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LINEAR HEAT TRANSFER COEFFICIENTS OF COMBINED ROOF STRUCTURAL UNITS

ABSTRACT

The paper aims to elaborate the engineering methods of calculating heat loss through combined roof constructions. The roof heat losses can reach up to 40% of total heat losses of a building and affect its energy efficiency class. In Ukrainian construction regulations there are no roof heat loss determination methods, which would take into account the structural features as well as linear heat transfer coefficients values. For typical structural units only the linear heat transfer coefficients values for wall structures and their elements are given in the State construction standard of Ukraine DSTU Б В.2.6-189:2013 Annex Г. Putting into the insulation practice of typical energy-efficient structural units of the combined roof eaves, adjoining to the ventilation shafts and roof superstructures will significantly increase the building thermal protection. The results of these units temperature field simulation allow to use the method of State construction standard of Ukraine DSTU ISO 10211:2005 for determining the linear heat transfer coefficients that can be used in engineering calculations of the heat transfer resistance of the respective structures and to supplement the State construction standard of Ukraine DSTU Б В.2.6-189:2013 Annex Г. The combined roof structural units modeling was implemented by the finite element method. The paper is a continuation of the author's previous scientific research. The main papers are given in the bibliography.

The aim of this paper is to clarify the calculation methods of combined roofing heat losses considering heat transfer linear coefficients of roof structural units and to develop constructional solutions for typical energy efficient units.

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

KEYWORDS: heat transfer resistance, heat loss, combined roof, thermal insulation, heat transfer linear coefficient, eave, temperature field.

ЛІНІЙНІ КОЕФІЦІЄНТИ ТЕПЛОПЕРЕДАЧІ КОНСТРУКТИВНИХ ВУЗЛІВ СУМІЩЕНОЇ ПОКРІВЛІ

АНОТАЦІЯ

Стаття присвячена уточненню інженерних методів розрахунку тепловтрат крізь конструкції суміщених дахів. Тепловтрати покрівлею можуть досягати до 40% від загальних тепловтрат будинком і впливати на його клас енергоефективность.

В Українських нормативних документа не наведено методики визначення тепловтрат крізь дахи 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 стінових конструкцій та їх елементів. Впровадження в практику утеплення типових енергоефективних конструктивних вузлів карнизної частини суміщеної покрівлі, примикання до вентиляційних шахт та дахових надбудов дозволить значно підвищити теплозахист будинку. Результати моделювання температурного поля цих вузлів дозволяють за методикою ДСТУ ISO 10211:2005 визначити лінійних коефіцієнтів 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 суміщеної покрівлі реалізовано методом скінчених елементів. Стаття є продовженням попередніх наукових робіт автора, основні з яких наведено у бібліографії.

Мета роботи полягає в уточненні методів розрахунку тепловтрат суміщеними дахами з врахуванням лінійних коефіцієнтів теплопередачі їх конструктивних вузлів та розробці конструктивних рішень типових енергоефективних вузлів.

Методи дослідження базуються на розрахунку двовимірних температурних полів методом кінцевих елементів та інженерних методиках визначення лінійних коефіцієнтів теплопередачі.

КЛЮЧОВІ СЛОВА: опір теплопередачі, тепловтрати, суміщена покрівля, утеплювач, лінійний коефіцієнт теплопередачі, карниз, температурне поле.

ЛИНЕЙНЫЕ КОЭФФИЦИЕНТЫ ТЕПЛОПЕРЕДАЧИ КОНСТРУКТИВНЫХ УЗЛОВ СОВМЕЩЕННОЙ КРОВЛЕЙ

АННОТАЦИЯ

Статья посвящена уточнению инженерных методов расчета теплопотерь через конструкции совмещенных крыш. Теплопотери кровлей могут достигать до 40% от общих теплопотерь здания и влиять на его класс энергоэффективности. В Украинских нормативных документах не представлены методики определения теплопотерь через крыши с учетом конструктивных особенностей и значения линейных коэффициентов теплопередачи.

Для типовых конструктивных узлов в Приложении Г ГОСТ В.2.6-189: 2013 представлены только значения линейных коэффициентов теплопередачи для стенных конструкций и их элементов. Внедрение в практику утепления типовых энергоэффективных конструктивных узлов карнизной части совмещенной кровли, примыкания к вентиляционным шахтам и кровельных надстроек позволит значительно повысить теплозащиту дома. Результаты моделирования температурного поля этих узлов позволяют по методике ДСТУ ISO 10211: 2005 определить линейные коэффициенты теплопередачи, которые можно применять в инженерных расчетах сопротивления теплопередачи соответствующих конструкций и дополнить Приложение Г ГОСТ В.2.6-189: 2013.

Цель работы заключается в уточнении методов расчета теплопотерь совмещенными крышами с учетом линейных коэффициентов теплопередачи их конструктивных узлов и разработке конструктивных решений типовых энергоэффективных узлов.

Методы исследования базируются на расчете двумерных температурных полей методом конечных элементов и инженерных методиках определения линейных коэффициентов теплопередачи.

КЛЮЧЕВЫЕ СЛОВА: сопротивление теплопередачи, теплопотери, совмещенная кровля, утеплитель, линейный коэффициент теплопередачи, карниз, температурное поле.

INTRODUCTION

The change in conditions of economic environment in Ukraine, which occurred due to the pressure from a number of political and economic factors, including the change in pricing policy for services in the housing and utility services sector and in the market for construction products enhanced the need for rigid energy savings, thermal protection and thermal modernization of buildings in line with European standards. The introduction of new mechanisms to ensure the energy efficiency of construction and to increase the requirements for predicting the hydrothermal conditions of buildings and their structural elements will allow providing a higher level of energy savings.

Depending on the construction solution, roof heat loss can reach up to 40% of the total house heat loss. According to the laws of convection, heated air rises, so heat losses through the roof are more noticeable. In addition, the contact of heated air from the room with a cold surface of the coating will inevitably cause condensation unless the roof is insulated. Water will gradually destroy the structure of the roof, and in the case of combined roof it will flow back into the habitable inner space. Insulation is essential in creating favorable microclimate conditions in rooms that are located directly below the combined roof in both the heating and cooling period conditions.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The paper [1] provides systematization of construction systems used in planar and pitched roofs for insulation. Taking into account the experience of leading companies, the peculiarities of exterior decoration systems use were considered in the paper: construction solutions, material requirements and installation recommendations for installation of these systems. Insulating the eaves of the roof is necessary to avoid cold bridges. Sketches with practical design solutions and examples were presented in the paper [2]. The calculation of heat accumulation, taking into account the thermal stability of structures shows the need to specify the engineering methods for predicting the thermal behavior in buildings.

Roofs also require attention in the summer, as they make up a large part of the building total area and significantly absorb solar radiation. In the papers [3, 4], the advantages of using ventilated roofs to reduce cooling loads in hot climates were studied. This is the first step towards ideas that transform local construction methods to make them effective in energetic, economic and functional dimensions.

The development of energy efficient solutions for the construction of combined roofs is a continuation of the author's previous scientific research [5 - 8].

Research objective

Combined roofing is a multi-layer envelope with variable thickness layers (for example, to create a slope for organized drainage system). Therefore, the total thermal resistance varies in different areas of the structure. There are many areas where the temperature field is two or three-dimensional in the design of combined roofs. In most cases, the thermal insulation envelope in such units has intentional gaps that, when operating the building, become significant "cold bridges".

Ukrainian construction regulations do not specify any methods of roof heat loss determination which would take into account structural features as well as the values of linear heat transfer coefficients. For typical structural units in Annex *Г* of State construction standards of Ukraine DSSTU Б В.2.6-189:2013, only the values of linear heat transfer coefficients for wall structures and their elements are given. Putting into practice the insulation of typical energy efficient structural units of combined roof eaves, adjoining the ventilation shafts, parapets and roof superstructures will significantly increase the thermal protection of the house. The results of the temperature field simulation of these units allow to determine, by the method of State construction standards of Ukraine DSTU ISO 10211:2005 linear heat transfer coefficients that can be used in engineering calculations of the heat transfer resistance of the according structures and to supplement Annex *Г* of State construction standards of Ukraine DSTU Б В.2.6-189:2013.

MAIN MATERIAL AND RESULTS

There are no recommendations in Ukrainian construction regulations to consider the change in heat transfer resistance when changing the thickness of layers in the combined roof constructions. For typical structural units in Annex *Г* of State construction standards of Ukraine DSTU Б В.2.6-189:2013 only the values of linear heat transfer coefficients for wall structures and their elements are given. Therefore, when calculating the total heat transfer by transmission through a building zone according to State construction standards of Ukraine DSTU Б А.2.2-12: 2015, the direct heat transfer generic transmission coefficient to the external environment, W/K, by the formula (12) of the State construction standards of Ukraine DSTU Б А.2.2-12:2015:

$$H_x = b_{\mathrm{tr},x} \sum_i A_i U_i$$

where A_i is the area of the ith element of the building envelope, m^2;

U_i is the reduced heat transfer coefficient of the ith element of the building envelope, $W/(m^2*K)$ which equals $U_i = 1/R\Sigma_{npi}$;

$R\Sigma_{npi}$ is the reduced thermal resistance of the ith element of the building envelope, m^2*K/W, which is calculated for non-transparent elements according to the State construction standards of Ukraine DSTU Б В.2.6-189.

$b_{tr,x}$ is the correction factor: $b_{tr,x} = 1$when calculating H_D;

If there is no information (or it is insufficient) on heat-conducting inclusions in a structure, it is recommended to use a correction factor to the heat transfer coefficient to take into account the effect of heat-conducting inclusions, according to the formula (21) of the State construction standards of Ukraine DSTU Б А.2.2-12: 2015:

$$U_{\mathrm{op,corr}} = U_{\mathrm{op,mn}} + \Delta U_{\mathrm{tb}}$$

where $U_{op,mn}$ is heat transfer coefficient of a non-transparent part of the construction (on the main field), $W/(m^2*K)$, ΔU_{tb} is an additional component by default to the heat transfer coefficient of non-transparent structures, U_{op} , which includes the effect of heat-conducting inclusions, $W/(m^2*K)$, calculated values are given in Table 4 of the State construction standards of Ukraine DSTU Б А.2.2-12:2015, and for the average value of the heat transfer coefficient of non-transparent parts of construction it is $U_{op,mn} < 0{,}4$ $\Delta U_{tb} = 0{,}15\ W/(m^2*K)$.

Such a significant amount of additional component can at times reduce the actual value of combined roof thermal resistance. Therefore, to improve the accuracy of calculations, it is advisable to use the formula of the reduced thermal resistance of a thermally inhomogeneous non-transparent building envelope structure (3) in the State construction standards of Ukraine DSTU Б В.2.6-189:2013. The heat transfer linear coefficients can be calculated by the guidelines for the design and calculation of energy efficient structural solutions of combined roof elements given below.

The calculation of heat transfer linear coefficients is done on the basis of calculations of two-dimensional temperature fields and the methodology of the State construction standards of Ukraine DSTU ISO 10211-1, the State construction standards of Ukraine DSTU ISO 10211-2.

If the heat-conducting inclusion is located on the boundary of two zones, then a half of the linear heat transfer coefficient value of the heat-conducting inclusion is assigned to each zone (clause 8.2.2.5.3 of the State construction standards of Ukraine DSTU Б А.2.2-12: 2015).

The parapet of combined insulated roof has to be insulated according to the scheme (Table 1) to avoid freezing of the contact angle of the roof slab and the outer wall. The linear heat transfer coefficients of such a solution are shown in Table 1.

The thermal insulation layer of the combined roof must be indissoluble with thermal insulation of the outer wall according to the scheme (Table 2) in order to avoid freezing of the contact angle of the

Table 1 – Parapet of the combined roof

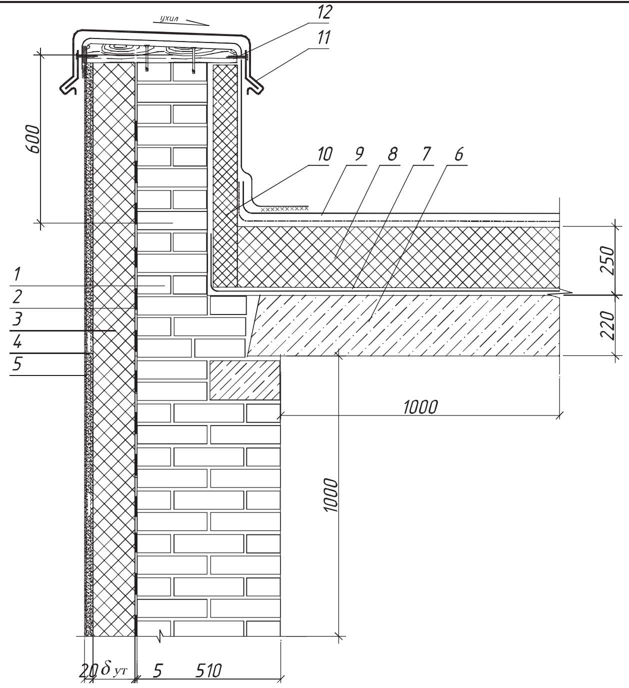
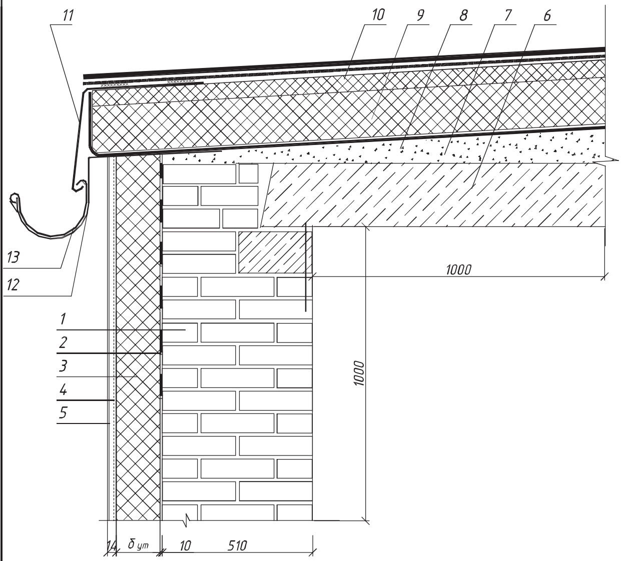
Scheme of heat-conducting inclusion	Linear heat transfer coefficients, W/(m·K), depending on the parameters of the thermal insulation layer			
	Estimated thermal conductivity, W/(m·K)	Thickness of external wall thermal insulation, *δin*		
		120 mm	150 mm	180 mm
	0,035	0,245	0,241	0,237
	0,040	0,252	0,248	0,243
	0,045	0,259	0,254	0,249
	1 – brick wall; 2 – adhesive layer for bonding the insulation boards to the base, as well as for leveling the surface of the base; 3 – thermal insulation layer - mineral wool; 4 – reinforcing fiberglass; 5 – multilayer plaster; 6 – reinforced concrete floor slab; 7 – vapor barrier; 8 – thermal insulation layer - mineral wool, 250 mm; 9 – two layers of roofing material; 10 – thermal insulation layer - mineral wool, 100 mm; 11 – sheet steel; 12 – antiseptic board.			

Table 2 – Combined roof without eaves

Scheme of heat-conducting inclusion	Linear heat transfer coefficients, W/(m·K), depending on the parameters of the thermal insulation layer			
	Estimated thermal conductivity, W/(m·K)	Thickness of external wall thermal insulation, δ*in*		
		120 mm	150 mm	120 mm
	0,040	0,162	**0,152**	0,144
	0,045	0,168	0,157	0,149
	0,050	0,175	0,162	0,153
	1 – brick wall; 2 – adhesive layer for bonding the insulation boards to the base, as well as for leveling the surface of the base; 3 – thermal insulation layer - mineral wool; 4 – reinforcing fiberglass; 5 – multilayer plaster; 6 – reinforced concrete floor slab; 7 – a layer of lightweight concrete; 8 – vapor barrier; 9 – thermal insulation layer - mineral wool, 250 mm; 10 – two layers of roofing material; 11 – cornice plate; 12 – bracket ; 13 – tray.			

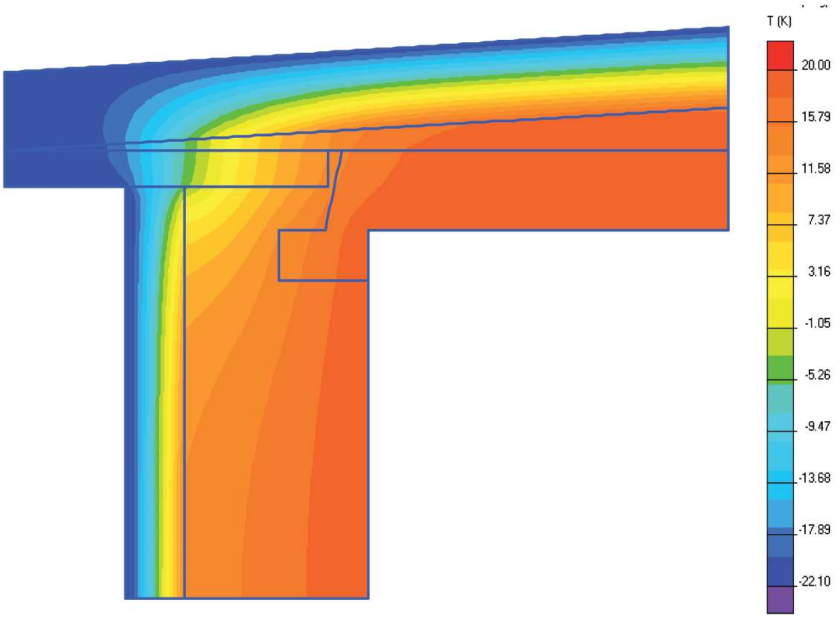
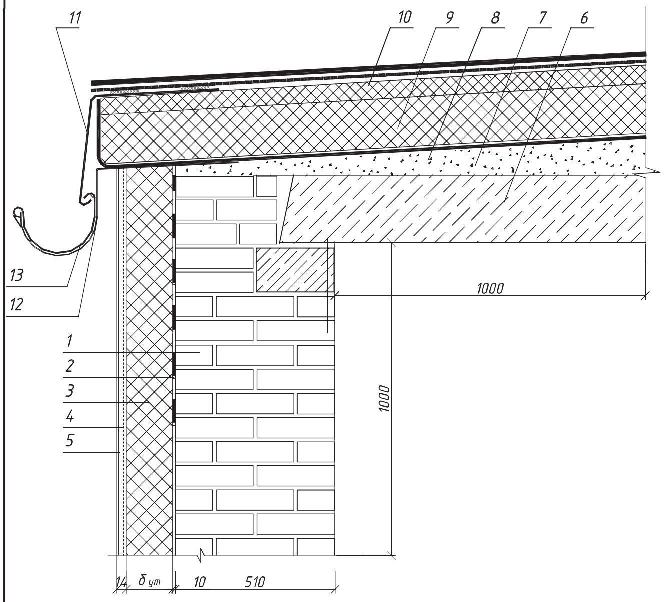


Figure 1 - Picture of the temperature field of the reinforced concrete slab eave

Table 3 – Combined roof with eaves slab

Scheme of heat-conducting inclusion	Linear heat transfer coefficients, W/(m·K), depending on the parameters of the thermal insulation layer			
	Estimated thermal conductivity, W/(m·K)	Thickness of external wall thermal insulation, δ*in*		
		120 mm	150 mm	120 mm
	0,040	0,162	**0,152**	0,144
	0,045	0,168	0,157	0,149
	0,050	0,175	0,162	0,153
	1 – brick wall; 2 – adhesive layer for bonding the insulation boards to the base, as well as for leveling the surface of the base; 3 – thermal insulation layer - mineral wool; 4 – reinforcing fiberglass; 5 – multilayer plaster; 6 – reinforced concrete floor slab; 7 – a layer of lightweight concrete; 8 – vapor barrier; 9 – thermal insulation layer - mineral wool, 250 mm; 10 – two layers of roofing material; 11 – cornice plate; 12 – bracket ; 13 – tray.			

roof slab and the outer wall. The heat transfer linear coefficients of such a solution are shown in Table 2. Design solutions for the arrangement of the external drainage system and roof edge railing should have minimal impact on the integrity of the thermal insulation and waterproofing layer of the roof.

Temperature field calculation of building eaves with a reinforced concrete slab insulated on one side only (Figure 1) shows to what extent a technological gap in thermal insulation envelope reduces its efficiency.

CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

The use of a correction factor to the heat transfer coefficient for considering the effect of heat-conducting inclusions according to the formula (21) of the State construction standards of Ukraine DSTU Б А.2.2-12:2015 leads to a decrease of thermal resistance actual value of the multilayered combined roof construction by two times. Obtaining a certain class of energy efficiency of the building, as a whole, does not lead to economically impractical waste of thermal insulation material in the roof, the energy efficiency of which is significantly reduced. Refining calculation methods of heat losses through combined roofing and putting into practice the insulation of typical energy-efficient structural units of the combined roof eaves, adjoining the ventilation shafts and roof superstructures will significantly increase the thermal protection of the house. The structural solutions proposed in this paper were used to carry out thermal modernization projects of the academic buildings of the National University "Yuri Kondratyuk Poltava Polytechnic" and to increase combined roof insulation efficiency.

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