Buildings Enclosures Coupling by Its Energy Efficiency, Seismic Resistance and Microclimate

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Abstract. Features of a constructive solution of coupling an external brick wall and reinforced concrete attic flooring of existing low-rise residential buildings forced with a reinforced concrete monolithic frame are studied. A photograph presented shows mold on the intersection zone of the inner surfaces of the external wall and the attic flooring. The calculation of the building frame carried out using the program LiraCAD 2013 on a seismic load intensity of 9 points on the MSK-64 scale. Two-dimensional temperature distributions in the cross section of the enclosures, in particular in the area of thermal bridges, presented as isotherms using the ArchiCAD 20 software package. The multidisciplinary task of ensuring the required seismic resistance, energy efficiency and microclimate of the building has been solved. An expedient constructive solution of the coupling external brick wall and reinforced concrete attic flooring for the reconstruction of existing and design of new buildings is proposed. The dimensions of the cross section of monolithic reinforced concrete columns and crossbars of the building frame and thickness of an additional layer of thermal insulation of the thermal bridge zones are determined. A new mounting unit is developed to attach the pitched roof's Mauerlat to the anti-seismic belt. Practical recommendations are given that aim to reduce the negative temperature and thermal effects of the thermal bridges. The proposed constructive solutions made it possible to exclude the main causes of violations of sanitary conditions in the premises caused by mold growth on the surfaces of hygroscopic enclosures materials.

Keywords: Building, energy efficiency, seismic resistance, microclimate, wall, flooring, thermal bridges

The main goal of this research is to consider and solve the interdisciplinary practical problem of the expedient coupling of building's external enclosures. The problem of ensuring the efficiency and safety of building operations while creating favourable conditions in the internal space is considered.

The proposed path is aimed at reducing the energy consumption of buildings, which leads to a decrease in greenhouse gas emissions into the atmosphere – and so to a decrease in the rate of warming of the global climate of our planet.

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In particular, the task of increasing the energy efficiency of buildings is being solved in order to provide the required internal microclimate with lower energy consumption.

The energy efficiency and microclimate of a building primarily depends on the characteristics of the building enclosures. In areas with high seismicity, buildings have special design solutions such as a reinforced concrete frame. In many cases, such a frame significantly reduces the heat-shielding capacity of the building envelope. In this article, the authors for the first time considered the multidisciplinary problem of ensuring the required level of energy efficiency, seismic resistance and microclimate of low-rise residential buildings. This task is relevant in many regions, where, on the one hand, the climate features require large energy consumption for the formation and maintenance of comfortable conditions of the building microclimate, and on the other hand, there is a high seismic hazard. This problem requires a mutually agreed consideration in the planning, design, reconstruction and operation of buildings in many parts of the world; in particular, in the vast regions of the Russian Federation and the mountainous countries of Central Asia.

The article [1] presented scientific and technical foundations of mutually coordinated provision of energy efficiency and seismic resistance of low-rise civil buildings. Studies of the features of construction of seismic resistant and energetically passive houses are rare [2].On the other hand, many authors note the importance of implementing constructive solutions to achieve the required thermal protection [3, 4], optimization [5] and increase [6-8] of the energy efficiency of buildings. It is especially important to solve the problems of ensuring energy efficiency of external walls [4, 5, 7, 9].

We used software packages for numerical methods of research, calculation and visual presentation of results. The program LiraCAD 2013 on a seismic load intensity of 9 points on the MSK-64 scale was used to calculate the seismic resistance of a two-story residential building with a monolithic reinforced concrete frame structure and brick-infill exterior walls.

To determine the two-dimensional temperature distribution at the cross section of the junction of the exterior wall with the building covering, the ArchiCAD 20 software package was used. In this case, it was found, that at the specified junction area, such interior surfaces of the corners are observed on which the temperature is lower than the one required by the microclimate standards.

As a result of the adopted method of visual inspection of existing buildings, it was established that, due to the indicated lower temperature, mold appears in this intersecting area of the interior surfaces of the exterior wall and attic floor.

In regions with high seismicity hazard, where scaffolding is less accessible, low-rise civil buildings are constructed from a monolithic reinforced concrete frame structure and brick-infill exterior walls. A representative of such buildings is a two-story residential building, a fragment of the appearance of which is shown in Fig. 1, and Fig. 2 is a photo of mold in the junction area of the exterior wall and attic floor surface.

Fig. 1. Exterior view of a two-story residential building at address: 56, Bishkek, Kyrgyzstan

Fig. 2. Photo of mold in the junction area of the exterior wall and attic floor surface

Such frame buildings are widespread in rural areas and small towns of Central Asia where, for example, more than half of the population of Kyrgyzstan and Tajikistan lives. Consequently, a large number of residential and public buildings in high seismic hazard regions have problems associated with the presence of iron-concrete elements in the exterior wall, which are thermal bridges [6].

The authors of this article have established that the features of the structural unit of the junction between the exterior wall and the attic floor have been not widely studied from the standpoint of ensuring the standard indicators of energy efficiency and the microclimate of the building. The inner corner area of this junction is exposed to low outside air temperatures, both from the walls and from the floor. In addition, this angle is formed by reinforced concrete elements with high thermal conductivity. Accordingly, two-sided intense cooling of the corner zone is observed.

Field surveys of residential buildings showed mold growth at the intersection zone of the inner surfaces of the outer walls and the attic floor. It established that mold appears (see Fig. 2) even in cases when the temperature and relative humidity of the air are near the standard values. The main reason for mold growth is the low temperature and high humidity of building paint and plaster.

We studied a two-story occupied house without thermal insulation (as in Fig. 1) in Khujand, Tajikistan, with a total area of 140.2 m^2.The documentation for the development and design of this building's reconstruction showed that the thermal insulation of the building enclosure will have a gap at the junction of the exterior wall and the attic floor (Fig. 3, a).
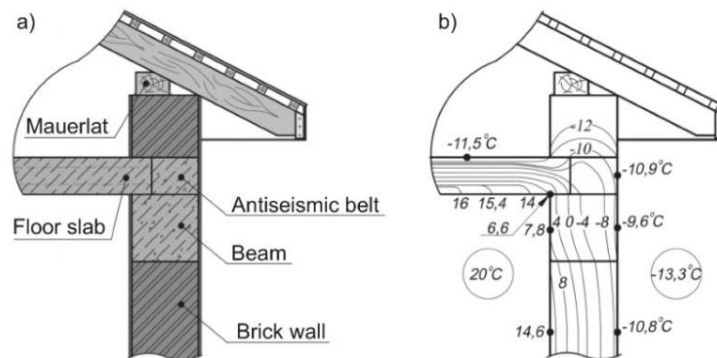

Fig. 3. Coupling of the exterior wall and the attic floor of an existing residential building in Khujand, Tajikistan; a – cross section; b –isotherms in the cross section

The specified gap is associated with the widespread fastening of the Mauerlat wooden structure of the pitched roof to the outgrowth part of the brick wall, the height of which is usually 300-600 mm higher than the upper level of the ceiling (Fig. 3, a). The desire to eliminate the specified gap by completely covering this wall branch with a layer of thermal insulation does not give the desired result, since the position of the Mauerlat does not allow this.

A two-dimensional temperature distribution in the zone of the considered coupling of two enclosures in the form of isotherms (Fig. 3, b) was obtained using the ArchiCAD 20 software package. As can be seen, before the thermal protection reconstruction, the difference between the room air temperature and the temperature on the inner surface of the main surface of the exterior wall and the attic floor is greater than their standard values, equal to 4 °C and 3 °C, respectively (according to SP 50.13330.2012. Thermal protection of buildings. Updated edition of SNiP 23-02-2003). This difference is 5.4 °C for the exterior wall and 4 °C for the attic floor.

At the intersection of the inner surfaces of the two enclosures, the temperature is 6.6 °C, and the specified temperature drop is 13.4 °C. Under these conditions, there is a high probability of moisture condensation and mold growth on these surfaces. It is known that mold growth begins when the temperature on the inner surface of the enclosure is 12.6 °C at an air temperature of 20 °C, its relative humidity is 50% and the humidity of the surface layer of hygroscopic material is about 80% (see SP KR 23-101-2013*. Thermal performance design of buildings).

With the aforementioned data, a structural unit was developed and proposed (Fig. 4, a) for attaching the pitched roof Mauerlat to a monolithic anti-seismic belt.
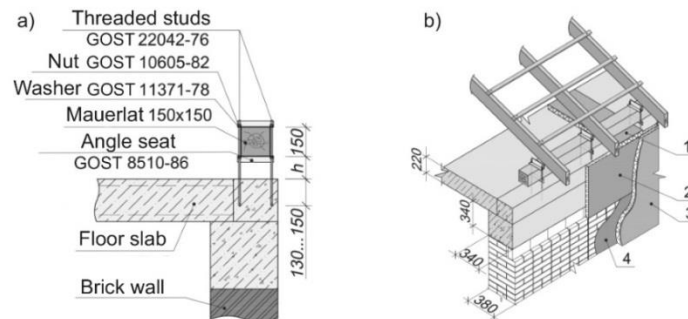

Fig. 4. Constructive solution of the coupling exterior wall and the attic floor: a – structure for the Mauerlat attachment; b – constructive scheme: 1– attic floor insulation; 2 and 3 – additional and main layer of thermal insulation; 4 – plaster

On each pair of steel threaded rods embedded in a monolithic anti-seismic belt, an equal-flange steel angle is put through the holes, the level of which is adjusted using nuts. It serves as a support for the Mauerlat, which is attached from above with a similar steel corner and nuts. The step between these attachment points (Fig. 4, b), the diameter of the pins and the dimensions of the corners are taken depending on the magnitude of seismic, wind and snow loads.

The temperature distributions are studied at the designated coupling of the enclosures where the proposed attachment unit is not used (Fig. 5, a) and used (Fig. 5, b).

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*The authors E. Boronbaev and A. Abdyldaeva are members of the development team of this national code
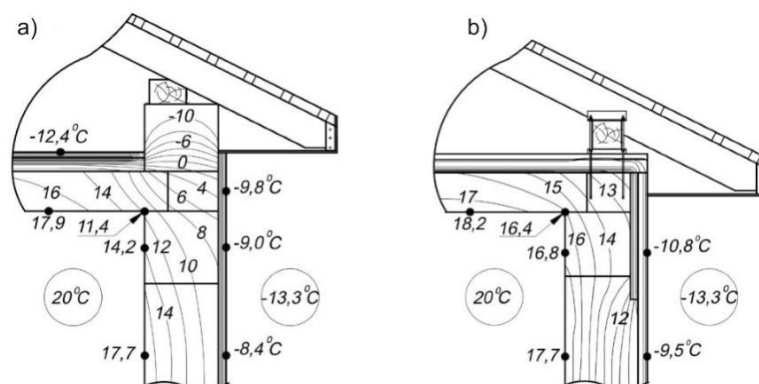
Fig. 5. Temperature distribution on the cross-section of the coupling zone of the exterior wall and attic floor: a – with the main layer of thermal insulation; b – with the main and additional layers of thermal insulation

The thickness of the insulation layers in Fig. 5, made from mineral wool slabs (with a density of 75 kg/m^3 and a thermal conductivity coefficient of 0.04 W/m^2 ºC), was determined in accordance with SP 50.13330.2012 at degree days of the calculated heating period 1984 ºC·day for the city of Khujand. For the exterior wall, the thickness of the thermal insulation layer is 40 mm, and for the attic floor, 70 mm.

It was found that even with the provision of standard thermal protection of both building enclosures, the temperature requirements of SP 50.13330.2012 are not met at the thermal bridge zone. The observed temperature on the corner is 11.4 °C, and the aforementioned required temperature difference is 8.6 °C (instead normative of 4 °C for the walls and 3 °C for the ceiling).

The calculation for the seismic resistance of a monolithic reinforced concrete frame of the two-story building under consideration was carried out (according to the design scheme developed in [1]) using the LiraCAD 2013 program with a seismic load of 9 points on the MSK-64 scale. In this case, it was found that the accepted dimensions of the cross-section of the middle and extreme girders and columns (see Fig. 1) can be reduced to 340x340 mm. Accordingly, with a brick wall of 1.5 bricks, the thickness of the additional layer of thermal insulation of the thermal bridge zone is determined to be 40 mm. With a thickness at the additional and main thermal insulating layers of the exterior wall of 40 mm, with a reduced cross-section of the crossbar and the using of the proposed Mauerlat attachment unit (Fig. 4, b), the temperature values on the inner surfaces (Fig. 5, b) of the junction area correspond to the requirements of SP 50.13330.2012. In this case, the temperature difference on the corner of the wall, equal to 3.6 °C, is less than the required 4 °C.

The values of temperatures achieved on the inner surfaces of the thermal bridges zones and on the main surface of the exterior walls and the attic, above 16.4 °C, provide, firstly, significantly improved conditions of the microclimate of the room by increasing its radiation temperature (according to GOST 30494 - 2011. Residential and public buildings. Parameters of indoor microclimate), secondly, prevents violations of sanitary-hygienic conditions in the premises which occur when mold grows on room enclosures.

The main indicators of practical recommendations on seismic resistance and energy efficiency of low-rise civil buildings in six characteristic settlements of the Russian Federation, Kyrgyzstan and Tajikistan, are presented in the table.

Table. Recommended indicators for typical localities of three countries

Cities	By seismic resistance		According to energy efficiency, thermal insulation layer thickness, mm			
	Point	Column mm x mm	Main layer		Additional layer	
			calculated	accepted	calculated	accepted
Russian Federation						
Krasnodar	8	340x340	62	70	23	40
Magadan	9		134	140	23	40
Kyrgyzstan						
Osh	9	340x340	64	70	23	40
Kyzyl-Jar	8		120	120	23	40
Tajikistan						
Dushanbe	9	340x340	33	40	23	40
Khujand	8		39	40	23	40

For the building under consideration in Khujand, the following has been achieved: 1) improvement of microclimate parameters and sanitary-hygienic conditions; 2) an increase in the economic indicators of construction while reducing the consumption of concrete by 5.3 m^3; 3) energy savings of 117.7 kWh per year. Certainly, the indicated heat energy savings are significantly higher for areas with colder climates.

The results of the authors' research presented above do not contradict the conclusions in works [10, 11] that the heterogeneity of the building envelope leads to a discrepancy between the actual level of thermal protection of modern buildings and regulatory requirements. This circumstance is also observed when solving the problems of seismic resistance of buildings by reinforcing brick walls with composite materials [12] and using a reinforced concrete frame structure [1, 13]. The authors of works [4, 6, 14, 15] similarly established that it is important to study the processes of heat exchange in the zone of thermal bridge areas of external enclosures, which leads to an increase in heat loss of a building.

It should be noted that the results of our research were obtained when considering the influence of elements of seismic resistant monolithic reinforced concrete frame on the energy efficiency of a building, the levels of microclimate and sanitary-hygienic condition in the premises. The mentioned concrete elements of the building enclosure are also considered as thermal bridges.

The analysis of the published works of many authors showed that in modern conditions the results of those studies that are also devoted to solving practical problems to reduce the negative effect of thermal bridges in enclosing structures are of big interest [6, 14, 16, 17]. For the first time, in [16] scientifically and practically substantiated and published both the definition of thermal bridges and their classification, which were presented as architectural, structural, and operational thermal bridges. When optimizing of year-round building's thermal regimes to ensure its microclimate [18], it is required to study the negative impact of thermal bridges on the economic performance of a building in the cold season [16]. To solve such a practically important problem, numerical methods of studying [17] and thermo-graphic visualization of the results [19] are also used. Moreover, the results of the study are based, as in [20, 21], on a graphical representation of the temperature distribution in the cross section of the thermal bridge zone as a set of isotherms.

In the cold period, all three types [16] of thermal bridges cause not only an increase in heat losses, but also deterioration in the microclimate conditions in the corresponding rooms. Such deterioration manifests itself through relatively low temperatures on the inner surfaces of the outer enclosure in the thermal bridge zone.

The authors of works [22-24] also note the significant influence of such local temperatures on the formation of microclimate parameters. The author of the work [25, 26] also notes the need to constantly maintain the regulatory parameters of the microclimate and prevent an increase in the concentration of impurities in the indoor air above the permissible level. Articles [27, 28] also discuss the harmful effects of mold on human health.

Conclusions

1. The solution of a multidisciplinary task to ensure the required energy efficiency, seismic resistance and microclimate of a low-rise frame building made it possible to propose a construction solution for coupling an external brick wall and a reinforced concrete attic floor for reconstruction of existing and the design of new buildings.

2. Expedient solutions are proposed: a) the dimensions of the cross-section of monolithic rein-forced concrete columns and crossbars of the building frame; b) the thickness of the additional layer of thermal insulation of the thermal bridge zone; c) a new construction solution for fixing the pitched roof Mauerlat to the exterior wall seismic belt. Practical recommendations for reducing the negative impact of thermal bridges on the microclimate and energy efficiency of buildings are presented.

3. The recommended constructive solutions made it possible to exclude the causes of violation of sanitary-hygienic conditions in the premises caused by the growth of mold on the inner surfaces of hygroscopic materials of the building enclosures.

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