UDC 636.089:519.8
DOI: 10.37128/2520-6168-2024-3-4

ALGORITHM OF OPERATION OF THE MECHATRONIC SYSTEM FOR PROVIDING MICROCLIMATE OF PIGSTIES

Vitaliy YAROPUD, Candidate of Technical Sciences, Associate Professor
Vinnytsia National Agrarian University

ЯРОПУД Віталій Миколайович, к.т.н., доцент
Вінницький національний аграрний університет

The article analyzes modern technologies for keeping pigs, in particular the prospects for using mechatronic systems to ensure microclimate in pig houses. It was determined that deviations in microclimate parameters negatively affect the health, reproductive functions and growth of pigs, which leads to a decrease in the profitability of farms. An algorithm for the operation of a mechatronic system with adaptive air ventilation and energy-saving technical means has been developed, the parameters of which have been optimized using software modeling. Based on the adopted design and technological scheme of the mechatronic system for ensuring the microclimate of pig houses and the theoretical and experimental studies of its elements, an algorithm for its operation has been developed. The developed algorithm is implemented in the created simulation of the microclimate of a pig house in the Simcenter Star-CCM+ software package. According to the modeling, the temperature dynamics at each stage of the passage of the air flow through the developed microclimate system in the pig house throughout the year were obtained. The temperature of the air flow after passing through the ground heat exchanger and the indirect evaporation type heat exchanger approaches the values of zootechnical requirements. The process of cooling the air to a given temperature (22 °C) occurs without the use of additional air conditioning systems, and heating the air to a temperature of 18 °C requires additional switching on of heating elements. The dynamics of power consumption of the developed and classical microclimate systems in a pigsty for 16 machines was obtained. The obtained annual energy consumption for the developed microclimate system is 17528 kWh, which is 28.6 % less than the classical system (ventilation with a ground channel and a heating and air conditioning heat exchanger).

Key words: *pig housing, microclimate, mechatronic system, energy saving, ventilation, modeling, resource saving.*

Eq. 14. Fig. 11. Ref. 13.

1. Analysis of recent research and publications

According to the State Statistics Service, the total number of pigs in Ukraine is 5,608,800. heads (excluding temporarily occupied territories). At the same time, 49% are held in the private sector and 51% in rural areas. enterprises. Most of the livestock is concentrated in enterprises with more than 6,000 livestock. heads (32%) [1].

The most promising technology for keeping pigs in the world and in Ukraine is the new (Western) technology, which is characterized by the fact that all livestock are kept on a partially or completely slatted floor in capital premises, the premises are specialized for different technological groups, divided into isolated sections, with that is, the maintenance system is free-range, the method of maintenance is floor-stand, the method of reproduction is year-round-uniform, the method of cultivation is three-phase, microclimate is a forced system of negative pressure [2, 3].

According to the results of the analysis of the parameters of the microclimate in pig farms and their impact on the health of pigs, their reproductive functions and growth, it was found that their deviation leads to a deterioration in the health of animals, a decrease in their number and, as a result, to a decrease in the profitability of farms [4] .

Resource- and energy-saving cooling and heating systems based on automated and adaptive control systems are promising directions in creating and maintaining a microclimate in pig farms. However, their optimal parameters, location, and energy efficiency limits are not sufficiently covered in the scientific and technical literature [5, 6].

Based on this, the development and improvement of mechatronic systems to ensure the microclimate of piggery premises with adaptive air ventilation and energy-saving technical means with rationally justified parameters is an urgent problem of existing technologies for keeping pigs.

2. The purpose of the study

The purpose of the research is to develop an algorithm for the operation of a mechatronic system for ensuring the microclimate of piggery premises and to determine its effectiveness.

3. Research materials and methods

Based on the accepted structural and technological scheme of the microclimate system for piggery premises (Fig. 1) [7] and the conducted theoretical [8] and experimental studies [9, 10] of its elements, we will describe the algorithm of its work.

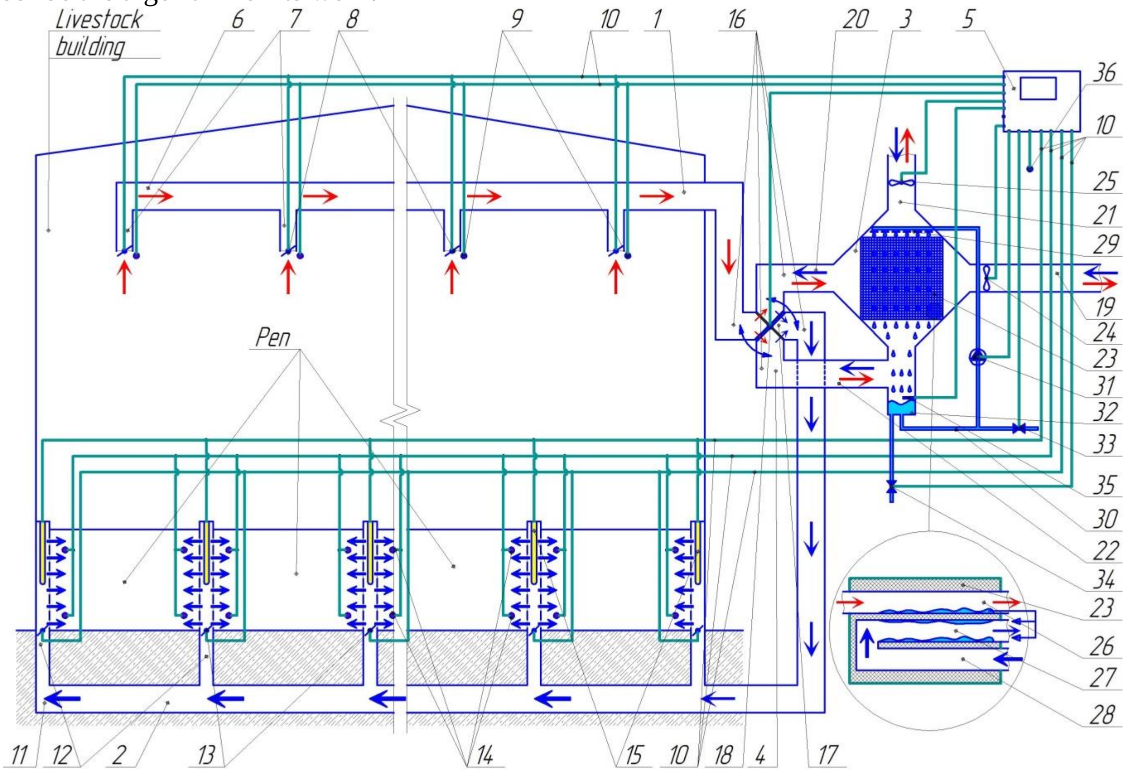

Fig.1. Structural and technological scheme of the mechatronic system for ensuring the microclimate of piggery premises:

1 – ventilation system for intake of polluted air; 2 – ventilation system for injecting clean air; 3 – indirect evaporative air heat exchanger; 4 – U-shaped vertical soil heat exchanger; 5 – control unit; 6 – central duct for air intake; 7 – nozzles for air intake; 8 – intake valves with servo drives; 9 – temperature, humidity and air quality sensors; 10 – electrical wires; 11 – central duct for air injection; 12 – nozzles for air injection; 13 – discharge valves with servo drives; 14 – temperature and air humidity sensors; 15 – heating elements; 16 – damper of the indirect-evaporative type heat exchanger; 17 – damper of the soil heat exchanger; 18 – disposal valve; 19 – external nozzle for working air; 20 – internal nozzle for working air; 21 – external nozzle for recycled air; 22 – internal pipe for recycled air; 23 – a set of cross channels; 24 – discharge fan; 25 – exhaust fan; 26 – working channels; 27 – wet channels; 28 – dry channels; 29 – nozzles for water supply; 30 – pipeline system; 31 – water pump; 32 – water intake tank; 33 – electromagnetic faucet for adding water; 34 – electromagnetic faucet for draining water; 35 – level sensor; 36 – external temperature and humidity sensors

The first stage of the algorithm is to determine the operating modes of the automatic ventilation system for the intake of polluted air.

The volume of ventilation can be determined by the amount of gases released by animals. The hourly volume of ventilation is the volume of air that must be removed from the livestock building per hour so that the percentage of carbon dioxide does not exceed the permissible limit.

The hourly volume of ventilation from the accumulation of carbon dioxide is calculated according to the formula:

$$O_{CO_2} = \frac{E}{\varepsilon_1 - \varepsilon_2}. \tag{1}$$

O_{CO_2} – hourly volume of ventilation, m^3/hours.; E – the amount of gas released by all animals per hour, l/hours.; ε_2– amount of gas in 1 m^3 atmospheric air, l/m^3; ε_1– permissible amount of gas in 1 m^3 air in the livestock building, l/m^3.

Depending on the concentration of gases (carbon dioxide, ammonia, and hydrogen sulfide) located above the machines, the automatic ventilation system for the intake of contaminated air closes/opens the corresponding dampers, forming openings with a plane:

$$\sigma_i = \begin{cases} \dfrac{k(n_{gi} - n_{g\,norm})}{\mu\sqrt{\dfrac{2}{\rho}\left(p_a - p_i - \dfrac{\rho w_k^2}{2}\dfrac{1}{N^2}\left[\left(\dfrac{\lambda P L_0}{4F} - 1\right)(i-1)^2 + i^2\right]\right)}}, & n_{gi} > n_{g\,norm}, \\ 0, \; n_{gi} \le n_{g\,norm}. \end{cases} \tag{2}$$

k –coefficient of proportionality, m^3/(s,·%); n_{gi} –concentration of gases (carbon dioxide, ammonia and hydrogen sulfide) above the machines, %; i – machine number; $n_{g\,norm}$ – limit values of gas concentration in the piggery, %; μ –coefficient of friction through the hole; ρ – air density, kg/m^3; p_a – atmospheric pressure, Pa; p_i – pressure in the i-th hole of the air intake pipe, Pa; w_k – air speed at the end of the duct, m/s; N – total number of machines, pcs.; L_0 – width of the machine (provided that the geometric dimensions of all machines are the same), m; F – cross-sectional area of the central duct, m^2; P – perimeter of the cross-section of the central duct, m^2.

The total air consumption of the ventilation system for the intake of polluted air is then determined as follows:

$$Q_{s\_out} = \sum_{i=1}^{N} q_i = \sum_{i=1}^{N} \begin{cases} q_0 + k(n_{gi} - n_{g\,norm}), & n_{gi} > n_{g\,norm} \\ q_0, & n_{gi} \le n_{g\,norm}. \end{cases} \tag{3}$$

q_0 – volume flow of air through the air intake pipe when the servo-driven intake damper is fully closed, m^3/s.

The power required to pump air through the ventilation system for the intake of contaminated air:

$$N_{s\_out} = \frac{W_k F}{\eta_\Pi}\left(\sum_{i=1}^{N} 0{,}11\frac{L_{0P}}{4F}\frac{\rho w_i^2}{2}\sqrt[4]{\frac{68\mu_a P}{4F\cdot w_i\cdot\rho} + \frac{\psi P}{4F}} + \sum_{i=2}^{N}\eta_{tee}\frac{\rho}{2}\left(w_i^2 - V_i^2\right) + \alpha\rho w_1^2 \right. \\ \left. + \sum_{i=1}^{N} 0{,}11\frac{H}{d_H}\frac{\rho V_i^2}{2}\sqrt[4]{\frac{68\mu_a}{d_H\cdot V_i\cdot\rho} + \frac{\psi}{d_H}} + \sum_{i=1}^{N}\left(1 - \frac{\sigma_i}{f}\right)\frac{\rho V_i^2}{2}\right), \tag{4}$$

$\eta_п$ – full fan efficiency; L_0 – length of the i-th section of the central duct, m; μ_a – dynamic viscosity of air, H·s/m^2; η_{tee} – coefficient of friction resistance of the tee; α – impact mitigation factor for a knee of constant section; ζ – coefficient of local constriction resistance; ψ – equivalent roughness of the walls of the central duct.

To ensure stable atmospheric pressure in the area of the machine, it is necessary that the amount of exhaust air is equal to the amount of supply air per unit of time. Therefore, the volume flow of air after the discharge dampers of the ventilation system for the injection of clean air should be equal to

$$q_i = q_i, \tag{5}$$

q_i` – volume flow of air through the open i-th discharge valve with a servo drive, m^3/s; q_i – volume flow of air through the open i-th intake damper with a servo drive, m^3/s.

The total air consumption of the ventilation system of clean air injection is then determined as follows:

$$Q_{s\_in} = Q_{s\_out} = \sum_{i=1}^{N} \begin{cases} q_0 + k(n_{gi} - n_{g\,norm}), & n_{gi} > n_{g\,norm} \\ q_0, & n_{gi} \le n_{g\,norm}. \end{cases} \tag{6}$$

The power required for pumping air through the ventilation system for injecting clean air:

$$N_{s\_in} = \frac{V`}{\eta_\Pi`}\left(\sum_{i=1}^{N}\frac{(V_i`)^2}{\mu^2(\sigma_i`/F_{i-1,x}`)^2(\sum_{i=1}^{N}V_i`)^2}\frac{\rho(w_i`)^2}{2} + \sum_{i=2}^{N}\eta_{tee}\frac{\rho}{2}((w_i`)^2 - (V_i`)^2) + \alpha\rho(w_1`)^2 + \right. \\ \left. \sum_{i=1}^{N}\left(\frac{(F`)^2}{\mu^2(H`)^2(\delta_0`)^2} + 1\right)\frac{\rho(w_k`)^2}{2} + \sum_{i=1}^{N}\left(1 - \frac{\sigma_i`}{F`}\right)\frac{\rho(V_i`)^2}{2}\right), \tag{7}$$

$\eta_п$ – full fan efficiency; σ_i` –area of the hole formed as a result of opening the discharge valve of the ith nozzle for air injection, $m^2$; $w_k$` – air speed at the entrance to the i-th nozzle for air injection, m/s; δ_0` – width of the gap near the closed end of the nozzle for air injection, m; F` –cross-sectional area of the nozzle for air injection, m^2; H` – height of the nozzle for air injection, m; V` –air speed, m/s.

The second stage of the algorithm is the determination of the operating modes of the mechatronic system for ensuring the microclimate of the piggery premises, depending on the temperature and humidity of the ambient air and in the livestock building in the area of the intake of polluted air and zootechnical requirements. For this purpose, a technological diagram of the mechatronic system for ensuring the microclimate of piggery premises was drawn up, which is shown in fig. 2.

In fig. 2 marked supporting elements of the microclimate system of piggery premises: ventilation system of intake of polluted air, ventilation system of intake of clean air injection, indirect-evaporative type heat exchanger, vertical soil heat exchanger. Also listed are three flaps Z_1, Z_2, Z_3,which move in a relative value from 0 to 1, changing their position between the two directions. Thus, the position 0.4 corresponds to the fact that the areas of the holes between the two directions correspond to 40 % : 60 %, and 0 to 0 % : 100 %, 1 to 100 % : 0%. The fourth valve Z_4designed to turn off (position 0) and turn on (position 1) the supply of water for moistening the channels of the indirect-evaporative type heat exchanger.

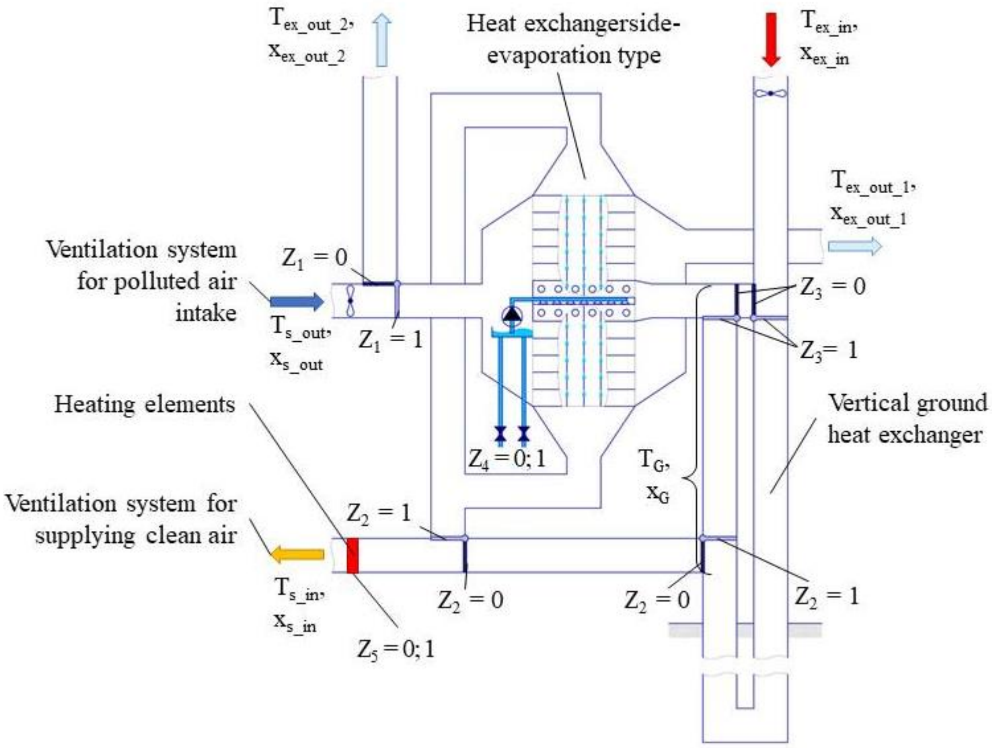

Fig. 2. Technological scheme of the mechatronic system for ensuring the microclimate of piggery premises

In fig. 2 marked temperatures T (°C) and humidity x (g/kg) for the air that is removed from the livestock building (index s_out), supplied to the livestock building (index s_in), supplied to the external environment (indexes ex_out_1, ex_out_2), which is taken from the external environment (index ex_in). Temperature T_{ex_in} and humidity x_{ex_in} the air of the external environment is variable and fluctuates. Temperature T_{s_in} (18–22 °C) and humidity x_{s_in} (70 % – 8,9–11,4 g/kg) of the air supplied to the livestock building must meet zootechnical requirements [4]. Temperature T_{s_out} and humidity x_{s_out} air depend on many uncontrolled factors, which are determined by animals and can be within certain limits: 12–30 °C, 80–95 % (6.9–24.8 g/kg), respectively.

To determine the most effective algorithm, it is necessary to consider the obtained patterns of change in the output temperature of the heat exchanger of the indirect-evaporative type and the vertical soil heat exchanger depending on the input temperature and air flow rate. For the soil heat exchanger, it is also necessary to take into account the change in soil temperature depending on the season.

Outlet temperature T_M (°C) from the indirect-evaporative type heat exchanger (when the width of the initial part is related to the total width of the heat exchanger $\overline{l_y^w}$ = 0,125):

$$T_M = 0{,}07828471875 + 0{,}00088195\, Q_{in} + 0{,}657823875\, t_{in} + 0{,}000308571\, Q_{in} T_{in} - 0{,}00562184\, T_{in}^2 + 0{,}160149\, x_{in} - 0{,}000259552\, Q_{in} x_{in} + 0{,}0144164\, T_{in} x_{in} - 0{,}00693641\, x_{in}^2, \quad (8)$$

T_{in} – primary air temperature at the inlet, °C; x_{in} – absolute air humidity at the heat exchanger inlet, g/kg; Q_{in} – flow rate of air at the entrance to the heat exchanger, m^3/hours.

The power required to pump air through the indirect-evaporative heat exchanger is determined by the formula:

$$N_м = \left(\frac{\rho(V`)^2}{2}\left[\eta_1\left(1-\frac{N_kF_k}{F_T}\right)+0{,}11N_k\frac{P_kA_T}{4F_k}\sqrt[4]{\frac{17\mu_aP_k}{F_k\cdot V`\cdot\rho}+\frac{\psi_kP_k}{4F_k}}+\eta_2\left(1-\frac{N_kF_k}{F_T}\right)^2\right]+\frac{\rho(V`)^2}{2}\left[\eta_1\left(1-\frac{N_kF_k}{F_T}\right)+0{,}11N_k\frac{P_kB_T}{4F_k}\sqrt[4]{\frac{17\mu_aP_k}{F_k\cdot V`\cdot\rho}+\frac{\psi_k`P_k}{4F_k}}+\varsigma_{k80}+0{,}11N_k\frac{P_kB_T}{4F_k}\sqrt[4]{\frac{17\mu_aP_k}{F_k\cdot V`\cdot\rho}+\frac{\psi_k``P_k}{4F_k}}+\eta_2\left(1-\frac{N_kF_k}{F_T}\right)^2\right]\right)\frac{V`}{\eta_П}, \quad (9)$$

$\eta_п$ – full fan efficiency; η_1 – impact mitigation factor, η_1 = 0,5; N_k – number of channels; F_T – cross-sectional area of the inlet duct, m^2; F_k – cross-sectional area of the canal, m^2; P_k – perimeter of the channel section, m; A_T – length of the working channel, m; ψ_k – equivalent roughness of the walls of the working channel; μ_a – dynamic air viscosity; η_2 – impact mitigation factor; ζ_{k80}` – coefficient of local resistance for spatial (circular) rotation at 180°; $B_T$ – length of dry and wet channels, m; $\psi_k$` – equivalent roughness of the walls of dry and wet channels; V` – air speed, m/s.

Let's use the dependencies for a U-shaped vertical soil heat exchanger.

Outlet temperature T_G (°C) from the soil heat exchanger:

$$T_G = T_{in} + \Delta T_{aU} = T_{in} \pm (7{,}81976 - 0{,}00955501\, Q_{in} - 0{,}42689\, T_{in} + 0{,}000105189\, Q_{in}\, T_{in} + 0{,}018366\, T_{in}^2), \quad (10)$$

T_{in} – primary air temperature at the inlet, °C; Q_{in} – flow rate of air at the entrance to the heat exchanger, m^3/hours; «+» – for T_{in} < 9,73 °C; «–» – for T_{in} > 9,73 °C.

The power required for pumping air through the soil heat exchanger is determined by the formula:

$$N_G = \frac{q_{in}}{\eta_П}\left(0{,}11\frac{273\rho_{н.у.}L_U}{2TD_{U1}}\left(\frac{4q_{in}}{\pi D_{U1}^2}\right)^2\times\left(\sqrt[4]{\frac{17\mu T\pi D_{U1}}{273q_{in}\rho_{н.у.}}}+\frac{\psi}{D_{U1}}\right)+2\frac{273\alpha\rho_{н.у.}}{T}\left(\frac{4q_{in}}{\pi D_{U1}^2}\right)^2+0{,}11\frac{273\rho_{н.у.}(L_U-L_{U1})}{2TD_{U1}}\times\left(\frac{4q_{in}}{\pi D_{U1}^2}\right)^2\left(\sqrt[4]{\frac{17\mu T\pi D_{U1}}{273q_{in}\rho_{н.у.}}}+\frac{\psi}{D_{U1}}\right)+\frac{273\rho_{н.у.}}{T}\left(\frac{4q_{in}}{\pi D_{U1}^2}\right)^2+0{,}11\frac{273\rho_{н.у.}L_{U2}}{2TD_{U1}}\left(\frac{4q_{in}}{\pi D_{U1}^2}\right)^2\left(\sqrt[4]{\frac{17\mu T\pi D_{U1}}{273q_{in}\rho_{н.у.}}}+\frac{\psi}{D_{U1}}\right)\right), \quad (11)$$

$\eta_п$ – full fan efficiency; $\rho_{н.у.}$ – air density under normal conditions; L – duct length, m; T – air flow temperature, K; D – duct diameter, m; q_{in} – air flow input costs, m^3/s; μ – dynamic air viscosity; ψ – equivalent roughness of the duct walls; ζ – coefficient of local resistance for spatial rotation by 180° during injection; α – impact mitigation factor for a knee of constant cross-section.

In case of temperature value T_{s_in} less than the zootechnical requirements (< 18 °C), the heating elements should be turned on (Fig. 2, Z_5 = 1 – are on, Z_5 = 0 – off), while consuming additional energy:

$$N_Q = q_{in}\frac{273}{273+T_{s\,in}}\rho_{н.у.}c_a(18 - T_{s\,in}), \quad (12)$$

$\rho_{н.у.}$ –air density under normal conditions; T_{s_in} – inlet air temperature, °C; c_a – specific heat capacity of air; q_{in} – air flow input costs, m^3/s.

4. Results of the researches

Taking into account the obtained dependences for temperature (8) and (10) and conditions for temperatures, we will develop an algorithm for the operation of the mechatronic system for ensuring the microclimate of piggery premises, the block diagram of which is shown in Fig. 3.

In fig. 3 T_m = 9,79 °C –the soil temperature at the depth of the soil heat exchanger is not variable; ΔT_G = 9,3 °C –the temperature difference at which the U-shaped vertical soil heat exchanger is effectively used; T_{min} = 18 °C, T_{max} = 22 °C – minimum and maximum temperature values according to zootechnical requirements.

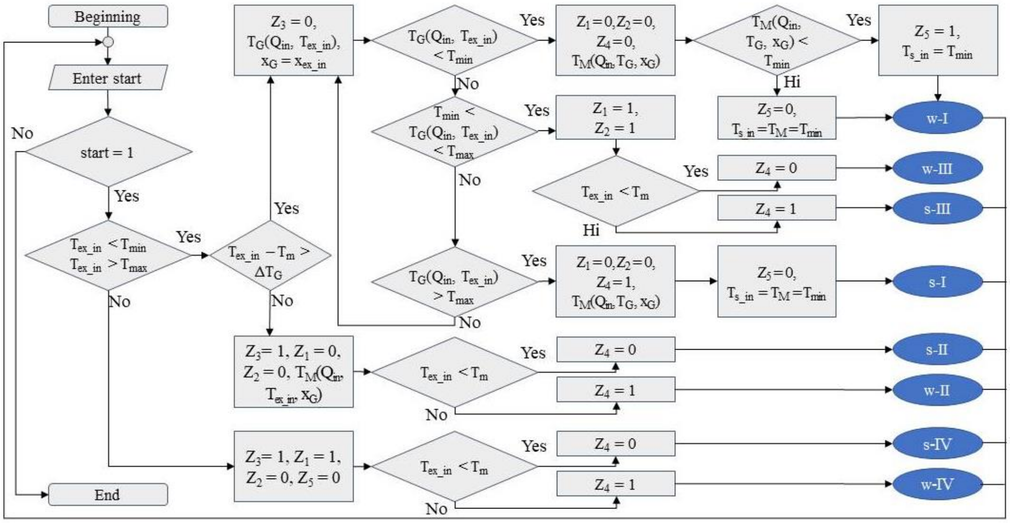

Fig. 3. Block diagram of the algorithm for the operation of the mechatronic system for ensuring the microclimate of piggery premises

The developed algorithm is implemented in the created simulation of the microclimate of the livestock building in the Simcenter Star-CCM+ software package [11, 12]. Appropriate 3D models of the areas where heat and air flows move were built for the adopted piggery premises. The description of the elements, the geometric dimensions and the generated grids of premises for pigs are shown in fig. 4.

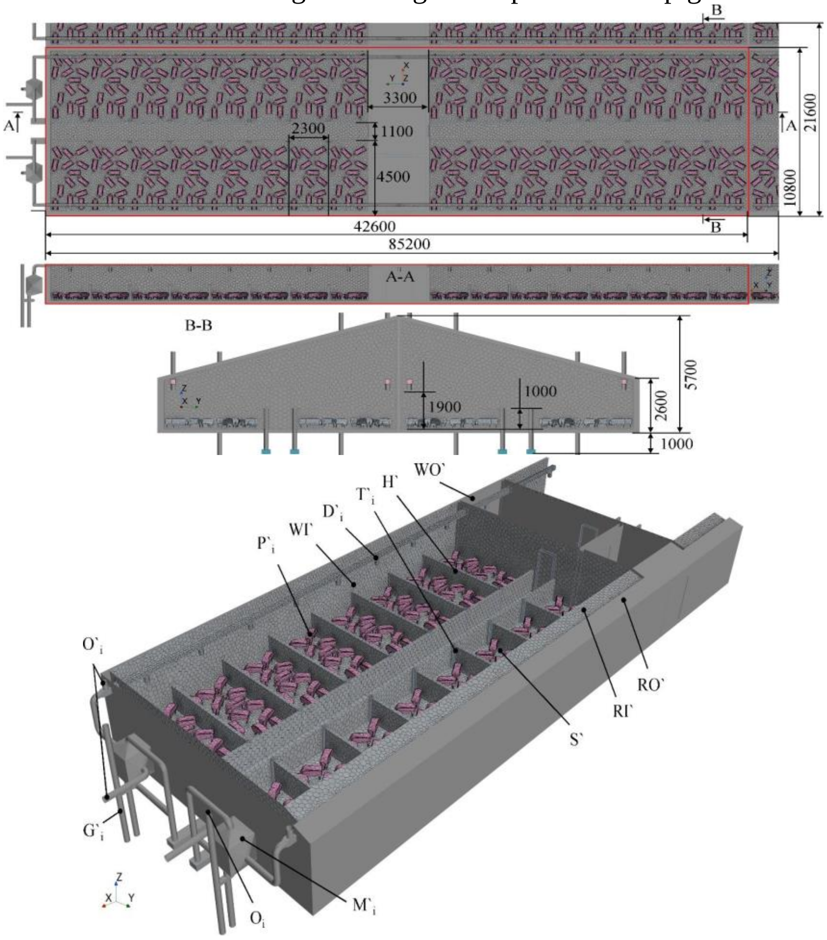

Fig. 4. Grid model of a premises for keeping pigs with a developed microclimate system

$T`_i$ –nozzles of the clean air injection system; $D`_i$ – nozzles of the contaminated air intake system; H` – machine enclosure; WO` – outer wall surface; WI` – the inner surface of the wall; RO`– roof; RI – ceiling; S` – slatted floor; $P`_i$ –pig skin; O`i –air outlets; $O_i$ –air inlets; $M`_i$ – indirect evaporative type heat exchangers; $G`_i$ – U-shaped vertical soil heat exchanger

In fig. 5 shows the distribution of premises temperatures, which were obtained by the results of numerical simulation. Also in fig. 5 marked intersection planes, which were studied in more detail.

The obtained visualizations provide an opportunity to visually assess the distribution of temperature (Fig. 5, a), air velocity (Fig. 5, b) and humidity level (Fig. 5, c) in the livestock building where the developed mechatronic system for providing microclimate is used.

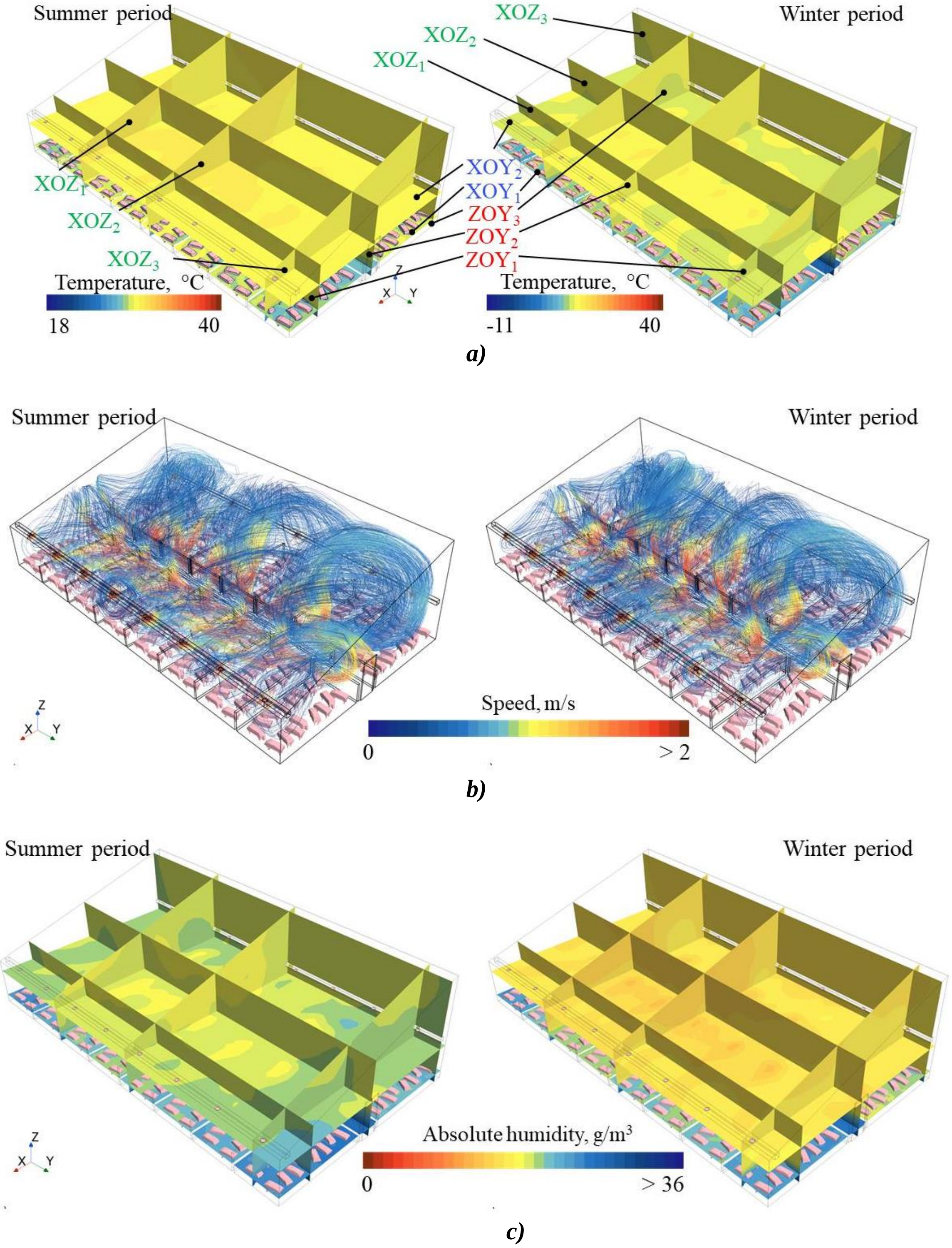

Fig. 5. Distributions of temperature (a), air flow lines (b) and pressure (c) in the premises of the piggery with a developed microclimate system

Analyzing the temperature field in the area where the pigs are located, it was found that the temperature fluctuates between 18.4 and 21.8 °C in summer and winter, which fully meets zootechnical requirements. In other areas of the pigsty, the temperature is different: in summer it is more than 22 °C, and in winter it is less than 18 °C. The presence of solid partitions in the machines protects animals from warm air in summer and cold air in winter (Fig. 6).

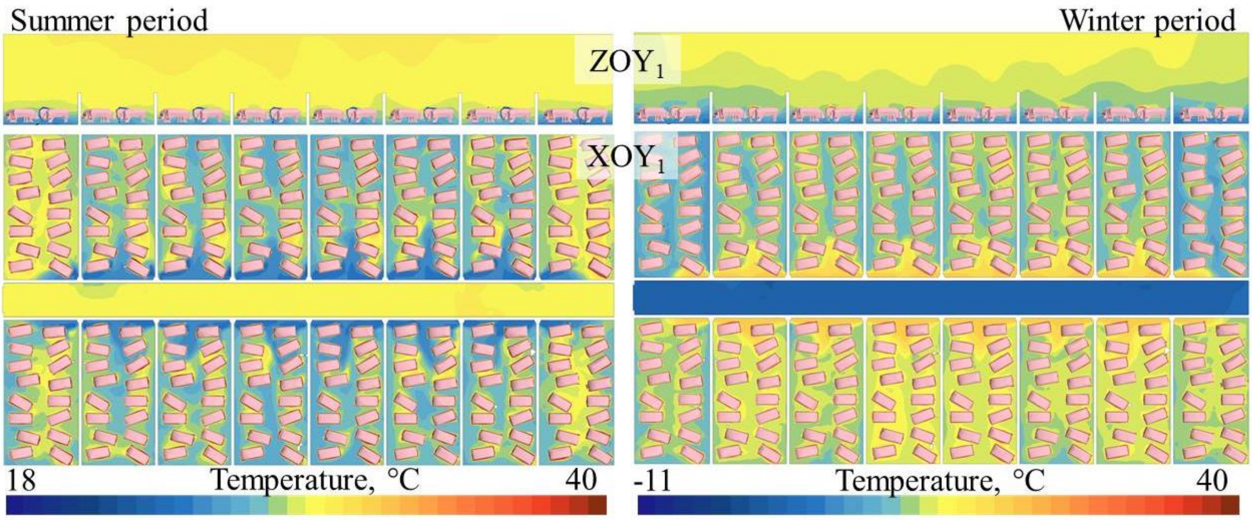

Fig. 6. Temperature distributions in a piggery with a developed microclimate system

When conducting a study of the vector field of velocities in the premises of the piggery (Fig. 7), the presence of a turbulent flow in the area of the animals was revealed. The process of air movement is interesting: from the ground channel, it goes around the partition of the machine and rises up near the walls into the air intake system. At the same time, the air speed in the area where the animals stay is up to 0.5 m/s and is sufficiently uniform. This indicates comfortable conditions of stay.

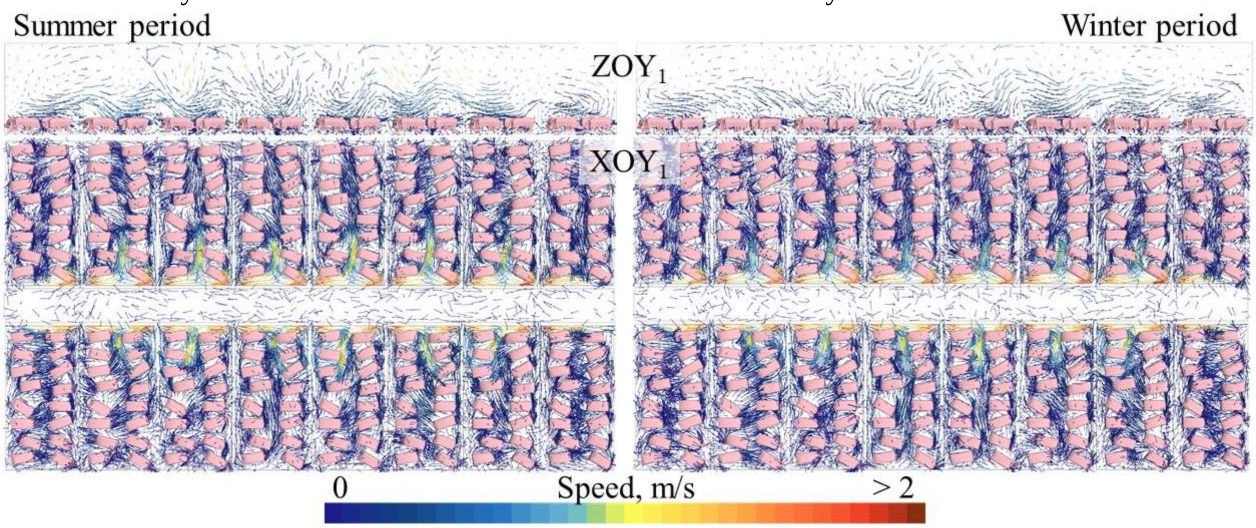

Fig. 7. Speed distributions in a piggery with a developed microclimate system

As for humidity (Fig. 8), it is important to note that in the summer there is a significantly increased level of humidity. The highest value in this area, where the animals are, reaches 14 g/m³, which in the context of an air temperature of 22 °C corresponds to 71.6 %, which is quite a significant indicator. In winter, the moisture content in the air near the animals is from 10 to 12 g/m³, which at a temperature of 18 °C corresponds from 64.9 % to 77.4 % and satisfies zootechnical requirements.

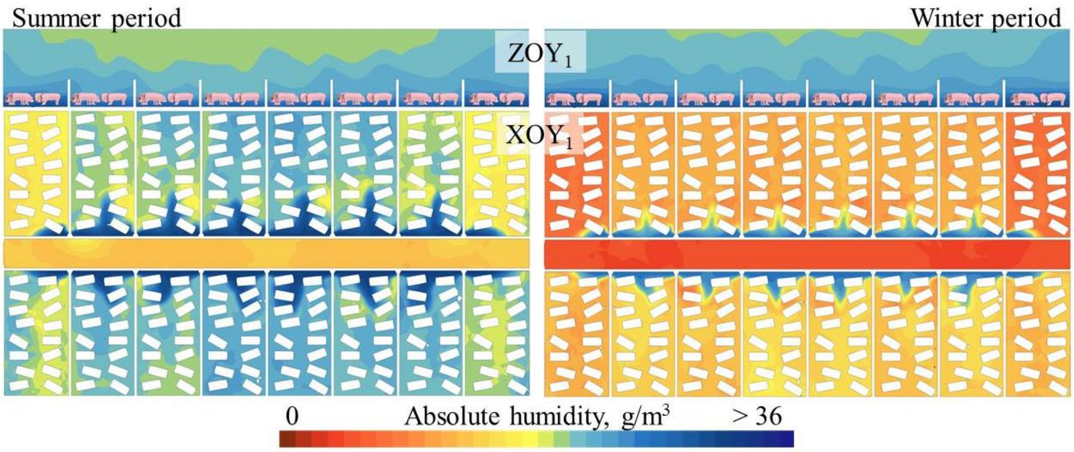

Fig. 8. Distribution of humidity in a piggery with a developed microclimate system

A general analysis of the ventilation system of the above-ground channel indicates a sufficiently effective provision of the microclimate. This is manifested in the uniformity of the distribution of air flow speed, which does not exceed normalized values (up to 0.5 m/s), temperature conditions (18.4–21.8 °C) and air humidity (64.9–77.4 %) .

According to the conducted modeling, the temperature dynamics (Fig. 9) were obtained at each stage of the passage of the air flow through the developed system of ensuring the microclimate in the pigsty throughout the year. The resulting dependence is built on the basis of the proposed algorithm (Fig. 3). Therefore, the passage of air flow through heat exchangers and heating elements depends on the air temperature.

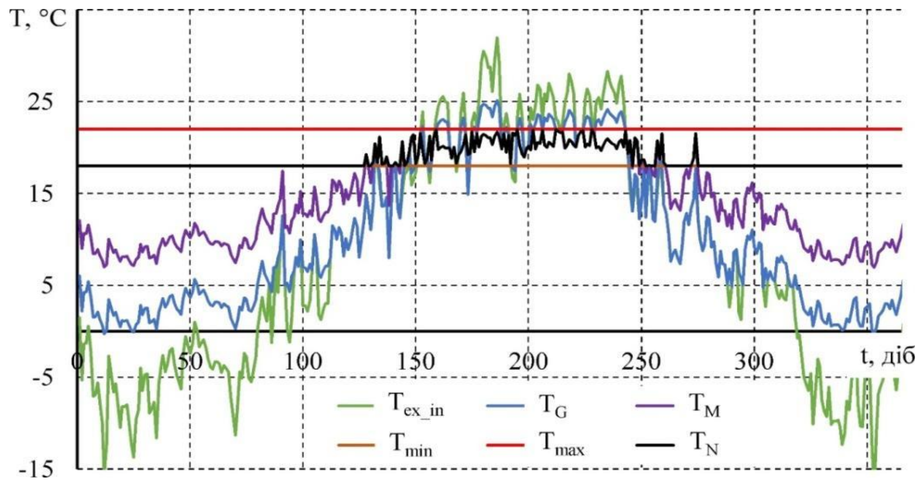

Fig. 9. Temperature dynamics at each stage of air flow through the developed system for providing a microclimate in the pigsty throughout the year:
T_{ex_in} – ambient air temperature; T_G – air temperature after passing through a U-shaped vertical soil heat exchanger; T_M – air temperature after passing through the indirect-evaporative heat exchanger; T_N – air temperature after passing through the heating elements; T_{min} = 18 °C, T_{max} = 22 °C –minimum and maximum temperature values according to zootechnical requirements

Fig. 9 shows that the temperature of the air flow after passing through the soil heat exchanger and the heat exchanger of the indirect-evaporative type approaches the values of zootechnical requirements. The process of cooling the air to the set temperature (22 °C) takes place without the use of additional air conditioning systems, and heating the air to a temperature of 18 °C requires additional switching on of the heating elements.

For further comparison, consider the microclimate system of the piggery with an above-ground channel with a classic heat exchanger for heating and air conditioning. The flow of air that enters from the external environment is heated and cooled directly (Fig. 10).

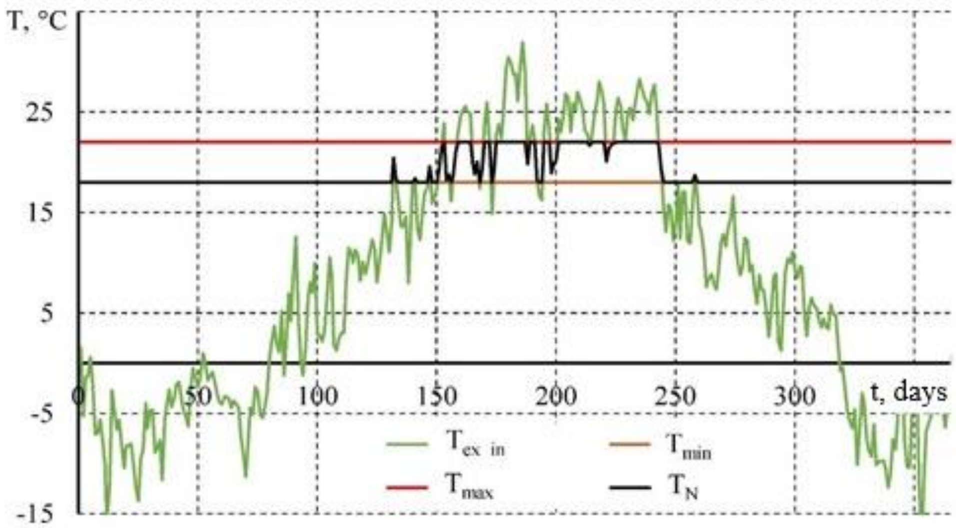

Fig. 10. Temperature dynamics at each stage of the passage of the air flow through the classic system of providing a microclimate in the pig house throughout the year:
T_{ex_in} – ambient air temperature; T_N – air temperature after passing through a classic heating and air conditioning heat exchanger; T_{min} = 18 °C, T_{max} = 22 °C – minimum and maximum temperature values according to zootechnical requirements

To determine the power consumed by the developed microclimate system in the piggery, we will use the formula:

$$N_{\Sigma GM} = N_{s\_out} + N_{s\_in} + (1 - Z_3)N_G + (1 - Z_2)N_M + Z_5 N_Q. \quad (13)$$

To determine the power consumed by the classic microclimate system in the piggery, we use the formula:

$$N_{\Sigma N} = N_{s\_out} + N_{s\_in} + \begin{cases} 0, & T_{min} \le T_{s\_in} \le T_{max} \\ N_Q, & T_{s\_in} \le T_{min}, T_{s\_in} \ge T_{max} \end{cases}. \quad (14)$$

According to fig. 8–9 and formulas (13)–(14), we obtain the dynamics of power consumption of the developed and classic microclimate support system in a 16-stall piggery, which is shown in Fig. 11.

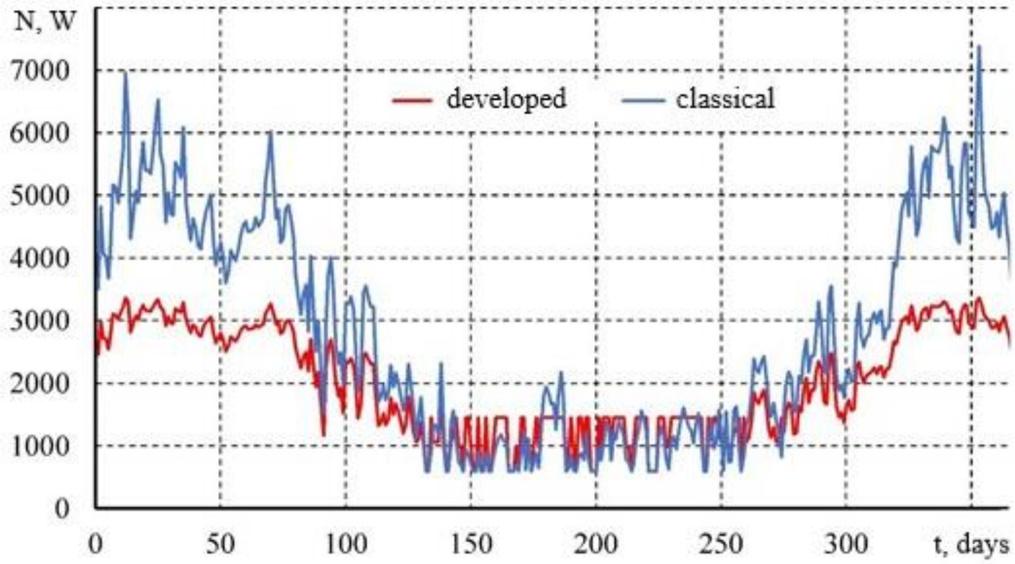

Fig. 11. Dynamics of power consumption of the developed and classic microclimate systems in the piggery throughout the year

Having integrated the dependencies of fig. 11, we get the annual energy consumption for the developed (17528 kWh) and classic (24559 kWh) microclimate support systems. The annual energy consumption of the developed system is 28.6% less than that of the classic system.

5. Conclusions

According to the accepted structural and technological scheme of the mechatronic system for ensuring the microclimate of piggery premises (Fig. 1) and the conducted theoretical and experimental studies (2)–(12) of its elements, the algorithm of its work was developed (Fig. 2–3). The developed algorithm is implemented in the created simulation of the microclimate of the livestock building in the Simcenter Star-CCM+ software package. According to the conducted modeling, the temperature dynamics (Fig. 9) were obtained at each stage of the passage of the air flow through the developed system of ensuring the microclimate in the pigsty throughout the year. The temperature of the air flow after passing through the soil heat exchanger and the heat exchanger of the indirect-evaporative type approaches the values of zootechnical requirements. The process of cooling the air to the set temperature (22 °C) takes place without the use of additional air conditioning systems, and heating the air to a temperature of 18 °C requires additional switching on of the heating elements. The dynamics of power consumption of the developed and classic microclimate support systems in a piggery with 16 machines were obtained (Fig. 11). The obtained annual energy consumption for the developed microclimate maintenance system is 17,528 kWh, which is 28.6% less compared to the classic system (ventilation with a ground channel and heat exchanger for heating and air conditioning).

References

1. Derzhavna sluzhba statystyky (2022). Ekonomichna statystyka / Ekonomichna diialnist / Silske, lisove ta rybne hospodarstvo. URL: https://ukrstat.gov.ua/ [in Ukrainian].
2. Lykhach, V.Ia., Lykhach, A.V. (2020). *Tekhnolohichni innovatsii u svynarstvi [Technological innovations in pig production] : monograph*. Kyiv : FOP Yamchynskyi O.V. [in Ukrainian].
3. Povod, M., Bondarska, O., Lykhach, V., Zhyzhka, S., Nechmilov, V., Dudin, V. (2021). *Tekhnolohiia vyrobnytstva i pererobky produktsii svynarstva [Technology for the production and processing of pig products]: Textbook.* Kyiv: Naukovo-metodychnyi tsentr VFPO. [in Ukrainian].
4. Samokhina, Ye.A., Povod, M.H., Mylostyvyi, R.V. (2018). Parametry mikroklimatu v svynarskykh prymishchenniakh vlitku za riznykh system ventyliatsii ta yikhnii vplyv na produktyvnist laktuiuchykh svynomatok i rist pidsysnykh porosiat [Microclimate parameters in pigsties in summer with different ventilation systems and their influence on the productivity of lactating sows and growth of suckling piglets]. *Visnyk Sumskoho natsionalnoho ahrarnoho universytetu. Seriia: Tvarynnytstvo, 2,* 218–223. [in Ukrainian].
5. Vidomchi normy tekhnolohichnoho proektuvannia [Departmental standards of technological design]. Svynarski pidpryiemstva. VNTP-APK-02.05. (2005). K.: Ministerstvo ahrarnoi polityky Ukrainy (Minahro-polityky Ukrainy). [in Ukrainian].
6. Revenko, I.I., Brahinets, M.V., Zabolotko, O.O. (2012). *Mashyny ta obladnannia dlia tvarynnytstva: posib.-praktykum [Machinery and equipment for animal husbandry]. 2-he vyd*. Kyiv: Kondor. [in Ukrainian].
7. Kaletnik, H.M., Yaropud, V.M. (2021). Mekhatronna systema zabezpechennia mikroklimatu tvarynnytskykh prymishchen [Mechatronic system for providing a microclimate for livestock premises]. Pat. № 127795 UA, IPC (2023.01) A01K 1/00, F24F 3/00, F24F 3/044 (2006.01), F24F 3/14 (2006.01), F24F 6/12 (2006.01), F24F 7/007 (2006.01), F24F 11/00; № a202102134; stat. 22.04.2021; publ. 03.01.2024, Bul. № 1. [in Ukrainian].
8. Yaropud, V. (2021). Analytical study of the automatic ventilation system for the intake of polluted air from the pigsty. *Scientific Horizons, 24 (3),* 19–27. DOI: 10.48077/scihor.24(3).2021.19-27. [in English].
9. Kaletnik, H., Yaropud, V. (2021). Theoretical studies of air losses of air heat exchanger of indirect-evaporative type of livestock premises. *Machinery and Energetics, 12 (4),* 35–41. DOI: 10.31548/machenergy2021.04.035. [in English].
10. Yaropud, V., Kupchuk, I., Burlaka, S., Poberezhets, J., Babyn, I. (2022). Experimental studies of design-and-technological parameters of heat exchanger. *Przeglad Elektrotechniczny, 98 (10),* 57–60. DOI: 10.15199/48.2022.10.10. [in English].
11. Kaletnik, H., Yaropud, V. (2023). Research of pressure losses and justification of forms of side-evaporative heat exchangers channels in livestock premises. *Przeglad Elektrotechniczny, 99 (7).* 247–252. DOI: 10.15199/48.2023.07.46. [in English].
12. Aliiev, E.B. (2023). *Chyselne modeliuvannia protsesiv ahropromyslovoho vyrobnytstva [Numerical modeling of agricultural production processes]: Textbook*. Kyiv: Ahrarna nauka. ISBN 978-966-540-

584-9. DOI: 10.31073/978-966-540-584-9. [in Ukrainian].
13. Yaropud, V., Hunko, I., Aliiev, E., Kupchuk, I. (2021). Justification of the mechatronic system for pigsty microclimate maintenance. *Agraarteadus, Journal of Agricultural Science, XXXII (2),* 341–351. DOI: 10.15159/jas.21.23. [in English].

АЛГОРИТМ РОБОТИ МЕХАТРОННОЇ СИСТЕМИ ЗАБЕЗПЕЧЕННЯ МІКРОКЛІМАТУ СВИНАРСЬКИХ ПРИМІЩЕНЬ

У статті проаналізовано сучасні технології утримання свиней, зокрема перспективи використання мехатронних систем для забезпечення мікроклімату в свинарських приміщеннях. Визначено, що відхилення параметрів мікроклімату негативно впливає на здоров'я, репродуктивні функції та прирости свиней, що призводить до зниження рентабельності господарств. Розроблено алгоритм роботи мехатронної системи із адаптивною вентиляцією повітря та енергозберігаючими технічними засобами, параметри якої оптимізовано за допомогою програмного моделювання. За прийнятою конструктивно-технологічною схемою мехатронної системи забезпечення мікроклімату свинарських приміщень та проведених теоретичних і експериментальних досліджень її елементів розроблено алгоритм її роботи. Розроблений алгоритм реалізований у створеній симуляції мікроклімату свинарського приміщення у програмному пакеті Simcenter Star-CCM+. Згідно проведеного моделювання отримано динаміку температури на кожному етапі проходження потоку повітря через розроблену систему забезпечення мікроклімату у свинарник впродовж всього року. Температура потоку повітря після проходження через ґрунтовий теплообмінник і теплообмінник побічно-випарного типу наближається до значень зоотехнічних вимог. Процес охолодження повітря до заданої температури (22 °C) відбувається без застосування додаткових систем кондиціонування, а нагрівання повітря до температури 18 °C потребує додаткового вмикання нагрівальних елементів. Отримано динаміку споживаної потужності розробленої та класичної систем забезпечення мікроклімату у свинарнику на 16 станків. Отримані річні витрати енергії для розробленої систем забезпечення мікроклімату складають 17528 кВт·год, що в порівняння із класичної системою (вентиляція із наземним каналом і теплообмінником обігрівання та кондиціонування) на 28,6 % менше.

Ключові слова: *утримання свиней, мікроклімат, мехатронна система, енергозбереження, вентиляція, моделювання, ресурсозбереження.*

Ф. 14. Рис. 11. Літ. 13.

INFORMATION ABOUT THE AUTHOR

Vitalii YAROPUD – Candidate of Technical Sciences, Associate Professor of the Department of machinery and equipment for agricultural production of Vinnytsia National Agrarian University (St. Soniachna, 3, Vinnytsia, Ukraine, 21008, e-mail: yaropud77@gmail.com, https://orcid.org/0000-0003-0502-1356).

ЯРОПУД Віталій Миколайович – кандидат технічних наук, доцент кафедри машин та обладнання сільськогосподарського виробництва Вінницького національного аграрного університету (вул. Сонячна, 3, м. Вінниця, Україна, 21008, e-mail: yaropud77@gmail.com, https://orcid.org/0000-0003-0502-1356).