DOI: 10.23968/2500-0055-2024-9-3-63-74

# REDUCING THE INFLUENCE OF THERMAL BRIDGES IN THE BASEMENT SLAB OF CAST-IN-SITU FRAME BUILDINGS IN EXTREMELY COLD REGIONS

Terentii Afanasevich Kornilov*, Petr Anatolevich Fedotov, Alexey Terentevich Kornilov

M. K. Ammosov North-Eastern Federal University, Russian Federation

*Corresponding author: kornt@mail.ru

**Abstract**

**Introduction.** Heat insulation of multi-story buildings with a reinforced concrete frame on pile foundations under climatic conditions with extremely low outdoor air temperatures is complicated by high air infiltration. When such buildings are used in winter, the most characteristic are temperature regime violations on the first floor. **Purpose of the study:** The study aimed to evaluate various methods to reduce the influence of thermal bridges in the basement floor of a cast-in-situ frame building with pile foundations under extreme climatic conditions. **Methods:** Thermal performance of 3D models of enclosing structures was determined using the certified HEAT3 program. Options of internal and external heat insulation of the basement floor with thermal breaks in the structures were considered. **Results:** As a result of numerical analysis of standard basement floor designs, it was established that low temperature on the inner surface and significant heat losses are associated with the presence of through thermal bridges: reinforced concrete raft — basement slab — column — concrete block masonry. The most effective solution for heat insulation of cast-in-situ frame buildings is external heat insulation of the basement floor with a thermal break in the raft. Compared to the standard solution, heat losses through the corner section of the slab with the offset column are reduced by 33.6 %, and the minimum temperature on the inner surface is higher than the dew point.

**Keywords**: thermal bridge, basement floor, thermal break, column, raft.

## Introduction

Nowadays, the construction of low-energy buildings has become one of the ways to improve the world's environment. Many developed countries have adopted legislative acts and energy saving programs that encourage the construction of energy efficient buildings and introduction of energy saving technologies. The countries of Europe and the United States of America were the first in the world to pay special attention to the issue of energy saving. According to the global ranking of energy-efficient countries published at the end of 2018 by the American Council for an Energy-Efficient Economy (ACEEE), Western European countries are the most advanced and developed in terms of development and application of energy efficiency measures (Castro-Alvarez et al., 2018; Gushchin et al., 2020). Looking forward, Germany is focused on only passive buildings with an energy consumption of less than 15 kW·h/m² or even zero energy consumption.

Energy-efficient buildings are, first of all, characterized by a high level of heat insulation of external enclosing structures. The minimum requirements for heat insulation of external enclosing structures in the regulatory documents of various countries are determined by economic criteria with account for natural and climatic conditions, and, therefore, have different levels. Buildings of any design have thermal bridges that increase heat losses through the enclosing structures. Therefore, one of the basic rules for designing energy-efficient buildings is to reduce the influence of thermal bridges by structural methods and properly take them into account when determining the thermal performance. The development of innovative thermal breaks using advanced heat insulation and structural materials is paramount to reduce the influence of thermal bridges (Alhawari and Mukhopadhyaya, 2018).

Numerous works address mathematical modeling of heat flow through enclosing structures with thermal bridges under steady and unsteady influence of air temperature (François et al., 2019; Fuchs, 2022; Gagarin and Kozlov, 2010; Kang et al., 2021; Kim and Yeo, 2020; Kim et al., 2022b). It should be noted that the thermal performance of thermal bridges in operating buildings may differ from the design performance of thermal bridges obtained theoretically due to the actual construction conditions. Currently, there are methods available to quantify heat losses of enclosing structures due to thermal bridges inside using IR thermography (François et al., 2019; Kang et al., 2021; Mayer et al., 2021). In sections of enclosing structures with thermal bridges, in addition to increasing heat losses, the temperature on the inner surface decreases, which can lead to condensate formation both inside and on the surface of the structures.

The applicable regulatory documents on heat insulation of buildings employ engineering methods for calculating the reduced resistance of external enclosing structures with account for different

**For citations:** Kornilov, T. A. , Fedotov, P. A. , Kornilov, A. T. (2024). Reducing the influence of thermal bridges in the basement slab of cast-in-situ frame buildings in extremely cold regions. Architecture and Engineering, No 3 (9), pp. 63–74.
DOI: 10.23968/2500-0055-2024-9-3-63-74.

types of thermal bridges. In European countries, standards for thermal bridges are established separately, and in most cases their influence is not fully taken into account in the design of enclosing structures (Citterio, 2008; Gagarin and Dmitriev, 2013; Theodosiou et al., 2021). Modern software suites enable heating and heat insulation analysis of spatial units of building structures under steady and unsteady influence of air temperature.

Currently, the technology of frame construction with the use of cast-in-situ reinforced concrete structures is the most widely used in the construction of multi-story buildings. To ensure heat insulation of such buildings, depending on the climatic region of construction, two external wall options are usually used: a two-layer wall made of concrete blocks with external heat insulation made of mineral wool boards and a ventilated facade or a single-layer wall made of aerated concrete or other lightweight blocks. As for the first type of external wall, numerical and experimental studies have resulted in the development of methods for calculating the thermal performance of ventilated facades, with account for the thermally conductive elements of the cladding support, fasteners of heat insulation boards, air gap, and air filtration (Gagarin et al., 2016; Kornilov and Ambrosyev, 2008; Tusnina et al., 2013).

When using a single-layer external wall, one of the traditional solutions to reduce the influence of thermal bridges is the use of perforations in the reinforced concrete floors around the perimeter of the external walls. Umnyakova et al. (2012) presented the results of evaluating heat engineering homogeneity of external walls in the area of contact with balcony slabs with perforations depending on the thickness of the reinforced concrete slab, dimensions of perforations and the wall. In buildings with a reinforced concrete frame, when single-layer external walls are used, thermal bridges occur at the locations of columns. In this case, partial heat insulation of columns using aerated concrete blocks is suggested for cold regions in China. The results of numerical studies on the effect of thermal bridges in L-shaped and T-shaped aerated concrete wall structures were confirmed by a full-scale experiment (Li et al., 2018b). Additional heat insulation of the outer surface of columns with an EPS plate leads to a greater effect in reducing heat losses (Li et al., 2018a). Unfortunately, these works did not consider the sections of the external wall with columns, including reinforced concrete floors, especially in the corner sections of the building. It is known that at these sections of external walls, the reduced resistance and temperature on the inner surface decrease sharply as the angle between adjacent walls decreases (Ingeli, 2018a, 2018b). Evola and Gagliano (2024) performed numerical and experimental studies of the corner section of a lightweight block wall with a reinforced concrete column and established the thermal bridging effect.

In Russia, longitudinal perforation with a thermal liner made of polystyrene foam board in a reinforced concrete slab is most commonly used to reduce the impact of the balcony slab. In European countries and South Korea, load-bearing thermal breaks are used. Umnyakova et al. (2013b) presented the results of studies on the thermal performance of a section of a balcony slab and cast-in-situ external wall with perforations in the slab and installation of a Schöck (Germany) load-bearing heat insulation element. Umnyakova et al. (2013a) also demonstrated the effectiveness of using a load-bearing heat insulation element in the joints of a cast-in-situ reinforced concrete slab and balcony slab, external wall.

Numerical studies of a concrete balcony slab–wall section were conducted in South Korea by applying two types of thermal breaks using extruded polystyrene: TB — stainless steel reinforcement and TB-GFRP — glass fiber reinforcement. It was shown that the fragments of the balcony slab with the TB-GFRP thermal break in case of external wall heat insulation and floor heating system show the best thermal performance (Zhang et al., 2022). In other heat engineering studies (Kim et al., 2022a), a corner balcony with a thermal break along the long side was considered. In that case, heat losses of a three-story building were evaluated and their general reduction upon the application of thermal breaks in the balcony slabs by 4.5 % was established. In many other studies, based on numerical calculations, the thermal performance of balcony slabs of various designs was determined and the effectiveness of thermal break application was demonstrated (Aghasizadeh et al., 2022; Alhawari and Mukhopadhyaya, 2018).

The northern climatic zone of the Russian Federation is characterized by extreme climatic conditions with outdoor air temperatures below –40 °C for 50–60 days and permafrost soils. Under these conditions, multi-story buildings are mainly constructed using a cast-in-situ reinforced concrete frame on pile foundations with a ventilated under-floor space to preserve permafrost. The piles in a cluster under the frame column are united by a cast-in-situ reinforced concrete structure — a raft. Heat insulation of buildings is complicated by high air infiltration during the period of extremely low outdoor air temperatures. In the basement part of cast-in-situ frame buildings, there are extensive thermal bridges: reinforced concrete columns, rafts and piles, which significantly increase heat losses through the basement floor. Several studies (Kornilov and Vasilyeva, 2022; Kornilov et al., 2021) showed that particularly in these sections, the temperature regime of buildings is not observed and at the design outside air temperature of –52 °C, the temperature on the inner surface of the corner joints of external walls is lower than the dew point.

High air infiltration in winter especially affects the heat insulation of the basement part of buildings on pile foundations. For example, for the design outside air temperature $t_{ext}$ = –52 °C, the difference in air pressure on the outer and inner surfaces of the enclosing structures on the first floor of a 9-story and 16-story buildings is $\Delta p$ = 72.0 Pa and $\Delta p$ = 116.9 Pa, respectively. Nowadays, mostly 16-story frame cast-in-situ buildings are being constructed in Yakutsk. The experience of operating such buildings showed that high air infiltration of more than 110 Pa in winter and the presence of defects in the heat insulation of the basement floor leads to intensive penetration of cold air (Kornilov and Vasilyeva, 2022).

The studies aimed to evaluate methods to reduce the influence of thermal bridges in the basement floor of multi-story buildings with a reinforced concrete frame and pile foundations under extreme climatic conditions. In standard buildings, the basement floor is heat insulated from the inside for ease of installation. With this solution, there are extensive thermal bridges in the basement slab sections: reinforced concrete columns, rafts, and the slab itself, which are load-bearing structures. In case of 16-story buildings with a reinforced concrete frame, the columns have a cross-section of 600×600 mm, the size of the raft for clusters of four piles can reach 2500×2500 mm in plan and up to 1200 mm in height. Since the under-floor space of buildings on pile foundations is ventilated, then the cold space is located in the middle of the building on the bottom side, at the edges of the building on the bottom side and the outer side of the wall, and in the corner sections of the basement floor on three sides. All these structural features of cast-in-situ frame buildings with pile foundations pose difficulties in ensuring heat insulation of buildings under extreme climatic conditions. In case of long-lasting outside air temperatures below –40 °C, a massive reinforced concrete raft with high thermal conductivity and inertia essentially represents a cold storage.

## Methods

To evaluate the proposed methods of thermal bridge reduction for the basement floor of buildings with a reinforced concrete frame, the thermal performance of structural fragments was determined using the certified HEAT3 program. This computer program is designed for 3D modeling of steady and unsteady heat transfer processes. The software has been tested for compliance with EN ISO 10211–2022. In thermal bridge modeling, the design outside air temperature of the coldest five-day period with a probability of 0.92 was assumed to correspond to the climatic conditions of Yakutsk (Russia): $t_o$ = –52 °C, while the indoor air temperature was as follows: $t_i$ = +21 °C. Heating and heat insulation analysis was performed for 3D models of enclosing structures.

Thermal bridge reduction methods are evaluated based on the following thermal performance:

- minimum temperature on the inner surface of the enclosing structures (in this case, the minimum temperature on the floor);
- minimum distance from the floor surface to the zero temperature line inside the structure;
- heat losses through a fragment of the enclosing structure.

The dew point on the inner surface of the enclosing structures of residential buildings at design parameters of climate in Yakutsk and internal humidity of 50 % is 10.2 °C. The second characteristic is very important for comparative evaluation from a practical point of view. The close proximity of the zero temperature line to the floor surface leads to an unfavorable situation in the event of the slightest installation errors under conditions of increased air infiltration. Therefore, in climatic conditions with extremely low outside air temperatures, all connections of external enclosing structures must have high operational reliability.

- **Standard solutions**

At first, standard solutions of basement floor fragments in the outermost rows with an external wall, a corner basement floor section with a column and external wall are considered as models. In the outermost axes, there may still be structural solutions of the basement floor with a balcony. This case is not considered in this research, given that the first floor of multi-story buildings traditionally houses public spaces where balconies are not provided. The paper does not present the results of heat engineering studies on a basement floor section with a column in the middle rows, where the temperature regime is more favorable than at the edges of the building. For convenience of analysis, let us designate the row section of the basement floor with a column and external wall as type A, and the corner section of the basement floor with a column and two adjacent walls as type B (Fig. 1).

In all models, the reinforced concrete columns are assumed to be 600×600 mm in cross-section, the reinforced concrete raft connecting the piles is 1800×1800 mm in plan and 1200 mm in height. The thermal conductivity coefficient of reinforced concrete structures is $\lambda$ = 1.92 W/(m·°C). The characteristics of the other materials of the external wall and basement slab are taken in accordance with Russian standards for heat insulation of buildings (Table 1). Taking into account the materials used, the thermal resistance of the flat part of the external wall is 5.26 ($m^2$·°C)/W, and that of the basement slab is 7.74 ($m^2$·°C)/W, which is higher than the standard values for Yakutsk.

Fig. 1 shows that in standard designs of the basement slab with internal heat insulation, there are through thermal bridges in reinforced concrete elements with high thermal conductivity, occurring in

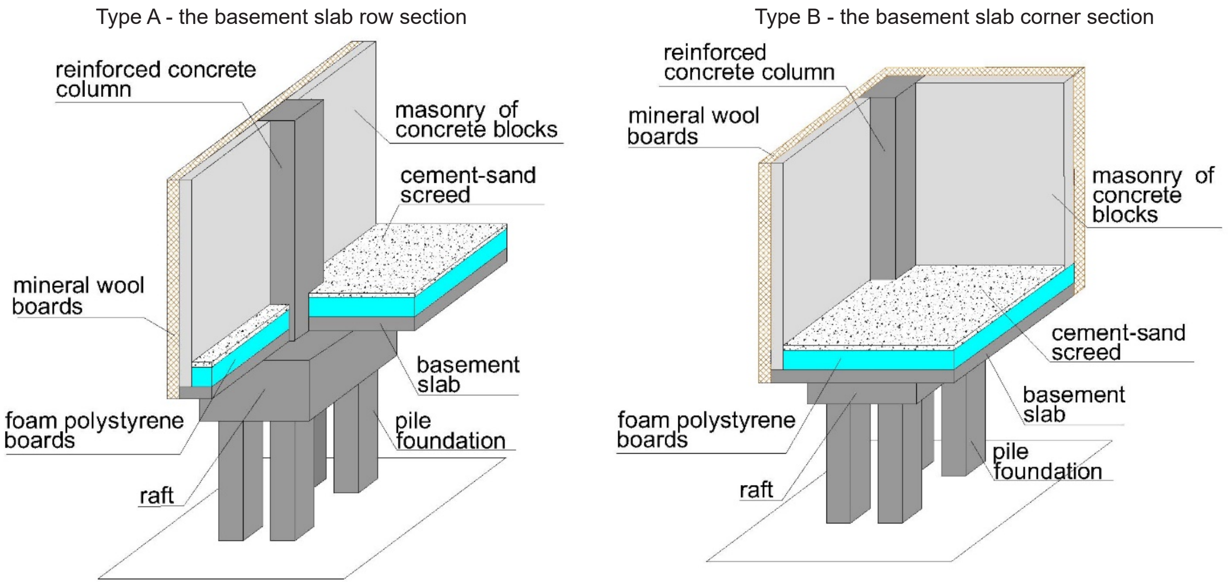


Fig. 1. Standard basement slab designs

Table 1. **Characteristics of materials for standard external wall and basement slab designs**

| **Structure** | **Material** | **Density, kg/m$^3$** | **Thickness, mm** | **Thermal conductivity, W/(m·°C)** |
|---|---|---|---|---|
| External wall | Cement-sand mortar plastering | 1800 | 20 | 0.76 |
| | Concrete block masonry | 1800 | 200 | 0.64 |
| | Mineral wool boards | 100 | 200 | 0.042 |
| Basement slab | Cement-sand screed | 1800 | 60 | 0.76 |
| | Foam polystyrene boards | 35 | 300 | 0.040 |
| | Reinforced concrete slab | 2500 | 220 | 1.92 |

the following sequence: raft – basement slab – column and concrete block masonry. In buildings with a reinforced concrete frame, the use of concrete blocks as the base of the external wall leads to the rupture of thermal protection. These thermal bridges have a particular adverse effect in the corner sections of the basement floor where two adjacent external walls are connected with the column and cold space is located on three sides (Fig. 1, type B).

- **Energy-efficient solutions**

The basic rule for reducing the influence of thermal bridges is to create thermal breaks using efficient heat insulation materials. With this in mind, the authors of the paper developed methods of constructing a basement floor with a column over cold and ventilated under-floor spaces and obtained corresponding patents. The idea is to install a thermal break made of extruded polystyrene foam between the reinforced concrete raft and the basement slab. Such a structural solution of the frame is quite possible if the load-bearing capacity of the reinforced concrete basement slab is ensured. In this case, the column is continuous and rests on the raft, which combines all the piles into a single cluster.

When a thermal break is made in the raft, there are two options of basement floor heat insulation: internal and external. It should be noted that labor intensity of installation for internal heat insulation is much lower than that for external heat insulation under the basement slab in constraint environment.

In case of internal heat insulation of the basement slab, it is suggested to use polystyrene foam boards as individual layers (Table 2). In case of internal heat insulation, all that is left to do is to solve the issue of thermal bridging occurring in areas where the concrete block masonry rests on the basement slab. Here, two options are possible to reduce the influence of this thermal bridge:

1. Types A-1 and B-1. Use of a perforated beam with a thermal insert made of extruded polystyrene foam instead of the first row of concrete block masonry (Patent RU117943U1 (Danilov et al., 2012) obtained by one of the authors). The perforated beam can be either cast-in-situ or prefabricated. The width of the beam should be equal to the width of the concrete block masonry, i. e., 200 mm. The thermal insert is made of 200 mm thick extruded polystyrene foam. The beam supports are spaced at 1500 mm. At the wall-column junctions, the beam has a cantilever, which reduces the influence of thermally conductive elements — beam supports (Fig. 2).

Table 2. **Characteristics of the materials for the proposed solutions for the internal and external heat insulation of the basement slab**

| Type of heat insulation | Material | Density, kg/m$^3$ | Thickness, mm | Thermal conductivity, W/(m·°C) |
|---|---|---|---|---|
| Internal | Cement-sand screed | 1800 | 60 | 0.76 |
| | Foam polystyrene boards | 35 | 300 | 0.040 |
| | Reinforced concrete slab | 2500 | 220 | 1.92 |
| External | Cement-sand screed | 1800 | 60 | 0.76 |
| | Reinforced concrete slab | 2500 | 220 | 1.92 |
| | Mineral wool boards | 125 | 300 | 0.042 |

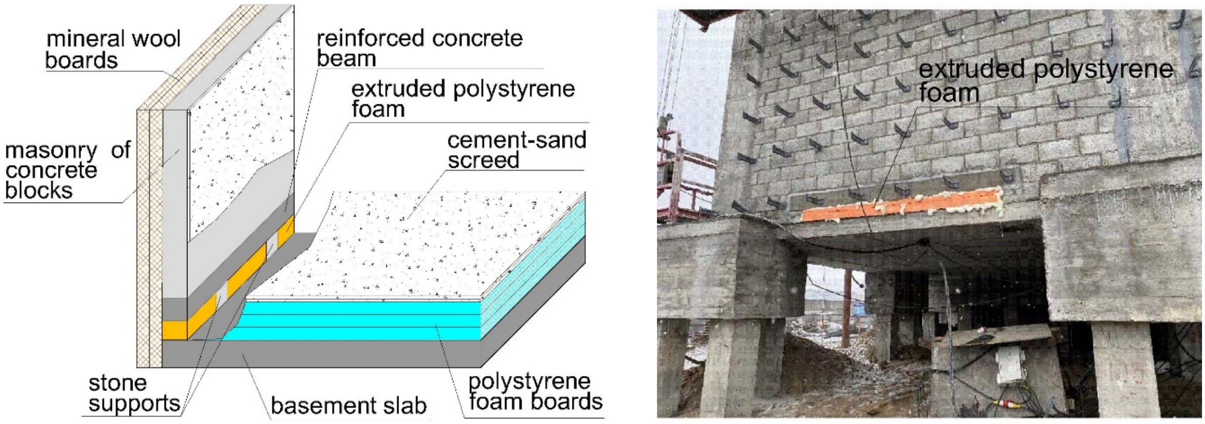


Fig. 2. Thermal break in masonry with the use of a perforated beam

2. Types A-2 and B-2. Use of lightweight blocks, e. g., polystyrene concrete blocks as the first row of wall masonry (Patent RU170253U1 (Kornilov et al., 2017) obtained by one of the authors). Polystyrene concrete blocks with a density of 500 kg/m$^3$ have a thermal conductivity coefficient of 0.14 W/(m·°C). It is recommended to use blocks of 200×300 mm cross-section. This ensures an L-shaped connection; the joint between the lightweight masonry blocks and the end of the heat insulation boards is covered by the top layer (Fig. 3).

3. Types A-3 and B-3. External heat insulation of the basement floor from the bottom side with thermal breaks in the raft ensures the continuity of thermal protection (Patent RU2780187C1 (Kornilov et al., 2022) obtained by the authors). For external heat insulation of the basement floor, mineral wool boards with a density of 90–125 kg/m$^3$ and a tensile strength perpendicular to the front surfaces of not less than 15 kPa should be used. The external heat insulation layer is recommended to be made of mineral wool boards with a laminated surface or to be covered

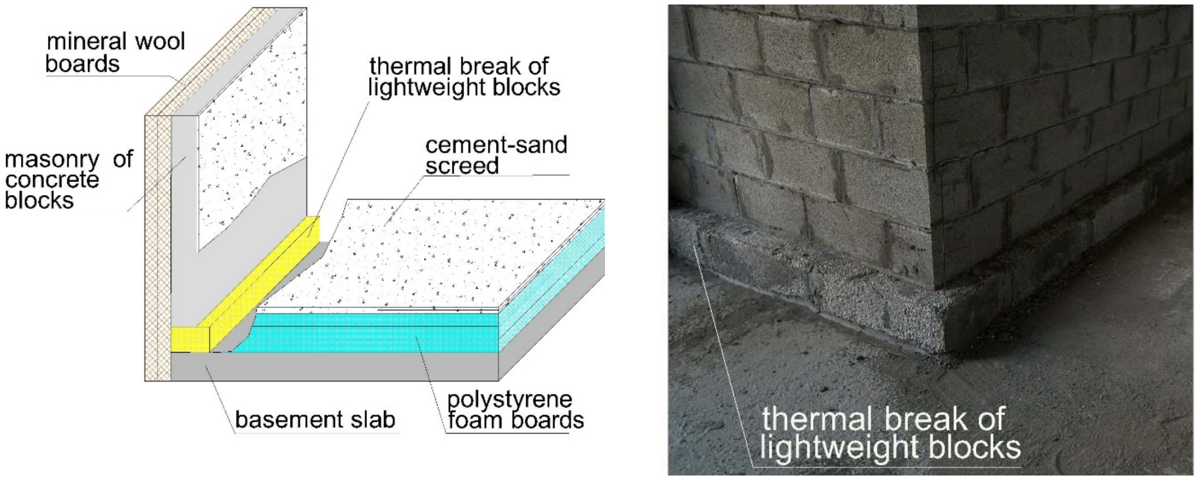


Fig. 3. Thermal break in masonry with the use of lightweight blocks

with a non-combustible water- and wind-proofing membrane. To ensure the integrity of the corner joint between the external heat insulation of the wall and the basement slab, galvanized wire mesh should be fixed in this area (Fig. 4).

Table 2 lists the materials used for the heat insulation of the basement slab. The fragments of the basement slab with internal and external heat insulation analyzed in the paper are summarized in Table 3. All the considered fragments of the enclosing structures have a thermal insert between the raft and the basement slab made of extruded polystyrene with a density of 30 kg/m$^3$ and thermal conductivity coefficient $\lambda = 0.030$ W/(m·°C). Extruded polystyrene is also used in the perforated wall beam.

## Results

- **Standard solutions**

In the middle part of a cast-in-situ frame building, the heat flow passes through the column to the raft, which form a through thermal bridge (Fig. 5A). In the outermost row sections of the basement floor, the heat flow (in addition to the column with the raft) also passes through the concrete block masonry, but with less intensity (Fig. 5B). In this section of the basement floor, the minimum temperature is observed in the corner area between the column, wall and floor and amounts to +5.59 °C, which is lower than the dew point (Table 4, type A).

The worst situation is observed in the corner section of the basement slab with the column. In this section, the minimum floor temperature occurs in the corner between the column and the external wall and has a negative value of –1.52 °C, which is significantly below the dew point. The zero temperature line is 60 mm from the floor surface, i. e., under the cement-sand screed (Table 5, type B). Such a temperature regime on the inner surface of the enclosing structures in the corner section of the basement floor is due to not only the influence of thermal bridges but also the presence of cold space on three sides.

To determine the significance of thermal bridges, the thermal performance of the corner section of the standard basement slab (Type B) was determined depending on the size of the column or raft cross-section. The following variable cross-sections were assumed for the calculations:

- columns of 0.3×0.3 m, 0.4×0.4 m, 0.6×0.6 m, and 0.8×0.8 m, with a fixed raft cross-section of 1.8×1.8 m;

- raft of 1.5×1.5 m, 1.8×1.8 m, 2.2×2.2 m, and 2.5×2.5 m with a fixed column cross-section of 0.6×0.6 m;

As a result of heating and heat insulation analysis, it was found that the thermal protection of the corner section of the basement slab is mostly affected by

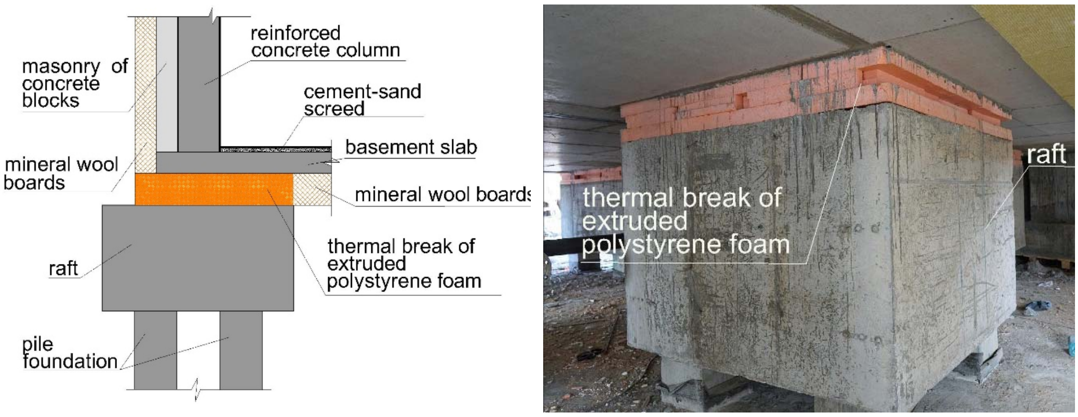


Fig. 4. External heat insulation of the basement slab with a thermal break in the raft in the section of the slab with a column of the outermost rows

Table 3. **Energy-efficient solutions for the basement slab with a column in the outermost axes in the row (A) and corner (B) sections**

| Type | Heat insulation of the basement slab | Thickness of the basement floor heat insulation layer, mm | | Thickness of the thermal break in the masonry wall, mm | Thickness of the thermal break in the raft, mm |
|---|---|---|---|---|---|
| | | Polystyrene foam | Mineral wool board | | |
| A-1<br>B-1 | Internal | 300 | | 200<br>(perforated beam) | 100 |
| A-2<br>B-2 | Internal | 300 | | 200<br>(lightweight block) | 100 |
| A-3<br>B-3 | External | - | 300 | - | 300 |

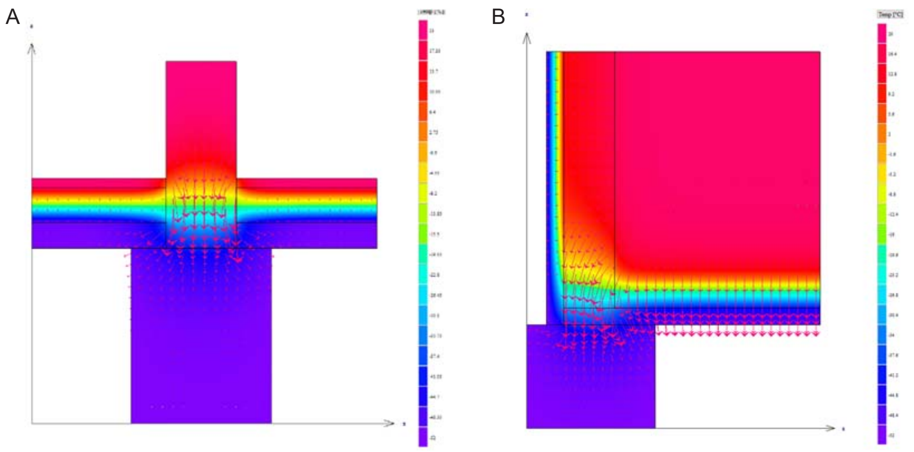
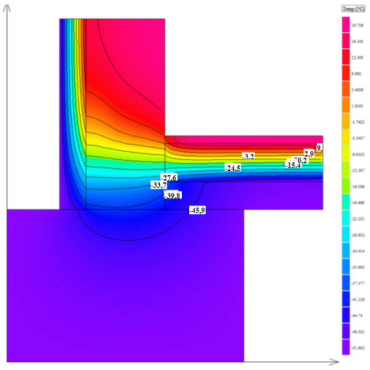
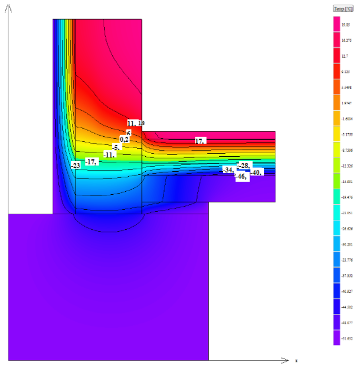
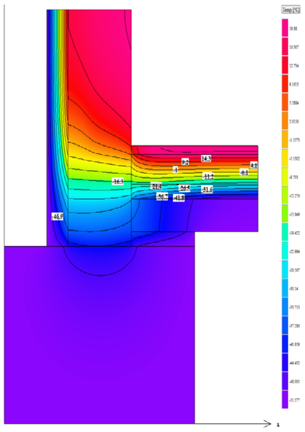
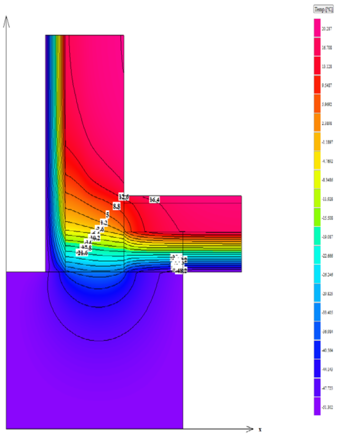


Fig. 5. Heat flow diagrams for the standard rafts and basement slab with a column of the middle (A) and outermost (B) rows

Table 4. **Results of heat transfer modeling in the basement slab row section**

| **Temperature distribution in the vertical section along the inner surface of the wall** | |
|---|---|
| Type A, standard: $t_{min}$ = +5.59 °C; L = 100 mm | Type A-1: $t_{min}$ = +6.82 °C; L = 150 mm |
|  |  |
| Type A-2: $t_{min}$ = +6.00 °C; L = 155 mm | Type A-3: $t_{min}$ = +11.88 °C; L = 340 mm |
|  |  |

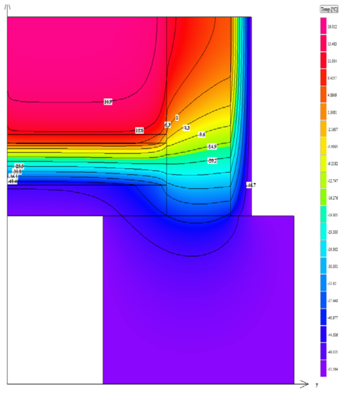
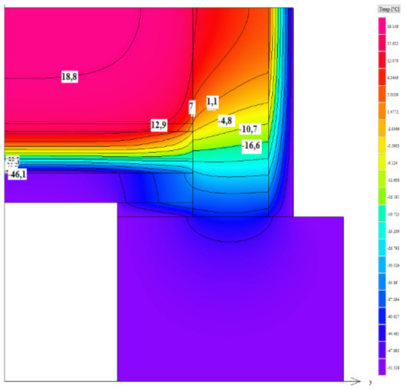
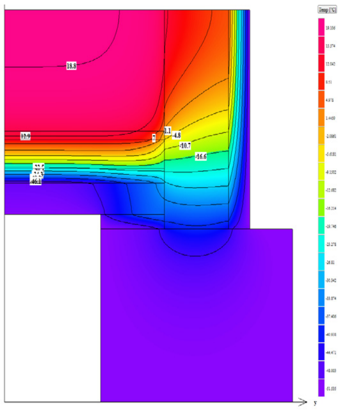
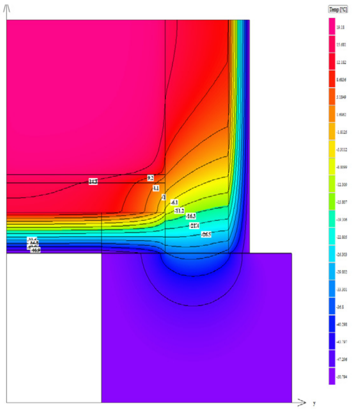
L — the distance from the inner corner of the structure to the zero temperature line

the size of the column cross-section. When the column cross-section is changed from 0.3×0.3 m to 0.8×0.8 m, the minimum floor temperature decreases from +0.2 °C to –2.88 °C, and heat losses increase by 37.0 % (Fig. 6A).

In standard designs, the reinforced concrete raft is completely in the cold zone and freezes through the entire volume, therefore, an increase in the cross-section results in a slight increase in the minimum floor temperature within 1 °C and a decrease in heat losses by only 3.9 % (Fig. 6B).

Thus, in standard basement floor designs, in all areas under consideration, the temperature regime does not meet the regulatory requirements and the

Table 5. **Results of heat transfer modeling in the basement slab corner section**

| **Temperature distribution in the vertical section along the inner surface of the wall** | |
|---|---|
| Type B, standard: $t_{min}$ = –1,52 °C; L = 60 mm | Type B-1: $t_{min}$ = +0.13 °C; L = 100 mm |
|  |  |
| Type B-2: $t_{min}$ = +0.25 °C; L = 170 mm | Type B-3: $t_{min}$ = +4.8 °C; L = 320 mm |
|  |  |

L — the distance from the inner corner of the structure to the zero temperature line

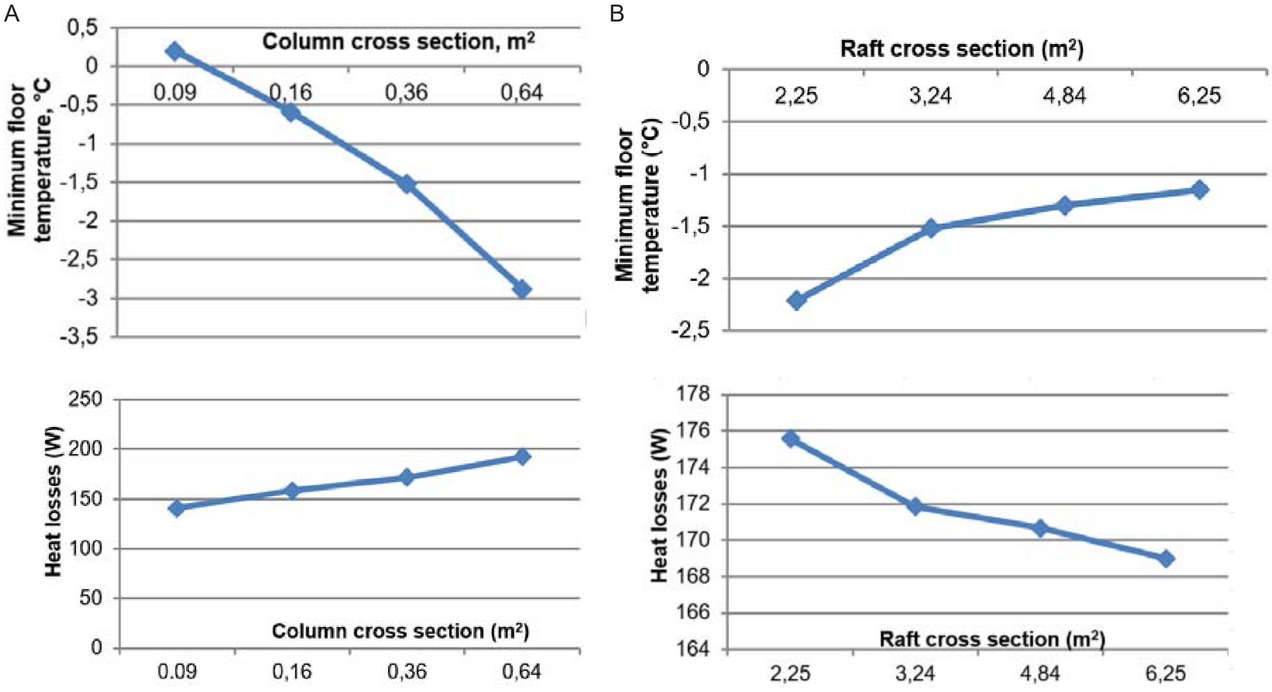


Fig. 6. Graphs of the minimum floor temperature and heat losses through the corner section of the slab as a function of the cross-section of the column (A) and raft (B)

minimum temperature on the inner surface of the enclosing structures is below the dew point.

- **Energy-efficient solutions with internal heat insulation of the basement slab**

In the proposed designs of the basement slab with internal heat insulation, the total heat flow passes through the column and raft. The heat flow through the concrete block masonry is interrupted by a perforated beam (Type A-1) or lightweight block (Type A-2) thermal insert.

In the row section of the basement slab with a column of the outermost rows, the minimum floor temperature increases by only 1.23–0.41 °C compared to the standard solution. The minimum floor temperature $t_{min}$ = +6.82 °C and $t_{min}$ = +6.00 °C when creating a thermal break in the masonry using a perforated beam and lightweight blocks, respectively, is significantly lower than the dew point. The zero temperature lines are 150 mm apart (Table 4, Types A-1 and A-2).

In the corner section of the basement slab with a column, the minimum floor temperature is observed in the corner between the column and the external wall and amounts only to +0.13 °C with the use of a perforated beam and +0.25 °C with the use of a lightweight concrete thermal insert, which is significantly below the dew point (Table 5, Types B-1 and B-2).

Particularly in these sections with the column, the thermal bridge in the form of the column has a significant influence on the temperature regime inside the structure. At a distance of 0.6 m from the column at the junction of the external wall to the basement slab, the minimum floor surface temperature is +12.5 °C when a perforated beam outside the support is used and +12.2 °C in case of a thermal insert made of lightweight concrete.

- **Energy-efficient solutions with external heat insulation of the basement slab**

The external heat insulation of the basement slab, along with the thermal break between the raft and the slab, significantly improves the thermal protection of all structural fragments under consideration. In the outermost sections of the basement slab with the column and the external wall, the thermal break between the raft and the slab completely excludes the concrete block masonry from the thermal bridge, which is confirmed by the heat flow distribution. The thermal protection of the building in these sections has no breaks, which has a positive effect on the temperature distribution inside the enclosing structures.

In the row section of the basement floor, the minimum floor temperature is +11.88 °C, which is higher than the dew point. The zero temperature line is in the external heat insulation layer of the basement floor (Table 4, Types A-3). When external basement floor heat insulation is used, the zero temperature line is shifted outwards and is far away from the inner surface at a distance of 320–340 mm. This is facilitated by the presence of a thermally conductive element in the form of a reinforced concrete slab on the inner side, which can be clearly seen in the heat flow distribution pattern within the structure (Table 4, Type A-3 and Table 5, Type B-3).

In the problematic corner section of the basement floor with the column and adjacent external walls, the minimum floor temperature rises to +4.80 °C, which is significantly higher compared to the temperature on the inner surface of the standard design. However, this temperature value is below the dew point. In the corner section of the basement floor, the presence of a through thermal bridge in the form of a reinforced concrete column with a cross-section of 600×600 mm has a negative impact on the temperature regime. The zero temperature line is at a significant distance from the floor — 320 mm (Table 5, Type B-3).

**Discussion**

The results of heat transfer modeling in different designs of basement slab sections showed that the use of a thermal break between the raft and the basement slab is crucial for reducing heat losses through the basement floor. In case of internal heat insulation of the basement slab, the formation of thermal breaks in the raft and wall masonry does not lead to a significant improvement in thermal protection. Compared to the standard design, heat losses through the row section of the basement floor with the column and the external wall are reduced by only 5.1–14.3 %, through the corner section — by 4.1–13.9 % (Fig. 7).

The use of external heat insulation of the basement slab together with the thermal break in the raft significantly reduces heat losses through all the sections considered. Compared to standard solutions, heat losses are reduced (Fig. 7):

- through the row section of the slab with the column of the outermost rows and the external wall — by 20.9 %;
- through the corner section of the slab with the column of the outermost rows and two adjacent walls — by 33.6 %.

At the design outside air temperature of –52.0 °C, the minimum temperature in the corner section with the use of external heat insulation of the basement floor and a thermal break in the raft is significantly lower than the dew point, which results in condensate formation (Table 5, Type B-3). To improve the situation, the option of shifting the column from the edge of the basement slab inward was considered. In this case, the thermal bridge in the form of a reinforced concrete column is completely eliminated in the corner area. When the column is displaced by 600 mm, the temperature on the floor in the corner between the adjacent external walls is $t_{1min}$ = +13.6 °C, the temperature in the corner between the column

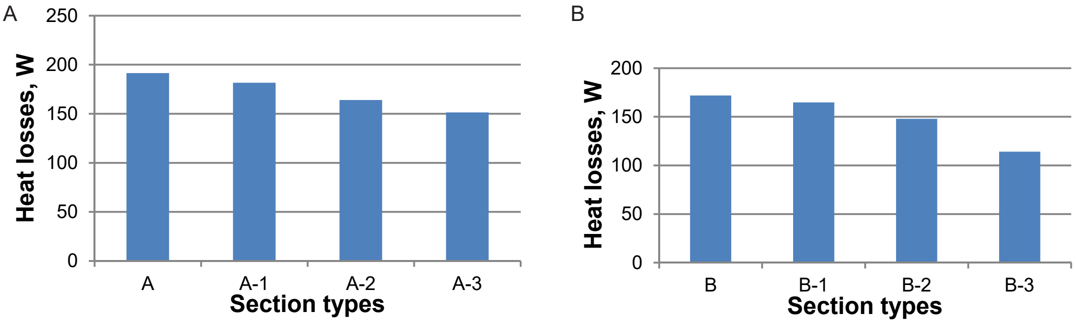
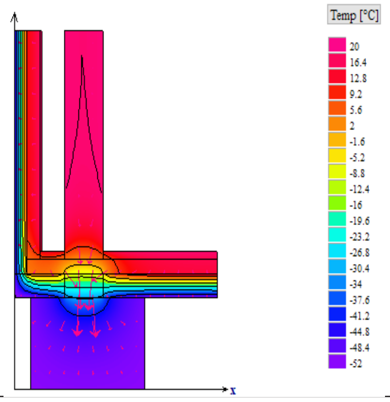
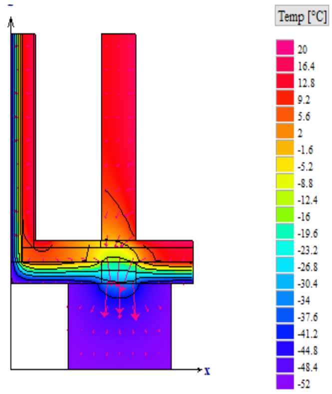


Fig. 7. Heat losses through the section of the slab with the column of the outermost rows (A) and the corner section of the slab (B)

Table 6. **Results of heat transfer modeling in the corner section of the basement slab with the column displacement from the edge of the basement slab**

| Temperature distribution in the vertical section along the inner surface of the wall | |
|---|---|
| Displacement of 600 mm: $t_{1min}$ = +13.6 °C and $t_{2min}$ = +9.5 °C; L = 350 mm | Displacement of 1200 mm: $t_{1min}$ = +14.8 °C and $t_{2min}$ = +9.6 °C; L = 360 mm |
|  |  |

and the wall is $t_{2min}$ = +9.5 °C, and when displaced by 1200 mm: $t_{1min}$ = +14.8 °C and $t_{2min}$ = +9.6 °C (Table 6).

## Conclusion

The specifics of constructing multi-story cast-in-situ frame buildings in permafrost soils is related to massive thermal bridges in the basement part and cold ventilated under-floor space. In the period of especially low outside air temperatures of –45 °C and below, a significant difference of air pressure on the inner and outer surface of the enclosing structures on the lower floors of more than 100 Pa leads to intensive infiltration processes. As a result of heat engineering analysis of standard design of the basement part of cast-in-situ frame buildings, it was shown that the main cause of low temperature on the inner surface of the enclosing structures is the presence of extensive through thermal bridges: reinforced concrete raft — basement slab — column — concrete block masonry. In this case, the cross-section of the reinforced concrete column has a greater negative effect. There is also a rupture of thermal protection in the connections between the external wall and the basement slab.

To reduce the influence of thermal bridges in the basement part of buildings, several options of structural solutions with internal and external heat insulation of the basement slab were proposed. The results of heat engineering analysis showed that external heat insulation of the basement floor with a thermal break between the raft and the basement slab is the most efficient for thermal protection of cast-in-situ frame buildings on pile foundations. Compared to the standard solutions, heat losses through the row section of the floor with the column of the outermost rows and external wall were reduced by 20.9 %, through the corner section of the floor with the column of the outermost rows and two adjacent walls — by 33.6 %. To improve the temperature regime in the corner section of the basement floor, it is recommended to locate the columns at the ends of the building with the inward displacement from the edge of the slab.

**Funding**: comprehensive research project “Development of scientifically-substantiated solutions in the design, construction, and operation of Arctic settlements meeting modern standards of sustainable development and comfortable living. Stage 1” (SC No. 8019).

**References**

Aghasizadeh, S., Kari, B. M., and Fayaz R. (2022). Thermal performance of balcony thermal bridge solutions in reinforced concrete and steel frame structures. *Journal of Building Engineering*, Vol. 48, 103984. DOI: 10.1016/j.jobe.2021.103984.

Alhawari, A. and Mukhopadhyaya P. (2018). Thermal bridges in building envelopes – An overview of impacts and solutions. *International Review of Applied Sciences and Engineering*, Vol. 9, Issue 1, pp. 31–40. DOI: 10.1556/1848.2018.9.1.5.

Castro-Alvarez, F., Vaidyanathan, S., Bastian, H., and King, J. (2018). *The 2018 International Energy Efficiency Scorecard*. [online] Available at: https://www.aceee.org/sites/default/files/publications/researchreports/i1801.pdf [Date accessed February 18, 2024].

Citterio, M., Cocco, M., and Erhorn-Kluttig, H. (2008). *Thermal bridges in the EBPD context: overview on MS approaches in regulations*. [online] Available at: https://build-up.ec.europa.eu/sites/default/files/P064_EN_ASIEPI_WP4_IP1_p3073.pdf [Date accessed February 18, 2024].

Danilov, N. D., Sobakin, A. A., Semyonov, A. A., and Fedotov, P. A. (2012). *Patent RU117943U1. Wall and monolithic floor covering assembly over cool or ventilated underground*.

Evola, G. and Gagliano, A. (2024). Experimental and numerical assessment of the thermal bridging effect in a reinforced concrete corner pillar. *Buildings*, Vol. 14, Issue 2, 378. DOI: 10.3390/buildings14020378.

François, A., Ibos, L., Feuillet, V., and Meulemans, J. (2019). Building thermal bridge heat losses quantification by infrared thermography. Steady-state evaluation and uncertainty calculation. *Journal of Physics: Conference Series*, Vol. 1343, 012171. DOI: 10.1088/1742-6596/1343/1/012171.

Fuchs, M. (2022). Conductive heat transfer in thermal bridges. *Encyclopedia*, Vol. 2, Issue 2, pp. 1019–1035. DOI: 10.3390/encyclopedia2020067.

Gagarin, V. G. and Dmitriev, K. A. (2013). Consideration of heat engineering heterogeneities in the analysis of thermal protection of enclosing structures in Russia and European countries. *Construction Materials*, No. 6, pp. 14–16.

Gagarin, V. G. and Kozlov, V. V. (2010). Theoretical prerequisites for calculating the reduced resistance to heat transfer of enclosing structures. *Construction Materials*, No. 12, pp. 4–12.

Gagarin, V. G., Kozlov, V. V., Lushin, K. I., and Plyushchenko, N. Yu. (2016). Accounting of heat-conducting inclusions and a ventilated layer when calculating the resistance to heat transfer of a wall with hinged façade system (HFS). *Construction Materials*, No. 6. pp. 32–35.

Gushchin, S. V., Seminenko, A. S., and Shen, C. (2020). Global trends in the development of energy-saving technologies. *Bulletin of BSTU named after V.G. Shukhov*, No. 5, pp. 31–43. DOI: 10.34031/2071-7318-2020-5-5- 31-43.

Ingeli, R. (2018a). *Analysis of atypical thermal bridges by a 3D method*. [online] Available at: https://www.researchgate.net/publication/329916337_Analysis_of_atypical_thermal_bridges_by_a_3D_method [Date accessed February 18, 2024].

Ingeli, R. (2018b). *Detection of thermal bridges in the building*. [online] Available at: https://www.researchgate.net/publication/329916338_Detection_of_thermal_bridges_in_the_building [Date accessed February 18, 2024].

Kang, E., Kim, D., Lee, H., and Yoon, J. (2021). In-situ thermal bridge evaluation of a building using bayesian inference with measured infrared thermography. *Journal of Energy Resources Technology*, Vol. 144, Issue 7, 070905. DOI: 10.1115/1.4052858.

Kim, M.-Y., Kim, H.-G., Kim, J.-S., and Hong, G. (2022a). Investigation of thermal and energy performance of the thermal bridge breaker for reinforced concrete residential buildings. *Energies*, Vol. 15, Issue 8, 2854. DOI: 10.3390/en15082854.

Kim, H., Kim, J., and Yeo, M. (2022b). Thermal bridge modeling according to time-varying indoor temperature for dynamic building energy simulation using system identification. *Buildings*, Vol. 12, Issue 12, 2178. DOI: 10.3390/buildings12122178.

Kim, H. and Yeo, M. (2020). Thermal bridge modeling and a dynamic analysis method using the analogy of a steady-state thermal bridge analysis and system identification process for building energy simulation: methodology and validation. *Energies*, Vol. 13, Issue 17, 4422. DOI: 10.3390/en13174422.

Kornilov, T. A. and Ambrosyev, V. V. (2008). Specifics of ventilated facade operation under conditions of steady low temperature based on the results of a field experiment. *Housing Construction*, No. 1, pp. 32–35.

Kornilov, T. A., Fedotov, P. A., Nazarov, T. A., and Vasilyeva, A. T. (2022). *Patent RU2780187C1. Method for constructing a basement floor unit with a column over cold and ventilated undergrounds*.

Kornilov, T., Fedotov, P., and Nikiforov, A. (2021). Evaluation of the effectiveness of additional thermal insulation of the basement floor of frame-monolithic buildings in extreme operating conditions. *E3S Web of Conferences*, Vol. 263, 04041. DOI: 10.1051/e3sconf/202126304041.

Kornilov, T. A., Kardashevsky, A. G., and Kychkin, I. R. (2017). *Patent RU170253U1. The junction of the building envelope and basement over cold and ventilated undergrounds*.

Kornilov, T. A. and Vasilyeva, A. T. (2022). Heat losses through the coupling of three-layer walls with reinforced concrete floors. *Industrial and Civil Engineering*, No. 8, pp. 25–31. DOI: 10.33622/0869-7019.2022.08.25-31.

Li, B., Guo, L., Li, Y., Zhang, T., and Tan, Y. (2018a). Partial insulation of aerated concrete wall in its thermal bridge regions. *IOP Conference Series: Earth and Environmental Science*, Vol. 108, Issue 2, 022068. DOI: 10.1088/1755-1315/108/2/022068.

Li, B., Guo, L., Li, Y., Zhang, T., and Tan, Y. (2018b). Thermal bridge effect of aerated concrete block wall in cold regions. *IOP Conference Series: Earth and Environmental Science*, Vol. 108, Issue 2, 022041. DOI: 10.1088/1755-1315/108/2/022041.

Mayer, Z., Heuer, J., Volk, R., and Schultmann, F. (2021). Aerial thermographic image-based assessment of thermal bridges using representative classifications and calculations. *Energies*, Vol. 14, Issue 21, 7360. DOI: 10.3390/en14217360.

Theodosiou, T., Tsikaloudaki, K., Kontoleon, K., and Giarma, C. (2021). Assessing the accuracy of predictive thermal bridge heat flow methodologies. *Renewable and Sustainable Energy Reviews*, Vol. 136, 110437. DOI: 10.1016/j.rser.2020.110437.

Tusnina, O. A., Emelianov, A. A., and Tusnina, V. M. (2013). Thermal insulation properties of various ventilated facade systems. *Magazine of Civil Engineering*, No. 8 (43), pp. 54–63.

Umnyakova, N. P., Andreytseva, K. S., and Smirnov, V. A. (2013a). The engineering method of calculating the temperature in the outer wall, monolithic floor and balcony slab interface with use of load-bearing heat-insulating element Shoeck Isokorb. *Building and Reconstruction*, No. 6 (50), pp. 53–64.

Umnyakova, N. P., Egorova, T. S., Andreitseva, K. S., Smirnov, V. A., and Lobanov, V. A. (2013b). New structural solution for the junction of exterior walls with cast-in-situ floor and balcony slabs. *Construction Materials*, No. 6, pp. 28–31.

Umnyakova, N. P., Egorova, T. S., Cherkas, V. E., Belogurov, P. B., and Andreitseva, K. S. (2012). Improving the energy efficiency of buildings by increasing the heat engineering homogeneity of exterior walls in the area of contact with balcony slabs. *Construction Materials*, No. 6, pp. 17–19.

Zhang, X., Jung, G.-J., and Rhee, K.-N. (2022). Performance evaluation of thermal bridge reduction method for balcony in apartment buildings. *Buildings*, Vol. 12, Issue 1, 63. DOI: 10.3390/buildings12010063.

---

# СНИЖЕНИЕ ВЛИЯНИЯ ТЕРМИЧЕСКИХ МОСТОВ ЦОКОЛЬНОЙ ПЛИТЫ КАРКАСНО-МОНОЛИТНЫХ ЗДАНИЙ В ЭКСТРЕМАЛЬНО ХОЛОДНЫХ РАЙОНАХ

Терентий Афанасьевич Корнилов*, Петр Анатольевич Федотов, Алексей Терентьевич Корнилов

Северо-Восточный федеральный университет имени М. К. Аммосова, Российская Федерация

*E-mail: kornt@mail.ru

**Аннотация**

**Введение.** Обеспечение теплозащиты многоэтажных зданий с железобетонным каркасом на свайных фундаментах в климатических условиях с экстремально низкой температурой наружного воздуха усложняется высокой инфильтрацией воздуха. При эксплуатации таких зданий в зимний период наиболее характерными являются нарушения температурного режима на первом этаже. **Цель:** оценка различных методов снижения влияния термических мостов в цокольном перекрытии каркасно-монолитного здания со свайными фундаментами в экстремальных климатических условиях. **Методы:** Теплотехнические характеристики 3D моделей ограждающих конструкций определены с использованием сертифицированной программы HEAT3. Рассмотрены варианты внутренней и наружной теплоизоляцией цокольного перекрытия с термическими разрывами в конструкциях. **Результаты:** В результате численного анализа типовых решений цокольных перекрытий зданий установлено, что низкая температура на внутренней поверхности и значительные тепловые потери связаны с наличием сквозных термических мостов: железобетонный ростверк – цокольная плита – колонна – кладка из бетонных блоков. Наиболее эффективным для тепловой защиты каркасно-монолитных зданий является наружная теплоизоляция цокольного перекрытия с термическим разрывом в ростверках. По сравнению с типовым решением тепловые потери через угловой участок перекрытия со смещенной колонной снижаются на 33,6 %, а минимальная температура на внутренней поверхности выше температуры точки росы.

**Ключевые слова**: термический мост, цокольное перекрытие, терморазрыв, колонна, ростверк.