APPLICATION OF MOISTURE POTENTIAL THEORY IN DESIGN OF FENCING STRUCTURES OF AGRICULTURAL BUILDINGS

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ABSTRACT

This paper provides the information on integrated approach to calculation of required thermal engineering and moisture characteristics of outer fences of industrial agricultural buildings based on moisture potential theory. The results of analytical and full-scale studies of temperature and moisture conditions of premises and outer fences of unheated industrial agricultural buildings (as single biological energetic complexes) are presented herein.

Keywords: moisture conductivity factor, moisture potential, moisture transfer resistance, agricultural building, microclimate.

INTRODUCTION

The quality of stored agricultural products and the productivity of animals and birds directly depend on the microclimate maintained in premises. The technological design standards provide the required values of temperatures and relative moisture of indoor air in agricultural buildings of various functional purposes. Only when these requirements are met, good performance of agricultural production can be provided.

Stable operation of microclimate maintenance systems is essential to maintain required parameters of indoor environment in livestock, poultry premises, as well as in premises for storing succulent plant raw materials. However, most agricultural buildings are operated as unheated. As a rule, designed mechanical ventilation systems are not operated with a view to economy cut.

Agricultural buildings are arranged to special class [1] according to the normalization of heating circuit thermal characteristics. The feature of forming temperature and moisture parameters of microclimate in such buildings is both the presence of permanent year-round apparent heat emissions and constant biological and physiological emissions of moisture from animals, birds and stored products. The required temperature of indoor air is maintained up to certain «critical» temperature of outdoor air due to specified heat emissions in premises of agricultural buildings. However, the lack of heat is observed in premises with further decrease in outdoor air temperature. At that the supply of outdoor air practically stops. In particular, the specific air exchange in cowhouse during cold period of year can be reduced to 2.5 ... 3.0 m^3/(hr·centner) [2]. The moisture begins accumulating in premise, the air relative moisture rises practically up to φ_{in} = 95 ... 100 %, the fog appears, the intensive condensation of water vapor occurs on inner surfaces of fences, the moistening is observed and the ice is formed on windows.

The subject of the study is temperature and moisture conditions of premises and outer fences of industrial agricultural buildings (as single biological energetic complexes) with minimization (up to zero) of using artificial energy sources by microclimate parameters maintenance systems. The reduction of energy consumption in year-round cycle of operation is achieved due to considering the functional purpose of premises and production technologies, complete utilization of apparent physiobiological heat Q_p, W and use of natural energy sources.

MATERIALS AND METHODS

The analysis of methods for calculating moisture conditions of outer fences related to the diffusion of water vapor and moisture conductivity theory showed that moisture conditions of fences in transient conditions of moisture transfer can be calculated only on the basis of total thermodynamic potential of heat transfer and moisture, i.e. humidity potential [3, 4, 5, 6]. The integrated method is developed for normalization of heat transfer resistance R_0^t, m^2·°C/W according to normalized specific heat flux, q_s^n, W/m^2, and moisture transfer resistance R_θ^t, m^2·hr·°C/kg, in moisture potential scale according to normalized specific moisture flux i_{out}, kg/(m^2·h), for outer fences. The method includes selection and calculation of driving forces of heat and moisture transfer in moisture potential scale, as well as analytical dependences of calculating moisture exchange factors on inner surfaces of fences.

The problem of energy saving through the utilization of apparent physiobiological heat is solved by the provision of required heat transfer resistance R_0^t at design stage. The provision of required moisture transfer resistance R_θ^t maintains stable quantitative indicators of thermal engineering characteristics of outer fences during entire design life.

RESULTS AND DISCUSSIONS

The normalized heat transfer resistance of outer fences of agricultural buildings is determined by the relationships [1, 7, 8]:

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$$R_0^t = (t_{in} - t_{out}) / q_s^n;\ q_s^n = (1-m)Q_p / F, \quad (1)$$

where F is area of above-ground walls and cover, m^2; m is factor that takes into account the share of heat losses through floors, underground and embank parts of outer fences [1]; t_{in} and t_{out} are temperatures of indoor and outdoor air, respectively, °C.

The possibility of applying classical thermodynamic representations to the phenomena of substance transfer was proved in the studies [9-14]. Therefore, the specific moisture flux i, kg/(m^2·hr), is proportional to the moisture potential gradient, $\nabla\theta$, °V by analogy with the basic thermal conductivity law:

$$i = \chi \nabla \theta, \quad (2)$$

where χ is moisture conductivity factor of material, kg/(m·h·°V).

The calculation of thermal and moisture conditions of building structures on the basis of moisture potential theory is hampered by the lack of thermal physical characteristics for the majority of building materials in moisture potential scale. The moisture potential for air in any range of temperature and relative moisture φ, %, is determined from the dependences [5]:

- at $t \leq 10$ °C independently from φ $\lg\theta = 0.057d + 0.829$; (3)

- at $t > 10$ °C and $\varphi \geq 80$ % $\lg\theta = 0.12d - 0.049t + 1.056$; (4)

- at $t > 10$ °C and $\varphi < 80$ % $\lg\theta = 0.096d + 0.082$ $(20 < d \leq 30)$; (5)

$\lg\theta = 0.057d + 0.829$ $(0 < d \leq 20)$. (6)

The moisture content d, g/kg of dry substance is equal to $\varphi = k_t d$, where $k_t = 24.39e^{-0.062t}$.

The dependence was obtained for calculating the reduced moisture transfer resistance $R_{\theta.0}$, m^2·hr·°V/kg by analogy of heat and moisture transfer processes. The values of moisture exchange resistance on surfaces of fences are negligible, therefore, the following dependence is used in engineering calculations of fencing structures:

$$R_{\theta,0} = \sum_{i=1}^{n} \frac{\delta_i}{\chi_i} \quad (7)$$

The moisture transfer resistance $R_{\theta.0}$, m^2·hr·°V/kg, shows the moisture potential difference $\Delta\theta$, °V, at which 1 kg of moisture is transferred through 1 m^2 of fence in 1 hour.

The analytical dependence for determining moisture conductivity factor χ, kg/(m·h·°V) of any building material with thickness δ, m, is obtained from the equality of moisture content I, kg, passing through flat wall, calculated on the basis of two theories of moisture transfer: the theory of water steam diffusion and the theory of moisture potential.

According to the theory of vapor diffusion, the moisture content I, kg, which diffuses through flat wall, consisting of homogeneous material, is determined by the formula:

$$I = (e_{in} - e_{out}) Fz\mu / \delta, \quad (8)$$

where F is area of fence, m^2; e_{in} and e_{out} are vapor pressures of indoor and outdoor air, Pa; z is time of steam passage (at the content of I, kg) through fence, hr; μ is vapor permeability factor of material, kg/(m·hr·Pa).

In terms of moisture potential theory, moisture content I, kg, passing through flat wall, is equal to:

$$I = (\theta_{in} - \theta_{out}) Fz\chi / \delta, \quad (9)$$

where θ_{in} and θ_{out} are moisture potentials of indoor and outdoor air, ^{0}V

Assuming the equality of moisture content I, obtained by (8) and (9), the system of equations for single-layer structure will be as follows:

$$\begin{cases} I = (e_{in} - e_{out}) Fz\mu / \delta; \\ I = (\theta_{in} - \theta_{out}) Fz\chi / \delta. \end{cases} \quad (10)$$

By solving this system we will determine moisture conductivity factor of material χ, kg/(m·hr·°V):

$$\chi = \frac{(e_{in} - e_{out})}{(\theta_{in} - \theta_{out})} \mu. \quad (11)$$

Figure-1 shows graphical relationship between moisture conductivity factor of foam concrete χ and moisture potential difference of indoor and outdoor air $\Delta\theta$, °V on the basis of formula (11). The values of water vapor pressure e_{in} and indoor air moisture potential θ_{in} were calculated at t_{in} = 20 °C and φ_{in} = 55 %. The values of e_{out} and θ_{out} were calculated at outdoor temperatures t_{out} = 10…- 50 °C and the value of relative outdoor air moisture φ_{out} = 80 %, which is characteristic for the coldest month in most cities of Russia. Table-1 presents the values of moisture conductivity factors for some building materials at design outdoor air parameters t_{out} = –30 °C, φ_{out} = 84 %, e_{out} = 220 Pa and indoor air parameters t_{in} = 20 °C, φ_{in} = 55 %.

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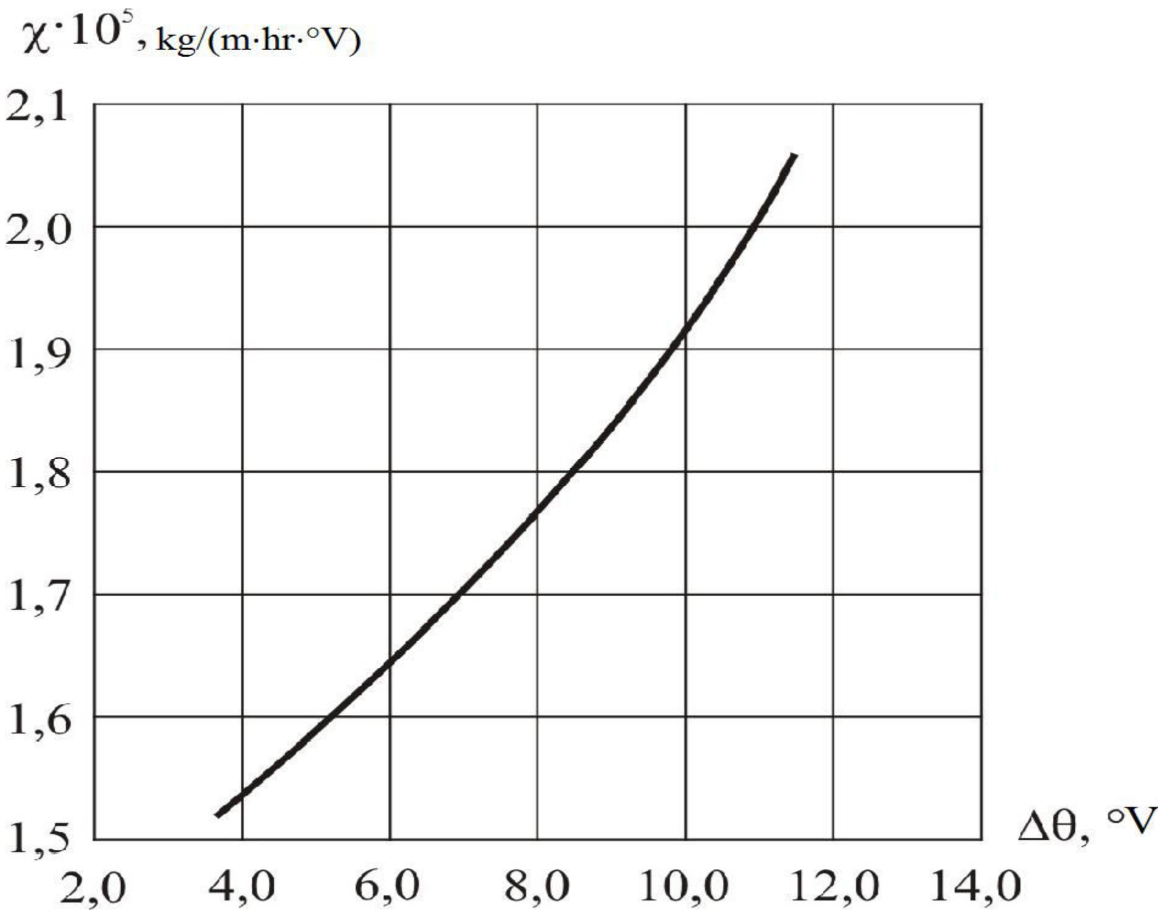

Figure-1. Dependence of moisture conductivity factor of foam concrete on moisture potential difference for indoor and outdoor air.

Table-1. Values of moisture conductivity factors for some building materials.

Item No.	Material name	Density ρ_0, kg/m^3	Vapor permeability factor μ, kg/(m·hr·Pa)	Moisture conductivity factor $\chi \times 10^5$, kg/(m·hr·°V)
1	Brick work of ceramic hollow brick with density of 1400 kg/m^3 based on cement and sand grout slurry	1600	0.14	1.4
2	Reinforced concrete	2500	0.03	0.3
3	Expanded-clay lightweight concrete based on keramsite sand and keramsite foam concrete	1800	0.09	0.9
4	Expanded-clay lightweight concrete based on keramsite sand and keramsite foam concrete	1000	0.14	1.4
5	Expanded-clay lightweight concrete based on keramsite sand and keramsite foam concrete	800	0.19	1.8
6	Polystyrene concrete (foam concrete)	600	0.068	0.7
7	Plain asbestos-cement sheets	1800	0.03	0.3
8	Pine and fir tree (along grain)	500	0.32	3.1
9	Mineral-cotton plates	100	0.56	5.4

For multilayer structures of outer fences the system of equations (10) is complicated by the number of structure layers, both on partial pressure difference and moisture potential difference.

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The required moisture transfer resistance R_θ^t, $m^2 \cdot h \cdot {}^oV/kg$, is determined from dependence similar to (1):

$$R_\theta^t = \frac{(\theta_{in} - \theta_{out})}{i_{out}}. \quad (12)$$

The specific moisture flux through fence i_{out}, $kg/(m^2 \cdot hr)$ is taken as basis for normalization. It is equal to

$$i_{out} = \Delta\theta_{out} \cdot \beta_e^\theta, \quad (13)$$

where $\Delta\theta_{out}$ is moisture potential difference for indoor air and inner surface of fencing structure, °V; β_e^θ is the moisture exchange factor, $kg/(hr \cdot m^2 \cdot {}^\circ V)$.

The physical meaning of accepted provision on normalizing specific moisture flux consists in the dispersion of excess moisture (through outer fences), which is released in the process of vital activity of animals, birds and stored products. This need is associated with the prevention of moistening materials of outer fence in cold period of year that results in reduction in their thermal protection characteristics, selected on the basis of thermal engineering calculations [1, 10]. In the absence of ventilation, the moisture G_m^0, kg/hr, released in premise, can only be removed through outer fences with area F, m^2. Therefore, the calculated (normalized) specific moisture flux i_{out}, $kg/(m^2 \cdot hr)$ through them is:

$$i_{out} = \frac{G_m^0}{F}. \quad (14)$$

The moisture exchange factor β_e^θ, is equal to:

$$\beta_e^\theta = \frac{G_m^0}{F\Delta\theta_{out}}. \quad (15)$$

The dependence (15) unambiguously characterizes the required intensity of moisture exchange on inner surfaces of outer fences. It interconnects temperature and moisture parameters of environment and outer fences ($\Delta\theta_{out}$, °V) with volume-planning and structural design of buildings (F, m^2), as well as production technology, species of animals, bi.rds, stored raw materials and operating modes (G_m^0, kg/hr).

The experimental data [15] were used to obtain values of moisture potential differences$\Delta\theta$, °V, between indoor air and inner surfaces of outer fences. The results were used to provide the dependences $\Delta\theta^{OW} = f(t_{in})$ for outer walls and $\Delta\theta^{RC} = f(t_{in})$ for flat roof cover of cowhouse (Figures 2 and 3). The following logarithmic functions are chosen as approximating functions:

- for outer walls: $\Delta\theta^{OW} = 1.23\ln(t_{in}) - 1,16$; (16)

- for building flat roof cover: $\Delta\theta^{RC} = 4.74\ln(t_{in})$-8,98. (17)

The presence of negative values of moisture potential difference indicates that the moisture transfers inside premise.

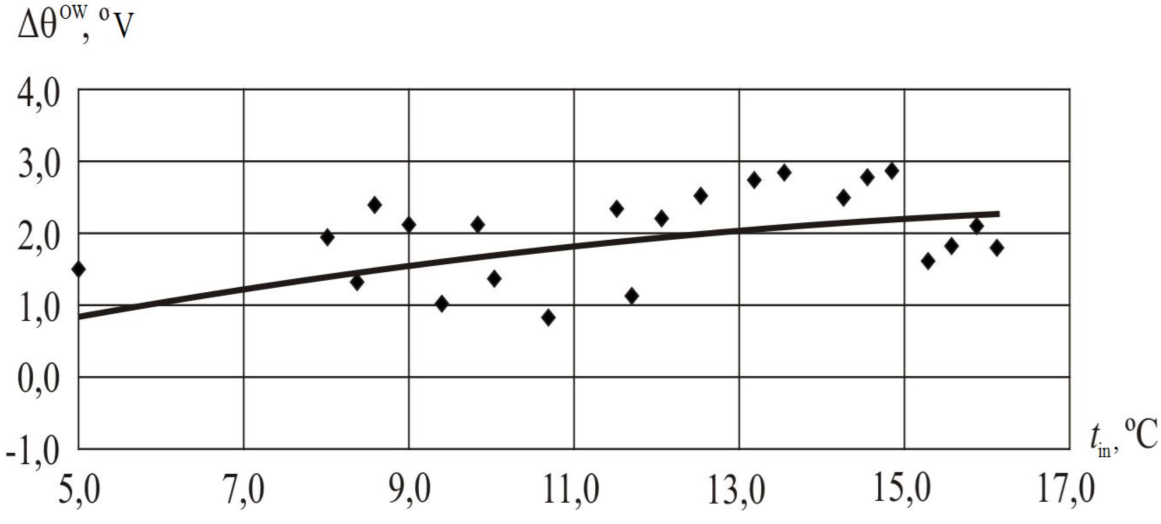

Figure-2. Dependence of moisture potential difference of indoor air and inner surface of cow house outer wall on indoor air temperature.

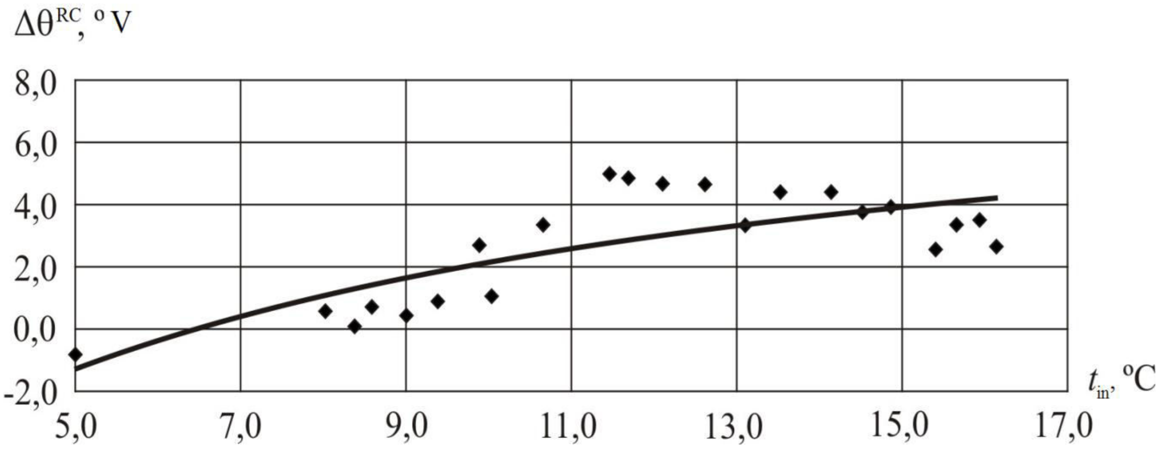

Figure-3. Dependence of moisture potential difference of indoor air and inner surface of cow house flat roof cover on indoor air temperature.

CONCLUSIONS

a) The normalization of thermal physical characteristics of outer fences of unheated industrial agricultural buildings according to thermal engineering requirements (R_0^t) and moisture transfer resistance requirements (R_θ^t) is common thermal physical interrelated process. The calculation of heat transfer resistance of outer fences is of high priority. Near-optimal volume-planning solutions for building premises are justified and designs of their outer fences are selected on the basis of thermal engineering calculation.

b) The developed methods for calculating required thermal engineering and moisture characteristics of outer fences of industrial agricultural buildings (as single biological energetic complexes) are suitable both for new construction (design) and reconstruction of structures. The provision of required heat transfer resistance at design stage solves the problem of energy saving through the utilization of physiological and biological heat. The maintenance of premise temperature conditions in the process of operation is achieved by the provision of required moisture transfer resistance due to the stability of quantitative indicators of thermal characteristics of outer fences specified at design stage.

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