

ALGORITHM OF AN ELECTRONIC MONITORING SYSTEM PERFORMANCE FOR EVALUATING THE THERMO-PHYSICAL CHARACTERISTICS OF AN ANIMAL FARM BUILDING

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Abstract: An algorithm of an electronic monitoring system performance for evaluating the overall heat transfer coefficient has been developed. It uses a model which describes the energy exchange in an animal farm building. The finite difference method has been applied in the modeling process. The input signals of the model are measured in real time values of the building parameters. Based on the algorithm, a software product has been developed to predict the temperature and the air relative humidity variations inside the building. A structural scheme of an electronic monitoring system for evaluating the overall heat transfer coefficient has been created.

Keywords: electronic system, monitoring, algorithm, model.

1. INTRODUCTION

The efficiency of animal breeding depends on the thermo-physical characteristics of the animal farm building [1]. They determine the microclimate maintenance energy expenses. In order to estimate the quality of the farm building, it is necessary to determine the overall heat transfer coefficient k . It is generally determined by indirect methods based on measuring the parameters of the building's different structural elements in settled conditions of heat transfer in a laboratory environment [2]. There are also methods applied which, due to a difficulty in achieving the settled conditions, determine the overall heat transfer coefficient for the different parts of a building in dynamic regime [3]. The disadvantage of such an approach is that it doesn't take the parameters of the whole building into account, but each of its elements separately.

2. METHODOLOGY

2.1. The goal of investigation is to develop a model of the energy exchange, a performance algorithm and a structural scheme of an electronic monitoring system for evaluating the overall heat transfer coefficient of an animal farm building.

2.2. The object of investigation is the thermo-physical characteristics of an animal farm building, represented through the overall heat transfer coefficient.

2.3. Substantiation of the basic approximations and dependencies.

In order to estimate the overall heat transfer coefficient, the energy balance of the building is used (Fig. 1). It can be described with the following equation:

$$E_{IN}^{EN} + E_{IN}^{AIR} + E_{IN}^{SUN} + E_{IN}^{AN} = E_{OUT}^{AIR} + E_{OUT}^{EN} + E_{OUT}^{ENC} + E_{OUT}^{FL}, \quad (1)$$

Where: E_{IN}^{EN} is the incoming energy (electricity, heated water, etc.), J; E_{IN}^{AIR} - the additional energy from the fresh air flow, J; E_{IN}^{SUN} - the additional energy from solar radiation, J; E_{IN}^{AN} - the energy produced by the animals, J; E_{OUT}^{AIR} - the energy of the outgoing air, J; E_{OUT}^{EN} - the energy of the outgoing energy carriers (heated water), J; E_{OUT}^{ENC} - the energy exchanged through the building enclosures, J; E_{OUT}^{FL} - the energy exchanged through the floor of the building, J.

The thermo-physical characteristics of the building enclosures determine the energy exchanged through them (E_{OUT}^{ENC}). In order to determine the overall heat transfer coefficient, the heat flow for the whole building surface is used. It is calculated on the basis of the energy balance.

$$Q = \frac{E_{OUT}^{ENC}(\tau) - E_{OUT}^{ENC}(\tau - \Delta\tau)}{\Delta\tau}, \text{ W}, \quad (2)$$

Where: τ is the current time, s; $\Delta\tau$ - the sampling interval, s.

The overall heat transfer coefficient is calculated with [4]:

$$k = \frac{Q}{F(t_{AIR}^B - t_{AIR}^{ENV})}, \text{ W.m}^{-2}.\text{K}^{-1}, \quad (3)$$

Where: Q is the heat flow passing through the building enclosures, W; F - the total area of the building enclosures, m^2 ; t_{AIR}^B , t_{AIR}^{ENV} - the temperatures of the air inside and outside the building respectively, $^{\circ}\text{C}$.

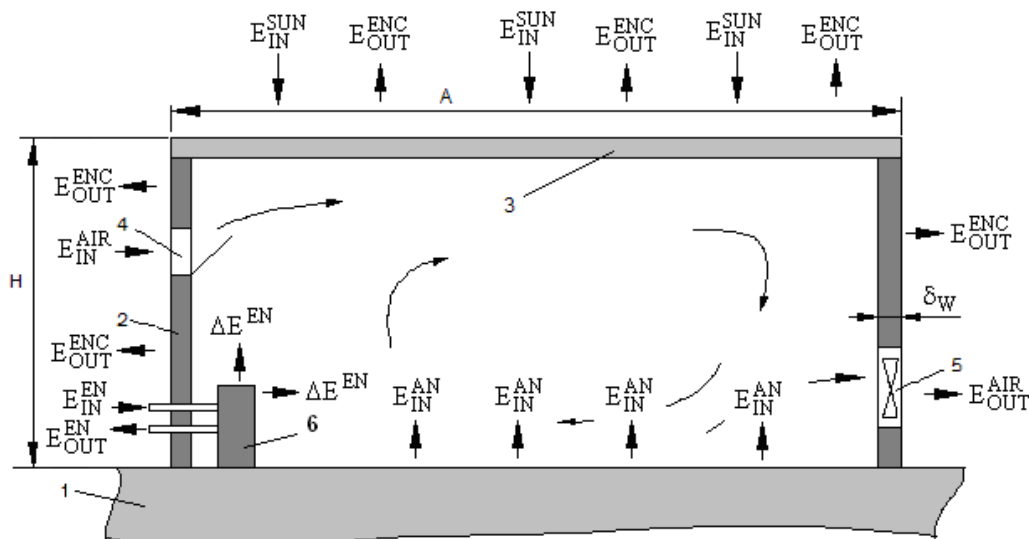


Fig. 1. General view of an animal building farm:

1 - floor; 2 - walls; 3 - ceiling; 4 - incoming air duct; 5 - fans; 6 - incoming energy carrier;

ΔE^{EN} - energy entering the building; δ_w - the width of the wall, m.

The connection between the overall heat transfer coefficient k and the overall thermo-physical characteristics of the building is represented with [4]:

$$k = \frac{1}{\frac{1}{\alpha_{IN}} + \frac{\delta_W}{\lambda_W} + \frac{1}{\alpha_{OUT}}}, \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}, \quad (4)$$

Where: α_{IN} and α_{OUT} are the coefficients of the convective heat transfer between the inside air and the internal surface of the walls, and between the outside air and the external surface of the walls respectively, $\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$; λ_W - the heat conductivity coefficient of the walls, $\text{W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$.

3. PROCESS MODELLING

3.1. Algorithm for evaluating the overall heat transfer coefficient through a monitoring system.

The difficulty in determining the overall heat transfer coefficient results from the energy flows dynamics. For its evaluation, a model of the energy exchange in an animal farm building has been used. This coefficient is calculated according to the algorithm in Figure 2.a, which is as follows: the initial conditions are set in block 1; in real time regime, the information from the monitoring system sensors is gathered for the fixed time period in block 2 and is consequently stored in a database.

The variation of the overall heat transfer coefficient is determined in blocks 3, 4 and 11, and the variation of the virtual time – in blocks 5, 6 and 9. In block 7, based on the virtual time τ , the values of the building parameters measured by the monitoring system are shown. In block 8, the model calculates the temperature and the relative humidity of the air, which depend on the set value of the overall heat transfer coefficient. In block 10, the calculated values from block 8 are compared with the measured ones. The comparison is based on a given criterion. The value $P_{KR}(k)$ is received in block 12. As a result, the value of the overall heat transfer coefficient k is determined, for which the $P_{KR}(k)$ value is minimal. The latter is accepted as the required overall heat transfer coefficient.

3.2. Modeling of the energy exchange in an animal farm building.

For this investigation, the model in Figure 2.b is used, which describes the energy exchange in an animal farm building. The finite difference method has been used for the modeling [4]. In block 1, the parameters of the incoming air are calculated – the partial pressure of the saturated air water vapor (5), the partial pressure of the air water vapor (6) and moisture content of the air (7). The enthalpy of the incoming air is determined with an equation (8), whereas the parameters of the mixed air are determined in block 2. (9) and (10) calculate the amount of incoming air and the humidity produced by the animals within a time period $\Delta\tau$. The mixing of the air flows is described with the relative humidity (11) and enthalpy (12) of the air inside the building [5]. In block 3, the energy balance of the air is calculated. Equations (13) and (14) [4] are used to calculate the heat flows between the air inside the building and the walls, and between the walls and the air outside respectively. Dependency (15) calculates the energy difference of the air for a period of time $\Delta\tau$, while (16) and (17) estimate the new values of the enthalpy and the temperature of the air [4]. In order to calculate the current relative humidity of the air (20), the partial pressure of saturation (18) and the current partial pressure (19) are calculated. In block 4, the energy state of the enclosures is determined; equation (21) calculates the additional amount of energy accumulated in them within a period of time $\Delta\tau$, and (22) - their current mean temperature[4].

Where: p_{AIR}^{SAT} - the partial pressure of the saturated incoming air water vapor, Pa; p_{AIR}^{ENV} - the partial pressure of the incoming air water vapor, Pa; ϕ_{AIR}^{ENV} - the relative humidity of the incoming air, %; x_{AIR}^{ENV} - the

moisture content of the incoming air, $kg \cdot kg^{-1}$; B - the atmosphere pressure, Pa; h_{AIR}^{ENV} - the enthalpy of the incoming air, $kJ \cdot kg^{-1}$; $m_{\Delta\tau}$ - the incoming air mass within a period of time $\Delta\tau$, kg; B_{AIR} - the flow rate of the incoming air, $m^3 \cdot s^{-1}$; ρ_{AIR} - the air density, $kg \cdot m^{-3}$; Δx_{AIR}^B - variation of the relative air humidity inside the building, $kg \cdot kg^{-1}$; w_B - the mass flow rate of the moisture produced by the animals, $kg \cdot s^{-1}$;

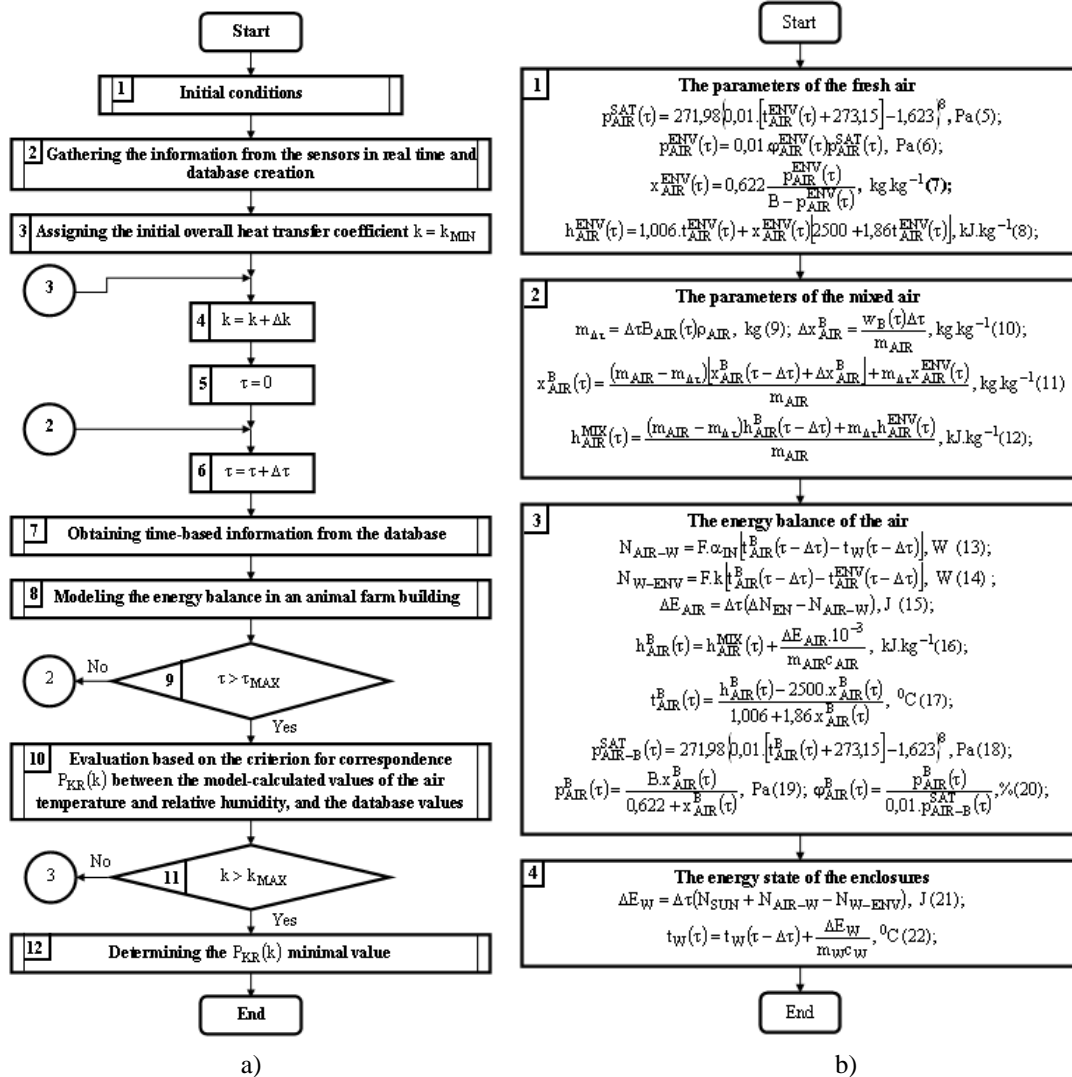


Fig. 2. a) Algorithm for estimating the overall heat transfer coefficient; b) Model of the energy exchange in an animal farm building.

m_{AIR} - the air mass inside the building, kg; x_{AIR}^B - the relative air humidity inside the building, $kg \cdot kg^{-1}$; h_{AIR}^{MIX} - the enthalpy of the mixed air inside the building, $kJ \cdot kg^{-1}$; h_{AIR}^{ENV} - the enthalpy of the air outside the building, $kJ \cdot kg^{-1}$; N_{AIR-W} - the heat flows between the air inside the building, W; t_W - the temperatures of the building enclosures, $^\circ C$; N_{W-ENV} - the heat flows between the walls and the air outside the building, W; ΔE_{AIR} - the energy difference of the air for a period of time $\Delta\tau$, J; ΔN_{EN} - the incoming heating power, W; h_{AIR}^B - the enthalpy of the air inside the building, $kJ \cdot kg^{-1}$; c_{AIR} - the air specific heat capacity,

$J \cdot kg^{-1} \cdot K^{-1}$; p_{AIR-B}^{SAT} - the partial pressure of the saturated air water vapor inside the building, Pa; φ_{AIR}^B - the relative air humidity inside the building, %; ΔE_W - the additional amount of energy accumulated in the enclosures within a period of time $\Delta \tau$, J; N_{SUN} - the incoming heating power from solar radiation, W; t_W - the temperatures of the enclosures, $^{\circ}C$ (22); m_W - the enclosures mass, kg; c_W - the enclosures specific heat capacity, $J \cdot kg^{-1} \cdot K^{-1}$.

Based on the algorithm, a software product has been developed, which describes the variation of the temperature and the relative humidity of the air inside the building (Fig. 3).

The graphics clearly illustrate that the increase of the incoming energy flow into the building results in a relative air humidity initial decrease, followed by a slow increase. The initial relative air humidity decrease is due to the air temperature increase, which leads to an increased partial pressure of the saturated air water vapor. The subsequent gradual increase results from the increased moisture production of the animals. Subsequently, the air temperature inside the building increases to a particular value.

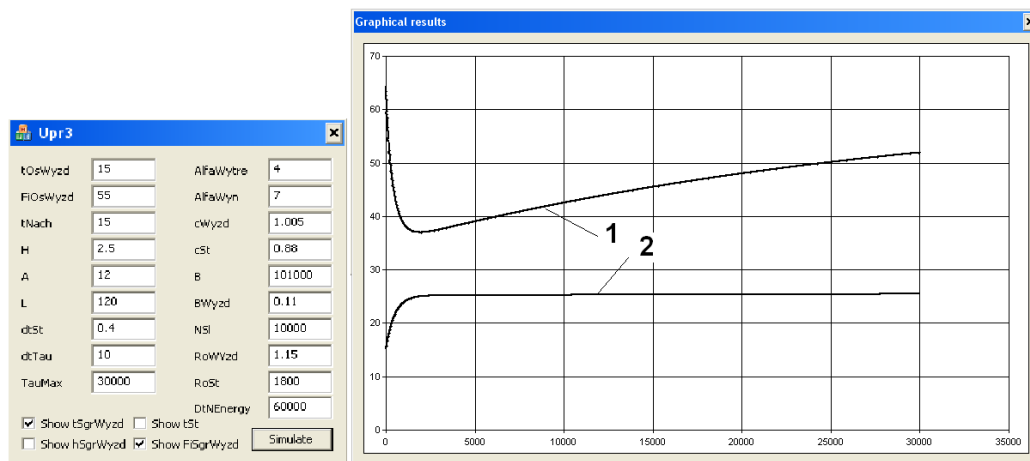


Fig. 3. Main window and result graphics of the software product for modeling the energy balance in an animal farm building: 1-variation of the air relative humidity inside the building; 2-variation of the air temperature inside the building.

3.3. Structural scheme of the electronic monitoring system

The structural scheme of the electronic monitoring system is shown in Figure 4.

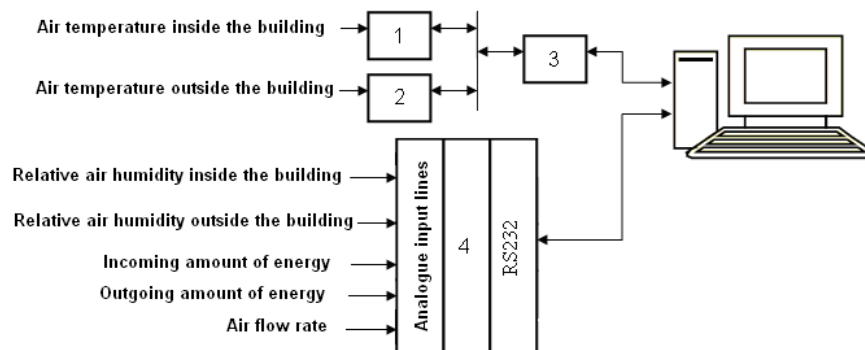


Fig. 4. Structural scheme of the electronic monitoring system for evaluating the thermo-physical characteristics of an animal farm building.

The temperature value is measured by DS18B20 sensors [6] (1 and 2), which are connected with a single wire network. An adapter 3 type DS90C97U is used [7] to coordinate the levels of the network μ Lan signals with those of the serial port RS232 of a PC [7]. The relative humidity of the air is measured with sensors DOL14 [8]. Their analogue inputs are connected with the analogue inputs of the specialized controller 4. The signals for the amount of incoming and outgoing energy as well as for the air debit are also conveyed to the analogue inputs of the controller. The information from the sensors is fed into the PC, where it is processed and stored in a database. For that purpose, the developed software product is installed in the computer.

4. RESULTS

The specifics of evaluating the thermo-physical characteristics of an animal farm building have been analyzed. These characteristics are represented through the overall heat transfer coefficient. The necessity for developing an electronic monitoring system to evaluate the overall heat transfer coefficient in dynamic regime has been substantiated.

The main approximations used in the modeling of the energy exchange in an animal farm building have been substantiated.

An algorithm for the electronic monitoring system has been developed to estimate the overall heat transfer coefficient. It uses a model which describes the energy exchange in an animal farm building. The assessment of the overall heat transfer coefficient is made by comparing the calculated and the actual values of the air temperature and relative humidity inside the building, during a process of setting different values of the overall heat transfer coefficient.

A model which describes the energy exchange in an animal farm building has been developed. During the modeling process, the finite difference method is used. The model input parameters are measured in real time energy parameters.

On the basis of the suggested model, a software product describing the variation of the temperature and the relative humidity of the air in the building has been created.

5. CONCLUSIONS

The developed model of energy exchange, the algorithm and structural scheme of the monitoring system for evaluating the overall heat transfer coefficient allow for assessing this coefficient in the process of a building's exploitation in dynamic regime.

The presented structural scheme of an electronic monitoring system for assessing the overall heat transfer coefficient uses the developed algorithm and model.

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