Heat Engineering Heterogeneity Of The Outer Walls Of Earthquake-Resistant Buildings

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ABSTRACT

When assessing the level of energy efficiency of civilian buildings, a special place is given to establishing the level of thermal protection of their external enclosing structures. Significant discrepancies in the results of theoretical and experimental studies of heat fluxes through the outer walls of buildings erected in seismic areas are associated with the design features of fences - the presence of reinforced concrete elements in them: anti-seismic belts at the level of floors, cores at intersections of walls and along the edges of large window openings ... In addition, in recent years, external walls have become widespread, which are filling of bricks or aerated concrete blocks between the main structural elements of the frame - monolithic reinforced concrete columns and crossbars.

The introduction of reinforced concrete elements into the structure of the external wall fencing provides strength, rigidity and stability of buildings, guarantees its seismic resistance. At the same time, reinforced concrete inclusions are significant "cold bridges" in warmer brick or aerated concrete masonry. Such heat engineering heterogeneity of earthquake-resistant outer walls significantly complicates the process of determining their heat-shielding properties. This, in turn, leads to errors in the design of heating systems, which inevitably affects the thermal comfort of the premises, the formation of condensation and mold zones in the cold zones of the inner surface of the fences.

 The article presents the results of theoretical and experimental studies to determine the heat-shielding properties of external heat-engineering heterogeneous walls of earthquake-resistant buildings. The most reliable method for calculating the reduced resistance to heat transfer of an inhomogeneous external structure and the coefficient of its thermal inhomogeneity have been established.

INTRODUCTION

A significant increase in energy prices in the world community was the reason for the tightening of requirements for saving fuel and energy resources in all sectors of the economy [1, 2, 3]. One of the most energy-intensive sectors of the national economy, consuming up to 40% of the country's fuel and energy resources, is the housing and utilities sector. At the same time, as noted by numerous researchers [4,5,6], the real potential of energy saving in this area can be from 20 to 30%. The solution to this problem is associated with increased requirements for the quality of building design and, first of all, its enclosing structures, since design errors lead to a decrease in the heat-shielding properties of fences and an increase in operating energy costs [7,8]. In this regard, research aimed at increasing the level of energy efficiency of civil buildings and improving methods for assessing the heat-shielding properties of external enclosing structures is of particular importance.

THEORETICAL AND EXPERIMENTAL RESEARCH

When assessing the level of energy efficiency of civilian buildings, a special place is given to establishing the level of thermal protection of their external enclosing structures. Significant discrepancies in the results of theoretical and experimental studies of heat fluxes through the outer walls of buildings erected in seismic areas are associated with the design features of the fences - the presence of the structure of reinforced concrete elements in them: anti-seismic belts at the floor level, cores at intersections of walls and along the edges of large window openings [nine]. In addition, in recent years, external walls have become widespread, which are filling of bricks or aerated concrete blocks between the main structural elements of the frame - monolithic reinforced concrete columns and crossbars.

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The normative document [10] provides for two approaches to the determination of the reduced resistance to heat transfer of heat-engineering heterogeneous external walls, depending on their design solution. In the first case, it is proposed to cut the wall and determine the thermal resistance first with planes parallel and then perpendicular to the heat flow. In this case, the reduced thermal resistance is determined by the formula:

$$R_{\kappa}^{ht} = \frac{R_a + 2R_b}{3}, \qquad (1)$$

where R_a – thermal resistance of a structure when cut by planes parallel to the heat flux,

R_b – thermal resistance of a structure when cutting it by planes perpendicular to the heat flow. R_a and R_b calculated according to the formulas given in [10]. The calculation turns out to be quite time consuming.

If R_a more 1,25 $R_б$ or the wall structure has protrusions, then it is recommended to use temperature fields to determine the reduced thermal resistance in [10]. This implies either the implementation of experimental studies, or the use of special calculation programs that make it possible to determine the average temperatures on the inside ($\tau_{в.ср}$) and outdoor ($\tau_{н.ср}$) surfaces of the structure. Then it is assumed to calculate the magnitude of the heat flux passing through the outer fence by the formula:

$$Q^{calc} = \alpha_в(t_в - \tau_{в.ср}) = \alpha_н(t_н - \tau_{н.ср}), \qquad (2)$$

where $\alpha_в$ – heat transfer coefficient of the inner surface of the building envelope, $\alpha_н$ – heat transfer coefficient for winter operating conditions of the outer surface of the enclosing structure, $t_в$ – design indoor air temperature, $t_н$ – design outdoor temperature.

Determination of the reduced resistance to heat transfer of a non-uniform enclosing structure (R_o) in this case, according to [10], it is produced by the formula:

$$R_o = \frac{t_в - t_н}{q^{calc}} \qquad (3)$$

The most accurate determination of the reduced resistance to heat transfer of a heat-engineering heterogeneous wall structure makes it possible to establish a really reasonable thickness of the insulation to ensure the required level of thermal protection of buildings. It would seem that the problem is completely solvable and does not require any additional research. However, the question is precisely in ensuring a sufficiently accurate determination of the thermal properties of fences, since the generalization of data on the value of the actual energy consumption of residential buildings of different years of construction shows that the specific consumption of thermal energy in old panel houses and modern residential buildings with two-layer walls of brickwork on cement sandy mortar and facing brick practically does not differ. One of the reasons for this phenomenon is that the structures of two-layer walls are often overestimated in terms of their thermal protection parameters.

In this regard, we have calculated the resistance to heat transfer of a two-layer wall structure by various known methods in order to establish their equivalence, on the one hand, and to identify the actual effect of "cold bridges" on the heat-shielding properties of fences, on the other hand.

For research, the structure of the outer wall in a building with a monolithic reinforced concrete frame was adopted, which is based on the floor by floor on reinforced concrete floors and consists of two layers (Fig. 1):

- an internal non-bearing layer made of brickwork on a cement-sand mortar with a thickness of 380 mm (taking into account the mortar for fixing the facing layer, a thickness of 390 mm was taken);
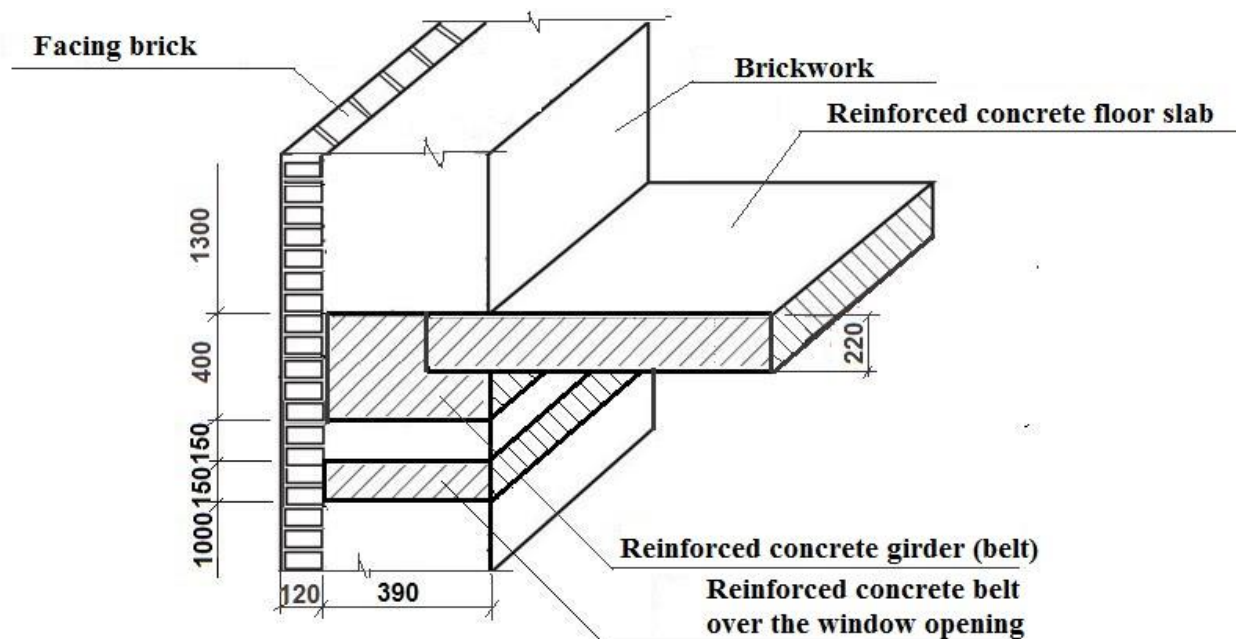- the outer facing layer of facing brick, one brick thick.

Fig.1. Constructive solution of the outer wall of the building

The reduced resistance to heat transfer of an inhomogeneous outer wall was determined for the intermediate floor and without taking into account the presence of windows. The design diagram of a fragment of the outer wall is shown in Fig. 2.
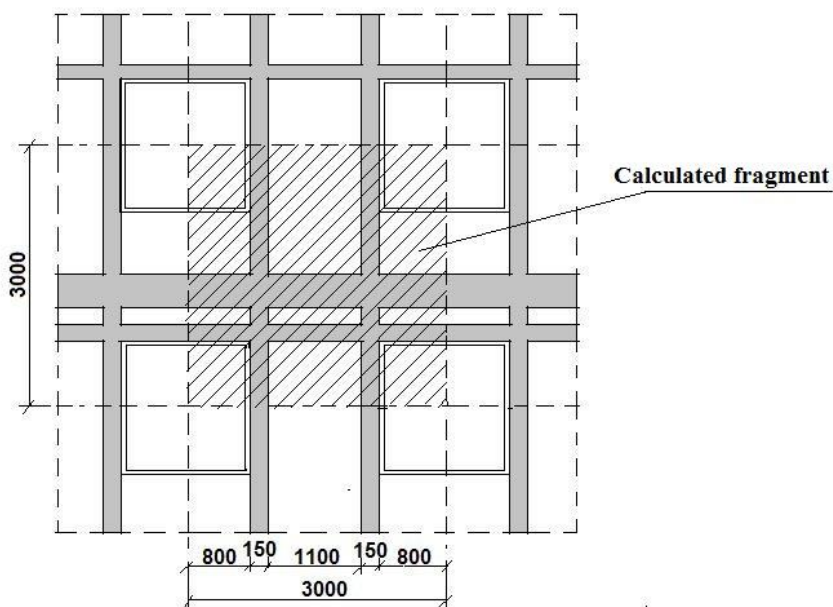

Fig. 2. Scheme of the calculated fragment of the wall of a residential building

Thermal characteristics of materials and boundary conditions were adopted according to the normative document [10]. The masonry of the walls was taken from ordinary bricks on a cement-sand mortar, and the facing layer was made of ceramic hollow bricks with a density of 1300 kg / m³ on a cement-sand mortar.

According to the methodology given in the normative document [10], the values of the thermal resistance of the outer wall were determined:

- when cutting it by planes parallel to the heat flow R_a;
- when cutting it by planes perpendicular to the heat flow R_b.

The accepted design scheme is shown in Fig. 3. The calculation was carried out on a site without window openings.
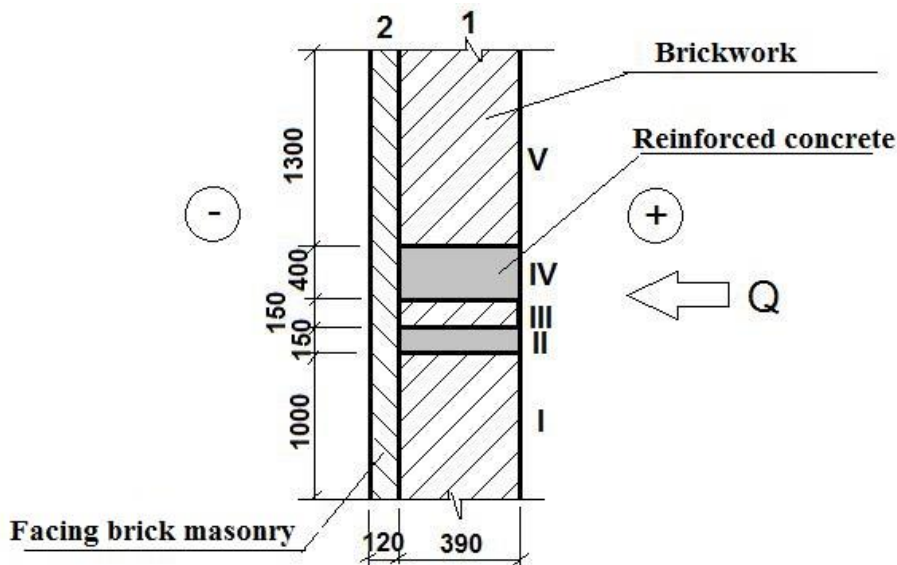

Fig. 3. Calculation scheme for determining the reduced thermal resistance
1, 2 - areas perpendicular to the heat flow; I –V - sections parallel to the heat flow; Q - heat flow

Since, as a result of the calculation, it was determined that R_a= 0,558 $[\frac{м^2 \cdot {}^0С}{Вm}]$ < R_b = 0,653 $[\frac{м^2 \cdot {}^0С}{Вm}]$, then the reduced thermal resistance of a heat-engineering non-uniform outer wall was determined by the formula (1):

$$R_к^{tr} = \frac{0,558 + 2*0,653}{3} = 0,621 \, [\frac{м^2 \cdot {}^0С}{Вm}],$$

At the same time, the reduced resistance to heat transfer of the outer wall was:

$$R_0 = \frac{1}{\alpha_в} + R_к^{tr} + \frac{1}{\alpha_н} = \frac{1}{8,7} + 0,621 + \frac{1}{23} = 0,779 \, [\frac{м^2 \cdot {}^0С}{Вm}],$$

$\alpha_н$, $\alpha_в$ – heat transfer coefficients, respectively, on the outer and inner surfaces of the wall, taken according to the regulatory document [10].

The coefficient of thermal engineering heterogeneity was r=0,823.

Taking into account that in many advanced countries of the world, in order to improve the accuracy of determining heat losses through heterogeneous external enclosing structures of buildings, they switched to the method of calculating the reduced resistance to heat transfer, based on streamlining the accounting of additional heat losses through heat-conducting inclusions [11], the specified technique. For the selected fragment of the outer wall of the building (Fig. 2), specific heat losses through the "cold bridges" were determined under the same initial conditions.

Calculation of specific heat losses through the "cold bridges" of the outer wall consisted of the following stages:
- marking of nodes on a fragment of an external wall containing heat-conducting inclusions and determination of their geometric dimensions;
- determination of the temperature field of a unit with a heat-conducting connection;
- calculation of specific heat losses through a heat-conducting connection [12].

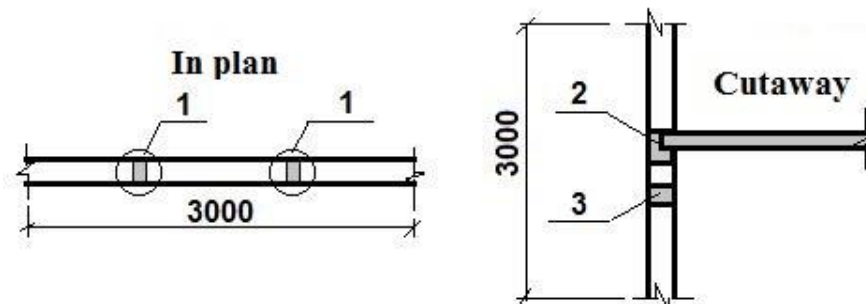The designation of the design nodes on the selected wall fragment is given in Fig. 4.

Fig. 4. Marking of units with heat-conducting inclusions

In accordance with the geometric dimensions of a fragment of the building wall (Fig. 2), the geometric and specific geometric indicators of elements with heat-conducting inclusions were determined, which are presented in Table. 1.

Table 1. Geometric characteristics of units with heat-conducting inclusions

Node marking	Node type	Brief description of the node	Geometric indicator	Specific geometric indicator
1	Linear vertical	Junction of the outer wall to the core	4,9 м	0,5444 м/м²
2	Linear horizontal	Adjacency of the outer wall to the interfloor ceiling and seismic belt	3,0 м	0,3333 м/м²
3	Linear horizontal	Adjoining the outer wall to the belt above the window opening	3,0 м	0,3333 м/м²

Table 2.Calculations of the temperature fields of the nodes with heat-conducting inclusions were carried out using the TEMPER 3D computer program

Construction element № / node	Specific geom. index	Specific heat loss, $Вт/(м^{2\cdot0}C)$	Specific heat flux due to the element, $Вт/(м^{2\cdot0}C)$	The share of the total heat flux through the fragment, %
Flat element /-	$a=1м^2/м^2$	$U_1=1{,}0571$	1,0571	63,3
Linear vertical /1	$l_1=0{,}5444$ $м/м^2$	$\Psi_1=0{,}3356$	0,1827	11,0
Linear horizontal /2	$l_2=0{,}3333$ $м/м^2$	$\Psi_2=0{,}9170$	0,3056	18,4
Linear horizontal /3	$l_3=0{,}3333$ $м/м^2$	$\Psi_3=0{,}3636$	0,1212	7,3
			$1/R_{пр}=1{,}661$	100

In accordance with the performed calculation, the reduced resistance of a non-uniform wall of a residential building was 0,602 $м^{2\cdot0}C/Вт$ with the coefficient of heat engineering heterogeneity $r=0{,}636$.

Comparison of the results of calculations using the two methods showed that the discrepancy is quite significant and amounts to 22,7%.

To establish the most accurate method, field studies were carried out. A grid with 10x10 cm cells was applied to the selected section of the wall from the outside.At the nodes of the grid, the temperature was measured on the surfaces of the wall fence using a pyrometer in the evening in order to avoid exposure to the structure of direct and reflected sunlight. The obtained measurement results were processed and, by averaging, the temperature on the outer surface of the building wall was determined, which was: +4,3°C. At the same time, the external temperature was fixed at + 3°C, and the internal air temperature was +20,5°C. As a result, the actual value of the reduced resistance to heat transfer of the outer wall of the building was determined, which was $R_0= 0{,}581 \left[\frac{м^2\cdot{}^0C}{Вm}\right]$.

The discrepancies in the values of the reduced resistance to heat transfer of a heat-engineering non-uniform outer wall, obtained experimentally and by the two methods used, amounted to: 25% and 3,5%.

CONCLUSION

The studies carried out have proved that the outer small-element walls of earthquake-resistant buildings have significant thermal engineering heterogeneity, which significantly affects the heat-shielding properties of the outer shell of the building.

Comparison of the results of theoretical calculations and a full-scale experiment, as well as data from previously performed studies [13, 14], confirmed that the transition to mandatory accounting for the values of specific heat losses of enclosing structures when determining the thermal properties of the outer shell of buildings is advisable. It will improve the quality of assessing the energy characteristics of buildings, as well as the design of their enclosing structures and heating systems.

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