http://www.moderntechno.de/index.php/meit/article/view/meit26-02-011
DOI: 10.30890/2567-5273.2023-26-02-011

UDC 692.231.2:624.042.5

STATISTICAL CHARACTERISTICS OF WALL TEMPERATURE FOR ASSESSING THERMAL RELIABILITY AND ENERGY EFFICIENCY OF RESIDENTIAL BUILDINGS

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Abstract. *The paper presents the results of field experimental studies of the temperature regime of the walls of three residential buildings during the heating season. The temperatures of the outside air and the outer surface of the walls are quasi-stationary random processes. Indoor air temperature, the inner surface of the walls' temperature and the difference between them can be presented in the form of stationary random processes or random variables with a normal distribution law. The obtained statistical characteristics of these temperatures can be used in the probabilistic assessment of the thermal reliability level of enclosing structures.*

Keywords: *walls of residential buildings, temperature regime, statistical characteristics of temperatures*

Introduction.

To ensure a sufficient level of thermal reliability of enclosing structures, design standards [1] set the minimum allowable value of heat transfer resistance, the maximum allowable difference between the temperature of the inner surface of the wall and indoor temperature, and establish the inadmissibility of condensation due to drop of inner surface temperature below dew point. Calculations according to the method [1, 2] are performed taking into account the determined design values of indoor and outdoor air temperature, dew point temperature, as well as the size of the structure and thermophysical characteristics of materials.

General principles and probabilistic methods for estimating the level of thermal reliability, taking into account the stochastic nature of these design parameters are set out in [3, 4, 5]. For the practical use of calculation methods [4, 5] it is necessary to present all the design parameters in the form of random variables. Probabilistic description of atmospheric air temperature based on the results of long-term meteorological observations was performed in [6, 7] and other works. Experimental studies and probabilistic representation of thermophysical characteristics of some building materials were performed in [8, 9]. The norms [1] set the design values of air temperature in room for various purposes, but data on its real statistical variability in the available scientific literature are missing.

Based on the information above, the task of this work is formulated: to experimentally obtain the implementation of random processes of temperature changes in the typical points of the walls, of the outdoor and indoor air temperature and perform a probabilistic representation of these temperatures.

Objects and methods of research.

Experimental studies of the thermal regime of the walls were conducted for three residential buildings in the city of Kropyvnytskyi according to the method developed in [10]. Preliminary results of the experiment on the object №1 are presented in [11].

The object of study №1 is the outer wall on the eighth floor of a precast concrete residential building, oriented to the northeast. The wall is made of expanded clay concrete with a thickness of 350 mm with external facade insulation of expanded polystyrene with a thickness of 50 mm and has a heat transfer resistance of 2.05 $m^2·K/W$. Autonomous heating with manual temperature control of the heat carrier.

Object of study №2 - expanded clay concrete wall on the fourth floor of a precast concrete residential building, oriented to the north-west. The 300 mm thick wall has a heat transfer resistance of 1.07 $m^2·K/W$. Autonomous heating with automatic temperature control of the heat carrier.

The object of study №3 - the wall of a residential building made of expanded clay concrete with a thickness of 400 mm, which has a heat transfer resistance of 1.36 $m^2·K/W$ and is oriented to the northeast. Autonomous heating with manual temperature control of the heat carrier.

At each of the objects of the study, electronic thermometers measured temperatures at five points:

1) outside air in the shade of a specially constructed shed;
2) the outer surface of the wall in the shade of a specially arranged shed;
3) the outer surface of the wall, exposed to sunlight;
4) the inner surface of the wall;
5) indoor air in the room.

The measurements were carried out daily three times a day at hours close to the regular periods of daily atmospheric air variability:

6-7 hours - the lowest temperature of the atmospheric air;

14-15 hours - the highest temperature of the atmospheric air;

22-23 hours - complete absence of solar radiation.

For the purpose of further statistical processing, the measurement results were recorded in a log created in the Microsoft Excel spreadsheet environment. The measurements were carried out during the heating season from October to April. As a result of the experiment, realizations of temperature change processes were obtained with a duration of 21 decades for object №1, 16 decades for object №2, and 18 decades for object №3.

Statistical analysis of experimental data.

Based on the results of the performed measurements, implementations of 480…630 temperature values were formed with a quantization time step of 8 hours. The available data make it possible to perform statistical processing according to the method [6, 12] and represent temperature changes at chosen points in the form of random processes or random variables.

As an example, Figure 1 shows the implementation of random processes of temperature change at object №2. The time from the beginning of the experiment (in days) is set along the abscissa axis, and the temperatures at five measurement points (in Celsius) are set along the ordinate axis.

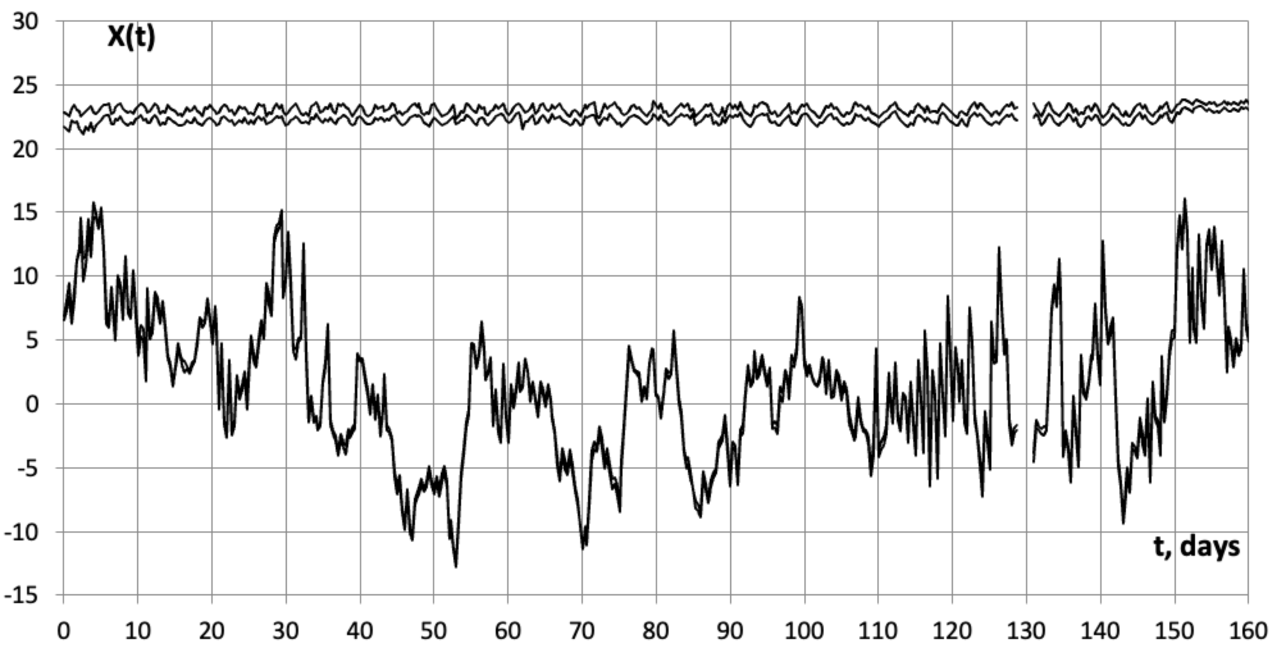

Figure 1 - Processes of temperature change at object of study №2

Figure 1 shows that the temperatures at all measurement points change randomly over time. The two upper lines, which reflect changes in the temperature of the internal air and the internal surface of the wall, can be considered as implementations of stationary random processes. The temperature of the wall surface (point 4) is always lower than the temperature of the indoor air. The three lower implementations practically merge into one line, because the temperatures of the outer surface of the wall in the shade and in the open area are almost equal and exceed the temperature of the outside air within 1°C. These implementations have fairly regular daily changes, stochastic daily variability, as well as pronounced non-stationarity, which is due to seasonal changes in atmospheric air temperature.

All realizations are divided into ten-day segments, during which random processes of temperature change can be considered stationary. Statistical processing of ten-day realizations was performed in the Microsoft Excel environment according to the well-known method for analyzing random variables [12].

In Figure 2, based on the results of statistical processing of ten-day segments of implementations, graphs of the mathematical expectation functions M(t) and the standard S(t) of random processes of air temperature change are shown. The mathematical expectation functions for the three studied objects were found to be quite close and generally correspond to the seasonal changes in air temperature, the average monthly values of which according to long-term data [6] are shown in the graph by bold dots. It can be seen from the graph above that the winter, during which the measurements were taken, was noticeably warmer than the long-term regular. The values of the outdoor air temperature standards are also close for the three objects studied, but change rather chaotically over time within 2…6°C. The functions of the numerical characteristics of the temperature of the outer surface of the wall (measurement points 2 and 3) are close to those shown in Figure 2.

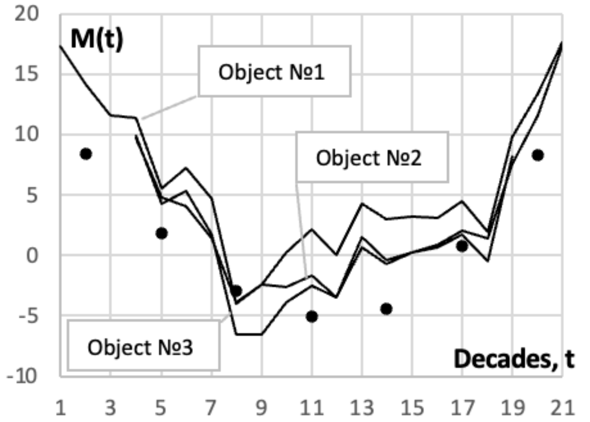

Figure 2 - Functions of the numerical characteristics of random processes of changing the outdoor temperature

Changes in the temperature of the internal air and the internal surface of the wall (measurement points 5 and 4) can be considered stationary random processes. Mean values M and standard deviations S of these processes, calculated taking into account the total durations of the available implementations, are shown in Table 1. The table also shows the statistical characteristics of the temperature difference, which is used in [1, 4, 5] when assessing the level of thermal reliability of enclosing structures according to the criterion of comfort in the room. These characteristics are obtained by statistical processing of data obtained as differences between the internal air temperature and the temperature of the internal surface of the wall at the corresponding points in time.

Table 1 - Statistical characteristics of temperature processes

Research process	Characteristics	Data for objects		
		№ 1	№ 2	№ 3
Indoor air temperature (point 5)	M=	24,4	23,1	24,6
	S=	0,587	0,341	0,500
Temperature of the inner surface of the wall (point 4)	M=	22,4	22,3	23,8
	S=	0,944	0,363	0,625
Temperature difference (temperature difference of points 5 and 4)	M=	1,97	0,80	0,78
	S=	0,830	0,184	0,536

Data analysis in Table 1 shows that due to autonomous heating systems in the studied rooms maintained air temperatures were +23…25°C, that is higher than the established by the norms [1] value +20°C. With manual regulation of the autonomous heat system (objects of study № 2 and № 3), the temperature standard of the internal heat can be taken equal to 0,5…0,6°C. The automatic regulation of the heat transfer temperature at object of study № 2 changed the temperature deviation, which gave a standard value of 0,35°C. These values can be recommended for use in probabilistic calculations of thermal reliability of enclosing structures.

Mean values of the temperature of the inner surface of the wall are lower than for the indoor air temperature, and the standards are higher due to the influence of large random fluctuations in the outdoor air temperature.

Noteworthy are the values of temperature differences at the object of study № 1, twice as large as the values for objects № 2 and № 3. This is due to much higher heat transfer resistance of the wall of the object № 1, which has additional facade insulation.

When performing probabilistic calculations of thermal reliability according to the method [4, 5], the design parameters must be presented in the form of random variables. According to research [8, 9], the thermophysical characteristics of building materials can be represented in the form of random variables with a normal distribution law. The possibility of using the normal distribution to represent the outside air temperature is justified in [6]. In order to establish the type of laws of distribution of internal temperatures according to the available experimental data, histograms of the distribution of indoor air temperatures, the inner surface of the wall and the difference between them are made.

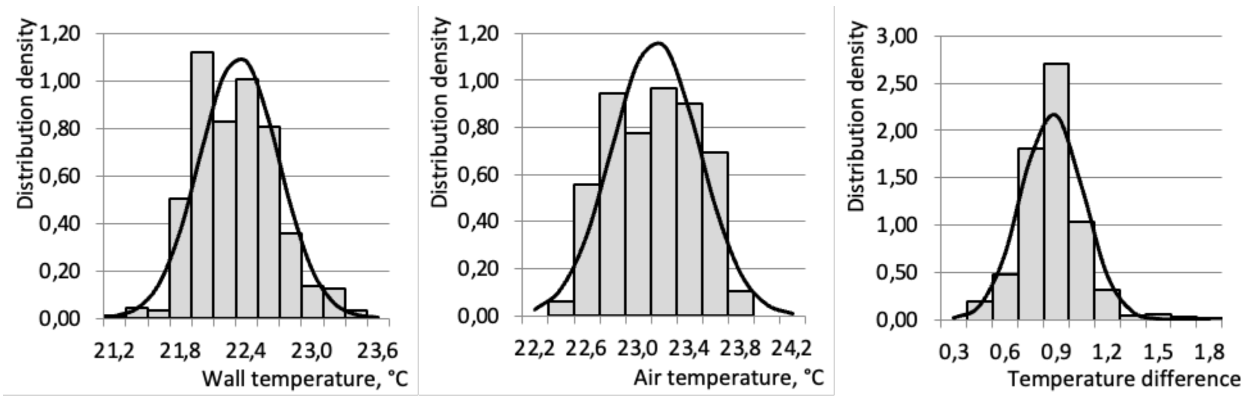

Figure 3 - Histograms of measured temperature distribution

The histograms shown in Figure 3 for the object of study № 2 are close to the normal distribution. Similar histograms for objects of study № 1 and № 3 have a similar appearance. Pearson's chi-squared test [12] showed that the normal distribution does not contradict the experimental data and can be used to probabilistically describe the temperature of indoor air temperature, indoor wall temperature and temperature difference between them.

Conclusions.

1. As a result of the experiment, quite complete and reliable data on the thermal regime of the walls of residential buildings during the heating period are get, which can be used to verify the calculation methods for assessing thermal reliability.
2. The temperatures of the outside air and the outer surface of the walls are quasi-stationary random processes with a normal distribution law. The indoor air temperatures, the temperatures of the inner surface of the walls and the difference between them can be presented in the form of a stationary random process or a random variable with a normal distribution law.

3. The statistical variability of indoor air temperature and interior wall temperature is significantly influenced by the type of heating system and the method of regulating the coolant temperature.

4. The statistical characteristics of the indoor air temperature in residential premises obtained as a result of the experiment can be used when performing probabilistic calculations of the thermal reliability of enclosing structures.

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Анотація. *В роботі викладені результати натурних експериментальних досліджень температурного режиму стін трьох житлових будинків на протязі опалювального сезону. Тричі на добу вимірювалися температури зовнішнього повітря, зовнішньої поверхні стіни в затінку та на сонці, внутрішньої поверхні стіни та внутрішнього повітря в приміщенні. Температури зовнішнього повітря та зовнішньої поверхні стін представляють собою квазістаціонарні випадкові процеси. Температури внутрішнього повітря в приміщеннях, внутрішньої поверхні стін та різниця між ними можуть бути подані у формі стаціонарних випадкових процесів або випадкових величин з нормальним законом розподілу. Показано, що на статистичну мінливість температур внутрішнього повітря та внутрішньої поверхні стін істотно впливає тип системи опалення та спосіб регулювання температури теплоносія. Отримані в результаті експерименту статистичні характеристики температури внутрішнього повітря в житлових приміщеннях можуть використовуватися при імовірнісному оцінюванні рівня теплової надійності огороджувальних конструкцій.*

Ключові слова: *стіни житлових будівель, температурний режим, статистичні характеристики температур*

Article sent: 13.03.2023