Energy-efficient double-row masonry of the exterior walls in the buildings made of cellular concrete blocks

L A Suleymanova*, I A Pogorelova, M V Marushko, I S Ryabchevsky
Belgorod State Technological University named after V.G. Shukhov, 46 Kostyukova street, Belgorod, 308012, Russia

E-mail: ludmilasuleimanova@yandex.ru

Abstract. Ensuring the increased requirements for heat saving, environmental safety and comfort of residential and public buildings is one of the main directions of scientific and technological progress in construction. In particular, the cellular concrete products’ use in building envelopes is aimed at solving these problems. Cellular concrete blocks perform the wall-forming material functions and insulation simultaneously due to their thermophysical and strength characteristics. However, the factor reducing the energy efficiency of aerated concrete masonry is the filling of masonry joints with adhesive or cement-sand mortar, which are the thermometer bridges, and the use of polyurethane adhesive, which has lower thermal conductivity compared to adhesive mixtures, as an aggregate of vertical and horizontal joints is unacceptable due to its high deformability and low shear stiffness. The authors examined the systems of building envelopes made of cellular concrete blocks used in civil engineering, and identified their shortcomings that affect the energy efficiency of the entire building. The authors have developed an energy-efficient two-row masonry of cellular concrete blocks, the device of which allows to reduce the masonry thickness and facilitate the installation of the enclosing structure with equal masonry thermal conductivity.

Introduction
Wall masonry made of cellular concrete blocks is one of the most popular technologies for the construction of external walls of residential and public buildings today. The use of cellular concrete blocks is due to their thermophysical and strength characteristics.

However, when assessing the energy efficiency of the masonry, the influence of heat-conducting inclusions on the parameters of the external walls’ thermal engineering uniformity should be taken into account [1-3].

Considering the fact that the thickness of a single-row aerated concrete masonry (Figure 1, a) does not provide the required thermal insulation [4, 5], in practice, often, a building system with a facing layer of bricks fixed to the blocks by the flexible connections is used (Figure 1, b) [6]. But with the coefficient of thermo-technical homogeneity of the wall structure, consisting of aerated concrete blocks of the brand D400 375 mm thick with a front layer of facing brick 120 mm thick equal to 0.61, the conditional resistance to heat transfer is 2.99 (m²·°C) / W, which for the II and III climatic zones of Russia is less than the required value – 3,08 (m²·°C) / W [1, 4]. And the device of the heat-insulating layer increases the material consumption and the complexity of mounting the wall structure by providing a heat-insulating layer of wind and vapor protection.
In this case, the most optimal way of mounting enclosing structures is a double-row wall masonry made of cellular concrete blocks with transverse blocks’ bonding, made on a thin-layer adhesive solution with a joint thickness of 1...3 mm (Figure 1, c).

![Figure 1](image1.png)

**Figure 1.** Building envelope made of cellular concrete blocks:
a – single row masonry; b – single-layer masonry with a facing layer of facing brick; c – double-row masonry with cross-bonding blocks

This masonry is not energy efficient enough due to the presence of a large number of through horizontal joints, which are the “cold bridges” and reduce its heat-shielding properties [7-9].

The authors have developed an energy-efficient two-row masonry of walls made of cellular concrete blocks (Figure 2), eliminating the above-mentioned disadvantages.

![Figure 2](image2.png)

**Figure 2.** Energy-efficient masonry of walls made of cellular concrete blocks:
a – general view of the masonry; b – cross section; 1 – thin-layer adhesive as a joint filler; 2 – tier; 3 – lower section of the tier; 4 – upper section of the tier; 5 – patch bonding; 6 – inner vertical row of lower section; 7 – inner vertical row of upper section; 8 – outer vertical row of lower section; 9 – outer vertical row of upper section

This masonry is made on a thin layer of adhesive solution (Figure 2, pos. 1) with a joint thickness of 1...3 mm and includes two vertical rows of aerated concrete blocks. The masonry consists of
alternating tiers (Figure 2, pos. 2). Each tier is made in the form of two sections (Figure 2, pos. 3 and 4) with ram bonding of sutures (Figure 2, pos. 5) between them. The sections (Figure 2, pos. 3 and 4) are represented by the internal (Figure 2, pos. 6 and 7) and the external (Figure 2, pos. 8 and 9) vertical row of blocks. The internal vertical row (Figure 2, pos. 6) of the first section consists of blocks laid down in stretcher. The outdoor vertical row (Figure 2, pos. 8) consists of blocks laid down on the bottom.

The section (Figure 2, pos. 4) is also represented by the internal (Figure 2, pos. 7) and outdoor (Figure 2, pos. 9) vertical rows of blocks. The internal vertical row (Figure 2, pos. 7) consists of blocks stacked with the stretcher down. The outdoor vertical row (Figure 2, pos. 9) consists of blocks laid down on the bottom. The height of the outer and inner vertical row of blocks in the section is the same.

By laying two sections in a tier with a die bonding of the joints between the sections, a masonry is created with a minimum number of through horizontal seams, which reduces the masonry blow-off and, as a result, increases its heat-shielding properties, providing the heat engineering uniformity [10].

The reduced resistance determination to the building envelope heat transfer

To calculate the reduced heat transfer resistance, we consider a fragment of aerated concrete masonry 600 mm thick, consisting of D400 blocks 200 × 300 × 600 mm with transverse bonding through a row and performed on a thin-layer adhesive mortar with a weld thickness of 3 mm and a fragment of an energy-efficient double-row masonry 500 mm thick developed by the authors, consisting of the aerated concrete blocks 200 × 300 × 600 mm in size and made on a thin-layer adhesive solution with a weld thickness of 3 mm, an area of 1 m² each (Figure 3).

![Figure 3](image)

**Figure 3.** Cross section and general view of the masonry fragments made of aerated concrete blocks to determine the reduced heat transfer resistance: a – energy efficient masonry; b – aerated concrete masonry with transverse bonding through a row; 1 - plot ligation of horizontal rows of masonry; 2 - a section of masonry in the form of a layered structure; 3 - plot ligation of vertical masonry joints

The reduced heat transfer resistance calculation of the energy-efficient masonry and aerated concrete masonry with transverse bonding through a row is made in accordance with [11].

The fragments under consideration are represented by three types of a homogeneous part of the structure:

– the ligation section of the masonry horizontal rows in the form of a through horizontal seam (Figure 3, pos. 1);

– masonry section in the form of a layered structure consisting of two vertical rows of cellular concrete blocks interconnected by a thin layer of adhesive solution (Figure 3, pos. 2);

– ligation section of vertical masonry joints (Figure 3, pos. 3).

The reduced heat transfer resistance of the calculated fragment’s structure is determined by the formula (1) [11]:

\[ R'_{po} = \frac{\sum A_i}{(\sum A_i/R_{o,i} + \sum L_j/\psi_j + \sum N_k K_k)} \]  

(1)
where $A_i$ is the construction area $i$-th species in the considered fragment, m$^2$;
$L_i$ is the length of all joints of the $i$-th type in the considered fragment, m;
$N_k$ is the number of point heat engineering heterogeneities of the $k$-th type in the considered fragment, pcs.;
$R_{o,i}$ is the heat transfer resistance of the $i$-type structure’s homogeneous part, (m$^2$·°C)/W;
$\gamma_j$ is the additional specific linear heat loss through the $j$-th joint, W/(m·°C);
$K_k$ is the additional specific heat loss through a point heat engineering heterogeneity of the $k$-th type, W/°C.

Taking this into considerations, the areas of each fragment are determined.

The heat transfer resistance of the $i$-type structure’s homogeneous part is determined by the formula (2):

$$R_{o,i} = R_{st} + R_{se} + R_{k}$$

(2)

where $R_{st} = 1/\alpha_{st}$; $\alpha_{st}$ denotes the heat transfer coefficient of the building envelope’s inner surface, W/(m$^2$·°C), taken for walls equal to 8.7, for the windows - 8.0 W/(m$^2$·°C);
$R_{se} = 1/\alpha_{ext}$; $\alpha_{ext}$ defines the heat transfer coefficient of the building envelope’s outer surface for the conditions of the cold period, W/(m$^2$·°C), taken for the external walls equal to 23.0, for the walls facing cooler rooms - 6.0 W/(m$^2$·°C);
$R_k$ is the thermal resistance of a single or multi-layer building envelope, (m$^2$·°C)/W.

Let us consider the heat transfer resistance calculation of the structure’s homogeneous part using the example of an energy-efficient masonry developed by the authors, determined by the formula (2):

The composition of the section through the horizontal junction:
- thick adhesive $\delta_{pc} = 0.503$ m, thermal conductivity of the material for design conditions $B\lambda_{pc} = 0.47$ W/(m$^2$·°C);

$$R_{o,i} = 1/8.7 + 0.503/0.47 + 1/23 = 1.22$$ W/(m$^2$·°C).

The composition of the plot in the form of a layered structure:
- thick aerated concrete block $\delta_{pc} = 0.3$ m, thermal conductivity of the material for the design conditions $B\lambda_{pc} = 0.12$ W/(m$^2$·°C);
- thick adhesive $\delta_{pc} = 0.003$ m, thermal conductivity of the material for the design conditions $B\lambda_{pc} = 0.47$ W/(m$^2$·°C);
- thick aerated concrete block $\delta_{pc} = 0.2$ m, thermal conductivity of the material for the design conditions $B\lambda_{pc} = 0.12$ W/(m$^2$·°C);

$$R_{o,1} = 1/8.7 + 0.3/0.12 + 0.003/0.47 + 0.2/0.12 + 1/23 = 4.337$$ W/(m$^2$·°C).

The composition of the vertical masonry joints’ ligation section in the block with a larger width is:
- aerated concrete block thickness $\delta_{pc} = 0.3$ m, thermal conductivity of the material for the design conditions $B\lambda_{pc} = 0.12$ W/(m$^2$·°C);
- thick adhesive solution $\delta_{pc} = 0.203$ m, thermal conductivity of the material for the design conditions $B\lambda_{pc} = 0.47$ W/(m$^2$·°C);

$$R_{o,1} = 1/8.7 + 0.3/0.12 + 0.203/0.47 + 1/23 = 3.096$$ W/(m$^2$·°C).

The composition of the ligation of the vertical masonry joints in a smaller block:
- thick aerated concrete block $\delta_{pc} = 0.2$ m, thermal conductivity of the material for the design conditions $B\lambda_{pc} = 0.12$ W/(m$^2$·°C);
- thick adhesive $\delta_{pc} = 0.303$ m, thermal conductivity of the material for the design conditions $B\lambda_{pc} = 0.47$ W/(m$^2$·°C);

$$R_{o,2} = 1/8.7 + 0.2/0.12 + 0.303/0.47 + 1/23 = 2.476$$ W/(m$^2$·°C).

To determine the additional specific linear heat losses through the joint between the masonry fragment structures, the joints of the aerated concrete block and the adhesive solution in the through
horizontal joint are considered (Figure 3, pos. 1) and in the vertical ligation of blocks (Figure 3, pos. 2) area 0.01 m² each according to the formula (3):

$$\psi_j = \frac{\Delta Q_j}{(t_{int} - t_{ext})}$$  (3)

where $t_{int}$ is the calculated air temperature from the structure’s internal surface side, for the calculation taken equal to +20 °C;

$t_{ext}$ is the calculated air temperature from the side of the outer structure’s surface, for the calculation taken equal to -10 °C;

$\Delta Q_j$ is the additional heat losses through the $j$-th joint per one running meter of the joint, W / m, determined by the formula (4):

$$\Delta Q_j = Q_j - Q_{j2}$$  (4)

where $Q_j$ defines the heat losses through the $j$-th joint per one running meter of the joint, resulting from the temperature field calculation, taken to be equal to 0.266 W / m [12];

$Q_{j1}$, $Q_{j2}$ denotes the heat loss through the homogeneous filling area, which entered the calculation area when calculating the temperature field of the $j$-type joint, W / m, determined by the formulas (5) and (6):

$$Q_{j1} = [(t_{int} - t_{ext})/R_{o,j1}]A_{j1}$$  (5)

$$Q_{j2} = [(t_{int} - t_{ext})/R_{o,j2}]A_{j2}$$  (6)

where $l$ is the length of the computational domain when calculating a two-dimensional temperature field in the direction perpendicular to the cross section, equal to 1 m;

$A_{j1}$, $A_{j2}$ is an area of homogeneous fillings included in the calculation area when calculating the temperature field, m². In this case, the sum of $A_{j1} + A_{j2}$ equal to the area of the computational domain when calculating the temperature field;

$R_{o,j1}$, $R_{o,j2}$ are the resistance to the heat transfer of the first and second sections forming the joint of the fragment, (m²·°C)/W.

The additional specific linear heat losses through the joint between the fragment designs of the masonry developed by the authors of the masonry are determined by the formulas (3), (4), (5), (6):

- the section of the junction of the aerated concrete block and adhesive solution in the through horizontal junction (Figure 3, pos. 1)

$$\psi_j = 0.1915 / [20 - (-10)] = 0.00638 \text{ W/(m·°C)}$$

$$\Delta Q_j = 0.266 - 0.0074 - 0.0671 = 0.1915 \text{ W/m}$$

$$Q_{j1} = [(20 - (-10)) / 1.12]0.0003 = 0.0074 \text{ W/m}$$

$$Q_{j2} = [(20 - (-10)) / 4.337]0.0097 = 0.0671 \text{ W/m}.$$  

- the junction of the aerated concrete block and adhesive solution in the vertical bandaging of blocks (Figure 3, pos. 2)

$$\psi_j = 0.1954 / [20 - (-10)] = 0.0065 \text{ W/(m·°C)}$$

$$\Delta Q_j = 0.266 - 0.0029 - 0.0671 = 0.1954 \text{ W/m}$$

$$Q_{j1} = [(20 - (-10)) / 3.096]0.0003 = 0.0029 \text{ W/m}$$

$$Q_{j2} = [(20 - (-10)) / 4.337]0.0097 = 0.0671 \text{ W/m}.$$  

Since there is no point heat engineering heterogeneity in the fragments under consideration, $\Sigma N_kK_k = 0$.

The reduced heat transfer resistance of the energy-efficient masonry calculated fragment is determined by the formula (1):

$$R'_o = 1 / [(0.003 / 1.22 + 0.0096 / 2.476 + 0.0053 / 2.476 + 0.0063 \cdot 2 + 0.0065 \cdot 3.096 + 0.0065 \cdot 3.552) = 1 / 0.295 = 3.39 \text{ (m²·°C)/W}$$

Similarly, the reduced heat transfer resistance of the calculated masonry fragment with transverse bonding through the row is determined. The calculation data can be seen in the Table.

**Table 1.** Thermal performance to determine the reduced heat transfer resistance
| Indicators | Cross-bonding masonry | Energy efficient double row masonry |
|------------|-----------------------|----------------------------------|
|            | Through horizontal seam | Through horizontal seam |
|            | Layered section | Layered section |
|            | Vertical bonding | Vertical bonding |
| Masonry thickness, [m] | 600 | 500 |
| Fragment area $A_i$, [m$^2$] | 0.0168 | 0.9581 | 0.0251 | 0.003 | 0.9821 | 0.0096* |
| Heat transfer resistance of a homogeneous part of the structure $R_{o,i}$, [(m$^2$·°C)/W] | 1.442 | 5.165 | 3.304 | 1.22 | 4.337 | 3.096* |
| Additional specific linear heat loss through $j$-type joint $\psi_j$, [W/(m·°C)] | 0.00678 | 0.0069 | 0.00638 | 0.0065 |
| The length of all joints of the $j$-th type in the fragment under consideration $L_j$, [m] | 11.2 | 2.352 | 2.0 | 3.952* |
| The reduced design heat transfer resistance $R_r$, [(m$^2$·°C)/W] | 3.368 | 3.39 |

*Note: The upper number refers to the area in which the bonding on a block of a larger width is performed, the lower number is on a block with a smaller width, respectively.

From the data given in the Table, it follows that the energy-efficient double-row masonry developed by the authors has the same reduced heat transfer resistance as the aerated concrete masonry with transverse bonding through a row having a thickness exceeding the considered 1.2 times.

**Summary**

An energy-efficient two-row masonry of cellular concrete blocks for the civil buildings building envelopes’ construction has been developed. To determine the masonry effectiveness, a calculation to determine the reduced resistance to heat transfer of the masonry of the standard design solution has been made and the developed energy-efficient masonry and conclusions have been established. The use of energy-efficient two-row masonry of walls made of cellular concrete blocks when installing the outer walls of civil buildings allows:

– to provide the required thermal performance without the use of thermal insulation materials;
– to eliminate the need for reinforcing masonry with a reinforcing mesh or rods that reduce heat engineering uniformity due to the blocks die bonding device;
– to reduce the masonry flow;
– to reduce the consumption of masonry by 20% by reducing the thickness of the masonry, which also increases the useful area of the room;
– to use one-size blocks of any length, which reduces the complexity of mounting the enclosing structure.

The implementation of the developed energy-efficient solution for the enclosing structures construction made of cellular concrete blocks during the construction of civil buildings will make it possible to optimize the economic and technological factors of the modern capital construction projects’ design decisions.
References
[1] Vatin N I, Gorshkov A S, Kornienko S V, Pestryakov I I 2016 The main advantages and disadvantages of wall structures from aerated concrete blocks Roofing and insulation materials 2 22-31.
[2] Harmati N, Jakšić Ž, Vatin N 2015 Energy consumption modelling via heat balance method for energy performance of a building Procedia Engineering 786-794.
[3] Vatin N, Gamayunova O 2014 Energy saving at home Applied Mechanics and Materials.
[4] BC 131.13330.2012 Construction climatology. Updated edition of SNiP 23-01-99 * (as amended) № 1, 2), The official publication. Ministry of Construction of Russia. (2015).
[5] Suleymanova L A, Pogorelova I A, Marushko M V 2018 Theoretical basis of formation highly organized porous structure of aerated concrete Materials Science Forum 945 309-317.
[6] Pukhkal V A, Mottaeva A B 2018 FEM modeling of external walls made of autoclaved aerated concrete blocks Civil Engineering Journal 5 202-211.
[7] Suleymanova L A 2017 High-quality energy-saving and competitive building materials, products and structures Bulletin of BSTU named after V.G. Shukhov 1 9-16.
[8] Suleymanova L A, Pogorelova I A, Kondrashev K R, Suleymanov K A, Piriev Yu S 2016 Energy-saving aerated concrete on composite binders Bulletin of BSTU them. V.G. Shukhov 4 73-83.
[9] Suleymanova L A, Kolomatsky A S, Pogorelova I A, Marushko M V 2017 Improving the efficiency of production and use of cellular concrete Bulletin of BSTU named after V.G. Shukhov 11 34-42.
[10] Suleymanova L A, Ryabchevsky I S, Kolomatsky A S, Pogorelova I A, Marushko M V, Bazhenova O O 2019 RF patent No. 2019141142, 12/11/2019. Energy-efficient masonry of walls made of cellular concrete blocks, Russian Patent № 196502. 2019. Bulletin № 7.
[11] GOST R 54851-2011 Buildings enclosing heterogeneous. Calculation of reduced heat transfer resistance, Official publication. Standartinform. (2012).
[12] SP 50.13330.2012 Thermal protection of buildings. Updated version of SNiP 23-02-2003 (as amended by No. 1, Official publication. Ministry of Regional Development of Russia. (2012).