EXPERIMENTAL STUDIES AND NUMERICAL SIMULATION OF SPEED MODES OF AIR ENVIRONMENT IN A POULTRY HOUSE
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ЕКСПЕРИМЕНТАЛЬНЕ ДОСЛІДЖЕННЯ ТА ЧИСЕЛЬНЕ МОДЕЛЮВАННЯ ШВИДКІСНИХ РЕЖИМІВ ПОВІТРЯНОГО СЕРЕДОВИЩА В ПТАШНИКУ

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DOI: 10.35633/INMATEH-59-01

***Keywords**: numerical simulation, heat- and mass-exchange, range of control, poultry house, system performance.*

ABSTRACT
Due to the range of indeterminate factors that influence energy consumption and quality indicators of the air medium while providing the necessary conditions for poultry management, the use of analytical methods for determining the patterns of heat-, mass- and energy-exchange processes happening there is not sufficient enough and additional experimental research is required.

For that purpose, numerical simulation and experimental investigations on the performance of the environment support system in a typical broiler poultry house according to technological conditions have been conducted. In the course of the experiment, quality indicators of the air medium and the process energy performance have been determined.

РЕЗЮМЕ
У зв'язку із невизначеністю ряду факторів, що впливають на витрати енергії та якісні показники повітряного середовища під час забезпечення необхідних умов утримання птиці, застосування аналітичних методів виявлення закономірностей тепло-, масо- та енергообмінних процесів, які там відбуваються, є недостатнім і додатково вимагає проведення експериментальних досліджень.

З цією метою нами проведено чисельне моделювання та експериментальні дослідження функціонування системи забезпечення мікроклімату у типовому пташнику-бройлернику на відповідність технологічним вимогам. Під час їх виконання досліджено якісні показники повітряного середовища та енергетику процесу.

INTRODUCTION
Papers of *Blanes-Vidal V. et.al., (2008), Bustamante E. et.al., (2017)* cover computational fluid dynamics (CFD) simulation of the flows of air and heat-mass exchange in a poultry house, where there is side system of ventilation used. The authors *Blanes-Vidal V. et. al., (2008); Bustamante E. et.al. (2017)* believe that the method of side mechanical system of ventilation is more effective compared to other methods and make it possible to reduce heat stress and increase productivity of summer poultry raising. As a result of numerical simulation presented in *(Blanes-Vidal V. et.al. (2008); Bustamante E. et.al. (2017)*, the distribution of velocities, pressures and temperatures of the air flow in poultry houses for a side system of ventilation have been obtained. The results of numerical simulation have been compared to the data obtained from experimental studies; here the difference between them does not exceed 12%.

The paper of *Zajicek M. and Kic P. (2012)* presents the CFD solution of miscellaneously improved cases for the various flow and shape configurations of the broiler house. Effects of the transversal and longitudinal ventilation are combined with the changes of inlet air streams directions and also with the different cross-section shaping obtained using curtains.

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Papers of *Gorobets V.G. et al. (2018); Gorobets V.G. et al. (2018)* covers the system of cooling the outside air with the help of heat exchange apparatuses of special design *(Gorobets V.G. et al. 2019)*, in which water from subterranean wells is used as a cooler. Mathematical simulation of the processes of heat and mass transfer during air ventilation in the poultry houses, where the location of ventilation equipment is changed height wise, has been conducted. As a result of numerical simulation, the fields of velocities, temperatures and pressures in a poultry building have been obtained.

The developed CFD model *(Fidaros D. et al. 2018)* is validated against measurements of temperature (16 points) and air velocity (6 points). According to the simulation results, it is drawn the conclusion that the vertical temperature gradient should be taken into account when the operational sensors for the cooling devices are positioned inside the chamber since there is a deviation higher than 2°C between the air content above and among the birds. Also, various combinations of the available five fans, operating in two possible modes of the examined poultry chamber are studied in order to assess their effect to the internal microclimate. The operation of two or three central fans is proven to be the optimum choice in terms of temperature, ventilation and air velocity. The operation of only one fan fails to preserve the required temperature, while the operation of more than three fans does not improve the ventilation rates.

Based on the conducted analysis, the main drawbacks of numerical simulation in greenhouses have been determined *(Trokhaniak V. and Klendii O., 2018)*. Numerical simulation of the processes of hydrodynamics and heat-mass exchange, that take place within the limits of commercial-scale greenhouses, has been conducted.

Pourvosoghi N. et al. (2018) focused on evaluation and numerical analysis of the influence of differential pressure (20, 30 and 40 Pa) and fan activation scenarios on indoor air velocity and temperature distribution in a poultry house. Results showed that air velocity tends to be maximum toward the centre of the cross-section of the house and minimum near the floor next to the side walls. Furthermore, it is elucidated that considerable thermal discomfort for chickens is likely due to temperature variation at the proximity to the exhaust fans.

Maintaining proper environment in hen house by mechanical ventilation is essential for the production. In order to fully mix the cold inlet air in winter with room air, the free space beneath ceiling of hen house is normally large. However, in summer, such a design is not optimal for tunnel ventilation where air is drawn into one end of the house and exhausted at the other end, i.e., a large portion of the ventilation air would pass through the free space under ceiling instead of caged-hen occupied zone (CZ), which leads to reduced air speed in CZ as well as wind chill effect. To solve this problem, application of deflectors beneath the ceiling was investigated by CFD simulations. To assess the effect of deflectors *(Cheng, Q.Y. et al. 2018)*, the indoor air speed and distribution with deflectors were compared to those without deflectors. The effects of heights (0.4 m, 0.55 m, 0.7 m, 0.85 m and 1 m) and intervals (6 m, 9 m, 12 m, 15 m and 18 m) of deflectors on air speed and distribution in CZ were analyzed. The CZ was modelled as porous media in simulations to reduce mesh numbers.

Rojano F. et al., (2019), propose a three-dimensional modelling tool that uses CFD. External and internal climate and the sensible and latent heat emitted by the hens were included in the model in accordance with the principles that govern heat and mass transport, momentum and radiative energy. Experimental data were used in the proposed 3D CFD model to predict the internal climate, considering a time series when wind blew perpendicular to the ridgeline. A period of 3h30min, occurring under a stable wind direction was replicated, resulting in an overall RMSE of 1 degrees C and 1 g [H_2O] kg [dry air] for temperature and absolute humidity, respectively. In addition, the coefficient of variation indicated that the experimental data pertaining to the internal climate showed less overall variability than did predicted data.

A calculation method of the characteristics of compensated asynchronous machines taking into account the change of the magnetizing contour resistance is presented. The advantages of compensated asynchronous motors and compensated asynchronous generators are determined. Recommendations as to their effective practical use are given *(Mishin V.I. et al. 2016)*.

To ensure stable joint operation of asynchronous machines in an autonomous system under extreme conditions, separation of excitation capacitances and their distribution between branches of a unified electric circuit that are separate for the motor and the generator and not interrelated by the condition of the voltage resonance are proposed using an isolated induction generator with internal capacitive excitation *(Mishin V.I. et al. 2013)*.

MATERIALS AND METHODS

The investigations were conducted on one of the poultry farms in Ternopil region (Public Company “Ptakhofabryka Ternopilska”, Company “Skalat-Produkt”) in a poultry building for raising broiler chicken (10 thousand heads) with floor housing on a deep wood chips litter during a transient period (February-March).

In order to determine the behaviour and the dynamics of temperature change in a poultry building, the measurement of the indicated parameters was conducted immediately during the technological process. During this period the average temperature of the atmospheric air was +4°C, the value of ventilation air exchange was 0.8–1.1 m³/h per 1 kg bird body weight.

In a standard building (12×76 m) there are 5 rows of technological equipment located. The investigations were conducted during the operation of heating-ventilation system. The maintenance of the predetermined temperature was conducted by means of the equipment set of "Climate-4" type (Airstream Ventilation Systems, Big Dutchman) (with 10 extractor type fans (VO-7.1) and 5 fresh air fans (VO-5.6) with electric motors P = 0.37 kW.

Spatial temperature distribution was investigated at the level of bird location (0.3 m from the floor level) at 27 points of the building (Figure 1).

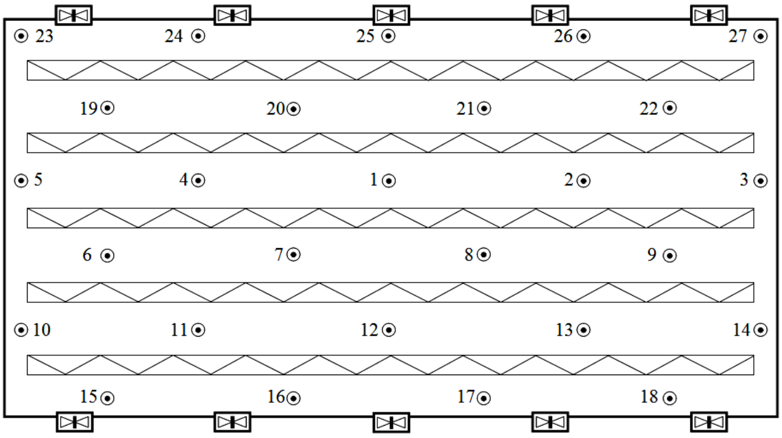
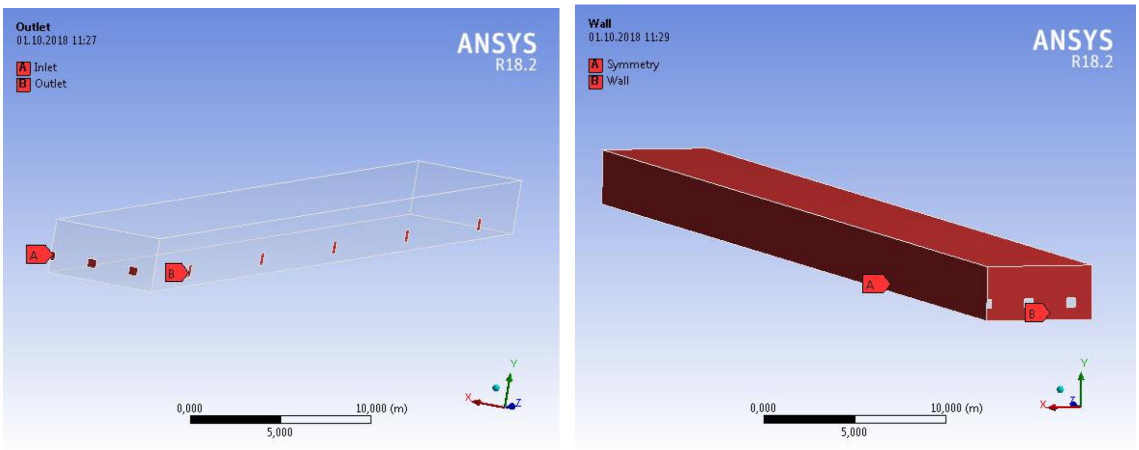


Fig. 1 - Location schematic of experimental measurements points

Mathematical simulation of hydrodynamic processes and the processes of heat transfer in a poultry house was conducted. For this purpose, the CFD based on ANSYS Fluent software package was used. The mathematical model is based on Navier-Stokes equations *(Khmelnik S.I., 2018)* and energy transfer equation for convective currents. Spalarta-Allmarasa turbulence model *(Spalart P.R. and Rumsey C.L., 2007; Allmaras S.R. et.al., 2012; Bailly C. and Comte-Bello G., 2015)* and Discrete Ordinates radiation model (DO) *(ANSYS, 2017)* were used in the calculations.

Figure 2 a presents boundary conditions at the "inlet" and the "outlet" and Figure 2 b shows "symmetry" and "wall", which were predetermined for conducting numerical simulation in a poultry house.



a) b)

Fig. 2 - Boundary conditions in a poultry house:

a) – "inlet" and "outlet"; b) – "symmetry" and "wall"

At the boundary “inlet” the mass air flow was predetermined to be 5.555 kg/s with the temperature of +4°C. The walls and the floor were made of keramzite concrete 0.4 m in thickness. At the boundary "wall" the temperature of the outside air was preset to be +4°C, taking into account DO radiation model. In the poultry building there were birds kept with floor housing, which is the source of heat generation of +41°C.

RESULTS

According to the investigation results, temperature fields (Figure 3) that present the pattern of its distribution in a poultry house during a raising cycle have been built. The significant extremums presented in the graphs (30 and 21°C, see Figure 3) indicate the exceedance of zoo-hygienic norms for the parameters of the air medium (26 – 28°C at the beginning of a cycle and 16 – 19°C beginning from the 5th week) generated by the presence of heat sources (birds’ heat production), which caused its local increase and non-uniformity of temperature and gas distribution in a building.

Since the divergence of the technological parameters was determined at the beginning of a poultry raising cycle, it can be assumed that the causes of these phenomena could be the imperfection of the existing system of heating-ventilation equipment control as well as the openings in the structures of a building and the baffle systems of ventilation devices.

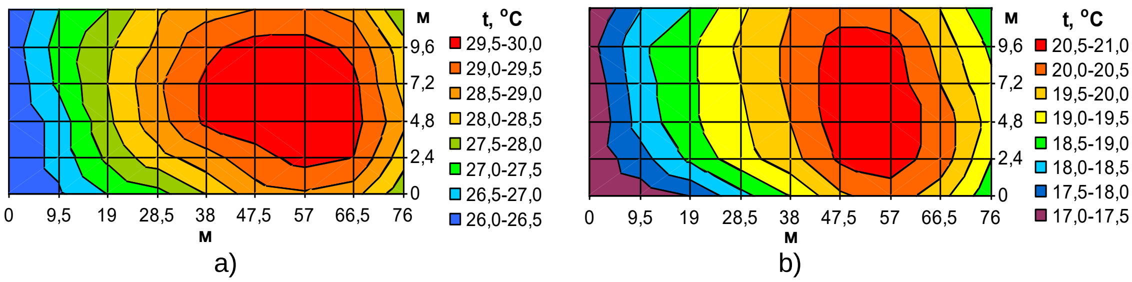


Fig. 3 - Temperature distribution in a poultry building during a poultry raising cycle

a) – day 14; b) – day 42

According to the results of the measurements, statistical analysis has been conducted and the graphs of the distribution of root-mean square deviations and error dispersions of the controlled variables have been built in order to make a comparison with the specified parameters according to X (length), Y (width) coordinates of displacement (Figure 4).

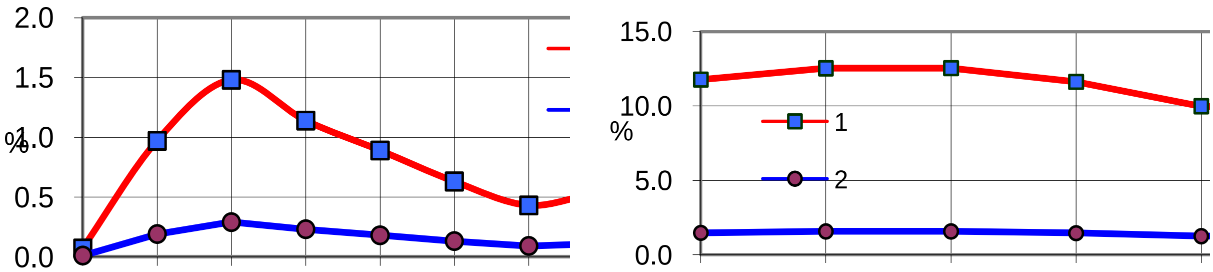


Fig. 4 - Root-mean square deviations and error dispersions of temperature distributions

(1, 2) according to X, Y coordinates of displacement

Based on the results of the experimental investigations and the production inspection of the quality indicators of the air medium in a poultry house, numerical mathematical simulation has been conducted in order to evaluate the validity degree of the obtained results.

Finite element method (FEM) was used in the numerical calculation of hydrodynamics and heat transfer problems. Figure 5 presents the FEM mesh built in ANSYS Meshing mesh generator based on Workbench framework by means of "CutCell" method. The minimum size of the boundary is equal to 0.05 m and the maximum one is 0.4 m. According to "Orthogonal Quality" criteria, the quality of the mesh is 0.75.

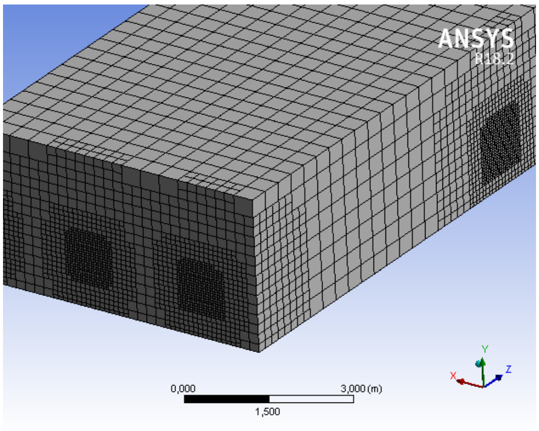


Fig. 5 - Finite-element mesh generation

Figure 6 and Figure 7 present the results of the numerical simulation for a half of the poultry building of the specified design. Figure 6 shows that higher temperature is observed in the center of a poultry building. It is shown that temperature distribution in a poultry building is within the limits from +24 to +31°C (see Figure 6). Figure 7 presents the distribution of the temperature field in a poultry house at the distance of 15, 30, 45 and 60 m from extractor type fans. As expected, in the transient period of the year, the air being +4°C is concentrated near the flooring of a poultry house. At a height of 0.8 m near the birds the temperature is +17°C, which meets the norms.

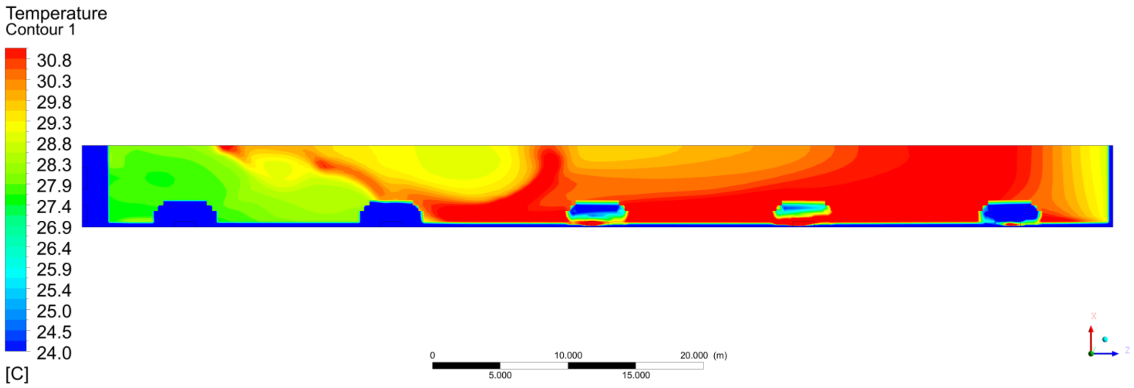


Fig. 6 - Temperature field in a poultry house ranging from +24 to +31°C at a height of 0.3 m from the floor level along xz axis

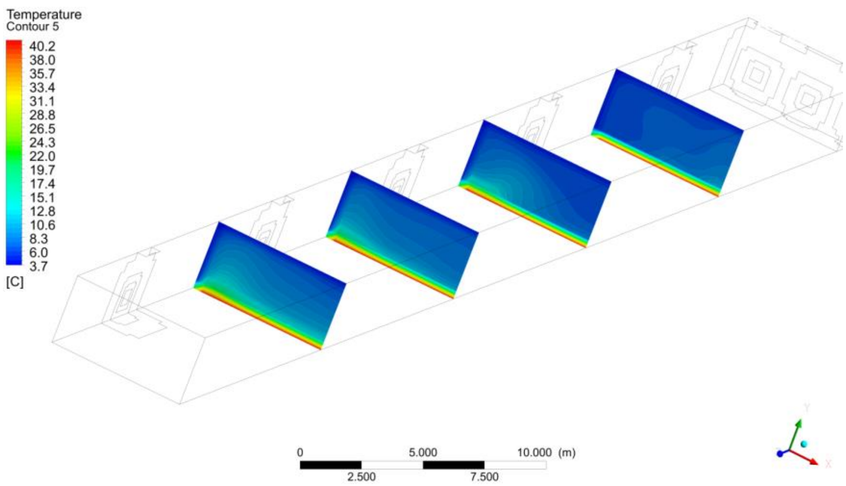


Fig. 7 - Temperature field in a poultry house at a distance 15, 30, 45 and 60 m from extractor type fans along xy axis

The graphs in Fig.8 characterize air temperature distributions along the length of the building and the ones obtained as a result of the numerical simulation and the experimental investigations (see Fig.3 a) at a distance of 2.4 m (see Fig.8 a) and 4.8 m (see Fig.8 b). The deviation of the results does not exceed 6.5%.

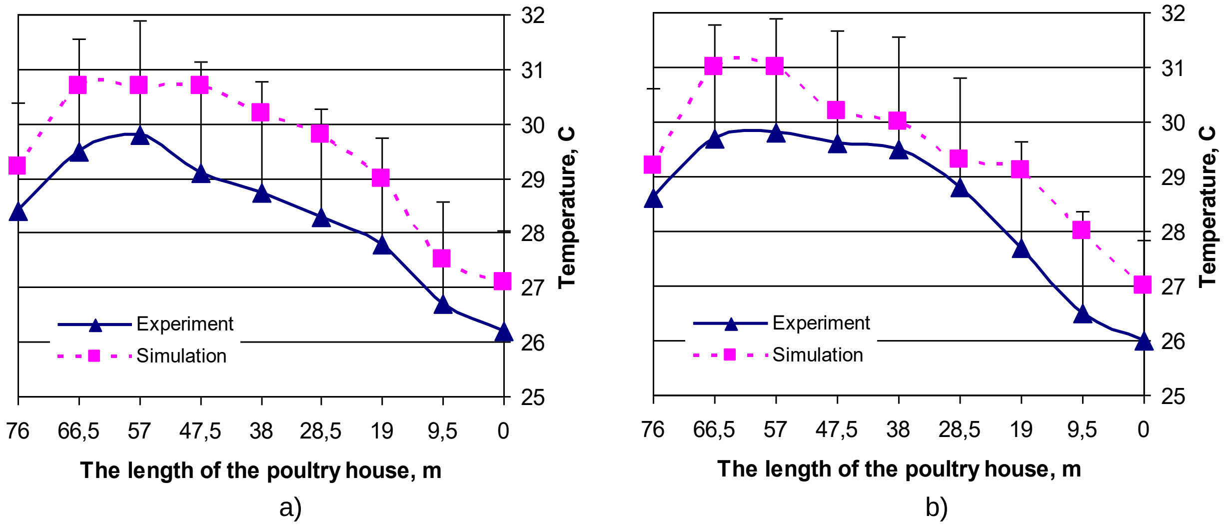


Fig. 8 - Air temperature distribution along the length of a building from the side wall of a poultry house
a) – 2.4 m; b) – 4.8 m

The ventilation system is controlled in terms of providing the predetermined temperature and gas concentration (NH_3). Under these conditions, depending on the balance of the inside and outside temperature, the efficiency of the ventilation system (VS) ranges from nominal (the maximum) L_n to the minimum L_{min}. The values of the outside temperatures T_{max} and T_{min} correspond to these values – the beginnings of cooling and heating seasons, when inside temperature control is determined by the nominal or the minimum values of air exchange, respectively:

$$n^* = \frac{1}{L_n}\left[\frac{1}{\gamma c}\left(\frac{q_\Sigma(t)}{T_{in} - T} - \left(k_j F_j\right)_\Sigma\right)\right] \tag{1}$$

As already noted, the range of VS efficiency control should be from L_{min} to L_{max} at the change of outside temperatures from T_{min} to T_{max} that are determined from heat-balance equations reduced to the following form:

$$T_{\min} = T_{in} - \frac{q_\Sigma(t)}{\gamma c L_{\min} + \left(k_j F_j\right)_\Sigma}\,;\ T_{\max} = T_{in} - \frac{q_\Sigma(t)}{\gamma c L_{\max} + \left(k_j F_j\right)_\Sigma}$$

Current ventilator efficiency values are determined by means of processing hourly data on the temperature of the outside air taken from data books. For a certain period of time, let us determine the number of hours of temperature duration within the range of $T_{max} - T_{min}$ at a pitch of 1°C. The minimum VS efficiency is determined with the condition of NH_3 emission depending on the age of birds $L_{min} = f(t)$.

In the temperature range of $T_{max} - T_{min}$ with the pitch of 1°C, according to the formula (1), VS running time with its correspondent efficiency is obtained. Running time with nominal efficiency is equal to the temperature duration of more than T_{max} and running time with the minimum efficiency – less than T_{min}. As a result of adding time intervals with the same efficiency based on the obtained data, it follows that VS running time in a nominal mode is about 15% of the total operating time and VS running time with the minimum velocity – 7%. The rest of the time – 78% – ventilators operate with the controlled efficiency.

In order to calculate energy consumption for heating a poultry house, firstly, it is necessary to determine the beginning of a bird raising period, since cycle distribution during a year greatly influences the overall energy consumption. According to the investigation data and the methodology presented in *(Ivanova V. M., 1987; Shutka O.V. and Sukach S.V., 2010)*, cycle arrangement in a row is determined. Thus, the beginning of a raising period, which falls on the first days of November, corresponds to rational cycle distribution, at which heat energy saving up to 15% is provided.

According to the data covered above and having assumed that, currently, the minimum period of broiler raising is equal to 43 days and 9 days of sanitary period, 7 raising cycles are obtained under the condition of their optimal arrangement. According to climatological reference books, graphs of distribution of the average monthly air temperature and the change of the inside temperature in a poultry house within every raising cycle in the selected area (climatic zone) are built.

The energy consumed by heat-producing equipment of a broiler farm is calculated according to the heat balance equation:

$$Q=\int_{t_\Pi}^{t_K}\left[\left(k_jF_j+\gamma cL_{\min}(t)\right)\left(T_{in}-T_{out}\right)-q_\Sigma(t)\right]dt \tag{2}$$

While determining energy consumption during a cycle, when the preset temperature of the inside air is changed according to the birds' age, variable values in the expression (2) are T_{in} and T_{out} and after a 30-day age – only T_{out}. In order to simplify further calculations and transformations, let us set the constants:

$$\alpha=\left(k_jF_j+\gamma cL_{\min}(t)\right);\; b=T_{\max\_in}-T_{\min\_out};\; c=Q_{T_{in}}+Q_T-Q_{out} \tag{3}$$

where T_{max_in} – inside air temperature during bird placing; T_{min_out} – minimum temperature of the outside air.

For the first and the last cycles of raising, in case of linear approximation of outside temperature distribution, $T_{min} = T_{max}'$.

Having substituted (3) into (2), for the first cycle we obtain:

$$Q=\int_{t_{ny}}^{t_{ny}+\tau}\left[\alpha\left(b-r\left(t-t_{ny}\right)+gt\right)-c\right]dt \tag{4}$$

where τ – duration of the period of raising at changeable air temperature, twenty-four hours; t_{ny} – the beginning of broiler raising cycle, calendar day; r, g – constant coefficients of linear functions.

Having integrated and simplified the expression (4), we obtain:

$$Q=\tau\left[\alpha\left(b+gt_{ny}-\frac{(r-g)\tau}{2}\right)-c\right] \tag{5}$$

Analogically, we obtain the dependence for calculating energy demand in the last raising cycle:

$$Q=\tau\left[\alpha\left(b-gt_{ny}-\frac{(r+g)\tau}{2}\right)-c\right] \tag{6}$$

The number of twenty-four hours τ, during which it is necessary to heat the air, can be determined by differentiating the expressions (5) and (6). As a result, we obtain:

$$n_1=\frac{\alpha\left(b+gt_{ny}\right)-c}{\alpha(r-g)};\; n_1=\frac{\alpha\left(b-gt_{ny}\right)-c}{\alpha(r+g)} \tag{7}$$

For the cycles of raising, in which the approximation of the outside temperatures causes significant errors, their distribution should be presented in the form of a quadratic dependence

$$T_{out}=T_{\min.av}+kt^2 \tag{8}$$

where $T_{min.av}$ – the minimum average air temperature, which is typical of this area; k – constant coefficient of the parabolic function of temperature distribution.

From the expressions (2) and (8) we obtain the equation for calculation the necessary amount of heat from the 2nd to the 6th cycle of raising:

$$Q_{(2-6)}=\int_{t_{ny}}^{t_{ny}+\tau}\left[\alpha\left(b'-r\left(t-t_{ny}\right)+kt^2\right)-c\right]dt \tag{9}$$

where $b'=T_{max\_in} - T_{min\_out}$ – the difference between the maximum inside temperature and the minimum (average monthly in the coldest period) outside temperature, ºC.

After integration and transformation, we obtain:

$$Q_{(2-6)}=\tau\left[\alpha\left(b-\frac{rt}{2}-kt_{ny}^2-kt_{ny}\tau\frac{k\tau^2}{2}\right)-c\right] \tag{10}$$

In order to calculate heat demand according to the formula (10), it is necessary to substitute the correspondent to a certain cycle values of t_{ny}, which characterize the time of chicken placement, in it. This is the value that significantly influences heat energy consumption.

Based on the analysis and generalization of the investigation results on the fields distribution of air medium technological parameters in a poultry house, the function of the required air exchange is obtained and it determined the minimum volume of fresh air (m³) and, correspondingly, the minimum artificial ventilation heat exchange in order to create the optimal microclimate conditions according to NH_3 content, which provides the minimum heat energy consumption for medium heating:

$$G = 24k\int_a^b q(i_{NH_3})di \tag{11}$$

where k – the number of twenty-four hours in the cycles of broiler raising during the period under study; $q(i_{NH3})$ – functional dependence of the minimum necessary air exchange depending on the bird's age (from $i = a$ to $i = b$), m³/h.

The amount of heat (J) required for heating the incoming air is determined as follows:

$$Q = c\rho G(T_{in.av} - T_{out.av}) \tag{12}$$

where c – specific heat capacity of dry air, J/(kg·K); ρ – air density, kg/m³; $T_{in.av}$ – average inside air temperature, °K; $T_{out.av}$ – average outside air temperature, °K.

From the expressions (11), (12) we obtain the equation necessary to determine the required amount of heat to provide the preselected temperature in a poultry house during air exchange according to NH_3 content:

$$Q = 24kc\rho(T_{in.av} - T_{out.av})\cdot\int_a^b q(i_{NH_3})di \tag{13}$$

Heat consumption for heating the incoming air is determined by the range of ventilation system efficiency control, which was chosen with the condition of providing the maximum required demand of poultry for fresh air (m³/h):

$$L_{max} = L_n = nq_{max}m_{max} \tag{14}$$

where n – the number of heads in a poultry house, unit; q_{max} – summer norm of air exchange per 1 kg of body weight, m³/h; m_{max} – weight of one bird at the end of a raising period, kg.

According to the technological conditions, the maximum control range of D in order to provide the necessary air exchange $L_{min}(i)$ in poultry houses for young broilers should be 1:80, while the existing ventilation systems provide the maximum range of efficiency control about 1:10, its minimum limit corresponds to the value of $L_{max}(i)$ (Figure 9).

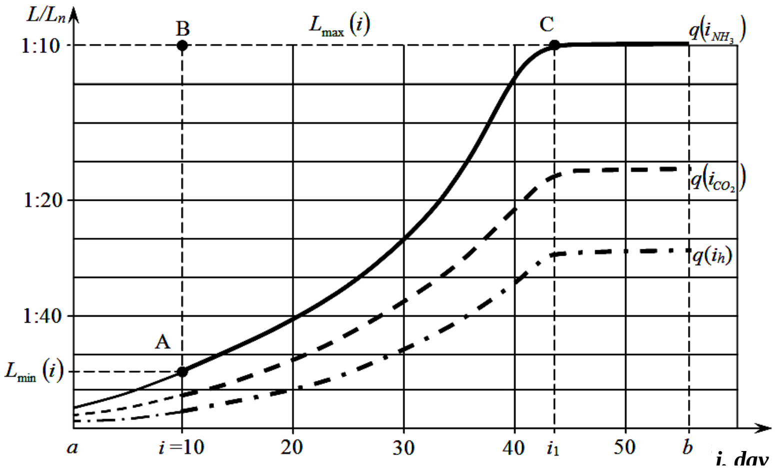


Fig. 9 - Relative dependences of air exchange values on the birds' age in winter and transient periods of the year

according to ammonia $q(i_{NH3})$ content, carbon dioxide $q(i_{CO2})$ content and excess water $q(i_h)$

According to the control range of the frequency of ventilator rotation, the calculation of the minimum value of air exchange (m³/h) is conducted according to the formula:

$$L_{min} = L_n D \tag{15}$$

The figure below (see Figure 9) presents the graphs of the relative dependences of the required efficiency L of a ventilation system, according to the current birds' need for fresh air $q(i)$, on the age and the content of harmful substances.

The obtained results show that beginning from the moment of exhaust ventilation operation i = 10 and to the birds' age $i = i_1$ (43 day), there is overconsumption of the air (m^3), which is heated to the poultry house temperature. In the adjusted scale, it is determined by the area of the ABC plot (see Figure 9) as the difference of the integrals $L_{max}(i)$ and q(i_{NH3}) within the interval $i - i_1$:

$$G = L_{\max} \int_{i}^{i_1} di - \int_{i}^{i_1} q(i_{NH_3})di \quad (16)$$

From the equations (12) and (16) we obtain the value of heat energy overconsumption (J), which is caused by insufficient range of ventilation system control:

$$\Delta Q = c\rho(T_{in.av} - T_{out.av})\left(L_{\max} \int_{i}^{i_1} di - \int_{i}^{i_1} q(i_{NH_3})di \right) \quad (17)$$

Thus, the investigation results presented above prove that specific heat and electric energy consumption can be decreased by means of extending the range of ventilation system control (not less than 1:50) with the help of variable-frequency asynchronous electric drive with adaptive control system, which is based on the analysis of microclimatic parameters of the air medium in poultry houses.

CONCLUSIONS

Based on the conducted research, it is possible to draw the following conclusions:

Numerical simulation of the processes of heat and mass transfer of the ventilated air in a poultry house in order to verify the results has been conducted together with the experimental investigations. According to the investigation results, with the help of ANSYS Fluent software, 3D temperature fields in a poultry house have been obtained;

Energy consumption and quality characteristics of the environment support technology depend heavily on the organization of the speed range of technological equipment;

The solution of the stated problems makes it possible to decrease energy consumption of the environment support technology during broilers raising, increase the quality of the air medium in poultry houses, reduce feed consumption and the loss of poultry stock and, as a result, increase economic efficiency of the production process and the quality of the finished product.

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