region of positive temperatures, the probability of condensation formation is reduced and the possibility of its freezing in the masonry body of the supporting structure is excluded.

In the second version, the insulation layer is located on the side of the building’s internal environment, the temperature in the masonry in winter will be in the region of negative temperatures (the average temperature of the enclosing structure is -1.5 °C). Thus, with sharp changes in air temperature during the annual course, as well as with a sharp change in weather conditions (warming, cooling), the masonry will be exposed to large temperature fluctuations, which can lead to the appearance of cracks from temperature deformations in it.

In addition, in the transitional seasons, when in the daily course the temperature of the environment passes through 0 °C, condensate can accumulate in the masonry, and when the isotherm is zero inside the structural layer of the structure, it will freeze and, as a result, the possibility of cracking will appear, associated with an increase in the volume of water when it turns into ice (physical weathering).

3. Results and discussion

Typical development, as a rule, allows you to build buildings faster and cheaper. But we must not forget that a standard project, which today meets all the needs, after a while should go to a new, more advanced level.

In this work, the thermotechnical calculation of the building envelope of series 1-447 houses was made, on the basis of which a decision was made on the need to increase the energy efficiency of buildings. Using calculations, it was shown that the position of the insulation layer in the building envelope in the general case does not affect the temperature values of the inner and outer surfaces. Despite this, in a structural respect, the insulation layer is advisable to be placed on the outside of the enclosing structures of residential buildings and other buildings, the premises of which are required to maintain a stable positive temperature throughout the entire period of their operation.
In further studies, it is planned to continue work on finding the best option for warming residential buildings, expanding the object of research with houses of other mass series, as well as searching for more effective and cost-effective thermal insulation materials.

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