INVESTIGATION OF AN IMPROVED SIDE VENTILATION SYSTEM IN A POULTRY HOUSE USING CFD
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ДОСЛІДЖЕННЯ ВДОСКОНАЛЕНОЇ БОКОВОЇ СИСТЕМИ ВЕНТИЛЯЦІЇ В ПТАШНИКУ ЗА ДОПОМОГОЮ CFD

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ABSTRACT
One of the main factors in the poultry house is maintaining a standardized microclimate. The quality of the product output in the final result depends precisely on the quality indicators of the air parameters. Poultry during its maintenance requires significant efforts and technological solutions. In this regard, authors improved microclimate system in air environment of the poultry house by installing exhaust fans on the side wall in a total number of 8 units. CFD modeling using ANSYS Fluent is a powerful tool for predicting the air flow scheme in a poultry house and is considered an alternative to experimental studies. Based on the obtained results of CFD modeling, it was established that the valves located at a height of 210 mm from the ceiling work most efficiently. Pressure drop for the inlet valves is 45.85 Pa. Air velocity at the inlet of the supply valves is equal to 9.17 m/s. Air velocity at a height of 0.7 m from the floor level varies within 0.57 m/s, the temperature is 9.91°C.

РЕЗЮМЕ
Одним із основних факторів у птахівничому приміщенні є підтримання нормованого мікроклімату. Якість виходу продукції в кінцевому результаті залежить саме від якісних показників параметрів повітря. Птиця під час її утримання вимагає значних зусиль та технологічних рішень. В зв'язку із цим авторами виконувалось вдосконалення системи мікроклімату у повітряному середовищі пташника за допомогою монтажу витяжних вентиляторів на боковій стінці в загальній кількості 8 шт. Моделювання CFD за допомогою ANSYS Fluent є потужним інструментом прогнозування схеми повітряного потоку в пташнику і вважається альтернативою експериментальним дослідженням. На основі отриманих результатів CFD моделювання встановлено, що клапани най ефективніше працюють ті, які розташовані на висоті 210 мм від перекриття. Перепад тиску для припливних клапанів становить 45,85 Па. Швидкість повітря на вході припливних клапанів рівна 9,17 м/с. Швидкість повітря на висоті 0,7 м. від рівня підлоги коливається в межах 0,57 м/с, температура – 9,91 ºС.

INTRODUCTION
Evaluating the performance of new ventilation systems can be a difficult task because it is time-consuming and quite expensive. As an alternative to field measurements, Computational Fluid Dynamics (CFD) modeling is a powerful tool for predicting air flow patterns, particle and gas concentrations, and the thermal environment in livestock premises. It has also been used to evaluate the effectiveness of existing ventilation systems and new designs (*Manbeck H.B. et al., 2016; Ionita C. et al., 2022*).

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According to authors *Ma, Y.X. and Zou H.F.,* (*2020*), the design of air intake devices was optimized for this typical broiler house in a cold region with cross ventilation based on two influencing factors: the length of the device and the direction of the air flow.

The optimized air supply devices helped to improve the air flow in the broiler house, thereby changing environmental factors such as internal temperature distribution, wind speed distribution and carbon dioxide distribution. The length of an ideal flow direction device should be approximately 1 m and no more than 2 m.

In the cold regions of northern China, the summer temperature is high, the winter is long and cold, and the spring and autumn are short, which makes it necessary to use a closed structure of broiler poultry houses (*Jinguo N. et al., 2016*). In this study, a typical broiler plant in the cold regions of northern China was chosen as the research object. Air supply devices commonly used in broiler houses in northern China were studied and optimized using simulation software.

The purpose of this work is to create a 3D CFD model using *ANSYS,* (*2020*), capable of reproducing real operating conditions inside the poultry house. The improvement consists in the integration of the main apparent and latent heat sources according to the procedure described in *Rojano F. et al.,* (*2015*), which was previously applied to a 2D CFD model. Model results were first validated against experimental data to assess the model's performance in predicting temperature and humidity gradients. Then the simulated field velocity was used to calculate the ventilation intensity.

In order to make the most of the advantages of weather conditions, the authors *Rojano F. et al., (2016*) analyze the effect of natural ventilation on the dynamics of the internal climate of the poultry house with an emphasis on the role of external climatic parameters, except for the direction of the wind. According to the experimental data, seven periods with a stable wind direction of at least 4 hours were selected with the prevailing north-easterly wind direction. Three of these periods were chosen as typical examples and used to validate a three-dimensional CFD model for the integration of the main elements, indoor climate: release of heat by animals and water vapor, radiative heat transfer and ventilation. The predictions of the 3D CFD model were then analyzed using the air residence time concept to estimate the ventilation rate and to investigate the apparent and latent heat transfer.

Authors *Tong, X. et al.,* (*2019a*), developed a 3D CFD model to simulate air velocity, air temperature, humidity, and heat stress in a commercial poultry house for laying hens. The model was successfully confirmed by field measurements in warm, transitional and cold periods of the year. Heat stress was detected in 69.1%, 78.0% and 18.4% of nurseries in summer, autumn and winter according to the temperature-humidity index at the incoming air temperature of 26.0°C, 15.0°C and 2.5°C with the intensity of ventilation 85.8, 15.5 and 11.7 air changes per hour, respectively. As a continuation of the research, the authors *Tong, X. et al.,* (*2019b*), developed a new ventilation system, a ventilation system with upward displacement of air flow (UDAF), which allows fresh air to enter the poultry house through air ducts located in the lower part of the cages, move upward due to the thermal buoyancy caused by the poultry and the static pressure difference caused by the exhaust fans and eventually exit the house through the fans installed on the roof. The results showed that the UDAF system resulted in a 46-129% increase in cage air exchange efficiency and provided a more uniform thermal environment with 9.4% less heat stress in summer and 68% less cold stress in winter compared to the TV system.

The article authors *Dudnyk, A. et al.,* (*2019*), gives the results of the study of intelligent management systems of biotechnological facilities using the example of a greenhouse. A measuring system has been developed for effective solar radiation research and forecasting of possible information violations. Neural networks have been used as a mathematical tool for forecasting temperature time series. Later, in *Lysenko V. et al., (2020), Lendiel T. Et al., (2021*), a software-hardware subsystem of phytomonitoring was created in a modern greenhouse building, provided with the help of LabVIEW software and Arduino equipment, which is tested directly in production. To conduct experiments, *Lysenko, V.P. et al.,* (*2021*), developed a mobile robot for monitoring the state of the atmosphere and phytostatus in protected ground facilities for the formation of control strategies that maximize production profit. As a final stage, the authors *Lysenko, V.P. et al.,* (*2019*), developed an energy-efficient control system for the electrotechnological complex of an industrial greenhouse - evaluation of the quality of plant products based on the use of Harrington's desirability functions. This allows to determine the microclimate parameters (plant temperature, air temperature and humidity), maximizing the profit of products. All these methods that were used to create, analyze and forecast the microclimate in greenhouses can be used to a large extent for poultry farms.

The authors *Spodyniuk N. and Lis A.* (*2020*), *Trokhaniak V.I. et al.,* (*2021*), conducted a study of modular poultry housing. The design of the module for growing poultry with an infrared heater has been developed.

The proposed design is energy efficient and recommended for installation in poultry houses. Microclimate in the module was analyzed. The air temperature near the poultry in the module reaches 18.6 ºC, and the average velocity does not exceed 0.75 m/s.

This publication is a continuation of scientific and practical research on improving the aerodynamic characteristics of the air environment in the poultry house (*Trokhaniak V.I. et al., 2021*). Thus, the purpose of the article is to improve the microclimate system in the air environment of the poultry house due to the installation of exhaust fans on the side wall in the total number of 8 pcs.

MATERIALS AND METHODS

According to the purpose of the work, the location of the exhaust fans was changed. The essence is summed up in the following. In the traditional design of the poultry house, the exhaust fans are not mounted on the back end wall of the poultry house, but on the side (Fig. 1), four pieces for each wall, a total of 8 pieces. Current indicators in the poultry house can be seen in Table 1.

Table 1

Current indicators in the poultry house

Current indicators	Livestock	Cross	Age/ Weight, g	Density of poultry heads/m^2	Density kg/m^2	Outside temperature, °C	Internal humidity, %	External humidity, %
	57971	ross	18/707	24.15	15.46	2	72	92

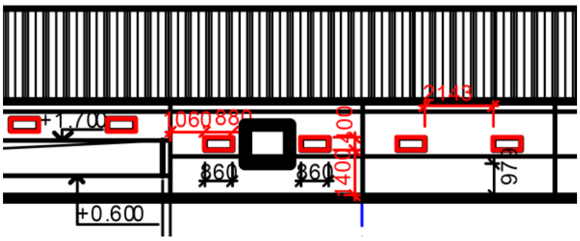
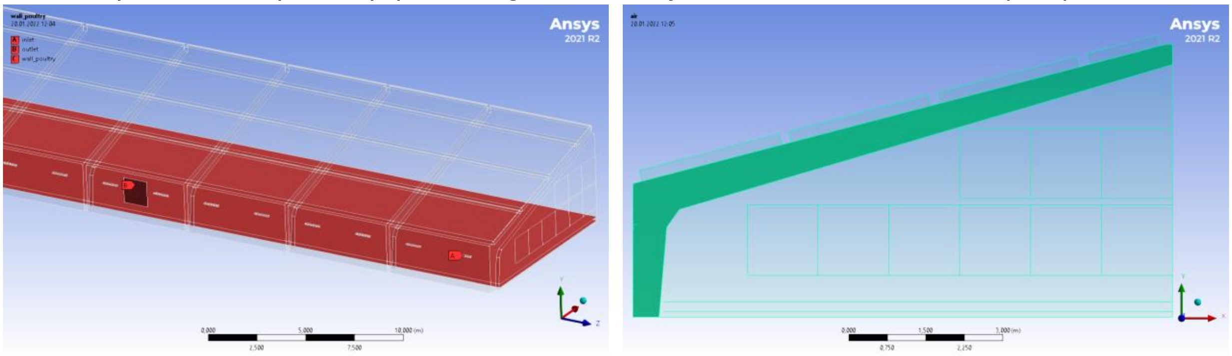


Fig. 1 – Location of the first exhaust fan on the side wall

In Fig. 2 is shown the 3D geometry of the poultry house for CFD simulation, made in 100% scale, but only half of the poultry house. The limit condition "symmetry" is set at the center of the poultry house. The rest of the boundary conditions are shown in Fig. 2a. These measures were taken in connection with the insufficient power of computer equipment. Figure 2b clearly shows the concrete frame (stick).



a) b)

Fig. 2 - 3D geometry of the poultry house

a - with the indication of boundary conditions, b – with the selection of a concrete frame.

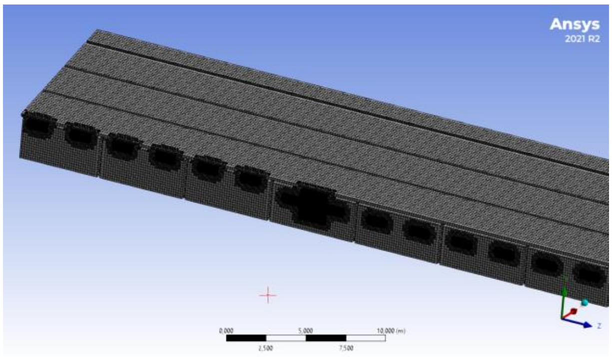
Table 2 shows the design parameters of the mesh in air environment of poultry house. Using the ANSYS Meshing software in particular volumetric element method, a 3D calculation grid was constructed. CutCell mesh construction method was applied. The number of elements reached 4.3 million. The mesh orthogonal quality index was equal to 0.22. The minimum size of the element of exhaust fans on the side wall of the poultry house was 0.01 m. It was smaller than the element size of the inlet valves by 0.03. This decision was made due to the fact that this study is more interested in the nature of air movement in exhaust fans. How the air behaves in the inlet valves was already studied in the publication (*Trokhaniak V.I. et al. 2021*).

In Fig. 3 is shown the constructed mesh in the air environment of the poultry house from the side. The openings of exhaust fans and supply valves are presented in a close-up view (see Fig. 3b). In the openings of exhaust fans and supply valves, the mesh is reduced relative to the rest of the wall area, also near the floor, where the poultry is located. Mesh refinement was carried out for more accurate calculation of hydrodynamics and heat and mass transfer by numerical method.

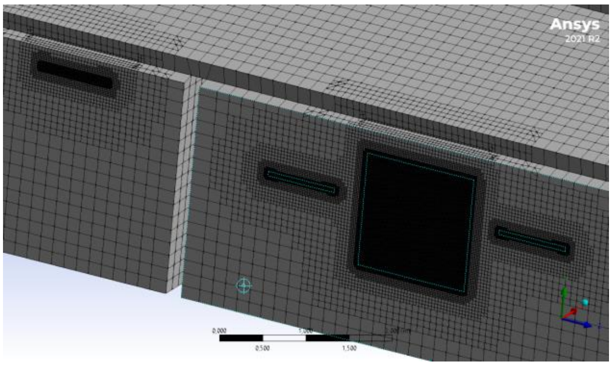
Table 2

Mesh construction parameters for a poultry house

Settings options	Indicator	Dim.
Mesh quality index (orthogonal quality)	0.22	–
Number of elements	4291613	piece
Number of nodes	4849379	piece
Method	CutCell	–
Maximum face size	0.16	m
Minimum face size	0.04	m
Minimum size of the supply valve element	0.04	m
Minimum size of the element of exhaust fans	0.01	m



a)



b)

Fig. 3 – Mesh in the air environment of the poultry house
a – distant, b – close.

Calculations were carried out at an air consumption of 21.5 kg/s. Temperature of the outside air was assumed equal to +2°C and the parameters of thermal radiation were entered. The walls were made of concrete and insulated with foam plastic with a density of 35 kg/m^3 and a thickness of 60/100/60 mm, respectively. The roof was insulated with "Izovat" with a density of 30 kg/m^3, and a thickness of 100 mm. The floor was insulated with polystyrene foam with a density of 45 kg/m^3 and a thickness of 100 mm on a width of 2 m from the wall along the perimeter, the entire remaining area was 50 mm. In poultry houses, poultry grown on the floor is a source of heat and has a temperature of +41 °C. The heating system was not provided. Exhaust fans of the type Munters EM50 1.5Hp in the amount of 4 pcs. were used for air removal. Inflow valves Wlotpowietrza 3000-VFG were installed in a total number of 79 pcs. Spoilers were mounted above the valves at an angle of inclination of 75º from the vertical.

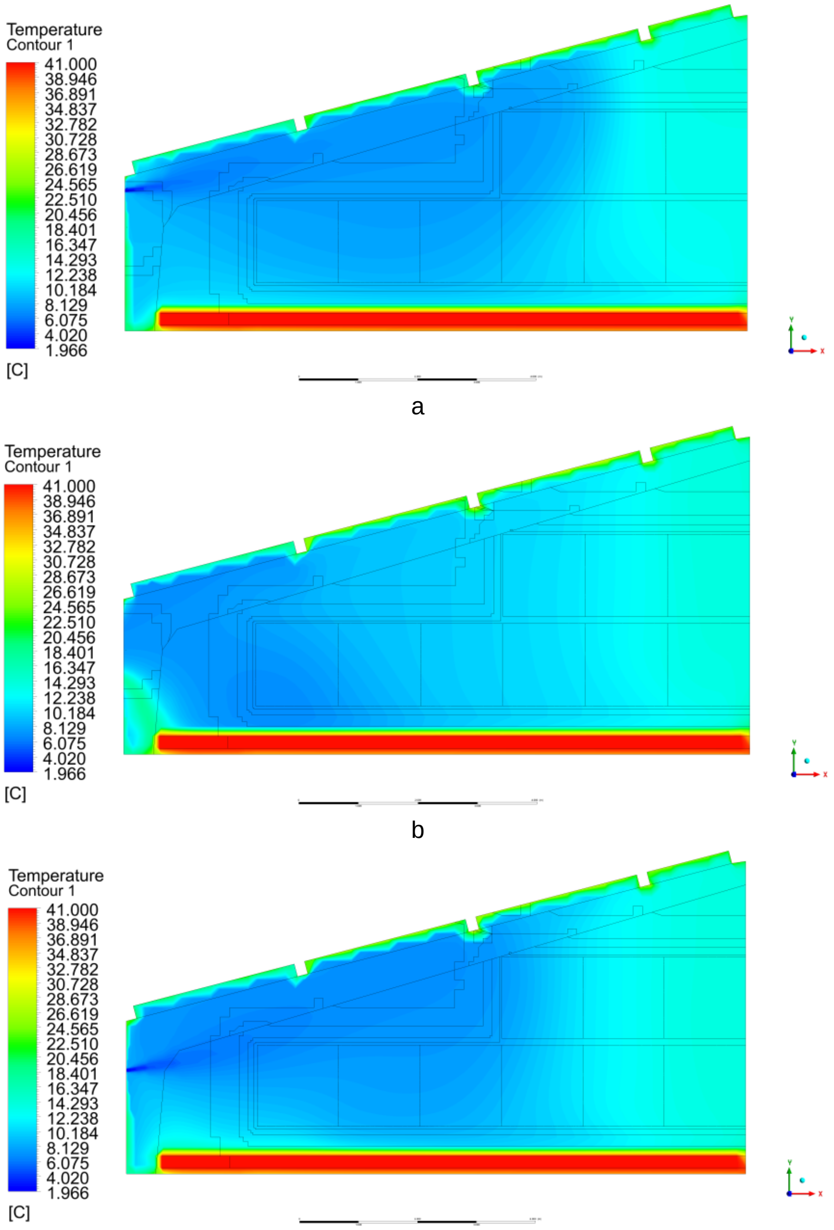
The CFD model was performed on the Navier-Stokes equations for convective flows (*Khmelnik S.I., 2018; Trokhaniak V. and Klendii O., 2018; Marzouk S.A. et al., 2022*). The Spalart-Allmaras turbulence model (*Allmaras S.R. et al., 2012*) and the Discrete Ordinates radiation model were used in calculations (*ANSYS, 2017; Moreno J. et al., 2019*).

RESULTS

This section presents the results of numerical simulation of poultry house in 3D using ANSYS Fluent. This makes it possible to evaluate hydrodynamic air flows in the poultry house. For numerical modeling, a 3D grid is first constructed using the method of volumetric elements in ANSYS Meshing.

In Fig. 4–9 the results of numerical modeling of the poultry house on three sections along the length of the room - 16.23 m, 50.78 m and 85.25 m are shown. The first section is the middle of the 6th inlet valve, the second is the 2nd exhaust fan (between the 17th and 18th supply valve) and the third section is in the middle of the 29th inflow valve. There are 40 inlet valves along the length of the poultry house.

In Fig. 4 is shown the temperature field in different areas of the poultry house at a constant air flow rate of 77402 m^3/h and an inlet air temperature of +2 °C. The upper air layers near the ceiling and near the side wall have a slightly higher temperature. This is accompanied by radiation from the sun and ranges from +22 to +24°C. Since the poultry is a source of heat, as well as in combination with radiation, the air in the room is partially heated. In the center of the room along the entire height, the temperature reaches +16 °C. Cool air with a temperature of +2°C is directed to the center of the room and bypasses the poultry. In the area where the incoming air actively mixes with the air in the poultry house, the air temperature does not exceed +9.85 °C (Fig. 4 a, c). In Fig. 4 b, can be observed how the exhaust fan extracts part of the heat from the poultry, which is unacceptable. The average air temperature at the exhaust fans is +8.535 °C.



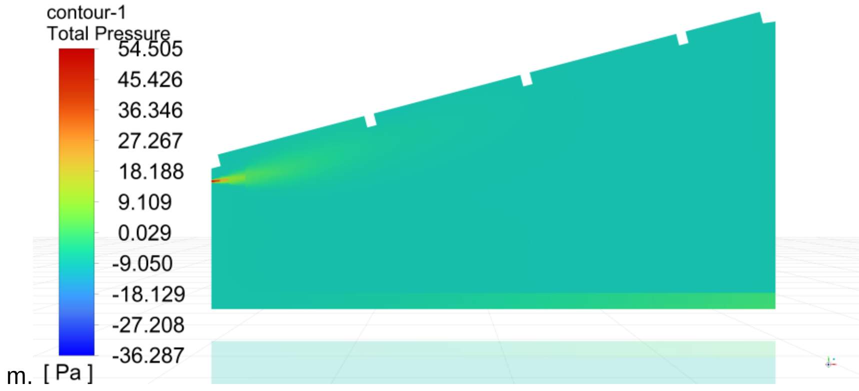
c

Fig. 4 – Temperature field (°C) in the poultry house at a distance from the front end wall at:
a – 16.23 m.; b – 50.78 m.; c - 85.25

In Fig. 5 is shown the pressure field in the poultry house. At the inlet of the inlet valves, the pressure is 45.846271 Pa (Fig. 5 a, c). A certain vacuum can be observed on the exhaust fans -8.4171922 Pa (Fig. 5 b). At certain points, the maximum pressure reaches 54.505 Pa.

Fig. 6 shows the hydrodynamics of air flow in the poultry house. As already mentioned above, the air flow is directed upwards by the inlet valves. However, due to low pressures and velocities at the entrance, the air falls down after passing a third of the room. Only in the case of valves that are at a height of 210 mm. from the ceiling (Fig. 6a, c; Fig. 6a, c), the air flow smoothly passes near the surface of the ceiling. The air is partially trapped due to the concrete protrusions of the floor (see Fig. 2.a).

After that, it goes to the center of the room, but reaches a third of the room. The average air velocity at the inlet of the inlet valves is 9.166368 m/s. At certain points of the poultry house, the maximum velocity can reach up to 9.871124 m/s. Two vortices are formed in the center along the length of the poultry house at 16.23 m (Fig. 6a).



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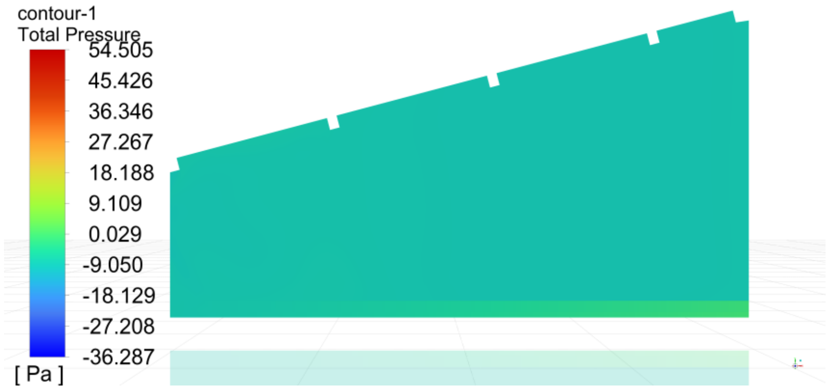

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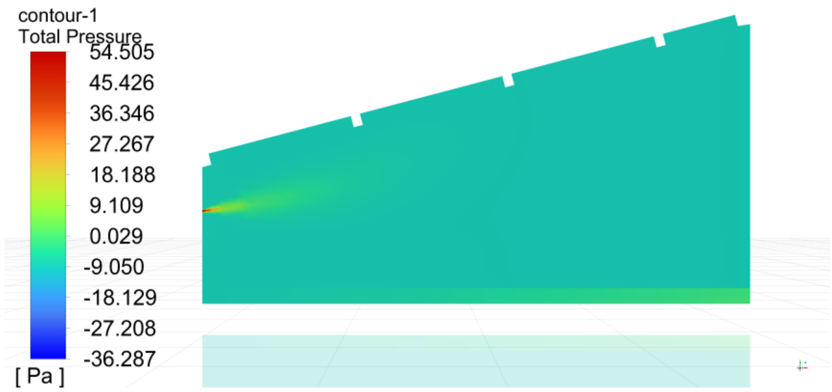
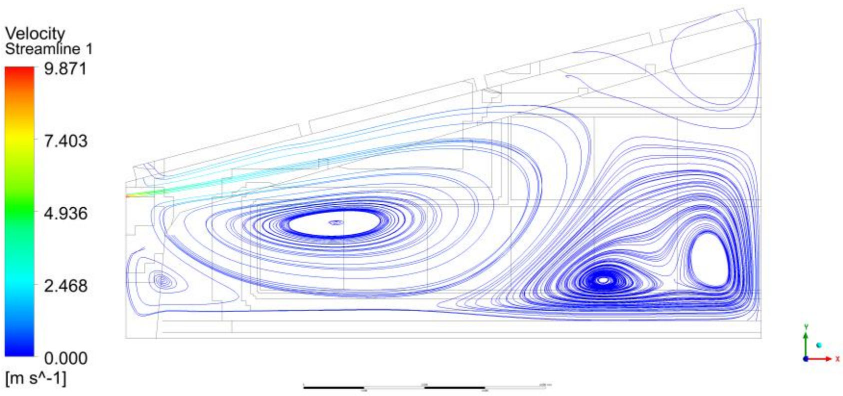


c

Fig. 5 – Pressure losses (Pa) in the poultry house at a distance from the front end wall at:
a – 16.23 m.; b – 50.78 m.; c - 85.25 m.



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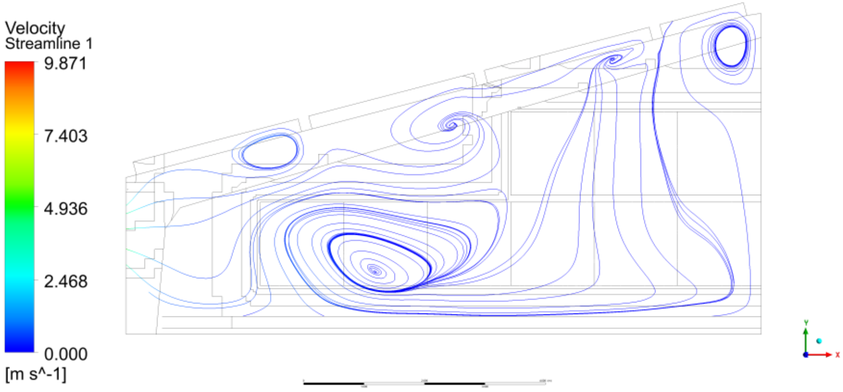

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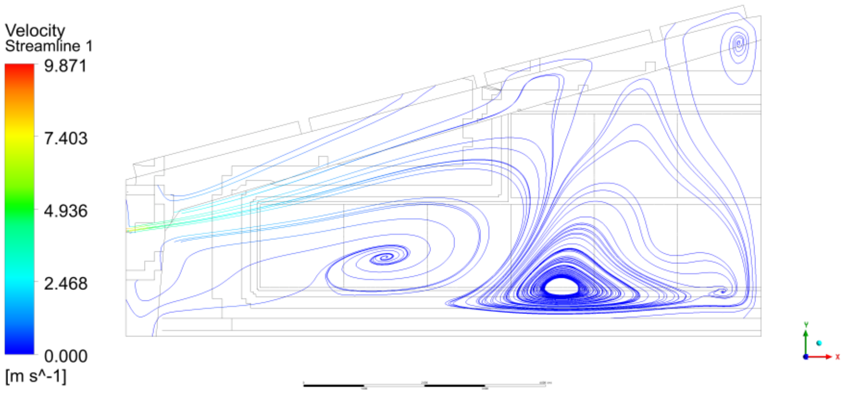
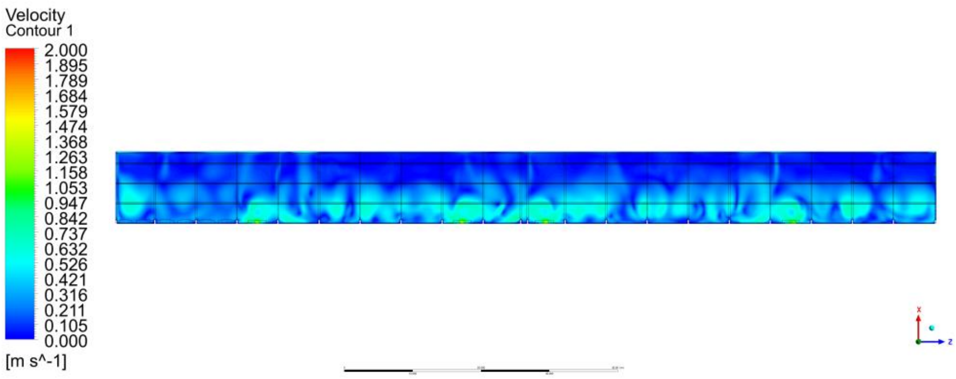


c

Fig. 6 – Flow lines (m/s) in the poultry house at a distance from the front end wall at:
a – 16.23 m.; b – 50.78 m.; c - 85.25 m.

Due to disturbance near the exhaust fans, along the length of the poultry house for 50.78 m (Fig. 6b), stagnant zones occur near the overlap. A vortex forms at a distance of 4.15 m from the side wall. This is due to low velocities at the outlet of the fan. In the section of exhaust fans, the average velocity is 3.4614946 m/s (Fig. 6b). Several vortices are formed at a distance of 85.25 m from the front end wall of the poultry house (Fig. 6c). The air that is pumped through the supply valves at a height of 810 mm does not reach the center of the room. This can be caused by the disturbance that occurs due to the large volumes of the room. And it is also due to low air velocity, low pressures on these inlet valves and protrusions in the concrete floor.

Figure 7 shows the field of velocities and temperatures along the plane of the room at a height of 0.7 m from the floor level. These results are the most interesting, which will help to evaluate the hydrodynamics and heat exchange of air above the poultry. The average air velocity is 0.57 m/s, the temperature is 9.91 °C. Only at some points the velocity is slightly higher than 2 m/s. The main array of poultry will not feel discomfort.



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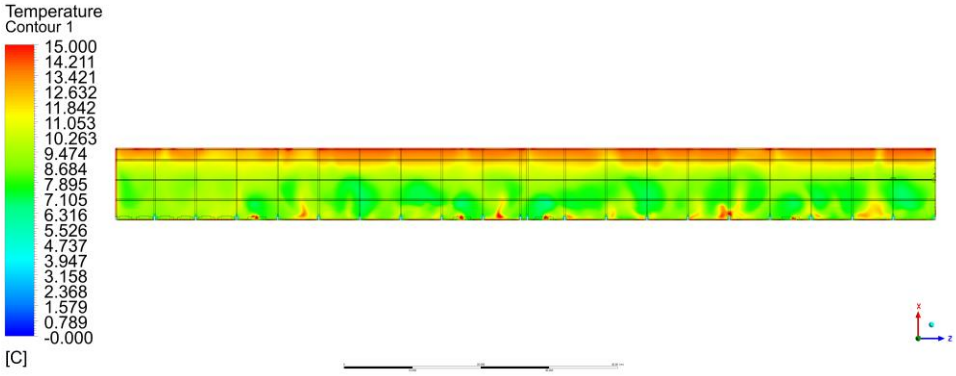

b

Fig. 7 – Velocity field, m/s (a), and temperature field, °C (b) in the poultry house at a height of 0.7 m from the floor level

Due to disturbance and stagnant zones in the center of the poultry house, the air velocity is about 0.32156 m/s. It was indicated above that the temperature reaches +16°C throughout the height. In the scientific work of *Trokhaniak V.I. et al., (2022)*, the exhaust fans are located on the upper line of the rear end wall. This arrangement accompanies the creation of a tunnel effect in the center of the poultry house. In this regard, in the future, the authors propose to install two additional exhaust fans on the rear end wall to the already existing ones. This will increase the air velocity in the center of the poultry house.

Fig. 8-9 present 3D streamlines and visualization of volumetric air flow in the range from 0 to 2 m/s for a poultry house. The results show that the valves located 810 mm from the ceiling do not work efficiently. Valves located at 210 mm work a little better. The first valves located to the right and left of the exhaust fans practically do not work. All air enters through them, immediately entering the exhaust fan. The authors suggest that these 8 valves be closed and not used. In this way, there will not be such a large disturbance in certain areas of the poultry house. And also the velocity of the remaining valves will rise to 0.1-0.2 m/s.

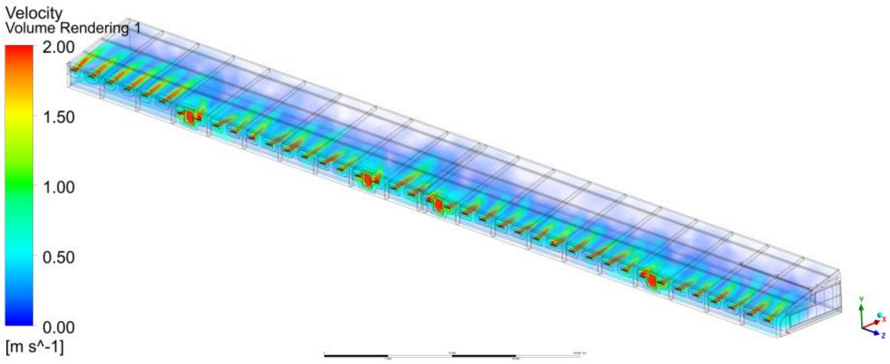

Fig. 8 – Visualization of the volume flow rate of the poultry house in the range from 0 to 2 m/s

Detailed information on the average parameters of the air environment in the poultry house as a result of the numerical simulation is presented in Table 3.

Table 3

Average indicators of the air environment in the poultry house

Parameter	Dim.	Inlet valves (inlet)	Exhaust fans (outlet)
Air consumption at the entrance for half of the poultry house	kg/s	21.5	21.50209
Air consumption at the entrance for half of the poultry house	m^3/h	77402	77402
Air consumption at the entrance for a full poultry house	m^3/h	154804	154804
Air pressure	Pa	45.846271	-8.4171922
Air temperature	ºC	2.0757952	8.5349084
Air velocity	m/s	9.166368	3.4614946
Air density	kg/m^3	1.2816432	1.2532063
Thermal conductivity coefficient of air	w/m·K	0.024559	0.025
Kinematic air viscosity	kg/m·s	$1.68137 \cdot 10^{-5}$	$1.71239 \cdot 10^{-5}$

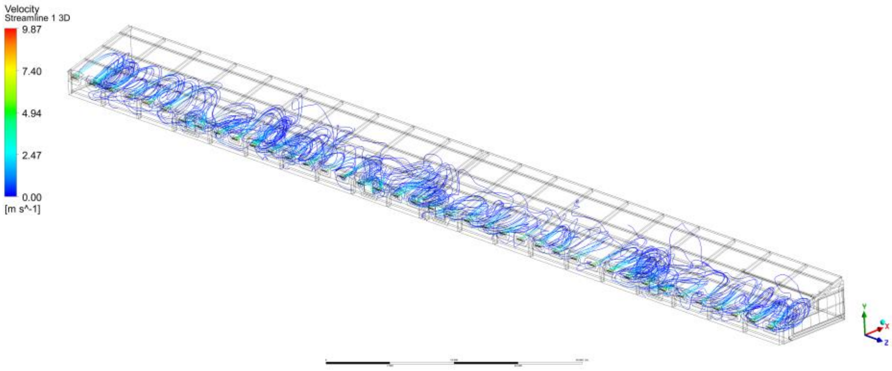

Fig. 9 – 3D streamlines (m/s) in the poultry house

With the practical experience of raising poultry, traditional poultry farms are divided into 16 uniform zones according to the output and quality of meat. Along the perimeter of the zone near the side walls of the poultry house, the quality of the meat is much worse. In the center of the poultry house, the output quality of the products is much better. From the obtained results of CFD modeling, it can be seen that due to lower speeds over the poultry and more uniform temperatures, the quality of products will be higher, compared to the traditional arrangement of exhaust fans. However, the presented results have both positive and negative effects on poultry as a whole. The authors evaluated all the pros and cons of the proposed ventilation system and will work on eliminating the shortcomings in the future.

CONCLUSIONS

1. CFD modeling of heat and mass transfer in the poultry house was carried out. To carry out CFD modeling, a mesh was built using the method of volumetric elements of the air environment of the poultry house in 3D. The CutCell method was used to build the mesh in the ANSYS Meshing preprocessor. The maximum size of the grid face is 0.16 m. The number of elements is about 4.3 million. Mesh quality indicator Orthogonal Quality is 0.22.

2. The results of the numerical modeling showed that the valves located at a height of 210 mm from the ceiling work most efficiently. The pressure drop at the inlet valves is 45.85 Pa. The air velocity at the inlet of the supply valves is 9.17 m/s. The air velocity at a height of 0.7 m from the floor level varies within 0.57 m/s, the temperature is 9.91 °C. The angle of inclination of the valve relative to the wall is 75°. The opening of the valve is 49 mm. However, with the proposed arrangement of exhaust fans on the side wall of the poultry house, the ventilation system does not work efficiently enough.

3. Authors recommend not to use two supply valves (total of 8 pcs) located on the right and left of the exhaust fans in the future. This will make it possible to increase the velocity of the remaining valves to 0.1-0.2 m/s, also include two additional fans on the rear end wall of the poultry house along the top line. This will make it possible to create a tunnel effect in the center of the poultry house. And this accompanies an increase in air velocity and at the same time reduces disturbances in the air environment of the poultry house.

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