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Thermal protection of low-rise buildings from light steel thin-walled structures

Теплозащита малоэтажных зданий из легких стальных тонкостенных конструкций

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Key words: thermal protection; infiltration; temperature; light steel thin-walled structures; cold bridges; wall structures; basement floor

Ключевые слова: тепловая защита; инфильтрация; температура; легкие стальные тонкостенные конструкции; мостики холода; стеновые конструкции; цокольное перекрытие

Abstract. Thermal protection providing of frame buildings in the extreme conditions of the Far North depends on air infiltration. Elements of buildings frame on light steel thin-walled structures (LSTS below) technology – lightweight, thin-walled steel profiles make up multiple thermal bridges. The basic principles of designing the exterior walling of low-rise buildings from LSTS in the Far North are developed with taking into account the increased air infiltration and the heat transfer components and assemblies. The construction with double insulation layer and the intermediate airtight barrier of particleboard, the indicative panels (OSB below) are proposed as the exterior walls. The concrete ground slab and thermofiller using of lightweight concrete blocks are recommended in buildings with pile foundation. The two-stage disposition of blocks between the steel frame elements and the basement ceiling allow to overlap joints of thermal insulation materials with other structural elements which reduces the impact of air infiltration. The specific heat loss values for a multilayer wall construction and assembly of its coupling with a ground overlap, depending on various parameters are obtained with the calculating program application of three-dimensional temperature fields.

Аннотация. Обеспечение тепловой защиты каркасных зданий в экстремальных условиях Крайнего Севера во многом зависит от инфильтрации воздуха. Элементы каркаса зданий по технологии ЛСТК – легкие стальные тонкостенные профили создают многочисленные мостики холода. Разработаны основные принципы проектирования наружных ограждающих конструкций малоэтажных зданий из ЛСТК в условиях Крайнего Севера, учитывающие повышенную инфильтрацию воздуха и наличие теплопроводных элементов и узлов. В качестве наружных стен предложены конструкции с двухслойным теплоизоляционным слоем и промежуточным воздухонепроницаемым барьером из стружечно-ориентировочных плит (OSB). В зданиях со свайными фундаментами рекомендовано устройство железобетонного цокольного перекрытия и применение термовкладышей из легких бетонных блоков. Двухступенчатое расположение блоков между стальными элементами каркаса и цокольным перекрытием позволяет перекрывать стыки теплоизоляционных материалов с другими конструктивными элементами, что снижает влияние инфильтрации воздуха. С применением программы расчета трехмерных температурных полей получены значения удельных потерь теплоты для многослойной стеновой конструкции и узла ее сопряжения с цокольным перекрытием в зависимости от различных параметров.

1. Introduction

The Sakha (Yakutia) Republic is the largest federal subject of Russia located in the North-East of the country. Almost half of the region is located in the Arctic Circle. The territory of the Yakutia is characterized by extreme climate conditions for the construction of buildings and structures. Almost the entire territory located in the permafrost zone, which is the most powerful in the world. Subarctic climate of Yakutia is sharply continental. The period with negative daily temperatures has no analogues in the world and varies from 312 days in the distant Arctic islands to 202 days in South Yakutia. In winter, the outdoor temperature in the central part of Yakutia during 50–60 days, and in the Arctic regions 60–80 days is below –40 °C. The calculated air parameters for regions of Yakutia include: outdoor temperature in the coldest period from –40 °C to –59 °C; during the heating period average temperature is from –13.6 °C to –25.0 °C; duration of the heating period from 239 to 308 days. In such climate, the energy efficiency of buildings has special urgency.

In recent years construction of low-rise buildings in the Yakutia actively applied frame housing technology of light steel thin-walled structures. The main advantage of this technology is simplicity and convenience of assembly elements, combining functions of bearing and protecting thin-walled profiles. In permafrost conditions, lightweight buildings of such structures allows using surface foundations or screw piles. LSTS technology is an important advantage for isolated locations and remote regions by prefabricated buildings and high transportability, thereby decreasing the cost of transportation materials [1]. At the same time, this constructing technology is based on using cold carcass profiles from thin sheet galvanized steel with high thermal conductivity and accordingly it creates “cold bridges”, which is very confusing the provision of thermal protection buildings in the extreme conditions of the Far North.

Basic design and construction principles of energy efficient buildings are in using the external enclosing structures with a high level of thermal protection, the rational choice of architectural and planning decisions, the application of modern heating and ventilation systems, renewable energy [2–3]. The most important question in the design of buildings thermal protection is calculation of the filler structures transfer resistance considering heat-conducting inclusions [4–5]. In the frame structure buildings from LSTS in terms of thermal protection, the most vulnerable point are “cold bridges” – thin-walled steel profiles and their connections [6–8]. Thermal perfomance of lightweight steel-framed walls of various constructions and insulation materials considered in [9–14]. In the result of thermal calculations P. Santos [9] found, that the position of thermal insulation in LSF facade walls plays a major role in its thermal performance effectiveness. Most manufacturers offer for use thermo-profiles with special perforation on a wall. In [15, 17] presented the results of researches about effect of the thin steel profiles perforation on the thermal characteristics of filler structures. The results of researches about heat keeping properties various filler structures with application of steel profiles are in [18–21]. In [22] based on theoretical and experimental researches are expediency to use polystyrene-concrete as a filler for walling of steel profiles. In [23] presented the results of a natural experiment in the Leningrad region about determination of thermal characteristics of light frame structures using steel thermo-profiles and thermal insulation material efficiency. A review of work showed that in the previous researches were considered a filler structures by thin-walled steel profiles with a single insulating layer of mineral wool or other effective materials in temperate climates.

Experience in the construction and operation of buildings in the Far North shows that the one of the main reasons for decreasing of buildings thermal protection is a high air infiltration. Specific for the Yakutia outdoor temperature is for –40 °C to –59 °C the difference of indoor and outdoor air pressure on the first floor of a two-storey house with a wind speed about 1 m/s is from 5.9 Pa to 10.5 Pa, which is ten times higher than if outdoor temperature is –10 °C. For the Arctic regions, the average wind speed in the coldest months reaches up to 5–6 m/s. Consequently, the air infiltration in these areas even higher and reaches 23–26 Pa. In such climatic conditions and the presence of ventilated underground using pile foundation the negative impact of air infiltration is particularly evident in low-rise frame houses using LSTS. Any violation of the outer shell of buildings, for example, the poor performance of joints different structural elements or junction leakage of thermal insulation materials, produces in winter to cold air infiltration and to disruption of the buildings thermal protection. By V.G. Gagarin etc. [24–26] carried out the researches of air infiltration impact on heat-shielding properties enclosing structures and showed the reduce of heat-shielding properties of external fences.

The purpose of research is to increase the thermal protection of low-rise LSTS houses, taking into account the climatic conditions of the Far North. To achieve that purpose were delivered the following tasks:

– development of the basic design principles of LSTS buildings taking into account high air infiltration and the presence of numerous heat transfer elements;

– calculation and analysis of thermal fields of wall fences and nodes and their contiguity to the ground overlap.

2. Methods

With the aim of identifying the reasons for the breach of the thermal protection carried out on-site inspections of low-rise LSTS buildings of, built on the territory of the Republic of Sakha (Yakutia) in 2012–2016. The objects are two-storey buildings with an area of 120–1350 m^2: kindergartens and schools, apartment buildings. The outer walls of buildings were a frame of thin-walled steel profiles 150 mm wide, usually, arranged in increments of 600 mm and filled with mineral wool plates with a density of 50–75 kg/m^3. The inner and outer sides of the outer walls are provided with additional thermal insulation layers each 50 mm thick and the covering. The frame of the LSTS house is established on bearing rolling steel beams on screw piles.

On-site surveys of objects included instrumental monitoring of the temperature and humidity conditions of the interior of buildings and thermal imaging of the surface of the external enclosing structures. In the beginning, for the formation of the пeneral characteristics of the object, an overview thermography of the external and internal surfaces of the enclosing structures was carried out, then on the identified problem areas – detailed thermography of the internal surfaces with the preservation of thermograms. To measure temperature, humidity and speed of movement of interior air in buildings used instrument Testo 435-4 with the trifunctional probe, to conduct thermal imaging – a thermographic camera SATG-90. Thermal imaging measurements are made at an ambient temperature below –30 °C, i.e. at a temperature difference between outside and inside air exceeding the minimum permissible difference. On each object the report on thermal imaging inspection is made.

Calculations of temperature fields and thermal characteristics according to the certified program “Shaddan 3D ST” were performed for the numerical analysis of external walling structures and units of LSTS buildings. This program allows you to determine the spatial temperature fields of structures of any complex configuration, bordering environments with different parameters. The problem is solved by the method of grids with the help of a difference scheme of the second order of accuracy on spatial variables on an uneven rectangular grid. Testing of the program is carried out with application of earlier developed programs of calculation of two-dimensional and three-dimensional temperature fields [27, 28].

3. Results and Discussion

Thermal imaging survey of low-rise houses, built for the first time on the territory of Yakutia by LSTS technology, revealed the presence of numerous sites with heat leakage. From thermograms presented on Figure 1, you can clearly see the impact of heat-conducting inclusions in the form of steel profiles, joints of separate wall panels and insulating materials. The most problematic areas of low-rise LSTS houses is the connection of the outer wall fence with a basement ceiling. In most cases, the heat losses occur in abutting the steel rack profiles for horizontal track.

The main causes of violations of the thermal protection LSTS houses more thoroughly analyzed in [29] and are as follows:

– designing covering constructions performed without taking into account the increased air infiltration in the northern conditions and the presence of numerous thermal bridges in the form of light steel profiles and rolled steel beams on screw piles;

– allowance on the construction of buildings low quality insulation work and thermal insulation materials are used having a low elasticity;

– thermofiller and sealing tape between steel elements do not perform their functions;

– violated the integrity of the building airtight envelope in the joints, in areas abutting the wall fencing in the basement and attic floors, in the areas around the perimeter of window and door openings.

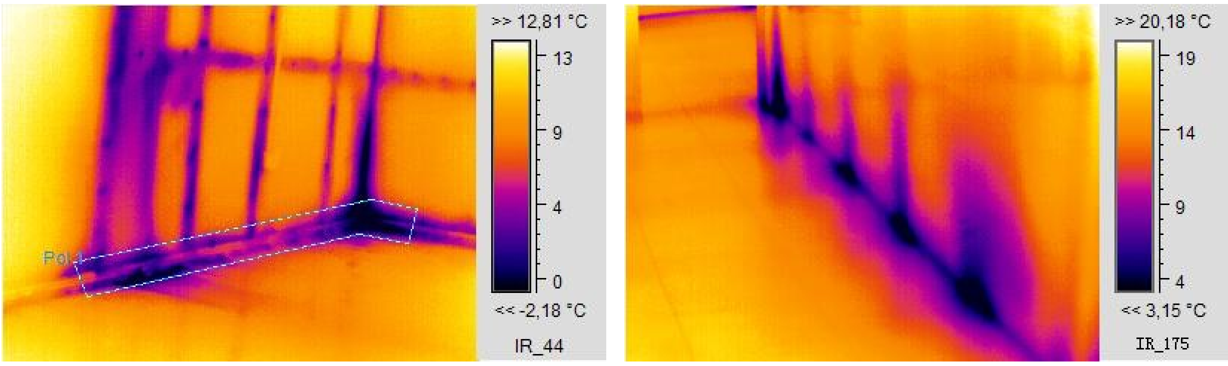


Figure 1. Thermograms wall surfaces of LSTS at an air temperature of t_o = –42 °C and t_i = +25 °C.

In traditional solutions of buildings from LSTS is a single-layer wall construction with a frame made of thin-walled steel profiles (Figure 2). To fill the wall fencing used fiberglass material density of 10–20 kg/m^3 or mineral wool density of 50–75 kg/m^3. These materials are breathable materials. When performing installation work on the construction site it is difficult to provide high-quality thermal insulation materials laying between the profiles due to the presence of bends rack shelves profiles, projections self-tapping screws.

Figure 2. Typical design solution for low-rise home of LSTS for temperate climate.

The main provisions of the design heat protection of external covering constructions are regulated by the updated Construction norms and regulations SNIP 23-02-2003 "Thermal protection of buildings" – Code of Practice SP 50.13330.2012. According to the regulations, in the first place need to comply with thermal performance of external walling normalized values based thermally conductive inclusions depending on the area of building industry. In addition to these requirements, taking into account the increased air infiltration and the presence of numerous thermal bridges are offered to consider the following basic principles for the design of low-rise buildings walling from LSTS in the Far North:

– multilayer external walling airtight;

– in the compounds of the wall fence with a ground location of the overlap frame of steel profiles in a warm area of the building;

– use in conjunction with a ground wall protections overlapping multi thermofiller of materials with low thermal conductivity.

When the multi-layer wall structures decision with LSTS decreases influence of thermal bridges and improves the heat-shielding properties of the fence. The joints between the insulation boards and rack-mount profiles overlap the separate layers. Unlike traditional solutions offered below constructive decisions of walls from LSTS to decrease the impact of air infiltration in the northern regions should be placed OSB boards with mandatory sizing joints airtight tape between the separate layers of thermal insulation wall. The outer insulating layer framing walls are encouraged to take out at least 100 kg/m^3 density mineral wool slabs, which will also help reduce the impact of air infiltration. In the inner layers of the insulating panels must have a certain elasticity in order to facilitate the installation of the material in the construction of a metal frame.

The article [30] various options multilayer walls of houses from LSTS were considered for the averaged calculated parameters to ensure the heat protection of buildings in the Arctic: the design outdoor air temperature t_o = –54 °C; rated value reduced thermal resistance of the wall at least R_o = 5.25 (m^2•°C)/W; indoor air temperature t_i = +21 °C. The analysis of temperature fields and thermal performance, the unit cost for the installation of wall structures found that the best solution is two-layered fencing wall (Figure 3). The two-layer construction of the walls LSTS line with zero temperature in place of steel profiles rack arrangement is located in the outer insulating layer, and on the wall portion between the steel profiles placed in the middle of the inner layer. This fact is particularly important to ensure that the rated values of the temperature on the inner wall surface. It should be noted that the first facility built on the territory of Yakutia, were applied three-layer wall construction with mineral wool insulation thickness of 50 mm on the inside, which led to a breach of the temperature regime of buildings. One of the reasons for such a breach is offset line with the zero point at the inner side in the locations of rack profiles [30].

The specific heat loss, which can be widely used by designers is determined to unify the calculations reduced heat transfer resistance of double-layer wall fencing with LSTS. In the design of low-rise buildings of LSTS step rack mountable steel profiles take in most cases mineral wool slabs with the width of 600 mm. Therefore, to determine the specific heat losses, taking into account the characteristic step rack mountable profiles examined the wall fencing portion of width 0.6 m and height 0.6 m in the space scheme (Figure 3).

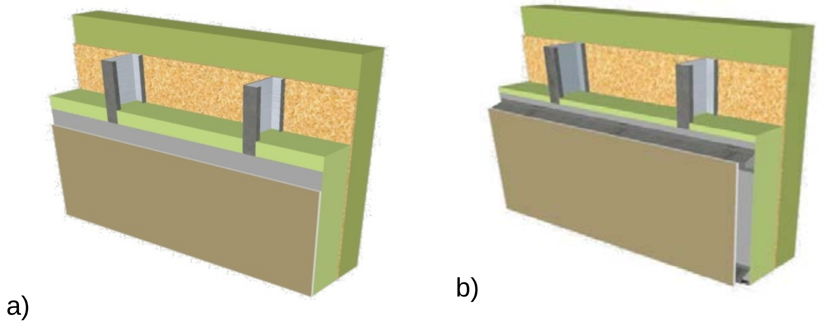
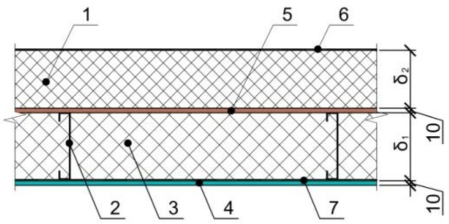


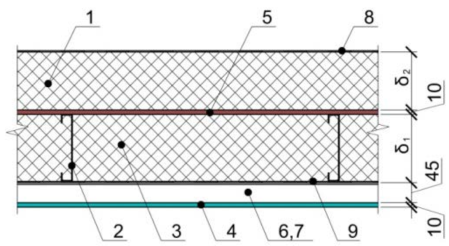
Figure 3. The proposed designs of external walls of buildings from LSTS: (a) double-layer wall fence, (b) double-layer wall fence with an air gap.

On the heat loss through the double-layer wall fencing with LSTS following parameters affect: the thermal conductivity of applied materials; the thickness of the outer and inner layers; the thickness and size of steel profiles; the presence of plate dowels; the presence of a steel bracket. As a hate-insulating material considered mineral wool slabs having a density of 40 kg/m^3 in the inner layer (λ = 0.041 W/(m•°C) and density of 125 kg/m^3 in the outer layer with (λ = 0.042 W/(m•°C). Thermal characteristics of other materials are given in Table 1. The thickness of the steel profiles, plate dowels and bracket are not taken into account in the calculations of specific losses wall fences.

Specific heat loss calculation results are shown in Table 1.

Table 1. Specific heat losses Ψ, W/(m^2•°C) for a double-layer wall fencing with thin-walled steel profiles.

<table>
<tr><th>Sketch of wall fencing and thermal characteristics</th><th>δ_1 (mm)</th><th>δ_2 (mm)</th><th>Specific heat losses Ψ (W/(m^2•°C))</th></tr>
<tr><td rowspan="9">

(1) mineral wool P125 mark slabs (λ = 0.042 W/(m•°C), (2) rack mountable steel profile thickness of 1.8 mm and step of 600 mm (λ = 58 W/(m•°C), (3) mineral wool P40 mark slabs (λ = 0.041 W/(m•°C), (4) gypsum plasterboard (λ = 0.21 W/(m•°C), (5) roughly strand slabs OSB (λ = 0.34 W/(m•°C), (6) wind-hydroprotective membrane, (7) vapor barrier membrane.</td><td rowspan="3">150</td><td>100</td><td>0.22</td></tr>
<tr><td>150</td><td>0.175</td></tr>
<tr><td>200</td><td>0.146</td></tr>
<tr><td rowspan="3">200</td><td>50</td><td>0.272</td></tr>
<tr><td>100</td><td>0.203</td></tr>
<tr><td>150</td><td>0.164</td></tr>
<tr><td rowspan="3">250</td><td>50</td><td>0.251</td></tr>
<tr><td>100</td><td>0.191</td></tr>
<tr><td>150</td><td>0.156</td></tr>
<tr><td rowspan="9">

(1) mineral wool P125 mark slabs (λ = 0.042 W/(m•°C), (2) rack mountable steel profile thickness of 1.8 mm and step of 600 mm (λ = 58 W/(m•°C), (3) mineral wool P40 mark slabs (λ = 0.041 W/(m•°C), (4) gypsum plasterboard (λ = 0.21 W/(m•°C), (5) roughly strand slabs OSB (λ = 0.34 W/(m•°C), (6) layer of air (λ = 0.357 W/(m•°C), (7) hatter steel profile thickness of 1.8 mm and step of 600 mm (λ = 58 W/(m•°C), (8) wind-hydroprotective membrane, (9) vapor barrier membrane.</td><td rowspan="3">150</td><td>100</td><td>0.216</td></tr>
<tr><td>150</td><td>0.173</td></tr>
<tr><td>200</td><td>0.145</td></tr>
<tr><td rowspan="3">200</td><td>50</td><td>0.267</td></tr>
<tr><td>100</td><td>0.2</td></tr>
<tr><td>150</td><td>0.162</td></tr>
<tr><td rowspan="3">250</td><td>50</td><td>0.248</td></tr>
<tr><td>100</td><td>0.189</td></tr>
<tr><td>150</td><td>0.154</td></tr>
</table>

Steel profiles used for the frame thickness generally of 0.8 to 1.8 mm. The analysis shows that changes in the thickness of the steel profiles within the specified limits has little effect on the values of specific heat loss through the wall fence considered. In this case, profiles adopted maximum thickness of 1.8 mm, which will create some margin for evaluation thermal performance walling with using smaller thickness of steel profiles. As a result, thermal calculations that sets the plate dowel for fastening hate-insulating slabs made of fiberglass plays a minor role in the formation of the temperature field for wall fencing and steel bracket has a local effect on the temperature distribution. The temperature is leveled at the area in the middle of the inner heat-insulating layer and does not differ from areas on the inner surface of the wall section in the bracket. This situation is due to the presence of an intermediate barrier OSB slabs with a lower thermal conductivity. Therefore, the presence of plate dowels and steel bracket do not considered when determining the specific heat loss wall fencing.

From a comparison of the specific heat loss values with the same total thickness of the walls it is seen that the most effective to take a smaller thickness of the inner layer and vary the thickness of the outer layer to provide normalized values of the wall fencing reduced thermal resistance. For example, the specific heat loss through the building wall structure of the total thickness of 330 mm:

– Ψ = 0.175 W/(m²•°C) if δ_1 = 150 mm и δ_2 = 150 mm;

– Ψ = 0.203 W/(m²•°C) if δ_1 = 200 mm и δ_2 = 100 mm;

– Ψ = 0.251 W/(m²•°C) if δ_1 = 250 mm и δ_2 = 50 mm.

Heat loss through the wall fencing from LSTS in the presence of an air layer is somewhat reduced as compared to the first option (Table 1). Also previously [11], it was established that the inner surface temperature of steel profiles location areas is increased by 1.1°C in the presence of an air layer.

In the previous works considered fundamentally different structural solution panels from LSTS, mainly intended for a temperate climate [6–23]. Comparison of the results obtained on proposed solutions panels with data of other authors obtained several incorrect. Double-layer wall fence with an intermediate layer of roughly strand slabs OSB effectively reduces the impact of thermal bridges and increased infiltration of air at very low outside temperature during winter.

Under the conditions of permafrost lightweight buildings from LSTS allows the use of screw piles. As a rule, on steel screw piles installed rolled I-beams, in which is being built from LSTS frame house. With this solution (Figure 4) in this frame section there is a plurality cold bridges. As the experience of operation buildings, this design solution is not suitable for the construction of buildings in the northern climate zone. Therefore, based on the above design principles of the buildings from LSTS offered to create airtight layer from the lower side of the building by device of reinforced concrete basement ceiling. The thermofiller can be used in the form of masonry materials such as autoclaved aerated concrete blocks, with a lower coefficient thermal conductivity $\lambda \leq 0.16$ W/(m·°C) (Table 2) to reduce the influence of cold bridges. The configuration of the masonry rater to take a stage that allows overlap the joints of lower heat-insulation layer by the upper heat-insulating layer. With such a design solution as the calculations of temperature fields, steel elements are located in a zone with a positive temperature (Figure 5).

To evaluate the thermal performance and determine the specific heat loss calculated the three-dimensional temperature field fragments nodes conjugation double-layer wall fencing from LSTS with a basement ceiling. Angle conjugation considered in three-dimensional variations with the following parameters: the height of the wall fencing of 1.2 m, the length and width of track of 0.6 m, taking the step profiles.

On the heat loss through the node interface wall fencing with a basement ceiling influenced by the following parameters: the thermal conductivity of using materials; the thickness of the basement ceiling, heat insulating thickness of the basement ceiling, the thickness of the outer and inner layers. Thermal characteristics of the materials shown in Table 2. The thickness of the steel profiles taken closer to the maximum of 1.8 mm and a reinforced concrete slab – 200 mm. Components of the floor in the calculations not considered that will create some stock of heat-shielding properties for under conjugation.

In under consideration conjugations of the walls with a basement ceiling the line of zero temperature is located below the placement areas of steel profiles in sections of both steel rack mountable profile and section heat-insulation, i.e., all steel profiles are in the warm zone. The lowest temperature of the inner surface ($t_{s,min}$) is observed in the corner zones of location rack mountable profiles. For example, for the variant δ_1 = 150 mm, δ_2 = 130 mm and δ_3 = 300 mm is $t_{s,min}$ = +14.4 °C at the design outdoor air temperature t_o = –54 °C and indoor air temperature t_i = +21 °C. The average temperature on the inner surface of the conjugation under consideration is $t_{s,a}$ = +18.3 °C.

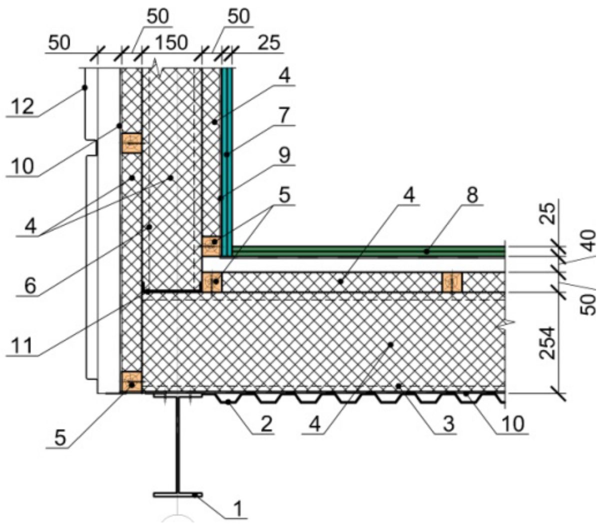


Figure 4. Typical solution of the conjugation of the outer wall with a basement ceiling; (1) foundation I-beam, (2) profiled decking, (3) thin-walled steel profile, (4) rock wool density 75 kg/m^3, (5) block of wood, (6) rack mountable steel profile, (7) gypsum plasterboard, (8) glass-magnesium sheets, (9) vapor barrier membrane, (10) wind-water-proof membrane, (11) thin-walled steel guide profile and sealing tape Knauf- Dihntungsband, (12) front sheet.

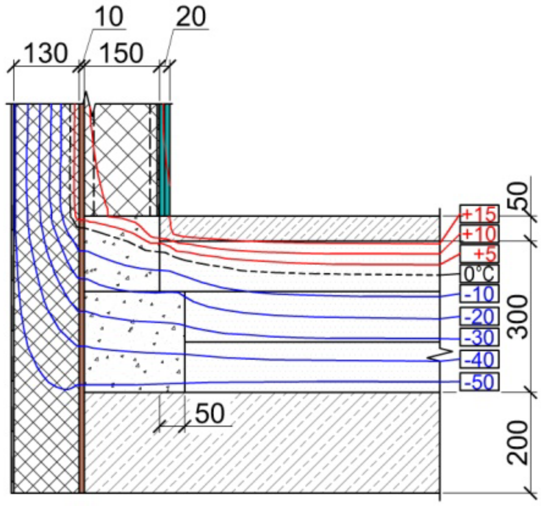
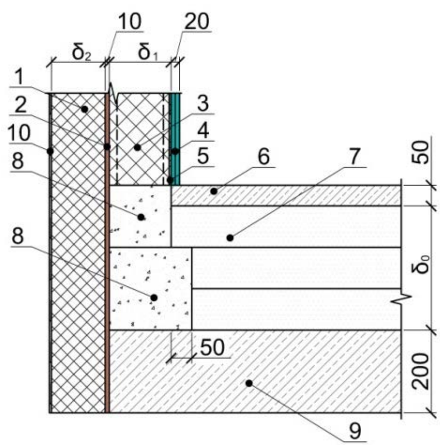


Figure 5. The distribution of temperature in the corner joints in the vertical section at the location of the rack mountable steel profile with an air temperature t_o = –54 °C and t_i = +21 °C.

Table 2. Specific heat losses Ψ, W/(m^2• °C) for a double-layer wall fencing conjugation with a basement ceiling.

Sketch of wall fencing and thermal characteristics	δ_o (mm)	δ_1 (mm)	δ_2 (mm)	Specific heat losses Ψ (W/(m^2•°C))
 **(1)** mineral wool P125 mark slabs (λ = 0.042 W/(m•°C), **(2)** roughly strand slab OSB (λ = 0.34 W/(m•°C), **(3)** mineral wool P40 mark slabs (λ = 0.041 W/(m•°C) between the rack mountable steel profiles thickness of 1.8 mm and a step of 600 mm (λ = 58 W/(m•°C), **(4)** gypsum plasterboard (λ = 0.21 W/(m•°C), **(5)** vapor barrier membrane, **(6)** cement-sand screed M150 (λ = 0.76 W/(m•°C), **(7)** polystyrene slab PSB-S-35 (λ = 0.04 W/(m•°C), **(8)** thermal break of lightweight concrete (λ = 0.16 W/(m•°C), **(9)** monolithic reinforced concrete slab (λ = 1.92 W/(m•°C), **(10)** wind-hydroprotective membrane.	300	150	100	0.341
			150	0.304
			200	0.282
		200	50	0.423
			100	0.353
			150	0.32
		250	50	0.426
			100	0.365
			150	0.335
	400	150	100	0.315
			150	0.275
			200	0.252
		200	50	0.399
			100	0.324
			150	0.287
		250	50	0.399
			100	0.332
			150	0.299

As a result of analysis of the specific heat loss values through the conjugation wall fencing with a basement ceiling found less heat loss with a smaller thickness of the internal layer of hate insulating wall fencing is installed of LSTS. By increasing the thickness of the heat insulation layer basement ceiling from 300 mm to 400 mm, the specific heat loss through the considered conjugation is reduced from 5.6 to 10.7 %.

4. Conclusion

The basic principles proposed for the design of wall fencing from thin-walled steel profiles in the Far North. Designed for low-rise buildings of LSTS multi-layer wall fencing and node conjugations with a basement ceiling consider for increased air infiltration in the northern climatic zone with a stable very low temperature of the outside air in the winter and the presence plentifully cold bridges in the form of thin-walled steel profiles. The values of specific heat loss depending on various parameters are calculated for the double-layer wall fencing and node conjugation with a basement ceiling. From the analysis of the specific heat loss values determined that the proposed solutions for wall fencing of LSTS most efficient to take a smaller thickness of the inner layer and vary the thickness of the outer heat-insulating layer. Proposed solutions for node conjugation of wall fencing with a basement ceiling allow dispose positioning steel profiles in the area with positive temperature by thermofiller and their echelon allow overlap joints of the lower insulation layer by a top layer.

References

1. Mezentseva, Ye.A., Lushnikov, S.D. Bystrovozvodimyye zdaniya iz legkikh stalnykh konstruktsiy [Lightweight steel buildings]. Vestnik MGSU. Spetsvypusk. 2009. No. 1. Pp. 62–64.
2. Gorshkov, A.S. Energoeffektivnost v stroitelstve: voprosy normirovaniya i mery po snizheniyu energopotrebleniya zdaniy [The energy efficiency in the field of construction: questions of norms and standarts and solutions for the reduction of energy consumption at buildings]. Magazine of Civil Engineering. 2010. No. 1. Pp. 9–13. (rus)
3. Vatin N.I., Nemova D.V., Rymkevich P.P., Gorshkov A.S. Influence of building envelope thermal protection on heat loss value in the building. Magazine of Civil Engineering. 2012. No. 8(34). Pp. 4–14. (rus)
4. Krivoshein, A.D., Fedorov, S.V. K voprosu o raschete privedennogo soprotivleniya teploperedache [About the calculation of reduced total thermal resistance of walling]. Magazine of Civil Engineering. 2010. No. 8(18). Pp. 21–27. (rus)
5. Gagarin, V.G., Kozlov, V.V. O normirovanii teplozashchity i trebovaniya raskhoda energii na otopleniye i ventilyatsiyu v proyekte aktualizirovannoy redaktsii SNiP «Teplovaya zashchita zdaniy [On the regulation of thermal protection and energy consumption requirements for heating and ventilation in the draft updated version of SNiP "Thermal protection of buildings]. Vestnik Volgogradskogo gosudarstvennogo arkhitekturno-stroitelnogo universiteta. Seriya: Stroitelstvo i arkhitektura. 2013. No. 31-2(50). Pp. 468–474. (rus)
6. Tenpierik, M.J., Van der Spoel, W.H., Cauber, J.M. Analytical model for computing thermal bridge effects in high performance building panels [Online]. URL: http://www.researchgate.net /publication/242269808_Analytical_Model_for_Computing_Thermal_Bridge_Effects_in_High_Performance_Building_Panels (date of application: 11.12.2017)
7. Garay, R., Uriarte, A, Apraiz, I. Performance assessment of thermal bridge elements into a full scale experimental study of a building façade. Energy and buildings, 2014. No. 85. Pp. 579–591.
8. Mao, G., Johannesson, G. Dynamic calculation of thermal bridges. Energy and Buildings. 1997. Vol. 26. No. 3. Pp. 233–240.
9. Santos, P, Energy efficiency of lightweight steel-framed buildings [Online]. URL https://www.intechopen.com/books/energy-efficient-buildings/energy-efficiency-of-lightweight-steel-framed-buildings (date of application: 11.12.2017).
10. Santos, P, Martins, C, Sim es da Silva, L. Thermal performance of lightweight steel-framed construction systems. Metall Res Technol. 2014. No. 111(6). Pp. 329–338.

Литература

1. Мезенцева Е.А., Лушников С.Д. Быстровозводимые здания из легких стальных конструкций // Вестник МГСУ. Спецвыпуск. 2009. № 1. С. 62–64.
2. Горшков А.С. Энергоэффективность в строительстве: вопросы нормирования и меры по снижению энергопотребления зданий // Инженерно-строительный журнал. 2010. № 1. С. 9–13.
3. Ватин Н.И., Немова Д.В., Рымкевич П.П., Горшков А.С., Влияние уровня тепловой защиты ограждающих конструкций на величину потерь тепловой энергии в здании // Инженерно-строительный журнал. 2012. № 8(34). С. 21–27.
4. Кривошеин А.Д., Федоров С.В. К вопросу о расчете приведенного сопротивления теплопередаче // Инженерно-строительный журнал. 2010. № 8 (18). С. 21–27.
5. Гагарин В.Г., Козлов В.В. О нормировании теплозащиты и требования расхода энергии на отопление и вентиляцию в проекте актуализированной редакции СНиП «Тепловая защита зданий» // Вестник Волгоградского государственного архитектурно-строительного университета. Серия: Строительство и архитектура. 2013. № 31-2 (50). С. 468–474.
6. Tenpierik M.J., Van der Spoel W.H., Cauber J.M. Analytical model for computing thermal bridge effects in high performance building panels [Электронный ресурс]. URL:http://www.researchgate.net/publication/242269808_Analytical_Model_for_Computing_Thermal_Bridge_Effects_in_High_Performance_Building_Panels (дата обращения: 11.12.2017)
7. Garay R., Uriarte A, Apraiz I. Performance assessment of thermal bridge elements into a full scale experimental study of a building façade // Energy and buildings, 2014. № 85. Pp. 579–591.
8. Mao G., Johannesson G. Dynamic calculation of thermal bridges // Energy and Buildings. 1997. Vol. 26. № 3. Pp. 233–240.
9. Santos P, Energy efficiency of lightweight steel-framed buildings [Электронный ресурс]. URL https://www.intechopen.com/books/energy-efficient-buildings/energy-efficiency-of-lightweight-steel-framed-buildings (дата обращения 11.12.2017).
10. Santos P, Martins C, Sim es da Silva L. Thermal performance of lightweight steel-framed construction systems // Metall Res Technol. 2014. № 111(6). Pp. 329–338.
11. Roque E, Santos P. The effectiveness of thermal insulation in lightweight steel-framed walls with respect to its position [Электронный ресурс]. URL: https://www.researchgate.net/publication/313813336_The_Effectiveness_of_Thermal_In

11. Roque, E, Santos, P. The effectiveness of thermal insulation in lightweight steel-framed walls with respect to its position [Online]. URL: https://www.researchgate.net/publication/313813336_The_Effectiveness_of_Thermal_Insulation_in_Lightweight_Steel-Framed_Walls_with_Respect_to_Its_Position (date of application: 11.12.2017).
12. Enrico de, Angelis, Ermanno, Serraa. Light steel-frame walls: thermal insulation performances and thermal bridges. Energy Procedia. 2014. No. 45. Pp. 362–371.
13. Santos, P., Martins, C., Simo es da Silva, L. Thermal performance of lightweight steel framed wall: the importance of flanking thermal losses. Journal of Building Physics. 2014. No. 38(1). Pp. 81–98.
14. Naji, S., Çelik, O.C., Alengaram, U.J., Jumaat, M.Z., Shamshirband S. Structure, energy and cost efficiency evaluation of three different lightweight construction systems used in low-rise residential buildings. Energy and buildings, 2014. No. 84. Pp. 727–739.
15. Chernyavskiy, V.V., Semko, V.O., Yurin, O.I., Prokhorenko, D.A. Vliyaniye perforatsii legkikh stalnykh tonkostennykh profiley na teplofizicheskiye kharakteristiki ograzhdayushchikh konstruktsiy [The effect of perforation of light steel thin-walled profiles on the thermophysical characteristics of enclosing structures]. Otraslevoye mashinostroyeniye, stroitelstvo. Sb. nauch. trudov. Poltava: PolNTU. 2011. No. 1(29). Pp. 194–199.
16. Semko, V.O., Leshchenko, M.V., Kotko, N.O. Issledovaniya vliyaniya konstruktivnykh parametrov na teploprovodnost legkikh stalnykh ograzhdayushchikh konstruktsiy [Studies of the influence of design parameters on the thermal conductivity of light steel enclosing structures]. Stroitelstvo, materialovedeniye, mashinostroyeniye. Sb. nauchn.trudov. Dnepropetrovsk: PGASA. 2012. No. 65. Pp. 567–571.
17. Veljkovic, M., Johansson, B. Light steel framing for residential buildings. Thin-Walled Structures. 2006. Vol. 44. No. 12. Pp. 1272–1279.
18. Semko, V.O., Leshchenko, M.V., Filippovich, L.M., Reznikov, A.A. Eksperimentalnyye issledovaniya teploprovodnosti ograzhdayushchikh konstruktsiy iz stalnykh tonkostennykh profiley [Experimental studies of the thermal conductivity of enclosing structures made of steel thin-walled profiles]. Resursosberegayushchiye materialy, konstruktsii, zdaniya i sooruzheniya. Sb.nauchn.trudov. Rovno. 2013. No. 25. Pp. 606–611.
19. Kuzmenko, D.V. Ograzhdayushchaya termopanel s karkasom iz termoprofiley [Enclosing thermopanel with a frame made of thermoprofiles]. Zhilishchnoye stroitelstvo. 2009. No. 4. Pp. 2–4. (rus)
20. Kuzmenko, D.V., Vatin, N.I. Ograzhdayushchiye konstruktsii «nulevoy» tolshchiny dlya karkasnykh zdaniy [Zero thickness fencing structures for frame buildings]. Magazine of Civil engineering. 2008. No. 1. Pp. 13–21. (rus)
21. Davies, J.M. Light gauge steel cassette wall construction – theory and practice. Journal of Constructional Steel Research. 2006. Vol. 62. No. 11. Pp. 1077–1086.
22. Leshchenko, M.V., Semko, V. Thermal characteristics of the external walling made of cold-formed steel studs and polystyrene concrete. Magazine of Civil Engineering. 2015. No. 8. Pp. 44–55. (rus)
23. Petrosova, D.V., Kuzmenko, N.M., Petrosov, D.V. Eksperimentalnoye issledovaniye teplovogo rezhima legkoy ograzhdayushchey konstruktsii v naturnykh usloviyakh [A field experimental investigation of the thermal regime of lightweight building envelope construction]. Magazine of Civil Engineering. 2013. No. 8(43). Pp. 31–37. (rus)
24. Gagarin, V.G., Kozlov, V.V., Sadchikov, A.V., Mekhnetsov, I.A. Prodolnaya filtratsiya vozdukha v sovremennykh ograzhdayushchikh konstruktsiyakh [Accounting for longitudinal air filtration in the evaluation of thermal protection of the wall with a ventilated facade]. AVOK. 2005. No. 8. Pp. 60–70. (rus)

sulation_in_Lightweight_Steel-Framed_Walls_with_Respect_to_Its_Position (дата обращения: 11.12.2017).

12. Enrico de Angelis, Ermanno Serraa. Light steel-frame walls: thermal insulation performances and thermal bridges// Energy Procedia. 2014. № 45. Pp. 362–371.
13. Santos P., Martins C., Simo es da Silva L. Thermal performance of lightweight steel framed wall: the importance of flanking thermal losses // Journal of Building Physics. 2014. № 38 (1). Pp. 81–98.
14. Naji S., Çelik O.C., Alengaram U. J., Jumaat M.Z., Shamshirband S. Structure, energy and cost efficiency evaluation of three different lightweight construction systems used in low-rise residential buildings// Energy and buildings, 2014. № 84. Pp. 727–739.
15. Чернявский В.В., Семко В.О., Юрин О.И., Прохоренко Д.А. Влияние перфорации легких стальных тонкостенных профилей на теплофизические характеристики ограждающих конструкций // Отраслевое машиностроение, строительство. Сб. науч. трудов. Полтава: ПолНТУ. 2011. №1(29). С. 194–199. URL: http://lib.pntu.edu.ua/?module=ellib*nid*7879
16. Семко В.О., Лещенко М.В., Котько Н.О. Исследования влияния конструктивных параметров на теплопроводность легких стальных ограждающих конструкций // Строительство, материаловедение, машиностроение. Сб. науч. трудов. Днепропетровск: ПГАСА. 2012. № 65. С. 567–571.
17. Veljkovic M., Johansson B. Light steel framing for residential buildings // Thin-Walled Structures. 2006. Vol 44. № 12. Pp. 1272–1279.
18. Семко В.О., Лещенко М.В., Филиппович Л.М., Резников А.А. Экспериментальные исследования теплопроводности ограждающих конструкций из стальных тонкостенных профилей // Ресурсосберегающие материалы, конструкции, здания и сооружения. Сб.научн.трудов. Ровно, 2013. № 25. С. 606–611.
19. Кузьменко Д.В. Ограждающая термопанель с каркасом из термопрофилей // Жилищное строительство. 2009. № 4. С. 2–4.
20. Кузьменко Д.В., Ватин Н.И. Ограждающие конструкции «нулевой» толщины для каркасных зданий // Инженерно-строительный журнал. 2008. № 1. С. 13–21.
21. Davies J.M. Light gauge steel cassette wall construction – theory and practice // Journal of Constructional Steel Research. 2006. Vol. 62. № 11. С. 1077–1086.
22. Лещенко М.В., Семко В.А. Теплотехнические свойства стеновых ограждающих конструкций из стальных тонкостенных профилей и полистиролбетона // Инженерно-строительный журнал. 2015. № 8. С. 44–55.
23. Петросова Д.В., Кузьменко Н.М., Петросов Д.В. Экспериментальные исследования теплового режима легкой ограждающей конструкции в натурных условиях // Инженерно-строительный журнал. 2013. № 8. С. 31–37.
24. Гагарин В.Г., Козлов В.В., Садчиков А.В., Мехнецов И.А. Продольная фильтрация воздуха в современных ограждающих конструкциях // АВОК. 2005.№ 8. С. 60–70.
25. Гагарин В.Г., Козлов В.В., Садчиков А.В. Учет продольной фильтрации воздуха при оценке теплозащиты стены с вентилируемым фасадом // Промышленное и гражданское строительство. 2005. № 6. С. 42–45.
26. Петриченко М.Р., Петросова Д.В., Петроченко М.В. Фильтрационный процесс воздухом консервативной примеси (температуры и теплоты) сквозь стену // Научно-технические ведомости СПбГПУ. 2012. № 4(159). С. 221–226.
27. Данилов Н.Д., Шадрин В.Ю., Павлов Н.Н. Прогнозирование температурного режима угловых соединений наружных ограждающих конструкций //

25. Gagarin, V.G., Kozlov, V.V., Sadchikov, A.V. Uchet prodolnoy filtratsii vozdukha pri otsenke teplozashchity steny s ventiliruyemym fasadom [Accounting for longitudinal air filtration in the evaluation of thermal protection of the wall with a ventilated facade]. Promyshlennoye i grazhdanskoye stroitelstvo. 2005. No. 6. Pp. 42–45.
26. Petrichenko, M.R., Petrosova, D.V., Petrochenko, M.V. Filtratsionnyy protsess vozdukhom konservativnoy primesi (temperatury i teploty) skvoz stenu [Air filtration process of a conservative impurity (temperature and heat) through the wall]. Nauchno-tekhnicheskiye vedomosti SPbGPU. 2012. No. 4(159). Pp. 221–226.
27. Danilov, N.D., Shadrin, V.Yu., Pavlov, N.N. Prognozirovaniye temperaturnogo rezhima uglovykh soyedineniy naruzhnykh ograzhdayushchikh konstruktsiy [Prediction of the temperature regime of the corner joints of external enclosing structures]. Promyshlennoye i grazhdanskoye stroitelstvo. 2010. No. 4. Pp. 20–22.
28. Danilov, N.D., Sobakin, A.A., Slobodchikov, Ye.G., Fedotov, P.A., Prokopyev, V.V Analiz formirovaniya temperaturnogo polya naruzhnoy steny s fasadnoy zhelezobetonnoy panelyu [Analysis of the formation of the temperature field of the outer wall with the facade reinforced concrete panel]. Zhilishchnoye stroitelstvo. 2013. No. 11. Pp. 46–49.
29. Kornilov, T.A., Gerasimov, G.N. O nekotorykh oshibkakh proyektirovaniya i stroitelstva maloetazhnykh domov iz LSTK v usloviyakh Kraynego Severa [On some mistakes in the design and construction of low-rise houses from LSTK in the conditions of the Far North]. Promyshlennoye i grazhdanskoye stroitelstvo. 2015. No. 3. Pp. 42–46.
30. Kornilov, T.A., Gerasimov, G.N. Naruzhnyye steny maloetazhnykh domov iz legkikh stalnykh tonkostennykh konstruktsiy dlya usloviy Kraynego Severa [External walls of low-rise houses from light steel thin-walled structures for the conditions of the Far North]. Zhilishchnoye stroitelstvo. 2016. No. 6. Pp. 20–24.

Промышленное и гражданское строительство. 2010. № 4. С. 20–22.
28. Данилов Н.Д., Собакин А.А., Слободчиков Е.Г., Федотов П.А., Прокопьев В.В Анализ формирования температурного поля наружной стены с фасадной железобетонной панелью // Жилищное строительство. 2013. № 11. С. 46–49.
29. Корнилов Т.А., Герасимов Г.Н. О некоторых ошибках проектирования и строительства малоэтажных домов из ЛСТК в условиях Крайнего Севера // Промышленное и гражданское строительство. 2015. № 3. С. 42–46.
30. Корнилов Т.А., Герасимов Г.Н. Наружные стены малоэтажных домов из легких стальных тонкостенных конструкций для условий Крайнего Севера // Жилищное строительство. 2016. № 6. С. 20–24.

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Kornilov, T.A., Nikiforov, A.Y. Thermal protection of low-rise buildings from light steel thin-walled structures. Magazine of Civil Engineering. 2018. 84(8). Pp. 140–149. doi: 10.18720/MCE.84.14.