International Journal of Engineering & Technology, 7 (3.2) (2018) 535-538

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

The Non-Stationary Thermal Mode for Barrier Building Constructions in Non-Symmetric Boundary Conditions

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Abstract

In barrier building constructions the heat transfer occurs both at the expense of thermal conductivity and as a result of liquid and air vapors resistance. The mechanism of such resistance differs from classical processes of diffusion and the laws of hydrodynamics for integral medium.
The temperature mode of the surface and deep layers of barrier building constructions in non-symmetric boundary conditions was analyzed. A mathematical model was developed that characterizes the change in the thermal state of barrier constructions during thermal diffusion. The method for calculating the non-stationary thermal modes of flat walls was presented.

Keywords: *barrier constructions, non-symmetric boundary conditions, thermal conductivity, thermal mode, thermophysical characteristics.*

1. Introduction

The features of barrier constructions requiring their analysis and consideration have significant influence on the results of thermophysical calculations. The reliability of calculations depends on the optimal choice for heat generating properties of barrier constructions affecting the thermal mode in the premises. For example, the moisture increasing for barrier constructions increases their heat conductivity which reduces their thermal protection properties compared with dry barriers. The use of wet barrier constructions is inadmissible from a hygienic point of view, as they create conditions for the development of fungi, mold and other biological processes.
Barrier constructions must comply with the following thermal conditions [1]:
1) optimality for heat resistance;
2) heat resistance: no possibility to change the temperature of indoor air in the room with irregular supply of heat from the heating system, and in summer - from over-heating with sunlight;
3) the temperature of the inner surface of barrier construction is higher than the dew point, which makes it impossible to condense the vapor from the air;
4) no accumulation of moisture in the inner layers, which is necessary for preservation of thermal protection and durability;
5) normative resistance of air permeability.
It is necessary to determine the temperatures on the surface and inside the layers of the barrier building constructions at any given time when considering the problems of determining their thermal mode, humidity mode, freezing and thawing of materials and analysis for thermal stability of the buildings.
It is also important to consider the dependence for thermal physical characteristics of materials such as density, thermal conductivity, heat capacity, mass and thickness on temperature and time.

2. Main Body

2.1 Overview of the Latest Sources of Research and Publications

The heat and moisture resistance in the material for barrier building construction is considered in works [2, 3, 4], without taking into account the heat-humidity characteristics of the air, washing the barrier building constructions. When developing practical recommendations for choosing air parameters, the authors superficially studied their influence on the process of heat and moisture resistance in the material of the barrier building construction, thus prejudicing the optimal energy expenditure. To study the influence of the air parameters for heat and moisture resistance, as well as to optimize energy costs, the authors of this work developed the mathematical model for quantifying the degree of the air parameters influence (temperature, moisture content and outlay) on heat and moisture resistance in the material.

2.2 Selection of the Unsolved Parts of General Problem

This work studies the influence of air parameters on the process of heat and moisture resistance and optimization of the energy outlay on the basis of the mathematical model for this process.

2.3 The Purpose of Work

The purpose of this work is to obtain the mathematical model that describes: the change in thermal state of the material for the barrier building constructions, the change of the air parameters in non-symmetric boundary conditions and an opportunity to quantify the influence of the air parameters on the process.

2.4 The Main Material

Let's consider the process of heat-moist change for the barrier building construction, which is washed from the opposite sides by the air with different parameters (Fig. 1). The process of heat-moist state for barrier building construction will not be axially symmetric, since the temperature of the internal and external air when moving along the construction will be different and variable. In this particular process, it is expedient to replace one-dimensional problem with a two-dimensional one, complicated with heat and moisture air exchange.

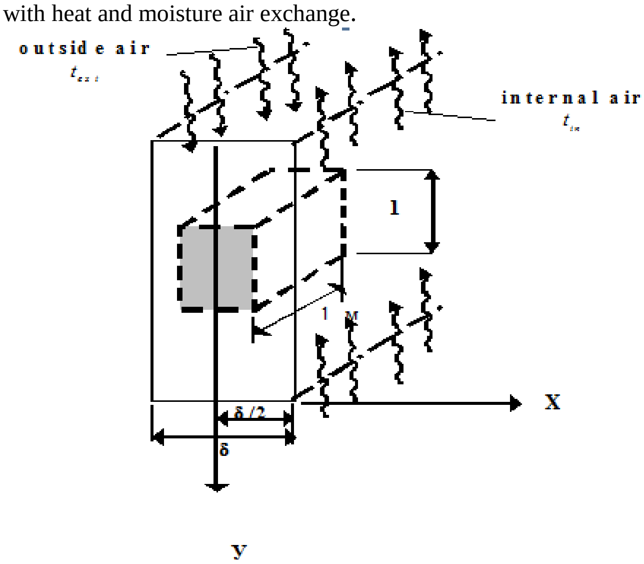

Fig. 1: Scheme for the process of changing the thermal state of a single-layer barrier construction

The processes of heat exchange and moisture resistance are described by the equations of heat conductivity and moisture conductivity, so:

$$\frac{\partial t}{\partial \tau} = a\frac{\partial^2 t}{\partial x^2} + \frac{r\varepsilon}{c}\cdot\frac{\partial^2 p}{\partial x^2}, \quad (1)$$

$$\frac{\partial p}{\partial \tau} = a_m\frac{\partial^2 p}{\partial x^2} + a_m\delta'\frac{\partial^2 t}{\partial x^2}, \quad (2)$$

Definition :

t – *temperature of the material, ^oC;* $t = f(x,\tau)$;

x - *coordinate, m;*

τ – *interval, s.;*

a – *coefficient of temperature conductivity, m^2/s;* $a = \frac{\lambda}{c\rho}$;

λ – *coefficient of thermal conductivity of the material, Вт/ (м · ^oC) ;*

c – *thermal capacity of the material, kJ/ (kg · ^oC) ;*

ε – *criterion of phase transformation;*

r – *heat of moisture vaporing (referred to the material), kJ/кg moisture;*

a_m – *coefficient of diffusion, $m^2/(s \cdot Pa)$;* $a_m = \frac{\beta}{10\rho}$;

β – *coefficient of moisture conductivity of the material, g/ (m · s) ;*

10 – *amount of moisture necessary for moisture increasing 1 кg of the material per 1 %, g ;*

ρ – *density of the material, кg/ $м^3$;*

p – *partial pressure, Па;* $p = f(x,\tau)$;

δ' - *thermal gradient coefficient, кg/(кg · gradient).*

We set the initial conditions that characterize the material state at the initial time interval and the boundary conditions. For equations (1) and (2), the boundary conditions are assumed to be in the form of boundary conditions of the third kind with a constant temperature and the known moisture content of the air. It is assumed that the air outlay is incredibly large.The process of changing the thermal state is due to the final air outlay, since the amount of the outlay significantly affects the whole process.

It is obvious that the temperature and moisture of the barrier construction depend on the coordinate and time interval $t = f(x,\tau)$ та $p = f(x,\tau)$. To determine the degree of inertia for the processes of heat resistance and moisture conductivity, we use a method to determine the time interval $\Delta\tau$ with the stationary conditions for the resistance of heat and moisture [5, 6]. The time interval for the stationary process establishing is determined on the basis of balanced ratios. According to the law of energy conservation, we have the finite-differential analogue [7, 8] of the differential equation of heat conductivity (for a homogeneous region), the nature of the temperature field is determined in the following interval of time (with thickness $\Delta = \Delta x$):

$$t_{x,\tau+1} = (1 - \frac{4\cdot\lambda\cdot\Delta\tau}{c\cdot\rho\cdot\Delta^2})\cdot t + \frac{\lambda}{c\cdot\rho}\cdot\frac{\Delta\tau}{\Delta x^2}t_{x+\Delta,\tau} + \frac{\lambda}{c\cdot\rho}\cdot\frac{\Delta\tau}{\Delta x^2}t_{x-\Delta,\tau}. \quad (3)$$

If the time interval $\Delta\tau$ equals $\frac{c\cdot\rho\cdot\Delta^2}{4\lambda}$, correlation (3) is transformed in equation of stationary temperature field:

$$t_{x,\tau+1} = \frac{t_{x+\Delta,\tau} + t_{x-\Delta,\tau}}{2}. \quad (4)$$

In condition:

$$\Delta\tau_t = \frac{0.25\cdot c\cdot\rho\cdot\Delta^2}{\lambda}, \quad (5)$$

the construction acquires the stationary process of heat transmitting.

By analogy with the thermal conductivity, the time of establishing the stationary process of conductivity will be determined by the correlation:

$$\Delta\tau_p = \frac{10\cdot\rho\cdot\Delta^2}{4\cdot\beta_w} = \frac{2,5\cdot\rho\cdot\Delta^2}{\beta_w}. \quad (6)$$

When positioning the coordinate axis as shown in Figure 1, the system of equations describing the heat and moisture content in the barrier construction will look like this:

$$\begin{cases} \dfrac{\partial t}{\partial \tau} = a\left(\dfrac{\partial^2 t}{\partial x^2}\right) + \dfrac{r \cdot c}{\varepsilon}\left(\dfrac{\partial^2 p}{\partial x^2}\right) \\ \dfrac{\partial p}{\partial \tau} = a_m\left(\dfrac{\partial^2 p}{\partial x^2}\right) + a_m \cdot \delta'\left(\dfrac{\partial^2 t}{\partial x^2}\right) \\ \dfrac{c_p \cdot g_{in}}{\alpha_{in}} \cdot \dfrac{\partial t_{in}}{\partial y} - \dfrac{\partial Q_w}{\alpha_{in} \cdot \partial y} = t_{in} - t\big|_{x=-\frac{\delta}{2}} \\ \dfrac{c_p \cdot g_{ext}}{\alpha_{iext}} \cdot \dfrac{\partial t_{ext}}{\partial y} - \dfrac{\partial Q_w}{\alpha_{ext} \cdot \partial y} = t_{ext} - t\big|_{x=\frac{\delta}{2}} \\ \dfrac{\psi \cdot g_{in}}{\beta_w} \cdot \dfrac{\partial p_{in}}{\partial y} = p\big|_{x=\frac{\delta}{2}} - p_{in} \\ \dfrac{\psi \cdot g_{ext}}{\beta_w} \cdot \dfrac{\partial p_{ext}}{\partial y} = p\big|_{x=-\frac{\delta}{2}} - p_{ext} \end{cases} \qquad (7)$$

The unknown functions in this system of equations are:

- temperature of the material for the barrier construction $t = f(x,\tau)$;
- the temperature of the internal and external air, washing the the barrier construction $t_{in} = f(y,\tau)$, $t_{ext} = f(y,\tau)$;
- moisture content of the barrier construction $p = f(x,\tau)$;- partial pressure of the water vapor in the internal and external air washes the barrier construction $p_{in} = f(y,\tau)$, $p_{ext} = f(y,\tau)$.

The given equations of thermal and moisture balance allow to determine the distribution of temperatures and moisture content in the barrier constructions at non-symmetric boundary conditions, the amount of accumulated or transmitted heat, the amount of moisture that will evaporate from the surface and the final parameters of air (temperature and moisture) at nonstationary process of changing the thermal state of the barrier construction at predetermined intervals of time.

In order to assess the change in thermal and moisture state of the barrier construction in non-symmetric boundary conditions, there was developed a computer program to calculate the heat-moist fields of a single-layer barrier construction with thermal and technical characteristics: δ =0,4 м, ρ =1000 кг/м^3, c =840 Дж/(кг·^{0}С), λ =0,41 Вт/(м·^{0}С). The initial temperature and moisture: t = 0 ^{0}С, φ =25 %. The temperature and moisture of the air, which washes the barrier construction from the inner surface: t_{in} = 15 ^{0}С та d_{in} = 7,4 g/кg and from the outer surface – t_{ext} = - 11 ^{0}С та d_{ext} = 0,95 g/кg.

There were constructed the graphs of temperature and moisture distribution in the barrier construction (Fig. 2-5) based on the results of calculations.

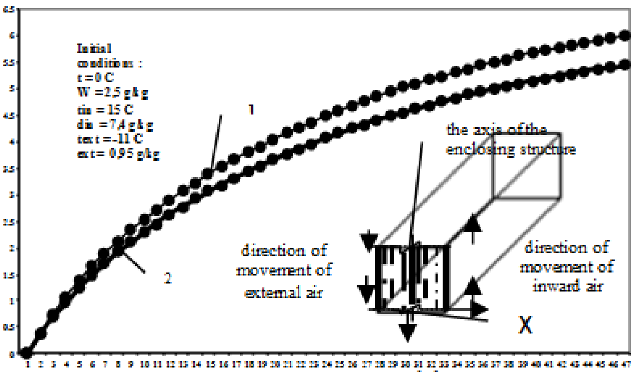

Fig.2: Change of the temperature for inner surface of the barrier construction without taking into account (1) and taking into account (2) the moisture mode

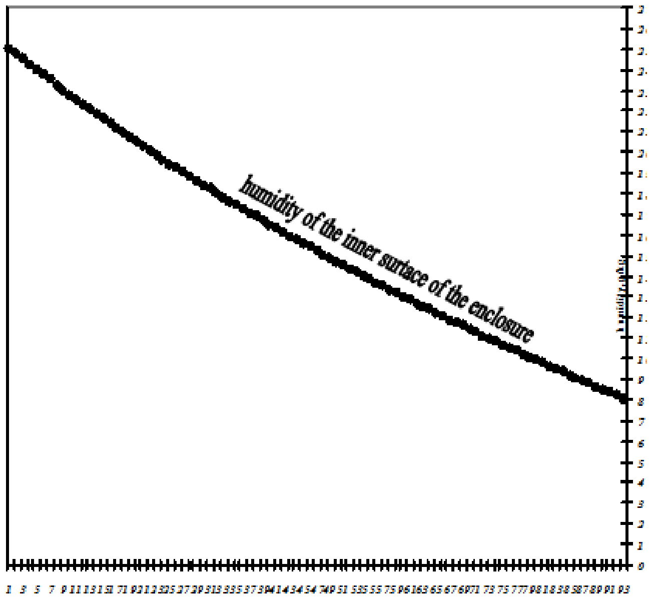

Fig. 3: Change of the moisture for inner surface of the barrier construction

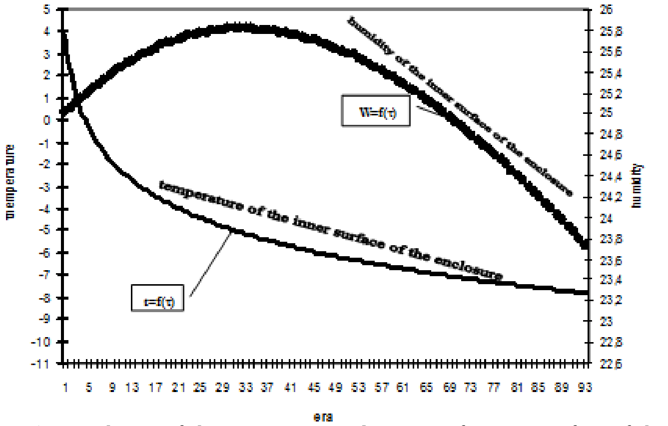

Fig. 4: Change of the temperature and moisture for outer surface of the barrier structure

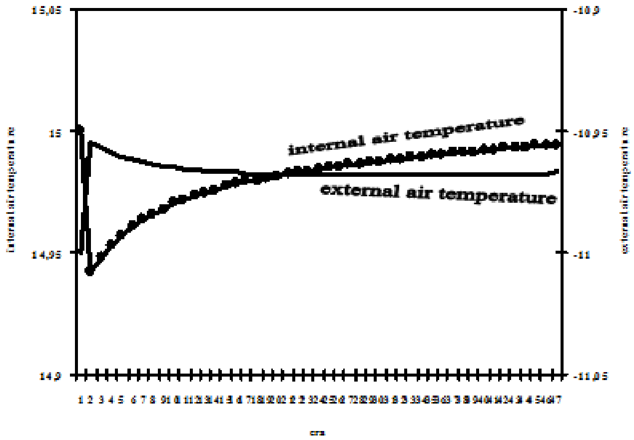

Fig. 5: Changes of the temperature for internal and external air after washing the surfaces of the barrier construction.

The results of the calculations obtained coincide with the known studies [9, 10, 11], so the proposed mathematical model adequately reproduces the nonstationary thermal mode of the barrier building constructions in non-symmetric boundary conditions.

3. Conclusion

1. The process of changing the thermal and moisture state of the barrier construction should be considered taking into account the effect of changes in external and internal air on the process of moisture moving.
2. There was formulated the problem and there was obtained the system of equations to describe thermal diffusion of moisture through the barrier construction taking into account the influence of changes in external and internal air.
3. There was developed the mathematical model for calculation of heat and moisture exchange processes in the barrier structure in non-metric boundary conditions.
4. There was developed the calculation algorithm to determine the influence of the parameters for external and internal air on the change of thermal state of the barrier construction

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