SCIENTIFIC PAPER
Published: February 16, 2023
https://doi.org/10.13167/2023.26.1

Long-term forecasting of thermal and humidity actions on buildings

Mykola Pashynskyi[1], Victor Pashynskyi[1], Andrii Tykhyi[1] and Serhii Karpushyn[1]

[1] Central Ukrainian National Technical University, Faculty of Construction and Transport, Department of building, road machines and construction, Universytetskyi Ave., 8, 25006, Kropyvnytskyi, Ukraine

Corresponding author:
Mykola Pashynskyi
filonalone@email.com

Received:
October 16, 2022

Accepted:
January 2, 2023

Published:
February 16, 2023

Citation:
Pashynskyi, M.; Pashynskyi, V.; Tykhyi, A.; and Karpushyn, S. (2023). Long-term forecasting of thermal and humidity actions on buildings. *Advances in Civil and Architectural Engineering*. Vol. 14, Issue No. 26. pp. 1-9
https://doi.org/10.13167/2023.26.1

ADVANCES IN CIVIL AND ARCHITECTURAL ENGINEERING (ISSN 2975-3848)

Faculty of Civil Engineering and Architecture Osijek
Josip Juraj Strossmayer University of Osijek
Vladimira Preloga 3
31000 Osijek
CROATIA

Abstract:
Global warming leads to significant long-term changes in climate loads and effects on structures, which must be considered when designing buildings. In this study, loads on buildings and structures were examined to evaluate long-term changes in temperature and humidity of the atmospheric air and to develop a method for forecasting the estimated values of these effects. According to the data obtained via weather stations in Ukraine, it was determined that long-term changes in thermal and humidity actions at different weather stations are qualitatively similar but vary numerically by a significant extent. The increase in air temperature is generally consistent with the known trend of global warming, and relative humidity is characterized by a decrease in the variance at almost constant average annual value. The proposed method of identifying and describing trends in long-term changes in climatic influences can be used in the development of regulatory documents and in directly designing buildings and structures by considering the predicted changes in climatic influences during the future life of buildings.

Keywords:
temperature; humidity; long-term changes; forecasting of design values

1 Introduction

Accurate consideration of the effects of the operating environment on the design of buildings is necessary to ensure the reliability and cost-effectiveness of building structures. The modern practice of climate action standardisation has been reduced to the establishment of characteristic and design values based on the statistical analysis of the results of previously performed meteorological observations. Sequences of annual minima, maxima, or mean annual values of the corresponding climatic characteristics are often used for this purpose [1-4]. The final stage of climate action study involves the generalisation of data from individual weather stations to reflect the territorial variability of actions in different ways [5, 6] and development of regulations that determine loads and impacts during the design of buildings and structures. A typical example of such regulations is the standard [7] that establishes the design values of climate loads in Ukraine.

The described procedure is based on the assumption of climate stability and invariance of climatic characteristics over time. Recently, significant attention has been focused on global warming. In [8-10], it was shown that during the last 100 years, the air temperature has increased by approximately 0,7 - 0,8 °C. Along with several negative phenomena reflected in [8, 9], long-term climate change has led to changes in climate actions on buildings and structures. To consider these types of changes, it is necessary to analyse the probable trends of changes in loads and impacts and develop a methodology for their consideration in the design of buildings and structures.

An attempt to detect and consider long-term changes in air temperature was made in [11]. The initial data were the results of air temperature measurements at 25 weather stations in Ukraine over 20 years. A general tendency for a slight increase in temperature was observed although a decrease in temperature was observed at certain weather stations. The increases in detected temperature did not exhibit pronounced territorial variability. In general, the results of this study [11] are consistent with the well-known trend of global warming [8-10]. The disadvantages reported in [11] correspond to the use of an insufficiently long series of observations and the paucity of clear recommendations for forecasting air temperature parameters in future years.

A review of scientific studies in this area showed that trends in long-term changes in air temperature parameters have been studied in detail. The issues related to identifying long-term changes in other climate actions, the development of methods for predicting the design values of these actions for standard updates, and the design of buildings remain open.

2 Initial data for the analysis

The generalised results of the meteorological observations at weather stations in the Kirovohrad region were used for the analysis. The region is located in the centre of Ukraine. Hence, its climatic conditions are typical for a large part of the state. A list of weather stations and their geographical characteristics is presented in Table 1. Weather stations are located close to each other in the region. The maximum distances between them were 215 km, from east to west, and 80 km from north to south. For each weather station, the following characteristics are listed in the table: name of the weather station, altitude H in meters, north latitude, and east longitude in degrees. The following columns contain the results of statistical data processing, which are described below.

According to a series of 65-year observations for each of the seven weather stations, six characteristics of climate actions are analysed, as listed in Table 1.

- mean T_{mid}, minimal T_{min}, and maximum T_{max} air temperatures during the year.
- mean W_{mid}, minimal W_{min}, and maximum W_{max} relative humidity during the year.

For each of the specified characteristics of climate actions, the following parameters are indicated in Table 1:

A and B denote coefficients of the linear equation, which determines the tendency of the long-term change in the corresponding characteristic.

S_Y = standard deviation of the actual data from the trend line.

Table 1. Geographical characteristics of weather stations and results of statistical data processing

Weather stations	**H** (m)	**North latitude** (DD)	**East longitude** (DD)	**Parameter names**	**Coefficients of dependence (1) and standard deviations of sequences of annual values:**					
					T_{min}	T_{max}	T_{mid}	W_{min}	W_{max}	W_{mid}
Bobrynets	142	48,04	32,09	A=	-64,1	-32,0	-37,2	-146,8	189,5	110,4
				B=	0,022	0,034	0,023	0,098	-0,048	-0,019
				S_Y=	3,94	2,18	0,86	5,27	1,99	2,47
Haivoron	150	48,21	29,52	A=	-129,1	-13,09	-36,8	-234,8	208,1	67,8
				B=	0,054	0,024	0,023	0,146	-0,058	0,004
				S_Y=	4,25	2,08	0,83	6,41	2,55	2,23
Dolynska	191	48,07	32,46	A=	-8,822	10,85	-40,8	-144,9	193,8	80,0
				B=	-0,006	0,012	0,025	0,098	-0,050	-0,002
				S_Y=	3,85	1,93	0,81	5,52	2,06	3,36
Znamianka	199	48,43	32,40	A=	-24,66	-32,99	-33,5	-187,3	112,0	10,9
				B=	0,001	0,034	0,021	0,120	-0,009	0,033
				S_Y=	3,76	2,14	0,85	5,78	2,06	2,22
Kropyvnytskyi	171	48,31	32,12	A=	-44,97	-13,68	-29,3	-129,9	110,3	66,7
				B=	0,011	0,024	0,019	0,090	-0,008	0,005
				S_Y=	3,72	2,16	0,87	5,53	1,77	2,14
Novomyrhorod	179	48,50	31,39	A=	-58,74	-11,75	-32,3	-30,44	195,6	127,1
				B=	0,018	0,023	0,020	0,042	-0,052	-0,026
				S_Y=	4,07	2,03	0,85	5,23	2,22	2,10
Pomichna	211	48,14	31,24	A=	-82,95	-13,27	-34,1	-48,23	102,5	93,8
				B=	0,031	0,024	0,021	0,050	-0,004	-0,009
				S_Y=	3,71	2,23	0,85	5,60	1,94	2,57

3 Long-term changes in parameters of air temperature and humidity

The results of the meteorological observations of temperature and humidity, which were selected for analysis, form sequences of annual characteristics X(t), where t denotes a calendar year. The sequences for the weather station in Kropyvnytskyi are shown in Figures 1 and 2.

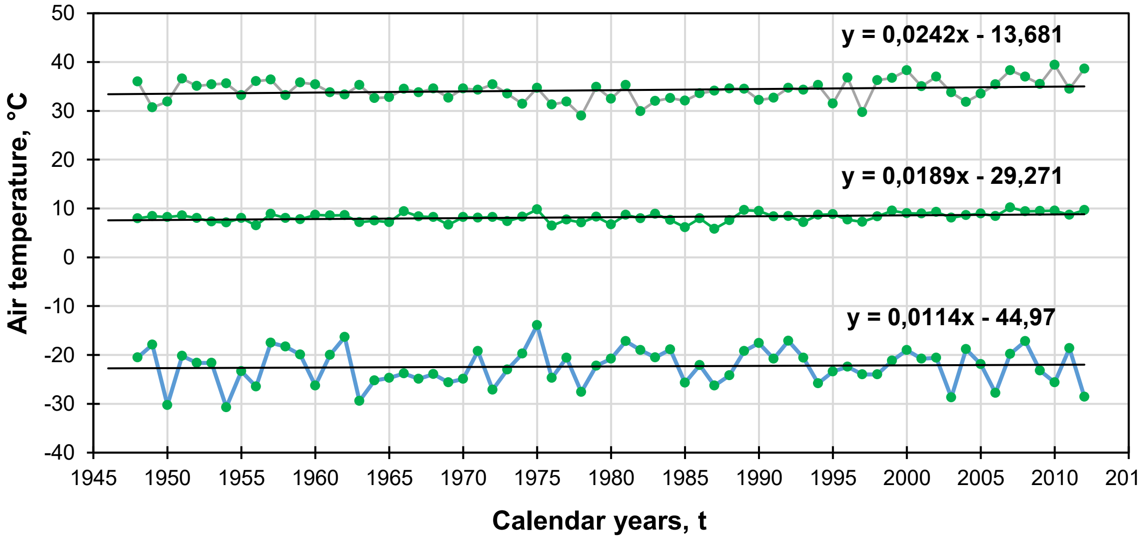

Figure 1. Sequences of annual values of air temperature at the weather station in Kropyvnytskyi

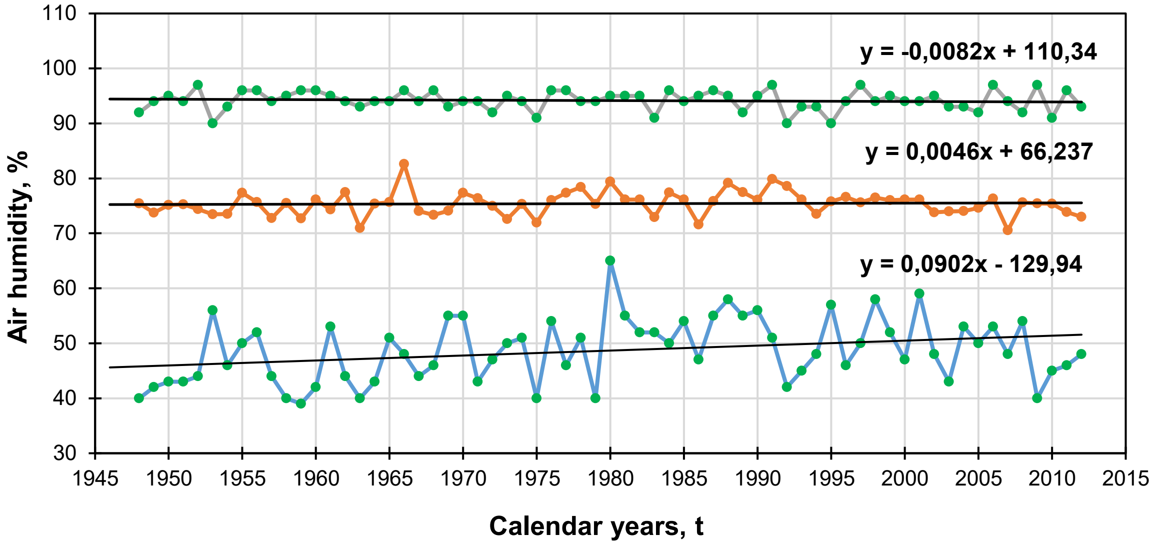

Figure 2. Sequences of annual values of humidity at the weather station in Kropyvnytskyi

The graphs in Figures 1 and 2 are random sequences that represent changes in the annual characteristics of temperature and humidity, but along with stochastic fluctuations, they exhibit trends of long-term changes, which are reflected by the following linear dependencies:

$$M_X(t) = A + B \cdot t \tag{1}$$

Where:

A and B denote coefficients determined by the least-squares method [12], and they are shown in Figures 1 and 2.

The parameters of temperature and humidity at other weather stations change over time, similar to that depicted in Figures 1 and 2. The coefficients A and B in (1) for all seven meteorological stations in the region are listed in Table 1. Coefficient B reflects the average rate of long-term change (annual increase) of the analysed climate parameters over time. Air temperature is expressed in degrees per year, and humidity is expressed in percent per year. Table 1 shows that the rates of change in the climate parameters differ significantly across weather stations. The samples of the largest, smallest, and average rates of change in climate parameters in the region are listed in Table 2.

Table 2. Generalized results of statistical processing

Analysed indicators		Values of climate parameters					
		T_{min}	T_{max}	T_{mid}	W_{min}	W_{max}	W_{mid}
Change rate of climate parameters (degrees per year for temperature and percentage per year for humidity)	least	-0,006	0,012	0,019	0,042	-0,058	-0,026
	highest	0,054	0,034	0,025	0,146	-0,004	0,033
	mean	0,019	0,025	0,022	0,092	-0,033	-0,002
Number of distributions that do not contradict the experimental data		7	7	6	7	6	6

The data in Table 2 show that the minimum, maximum, and average annual air temperatures generally increased over time. The growth rate varies from almost zero (-0,006 °C/year) to 0,054 °C/year. The average annual increase is 0,019 to 0,025 °C/year, which generally coincides with data [8-10] on the rate of global warming. The trend towards almost synchronous growth of air temperature parameters can be observed in Figure 1 and similar graphs for other weather stations.

The minimum annual humidity at the weather stations of the region increases at a rate of 0,042 to 0,146 %/year, and the maximum humidity decreases by 0,004 to 0,058 %/year. The average annual humidity remains almost stable. A decrease in the humidity range at an almost constant average annual value can be traced from Table 2 and Figure 2 and from similar graphs for other weather stations in the region.

4 Method of forecasting temperature and humidity parameters

The task of forecasting climate actions on buildings involves determining the average and design values of these actions, which can be performed in the future based on the results of the current meteorological observations. The forecasting period can correspond to the systematic review period of the climate action standards for buildings, wherein the design values can be specified, or can correspond to the established service life of the building.

To solve this problem, the weather station-centred sequences of all six climate parameters were calculated using the following formula:

$$\mathrm{Y}(t) = \mathrm{X}(t) - \mathrm{M}_X(t) = \mathrm{X}(t) - \mathrm{A} - \mathrm{B} \cdot \mathrm{t} \qquad (2)$$

Where:

X(t) denotes the initial sequence of the minimum, maximum, or average annual temperature or humidity values.

$\mathrm{M_X}$(t) – mean value of sequence X(t) determined using formula (1).

A, B – dependence coefficients (1) from Table 1.

Statistical processing of centred sequences Y(t) was performed using a previously described method [12]. The mean values of all the sequences Y(t) were equal to zero. The values of the standard deviations, S_Y, are obtained via processing as listed in Table 1. Histograms of the centred sequence distribution for the weather station in Kropyvnytskyi are shown in Figures 3 and 4. The symmetrical shapes of these histograms and all other histograms indicate the potential of describing the parameters of temperature and humidity using a normal distribution.

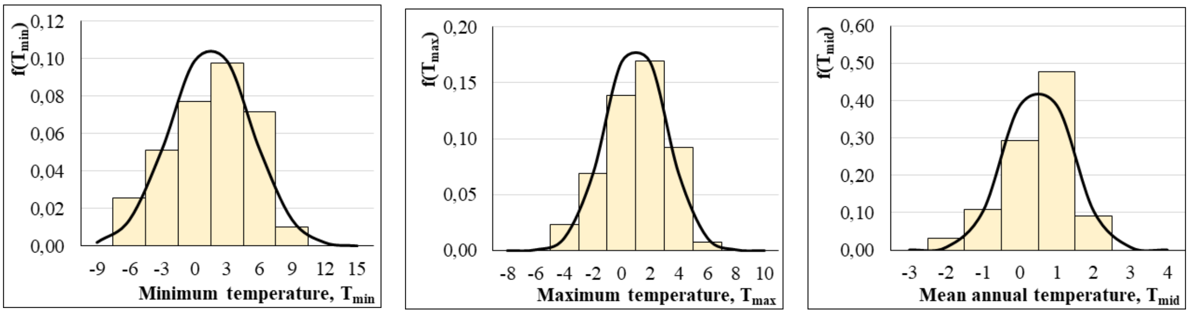

Figure 3. Distributions of air temperature parameters at the weather station in Kropyvnytskyi

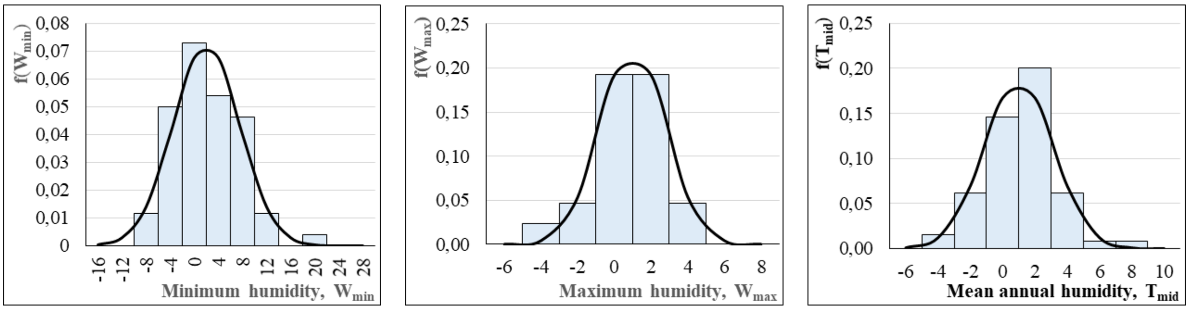

Figure 4. Distributions of humidity parameters at the weather station in Kropyvnytskyi

Compliance verification of the normal distribution with the experimental data was performed using Pearson's chi-square test [12]. The generalised results of this test are presented in the last row of Table 2, which indicates the number of cases in which the normal distribution does not contradict the experimental data at a significance level of 0,05. The consistency of 39 distributions out of the 42 tested suggests that the normal distribution can be used to probabilistically describe the centred sequences of the annual temperature and humidity parameters.

Based on the normal distribution and function of the expected value (1), we obtained a formula for calculating the design value of the climate parameters with the necessary security level:

$$X_{\beta}(\mathrm{t}) = A + B \cdot t \pm S_{\mathrm{Y}} \cdot z_{\beta} \tag{3}$$

Where:

t denotes the number of calendar years for which the forecast value was calculated.

A, B – dependence coefficients (1) from Table 1.

S_Y: standard deviation of the centred sequence of annual values of climate parameters from Table 1.

z_β denotes the argument of the normal distribution function, which corresponds to security level β.

For example, for a one-sided security of 0,98, which corresponds to the generally accepted return period of the characteristic values of climatic loads of 50 years, according to the table [12], it is recommended as z_β = 2,05, and for forecasting the average, it is recommended as z_β= 0. The sign of the last term in Equation (3) is selected depending on the climate action in such a manner that forecasting is conducted with a safety margin. For example, when predicting the maximum values of air temperature, the sign should correspond to "plus", and when predicting the minimum value, the sign should correspond to "minus".

Additionally, it is necessary to consider restrictions on the performance of certain types of work under the conditions of labour safety and to ensure the quality of technological processes during the construction of buildings and structures. The probabilistic models proposed above and the data in Table 1 allow the determination of the probabilities of the outside air temperature or humidity below (P_{below}) and above (P_{above}) the given value X according to the following formulae:

$$P_{\text{below}}(\mathrm{t}) = \mathrm{F}[\mathrm{X};\ (\mathrm{A} + \mathrm{B} \cdot \mathrm{t});\ \ S_Y\ ];\ \ P_{\text{above}}(\mathrm{t}) = 1 - \mathrm{F}[\mathrm{X};\ (\mathrm{A} + \mathrm{B} \cdot \mathrm{t});\ \ S_Y\ ] \tag{4}$$

Where:

X – given limit value of the climatic parameter;

t – the calendar year for the forecast;

A, B – dependence coefficients (1) from Table 1;

S_Y – standard deviation of the centred sequence of annual values of climate parameters from Table 1;

F(X; M; S_y) – function of the normal distribution of the climatic indicator for a given calendar year.

The probable duration of the outside air temperature or humidity below or above the given value X was calculated by multiplying the probability of P_{below} or P_{above} by the established service life of the building. It is necessary to increase the estimated duration of the technological process by this amount when planning construction work.

5 Uses and examples of climate parameters forecasting

The design parameters of the outside air temperature and humidity were used in the design, construction, and operation of construction objects in the following cases:

- Designing thermal insulation and heating systems of buildings - minimum values of outside air temperature with confidence interval of 0,92 and 0,98 (average return periods of 12,5 years and 50 years).
- Designing air-conditioning systems for buildings - maximum values of air temperature with a confidence interval of 0,95.
- Considering the force effect of temperature on the load-bearing structures - the installation completion temperatures of the structure in summer and winter are equal to

the average maximum and average minimum outside air temperature, as well as the maximum and minimum temperatures with an average return period of 50 years.

- Assessing the durability of facade materials according to the criterion of frost resistance - the average maximum relative air humidity can be used to determine the sorption humidity of the surface layer of the walls via the approximate empirical dependences.
- Planning for the time to complete erection work - the probable duration of the outside air temperature below or above the values at which it is not allowed to perform certain technological processes (for example, it is prohibited to work at a height with outside air temperature below −20 °C, and it is not possible to lay asphalt concrete at an air temperature lower than +10 °C).
- It is necessary to systematically moisten the concrete in monolithic structures at a relative humidity of less than 50 % until it solidifies.
- The listed and other similar restrictions on the execution of construction works are established by the State Construction Regulations of Ukraine on labour safety as well as the requirements for performing technological processes in construction. Some of the listed climate parameters for a network of cities in Ukraine are provided in the norms [7] as of the time when the norms were developed. Nevertheless, the data [7] does not remove the task of forecasting the values of these parameters for the established service life of the building.

As examples of the practical use of the proposed probabilistic models, a forecast of the design air temperature parameters for Kropyvnytskyi was performed.

The standard in [7] sets the minimum design value of the temperature of the coldest day with a security level of 0,98 T_{min} = –30 °C and the maximum design value of the temperature of the hottest day with a security level of 0,95 T_{max} = +29 °C. Considering the daily temperature amplitudes reported in [7] in January and July, the following design values of absolute temperature extremes were obtained: T_{min} = –33 °C and T_{max} = +36 °C. Substitution of parameters A, B, and S, from Table 1 and z_β = 2,06; in (3) leads to the following formula:

$$T_{\min}(\mathrm{t}) = -44{,}97 + 0{,}011 \cdot t - 2{,}06 \cdot 3{,}72 = 0{,}011 \cdot t - 54{,}6 \qquad (5)$$

Calculation based on formula (5) leads to T_{min} = –32,3 °C for the year 2025 (project completion) and T_{min} = –31,2 °C for the year 2125 (operation completion of a residential building).

Similar to (3) and the parameters in Table 1 and considering value z_β = 1
64, the following formula is obtained:

$$T_{\max}(\mathrm{t}) = -13{,}68 + 0{,}024 \cdot t + 1{,}64 \cdot 2{,}16 = 0{,}024 \cdot t - 10{,}1 \qquad (6)$$

Calculations based on (6) lead to T_{max} = +38,5 °C for 2025 (project completion) and T_{max} = +40,9 °C for 2125 (operation completion of a residential building).

The obtained results show that during the 100-year service life of the building, it is projected to reduce the load on the heating system and deteriorate the operating conditions of the air-conditioning system. Changes in the design values of temperature during the service life of a building are generally small, but it is advisable to use unsafe temperatures as design values.

The minimum and maximum values of the relative air humidity were determined based on formula (3) in the same manner as for the outside air temperature. Furthermore, it should be considered that the relative humidity is always in the range of 0-100 %. When obtaining physically impossible values outside this range, a humidity value of 0 % or 100 % should be considered.

The probable duration of air humidity below 50 % can be determined by formula (4) by considering the data from Table 1 for the minimum humidity W_{min}. For the city of Kropyvnytskyi, table 1 lists coefficients A = –129,9 %, B = 0,090 %, and S_Y = 5,53 %. Substituting these values into Equation (4) yields the working formula:

$$P_{\mathrm{below}}(\mathrm{t}) = \mathrm{F}[50; (0{,}09 \cdot \mathrm{t} - 129{,}9);\ 5{,}53\,] \qquad (7)$$

Calculations according to formula (7) and normal distribution tables for 2025 (construction period) provide a probability value of P_{below} = 0,335. Therefore, with a hardening time of 28 d, the probable duration of the period during which systematic moistening of monolithic concrete is required will be 0,335 - 28 = 9 d. The graph in Figure 2 shows that the minimum humidity increases over time. Therefore, in the later periods of construction, the requirement to moisten monolithic concrete decreases.

Similarly, based on Equation (4), it is possible to predict the probable duration of restrictions on the execution of technological processes as a result of excessively low or high air temperatures.

6 Conclusions

The proposed method allows identification of long-term trends in climate action changes and considers them when establishing design values and assessing the probably duration of restrictions on the performance of individual technological processes that can be implemented in future. Finally, it can be concluded:

- The forecasting period is equal to the established service life of the building or the systematic review period frequency of the climate action standards for buildings.
- Long-term changes in climate actions at the analysed weather stations have a qualitatively similar nature but significant numerical differences. Therefore, the design values should be forecasted separately for each weather station.
- An increase in air temperature was detected, which is generally consistent with the well-known trend of global warming. Furthermore, a decrease in relative humidity was detected at an almost constant average annual value.
- The next stage of the research should substantiate the forecasting technique of characteristic values of climate actions on load-bearing structures.

References

[1] Pashynskyi, M.; Pashynskyi, V.; Klymenko, E. Calculation of climate loads design values according to the probability model of annual maximum series. *Advances in Civil and Architectural Engineering,* 2021, 12 (23), pp. 61-71. https://doi.org/10.13167/2021.23.6

[2] Niemann, H. - J.; Diburg, S. Statistics of extreme climatic actions based on the Gumbel probability distributions with an upper limit. *Computers & Structures*, 126, pp. 193-198. https://doi.org/10.1016/j.compstruc.2013.03.016

[3] Yozgatlıgil, C.; Türkeş, M. Extreme value analysis and forecasting of maximum precipitation amounts in the western Black Sea subregion of Turkey. *International Journal of Climatology*, 2018, 38(15), pp. 5447– 5458. https://doi.org/10.1002/joc.5738

[4] Holický, M.; Sýkora, M. Probabilistic Models for Wind Actions. In: Proceedings Second International Symposium on Stochastic Models in Reliability Engineering, Life Science and Operations Management (SMRLO), Frenkel, I.; Lisnianski, A. (eds.). 15–18 February 2016, Beer Sheva, Israel, CPS Conference Publishing Services; 2016. pp. 172-175. https://doi.org/10.1109/SMRLO.2016.38

[5] Pashynskyi, V. et al. Method of administrative-territorial zoning of the design parameters of air temperature. *Advances in Civil and Architectural Engineering*, 2019, 10 (19), pp. 50-57. https://doi.org/10.13167/2019.19.5

[6] Kos, Ž. et al. Analysis of Methods for Determining Climate Loads at a Specified Territory Point by Meteorological Data. *Tehnički glasnik (Technical Journal)*, 2020, 14 (2), pp. 206-211. https://doi.org/10.31803/tg-20191125075805

[7] DSTU-N B V.1.1–27:2010 Zakhyst vid nebezpechnykh heolohichnykh protsesiv, shkidlyvykh ekspluatatsiinykh vplyviv, vid pozhezhi. Budivelna klimatolohiia, Kyiv, Ukraine, 2011. Accessed: 08.02.2023. Available at: https://dbn.co.ua/load/normativy/dstu/dstu_b_v_1_1_27_2010/5-1-0-929 [in Ukrainian]

[8] Wikipedia. Climate change. Accessed: 16.10.2022. Available at: https://en.wikipedia.org/wiki/Climate_change

[9] Zmina klimatu: naslidky ta zakhody adaptatsiyi. Analitychna dopovid. K.: Natsionalnyi instytut stratehichnykh doslidzhen, Ukraine, 2020. Accessed: 16.10.2022. Available at: https://niss.gov.ua/sites/default/files/2020-10/dop-climate-final-5_sait.pdf [in Ukrainian]

[10] World Meteorological Organization. State of Climate in 2021: Extreme events and major impacts. Accessed: 16.10.2022. Available at: https://public.wmo.int/en/media/press-release/state-of-climate-2021-extreme-events-and-major-impacts

[11] Karyuk, A. M. Zakonomirnosti mizhrichnoyi minlyvosti temperatury atmosfernoho povitrya. Resursoekonomni materialy, konstruktsiyi, budivli ta sporudy. 2013, 27, pp. 321-326. Accessed: 16.10.2022. Available at: http://irbis-nbuv.gov.ua/cgi-bin/irbis_nbuv/cgiirbis_64.exe?C21COM=2&I21DBN=UJRN&P21DBN=UJRN&IMAGE_FILE_DOWNLOAD=1&Image_file_name=PDF/rmkbs_2013_27_45.pdf [in Ukrainian]

[12] Gatti, P. L. *Probability Theory and Mathematical Statistics for Engineers.* 1st Edition, London, UK: CRC Press, 2005. https://doi.org/10.1201/9781482267761