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LINEAR HEAT-TRANSFER COEFFICIENT EQUATION FOR A WALL STRUCTURE MADE OF STEEL PROFILES

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Overall problem statement. In recent years, building structures made of cold-formed thin-walled steel profiles are finding a wide application in the building sector of Ukraine. These structures had found a wide application in low-rise construction, where they are used as a load-bearing elements of external and internal structures. Placing these profiles in walling puts the question of their influence on thermal resistance. One of the factors that affect on heat resistance of heterogeneous building envelopes is the linear heat-transfer coefficient. However, the process of its determining is quite labor-consuming and requires a simplification.

Connection with scientific and practical problems and analysis of recent research and publications. The present analysis was performed within the national budget sponsored research «Reliability and risk management of building structures» (state registration number 0113U000382).

Energy efficiency research for building envelopes made of steel thin-walled cold-formed structures are engaged by N. Vatin [3], N. Zhurina [4], P. Santos, L. Simöes da Silva, V. Ungureanu [5].

The purposeof this article is to establish the value of dependence of linear heat-transfer coefficient on geometrical parameters of thin-walled cold-formed steel profiles of U-shaped cross-section (profiles' height, shelf width, thickness and thickness of internal finishing) sited in the interior of the wall.

The core information and research results. When designing low-rise buildings and enclosures in which the bearing frame members are arranged in the body of the outer wall, special attention must be given to the thermal conductivity of these structures. Carriers appear as a heat-conductive inclusions that reduce the thermal resistance of the wall structure. According to existing standards [1, 2], the reduced thermal resistance for structures with specified values of the linear heat-transfer coefficients of heat-conductive inclusions kj can be calculated with formula:

$$R_{пр}=F_{\Sigma}/\left(\sum_{i=1}^{n} \frac{1}{R_{\Sigma i}} F_i + \sum_{j=1}^{m} k_j L_j\right)$$

where FΣ – the enclosure area, m2; R_i – the thermal resistance of the i-th thermally homogeneous zone of thermally homogeneous opaque enclosure, m2•K/W; F_i – the i-th thermally homogeneous zone area, m2; Lj – the j-th heat-conducting inclusion linear dimension on the inner surface of thermally heterogeneous enclosure, m.

Linear heat-transfer coefficient of is recommended to be determined basing the results of the computation of two-dimensional (or threedimensional) thermal fields. Computation of two-dimensional thermal fields is quite labor-consuming task for the designer. It should also be noted that for rational design engineer must consider several options and choose the best, which leads to time-consuming.

Hence, the authors have decided to derive an equation for determining the linear heat-transfer coefficient in a closed form. The equation was calculated for a wall sketch shown in Figure 1.

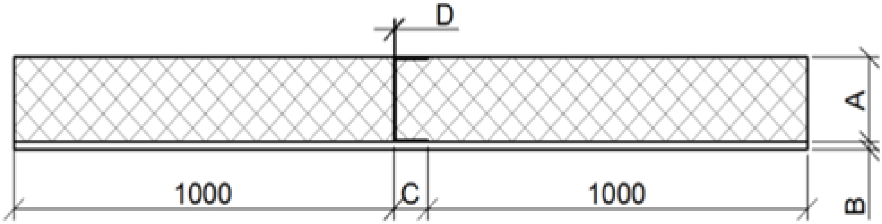

Fig. 1. The geometry of the enclosing structure

Figure 1 shows the geometry of the wall with a support section – U-shaped steel cold-formed profile. Linear dependence of the heat-transfer coefficient on four factors was determined: A - section height and therefore thickness of insulation, m; B - thickness of the inner layer of the finish, m; C - shelf width of U-shaped profile, m; D - thickness of steel profile, m.

As the material of the load-bearing profile a steel with a thermal conductivity coefficient of 58W/(m•K) was assumed. Thermal conductivity coefficient of insulation material – 0.036W/(m•K). Internal finishing layer was assumed as a gypsum plasterboard with a thermal conductivity coefficient equal to 0.21W/(m•K).

Outdoor temperature to was assumed equal to -20°C, indoor temperature ti = 22°C. Heat transfer conditions between the ambient air and the structure under study – convective heat transfer. Heat-transfer coefficients of internal and external surfaces of enclosures were adopted by Annex E [1] and made αi = 8.7W/(m2•K), αe = 23W/(m2•K).

The above parameters were the same for all models. Varying performed for four geometric parameters of walls, their values are shown in the Table 1.

Table 1

Values of variable factors for encosure's computational model

Cipher	Variables	Possible values, m
A	Profile height	0,075; 0,01; 0,125; 0,15; 0,2; 0,25
B	Thickness of the inner finishing layer	0,012; 0,025
C	Shelf width of U-shaped profile	0,04; 0,05; 0,06; 0,07; 0,08; 0,1
D	Thickness profile	0,001; 0,002; 0,003; 0,004; 0,005

With a combination of different values of variable factors 360 models have been created. For all models the two-dimensional temperature fields were obtained with the finite element method and the density of thermal flow diagrams was determined. Linear heat-transfer coefficients for each model were determined by the formula:

$$k=(q\_tv)^{\bar{}}\cdot C/((t\_i-t\_o)) \quad (2)$$

Where (q_tv)‾ – the average value of the density of a heat flow that passes through the heat conductive inclusion, W/m2, C – same as in the Table 1.

The multiple regression analysis [6] was used for obtaining the equation of the linear heat-transfer coefficient. A linear dependence was used for the approximation. As a result of analysis, the linear response function of the heat-transfer coefficient analysis was obtained:

$$k\,\hat{}=0{,}09752-0{,}37717A-4{,}16814B+2{,}1668C+25{,}43444D. \quad (3)$$

To analyze the raw data coefficients that determine the closeness of dependencebetween the response function, k and one of the factors (A, B, C, D) and the ratios indicating closeness of dependencebetween the two factors were calculated. The ratios are shown inthe Table 2.

Table 2

The coefficients of the bivariate correlation

Symbol	Meaning	Symbol	Meaning
r^{AK}	-0,326	rAC	0
r^{BK}	-0,393	rAD	0
r^{CK}	-0,621	rBC	0
r^{DK}	-0,522	rBD	0
r^{AB}	0	rCD	0

Negative correlation coefficients between the response function and the factors A and B shows that with increasing values of these factors, the value of the response function decrease. Positive values of the coefficients that determine the closeness of dependence between the factor and the response function suggests that with increasing of the value of the factor, the value of the response function increases. Zero values of pair correlation coefficients suggest that the relationship between these factors is absent.

The significance (the prediction quality) of the equation (3) can be checked with Fisher's exact test, which is equal to 12.47 in this case, which corresponds to a significance level of 1%.

The multiple correlation coefficient for the equation is (3) R= 0,959.

For convenience of writing and using, formula (3) can be simplified and written as:

$$k=0,1-0,4A-4B+2,2C+25D. \quad (4)$$

After simplifying the function its significance stays in the same range, a multiple correlation coefficient is slightly reduced to a value R = 0,957.

For testing the linear heat-transfer coefficient equation 3 models were developed, which fall within the range of considered factors (see Table 1), but does not overlap the source data for the function.

Table 3

Results' comparison

A, m	B, m	C, m	D, m	k(FEM)	k(4)	Δ, %
0,14	0,02	0,065	0,002	0,16	0,157	-1,8
0,16	0,015	0,075	0,003	0,222	0,216	-2,7
0,24	0,018	0,09	0,004	0,231	0,23	-0,4

It can be seen from the Table 3 that the delta between the results obtained using formula (4) and with the computation of two-dimensional thermal fields by finite-element modeling is about 2%. If approximated to two significant digits, this difference tends to zero.

Conclusions. As a result of research it was determined that the linear heat-transfer coefficient of a wall structure with a U-shaped profile dependence on the geometric parameters of the profile is well described by a linear function. This function could be used to analyze the effect of geometrical parameters of the profile on the thermal resistance of the wall structure and for the variant design of wall constructions.

LITERATURE

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