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Considering the availability of cold bridges in the design of thermal insulation shell of sandwich panels element-by-element assembly

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The work is devoted to the refinement of engineering methods for calculating heat loss through structures made of prefabricated sandwich panels. At buildings installation in places of steel structures adjunction "cold bridges" and, as a result, condensate and mildew are formed. Heat loss due to "cold bridges" can reach up to 50% of the total house heat loss and affect its energy efficiency class. The paper presents typical energy-efficient structural units of enclosing structures made of sandwich panels and the results of these nodes temperature field modelling, which allow by the DSTU ISO 10211: 2005 method to determine the linear heat transfer coefficients, which can be used in engineering calculations of relevant structures transfer resistance and supplement Annex G in DSTU B V.2.6-189: 2013. Calculation of the linear coefficient of thermal conductivity for different variants of structures adjacency will avoid thermal failures and increase the energy efficiency class of buildings

Keywords: heat loss, insulation, linear heat transfer coefficients, temperature field

Врахування наявності містків холоду при проектуванні теплоізоляційної оболонки з сендвич панелей поелементного збирання

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Роботу присвячено уточненню інженерних методів розрахунку тепловтрат крізь конструкції зі збірних сендвич панелей. При монтажі будівель в місцях примикання сталевих конструкцій утворюються «містки холоду» і, як наслідок, можливе утворення конденсату і цвілі. Тепловтрати за рахунок «містків холоду» можуть досягати до 50% від загальних тепловтрат будинком і впливати на його клас енергоефективності. В українських нормативних документах не наведено методики визначення тепловтрат крізь конструкції, які складаються з сендвич-панелей поелементної зборки, з врахуванням конструктивних особливостей та значення лінійних коефіцієнтів теплопередачі. Для типових конструктивних вузлів у додатку Г ДСТУ Б В.2.6-189:2013 наведені лише значення лінійних коефіцієнтів теплопередачі для кам'яних конструкцій та їх елементів. У роботі наведено типові енергоефективні конструктивні вузли примикання сендвич-панелей до існуючих кам'яних стін, стін із сендвич-панелей до бетонного фундаменту, карнизів із сендвич-панелей, улаштування лотків внутрішнього водовідведення та результати моделювання температурного поля цих вузлів, що дозволяють за методикою ДСТУ ISO 10211:2005 визначити лінійні коефіцієнти теплопередачі, які можна застосовувати в інженерних розрахунках опору теплопередачі відповідних конструкцій та доповнити додаток Г ДСТУ Б В.2.6-189:2013. Моделювання конструктивних вузлів реалізовано методом скінчених елементів. Обрахунок лінійного коефіцієнту теплопровідності різних варіантів примикання конструкцій дозволить уникнути теплових відмов та підвищити клас енергетичної ефективності будівель

Ключові слова: тепловтрати, утеплювач, лінійний коефіцієнт теплопередачі, температурне поле



Introduction

The use of mineral wool sandwich panels as enclosing structures allows constructing buildings with individual sizes and purposes, using typical design solutions. In addition, the use of such enclosing structures has an advantage over heavier enclosing wall panels and reinforced concrete floor slabs. However, there are also disadvantages, such as the possibility of heat loss through the prefabricated sandwich panels structure joints. At buildings installation in places of steel structures adjunction "cold bridges" and, as a result, condensate and mildew are formed. Heat loss due to "cold bridges" can reach up to 50% of the total house heat loss and affect its energy efficiency class. In the Ukrainian normative documents, there is no methodology for the heat loss designation for the structure, that is stored from the element-by-element sandwich panels' assembly, with the design features and values of linear heat transfer coefficients. For typical structural units in Annex G of DSTU B V.2.6-189: 2013 [13] only the values of linear heat transfer coefficients for stone structures and their elements are given. Therefore, the study of cold bridges' influence on the thermal insulation shell of the element-by-element sandwich panels' assembly design is an urgent task.

Review of the research sources and publications

Enclosing structures in the sandwich panels form for the houses construction began to be actively used in the late 90s of the 20th century. The advantages of such structures include the construction speed, high-quality fabricated buildings, and low cost. The panels themselves are multilayer plates, which consist of two specially treated metal sheets, with the insulation between them. Most often, mineral wool acts as insulation. It has such advantages as resistance to moisture and flame, excellent heat, and sound insulation properties. The functional characteristics of enclosing structures largely depend on the temperature fluctuations range on the inner surface. Accurate forecasting of temperature conditions for buildings enclosing structures at periodic thermal effects allows avoiding thermal failures that were investigated in [1]. Theoretical studies of temperature fluctuations amplitude on the inner surface of sandwich panels and the possibility of condensate formation on it were investigated in [2], the limits of sandwich panels' application for external walls of refrigerators buildings were revealed. In [3] the thermal insulation capacity of civil buildings' external walls based on a framework from steel profiles and dependence of thermophysical characteristics of thermos profiles on type of perforation is investigated. In [4], the actual values of linear heat transfer of complex nodal points of enclosing structures for typical building thermal insulation structural elements, which significantly affect the reduction of thermal resistance, are calculated. The shortcomings in the calculation and construction of the described elements were analysed and the further development of engineering calculation methods for enclosing structures in the study of their complex ele-

ments was provided. In [5-10] examples of thermal insulation calculations, difficult nodes in enclosing structures are given.

Definition of unsolved aspects of the problem

Sandwich panels, which are a multilayer enclosing element inhomogeneous in structure, have the main disadvantage from a thermophysical point of view – this is a significant number of assembly joints, through which heat loss occurs, condensate and mildew are formed. During building construction such "cold bridges" are not given enough attention, especially in custom solutions, such as reconstruction. In Ukrainian regulations, only a few values of linear heat transfer coefficients for standard designs of sandwich panels are given. The introduction of typical energy-efficient structural units of sandwich panels to existing stone walls or concrete foundations, sandwich panel cornices, installation of internal drainage trays, etc. will significantly increase the thermal protection of buildings. The results of modelling the temperature field of these nodes allow by the method of DSTU ISO 10211: 2005 [11] to determine the linear heat transfer coefficients that can be used in engineering calculations of heat transfer resistance of relevant structures and supplement Annex G in DSTU B V.2.6-189: 2013 [13].

Problem statement

The purpose of this work is to clarify the calculating heat loss methods of sandwich panels, taking into account the linear heat transfer coefficients of their structural units and the development of design solutions for typical energy-efficient units.

Methods of thermophysical calculations are based on the calculation of two-dimensional temperature fields by the finite element method and on engineering methods for determining linear heat transfer coefficients.

Basic material and results

Were analysed the enclosing constructions of the public building with the frame constructive scheme, the grid of columns is designed with a step 6×6 m. The roof of the building is combined with the coating. It has a small slope $i = 0,1$ and designed from sheets of profiled flooring. Between the two sheets of profiled flooring (covering and roof) light mineral wool insulation and intermediate Z-beams are provided for installation directly on the construction site. The wall protection is made of light hinged three-layer sandwich panels of factory production with a height of 1500 mm: light mineral wool insulation between two layers of profiled flooring.

For typical structural units of the light wall enclosing structures and their elements in Annex G in [13] only the values of linear heat transfer coefficients are given. Therefore, when calculating the total heat transfer by the transmission through the area of the building according to [14]

$$Q_{tr} = H_{tr,adj} (\varrho_{int,set.H} - \varrho_e) t$$

takes into account the direct generalized coefficient of heat transfer by transmission to the environment, W/K , according to the formula (12) in [14]:

$$H_x = b_{tr,x} \odot_i A_i U_i, \quad (1)$$

where A_i – the area of the i -th element of the building shell, m^2 ;

U_i – generalized heat transfer coefficient of the i -th element of the building shell, $W/(m^2 \cdot K)$;

$R_{\Sigma npi}$ – generalized heat transfer resistance of the i -th element of the building shell, $m^2 \cdot K/W$, that for opaque elements is determined in accordance with [13];

$b_{tr,x}$ – correction coefficient: $b_{tr,x} = 1$ – when calculating H_D .

In the absence of information or insufficient amount of heat-conducting inclusions in the structure, it is recommended to use an adjusting correction to the heat transfer coefficient to take into account the impact of heat-conducting inclusions, according to the formula (21) [14]:

$$U_{op,corr} = U_{op,mn} + \otimes U_{tb}, \quad (2)$$

where $U_{op,mn}$ – heat transfer coefficient of the opaque part of the structure (on the main field), $W/(m^2 \cdot K)$;

$\otimes U_{tb}$ – an additional component by default to the heat

transfer coefficient of opaque structures, U_{op} , taking into account the influence of heat-conducting inclusions, $W/(m^2 \cdot K)$, the calculated values are shown in table 4 of [14], and for the average value of the heat transfer coefficient for the opaque parts of the structures

$$U_{op,mn} < 0.4 \otimes U_{tb} = 0.15 W/(m^2 \cdot K).$$

Such a significant value of the additional component can reduce the actual value of the heat transfer resistance, so to increase the calculations accuracy, it is advisable to use the formula of the reduced heat transfer resistance of thermally inhomogeneous opaque enclosing structure (3) in [13]. Linear heat transfer coefficients can be determined by the recommendations for the design and calculation of energy-efficient design solutions of sandwich panel elements below. Determination of linear heat transfer coefficients is carried out based on calculations of two-dimensional temperature fields and methods according to [11-12].

The connection of the combined insulated roof to the stone walls of existing buildings during the reconstruction must be insulated to avoid freezing of the angle between the roof and the outer wall according to the scheme shown in figure 1.

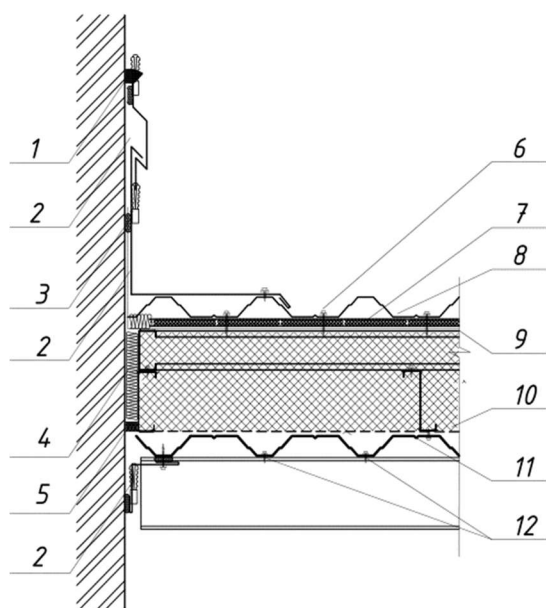


Figure 1 – The junction of the combined roof to the stone wall:

- 1 – polyurethane sealant;
- 2 – shaped strip;
- 3 – anchor with a seal;
- 4 – polyurethane gasket;
- 5 – sealing mastic;
- 6 – self-tapping screw 5,5×50;
- 7 – thermal gasket 10 mm / 50 mm;
- 8 – roof panel PK-35/0,7;
- 9 – super diffusion membrane;
- 10 – vapour barrier;
- 11 – roof panel PK -60/0,7;
- 12 – self-tapping screw 5,5×25.

The linear heat transfer coefficients of this solution are shown in table 1.

The result of the calculation of the temperature field with thermal liners for insulating metal elements from the surface with negative temperatures proved the need to comply with the design solution with a continuous insulating layer (see fig. 2).

Given that the main heat loss occurs through the uninsulated wall of the existing building, the linear coefficient is almost independent of the thermal characteristics of the roof.

Table 1 – The junction of the combined roof to the stone wall

Estimated thermal conductivity of the insulation in the combined roof, $W/(m \cdot K)$	Linear heat transfer coefficient, $W/(m \cdot K)$, depending on the availability of thermal inserts	
	with thermal inserts	without thermal inserts
0,035	-0,184	-0,163
0,040	-0,181	-0,154
0,045	-0,178	-0,145
0,050	-0,175	-0,136

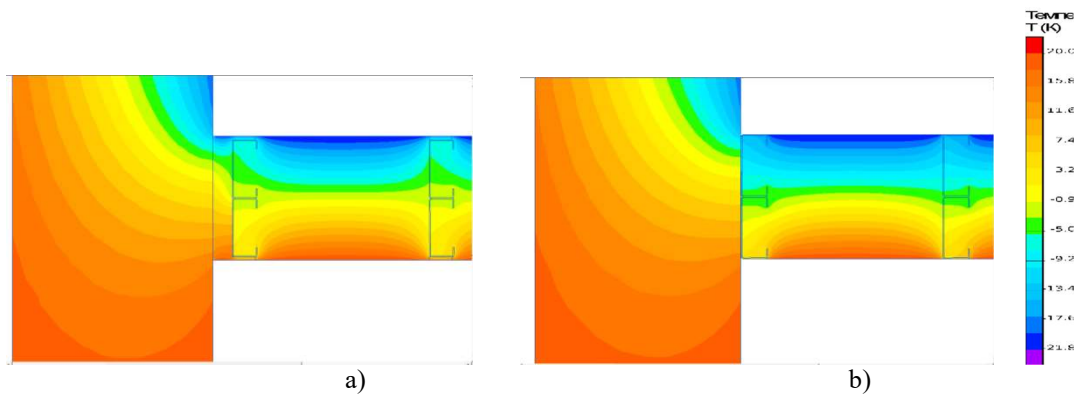


Figure 2 – The temperature field of the junction of the combined roof to the stone wall, taking into account the thermal gaskets (a) and without additional thermal insulation of metal elements (b)

The thermal insulation layer of the combined roof must be made inseparable from the thermal insulation of the insulated gutter according to the scheme shown in figure 3.

The linear heat transfer coefficients of this solution are shown in table 2. Design solutions for the installation of an external drainage system should have minimal impact on the integrity of the thermal and waterproofing layers of the roof (see fig. 4).

Table 2 – The junction of the combined roof to the gutter

Estimated thermal conductivity of the insulation in the combined roof, W/(m·K)	Linear heat transfer coefficient, W/(m·K), depending on the availability of thermal inserts	
	with thermal inserts	without thermal inserts
0,035	0,489	1,923
0,040	0,498	1,936
0,045	0,504	1,947
0,050	0,510	1,957

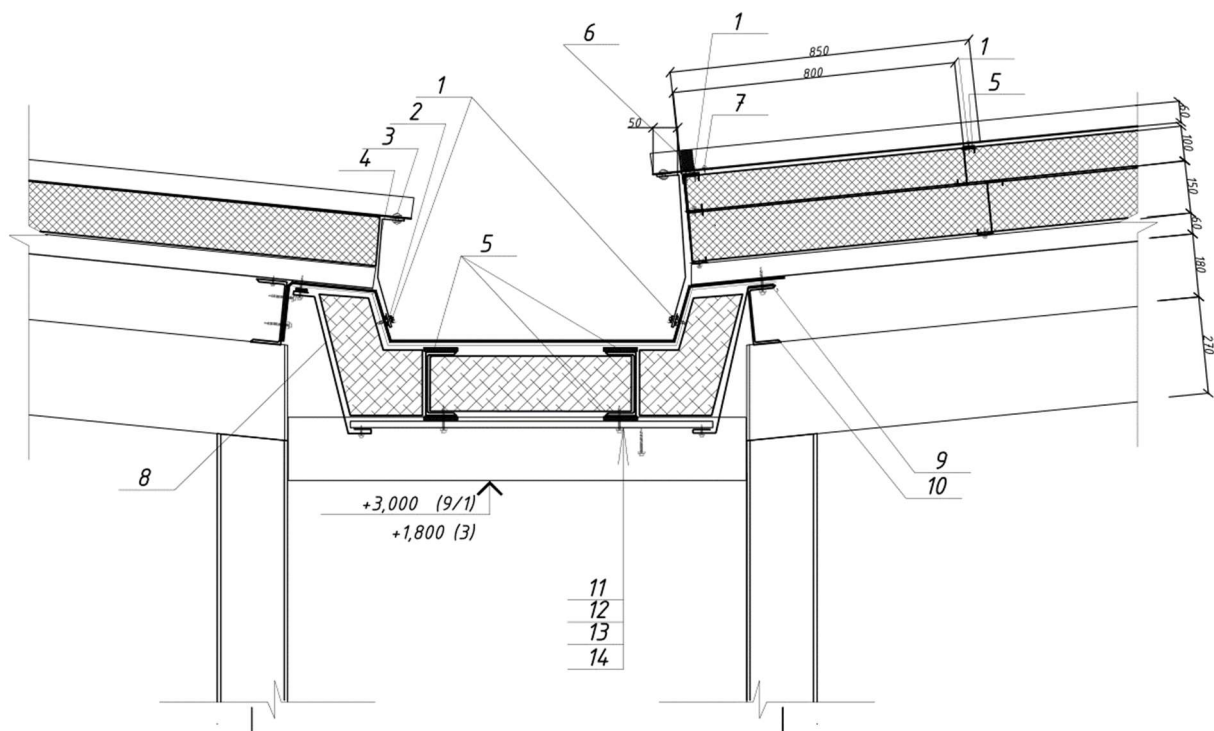


Figure 3 – The junction of the combined roof to the gutter

- 1 – self-tapping screw 5,5×50; 2 – sealant for external works; 3 – rivet (step 300 mm);
- 4 – shaped element 1; 5 – thermal gasket 10 mm / 50 mm; 6 – internal seal;
- 7 – self-tapping screw 4,8×16; 8 – shaped element 2; 9 – sealing tape; 10 – roofing beam;
- 11 – drainage gutter with electric heating, material - galvanized steel, thickness 4 mm;
- 12 – additional waterproofing layer; 13 – mineral wool of 180 mm in a polyethylene wrap;
- 14 – wall panel TP18.

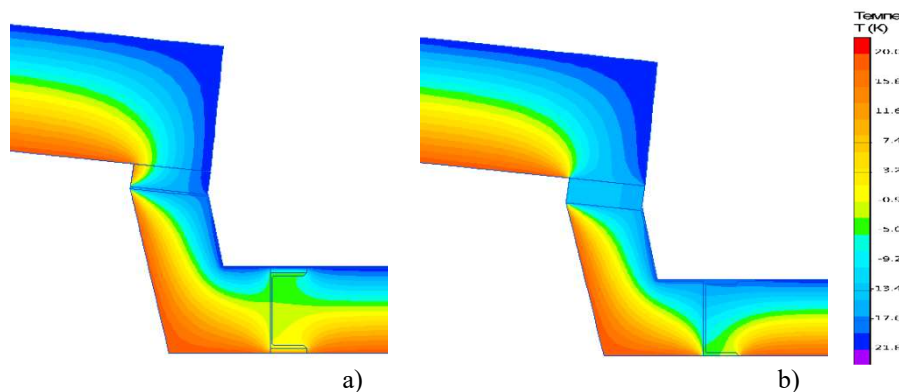


Figure 4 – The temperature field of the junction of the combined roof to the gutter, taking into account the thermal gaskets (a) and without additional thermal insulation of metal elements (b)

The temperature field modelling proved the significant influence of the gutter design on the reduced heat transfer resistance of the combined roof due to the complex geometric shape and the presence of "cold bridges".

The thermal insulation layer of eaves nodes of the combined roof must be made inseparable from the thermal insulation of the building's outer wall according to the scheme shown in figure 5.

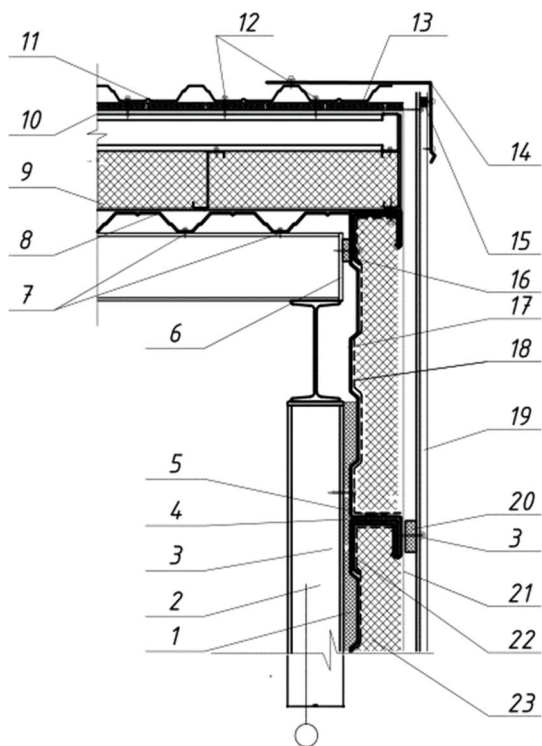


Figure 5 – The junction of the combined roof to the outer wall (eaves node)

- 1 – seal "column - sandwich";
- 2 – carcass column;
- 3 – self-tapping screw 4,8×28 with gasket;
- 4 – horizontal sandwich seal;
- 5 – self-tapping screw with a washer 4,2×16;
- 6 – plate 6 mm;
- 7 – self-tapping screw 5,5×25;
- 8 – roof panel P-60/0,7;
- 9 – vapour barrier;
- 10 – super diffusion membrane;
- 11 – roof panel PK-35/0,7;
- 12 – self-tapping screw 5,5×50;
- 13 – thermal gasket 10 mm / 50 mm;
- 14 – eaves strip;
- 15 – external seal;
- 16 – thermal gasket;
- 17 – ordinary sandwich profile;
- 18 – vapour barrier;
- 19 – metal panel TP-18;
- 20 – thermal separation strip;
- 21 – wind-waterproofing membrane;
- 22 – stiffness element 150×96,2 mm;
- 23 – thermal insulation.

The linear heat transfer coefficients of this solution are shown in table 3. Design solutions of the eaves node should prevent the formation of cold bridges, which can affect the overall heat loss of the building (see fig. 6).

To prevent the cold bridges formation, which can affect the overall heat loss of the building, proved the feasibility of using thermal gaskets that reduce the linear coefficient of thermal conductivity.

Table 3 – The junction of the combined roof to the outer wall (eaves node)

Estimated thermal conductivity of the insulation in the combined roof and wall, W/(m·K)	Linear heat transfer coefficient, W/(m·K), depending on the availability of thermal inserts	
	with thermal inserts	without thermal inserts
0,035	0,629	1,133
0,040	0,635	1,184
0,045	0,642	1,234
0,050	0,649	1,285

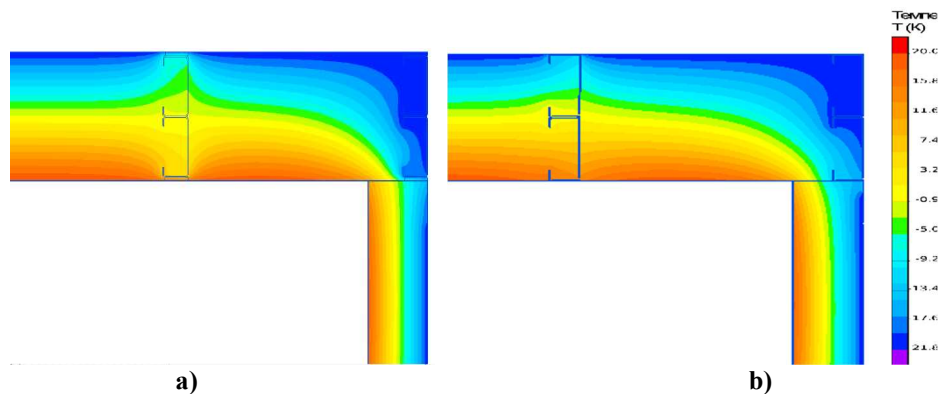


Figure 6 – The temperature field of the junction of the combined roof to the outer wall (eaves node), taking into account the thermal gaskets (a) and without additional thermal insulation of metal elements (b)

Conclusions

The use of the adjusting correction to the heat transfer coefficient to take into account the influence of heat-conducting inclusions according to the formula (21) DSTU B A.2.2-12: 2015 [14] leads to a reduction of the actual value of heat transfer resistance of multilayer structures by half. If it is necessary to obtain a certain energy efficiency class of the building as a whole, it leads to economically impractical overuse of thermal insulation material in structures and non-compliance with the condition of the thermal insulation layer continuity. The expediency of using thermal gaskets, that reduce the linear coefficient of thermal conductivity, to prevent the formation of cold bridges has been proved. The calculation of thermal conductivity linear coefficient for different options of connecting structures will avoid thermal failures and increase the energy efficiency class of buildings.

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