Research of Methods of Calculation of Thermal Characteristics of Enclosing Designs in Summer Conditions of Operation

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Abstract The methods of calculation of heat resistance of enclosing constructions are analyzed in the work. The dynamic thermal performance of a building envelope describes the thermal behavior of a component when it is subjected to varying boundary conditions. The result of the calculation according to the national method is represented by values that do not allow to include them in the assessment of the overall energy efficiency of buildings. To verify the results of a theoretical study of the dynamics of the temperature regime of the enclosing structure, experimental measurements were carried out.

Keywords Heat transfer resistance · Heat loss · Thermal insulation

1 Introduction

The rooms in which people are located must provide a certain level of comfort. The state of comfort is a subjective feeling that occurs in people under the complex influence of such basic factors: acoustic environment, color, temperature, humidity, air mobility, and the like.

The main factors that form the microclimate of the premises are: temperature, speed of movement and air humidity, as well as radiation temperature, that is, the average temperature of the surfaces of enclosing structures and objects.

Outside air temperature fluctuations (the effect of solar radiation, daily change in the outside air temperature) put additional requirements on the temperature regime of the enclosing structures in the summer.

The performance of the enclosing structures largely depends on the magnitude of temperature fluctuations on their inner surface. With a significant amplitude of fluctuations in the temperature of the enclosing structure in the summer, there may be

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a periodic increase in the temperature of the internal air, followed by the return of heat into the house and overheating of its premises. To assess the comfort indicators of the microclimate in the room, the heat resistance of the inner surface of the enclosing structures is calculated.

The purpose of the calculation is to provide the enclosing structures with the necessary heat-shielding qualities that guarantee the maintenance of an almost constant temperature on the inner surface of the structure with periodic changes in the parameters of the external environment.

The influence of local influences on thermal sensations in non-uniform environmental conditions is considered in the works [1, 2].

The assessment of the climatic parameters of the indoor environment of the room is carried out by the reaction of a person. Models based on a multi-node model are being developed, taking into account the countercurrent heat exchange of blood, a detailed view factor has been added to calculate the radiation heat transfer of a human body to the environment, including the load of solar radiation on people. The model can calculate human thermal reactions in transient and inhomogeneous environments [3]. The study of the thermal parameters of multilayer structures is presented in the works [4–10]. When designing modern structures, the use of extreme principles is promising [11–15].

For a detailed study of the internal parameters of the premises, it is necessary to clarify the methods for studying the thermal characteristics of the enclosing structures.

The purpose of the article is to compare various methods for calculating the dynamic thermal characteristics of the building envelope and experimental measurements.

Research methods are based on engineering methods for determining thermal characteristics.

2 Theoretical Study of the Dynamic Thermal Characteristics of the Enclosing Structures

The dynamic thermal performance of the building envelope describes the thermal behavior of a component when it is subjected to variable boundary conditions.

Dynamic thermal performance is used to calculate the indoor temperature of a room, heating or cooling equipment, and the effects of intermittent heating or cooling.

According to UNE-EN ISO 13,786: 2011 [8] dynamic thermal characteristics of any component:

The periodic thermal conductivity L_{mn} is a complex number that shows the relationship between periodic heat flux and periodic temperature in sinusoidal conditions. The value is determined by the formula:

$$\widehat{\Phi}_m = L_{mm}\widehat{\theta}_m - L_{mn}\widehat{\theta}_n \tag{1}$$

where $\widehat{\theta}_{m,n}$ and $\widehat{\Phi}_m$ are complex amplitudes of temperature and heat flow.

The heat capacity is the modulus of the ratio of periodic thermal conductivity and angular frequency. The value is determined by the formula

$$C_m = \frac{1}{\omega}|L_{mm} - L_{mn}| \tag{2}$$

where $\omega = 2\pi/T$ and T is the period of variation in seconds.

In Ukrainian standards, the influence of fluctuations in the outside air temperature on the temperature regime of the enclosing structures in the summer is taken into account by the following indicators:

- the amplitude of fluctuations in the outside air temperature $A_{t_{зроз}}$, °C is the maximum temperature deviation on the inner surface of the opaque enclosing structure from the average daily value when exposed to solar radiation in summer operating conditions;
- the value of attenuation of the amplitude of fluctuations in the temperature of the outside air ν;
- the coefficient of heat assimilation of the material of individual layers s, W/(m^2 K) - this is a physical parameter that reflects the ability of the material to perceive heat when the temperature fluctuates on its surface. It is determined by the ratio of the amplitude of heat flux fluctuations (W) to the amplitude of temperature fluctuations (K) on a unit surface area of the material (m^2) over a period of 24 h.

Method of calculation according to UNE-EN ISO 13,786: 2017 [16]:

The method given in this International Standard is based on heat conduction in building components composed of several plane, parallel, homogeneous layers, under regular sinusoidal boundary conditions and one dimensional heat flow.

That means that at any location in the component, the temperature variations can be modeled by

$$\theta_n(x,t) = \overline{\theta}(x) + \frac{\widehat{\theta}_{+n}(x)e^{j\omega t} + \widehat{\theta}_{-n}(x)e^{-j\omega t}}{2} \tag{3}$$

and the variations of the density of heat flow rate are

$$q_n(x,t) = \overline{q}(x) + \frac{\widehat{q}_{+n}(x)e^{j\omega t} + \widehat{q}_{-n}(x)e^{-j\omega t}}{2} \tag{4}$$

With $\widehat{\theta}_{\pm}(x) = \left|\overline{\theta}(x)\right|e^{\pm j\psi}$ and $\widehat{q}_{\pm}(x) = \left|\widehat{q}(x)\right|e^{\pm j\varphi}$.

Temperature and density of heat flow rate variations are those around the mean values *0* and *cj* of these variables, which are linked by

$$\overline{q} = U\left(\overline{\theta}_i - \overline{\theta}_e\right) \quad (5)$$

where U is the thermal transmittance of the component.

3 Methodological Aspects of Experimental Research

To check the results of a theoretical study of the dynamics of the temperature regime of the enclosing structure, experimental measurements were carried out. The essence of the methods for the experimental determination of the heat resistance of enclosing structures is to find the dynamics of changes in the temperature regime of the inner surface of the enclosing structure according to the results of thermal measurements in the summer period.

In natural conditions, tests were carried out in the summer period of the year, with a clear sky, when thermal conditions close to the calculated ones are established.

The purpose of experimental research:

when testing opaque enclosing structures, determine the amplitude of fluctuations in the temperature of the inner surface;

to verify theoretical studies.

Experimental studies were performed according to the method of DSTU V.2.6–100: 2010.

The study measured:

- temperatures of internal and external surfaces of a protection;
- indoor and outdoor air temperatures;
- humidity of internal and external air;
- heat flow through the wall.

Registration and display of controlled parameters (heat fluxes, temperatures and humidity) with reference to time and date was performed by the heat flux density and temperature meter.

The study was conducted from 07/27/2015 to 08/21/2015, as the hottest period of 2015. The object of research is an external solid brick wall with a thickness of 510 mm with an internal lime-sand plaster with a thickness of 20 mm.

The tests were carried out on the building envelope in use. Tests of the wall in the intermediate floor room with the orientation of the external enclosing structure to the south-west and the absence of shading by the surrounding buildings and trees.

The results of measuring the temperature of the indoor and outdoor air, the temperature on the inner surface of the structure and the heat flow during the calculated day are shown in Fig. 1. The values were recorded every 10 min.

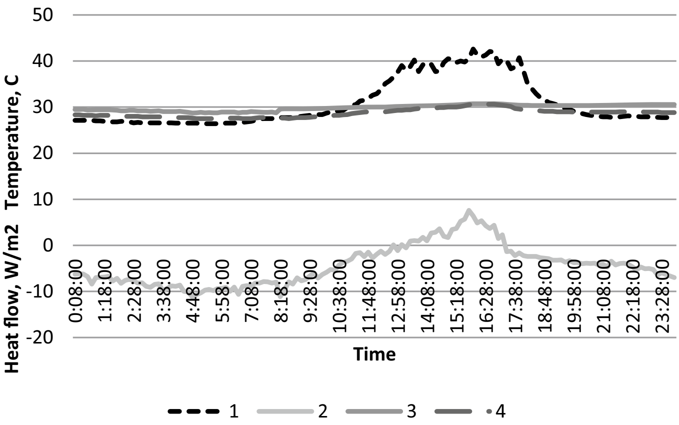

Fig. 1 The graph of the temperature distribution of the internal (4) and external (1) air, the temperature of the internal surface of the enclosure (3) and the heat flow (2) for the calculated day

4 Comparison of Theoretical Calculation Results and Experimental Data

To compare the theoretical and experimental studies, the dynamic parameters were calculated during the day with the initial data according to the measured values (Tables 1 and 2).

A comparison of the measured and calculated parameters is shown in the graph in Fig. 2. The result of statistical processing of the values measured in experimental conditions allows to accept them for the subsequent comparison with the calculated data (Fig. 3).

Table 1 Initial data for calculating dynamic parameters

Layer name	Thermal conductivity [W/m.K]	Gross density [kg/m^3]	Spec. heat capacity C [J/kg.K]	Heat absorption coefficient s, [W/(m^2•K)]	Layer thickness d [m]	R [m^{2}K/W]
Rsi						0,13
Plaster	0,810	1600,0	840	9,76	0,0200	0,025
Brickwork	0,810	1800,0	880	10,12	0,5100	0,630
Rse						0,04
		U-value:	1,2131		W/m^{2}K	
		Total thickness:	0,530		m	

Table 2 The result of the theoretical calculation of dynamic parameters

№	Name quantities	Value	Units
1	External thermal admittance:	7,418	W/(m^{2}K)
2	Time shift external side:	2,19	h
3	Internal thermal admittance:	4,563	W/(m^{2}K)
4	Time shift internal side:	1,31	h
5	Periodic thermal transmittance:	0,082	W/(m^{2}K)
6	Time shift periodic thermal transmittance:	−16,48	h
7	External areal heat capacity:	101,809	kJ/(m^{2}K)
8	Internal areal heat capacity	62,811	kJ/(m^{2}K)
9	Decrement factor f:	0,068	

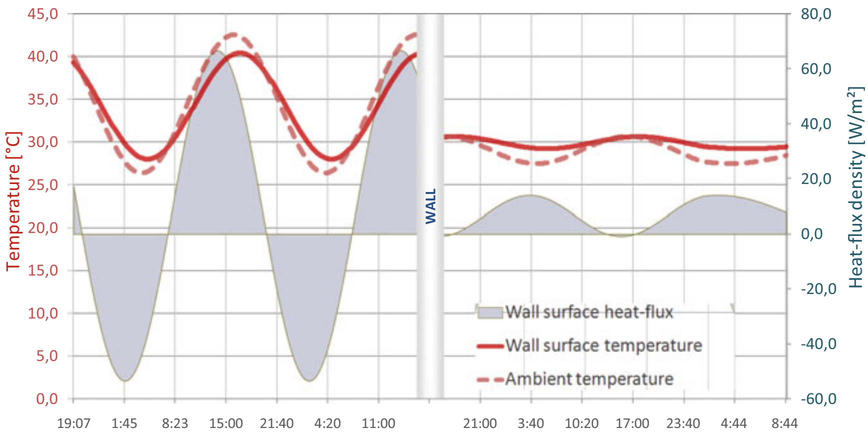

Fig. 2 The result of the theoretical calculation of the dynamic parameters of the wall

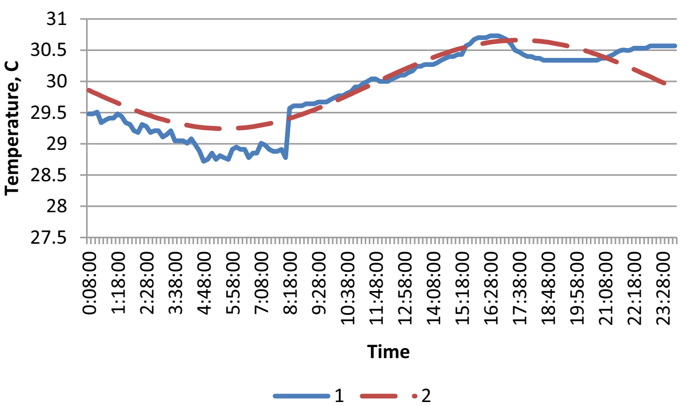

Fig. 3 The result of the calculation (2) and measurement (1) of the temperature on the inner surface of the wall during the day

The method for determining the coefficient of heat assimilation of the surface of the fence Y, set forth in the Ukrainian building codes, based on the theory of Professor Vlasov.

The coefficient of heat absorption of the material of the fence *S* characterizes its ability to perceive heat when the temperature on the surface fluctuates. The value of this coefficient depending on the thermophysical properties of the material (λ, c, ρ) and the cyclic frequency of temperature fluctuations $w = 2\,\pi\,/\,Z$:

$$S_{24} = \sqrt{\frac{2 \cdot \pi \cdot \lambda \cdot c \cdot \rho}{Z}}. \quad (6)$$

where λ is the coefficient of thermal conductivity, W/(m · K); s - heat capacity, J/(kg · K); ρ - material density, kg/m^3.

It is obvious that the coefficient *S* in a given design time period *T* depends only on the properties of the material, therefore it can be considered a physical characteristic of the material of the fence.

Usually, in the thermal engineering calculations of fences, in addition to the floor, the oscillation period $T = 24$ h is taken, then $S_{24} = 0,51\sqrt{\lambda \times c \times \rho}$.

Calculation of $Y_{вн}$ begins with determining the conditional thickness of the first layer, starting the numbering of layers from the inner surface of the fence.

a) when the inner layer of the enclosing structure has thermal inertia $D \geq 1$, then

$$Y_{вн} = s_1.$$

b) if the thermal inertia of the first layer of the enclosing structure D < 1, and the first and second layers of the structure $D_1 + D_2 \geq 1$, then the heat absorption coefficient of the inner surface is calculated by the formula

$$Y_{вн} = \frac{R_1 s_1^2 + s_2}{1 + R_1 s_2}; \quad (7)$$

where R_1, s_1, s_2 - thermal resistance and coefficient of heat absorption, respectively, of the first and second layers;

To compare the two methods, a calculation was performed with the same initial data.

The calculation results according to Ukrainian regulatory documents are presented in Table 3.

Table 3 Calculation of thermal inertia of each layer of the structure

Layer number	Designation	Value	Calculation
1	D_1	1,861	$D_1 = R_1 s_1 = 0{,}025 \cdot 9{,}76 = 0{,}244$
2	D_2	0,85	$D_2 = R_2 s_2 = 0{,}63 \cdot 10{,}12 = 6{,}376$

The thermal inertia of the first layer of the enclosing structure D < 1, and the first and second layers of the structure D1 + D2 ≥ 1, so the heat transfer coefficient of the inner surface is calculated by formula (7) and is: $Y_{вн} = 9,98 \mathrm{W/m^2} \cdot \mathrm{K}$

Coefficient of heat absorption B_j by the inner surface of the j-th opaque enclosing structure of the room is 4,65 W/m^{2}K.

5 Conclusions

The calculation results according to the UNE-EN ISO 13,786 and DSTU-N B V.2.6–190:2013 methods give values that characterize various physical phenomena in the structure. Therefore, they cannot be compared. But the UNE-EN ISO 13,786 methodology more accurately allows you to study the dynamic thermal characteristics, and use the obtained parameters in calculating the energy efficiency of the building as a whole. At the same time, the Ukrainian calculation method allows only checking compliance with the requirements of DBN V.2.6–31 [17], in terms of heat resistance in summer operating conditions of enclosing structures. In addition, the given requirements require revision in connection with changes in climatic parameters and increased requirements for thermal protection of buildings.

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