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HEAT-EFFICIENT SOLUTIONS FOR WALL-BASEMENT SLAB CONNECTIONS IN LIGHTWEIGHT STEEL-FRAMED CONSTRUCTIONS FOR ARCTIC REGIONS

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Abstract

Introduction: In Arctic regions, due to the scattered layout of settlements across vast territories and low population density, combined with logistical and transport difficulties, one of the promising technologies is the construction of rapidly erected buildings based on lightweight steel-framed (LSF) constructions. Thermal protection of such buildings in climatic conditions with design outdoor air temperatures of −44 °C to −58 °C is a relevant and complex challenge, especially due to the presence of thermal bridges in the form of steel profiles. Operational experience with LSF buildings on pile foundations shows that the main problems arise on the ground floor where a ventilated crawl space is used to preserve frozen soil. **Objective**: Development of heat-efficient solutions for wall-basement slab connections in LSF buildings for Arctic regions with extreme climatic conditions. **Methods:** To reduce the impact of thermal bridges in the form of steel profiles at the wall-basement slab connection, the use of thermal break (TB) beams is proposed. Numerical simulations of 3D models of different types of wall-basement slab connections were conducted using the certified HEAT 3 software. The results were compared with typical structures based on minimum interior surface temperature, heat losses, and effective thermal resistance. **Results:** As a result of implementing the new design, the influence of thermal bridges was minimized by shifting the steel profiles into the warm zone, creating a thermal break using beams, and maintaining the continuity of the building's thermal envelope. At an outdoor temperature of −55 °C, the minimum interior surface temperature in the wall-basement slab connections, unlike in typical solutions, exceeds the dew point. Compared to standard solutions, reduced thermal resistance of the external wall-basement slab connection were increased by 8.1 %, and the partition wall-basement slab connection — by 15.4 %.

Keywords: thermal bridge; lightweight steel-framed (LSF) constructions; thermal break; wall-basement slab connection; thermal resistance.

Introduction

The Arctic zone of the Russian Federation is characterized by a high proportion of dilapidated housing and a low level of infrastructure in populated areas (Polovinkin and Fomichev, 2013; Kornilov et al., 2023). For example, in the Arctic regions of Yakutia, 31.7 % of the total housing stock has a deterioration rate of over 65 %. Moreover, the housing stock mainly consists of wooden beam and log houses — 72.67 % of the total (Kornilov et al., 2023). Meanwhile, it is known that thermal energy losses through external enclosing structures are the main ones and account for more than 50 % in the structure of the building's thermal energy costs for heating during the heating period (Vatin et al., 2012; Gorshkov, 2010). Considering these circumstances, the development of the Arctic zone of the Russian Federation and its extreme natural and climatic conditions requires the creation of a comfortable living environment in Arctic settlements. The advancement of construction and the introduction of innovative technologies for house-building are essential conditions for improving the quality of life in Arctic territories and, accordingly, for the effective development of the Arctic. Construction methods must be adapted to the specific features of Arctic settlements: the vast distances between communities, low population density, difficult logistics and transport infrastructure, short building seasons, and the lack of a local construction industry and qualified builders. Under such conditions, one of the most promising approaches for Arctic regions, recognized internationally (Rodrigues et al., 2018; Liang et al., 2022; Santos, 2017), is the construction of low-rise buildings using lightweight steel-framed (LSF) constructions.

The structural basis of LSF technology includes cold-formed steel profiles with open or closed cross-sections, including perforated thin-walled profiles (thermal profiles) with thicknesses up to 3 mm designed to improve thermal performance. The structural solutions of LSF fully align with the concept of dry construction and frame housing. Many researchers (Santos, 2017; Moga et al., 2022; Anpilov et al., 2024; Soares et al., 2014; Soares et al., 2017) note the advantages of LSF: the possibility

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of factory prefabrication, architectural flexibility, combining load-bearing and enclosing functions in thin-walled profiles, and ease of assembly. One study (Soares et al., 2014) highlights the potential for recycling and reusing LSF elements, which reduces the environmental impact when buildings are dismantled at the end of their life cycle. A significant advantage of LSF buildings in remote and hard-to-reach Arctic regions is their transportability and fast, all-season installation (Kornilov et al., 2023). In permafrost conditions, the low weight of LSF buildings allows for the use of screw piles or surface structural foundations (Fig. 1).

At the same time, the main disadvantage of lightweight steel-framed (LSF) buildings is the presence of numerous thermal bridges, represented by the steel profiles (Liang et al., 2022; Anpilov et al., 2024). Multilayer enclosing structures are commonly used to improve thermal performance and reduce the impact of thermal bridges. A large volume of research on various types of LSF envelope assemblies has been conducted under the leadership of Paulo Santos and his collaborators (Santos, 2017; Moga et al., 2022; Soares et al., 2014; Soares et al., 2017; Santos et al., 2014; Roque and Santos, 2017; Santos et al.,2024). In particular, some studies (Soares et al., 2017; Santos et al., 2014) propose the use of phase change materials (PCMs) in the envelope layers of LSF buildings. The use of denser materials in combination with mineral wool — such as gypsum board, oriented strand board (OSB), and expanded polystyrene (EPS) panels in external walls, and a cement-sand screed on the floor — enhances thermal inertia and heat-storage capacity. This approach is especially useful for achieving indoor comfort in warmer climates.

The location of the thermal insulation within an LSF wall directly affects its thermal protection capability. Numerical simulations (Santos et al., 2014; Roque and Santos, 2017; Santos et al., 2024) have shown that for the same total thickness of insulation, the thermal performance may vary significantly depending on where the insulation is placed. The best performance is observed when EPS insulation panels are located on the exterior of the steel-framed wall. Other studies (De Angelis and Serraa, 2013) compare various wall compositions that include combinations of mineral wool, EPS boards, air cavities, the relative position of steel studs, etc. Air cavities used to route utilities may result in free air circulation inside the wall structure if sealing is insufficient, increasing heat losses through convection. Experimental and numerical simulations (Santos et al., 2013) have been conducted to determine the thermal properties of modular wall panels with internal air cavities, both with and without perimeter insulation. To mitigate heat losses from internal convection, Milovanović et al. (2022) recommend to completely fill the space between steel studs with mineral wool, and to install OSB and insulation materials on both sides. Additional modeling of wall connections with ceilings and roofs, taking into account steel columns, confirmed that external insulation significantly reduces the influence of thermal bridges. It is also essential to install reliable vapor barriers on the interior side of the wall to prevent moisture accumulation in the insulation layer (Bessonov et al., 2023). In some cases, the internal space of LSF walls is filled with materials like polystyrene concrete (Leshchenko and Semko, 2015) or foam gypsum (Bulatov et al., 2018).

Studies (Plotnikov, 2016; Sergeev et al., 2018; Petrosova et al., 2013) present the results of research on the influence of perforations in steel studs on the thermophysical characteristics of framed walls. The presence of longitudinal holes with staggered spacing in the web of the profile increases the thermal resistance of the steel stud, which overall leads to a slight increase in the minimum interior surface temperature of the envelope structure. However, even with the use of thermal profiles, to meet the regulatory requirements for single-layer walls in cold regions, the use of additional external insulation remains necessary (Plotnikov, 2016; Sergeev et al., 2018). It should be noted that field experimental

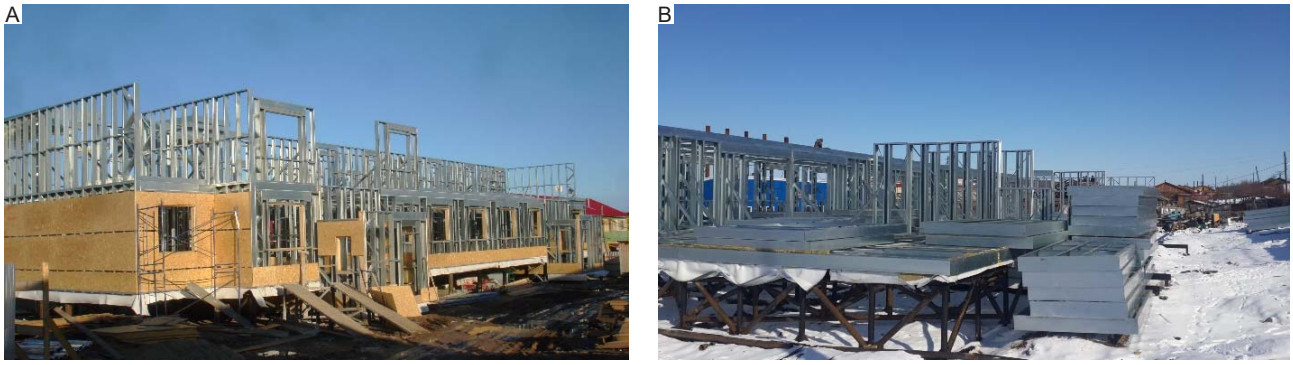


Fig. 1 Installation of the frame for a 16-apartment LSF building in Olenyok settlement (Republic of Sakha (Yakutia)) on screw (A) and pile (B) foundations (from the archive of LLC “Adgezia-MK”)

studies of a residential building with single-layer walls made of thermal profiles, conducted in the Leningrad region (Petrosova et al., 2013), do not fully reflect the thermal protection capabilities of the structure. This is because the tests were performed under relatively mild outdoor temperatures, from −7 °C to −13 °C. In low-rise LSF buildings, most of the defects and weaknesses typically appear during severe cold weather, when high air infiltration occurs.

The arrangement and size of thermal bridges formed by thin-walled steel profiles directly affect the thermal performance of the building envelope. One study (Santos and Poologanathan, 2021) presents the results of simulations of internal partitions and external walls with varying spacing and cross-sectional dimensions of C-shaped steel studs. Laboratory tests of a wall fragment confirmed a strong correlation between experimental values of thermal resistance and results from numerical simulations using ANSYS and TERM software. The greatest impact on the thermal performance of walls is made by the flange width, thickness of steel profiles, and spacing between studs (Santos and Poologanathan, 2021). In some works (Santos and Mateus, 2020; Santos et al., 2023; Santos and Ribeiro, 2021), to reduce the impact of thermal bridges, the use of thermal break (TB) strips — materials with low thermal conductivity — is proposed. These are placed along the flanges of the steel profiles. Numerical and experimental researches (Santos and Ribeiro, 2021) confirmed that for external thermal insulation composite systems (ETICS) with additional EPS insulation, the most effective configuration includes placing TB strips on the external flange of the steel studs. The thickness and thermal conductivity of these TB strips significantly influence the wall's thermal resistance. Moreover, the use of reflective foil insulation on both sides of the wall, in combination with TB strips, has been shown to substantially improve the wall's thermal efficiency (Santos and Ribeiro, 2021).

In the extreme conditions of the Arctic zone of the Russian Federation, the thermal protection of low-rise framed buildings is significantly influenced by increased air infiltration, especially at very low outdoor air temperatures and high wind speeds (Kornilov and Gerasimov, 2015; Kornilov and Nikiforov, 2018). Currently, to improve airtightness, during the construction of low-rise lightweight steel-framed (LSF) buildings in the territory of the Republic of Sakha (Yakutia), a monolithic reinforced concrete basement is used along steel foundation beam (Fig. 2). However, the issue of temperature regime disruption in LSF buildings remains unresolved: the steel stud profiles and the reinforced concrete basement slab create direct thermal bridges. Therefore, the aim of the research is to justify thermally efficient solutions for the wall-basement slab connection of low-rise LSF buildings in Arctic regions with extreme climatic conditions. Numerical simulations will be conducted to evaluate the temperature field and optimize heat loss reduction in the area of the wall-basement slab connection, including the use of thermal breaks to improve thermal efficiency.

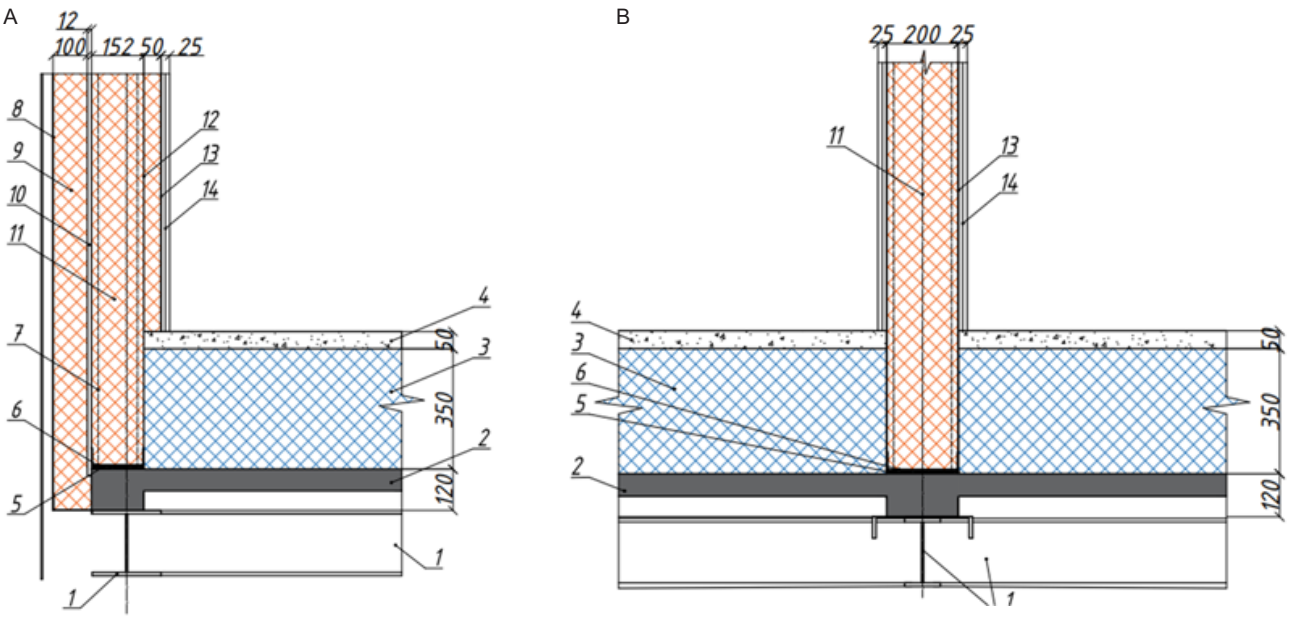


Fig. 2. Typical solutions for joints of external (A) and partition (B) wall-basement slab connections:
1 — foundation steel beams; 2 — reinforced concrete basement slab; 3 — EPS insulation; 4 — cement-sand screed; 5 — polyethylene backing layer; 6 — guide steel profile; 7 — steel stud; 8 — weather barrier; 9 — external insulation; 10 — OSB board; 11 — LSF wall with glass wools; 12 — internal insulation; 13 — vapour barrier; 14 — gypsum plasterboard

Methods

In previous studies (Kornilov and Nikiforov, 2018) the main principles for designing building envelopes made of lightweight steel-framed (LSF) constructions in extreme Arctic climates were outlined: multilayer external walls with ensured airtightness; positioning of steel frame profiles within the warm zone of the building at the wall-basement slab connections; and the use of multi-layer thermal inserts made of low thermal conductivity materials in the wall-basement slab connection. Based on these principles, a new design solution for the wall-basement slab connection has been developed. The main concept involves the use of a thermal break (TB) beam aligned with the axes of internal and external walls. The supports are spaced at 1200 mm intervals in such a way that they do not align vertically with the steel stud profiles, as shown in Fig. 3. Expanded polystyrene (EPS) boards of grade PPS35 or extruded polystyrene boards are used as thermal insulation in the basement slab. The lower layer of thermal insulation (200 mm thick) is laid directly on the reinforced concrete slab, including between beam supports. The ends of the EPS boards along the perimeter must align with the edge of the slab. After the TB beams are installed, steel guide profiles are fastened using anchors through 10 mm thick polyethylene thermal break (TB) strips. Vertical steel stud profiles, typically spaced 600 mm apart according to modular design standards, are mounted onto the guides. The wall is then assembled using a standard LSF framing system with thermal insulation materials. For external walls, additional thermal insulation layers on both sides are provided to ensure thermal protection and fire resistance of the steel frame. The upper insulation layer and the cement-sand floor screed are installed after wall assembly (Fig. 3).

To assess the thermal performance of the proposed LSF wall-basement slab connection nodes, fragment models were created and simulated using the certified HEAT3 software. This software is designed for 3D steady-state and transient heat transfer simulations and complies with EN ISO 10211:2022.

The basic value of the required thermal resistance of the enclosing structure according to SP 50.13330.2024 “Thermal Protection of Buildings” is taken depending on the degree-day of the heating period (HDD). For Arctic regions in the Republic of Sakha (Yakutia), the HDD ranges from 11.088 to 12.581 °C·days/year, according to SP 131.13330.2025 “SNIP 23-01–99. Construction Climatology”. When designing settlements in the Arctic regions of the republic, the required (normative) thermal resistance values are 5.28–5.80 m²·°C/W for walls, and 7.74–8.49 m²·°C/W for roofs and basement slabs. The design outdoor temperature for the coldest five-day period with a 0.92 probability is −44 °C to −58 °C. In the course of numerical analysis of the investigated thermal bridges, the design outdoor air temperature was set to t_{ext} = −55 °C, and the indoor air temperature to t_{int} = +21 °C. The numerical analysis of the study thermal bridges was performed at the calculated outdoor temperature of t_{ext} = –55 °C and indoor air t_{int} = +21 °C. The heat transfer coefficients of the internal and external surfaces of enclosing structure

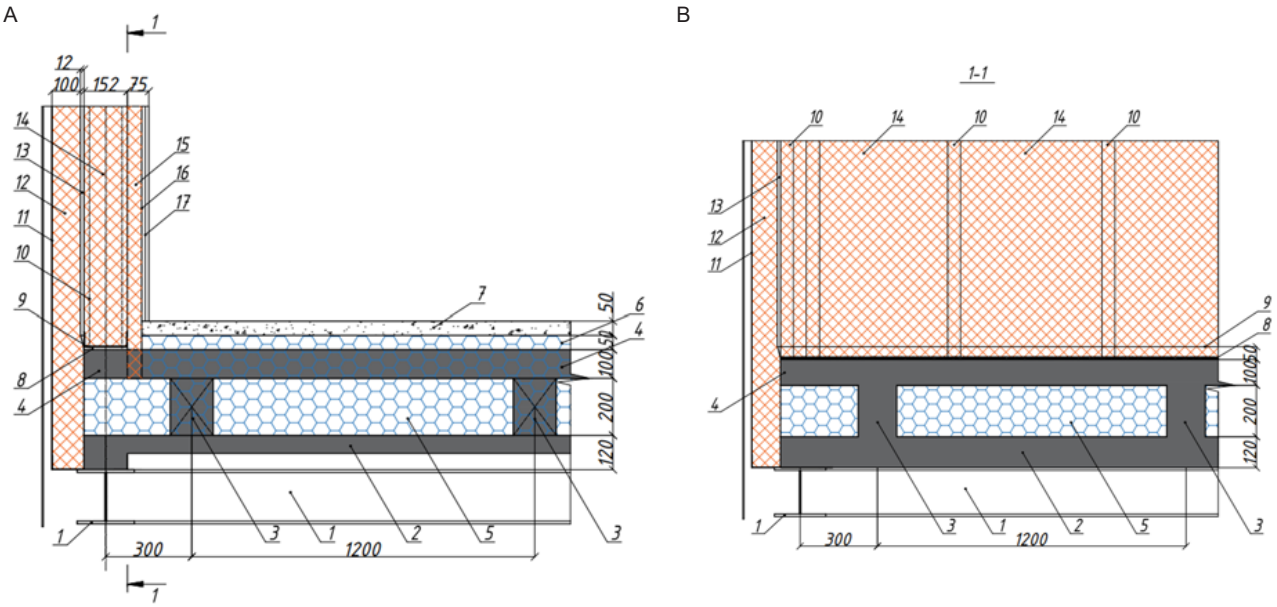


Fig. 3. Heat-efficient solution for the corner section of an external wall-basement slab connection: 1 — foundation steel beams; 2 — reinforced concrete basement slab; 3 — beam supports; 4 — TB beam; 5 — EPS insulation; 6 — top layer of EPS insulation; 7 — cement-sand screed; 8 — polyethylene backing layer; 9 — guide steel profile; 10 — steel stud; 11 — weather barrier; 12 — external insulation; 13 — OSB board; 14 — LSF wall with glass wools; 15 — internal insulation; 16 — vapour barrier; 17 — gypsum plasterboards

units according to SP 50.13330.2024 are adopted as 8.7 W/(m²·°C) and 23 W/(m² ·°C), respectively.

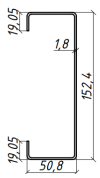
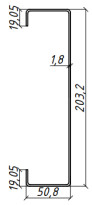
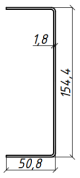
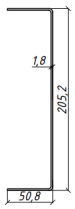
Previous research (Roque and Santos, 2017, Kornilov and Gerasimov, 2016) showed that external thermal insulation on LSF walls is most effective at minimizing thermal bridges created by steel studs. However, to meet fire resistance requirements for steel-framed walls, a 50 mm thick internal insulation layer is also required on exterior walls, and on both sides of interior walls. In the studied structures, S152×51×1.8 steel studs spaced 600 mm apart, and T152×51×1.8 steel guide profiles are used. The thermal resistance of walls and basement slabs was first calculated separately. Material specifications for walls and the basement slab are provided in Table 1.

This study presents numerical simulations of 3D models for the following components:

– external wall-basement slab connection;

– corner section of external wall-basement slab connection;

Table 1. **Characteristics of enclosing structure elements**

Building element	Layer (Internal to External)		Thickness [mm]	λ, W/(m·°C)	Note
External wall	Gypsum plasterboard		12.5	0.25	
	Gypsum plasterboard		12.5	0.25	
	Vapour barrier				Neglected
	Glass wool		50	0.04	
	Glass wool		150	0.04	
	OSB board		12	0.13	
	Glass wool		100	0.04	
	Weather barrier				Neglected
	Vented air layer				Neglected
	Profiled sheet				Neglected
Partition wall	Gypsum plasterboard		12.5	0.25	
	Gypsum plasterboard		12.5	0.25	
	Vapour barrier				Neglected
	Glass wool		150	0.04	
	Vapour barrier				Neglected
	Gypsum plasterboard		12.5	0.25	
	Gypsum plasterboard		12.5	0.25	
Basement slab	Cement-sand backing screed		50	0.76	
	Parchment		1		Neglected
	EPS insulation		350	0.04	
	Vapour barrier				Neglected
	Reinforced concrete slab		63	1.92	
Steel stud profile	S152×51×1.8	S203×51×1.8	1.8	58.0	Steel studs are installed at 600 mm intervals
					
Guide steel profile	T203×51×1,8	T203×51×1,8	1.8	58.0	Guide profiles are installed onto beams using TB strips
					
TB strip	Polyethylene strip 150 and 200 mm wide		10	0.039	TB strip is installed on TB beam
TB beam	Reinforced concrete			1.92	
	Larch wood			0.18	

λ is thermal conductivity for operating conditions A.

– partition wall-basement slab connection;

– external and partition wall-basement slab connection.

The TB beam and their supports can be made of reinforced concrete or wood, specifically Siberian larch. While timber offers better thermal performance, it is less durable than reinforced concrete. In the simulations, TB beams were initially modeled using reinforced concrete.

A comparison of the thermal performance of the proposed structural solutions with typical ones is carried out according to the following criteria:

– minimum temperature on the inner surface of the building envelope (in this case, on the floor);

– heat losses through a fragment of the building envelope;

– reduced thermal resistance R_{eff} (m²·°C/W) of the envelope fragment, which is calculated using the formula:

$$R_{eff} = \frac{t_{int} - t_{ext}}{Q} S,$$

where: t_{int} is indoor air temperature, °C;

t_{ext} is outdoor air temperature, °C;

Q is heat losses through the envelope fragment, W;

S is surface area of the inner side of the envelope fragment, m².

The temperature on the inner surface of the building envelope should be higher than the dew point temperature. At the calculated value of the indoor air temperature in residential premises in winter, t_{int} = +21 °C with a relative humidity of φ_{int} =50 % of the indoor air, the dew point temperature is t_p = +10.2 °C, with φ_{int} = 55 % — t_p = +11.6 °C. In northern areas with particularly low external temperatures, the actual relative humidity in the rooms does not exceed 30 %. With this in mind, the dew point temperature is considered in this paper at a humidity of 50 %.

Results and Discussion

Exterior Wall Made of LSF

In a previously conducted study (Kornilov and Gerasimov, 2016), four types of multilayer walls were analyzed. It was concluded that, from the standpoint of meeting thermal protection requirements for buildings in cold regions and minimizing installation costs, the most optimal solution is an LSF wall with external thermal insulation. In this study, an exterior wall configuration is examined with an additional 50 mm layer of internal thermal insulation to meet fire safety requirements for residential buildings. For comparison purposes, the following wall types were analyzed: an external wall without steel studs, an LSF wall with external insulation, and an LSF wall with both external and internal insulation. To maintain consistency across the models, the total thickness of mineral wool insulation was kept constant at 300 mm.

Field investigations of LSF buildings on pile foundations in extremely cold regions have shown that one of the recurring issues is insufficient fit of mineral wool boards within the profile sections due to flange bends and the protruding ends of self-tapping screws. The resulting voids inside the stud profiles allow cold air to penetrate and circulate freely, as clearly shown in the thermogram (Fig. 4). This problem can be mitigated by filling the lower parts of the steel studs with polyurethane foam or inserting mineral wool strips inside the profile prior to installing gypsum board and OSB sheathing. Based on this, the numerical heat transfer simulations for the wall-basement slab connection assume full filling of the steel profiles with insulation.

The key element for improving the thermal performance of the exterior wall is the continuous external thermal insulation, which serves as a thermal break for the steel frame and other conductive elements such as plastic anchors used for attaching insulation boards and steel brackets of ventilated façade systems. This has also been confirmed by similar studies (Milovanović et al., 2022; Santos and Mateus, 2020; Kornilov and Gerasimov, 2016). The modeling results for a wall with both external and internal insulation show that heat losses increased by 15.9 % and the reduced

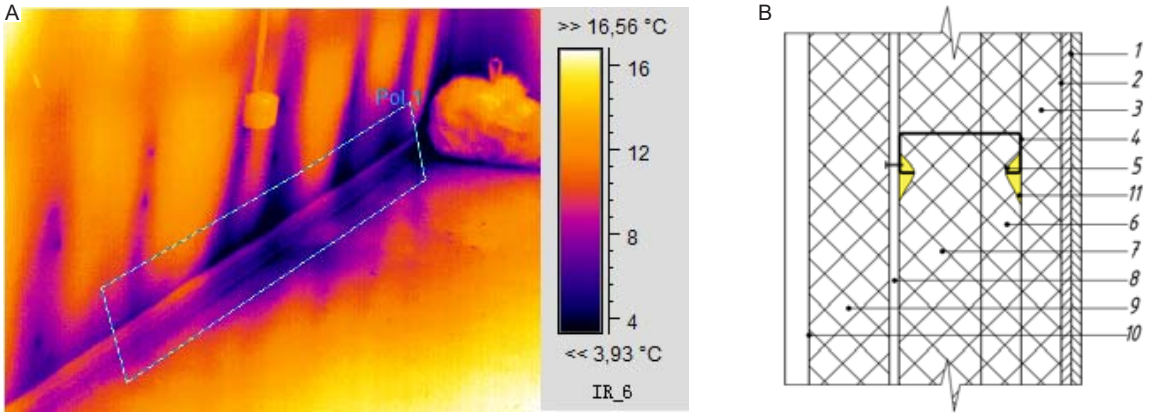


Fig. 4. Thermogram of LSF wall at temperature t_{int}=+16.5ºC and t_{ext}= –34.0 ºC (A) and cavity inside the steel stud profile (B)

thermal resistance decreased by 13.7 % compared to a wall model without steel studs (Table 2). The calculated reduced thermal resistance of the LSF wall is 6.78 m²·°C/W, which exceeds the normative value for Arctic regions.

Table 3 shows the temperature distributions inside the wall structures. In a double-layer wall, the 0 °C isotherm being located inside the outer thermal insulation layer at the locations of the steel posts due to their high thermal conductivity. The heat losses through the double-layer wall is the highest compared to other models. The use of an internal layer of thermal insulation to ensure fire resistance leads to a more uniform temperature distribution on the inner surface of the wall. However, the 0 °C isotherm bypasses the steel studs from the inside, which can be problematic in practice. Minor defects in the installation of mineral wool boards can lead to low interior surface temperatures and potentially condensation in the presence of high air infiltration. The minimum temperature is observed at vertical zones corresponding to steel stud locations and is t_{min} = +18.92 °C, which is a 4.6 % difference from a wall without steel studs.

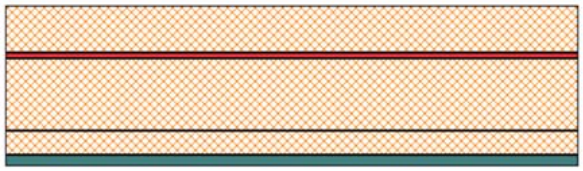
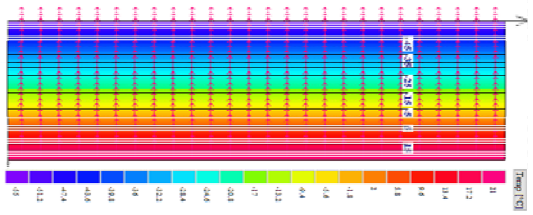
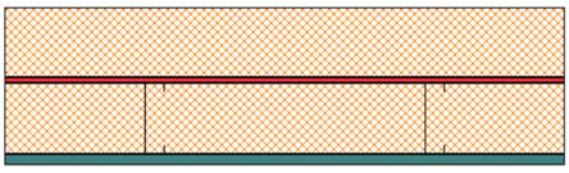
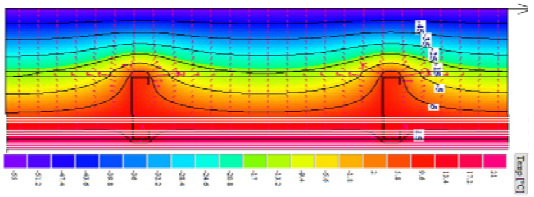
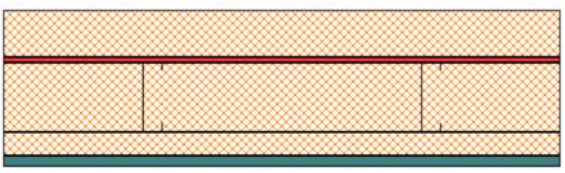
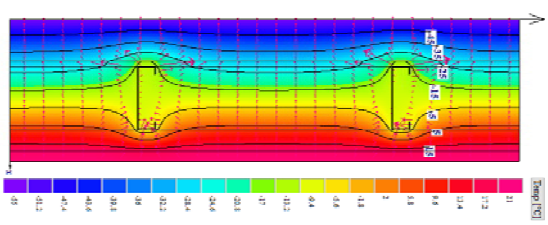
External Wall-basement Slab Connection

Table 4 presents the results of heat transfer simulations for the external wall-basement slab connection. In the typical solution, the steel studs in contact with the reinforced concrete slab act as direct thermal bridges, which is evident from the temperature distribution inside the connection. A 10 mm polyethylene strip placed between the guide profiles and the slab does not affect the temperature distribution within the assembly due to its small thickness. As a result, the minimum interior surface temperature at the steel stud locations is t_{min} = 10.48 °C.

Table 2. **Results of numerical analysis of exterior walls**

Wall type	Thermal characteristics		
	Minimum surface temperature t_{min}, °C	Reduced thermal resistance R_{eff}, m²·°C/W	Heat losses Q, W
Wall without steel studs	19.74	7.86	13.92
LSF double-layer wall with external insulation	16.81	6.34	17.25
LSF three-layer wall with external and internal insulation	18.92	6.78	16.13

Table 3. **Results of thermal transfer modeling of the external walls**

Calculation model	Temperature distribution
Wall without steel studs	
	
LSF wall with external insulation	
	
LSF wall with external and internal insulation	
	

In the proposed solution for the external wall-basement slab connection, thermal bridges in the form of steel profiles are shifted into the warm zone of the building using thermal break (TB) beams. The EPS inserts within the TB beams are joined with the external wall insulation, thereby ensuring the continuity of the building's thermal envelope. The effectiveness of using a TB beam is clearly visible from the heat flow direction in the temperature distribution along the vertical section of the external wall-basement slab connection (Table 4). The minimum surface temperature reaches t_{min} = 16.18 °C, which significantly reduces the risk of moisture condensation on the interior surface of this connection. The reduced thermal resistance of the proposed connection is 8.1 % higher than that of the typical solution.

Corner Section of the External Wall-basement Slab Connection

The corner section of the basement slab in buildings with pile foundations is one of the most critical thermal zones, as it is exposed to cold from three directions. At this junction, two adjacent steel stud profiles are used to connect the external walls, increasing the number of thermal bridges (Table 6). While heat loss is already a concern due to thermal bridging, an even more serious consequence is the very low surface temperature that can occur in the corner area. In the typical solution, the minimum surface temperature is only t_{min}= 2.42 °C, which is significantly below the dew point temperature t_p = 10.2 °C (Table 5). This can lead to surface condensation on gypsum board panels, deterioration of thermal performance and structural integrity, and mold growth in mineral wool insulation.

With the use of a TB beam and external wall insulation, the thermal performance of the corner joint is significantly improved. The interior surface temperature rises to t_{min} = 11.07 °C, exceeding the dew point temperature. Heat losses through the joint decrease, and the reduced thermal resistance reaches R_{eff} = 5.63 m²·°C/W, which is 8.9 % higher than that of the typical solution (Table 6).

Partition Wall-basement Slab Connection

Partition walls use T203×51×1.8 guide profiles and S203×51×1.8 stud profiles. The wall assembly

Table 4. **Results of thermal transfer modeling of the external wall-basement slab connection**

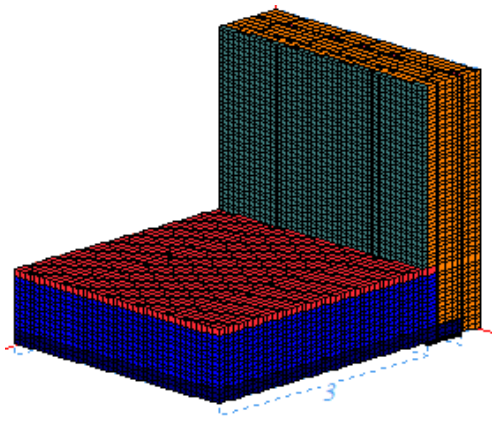
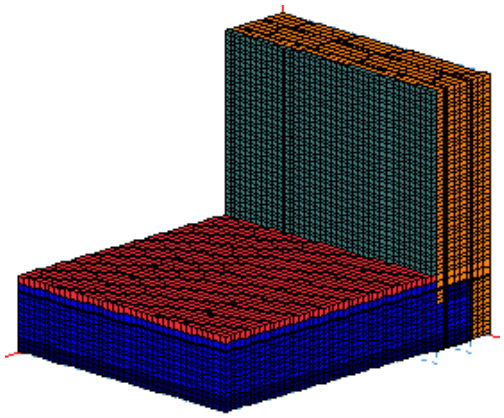
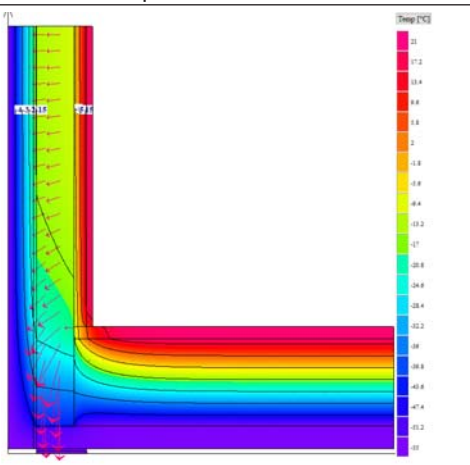
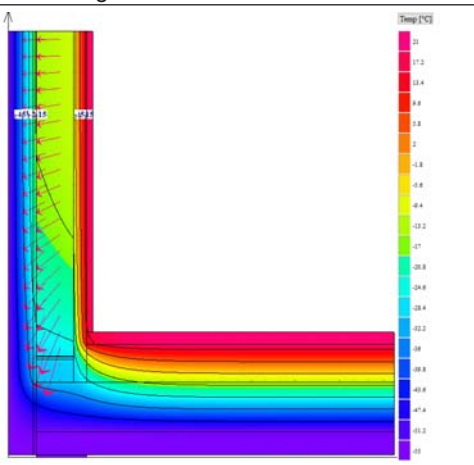
Typical solution	Proposed solution
Calculation model	
	
Temperature distribution in a vertical section along the wall of a steel stud	
	

Table 5. **Results of numerical analysis of wall-basement slab connections**

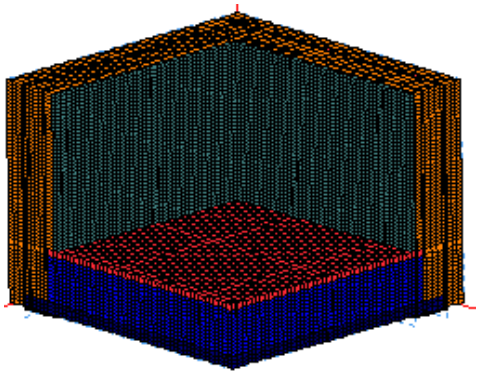
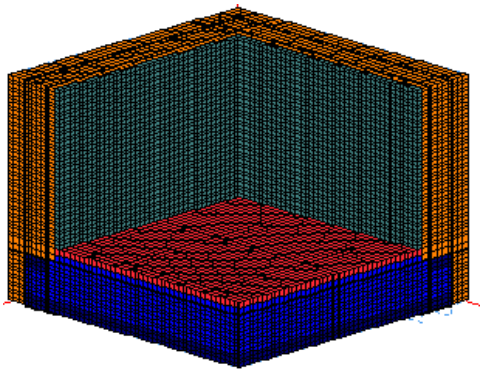
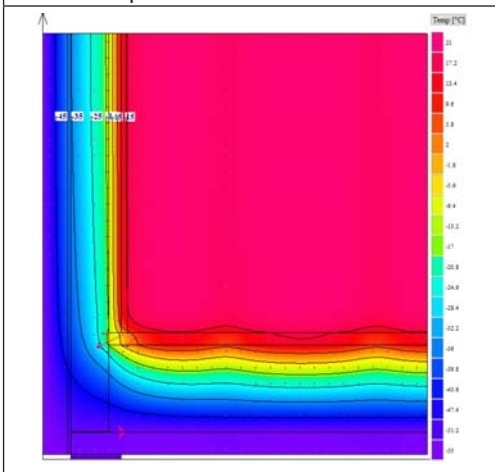
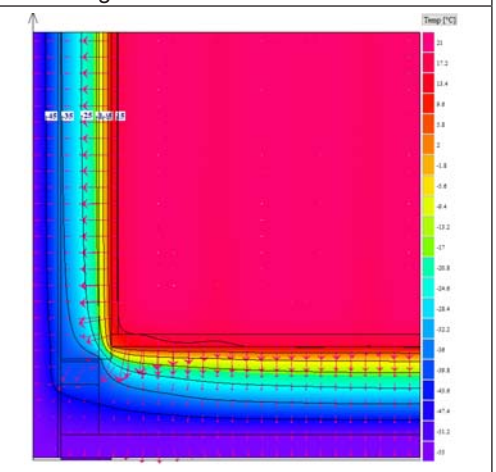
Element connection	Typical solutions			Heat-efficient solutions		
	Thermal characteristics					
	t_{min}, °C	$R_{eff,}$ m²·°C/W	Q, W	t_{min}, °C	R_{eff}, m²·°C/W	Q, W
External wall-basement slab	10.48	6.27	34.91	16.18	6.78	32.28
Corner section of the external wall-basement slab	2.42	5.17	63.53	11.07	5.63	58.35
Partition wall-basement slab	12.89	6.51	33.60	14.42	7.51	29.13
External and partition wall-basement slab	4.64	4.93	88.68	10.25	5.13	85.34

t_{min} is minimum temperature on the inner surface of the enclosing structures;
R_{eff} is reduced thermal resistance;
Q is heat losses.

is detailed in Table 1. In the typical configuration, guide profiles are anchored directly to the reinforced concrete basement slab using polyethylene strips, which do not effectively function as a thermal break — as seen in the temperature distribution (Table 7). The minimum temperature on the interior surface, at the steel stud locations, is t_{min} = 12.89 °C, while between studs the temperature in the corner area reaches up to 20.1 °C.

In the proposed solution with a TB beam, the minimum temperature on the interior surface rises to t_{min} = 14.16 °C, significantly higher than in the typical configuration. The 0 °C isotherm lies much deeper inside the assembly, indicating better protection from cold penetration. Steel profiles are located entirely within the warm zone. The reduced thermal resistance of the proposed connection is R_{eff} = 7.51 m²·°C/W, compared

Table 6. **Results of thermal modeling for the corner section of the external wall-basement slab connection**

Typical solution	Proposed solution
Calculation model	
	
Temperature distribution in a vertical section along the inner surface of the wall	
	

to R_{eff} = 9.02 m²·°C/W for the clear basement slab area without any framing.

External and Partition Wall-basement Slab Connection

This connection combines steel studs from the partition wall and two studs from the external wall, making it the location with the highest concentration of thermal bridges, which affects both the temperature distribution and heat losses (Table 8). In the typical solution, the minimum surface temperature in the floor corner between the two walls is only t_{min} = 4.64 °C, far below the dew point temperature.

In the proposed solution, the TB beam support is shifted away from the corner, creating a thermal break zone in the joint between the exterior and partition walls. With the TB beam made of reinforced concrete, only the supports remain as a thermal bridge (Table 8), but the minimum temperature on the interior surface increases to t_{min} = 10.25 °C. The reduced thermal resistance improves to R_{eff} = 5.13 m²·°C/W, which is 4.1 % higher than in the typical solution.

Wooden TB Beams

TB beams made of Siberian larch are preferable from a thermal performance perspective, although they are less durable than reinforced concrete. Siberian larch, when properly treated, offers high strength and fire resistance. Numerical analysis shows that when wooden TB beams are used instead of concrete ones, the thermal properties of the connections improve even further. For example, the minimum surface temperatures and reduced thermal resistance values for connections using wooden TB beams are:

- external wall-basement slab: t_{min} = 16.62 °C, R_{eff} = 6.75 m²·°C/W;
- corner section of external wall-basement slab: t_{min} = 11.93 °C, R_{eff} = 5.79 m²·°C/W;
- partition wall-basement slab: t_{min} = 17.19 °C, R_{eff} = 7.74 m²·°C/W;
- external and partition wall-basement slab: t_{min} = 14.44 °C, R_{eff} = 5.93 m²·°C/W.

Conclusions

Based on the operational experience of low-rise lightweight steel-framed (LSF) buildings on pile foundations in the extreme climate conditions of the Arctic regions of Yakutia, the use of thermal break (TB) beams is proposed for the connection of walls with reinforced concrete basement slabs. This design solution reduces the impact of thermal bridges formed by steel profiles by shifting them into the warm zone, introducing a thermal break, and ensuring the continuity of the building's thermal envelope.

Numerical simulations of 3D models for various wall-basement slab connections were carried out under an extremely low outdoor temperature of t_{ext} = −55 °C, characteristic of Arctic regions. In typical solutions, steel guide and stud profiles in contact with the basement slab act as direct thermal

Table 7. **Results of thermal modeling for the partition wall-basement slab connection**

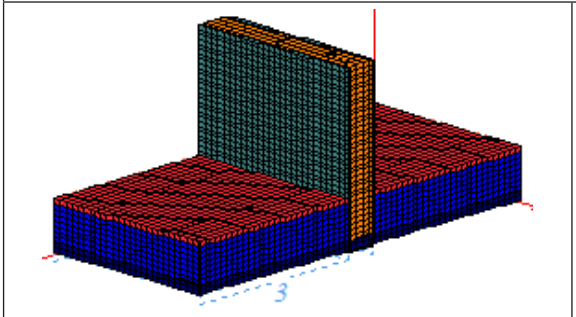
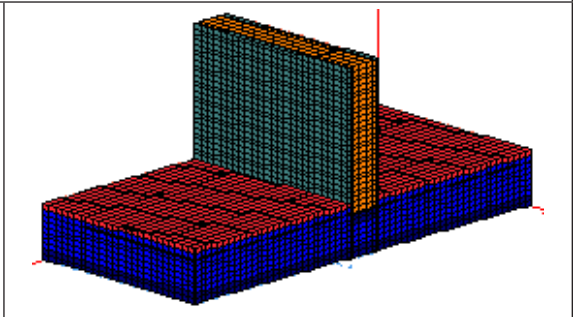
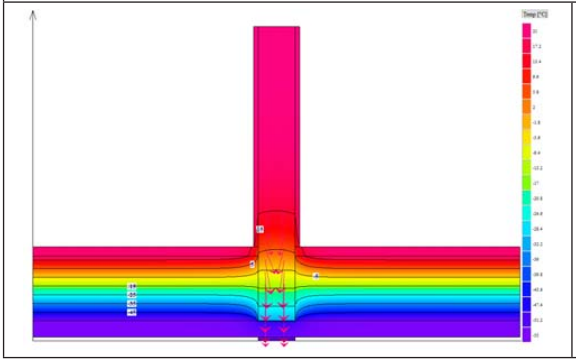
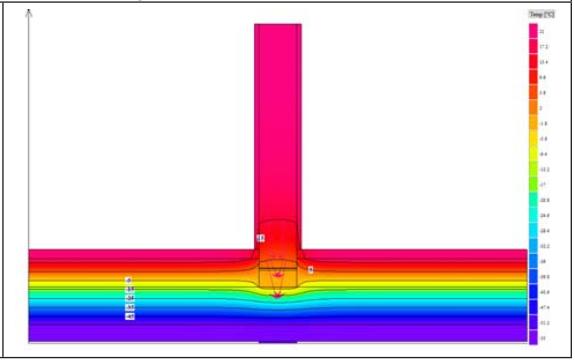
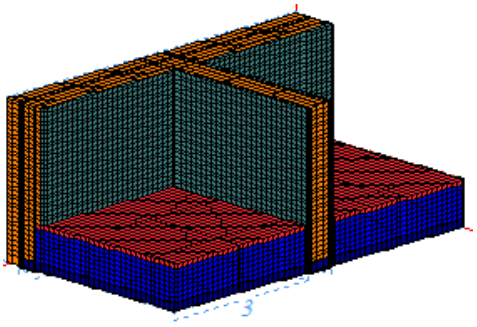
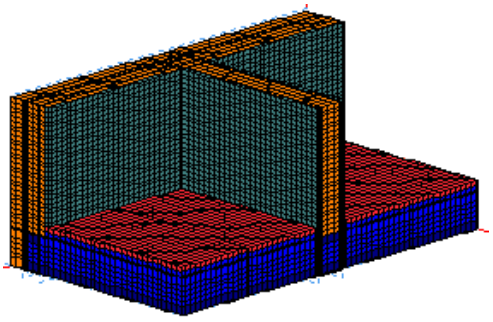
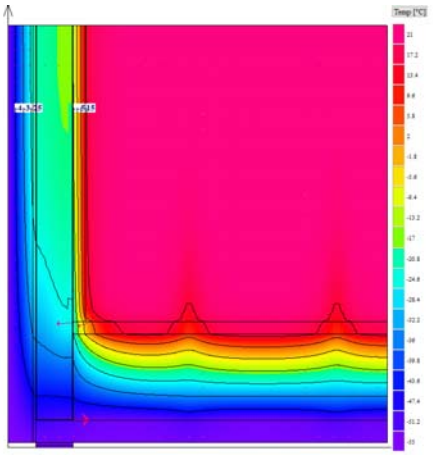
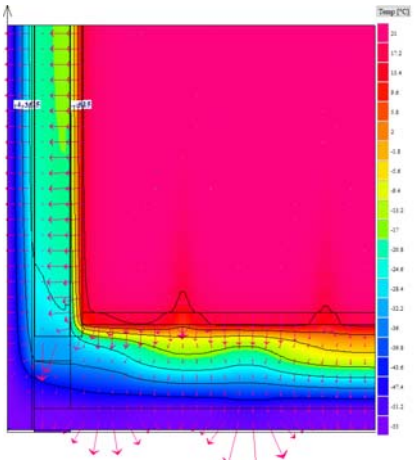
Typical solution	Proposed solutions
Calculation model	
	
Temperature distribution in a vertical section along the wall of a steel stud	
	

Table 8. **Results of thermal modeling for the external and partition wall-basement slab connection**

Typical solution	Proposed solution
Calculation model	
	
Temperature distribution in the vertical section along the surface of the partition wall	
	

bridges, which was confirmed by heat transfer simulation results. The polyethylene strip between the steel profiles and the basement slab has an insignificant effect on the internal temperature distribution due to its small thickness. In the corner section of external wall-basement slab connection and external and partition wall-basement slab connection, the minimum surface temperature was found to be below the dew point, which can lead to surface condensation on gypsum board, loss of thermal performance, structural degradation, and mold growth in mineral wool insulation.

The results of thermal simulations confirm the effectiveness of TB beams in the analyzed connections. In contrast to typical solutions, the minimum temperature on the inner surface of wall-basement slab joints with reinforced concrete TB beams exceeds the dew point. Compared to conventional configurations, the reduced thermal resistance increased by:

– 8.1 % for the external wall-basement slab connection;

– 8.9 % for the corner section of the external wall-basement slab connection;

– 15.4 % for the partition wall-basement slab connection;

– 4.1 % for the external and partition wall-basement slab connection.

When using timber, particularly durable Siberian larch, as the material for TB beams, the thermal performance of wall-basement slab connections improves even further.

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ТЕПЛОЭФФЕКТИВНЫЕ РЕШЕНИЯ СОПРЯЖЕНИЙ СТЕН С ЦОКОЛЬНЫМ ПЕРЕКРЫТИЕМ ЗДАНИЙ ИЗ ЛЕГКИХ СТАЛЬНЫХ ТОНКОСТЕННЫХ КОНСТРУКЦИЙ ДЛЯ АРКТИЧЕСКИХ РАЙОНОВ

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Аннотация
Введение: В арктических районах с учетом разбросанности поселений на обширных территориях при малой плотности расселения, трудности логистики и транспортной инфраструктуры одним из перспективных технологий является строительство быстровозводимых зданий из легких стальных тонкостенных конструкций (ЛСТК). Тепловая защита таких зданий в климатических условиях с расчетной температурой воздуха –44 °С …–58 °С является актуальной и трудной задачей с учетом термических мостов в виде стальных профилей. Опыт эксплуатации зданий из ЛСТК на свайных фундаментах показывает, что основные проблемы возникают на первом этаже при наличии проветриваемого подполья для сохранения мерзлых грунтов. **Цель:** разработка теплоэффективных решений сопряжений стен с цокольным перекрытием зданий из ЛСТК для арктических районов с экстремальными климатическими условиями. **Методы:** С целью снижения влияния термических мостов для соединений стен из ЛСТК с цокольным перекрытием предложены терморазрывные (ТВ) балки. Численные исследования 3D-моделей различных соединений стен с цокольным перекрытием проведены с использованием сертифицированной программы HEAT 3. Сравнение результатов с типовыми конструкциями выполнено по минимальной температуре на внутренней поверхности ограждающих конструкций, тепловым потерям и приведенному термическому сопротивлению. Результаты: **В результате** применения новых решений минимизировано влияние термических мостов путем смещения стальных профилей в теплую зону, создания терморазрыва с помощью балок и обеспечения неразрывности тепловой защитной оболочки зданий. При температуре наружного воздуха –55 °С минимальная температура на внутренней поверхности соединений стен с цокольным перекрытием, в отличие от типовых решений, превышает температуру точки росы. По сравнению с типовыми решениями приведенное сопротивление сопряжения наружной стены с плитой перекрытия подвала увеличивается на 8.1 %, сопряжения перегородочной стены с плитой перекрытия подвала — на 15.4 %.

Ключевые слова: тепловой мост, легкие стальные каркасные конструкции, терморазрыв, соединение стены и плиты перекрытия подвала, тепловое сопротивление.