Air temperature valuation for designing of thermal protective shell of buildings

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Abstract
The fundamentals of methodologies of valuating the temperature of atmospheric (free) air developed in order to clarify the calculated values necessary to design the thermal protective shell of buildings are stated.

Daily temperatures of free air are described by a probabilistic model of quasi-stationary differentiable random process. The expectation function is set by the Fourier series or sequence of monthly temperatures, the standard and asymmetry coeficient are determined by the math expectation. The Ordinates Distribution Law is described by a linear combination of Gauss and Gumbel distributions. The frequency structure is determined by the time-constant value of the effective frequency. The required statistical characteristics are determined by the results of systematic measurements of average daily air temperature at 485 observation points in Ukraine.

The calculated values of air temperature are determined by probabilistic methods taking into account the return period corresponding to the specified service life of the building, as well as the averaging interval of temperature, reflecting the thermal inertia of cladding. Territorial zoning map of Ukraine on characteristic values of the air temperature and analytical dependence that allows to proceed to the calculated values corresponding to the set frequency, averaging interval of temperature and height above sea level for mountain areas was designed.

Basing on the research findings, there was concluded that the developed methodology allows determining the minimum calculated values of air temperature, taking into account the above mentioned factors, and proposals on valuating allows counting the thermal inertia of the building envelope in thermal calculations and the specified period of their operation.

Keywords: AIR TEMPERATURE, THE BUILDING ENVELOPE/CLADDING, THE PROBABILITY REPRESENTATION, THE CALCULATED VALUES

Problem of energy saving holds one of the leading position in the scientific sphere of modern construction. Realized resistance in [2] raising standards of heat transfer of cladding, as well as the introduction of effective walling and facade insulation systems with different thermal inertia requires clarifying thermal calculations. The most variable parameter of these calculations is the temperature of free air. The determining factor during the designing of building cladding is calculated values of temperature in the cold season. Standards of Ukraine [3] provide only four calculated values of temperature: temperature of the coldest days and the coldest five days with provision of 0.92 and 0.98 that corresponds to average return period of the values - 12.5 and 50 years. Modern requirements and the increased capabilities of software systems that are used for thermal calculations provide the necessitate of more detailed valuating of calculated values of air taking into account the expected service life and the value of thermal inertia of building cladding. Another drawback of standards [3] is a discrete representation of the calculated values defined only for a limited list of settlements. And in case of other areas it is recommended to take the calculated values based on the nearest point of observation from number specified in the standards. However, the geographical location does not always guarantee the identity of climatic conditions and these results in possibility of a wrong choice of temperature, calculated by the designer. To clarify the choice one may by mapping the territorial zoning, as it is done in the loading instructions for structural units. [1]

The article is about foundations of the methodology of valuating of air temperature, designed as a result of years research carried by the author. Presentation of methodology is illustrated by the results of valuation made by [8] in the territory of Ukraine, although the methods of probabilistic describing of the temperature, determining, synthesis and territorial zoning for calculated values are quite applicable to other areas.

The principles of temperature valuation for designing the thermal protection cladding focus on solving these problems. The calculated values of air temperature should:

• to be determined by probabilistic methods under long-term results of systematic measurements of the temperature on a representative network of observation points;

•to take into account the return period that corresponds to the specified service life of the building, as well as the averaging interval of temperature, reflecting the thermal inertia of cladding;

• to be determined clearly and accurately for each geographic area of studied region, including mountain areas.

The probabilistic model of are temperature has been developed on the basis of a statistical analysis of results of measuring the daily temperatures at weather stations in Ukraine. According to the proposals [6] and in [8], seasonal changes and day to day variability of air temperature are presented in the form of a quasi-stationary differentiated random process. The function of the math expectation is rather accurately described by Fourier series:

$$M(t) = a_0 + a_1 \sin(0,01745\, t) + b_1 \cos(0,01745\, t)\ , \quad (1)$$

where a_0, a_1, b_1 - parameters calculated by the method of least squares.

Standard functions *S (t)* and asymmetry coefficient *A (t)* can be defined with the help of mathematical expectation function *M (t)* by the formulas:

$$S = 5,31 - 0,15M + 0,0075M^2 - 0,00024M^3\ ;$$
$$A = -0,36 + 0,045M - 0,002M^2 + 0,00003M^3\ , \quad (2)$$

that simplify significantly the probabilistic model of air temperature.

The Distribution Ordinates Law of the random process of the daily average air temperature is unimodal, but in winter and autumn months have a significant left-sided asymmetry. Experience histogram describes the Gauss - Gumbel mixed distribution with density:

$$f(x) = \frac{C}{0,78\,S}\exp[y - \exp(y)] + \frac{1-C}{S\sqrt{2\pi}}\exp\left[-\frac{(x-M)^2}{2S^2}\right], \quad (3)$$

where ***M*** and ***S*** – math expectation and distribution standard; $C = 0,8775\,|A|$ – weigh multiplier; $y = \frac{M-x}{0,78\ S}\,Sign\,(A) - 0,577$ – Gumbel distribution argument; |A| and Sign (A) – module and the asymmetry ratio.

You can also use the normal distribution for approximate calculations.

The frequency structure of random process of average daily air temperature is set by time-constant value of the effective frequency ω. According to the method [6], the effective frequencies have been calculated as a ratio of the derivative standard to a standard of this process. Taking in account the absence of predominate seasonal variability and minor territorial variability ($0,55 \le \omega \le 0,63$ 1/ per day), it is recommended to set the total effective frequency value = 0.6 1 / per day for whole territory of Ukraine.

Parameters of a probabilistic model of daily average temperatures are determined by the results of term measurements of air temperature on a network of 485 observation points, published in [4] and other specialized meteorological publications. Network of observation points adequately and evenly covers the territory of Ukraine. 91% of weather stations are located in the plain areas, and 45 observation points are located in the Carpathian and Crimean mountains at an altitude of 500 m above sea level. As shown in [5, 6], the duration of climatic series in 10 - 60 years provides the obtaining of reliable values of statistical characteristics.

The results obtained allow determining the statistical characteristics of quasi-stationary random process of daily air temperature changes for any geographic area in Ukraine in the following order:

• under designed map of territorial zoning [2, 5] one may determine the average annual temperature $M_Г$, which reduces for 6° C with increasing altitude up to 1 kilometer for the mountains with altitudes of over 500 meters.

• function of the math expectation of air temperature is determined by the formula:

$$M(t) = M_Г - 11,86\ \cos(0,01745\ t) - 3,82\ \sin(0,01745\ t)\ ; \quad (4)$$

• the corresponding values of standard and ratio of asymmetry are calculated by (2);

• the Ordinates Distribution Law is accepted as in the formula (3) or as normal;

• effective frequency is equal to = 0.6 1/per day

The characteristics shown in [8] may be used both to calculate the thermal reliability of buildings as described in [7, 9], and to normalize calculated values for the air temperature valuation (regulation).

Practical calculating methods of the estimated values of air temperature, necessary for designing of thermal protection envelope of building, have been designed and implemented in [8] on the basis of mathematical apparatus [6]. To consider thermal inertia of cladding, the calculated values of air temperature are calculated on the characteristics of the smoothed (averaged at the interval Z) random process of the temperature:

$$Y(t) = \frac{1}{Z}\int_{t-z}^{t} X(\tau)\,d\tau\ , \text{ for wich } \omega_Y = \sqrt{\frac{2}{Z}\left[1 - \exp\left(-\frac{Z}{3}\right)\right]},$$

$$M_Y(t) = M_X(t)\ ;$$

$$S_Y(t) = \frac{S_X(t)}{Z}\sqrt{6,6\,Z + 20\exp(-\alpha Z) - 20}\ . \quad (5)$$

In formulas (5) $M_X(t)$ and $M_Y(t)$ - math expectation functions for random process of daily average and smoothed temperature; $S_X(t)$ and $S_Y(t)$ - functions of the same processes for standards; Z - averaging interval of random process of air temperature depending on thermal inertia of the structure.

Considering the random process of smoothed temperature Y(t) as normal and quasi-stationary with statistical characteristics (5), set in the form of tabular sequences from 12 monthly values based on the Rice formula, there was obtained the formula for calculating the average number of exceedances of the deterministic level Y (emissions) within a year:

$$\lambda_P = \int_0^{1\,рік} \lambda(t)\,dt = 4,8\ \omega_Y \sum_{i=1}^{12}\exp\left[-\frac{(Y - M_i)^2}{2\ S_i^2}\right], \quad (6)$$

where M_i and S_i - values of functions $M_Y(t)$ and $S_Y(t)$ for the i-th month of the year according to (5); ω_Y - effective frequency of smoothed process (5), described as 1 per day; 4,8 – the ratio taking into account 30 days in a month and some of the parameters of Rice formula.

Equating (6) to the allowable frequency of exceedances, we obtain nonlinear equation, the numerical solution of which gives the minimum calculated air temperature in the area, depending on the given return period T and the averaging interval Z, which takes into account the thermal inertia of the building envelope (cladding). At approximating ordinate distribution by more accurate mixed-Gauss- Gumbel distribution into the formula (6) should be replaced by the density (3) instead of the normal distribution.

Minimum calculated values of temperature were obtained in [8] by the presented methodology and the data contained 485 observation points in Ukraine for return periods from $5 \leq T \leq 200$ years and averaging intervals from $1 \leq Z \leq$ days. According to the data of 117 observation points located at different altitudes of the Carpathian and Crimean Mountains, it was found that the minimum calculated temperature reduces for 1 º C at rise up per each 100 m above 500 m above sea level.

Generalizing of dependences of calculated values of air temperature on return period T (in years) and averaging interval Z (in days) was carried out by the introduction of relative return period $L = 365\,T / Z$. For the whole territory of Ukraine the averaged dependence of characteristic values of air temperature on the relative return period is described by a logarithmic function, as it is shown in [1, 6, 10] for atmospheric loads and effects on building structures.

Using the modified technique and program described in [6], it was developed the territorial zoning map of Ukraine on the characteristic values of minimum air temperature (calculated values of temperature corresponding to the period of relative frequency L = 10000 were taken as characteristic). Shown in Figure 1 the zoning map of Ukraine has 9 districts with the characteristic values of minimum air temperature from -12 º C up to -28 º C, which rise from the northeast to the south and west of Ukraine.

During design of heat protective cladding of buildings the minimum calculated values of air temperature are determined by taking into account the set lifetime of the building T and the specified interval Z of temperature averaging as it is shown below:

• according to the task of project and massiveness of building envelope, it is set the smoothing interval Z (in days) and return period T (in years) of calculated values of air temperature;

• from the map of the territorial zoning (Fig. 1) it is determined the characteristic value of temperature X_0, which corresponds to the relative frequency of period L = 10000;

• height of the construction area above sea level (at H <500 m should be H = 500 m) is determined;

• the calculated temperature value is calculated by the formula:

$$X(T,Z) = (X_0 - 36,5) \times [0,74 + 0,07\,\log(365\,T/Z)] + (4150 - H)/100\,, \qquad (7)$$

The designations are given above.

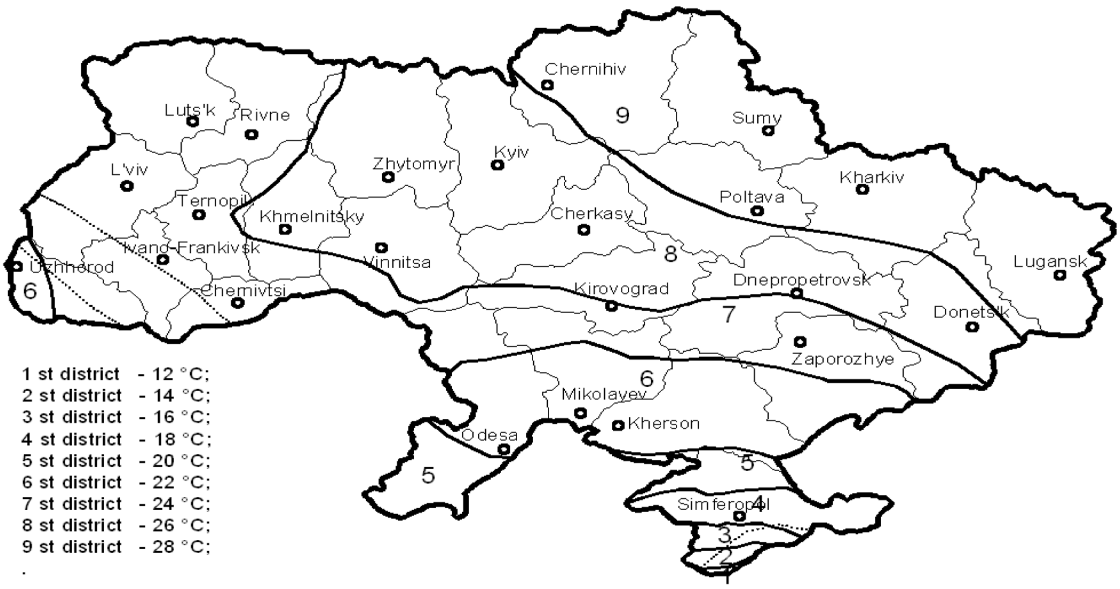

Figure 1. Zoning of Ukraine on the characteristic values of minimum air temperature X_0

Conclusions

1. The developed methodology allows determining the minimum calculated values of air temperature with specified return period and temperature averaging interval.

2. Statistical characteristics of random process of air temperature, obtained from data of observation points of Ukraine, allowed calculating, compiling and zoning the calculated values of air temperature on territory that are required for thermal calculating of building claddings

3. The given recommendations can extend the possibilities of design organizations concerning the accounting in thermal calculations of the thermal inertia of the claddings and the deadlines of their operation.

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