Increase of energy performance of residential buildings with enclosing structures made of masonries with application of ceramic blocks

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Abstract. Economy of energy resources in the Russian Federation is currently the urgent national environmental and economic problem as the package of measures providing energy saving has high profitability and environmental safety as compared with energy resources buildup. Therefore, much attention is paid to energy saving for the account of reducing heat loss through the enclosing structures at engineering and construction of residential buildings. Therewith, diverse elements of three-layer wall structures are reducing general reliability thereof at failure probability exposed to various factors. The buildings with the enclosing structures made of hollow porous blocks are slightly behind the three-layer wall structure by specific heat-resistant performance, with the base layer thereof consisting of solid ceramic brick and efficient heat insulation layer. The problem of construction and erection work quality is arising therewith. The heat engineering calculation of monolayer structure made as masonry of 510mm PORIKAM 14.3NF ceramic hollow porous blocks finished on the outside by heat insulation plaster is presented herein. Temperature fields are calculated in Therm 7.4 program. The design diagram for the structure part (cross section of the wall) is being made in the program for this purpose with indication of heat engineering data of the materials and overlaying of boundary conditions in both “inside” and “outside” surfaces. Graphic images of thermal fields and heat transfer are presented by the calculation results. Noncompliance with some regulatory requirements at making construction and erection operations are reviewed and simulated, with the reduced heat transfer resistance of the structures being calculated therewith. Noncompliance with the masonry technology results in increase of heat loss thereby reducing heat efficiency.

1. Introduction

Nowadays much attention is paid to energy efficiency issues by reducing heat loss through the enclosing structures under engineering and construction of residential buildings. Exterior walls of current residential buildings contain both base and heat insulation layers to provide for the required energy efficiency values [1, 2]. Diverse elements of the structures are reducing general reliability thereof at failure probability exposed to various factors influencing the building durability. Especially in practice the buildings with the enclosing structures made of hollow porous blocks are slightly behind the three-layer wall structure by specific heat-resistant performance, with the base layer thereof
consisting of solid ceramic brick and efficient heat insulation layer [3, 4]. The problem of construction
equipment work quality is arising therewith.

The authors have analyzed the heat engineering calculation of monolayer structure made of 510mm
PORIKAM 14.3NF ceramic hollow porous blocks finished on the outside by heat insulation plaster.
There are glazed recessed balconies preventing from heat energy infiltration along the façade walls.

2. Analysis of thermal calculation
The authors have analyzed the heat engineering calculation of monolayer structure [5, 6] made of
510mm PORIKAM 14.3NF ceramic hollow porous blocks finished on the outside by heat insulation plaster. There are glazed recessed balconies preventing from heat energy infiltration along the façade walls.

The following materials have been taken as initial data:
- inside plaster layer – 20mm sand-cement layer with heat conductivity coefficient $\lambda = 0.93$ W/(m·°C);
- masonry of 510mm PORIKAM ceramic hollow porous blocks with heat conductivity coefficient $\lambda = 0.16$ W/(m·°C);
- outside plaster layer – 30mm heat insulation plaster, $\lambda = 0.21$ W/(m·°C).

Window opening is to be infilled with “TATPROF” EK-69 pane glass with the reduced heat
transfer resistance of $R=0.623$ m$^2$·°C/W.

The reduced heat transfer resistance of a part of the thermal protective shell of the building, $R_0^{np}$
(m·°C)/W, is calculated in accordance with Attachment to SP 50.13330.2012 “Buildings Heat
Insulation” using temperature field calculation results.

The specific parts of the façade for the residential building design under review are the wall
surface and walls around the balcony areas.

Temperature fields are calculated in Therm 7.4 program. The design diagram for the structure
part (cross section of the wall) is being made in the program for this purpose with indication of heat
engineering data of the materials and overlaying of boundary conditions in both “inside” and “outside”
surfaces. Graphic images of thermal fields and heat transfer are the calculation results.

Calculation of heat engineering data of monolayer enclosing structure made of hollow porous
ceramic blocks [7-9] has shown that this version of the structure meets building heat insulation
requirements. However, the perfect model was taken for calculations, which is possible only under
strict compliance with the masonry technology and design of structures considering block dimensions
thereof.

The structure consists of:
1 – ceramic block;
2 – reinforced concrete floor slab;
3 – reinforced concrete lintel;
4 – slab perforated with foam polystyrene;
5 – foam polystyrene within the lintel;
6 – heat insulation plaster;
7 – inside plaster layer;
8 – pane glass;
9 – plastic window frame.

![Figure 1. Cross section of a monolayer wall made of 510mm ceramic blocks](image)
50% perforation with heat insulation liners at 200mm intervals is designed at the level of concrete floor slabs accessing façade. If extruded “Penoplex” foam polystyrene is applied as the heat insulation with heat conductivity coefficient of $\lambda = 0.032 \text{ W/(m}^\circ\text{C)}$, total heat transfer resistance of the wall in heat transfer inclusions places will be:

$$R_{0,1} = 1.1 \text{ m}^2\cdot\text{К}/\text{W},$$

$$R_{0,1} = \frac{1}{K_{\text{sp}}}= 1/0.91 = 1.1 \text{ m}^2\cdot\text{К}/\text{W};$$

$$K_{\text{sp}} = (K_1 + K_2)/2= (0.23+1.59)/2=0.91 \text{ W/(m}^2\cdot\text{°C)},$$

$$R_1 = \frac{1}{4.27} = 0.23\text{m}^2\cdot\text{К}/\text{W},$$

$$R_2 = \frac{1}{4} + \left(\frac{0.03}{0.21} + \frac{0.12}{0.92} + \frac{0.02}{0.76} + \frac{1}{8.7}\right) = 0.63\text{m}^2\cdot\text{К}/\text{W},$$

$$K_1 = \frac{1}{0.03} = 1.59\text{m}^2\cdot\text{К}/\text{W},$$

$$U_1 = 1/1.1 = 0.91 \text{ W/(m}^2\cdot\text{°C}).$$

For a section where the lintel is located (for 2D element 2):

$$R_{0,2} = \frac{1}{23} + \frac{0.03}{0.21} + \frac{0.12}{0.92} + \frac{0.02}{0.76} + \frac{1}{8.7} = 4.28 \text{ m}^2\cdot\text{К}/\text{Вт},$$

$$U_2 = 1/4.28 = 0.234 \text{ W/(m}^2\cdot\text{°C}).$$

For 2D element 3:

$$R_{0,3} = \frac{1}{23} + \frac{0.03}{0.21} + \frac{0.51}{0.92} + \frac{0.02}{0.76} + \frac{1}{8.7} = 3.49 \text{ m}^2\cdot\text{К}/\text{Вт},$$

$$U_3 = 1/3.49 = 0.287 \text{ W/(m}^2\cdot\text{°C}).$$

The temperature field of the structural component containing 2D element is calculated for 2D element 1. Heat loss $Q_1$ through a section containing this 2D element per 1 running meter is defined. Temperature distribution over the cross-section of the enclosing structure part is given in Figure 2, while the thermal field in the section – in Figure 3.

**Figure 2.** Temperature distribution in cross-section of the window header

**Figure 3.** 2D thermal field in cross-section of the window header

The calculated section is of 560x220mm. Cross-sectional area of the wall included into the calculated section is $S_{l,1}=0.12\text{m}^2$.

Heat loss through the wall with window jamb included into the section under the temperature field calculations is equal to $Q_1=4.56 \text{ W/m}$.

Heat loss through the section of the homogeneous wall of the same area is found by formula:
\[ Q_{1} = \frac{21 - (-35)}{4.28} \cdot 0.12 = 1.57 \text{ W/m}. \]

Additional heat loss through 1D element 1 is:

\[ \Delta Q_{1}^{L} = 4.56 - 1.57 = 2.99 \text{ W/m}. \]

Specific linear heat loss through element 1 is defined by formula

\[ \Psi_{1} = \frac{2.99}{21 - (-35)} = 0.065 \text{ Btu/(ft \cdot \circ F)}. \]

Elements included into the enclosing structure:
- butt of the reinforced concrete balcony slab – 2D element 1;
- reinforced concrete lintel lined with foam polystyrene covered by heat insulation plaster – 2D element 2;
- ceramic block masonry covered by heat insulation plaster – 2D element 3;
- window jamb formed by reinforced concrete lintel – 1D element 1;
- window jamb formed by block masonry – 1D element 2.

Specific values of other elements are calculated similarly and indicated in Table 1.

| Structural element | Specific geometric value | Specific heat loss | Specific heat flow stipulated by element | Share of total heat flow through a section, % |
|--------------------|--------------------------|--------------------|------------------------------------------|-------------------------------------------|
| 2D element 1       | \( a_{1} = 0.061 \text{ m}^{2}/\text{m} \) | \( U_{1} = 0.91 \text{ W/(m}^{2}\text{\circ C}) \)  | \( U_{1}a_{1} = 0.056 \text{ W/(m}^{2}\text{\circ C}) \) | 16.42 |
| 2D element 2       | \( a_{2} = 0.039 \text{ m}^{2}/\text{m} \) | \( U_{2} = 0.234 \text{ W/(m}^{2}\text{\circ C}) \)  | \( U_{2}a_{2} = 0.009 \text{ W/(m}^{2}\text{\circ C}) \) | 2.64 |
| 2D element 3       | \( a_{3} = 0.9 \text{ m}/\text{m}^{2} \) | \( U_{3} = 0.287 \text{ W/(m}^{2}\text{\circ C}) \)  | \( U_{3}a_{3} = 0.258 \text{ W/(m}^{2}\text{\circ C}) \) | 75.66 |
| 1D element 1       | \( l_{1} = 0.176 \text{ m}/\text{m}^{2} \) | \( \Psi_{1} = 0.065 \text{ W/(m}^{2}\text{\circ C}) \)  | \( \Psi_{1}l_{1} = 0.011 \text{ W/(m}^{2}\text{\circ C}) \) | 3.23 |
| 1D element 2       | \( l_{2} = 0.474 \text{ m}/\text{m}^{2} \) | \( \Psi_{2} = 0.015 \text{ W/(m}^{2}\text{\circ C}) \)  | \( \Psi_{2}l_{2} = 0.007 \text{ W/(m}^{2}\text{\circ C}) \) | 2.05 |
| Total              |                           |                   | \( I/R_{\text{pr}}^{0} = 0.341 \text{ W/(m}^{2}\text{\circ C}) \) | 100 |

The reduced total heat transfer resistance of the enclosing structure section will be

\[ R_{0}^{\text{pr}} = \frac{1}{0.341} = 2.93. \]

Heat conductivity coefficient

\[ r = \frac{0.059 + 0.009 + 0.258}{0.341} = 0.96. \]

However, there may take place noncompliance with some regulatory requirements under the construction and erection operations.

Each situation under review was simulated in Therm 7.4 program and total heat transfer resistance of structures was calculated [10-13].

1) If mortar technology is not complied with, the mortar may get into voids due to bad viscosity thereof. Let us consider how it affects heat homogeneity of the structure and heat transfer resistance thereof. The calculated scheme is given in Figure 4.
Figure 4. Noncompliance with mortar preparation technology

Table 2. Results of calculating specific values of enclosing structure elements

| Structural element | Specific geometric value | Specific heat loss | Specific heat flow stipulated by element | Share of total heat flow through a section, % |
|--------------------|--------------------------|--------------------|----------------------------------------|---------------------------------------------|
| 1                  |                          |                    |                                        |                                             |
| 2D element 1       | \( a_1 = 0.061 \text{ m}^2/\text{m}^2 \) | \( U_1 = 0.91 \text{ W/(m}^2\text{°C)} \) | \( U_1 a_1 = 0.056 \text{W/(m}^2\text{°C)} \) | 10.24                                       |
| 2D element 2       | \( a_2 = 0.039 \text{ m}^2/\text{m}^2 \) | \( U_2 = 0.234 \text{ W/(m}^2\text{°C)} \) | \( U_2 a_2 = 0.009 \text{W/(m}^2\text{°C)} \) | 1.65                                        |
| 2D element 3       | \( a_3 = 0.9 \text{ m/m}^2 \) | \( U_3 = 0.462 \text{ W/(m}^2\text{°C)} \) | \( U_3 a_3 = 0.416 \text{W/(m}^2\text{°C)} \) | 76.05                                       |
| 1D element 1       | \( l_1 = 0.176 \text{ m/m}^2 \) | \( \Psi_1 = 0.065 \text{W/(m}^3\text{°C)} \) | \( \Psi_1 l_1 = 0.011 \text{W/(m}^2\text{°C)} \) | 2.01                                        |
| 1D element 2       | \( l_2 = 0.474 \text{ m/m}^2 \) | \( \Psi_2 = 0.115 \text{W/(m}^3\text{°C)} \) | \( \Psi_2 l_2 = 0.055 \text{W/(m}^2\text{°C)} \) | 10.05                                       |
| Total              |                          |                    |                                        |                                             |

| Structural element | Specific geometric value | Specific heat loss | Specific heat flow stipulated by element | Share of total heat flow through a section, % |
|--------------------|--------------------------|--------------------|----------------------------------------|---------------------------------------------|
| 1                  |                          |                    |                                        |                                             |

Value of the reduced heat transfer resistance of the section will be
\[ R_0^{\text{np}} = \frac{1}{1 - R_0^{\text{pr}}} = 1.83. \]

Heat conductivity coefficient
\[ r = \frac{0.056 + 0.009 + 0.416}{0.547} = 0.88. \]

Filling of voids with mortar for even half of height reduces heat transfer resistance of the structure by 1.5 times according to calculation results.

2) Quite often there are situations when other mortars are applied instead of insulating plaster. Let us check how heat engineering characteristics are affected when heat insulating plaster is replaced by usual sand-cement one.
Figure 5. No heat insulating plaster layer

Temperature pattern is very similar, however, absolute temperature values in the interior surface of the structure have decreased.

Calculation of specific values of the structure elements is given in Table 3.

Table 3. Results of calculating specific values of enclosing structure elements

| Structural element | Specific geometric value | Specific heat loss | Specific heat flow stipulated by element | Share of total heat flow through a section, % |
|--------------------|--------------------------|--------------------|-----------------------------------------|---------------------------------------------|
| 2D element 1       | $a_1=0.061 \, \text{m}^2/\text{m}^2$ | $U_1=1.061 \, \text{W/(m}^2\text{°C})$ | $U_{1a1}=0.065 \, \text{W/(m}^2\text{°C})$ | 15.93 |
| 2D element 2       | $a_2=0.039 \, \text{m}^2/\text{m}^2$ | $U_2=0.239 \, \text{W/(m}^2\text{°C})$ | $U_{2a2}=0.009 \, \text{W/(m}^2\text{°C})$ | 2.21 |
| 2D element 3       | $a_3=0.9 \, \text{m/m}^2$ | $U_3=0.293 \, \text{W/(m}^2\text{°C})$ | $U_{3a3}=0.264 \, \text{W/(m}^2\text{°C})$ | 64.71 |
| 1D element 1       | $l_1=0.176 \, \text{m/m}^2$ | $\Psi_1=0.165 \, \text{W/(m}^2\text{°C})$ | $\Psi_{1l1}=0.029 \, \text{W/(m}^2\text{°C})$ | 7.11 |
| 1D element 2       | $l_2=0.474 \, \text{m/m}^2$ | $\Psi_2=0.086 \, \text{W/(m}^2\text{°C})$ | $\Psi_{2l2}=0.041 \, \text{W/(m}^2\text{°C})$ | 10.04 |
| Total              |                           |                    | $I/R_0^{np}=0.408 \, \text{W/(m}^2\text{°C})$ | 100  |

Value of the reduced heat transfer resistance of the section will be $R_0^{np}=\frac{1}{I/R_0^{np}}=2.45$.

Heat conductivity coefficient found by formula $r = \frac{0.065+0.009+0.264}{0.408} = 0.83$.

Value of the reduced heat transfer resistance of the structure is higher than minimum acceptable but it was greatly reduced in relation to initial version of the structure [14-16].

3) Let us analyze how the floor slab with no perforation and no insulant therein is affecting heat transfer resistance of the part of the structure. Such version of the structure is given in Figure 6.
Table 4. Results of calculating specific values of enclosing structure elements

| Structural element | Specific geometric value | Specific heat loss | Specific heat flow stipulated by element | Share of total heat flow through a section, % |
|---------------------|--------------------------|--------------------|-----------------------------------------|---------------------------------------------|
| 1                   |                          |                    |                                         |                                             |
| 2D element 1        | $a_1 = 0.061 \text{ m}^2$ | $U_1 = 1.733 \text{W/(m}^2\text{oC)}$ | $U_1a_1 = 0.106 \text{ W/(m}^2\text{oC)}$ | 27.11                                       |
| 2D element 2        | $a_2 = 0.039 \text{ m}^2$ | $U_2 = 0.234 \text{W/(m}^2\text{oC)}$ | $U_2a_2 = 0.009 \text{ W/(m}^2\text{oC)}$ | 2.3                                         |
| 2D element 3        | $a_3 = 0.9 \text{ m/m}^2$ | $U_3 = 0.287 \text{W/(m}^2\text{oC)}$ | $U_3a_3 = 0.258 \text{ W/(m}^2\text{oC)}$ | 65.99                                       |
| 1D element 1        | $l_1 = 0.176 \text{ m/m}^2$ | $\Psi_1 = 0.065 \text{W/(m}^2\text{oC)}$ | $\Psi_1l_1 = 0.011 \text{W/(m}^2\text{oC)}$ | 2.81                                        |
| 1D element 2        | $l_2 = 0.474 \text{ m/m}^2$ | $\Psi_2 = 0.015 \text{W/(m}^2\text{oC)}$ | $\Psi_2l_2 = 0.007 \text{W/(m}^2\text{oC)}$ | 1.79                                        |
| Total               |                          |                    |                                         | $1/R_{\text{pp}} = 0.391 \text{W/(m}^2\text{oC)}$ | 100                                         |

Value of the reduced heat transfer resistance of the section will be $R_{\text{pp}}^{-1} = 2.56$. Heat conductivity coefficient $r = \frac{0.106 + 0.009 + 0.258}{0.391} = 0.95$.

4) **The similar situation with the lintel will be considered further.** Schematic section of the wall with the lintel with no insulation is presented in Figure 6.
Calculation results of this version of the structure are given in Table 5.

**Table 5. Results of calculating specific values of enclosing structure elements**

| Structural element | Specific geometric value | Specific heat loss | Specific heat flow stipulated by element | Share of total heat flow through a section, % |
|--------------------|--------------------------|--------------------|-----------------------------------------|--------------------------------------------|
| 1                  |                          |                    |                                         |                                            |
| 2D element 1       | $a_1 = 0.061 \text{ m}^2$ | $U_1 = 0.91 \text{ W/(m}^2 \text{C)}$ | $U_1a_1 = 0.056 \text{ W/(m}^2 \text{C)}$ | 12.61                                       |
| 2D element 2       | $a_2 = 0.039 \text{ m}^2$ | $U_2 = 1.733 \text{ W/(m}^2 \text{C)}$ | $U_2a_2 = 0.068 \text{ W/(m}^2 \text{C)}$ | 15.31                                       |
| 2D element 3       | $a_3 = 0.9 \text{ m}^2$  | $U_3 = 0.287 \text{ W/(m}^2 \text{C)}$ | $U_3a_3 = 0.258 \text{ W/(m}^2 \text{C)}$ | 58.11                                       |
| 1D element 1       | $l_1 = 0.176 \text{ m/m}\text{2}$ | $\Psi_1 = 0.311 \text{ W/(m}\text{C)}$ | $\Psi_1 l_1 = 0.055 \text{ W/(m}^2 \text{C)}$ | 12.39                                       |
| 1D element 2       | $l_2 = 0.474 \text{ m/m}\text{2}$ | $\Psi_2 = 0.015 \text{ W/(m}\text{C)}$ | $\Psi_2 l_2 = 0.007 \text{ W/(m}^2 \text{C)}$ | 1.58                                        |
| Total              |                          |                    |                                          |                                            |
|                    |                          |                    | $I/R_{np} = 0.444 \text{ W/(m}^2 \text{C)}$ | 100                                         |

Value of the reduced heat transfer resistance of the section will be

$$R_0^{np} = \frac{1}{0.444} = 2.25.$$  

Heat conductivity coefficient

$$r = \frac{0.056 + 0.068 + 0.258}{0.444} = 0.86.$$  

The received value of the reduced heat transfer resistance of the structure is close to minimum acceptable one.

5) Another possible situation that may severely impair heat engineering properties of the structure is stuffing of gaps between blocks and the building frame (if the design considered no block sizes or due to noncompliance with erection procedure) by sand-cement mortar thereby making significant heat transfer inclusions within enclosing structure.
Figure 8. Stuffing of gaps between blocks and the building frame (noncompliance with erection procedure)

Calculating results are combined in Table 6.

Table 6. Results of calculating specific values of enclosing structure elements

| Structural element | Specific geometric value | Specific heat loss | Specific heat flow stipulated by element | Share of total heat flow through a section, % |
|--------------------|--------------------------|--------------------|----------------------------------------|---------------------------------------------|
| 2D element 1       | \( a_1 = 0.063 \text{m}^2/\text{m}^2 \) | \( U_1 = 0.91\text{W/(m}^2\text{°C)} \) | \( U_1a_1 = 0.057 \text{W/(m}^2\text{°C)} \) | 14.85 |
| 2D element 2       | \( a_2 = 0.037 \text{m}^2/\text{m}^2 \) | \( U_2 = 0.234\text{W/(m}^2\text{°C)} \) | \( U_2a_2 = 0.009 \text{W/(m}^2\text{°C)} \) | 2.29 |
| 2D element 3       | \( a_3 = 0.89 \text{m}^2/\text{m}^2 \) | \( U_3 = 0.287\text{W/(m}^2\text{°C)} \) | \( U_3a_3 = 0.256 \text{W/(m}^2\text{°C)} \) | 65.31 |
| 2D element 4       | \( a_4 = 0.01 \text{m}^2/\text{m}^2 \) | \( U_4 = 1.001\text{W/(m}^2\text{°C)} \) | \( U_4a_4 = 0.01 \text{W/(m}^2\text{°C)} \) | 2.25 |
| 1D element 1       | \( l_1 = 0.176 \text{m/m}^2 \) | \( \Psi_1 = 0.299\text{W/(m}^2\text{°C)} \) | \( \Psi_1l_1 = 0.053\text{W/(m}^2\text{°C)} \) | 13.52 |
| 1D element 2       | \( l_2 = 0.474 \text{m/m}^2 \) | \( \Psi_2 = 0.015 \text{W/(m}^2\text{°C)} \) | \( \Psi_2l_2 = 0.007 \text{W/(m}^2\text{°C)} \) | 1.78 |
| Total              |                          |                   | \( \frac{1}{R_0^{pp}} = 0.392 \text{W/(m}^2\text{°C)} \) | 100 |

Value of the reduced heat transfer resistance of the section will be

\[ R_0^{pp} = \frac{1}{0.392} = 2.55. \]

Heat conductivity coefficient

\[ r = 0.057 + 0.009 + 0.256 + 0.01 = 0.85. \]

Results of the analyzed situations are given in Table 7.

Table 7. Calculating results of the specific heat resistant performance

| Initial structure state (construction and erection defects) | Reduced heat transfer resistance \( R_0^{pp} \) | Heat conductivity coefficient \( r \) |
|-----------------------------------------------------------|---------------------------------------------|-------------------------------------|
| 1 Design solution                                         | 2.93                                       | 0.96                                |
| Non-compliance with mortar preparation technology          | 1.83                                       | 0.88                                |
| No heat insulating plaster layer                           | 2.45                                       | 0.83                                |
3. Results

After analysis of the calculating results the authors [17] have come to a conclusion that the monolayer masonry made of ceramic blocks is possessing high heat efficient properties however, noncompliance with the masonry technology results in increase of heat loss and in reduction of heat efficiency accordingly. Mortar getting inside the block voids is considered to be the most dangerous in this regard. Even slight filling of voids results in significant reduced heat transfer resistance of the structure.

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