

Comprehensive Constructive Achievements of the Regulatory Seismic-Resistance, Energy-Efficiency, Thermal Comfort, and Sanitary Conditions in Low-Rise Residential Building Design

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Abstract The multidisciplinary goal of the scientific research was achieved through the interdependent achievement of building design problems on its seismic-resistance, energy-efficiency, thermal comfort, and sanitary conditions. Practical issues in optimal design of low-rise buildings are solved by proposing joint structures of brick walls with monolithic reinforced concrete columns, tie beams, and foundations. Based on numerical investigations, the cross-sections of these elements are reduced, since the maximum displacements of the building frame's upper points along the X and Y axes under seismic loads are lower than the regulatory limits. The presented isotherms and heat flow intensities on the cross sections of the structural joints made it possible to eliminate the negative effects of thermal bridges and mold growth by installing additional layers of thermal insulation on them. Based on the developed schedules, the optimal width of these additional layers of thermal insulation and the radius of rounding of the inner corner of the outer wall with cement-sand mortar are proposed. The authors' comprehensive solutions enabled savings of 11.3% for

concrete and 3.54% for steel reinforcement, as well as a reduction in annual heat consumption of 6.61–8.08% for the studied building, located in six representative cities in Kyrgyzstan and Tajikistan.

Keywords Buildings, Energy-Efficiency, Seismic-Resistance, Thermal Comfort, Sanitary Conditions, Thermal Insulation, Thermal Bridges, Isotherms

1. Introduction

In many regions of the world with high seismicity, especially in mountainous areas, brick buildings with monolithic reinforced concrete seismic-resistant frames are widely used. However, many of these residential buildings often have poor design quality. This is due to the fact that the design features of low-rise buildings remain insufficiently studied, and design decisions in many cases

are made based on the experience of designing multi-story buildings.

The authors of this work have taken a comprehensive approach to ensuring the regulatory level of the seismic-resistance, energy-efficiency, internal thermal comfort, and sanitary conditions in the design of low-rise residential buildings. This necessity is connected not only with modern global challenges like climate change, but also with the emergence of new technologies for industry and scientific research.

The objectives of this research are based on the design features of common real buildings. For example, in Kyrgyzstan, about 60% of the population lives in rural areas in single-family houses. There are many of them in small towns, too. Similar buildings are also widespread in Tajikistan, other Central Asian countries, and many mountainous regions of the world.

The main goals of this multidisciplinary research are to ensure compliance with regulatory conditions, reduce the cost of reinforced concrete seismic-resistant structures, and improve the energy-efficiency of the buildings. The solutions to the latter task are of great importance because reducing the heat consumption for heating a building leads to a decrease in greenhouse gas emissions. Accordingly, it is possible to reduce the significant contribution of such buildings to global climate change.

In practice, many low-rise buildings, especially single-family residential buildings, are built with a large seismic margin [1]. The most commonly used methods for strengthening high-rise buildings with a seismic-resistant reinforced concrete frame were, in many cases, applied without accurate calculations. In addition, the design decisions appear to be reliable because they are similar to those for multi-story residential buildings and are justified by the relevant design results. For this reason, the construction of seismic-resistant low-rise buildings is accompanied by excessive use of monolithic concrete, reinforcing steel, and, most importantly, energy, for example, for heating. Such over expenditure of thermal energy is particularly significant for buildings located in mountainous regions with a sharply continental and cold climate.

In the zone of thermal bridges, the local resistance to heat transfer of external enclosures decreases, which leads to intense heat flows and low temperatures on the interior surface of this zone [2]. This negatively affects the well-being of people in the respective rooms, causes condensation of air moisture, and damage to structures.

The theoretical basis of this work is the comprehensive improvement of the characteristics of buildings' envelopes [3]. Based on thermo-physical studies, three types of theoretically possible thermal bridges have been established, which are classified accordingly as constructive, architectural, and operational thermal bridges [3]. The elements of an earthquake-resistant reinforced concrete frame of a building create constructive thermal bridges.

The problems of reducing the negative effect of thermal bridges that occur when designing balconies of multi-story residential buildings have been studied [4].

A similar effect of thermal bridges in various types of external walls was investigated from the standpoint of their influence on the thermal envelope of residential buildings in hot climates [5].

For eliminating the negative influence of thermal bridges in the junctions of reinforced concrete floors with seismic-resistant reinforced concrete columns, it was proposed to install an additional layer of external thermal insulation at the thermal bridge zone [6,7]. Calculation methods were considered for determining the appearance or absence of mold growth and air moisture condensate on the interior surfaces of exterior enclosures [8].

On the basis of numerical studies, the strength indicators of the junctions of a brick wall with a floor slab were studied since they are the most seismically vulnerable parts of an unreinforced brick building [9]. It is rightly stated that during an earthquake, first of all, these nodes are destroyed. Partly for this reason, in Kyrgyzstan, Kazakhstan, Tajikistan, and other countries of Central Asia, the construction of brick buildings with a seismic-resistant reinforced concrete frame has become widespread [7,9]. The features of similar buildings with brick filling of a seismic-resistant frame were studied [10].

Based on the results of special studies, regulatory and additional layers of thermal insulation were also adopted on the external areas of thermal bridges of the semi-basement foundation [7]. As a result, the required level of the indoor microclimate and seismic-resistance of the building was achieved while preventing condensation of air moisture and mold growth on the interior surfaces of outdoor enclosures, especially in the corner zones of the concrete walls of the semi-basement and foundation.

In practice, the technology of constructing buildings with monolithic reinforced concrete columns is often used, which has a rigid connection with monolithic reinforced concrete floor slabs of the building [11]. Figure 1 shows the pouring of concrete for a monolithic inter-floor slab.



Figure 1. Pouring concrete for a monolithic inter-floor slab

This construction method has several advantages. Firstly,

it offers a higher seismic-resistance of the building. Secondly, it provides the convenience of its construction technology, which eliminates the need for reinforced concrete inter-floor slabs and their crane-mounted installation. The monolithic floor slabs create a horizontal rigidity diaphragm, which is important to ensure the required seismic-resistance of the building in areas of high seismicity of 8, 9, and more than 9 points on the MSK-64 scale [12]. The authors found that in practice, single-family houses with the frame mentioned above are often designed without a detailed and accurate calculation of the building for the regulatory seismic-resistance. At the same time, the elements of such a frame are accepted with an unreasonably high margin of safety. This leads to overconsumption of concrete, reinforcement steel, and energy [6,13,14].

Experimental studies of the thermal conductivity of concrete and reinforced concrete show that reinforced concrete has a higher thermal conductivity than concrete without reinforcement [15]. It follows that the energy-efficiency of seismic-resistant buildings is reduced not only due to an increase in the cross sections of the elements of the reinforced concrete frame, but also due to their reinforcement above the norm.

Based on the above conducted analysis of seismic-resistance of buildings, the authors set a research goal, which is realized, in particular, through precise calculations of seismic-resistance of buildings.

2. Materials and Methods

In areas of high seismicity, cement, sand, brick, and reinforced concrete are most often used for the construction of low-rise residential buildings. Such buildings require reinforced concrete structural elements to reduce the risk of cracks in the brick walls.

To implement the tasks of multidisciplinary research, an existing representative of common brick buildings (Figure 2) is considered. The building has a reinforced monolithic concrete frame with columns, inter-floor slabs, and floor slabs.



Figure 2. The exterior of an existing residential building

Using experimental verification and numerical modeling techniques, it was established that numerical studies have broader capabilities than experimental measurements of a limited number of parameters [16]. Accordingly, in this work, the method of numerical studies was adopted to investigate the mutual influence of seismic-resistance, energy-efficiency, internal thermal comfort, and sanitary conditions.

Computer numerical research is aimed at improving the design solutions for the outer enclosures of the building. This research method is used to determine the sufficient level of seismic-resistance, energy-efficiency, thermal comfort, and sanitary conditions of the building. The thermal performance of structures of the joints between external brick walls with monolithic columns, inter-floor slabs and floor slabs was studied. Similar studies have been carried out to identify the thermal performance of the inter-floor slabs and the floor on the ground with a reinforced concrete foundation. The reinforced concrete frame, floor slabs, floor on the ground, and foundation form a single monolithic structure, made by pouring heavy class B25 concrete. The thickness of the reinforced concrete monolithic floor slabs and floor on the ground is 0.15 m.

It has been established that the inner corner of the outer wall at the floor slabs causes a negative effect of thermal bridges. This leads not only to a violation of the conditions of thermal comfort of the rooms but also reduces the energy-efficiency of the building. This is caused by low temperatures on the inner surface of the corner. Due to such low temperatures, condensation of ambient air moisture and mold growth (Figure 3) are observed at these corners, which are the cause of the violation of sanitary conditions in the respective rooms.

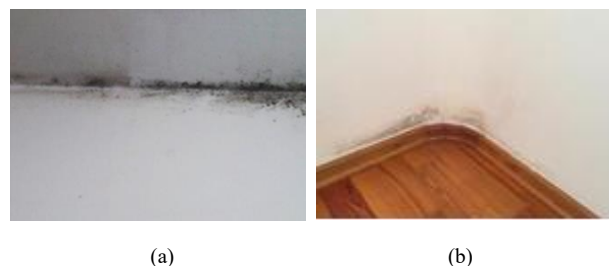


Figure 3. Mold growth on interior surfaces of a room: (a) corner area at the ceiling; (b) corner area at the floor, lying on the ground

3. Results

3.1. Results on Seismic-Resistance

The seismic-resistance of an existing residential building to static and dynamic loads was studied using the computer program Lira SAPR 2016 [17]. In the building under consideration (Figure 2), the external load-bearing walls, made of 0.38 m thick brickwork, are clamped by a reinforced concrete frame to prevent the frame from

moving beyond the normatively permissible value [18]. In this article, a calculation model of the building (Figure 4) with brick walls clamped by a reinforced concrete frame is adopted to conduct scientific research to exclude unacceptable displacement of the frame under the action of static and seismic loads.

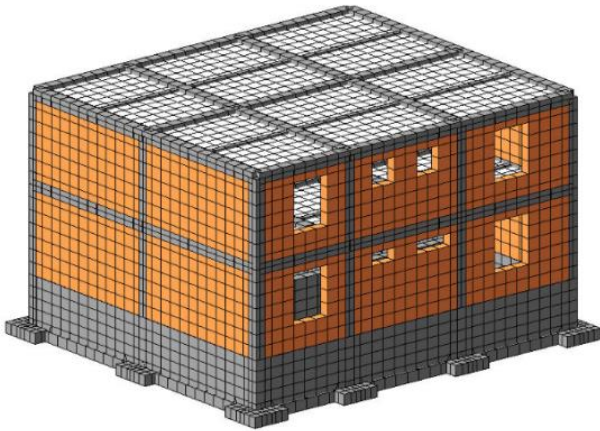


Figure 4. The calculation model of a residential building with rigid external enclosing brick walls to a reinforced concrete frame

The adopted calculation model of the building allows its seismic-resistance to be assessed using the finite element numerical method with the Lira SAPR 2016 software package. Observed static and seismic loads must be assessed using standard indicators of strength and stability of structural elements.

The required normative indicators are presented for conditions under which the forces and stresses in structural elements do not exceed the maximum permissible values.

They are regulated by normative documents [18,19]. A linear static analysis was carried out as part of the study by taking into account uniformly distributed and concentrated loads, as well as permanent loads from the self-weight of the structure. To simulate external impacts, the analysis included load characteristics over time based on specified accelerograms. In particular, natural accelerograms were used to adequately reflect the dynamic impact of seismic loads. The calculation was carried out for seismicity of the construction area, which is 9 points on the MSK-64 scale. The soil category is sand.

The calculations were carried out by the finite element method using the Lira SAPR 2016 software package. The seismicity of the construction area is 9 points on the MSK-64 scale. The soil category is sand. The calculation model of the building (Figure 2) is shown in Figure 5.

The structural analysis was performed using the Finite Element Method with automatic generation of the finite element mesh shell (plate) elements. The total number of nodes in the model was 4,064. The model included 812 beam elements and 3,870 assumed rigid connections between all elements. The interaction between structural components was modeled through appropriate finite

elements representing structural connections, ensuring a realistic simulation of the frame behavior under loads and accurate force transmission between connected elements.

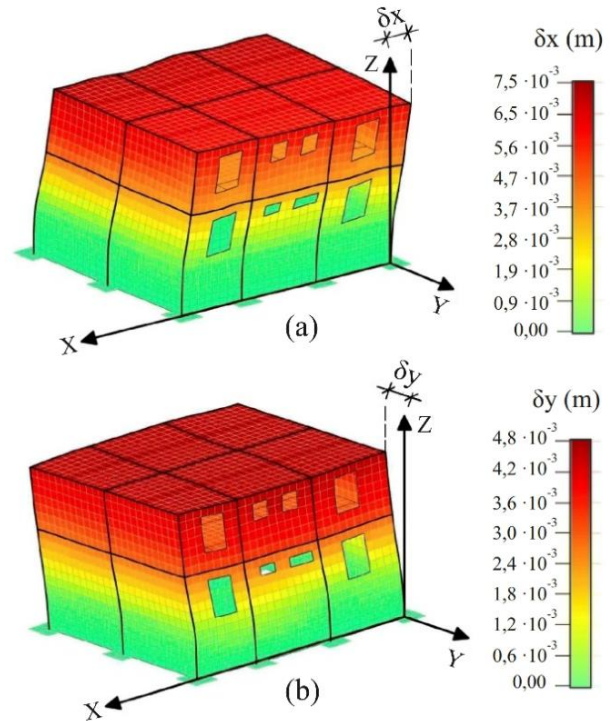


Figure 5. Deformations of the building from the impact of seismic forces: (a) displacement along the X axis, (b) displacement along the Y axis

Concrete grade B15 with an elastic modulus of $E = 2,350,000 \text{ t/m}^2$ was used for the foundations. For columns, beams, girders, floor slabs, and roof elements, concrete grade B20 with an elastic modulus of $E = 2,750,000 \text{ t/m}^2$ was applied. The exterior walls were made of brick masonry with a thickness of 0.38 m, for which an elastic modulus of $E = 54,000 \text{ t/m}^2$ was adopted.

Analysis of the calculation results showed that the maximum horizontal displacement of the upper point of the calculation scheme along the X axis is $7.50 \times 10^{-3} \text{ m}$, and along the Y axis is $4.80 \times 10^{-3} \text{ m}$. These design indicators do not exceed the maximum allowable displacement of $13.2 \times 10^{-3} \text{ m}$ according to [18]. The authors established that the maximum vertical displacements along the Z axis under constant and dynamic loads are insignificant and therefore they are not presented here.

According to the calculation, the maximum required percentage of reinforcement is 0.81% for columns and 1.58% for crossbars on their cross-sectional dimensions of $0.38 \times 0.38 \text{ m}$. Since these indicators are much lower than the normative ones [19], the authors proposed to reduce the dimensions of their sections to $0.34 \times 0.34 \text{ m}$. For these dimensions, the above-mentioned indicators are 0.99% for columns and 2.03% for tie beams. They are also below the maximum permissible value of 6% [19]. So, the authors

proposed the cross-section dimensions in 0.34x0.34 m as a more convenient structural solution for the building frame.

The proposed design solutions provide savings in the volume of concrete of the monolithic reinforced concrete frame of the seismic-resistant building by 11.21% and steel reinforcement by 3.84%. These material savings are achieved for the seismic-resistant building in site areas with seismicity of 9 points on the MKS-64 scale. A comparison of maximum regulatory displacements and calculated maximum displacements in Table 1 shows that it is possible to reduce the cross-section of monolithic reinforced concrete columns to 0.34x0.34 m, which is considered more convenient for construction technology.

3.2. Results on Energy-Efficiency and Thermal Comfort

The thermal performance of the connection construction between a monolithic inter-floor slab and an external brick wall in Figure 6(a) was investigated for stationary heat transfer processes in space heating design regulatory conditions for Bishkek.

The results of numerical investigations are presented as isotherms and heat flow intensities using the computer

program ArchiCAD 23 [20]. As seen in Figure 6(b), the reinforced concrete connection zone, which is a constructive thermal bridge, has significantly low temperatures on its interior surfaces of about 7 °C. According to the regulatory requirement [21], the difference between the air temperature in the room and the temperature on the interior surface of the exterior walls should not be more than 4 °C. Consequently, for this connection zone, the regulatory indicators of thermal comfort of the respective rooms are not achieved.

The authors of the article, through numerical studies, have established that the indicated temperature deviations cannot be reduced even with the regulatory thickness of the main layer of the wall's thermal insulation, made of mineral wool slabs of 0.07 m, which corresponds to the energy-efficiency class B of the building. The temperatures on the interior surfaces of the reinforced concrete inter-floor slab in Figure 7(a) show that the above-mentioned regulatory temperature difference is still greater than 4 °C.

To reduce the negative effect of the thermal bridge caused by the reinforced concrete monolithic floor and inter-floor slab, an additional layer of thermal insulation was adopted for this thermal bridge zone.

Table 1. The calculation results of seismic resistance of a brick wall and the concrete frame of the existing building

Comparison of calculated maximum displacements with regulatory displacements under seismic loads, m			
Indicators	Calculated maximum displacements		Maximum regulatory displacements
	0.38 x 0.38	0.34 x 0.34	
Horizontal movement along the X axis, δ_x	7.04×10^{-3}	7.50×10^{-3}	13.2×10^{-3} [13]
Horizontal movement along the Y axis, δ_y	4.73×10^{-3}	4.80×10^{-3}	13.2×10^{-3} [13]
Maximum floor skew, Δ_x	3.72×10^{-3}	3.96×10^{-3}	8.25×10^{-3} [14]
Maximum floor skew, Δ_y	2.77×10^{-3}	2.85×10^{-3}	8.25×10^{-3} [14]

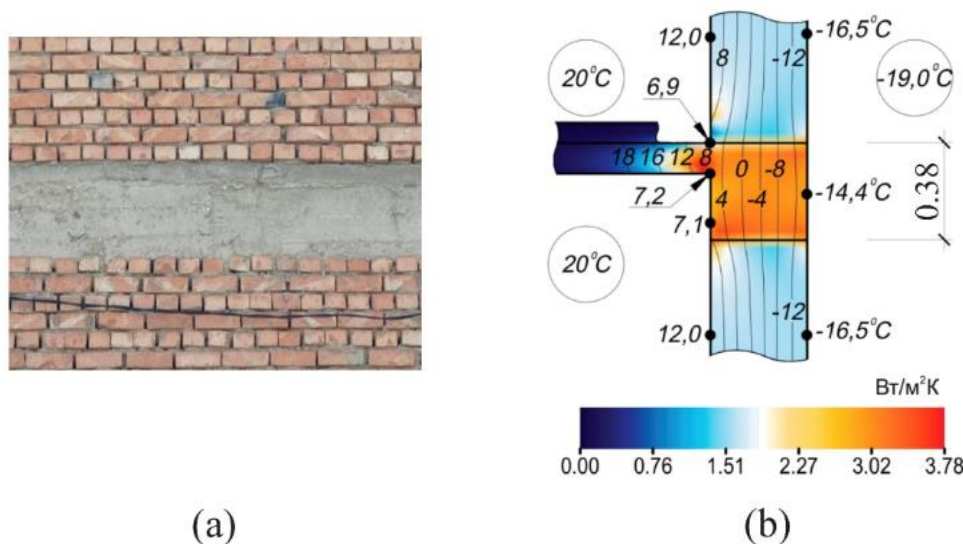


Figure 6. Connection construction of a monolithic inter-floor ceiling and brick wall: (a) exterior appearance; (b) Isotherms and heat flow intensities

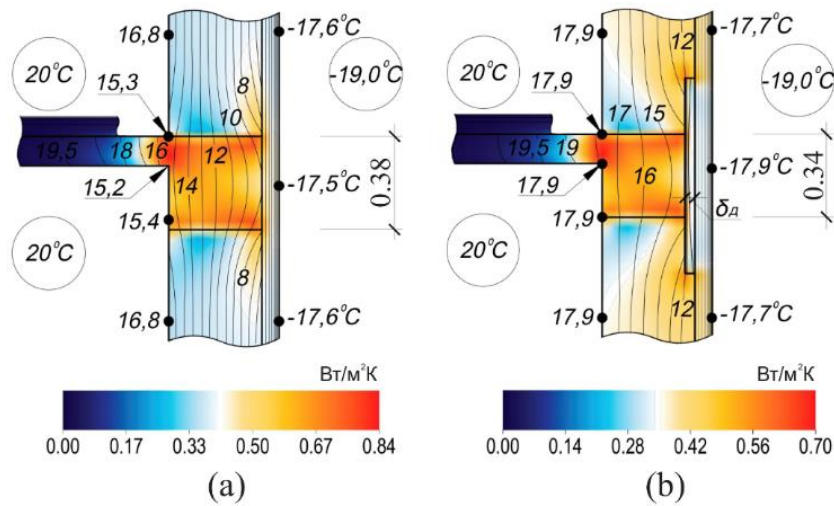


Figure 7. Isotherms and intensities of heat flow in the vertical cross-section corner zone of an external wall and a monolithic crossbar: a) with the main layer of thermal insulation; b) with the main and additional layers of thermal insulation

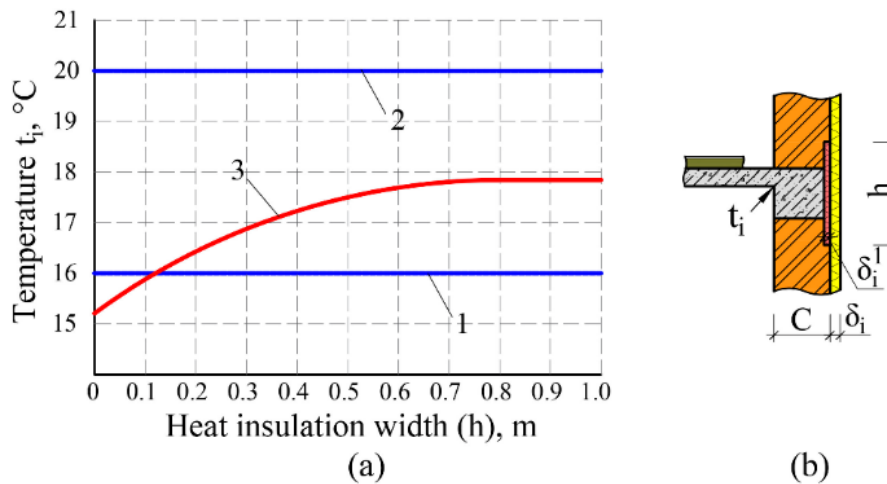


Figure 8. Determination of the width of the additional thermal insulation layer on the thermal bridge zone: (a) temperature graphs: 1 - minimum permissible regulatory temperature on the interior surface of the external wall; 2 - regulatory room's air temperature; 3 - graph of the interior surface temperature; (b) interface zone of the external brick wall with monolithic floor and crossbar

The authors found that the temperature on the corner t_i (Figure 8) depends on both the thickness of the additional layer and the width of this layer h . A graph of the dependence of t_i from the width of the extra layer h was established (Figure 8(a)) when the thickness of the additional layer is 0.040 m. According to this temperature graph, it was established that the temperature on the corner becomes equal to the temperature on the inner surface of the external wall 17.9 °C (Figure 7(b)) when the width of the additional thermal insulation layer is 0.8 m.

As can be seen from the graph, increasing this width over 0.8 m does not lead to an increase in the temperature in the corner zone. Based on this result, the authors established a scientifically substantiated important fact that constructive solutions allow for the complete elimination of the influence of thermal bridges of external enclosures.

On the basis of the above theoretical conclusion obtained by numerical studies, the authors have developed

a practically acceptable constructive assembly for the connection of a monolithic upper floor slab with an external wall. The proposed construction is presented in Figure 9.

In practice, there is a high negative effect of the thermal bridge of the monolithic upper floor slab interface on the thermal comfort and energy-efficiency of the building. With such exposure, mold growth is also observed in the corner area (Figure 3), which leads to sanitary condition below the regulatory level in the room. This result is also connected to the fact that this structural connection has significant heat losses through the thickness of the reinforced concrete upper floor slab. It has been established that the solution of this problem is complicated by the complexity of the external thermal insulation of this structural connection on the upper covering of the building. For this reason, the design of fastening the Mauerlat to a monolithic reinforced concrete upper floor slab is proposed.

Even with such a constructive solution, when the normative basic layers of thermal insulation of both the exterior wall and the upper floor slab are adopted, it is not possible to obtain the desired result. As can be seen from Figure 10(a), the temperature on the corner of 14.3 °C is significantly lower than the permissible temperature equal to 16 °C.

As a new scientific approach, for the first time, the authors proposed the junction node of a monolithic reinforced concrete ceiling-crossbar with a brick wall to reduce the influence of a thermal bridge by rounding the

interior corner with a cement-sand mortar. Such a constructive solution made it possible to obtain a temperature in the corner zone equal to 17.9 °C (Figure 10(b)) by this rounding.

The authors develop a dependence graph of the temperature on the surface of a rounded corner with cement-sand mortar with the radius of curvature of this rounding (Figure 11(a)). It was found that when the radius is above $R = 0.27$ m, this temperature (Figure 11(b)) does not change, since it reaches 17.9 °C.

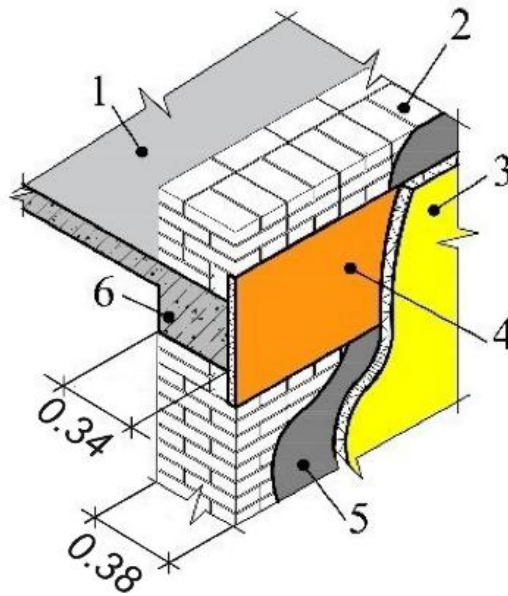


Figure 9. Structural joint solution of a monolithic crossbar-floor with an external brick wall: 1 - monolithic floor; 2 - brick wall; 3 - main layer of thermal insulation; 4 - additional layer of thermal insulation; 5 - plaster layer; 6 - monolithic crossbar

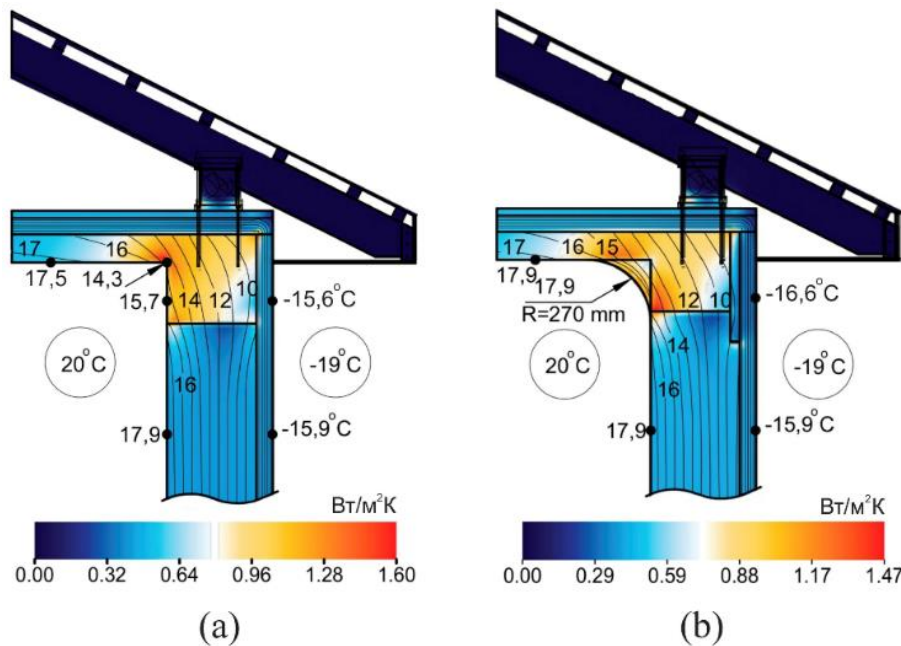


Figure 10. Isotherms and intensities of heat flow in the vertical cross-section of the corner zone of an external wall and a monolithic upper floor slab: (a) with the main layer of thermal insulation; (b) with the main and additional layers of thermal insulation

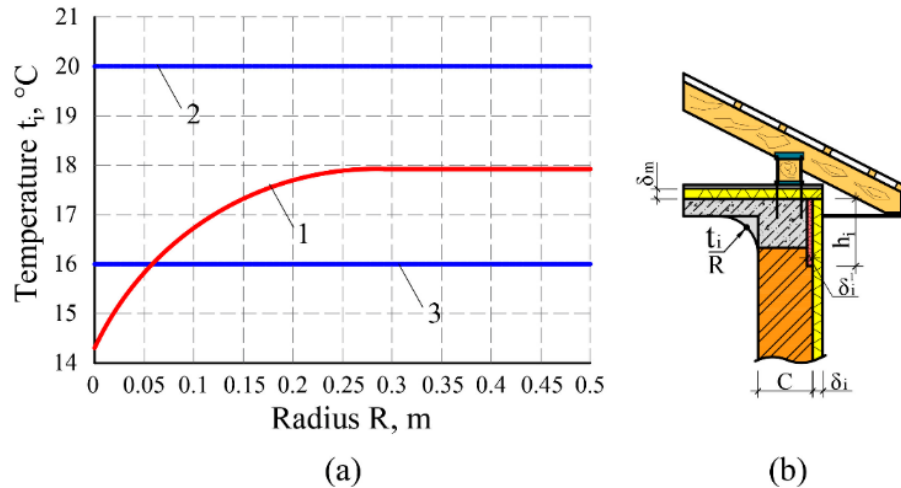


Figure 11. Determination of the temperature on the interior surface of the outer wall: (a) temperature graphs: 1 - minimum permissible regulatory temperature on the interior surface of the external wall; 2 - regulatory room air temperature; 3 - graph of the temperature of the inner surface; (b) the junction zone of the external brick wall with the monolithic upper floor slab

As a result of the present numerical investigations, a construction solution was obtained that makes it possible to achieve the same temperature both on the interior surface of the upper floor slab and on the interior surface of the outer wall, equal to 17.9 °C (Figure 10(b)). This means that the influence of the angular structural thermal bridge is completely eliminated.

This solution is based on the theoretical idea of energy-saving architecture, aimed at solving practical problems of improving the performance of thermal protective enclosures of a building [3]. This theory is based on the concept of a thermally ideal building in the form of a sphere [3]. Such a theoretical building does not have constructive and architectural thermal bridges. Thus, the authors of this article have obtained for a real building in the form of a parallelepiped the conditions of internal thermal comfort characteristics of a spherical theoretical building or a real building with a domed ceiling [3].

Accordingly, the authors recommended a constructive solution for the building under consideration (Figure 2) that excludes the negative effect of a thermal bridge in the area of the junction of the attic monolithic reinforced concrete upper floor slab with the exterior brick wall, shown in Figure 12.

The features of the thermal comfort of the room, which is under the influence of thermal bridges of the foundation, have been studied. Particular attention should be paid to those sections of the foundation that are adjacent to the ground. The processes of heat transfer through the junction zones of the foundation with the floor structure on the ground were studied by numerical investigations.

Figure 13 shows isotherms and color representations of heat flow densities across the vertical cross section of the foundation and adjacent sand mass. The part of the brick wall that is under the thermal influence of the foundation is also considered together.

It has been established that the external thermal insulation of the vertical part of the foundation, as a continuation of the regulatory thermal insulation layer of the external wall (Figure 13(a)) with a thickness of 0.07 m does not provide the required result. In this case, the temperature on the floor corner that is adjacent to the foundation is very low: the temperature of 11.4 °C on this surface may cause condensation of moisture from the room air. Moreover, this temperature is significantly lower than the regulatory one, equal to 16 °C.

The subsequent stage of numerical studies found that the installation of an additional layer of thermal insulation (0.04 m) on the vertical zone of the foundation, adopted for the wall (as in Figure 7), also does not give the desired effect. Therefore, a version with a thicker addition layer of thermal insulation was adopted. It was decided to install a second additional layer (with a similar thickness of 0.04 m) over the main layer of thermal insulation, which wraps around the base of the foundation over this main layer. In this case (Figure 13(b)), the temperature at the interior corner rises to 17.9 °C, which is equal to the temperature on the main surface of the external wall.

On the basis of the numerical studies above, a constructive version of the interface between the foundation and the floor on the ground was developed. The design of this structural connection, shown in Figure 14, can be put into practice without problems, since well-known foundation thermal insulation installation technologies are applied.

To determine the energy-efficiency of constructive solutions that are proposed and developed on the basis of the results presented in Figure 7(b), Figure 10(b), and Figure 13(b), a comparative analysis of the annual heat losses of two building options was carried out. The first option refers to the building that was built on the basis of regulatory conditions for thermal protection, and the

second option refers to the building built using the structures proposed by the authors. Annual heat losses for the considered building (Figure 2) were calculated using the VALTEC PRG [22] software package for six cities in Kyrgyzstan and Tajikistan. The calculation results are presented in Table 2.

The constructive solutions proposed by the authors make it possible to decrease heat consumption for heating

the building by 6.61 % to 8.08 %. Such energy savings are achieved using the example of the studied building, located in six cities in areas with seismicity of 9 points on the MSK-64 scale. For regions with similar seismicity, such as the western United States and Kamchatka of Russia, these indicators of buildings' energy consumption reductions vary depending on the degree-days of the heating period.

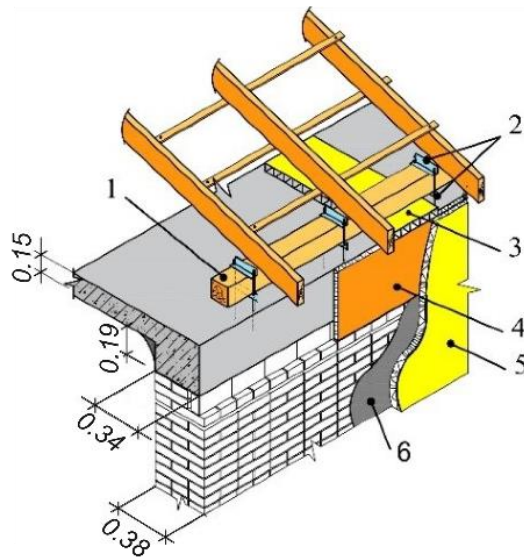


Figure 12. Constructive solution for the junction of the upper floor slab with the exterior brick wall: 1 - Mauerlat; 2 - metal support; 3 - a layer of thermal insulation; 4 - an additional layer of thermal insulation; 5 - the main layer of thermal insulation; 6 - plaster layer

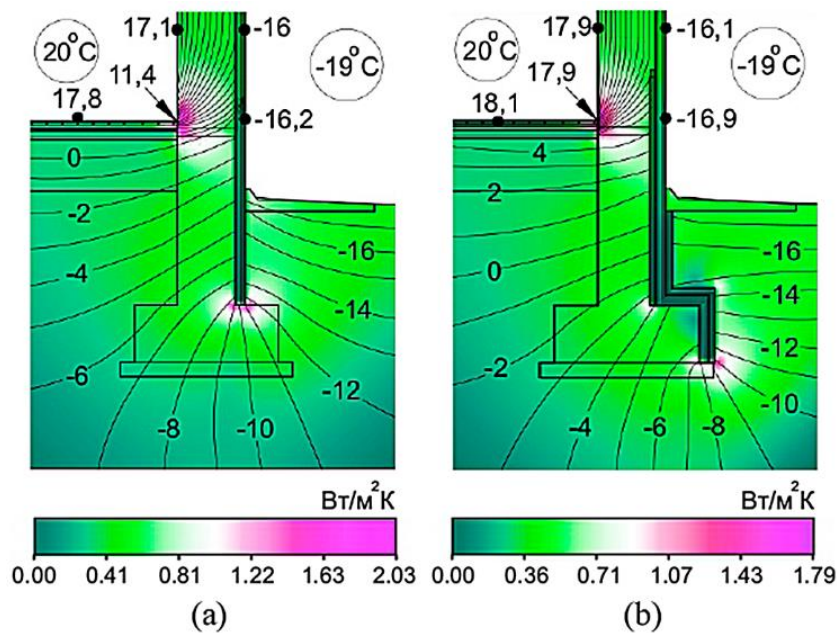


Figure 13. Isotherms and intensities of heat flow in the vertical cross-section of the foundation and its junction zones with the ground: (a) with the main layer of thermal insulation; (b) with the main and additional layers of thermal insulation

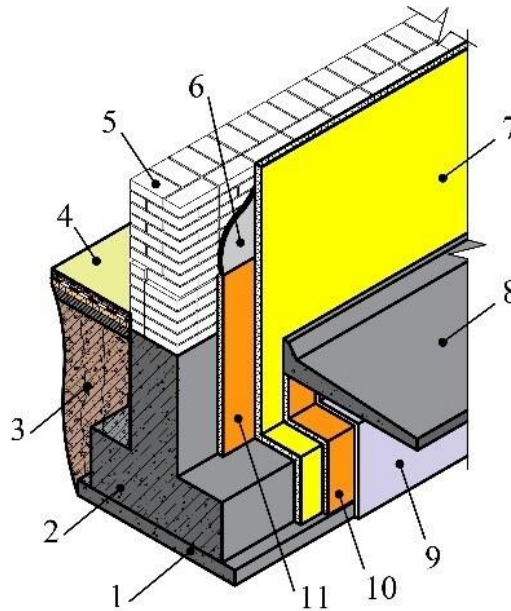


Figure 14. Constructive solution for the junction of the floor with the foundation; 1 - concrete preparation; 2 - foundation; 3 - soil; 4 - floor on the ground; 5 - brick wall; 6 - cement-sand plaster; 7 - regulatory layer of wall's thermal insulation; 8 - blind area; 9 - protective membrane; 10 - and 11 - additional layers of thermal insulation

Table 2. Annual heat losses before and after the application of proposed structural solutions for a residential building in the main cities of Kyrgyzstan and Tajikistan

№	Cities	Degree-days, °C days	Annual heat losses and savings of thermal energy, kW h per year		
			Regulatory data	After the application	Savings energy
Kyrgyzstan					
1	Bishkek	2970	108631	101395.9	7235.1 (6.61%)
2	Toktogul	3008	117388.5	108780.0	8608.5 (7.33%)
3	Naryn	4992	109438.6	101648.3	7790.3 (7.12%)
Tajikistan					
4	Dushanbe	1584	104450	96004.4	8445.6 (8.08%)
5	Khujand	1984	112657.8	105481.6	7176.2 (6.37%)
6	Khorog	3370	106636.5	98794.7	7841.8 (7.35%)

3.3. Results on Sanitary Conditions

According to sanitary regulations, in the air of the premises, there should be no mold spores. Being strong allergens, they can cause respiratory diseases such as asthma, bronchitis, and pneumonia. Mold spores can also cause human liver and kidney damage, and diseases of the nervous and cardiovascular systems.

The design solutions made it possible to eliminate the main cause of mold: Low temperatures on the surfaces of hygroscopic building materials were prevented, especially on the internal surfaces of the corner zones of external enclosures. Thus, by constructive solutions, the authors achieved the prevention of mold growth, shown in Figure 3.

4. Discussion

An analysis of scientific articles published in recent years has shown that many authors pay special attention to the joint consideration of the problems of ensuring acceptable energy-efficiency [23,24,25].

The formulation of the problems and conclusions obtained by this study regarding the seismic resistance of low-rise buildings are consistent with the data of other works [26,27,28,29] and the European standard [30] FprEN 1998-1-2:2023: Eurocode 8, which sets out the general principles and specific rules for buildings in seismic areas.

The energy modernization of existing residential buildings is considered as an important problem [25]. Three levels of energy modernization programs have been

proposed.

The authors concluded that the implementation of measures to improve the energy-efficiency of a number of buildings can save up to 43% of annual energy consumption. Similar problems are considered for the basement floors of historical buildings [31,32,33]. In [34], it is indicated that the study of the quality of the microclimate in educational buildings was the basis for choosing the direction of their thermal modernization.

Numerical studies of a reinforced concrete wall-frame structure were considered for building seismicity using the Lira SAPR 2016 software package [28]. The results of these studies made it possible to determine and evaluate the seismic-resistance of buildings in accordance with the requirements of current design standards.

On the basis of thermal calculations of the foundation of buildings in permafrost soils, the levels of standard parameters of strength and deformation were estimated [34,35]. Thermal processes associated with basement floor fragments have been investigated as an important problem for modern buildings [31]. Accordingly, the need to strengthen the external thermal insulation of individual sections of the exterior enclosures of frame-monolithic buildings through an additional layer of thermal insulation was determined. Therefore, it is necessary to study the influence of thermal bridges to reduce the heat consumption of buildings' lower-floor rooms [36]. The influence of indoor microclimate conditions on mold growth in buildings was also studied [37]. Comparisons and evaluations of the proposed simple method for calculating heat losses through a structural junction fragment of reinforced concrete floor slabs with a brick wall were carried out [38].

The results of the analysis devoted to the study of the features of the relationship between the parameters of the indoor thermal microclimate during radiant cooling of residential buildings, serve as a reliable basis for determining directions for improving design [39].

As in the present work, the relationship between the energy efficiency of buildings with design solutions [40,41], the connection nodes of external enclosure structures [42], and the thermal bridges [43] was investigated.

5. Conclusions

1. The multidisciplinary goal of the scientific research was achieved through the interdependent achievement of building design tasks on its seismic resistance, energy efficiency, thermal comfort, and sanitary conditions.

2. The authors of the research have established that widespread low-rise residential brick buildings with monolithic reinforced concrete frames are designed and built with a large seismic-resistance reserve. Numerical studies of such buildings in areas with seismicity of 9 points on the MSK-64 scale led to the decision to reduce

the cross-section of monolithic reinforced concrete columns and tie beams from 0.38x0.38 m to 0.34x0.34 m. In this case, the maximum displacements of the upper point of the reinforced concrete monolithic frame of the building by seismic loads are below the regulatory permissible values along the X and Y axes.

3. As a result of the adopted constructive solutions, the energy-efficiency, indoor thermal comfort, and sanitary conditions of the proposed seismic-resistant building in the form of a parallelepiped have achieved the indicators of a theoretical building in the form of a sphere.

4. Based on numerical investigations that allow representation of stationary heat flow intensities and isotherms in the cross-section of thermal bridge zones, structural connection of the external wall with elements of a monolithic reinforced concrete frame, a floor on the ground, and a foundation have been developed and proposed for practical use.

5. The proposed constructive solutions provide regulatory indicators of indoor thermal comfort and sanitary conditions. They are achieved by eliminating the negative effect of thermal bridges by increasing the abnormally low temperatures on the interior surfaces of external enclosures by installing an additional layer of thermal insulation on the areas of thermal bridges. This eliminates the possibility of condensation of air moisture and mold growth on the mentioned surfaces of hygroscopic building materials on the interior of rooms.

6. Based on the developed graphs, the optimal values for the width of the additional layer of thermal insulation of thermal bridge zones and the radius of rounding the external wall's inner corner using cement-sand mortar were determined.

7. The proposed design solutions provide savings in the volume of concrete of the monolithic reinforced concrete frame of the seismic-resistant building by 11.21% and steel reinforcement by 3.84%, as well as a reduction of the annual consumption of thermal energy for heating of this building by 6.61-8.08%. Such savings are achieved using the example of the studied building, located in six cities in areas with seismicity of 9 points on the MSK-64 scale and different climatic conditions in Kyrgyzstan and Tajikistan.

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