Thermal Renovation of Facade Systems in Block Buildings

S V Korniyenko¹, T N Astafurova¹, O P Kozlova¹
¹Institute of Architecture and Civil Engineering, Volgograd State Technical University, Lenin Avenue, 28, Volgograd, 400005, Russia

E-mail: svkorn2009@yandex.ru

Abstract. According to results of the carried out research, the most significant heat engineering heterogeneous sections of wall enclosing structures of three-dimensional block buildings were identified. The use of option with attaching a hinged panel to a three-dimensional block with the help of edges along the contour of panel worsens thermal technical mode of the structure. Horizontal junction of wall panels carries the greatest thermal risks and is most responsible when designing a building. Structures of outer wall panels with ribs have practically no potential for energy saving. Fastening a hinged panel to a three-dimensional block with the help of dowels equally spaced in the panel plane improves its thermal performance. Compared to the design solution in the proposed option the reduced resistance to heat transfer of outer walls is increased by 31%. High heat insulating effect in this case is achieved by improving design solution of the wall, rather than increasing thickness of insulation layer, which is an economically feasible measure. Designs of outer wall panels with dowel connections are promising from the point of view of thermal protection and can be used for thermal renovation of facade systems in three-dimension block buildings.

1. Introduction

Three-dimensional block construction system was developed and implemented in experimental construction in late 50s of the last century. In the 70s, technological methods of three-dimensional block production of various design solutions and methods of their installation were worked out. At that time, plants for three-dimensional block housing construction reached their project capacity, and new structures were introduced into mass housing construction.

Three-dimensional block buildings are erected from integrated spatial reinforced concrete elements weighing up to 25 tones. Three-dimensional block is a spatial structure, manufactured in the factory. This structure has the necessary strength, stiffness and stability. Three-dimensional block can contain a living room, a staircase and other building fragments. In the course of construction three-dimensional blocks establish one upon another, as a rule, like “columns”, without bandaging of seams. Three-dimensional block structures are diverse, which is reflected in their classification by mass, static function and material.

Buildings made of three-dimensional blocks have high consumer quality. As compared to panel three-dimensional block housing construction provides reduction in total labor costs by 12–15%, creating a progressive structure of these costs. Three-dimensional-block construction system is used mainly in mass housing construction. Three-dimensional block housing construction provides the greatest economic effect in case of high concentration of construction, its implementation in a short time and shortage of labor force. Three-dimensional block housing construction implements
progressive principles of constructing high-quality, socially-oriented, aesthetically-attractive, durable and technological housing (figures 1, 2).

**Figure 1.** Three-dimensional block construction.  
**Figure 2.** Three-dimensional block scheme:  
1 – spatial block element; 2 – floor plate.

Issues of improving thermal properties of buildings due to implementing different facade systems have been already discussed [1–27]. The feasibility study of thermal insulation in facade structures within renovation of residential and public buildings is given in articles [1–7]. These articles indicate the need for comprehensive and multi-factor assessment of thermal regime, thermal protection properties and energy efficiency of buildings. Some articles [8–14] are devoted to the problem of increasing thermal protection and energy efficiency of buildings by reducing heat loss through thermotechnically heterogeneous areas of enclosing structures (boundary zones). Issues of standardizing thermal protection in residential buildings in different climatic zones of construction are reflected in articles [15–23]. A comparative assessing thermal property of building materials within the boundaries of life cycle of buildings is given in articles [24–27].

The need to improve energy efficiency of buildings and structures is reflected in the Order of Ministry for Construction of Russia (17.11.2017 No. 1550). Implementation of requirements for energy efficiency in design, construction and reconstruction of buildings is ensured by achieving specific characteristics of heat consumption for heating and ventilation in compliance with sanitary-hygienic requirements for premises. For newly built apartment buildings, the specific characteristic of heat energy consumption for heating and ventilation should be reduced in relation to the required specific characteristic: from July 1, 2018 – by 20%, from January 1, 2023 – by 40%, and from January 1, 2028 – by 50%. To reduce heat losses necessary thermal renovation of buildings is necessary. Despite massive three-dimensional block housing construction thermal properties of the facade systems of these buildings are currently not fully studied. Design characteristics of various units of these structures in the Russian standard SP 230.1325800.2015 are not presented.

Lack of calculation results for temperature fields complicates designing or expert evaluating of structures. In this regard, the subject of the article is definitely relevant. The purpose of this work is to develop evidence-based proposals to improve calculated thermal performance of outer walls of three-dimensional block buildings. The object of the study is an apartment building. The building under consideration was constructed according to a standard project. Number of floors is 10, number of sections is 4. According to the project, the building is built of reinforced concrete three-dimensional blocks of the “cap” type, thickness of block walls is 70 mm. Distinctive feature of this design is connection of the floor plate to the block during its manufacturing. For thermal insulation of external walls two-layer hinged panels consisting of external protective-finishing layer and highly effective heat-insulating material are used. To attach hinged panel to three-dimensional block along the contour of the panel, edges made of expanded clay concrete are provided. Filling of light windows apertures and balcony doors is carried out by double-glazed windows in plastic covers. The roof of the building is made with a cold attic; the roof is flat with a roll waterproofing coating. The building is operated in a temperate continental climate of Russia, with moderately cold winters and hot summers. The
calculated value of the degree-day heating period is HDD 20/8 = 3925 K day / year.

2. Methods
Assessment of heat-protective properties of external building envelope is carried out by calculation and experimental method. Thermal imaging control of thermal insulation in external walls of the specified object is carried out on the basis of environmentally safe method of nondestructive control in the cold period of the year in daytime at a temperature difference of internal and external air about 20 K and mode of heat transfer close to stationary. The survey was carried out in absence of wind, precipitation, fog and smoke. In the course of measurements the surveyed external surfaces of walls were not exposed to direct and reflected solar irradiation. Thermal imaging survey is performed by imager brand IR 928I in accordance with the manual instruction of the device.

Thermal imaging measurements were performed on the squares. Breakdown into squares is made with the capture in the field of view of thermal imager the boundary zones of enclosing structures: vertical and horizontal joints of panels, junction points of window blocks to wall openings, other heat-conducting inclusions. Within each square, base areas are highlighted, i.e. zones without temperature anomalies. At the base areas, contact temperature measurements and adjustment of thermal imager were carried out.

The result of thermal imaging is a set of calibrated thermo grams of enclosing structures, obtained by thermography, decoding and calculation of thermal images. A thermo gram is a temperature field calculated in increments of 0.1–0.2 °С along the surface.

The calculated estimate of the level of thermal protection of buildings can most accurately be made on the basis of determining reduced resistance to heat transfer of enclosing structures based on calculation of two- and three-dimensional temperature fields.

The calculated estimate of thermal regime of enclosing structures was made on the basis of mathematical modeling of heat transfer using Energy Efficiency and Thermal Protection of Buildings (ENTEZA) software complex [8–10]. On the basis of calculating three-dimensional temperature fields, software-computing complex ENTEZA makes it possible to evaluate the influence of edge zones on heat-shielding properties of enclosing structures and outline ways of improving buildings’ envelope elements.

3. Results and discussion
Based on the results of thermography of the object (figures 3, 4), most significant boundary zones of wall enclosing structures were highlighted:

- Horizontal panel joints.
- Vertical joints of panels.
- Junction points of window blocks to wall openings.

Due to insignificant length of wall junctions to foundation and attic flooring, as well as joints with other types of wall structures, thermal insulation properties of external walls were not taken into account.

![Figure 3. Overview thermo gram of a fragment of the building’s yard façade.](image1)

![Figure 4. Detailed thermo gram of a fragment of the building’s front façade.](image2)
Analysis of the results on mathematical modeling of thermal regime of external walls shows that the greatest localization of temperature is observed in zone of horizontal junction of wall panels (figure 5). The specified node carries the greatest thermal risks and is mostly responsible for design of the building.

Figure 5. Temperature field in zone of horizontal joint of panels in external walls: 1 – wall of the block; 2 – heat insulation; 3 – outer protective and finishing layer (OX, OY – coordinate axes).

To reduce heat engineering risks, as an alternative to fastening the panel to three-dimensional block, it is proposed to use discrete claydite-concrete ties dowels instead of edges. Dowels are recommended to place evenly in the panel plane. A detailed description of dowels’ design is beyond the scope of this work. The use of dowels reduces the area of heat transfer through the joint and provides an energy-saving effect of the whole structure.

The results of calculation of heat losses through the external walls (per 1 m² of walls) according to the project and the proposed option are shown in figure 6.

Figure 6. Specific heat losses through external walls (a – according to the project, b – according to the proposed option): 1 – basic; 2 – horizontal joints of panels; 3 – vertical joints of panels; 4 – junction points of window blocks to wall openings.

Analysis of calculation results based on design data shows that the additional heat losses due to influence of boundary zones exceed the basic ones (figure 6, a). This means that design solution of thermal protection in the structure is not effective enough. Maximum contribution to additional heat loss is given by joints of panels (horizontal – 22%, vertical – 16%), which is qualitatively consistent with the results of thermal imaging control. Minimum additional heat loss (13%) is noted through nodes of window blocks adjacency to wall openings. Improving design of panels by replacing them with stiffeners dowels reduces additional heat loss, reducing the effect of joints in panels of external
walls (figure 6, b). The use of dowel joints evens temperature field and improves thermal regime of the wall. Analysis of calculation results shows that reduced heat transfer resistance of outer wall according to the project is 2.5 m²·K/W. This value is in the range of permissible values of heat transfer resistance according to the Russian standard SP 50.13330.2012, but below the required value (2.77 m²·K/W). The low value of coefficient of thermal homogeneity of outer wall (0.49) is due to inefficient design solution of thermal protection. Low values of coefficient of thermal homogeneity are typical of end-to-end linear heat-conducting inclusions of large extent. Constructions of outer wall panels with ribs have practically no energy saving potential.

Implementation of dowels in design of panel improves its thermal performance. The reduced heat transfer resistance (3.27 m²·K/W) is higher than the required value. Compared to design solution in the proposed option, the reduced heat transfer resistance of outer walls increases by 31%. A higher value of coefficient of thermal homogeneity in the proposed version (0.64) indicates an increase in efficiency of thermal protection of outer walls. This is achieved primarily through implementing point heat-conducting inclusions—dowels, having a much shorter length compared to ribs. High thermal insulation effect in this case is achieved by improving the design of wall, rather than increasing thickness of insulation layer, which is an economically feasible measure. The use of dowel joints evens temperature field and improves thermal regime of the wall. The design of outer wall panels is promising from the point of view of thermal protection and can be used for thermal renovation of facade systems in three-dimension block buildings.

4. Conclusion
According to results of the carried out research, the most significant heat engineering heterogeneous sections of wall enclosing structures of three-dimension block buildings were identified. The use of option with attaching a hinged panel to a three-dimensional block with the help of edges along the contour of panel worsens thermal technical mode of the structure. Horizontal junction of wall panels carries the greatest thermal risks and is most responsible when designing a building. Low values of coefficient of heat engineering homogeneity are characteristic of end-to-end linear heat-conducting inclusions of great length. Structures of outer wall panels with ribs have practically no potential for energy saving. Fastening a hinged panel to a three-dimension block with the help of dowels equally spaced in the panel plane improves its thermal performance. Compared to the design solution in the proposed option the reduced resistance to heat transfer of outer walls is increased by 31%. A higher value of the coefficient of heat engineering homogeneity in the proposed option indicates increase in effectiveness of thermal protection of outer walls. High heat insulating effect in this case is achieved by improving design solution of the wall, rather than increasing thickness of insulation layer, which is an economically feasible measure. The use of dowel joints equalizes temperature field and improves thermal regime of the wall. Designs of outer wall panels with dowel connections are promising from the point of view of thermal protection and can be used for thermal renovation of facade systems in three-dimension block buildings.

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