БУДІВНИЦТВО ТА ЦИВІЛЬНА ІНЖЕНЕРІЯ

UDK 624.042.5 DOI: https://doi.org/10.32515/2664-262X.2024.9(40).2.41-49

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Zoning of Thermal Actions on Load-Bearing Structures for the Territory of Ukraine

Based on the results of previously conducted research, an administrative-territorial zoning of the characteristic values of thermal changes during summer and winter structural welding of load-bearing elements was performed. The independence of temperature changes from the height above sea level has been revealed. Significant changes by the territory of Ukraine confirmed the need for territorial zoning of temperature on load-bearing structures.
thermal actions, meteorological data, territorial zoning

Formulation of the problem. Changes in outside air temperature can cause significant deformations and internal forces in the load-bearing structures. The current standard DBN B.1.2-2:2006 "Loads and impacts" establish uniform calculation parameters of outside air temperature for the entire territory of Ukraine, which are used to assess the stress-strain state of load-bearing structures. In the previously performed studies of the authors, significant variability of these parameters was revealed and their cartographic zoning across the territory of Ukraine was carried out. In addition, it is proposed to directly regulate outside temperature differences during cold and warm structural welding. There are also known works that indicate the advantages of administrative-territorial zoning of the design parameters of climate loads and impacts, in which the regional characteristic value of the load is established for each administrative region of Ukraine.

Analysis of recent research and publications. The state building regulations of Ukraine [1] establish four parameters of temperature, namely, the structural welding temperature in the warm and cold period of the year, as well as the temperature of the coldest and warmest day. Through them, the characteristic and design values of temperature drops are calculated, which are taken into account in the calculations of load-bearing structures. A similar approach is also implemented in the Eurocode [2]. The disadvantage of this approach is the need to standardize four calculation parameters, as well as their immutability for the entire territory of Ukraine in the standards [1].

Significant variability of design parameters of outside air temperature on the territory of Ukraine was revealed and maps of their territorial zoning were developed in works [3, 4]. Also, a simplified method of normalizing the influence of temperature by directly establishing temperature differences during winter and summer structural welding is proposed, and a corresponding map of the zoning of Ukraine is developed.

The methods of displaying the territorial variability of the estimated parameters of climate loads and impacts were developed and implemented in works [5...9]. The article [5] analyzes various methods of territorial zoning. Article [6] is devoted to the development of methods of territorial zoning of climate parameters based on the use of multidimensional statistics methods. In work [7], cartographic and administrative-territorial zoning of the characteristic values of snow load, maximum wind pressure, weight of ice and wind pressure during icing was carried out. In the works [7...9], the method of administrative-territorial zoning of the design parameters of climate loads and impacts is justified and tested. In particular, the method of determining regional values of design parameters is proposed in article [8], and regional values of design parameters of outside air temperature for thermal calculations of exterior walls are established in work [9]. In general, studies [7...9] have shown that replacing several zoning maps with a single table of regional characteristic values simplifies the use of standards and ensures error-free determination of loads based on the belonging of the construction site to a certain administrative region.

The purpose of this work is to analyze the variability of the characteristic values of atmospheric temperature drops during the summer and winter structural welding and perform their administrative-territorial zoning based on the data of previously performed research.

Presentation of the main material. The initial data for the analysis were taken from works [3, 4]. The database includes 50 seaside (at a distance of up to 10 km from the coast of the Black and Azov seas), 28 mountain (at heights of more than 500 m above sea level), and 330 plain observation points of Ukraine. The characteristic values of outside air temperature changes during summer and winter structural welding for each of the observation points and recorded in a Microsoft Excel worksheet.

Specifics of the temperature regime of the coastal areas of Ukraine were studied in [10]. It has been established that coastal areas in a strip about 10 km wide are characterized by 3…5°C higher winter temperatures than in adjacent areas. Summer temperatures vary in a range of 1…2°C.

A comparison of the characteristic values of temperature differences was made for 50 coastal and 83 continental observation points in the territories of Odesa, Mykolaiv, Zaporizhzhya, and Donetsk regions, as well as the Autonomous Republic of Crimea. It was established that when the structures are closed in the warm period of the year, temperature drops Δ_{tc} on the coast can be 0.6...1.4°C lower in absolute value, and when closed in the cold period of the year, the temperature drops Δ_{tw} by 0.2...0.6 °C are lower than in the adjacent flat areas. Such differences lead to a change in stresses in rigidly fixed steel rods by only 3.4 MPa, or by 1.4% of the design resistance of low-carbon steel. Such a small difference allows to combine coastal and other flat observation points into one sample within each region.

It is common knowledge that air temperature decreases by approximately 6°C with each kilometer of altitude above sea level. In work [10], based on data from the Crimea and the Carpathians, it is shown that the minimum winter and maximum summer design values of air temperature decrease by 4...7°C per kilometer of height above sea level in mountainous areas.

The influence of height above sea level on design parameters of outside air temperature was analyzed by comparing the data of 26 mountain and 89 plain observation points from five regions of Ukraine: Zakarpattia, Lviv, Ivano-Frankivsk, Chernivtsi, as well as the Autonomous Republic of Crimea. The analysis showed that with the increase in geographic altitude, the average temperatures of the warm and cold half-year, the coldest and warmest days decrease with height and for mountain observation points can be 1.4...5.5°C lower than in the adjacent flat areas. As a result of the synchronous drop of these temperatures, the characteristic values of the temperature drop when closing in the warm Δ_{tc} and in the cold Δ_{tw} period of the year differ from the temperatures in the flat area by no more than 1.4°C. This makes it possible to carry out territorial zoning of temperature differences taking into account the data of all 408 observation points, including plain, coastal and mountain ones, as well as not to introduce corrections to the geographical height when determining thermal actions. The revealed effect is an additional advantage of direct normalization of temperature differences during summer and winter structural welding.

As in a similar study [4], the regional characteristic values of negative Δ_{tc} (with summer structural welding) and positive Δ_{tw} (with winter structural welding) outside air temperature differences are determined by the formulae:

$$\Delta_{0c} = M_{tc} - t \cdot S_{tc}, \qquad \Delta_{0w} = M_{tw} + t \cdot S_{tw}, \tag{1}$$

where t_P – argument of the normal distribution function, which corresponds to the given confidence level P of the regional characteristic value of the temperature drop;

M_{tc} and M_{tw} – average values of air temperature differences within each region during summer and winter structural welding;

S_{tc} and S_{tw} – standard deviations of regional samples of outside air temperature differences during summer and winter structural welding.

The results of calculations according to formulae (1) showed that for confidence levels from 0.8 to 0.95, the regional characteristic values of temperature differences differ by no more than 1°C. This is due to the slight variability of temperature differences within each region of Ukraine. Taking into account the reliability of territorial zoning maps in DBN [1] revealed in [11], table 1 shows the regional characteristic values of temperature differences for the confidence level P = 0.9. This means that for approximately 90% of the territory, the values of Δ_{0w} and Δ_{0c} given in Table 1 provide a margin of reliability compared to the actual data. In addition to the regional characteristic values, table 1 shows the number of observation points in the region and the average values and standard deviations of the regional samples of the characteristic values of temperature changes indicated above.

From the last lines of Table 1, it can be seen that within the territory of Ukraine, the regional characteristic values of air temperature differences during summer structural welding are measured within Δ_{0c} = –39…–47°C, and during winter structural welding – within Δ_{0w} = 30…34°C. A simple calculation shows that changes in temperature differences of 8°C and 4°C result in stress changes in a rigid steel structure of 20 MPa and 10 MPa, respectively. This is 10...20% of the design resistance of low-carbon steel.

In the current DBN [1], the values of the structural welding temperatures, as well as the temperatures of the warmest and coldest days, are established for the entire territory of Ukraine. Taking these values into account gives the following temperature differences:

- temperature changes in the cold period of the year (with structural welding in the summer): $\Delta_{tc} = t_{ec} - t_{0w}$ = –20 – 15 = –35°C;
- temperature changes in the warm period of the year (with structural welding in the winter): $\Delta_{tw} = t_{ew} - t_{0c}$ = 28 – 0 = 28°C.

A comparison with the real changes of the regional characteristic values of outside air temperature differences given in Table 1 shows that the DBN [1] underestimate possible temperature differences by 2...12°C. The performed analysis confirms the need for territorial zoning of climate and thermal actions on load-bearing structures.

The correlation between the regional characteristic values of temperature differences and their actual distributions for individual observation points is shown in the histograms from Figure 1. Light rectangles highlight the intervals with the values of temperature differences that go beyond the change in the regional values from Table 1. From the histograms, it can be seen that regional characteristic values set in the table 1 underestimate negative temperature drops for one observation point, and positive drops - for five observation points. Negative temperature drops at 77 observation points exceed the lower limit of regional values, and positive temperature drops at 69 observation points, which creates significant reserves of territorial zoning.

Table 1 – Statistical characteristics and regional characteristic values of outside air temperature differences during summer and winter structural welding

Regions of Ukraine	N	During structural welding in the summer			During structural welding in the winter		
		M_{tc}	S_{tc}	Δ_{0c}	M_{tw}	S_{tw}	Δ_{0w}
Vinnytsia Oblast	16	-41,2	0,96	-42	30,9	0,55	32
Volyn Oblast	6	-38,3	0,24	-39	29,3	0,15	30
Dnipropetrovsk Oblast	13	-42,5	1,00	-44	32,1	0,55	33
Donetsk Oblast	17	-44,1	0,96	-45	33,0	0,50	34
Zhytomyr Oblast	11	-40,9	0,98	-42	30,8	0,62	32
Zakarpattia Oblast	20	-38,7	0,97	-40	28,9	0,50	30
Zaporizhzhia Oblast	12	-41,9	0,95	-43	32,1	0,48	33
Ivano-Frankivsk Oblast	26	-39,1	1,05	-40	29,4	0,47	30
Kyiv Oblast	16	-41,6	1,11	-43	31,2	0,55	32
Kirovohrad Oblast	13	-42,4	0,99	-44	31,8	0,57	33
Autonomous Republic of Crimea	59	-35,7	2,33	-39	28,7	1,27	30
Luhansk Oblast	10	-45,6	0,96	-47	33,7	0,56	34
Lviv Oblast	34	-38,2	0,74	-39	29,1	0,44	30
Mykolaiv Oblast	10	-40,5	1,14	-42	31,0	0,60	32
Odesa Oblast	22	-39,7	1,38	-42	30,4	0,75	31
Poltava Oblast	13	-43,6	0,66	-44	32,4	0,42	33
Rivne Oblast	4	-39,2	0,47	-40	29,7	0,31	30
Sumy Oblast	14	-44,0	1,24	-46	32,7	0,70	34
Ternopil Oblast	7	-39,7	0,93	-41	29,9	0,54	31
Kharkiv Oblast	17	-44,8	0,78	-46	33,2	0,46	34
Kherson Oblast	19	-40,5	0,84	-42	31,2	0,50	32
Khmelnytskyi Oblast	9	-40,4	0,74	-41	30,4	0,41	31
Cherkasy Oblast	20	-42,3	0,89	-43	31,6	0,57	32
Chernivtsi Oblast	4	-38,5	1,46	-40	29,4	0,59	30
Chernihiv Oblast	16	-43,3	0,81	-44	32,2	0,51	33
Min	4	-45,6	0,24	-47	28,7	0,15	30
Max	59	-35,7	2,33	-39	33,7	1,27	34

Source: developed by the authors

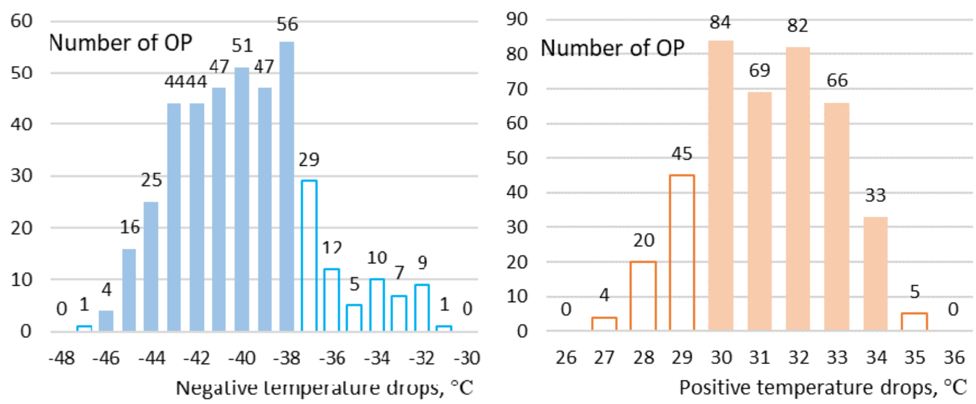

Figure 1 – Histograms of air temperature drops distribution

Source: developed by the authors

Changes in the regional characteristic values of atmospheric temperature drops across the territory of Ukraine are shown on the schematic maps from Figures 2 and 3. On these maps, according to the data in Table 1, for each region, the regional characteristic values of temperature drops during summer and winter structural welding for the confidence level of 0,9. The growth of differences is also shown in a darker color on both maps.

Figure 2 – Territorial variability of regional characteristic values of negative temperature drops during summer structural welding

Source: developed by the authors

Figure 3 – Territorial variability of regional characteristic values of positive temperature drops during winter structural welding

Source: developed by the authors

It can be seen from the maps that both positive and negative temperature differences increase quite systematically in absolute value in the direction from the southwest to the northeast of Ukraine, that is, to the regions with a continental climate. The territory of Crimea is characterized by slightly smaller differences, the sea environment of which significantly softens the climate.

The results of the performed territorial zoning of air temperature differences during the summer and winter structural welding determine the following changes to the scheme for determining the temperature and climate effects on the load-bearing structures adopted in the norms [1]. In particular, the maximum design values of temperature differences averaged over the cross-section of the structural element should be determined in the following order:

1. The characteristic value of the positive temperature drop in the warm period of the year during the winter structural welding is determined by the formula

$$\Delta_{tw} = \Delta_{0w} + \Theta_1 + \Theta_4\,, \tag{2}$$

where Δ_{0w} – the characteristic value of the positive temperature drop from Table 1;

Θ_1 – the increase in the temperature difference of the structure from the daily fluctuations of the outside air temperature according to table 11.2 DBN [1];

Θ_4 – increase in the temperature difference of the structure due to solar radiation according to clause 11.6 DBN [1].

2. The characteristic value of the negative temperature drops in the cold period of the year when the structures are closed in the summer is determined by the formula

$$\Delta_{tc} = \Delta_{0c} - 0,5 \cdot \Theta_1\,, \tag{3}$$

where Δ_{0c} – the characteristic value of the negative temperature drops from Table 1.

3. The design limit values of temperature drop during winter and summer structural welding are determined by multiplying the characteristic values (2) and (3) by the reliability coefficient, which depends on the estimated service life of the structure T:

$$\gamma_{fm} = 0,839 + 0,095 \cdot \lg(T)\,. \tag{4}$$

Formula (4) is borrowed from work [4] and for ease of use can be presented in the form of a table:

T=	10	20	30	40	50	60	80	100	120	150	200
γ_{fm}=	0,93	0,96	0,98	0,99	1,00	1,01	1,02	1,03	1,04	1,05	1,06

The presented procedure for normalization and determination of outside air temperature effects on load-bearing structures is simpler and more accurate compared to the current DBN methodology [1] and with the proposal [3, 4] regarding cartographic zoning due to the following factors:

- fewer design parameters;
- replacement of zoning maps with one table;
- independence of temperature changes from altitude above sea level, which excludes the need to take into account the factor of geographical altitude;
- absence of errors due to inaccurate determination of the location of the construction object near the borders of the territorial districts on the maps [1];
- guaranteed simplicity and accuracy of determining temperature differences depending on whether the construction site belongs to a certain administrative region.

The listed advantages make it possible to recommend the described method of normalization of outside air temperature effects for implementation in load standards and for use in calculations of load-bearing structures.

Conclusions:

1. The method of administrative-territorial zoning was used to standardize the characteristic values of outside air temperature differences, the essence of which is to establish a value that will be used throughout the region for each administrative region. Based

on the recommendations of the literature, the procedure for determining the regional characteristic values of outside air temperature differences during summer and winter structural welding has been specified.

2. According to the refined methodology, the regional characteristic values of temperature differences during summer and winter structural welding were determined for all regions of Ukraine at three levels of confidence P = 0,8, 0,9 і 0,95.

3. A change in the confidence level within the range of 0.8...0.95 has little effect on the regional characteristic values of outside air temperature differences, therefore, it is recommended to use characteristic values with a level of confidence which is equal to 0.9 for construction calculations.

4. The regional characteristic values of outside air temperature differences on the territory of Ukraine during summer structural welding are measured within –39°C…–47°C, and during winter structural welding – within 30°C…34°C.

5. Both positive temperature changes during winter structural welding and negative temperature differences during summer structural welding systematically increase in absolute value in the direction from the southwest to the northeast of Ukraine, i.e., to regions with a pronounced continental climate. The territory of Crimea is characterized by somewhat smaller differences, the sea environment of which significantly softens the climate.

6. Taking into account the results of the study, amendments were developed to the standard DBN V.1.2-2:2006 "Loads and impacts" in the procedure for determining temperature and climate effects on load-bearing structures.

7. The proposed method of normalization provides simplicity and error-free determination of outside air temperature effects on load-bearing structures due to a smaller number of design parameters, independence of temperature differences from height above sea level, replacement of zoning maps with one table, as well as accurate determination of temperature differences according to the belonging of the construction site to certain administrative region.

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Районування температурних кліматичних впливів на несучі будівельні конструкції для території України

Мета роботи полягає в аналізі та адміністративно-територіальному районуванні перепадів кліматичної температури, як силового впливу на будівельні конструкції. Для території кожної з адміністративних областей України встановлені характеристичні значення перепадів температури при літньому та при зимовому замиканні конструкцій.

Сформована в середовищі Microsoft Excel база даних включає 50 приморських, 28 гірських (на висотах понад 500 м над рівнем моря), та 330 рівнинних пунктів спостереження України. Для кожного пункту спостереження наявні температури холодного й теплого півріччя, найхолоднішої та найтеплішої доби, перепади температури при літньому та зимовому замиканні конструкцій, запозичені з раніше виконаних досліджень. Встановлено, що параметри температури повітря на приморських пунктах спостереження мало відрізняються від даних для суміжних рівнинних територій. На гірських пунктах спостереження температури холодного й теплого півріччя, найхолоднішої та найтеплішої доби є істотно нижчими, ніж на суміжних рівнинних територіях, але перепади температур при літньому та при зимовому замиканні конструкцій практично не залежать від висоти над рівнем моря.

Обласні характеристичні значення перепадів температури повітря при літньому замиканні конструкцій змінюються в межах –39°C…–47°C, а при зимовому замиканні – в межах +30°C…+34°C. Загалом додатні та від'ємні перепади температури зростають за абсолютною величиною в напрямку з південного заходу на північний схід України.

Розроблені зміни до наведеного в ДБН В.1.2-2:2006 «Навантаження і впливи» порядку визначення температурних кліматичних впливів на несучі будівельні конструкції забезпечують простоту визначення характеристичних значень перепадів температури за рахунок меншої кількості розрахункових параметрів, незалежності перепадів температури від висоти над рівнем моря, заміни карт районування однією таблицею, а також безпомилкове визначення перепадів температури за належністю будівельного майданчика до певної адміністративної області.

температурні впливи, метеорологічні дані, територіальне районування

Одержано (Received) 22.03.2024 *Прорецензовано (Reviewed) 30.04.2024*
Прийнято до друку (Approved) 26.06.2024

УДК 624.042 DOI: https://doi.org/10.32515/2664-262X.2024.9(40).2.49-59

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Аналіз тенденцій довготривалих змін кліматичних навантажень

За результатами метеорологічних спостережень протягом 1950…2020 років проаналізовані зміни в часі характеристичних значень вітрового тиску та ваги снігового покриву. Попри значні відмінності для різних метеостанцій та різних періодів спостереження, спостерігається загальна тенденція до зменшення навантажень протягом останніх 70 років. Враховуючи несистематичний характер та порівняно невелику інтенсивність виявлених змін, рекомендовано для нормування навантажень об'єднувати дані, отримані в усі періоди спостережень.

кліматичні навантаження, характеристичні значення, зміни в часі