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THE INFLUENCE OF SOLAR RADIATION ON THE TEMPERATURE OF OUTDOOR METAL STRUCTURES

ВПЛИВ СОНЯЧНОЇ РАДІАЦІЇ НА ТЕМПЕРАТУРУ ВІДКРИТИХ МЕТАЛЕВИХ КОНСТРУКЦІЙ

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Through comparative analysis of national and foreign normative documents, expediency of generalization of values of solar radiation on all territory of Ukraine is defined. The numerical values of the temperature increments determined by the rules of Ukraine are significantly different from European standards, this leads to further research.

Європейські норми теплових ефектів відрізняються від національних більш простими методами визначення приросту температури будівельних конструкцій від впливу сонячної радіації. Під час експерименту протягом року спостерігалась температура повітря та металевих конструкцій, які були відкриті до сонячного світла. Числові значення приросту температури, визначені за нормами України, відповідають результатам експерименту, але значно відрізняються від європейських стандартів. Це потребує подальших досліджень впливу сонячної радіації на температуру відкритих металевих конструкцій.

Keywords: metal structures, temperature effects, solar radiation.

Ключові слова: металеві конструкції, температурні впливи, сонячна радіація.

Stress-strain state of metal structures that are operated outdoors, largely depends on the random changes of temperature air and direct action of solar radiation. Peculiarities of impact of solar radiation on building structures investigated in [1, 2]. Engineering method of determining the operating temperature of building structures with the influence of air and solar radiation outlined in design standards [3, 4, 5]. In state building codes of Ukraine [3] some design parameters are summarized in the margin of safety throughout the territory. Such approach simplifies the use of norms [3], but doubt about the possible errors of the calculated values of the determination of the temperature structures due to incomplete taking into account territorial variability of climatic factors. The validity of this decision relatively to the effect of solar radiation is analyzed by comparing with the previous rules [5] and European norms thermal effects [4] and the results of experimental studies of temperature of field metal structures by the method described in [7].

The normative methodology of considering the impact of solar radiation on the temperature of open building structures [3, 4, 5] regulates determination of the increments of the temperature of building structures of two types:

- average temperature on-sectional design element that causes the longitudinal thermal deformation. Determined by the formula

$$\boldsymbol{\theta_4 = 0{,}05\,\rho\, S_{max} k\, k_1}\,; \qquad (1)$$

- temperature difference within the cross-section that causes bending deformation. Determined by the formula

$$\boldsymbol{\theta_5 = 0{,}05\,\rho\, S_{max} k\,(1 - k_1)}\,. \qquad (2)$$

In formulas (1) and (2) marked:

$\boldsymbol{\rho}$ – coefficient of absorption of solar radiation by the material of the outer surface design, which according to [3] can take values from 0.3 to 0.9;

$\boldsymbol{S_{max}}$ – maximum value of the total solar radiation (W/m^2) at the surface of the corresponding orientation;

$\boldsymbol{k}$ – coefficient taking into account the orientation of exposed surfaces of structures, taking values from 0.7 to 1.0;

$\boldsymbol{k_1}$ – coefficient taking into account heat transfer through the thickness of structures (for metal structures assumed to be 0.7).

The difference between the norms [3] and [5] is that the SNIP [5] need to calculate $\boldsymbol{S_{max}}$ taking into account the geographical latitude of construction and orientation of the surface of structure, and in the DBN [3] for each surface orientation given S_{max} values common to the entire territory of Ukraine.

The necessity of taking into account the geographical location in determining changes of temperature of metal structures as a result of solar radiation is analyzed by performing comparative calculations in accordance with DBN [3] and SNIP [5] by (1) and (2). In the calculations taken into account the intensity of solar radiation for the whole territory of Ukraine, located between 44° and 52° north latitude. Solar radiation absorption coefficient ρ = 0,7 corresponds to structures of concrete and steel, painted in bright colors. The results of calculations (values of S_{max}, θ_4 i θ_5) shown in Table 1.

Table 1

The influence of solar radiation on the temperature increment of metal structures

Surface orientation	Value given by SNIP for geographical latitude			By DBN B.1.2-2:2006
	44°	48°	52°	
	The maximum solar radiation, W/m^2			
horizontal	894	866	852	890
south	428	490	547	540
west	756	764	781	780
east	756	764	781	780
	Increase of temperature θ_4 , °C			
horizontal	21,9	21,2	20,9	21,8
south	10,5	12,0	13,4	13,2
west	16,7	16,8	17,2	17,2
east	13,0	13,1	13,4	13,4
	Increase of temperature θ_5 , °C			
horizontal	9,4	9,1	8,9	9,3
south	4,5	5,1	5,7	5,7
west	7,1	7,2	7,4	7,4
east	5,6	5,6	5,7	5,7

The table shows that the total quantity of solar radiation on a horizontal surface and a surface oriented east and west, in Ukraine does not change by more than 5%. For surfaces southern orientation difference can reach 27%. Proportionally to these changes also change the temperature increments θ_4 і θ_5. The largest deviation of temperature structures determined by SNIP and DBN is Δt=2,7°C. When clamped steel elements, it causes stress difference $\Delta\sigma = \Delta t \times \alpha \times E = 2{,}7 \times 1{,}2 \cdot 10^{-5} \times 2{,}06 \cdot 10^{5} = 6{,}7$ MPa, less than 3% of the calculated resistance of mild steel. This error in measuring the stress state of the metal structure is negligible, and therefore implemented in DBN [3] refusal to taking into account the geographical position of the object construction in Ukraine in determining changes of temperature of structures from the effects of solar radiation should be considered justified.

European norms EN 1991-2-5:2003 [4], developed on the basis of [6], are more simple. If the methodology of taking into account the solar radiation is not established by national annex, EN [4] recommend in hot period to took into account the temperature increment T_3, T_4 or T_5. They are listed in Table 2, depending on the color and orientation of the surface by parts of the world. There also listed temperature increment θ_4, calculated by formula (1) DBN [3] for the same color and orientation of surfaces.

Noticeable big differences between the data EN [4] and DBN [3]. For surfaces northeastern orientation EN set much lower temperature increments than DBN, and for other surface orientations – significantly higher. This difference gives grounds for a more detailed study of the effect of solar radiation on the open structures of buildings.

Experimental investigation of the effect of solar radiation on the temperature of outdoor metal structures performed by the method published in [7]. During the year, conducted simultaneous daily observation of air temperature in the shade, beams, protected from direct sunlight by metallic screen, and beams, open to sunlight. The temperatures of both beams simultaneously varied with air temperature, but the temperature of the open beams often took somewhat higher values as a result of solar radiation.

To analyze the effect of solar radiation by the results of observations formed the sampling of temperature increment of open beams compared with air temperature. The largest increases in temperature observed during the spring-summer season (from March to August). In autumn and winter the temperature increments were significantly lower. This is consistent with the nature of seasonal changes in the intensity of solar radiation in Ukraine.

Table 2

Increases in air temperature and steel structures from the effects of solar radiation by EN 1991-2-5:2003 and DBN B.1.2-2:2006

Type of surface	Solar radiation absorption coefficient	Designation of temperature increases	Increases of temperature in degrees at the surface orientation of structures	
			northeast	southwest and horizontal
radiant light (aluminum, steel, painted with white)	0,5	T_3 by EN	0	18
		θ_4 by DBN	10	9–16
bright colored (steel painted with color)	0,7	T_4 by EN	2	30
		θ_4 by DBN	13	13–22
dark (steel painted with dark red)	0,9	T_5 by EN	4	42
		θ_4 by DNB	17	17–28

In order to find the temperature increases depending on the state of the sky (sunny, the sun behind the clouds, cloudy) available set of data is divided into three samplings, results of the statistical analysis are shown in Table 3.

Table 3

Characteristics of increases of temperature of structures depending on the sky

State of sky	Statistical characteristics			Calculated increments for hours of day		
	M	S	D_{max}	8	10	12
sunny	3,45	2,77	12,0	13,3	10,1	3,5
the sun behind the clouds	2,11	1,55	11,0	–	–	–
cloudy	1,69	1,10	6,5	3,0	2,3	1,7

Temperature increment of open beams caused the solar radiation, is systematically increased during the transition from cloud to sunny. This is apparent as from changes mean value M and standard S, in increasing the largest observed increases of temperature D_{max}.

Comparison of experimental results with the calculated values of temperature changes is also made in Table 3. The right column contains temperature changes, calculated by formula (1) for those times of the day, in which mainly performed measurements. In the first line of the table (sunny weather) are changes in temperature, calculated from the values of total solar radiation in July. In the last line of the table (cloudy) are changes in temperature, calculated from the values of scattered solar radiation in July. The table shows that the average and largest observed values for a year measuring temperature changes are consistent with the calculated values.

The analysis found that solar radiation significant effect on the temperature of outdoor building structures. Slight variability of values of solar radiation within the territory of Ukraine allows to set summarized values that are dependent on the orientation of the surface by parts of the world. Calculated temperature increment of steel structures, open sunlight, in general agree with experimental data, but large differences between national and European norms motivate to further studies of the effect of solar radiation on the temperature of open building structures.

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