Machinery & Energetics
Vol. 13, No. 3. 2022

Journal homepage:
https://technicalscience.com.ua/en

UDC 681.511;681.527
DOI: 10.31548/machenergy.13(3).2022.81-91

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Investigation of the Lateral Ventilation System in a Poultry House Using CFD

Abstract. Maintaining a normalised microclimate in a poultry house is one of the main factors. It is the quality indicators of air parameters that ultimately determine the quality of product output. Keeping poultry requires considerable efforts and technological solutions. In this regard, the purpose of the study is to improve the microclimate system in the poultry house by installing ventilation equipment on the side wall. A powerful tool for predicting the air flow pattern in a poultry house is Computational Fluid Dynamics (CFD) modelling using ANSYS Fluent. This is an alternative to experimental research. CFD modelling results have shown that the valves operate most efficiently at 330 mm from the ceiling. The pressure drop of the supply 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 – 9.91°C

Keywords: hinged screw sections, inactive zone between sections, material flight length, straight and curved routes, material departure angle

Article's History: Received: 30.03.2022; Revised: 07.07.2022; Accepted: 11.08.2022

INTRODUCTION

Evaluating the performance of new ventilation systems can be a difficult task, as it is time-consuming and rather expensive [1]. As an alternative to field measurements, Computational Fluid Dynamics (CFD) modelling is a powerful tool for predicting air flow patterns, particle and gas concentrations, and the thermal environment in livestock premises [2-4]. It was also used to evaluate the effectiveness of existing ventilation systems and new structures [5; 6].

In the study [7], three k-ε turbulence models were evaluated: standard k-ε, renormalisation group (RNG) k-ε, and realistic k-ε for estimating the internal environment of poultry based on temperature and air velocity measurements. The purpose of the study was to determine which turbulence model best reproduces experimental results using CFDs. Choosing a suitable turbulence model is important because it can significantly affect the results. In this study, the RNG k-3 model was best consistent with air velocity and temperature measurements, and therefore, its use and typical parameters were recommended for modelling the internal environment of poultry houses.

In [8], the design of air intake devices for this typical broiler room in a cold region under the condition of transverse ventilation was optimised based on two influencing factors: the length of the flow direction device and the air flow direction. Optimised air supply devices have helped improve air flow in the broiler room, thereby changing environmental factors such as internal temperature distribution, wind speed distribution, and carbon dioxide distribution. The ideal flow direction device should be approximately 1 m or 2 m long but no more.

The purpose of [9] is to create a 3D model using CFD that can reproduce real operating conditions inside the poultry housing. The improvement consists in integrating the main explicit and latent heat sources in accordance with the procedure described in [10], which was previously applied to a 2D CFD model. To investigate the typical cooling and heating processes observed in the poultry house, they were identified and considered for modelling. The results of the model were first tested on the basis of experimental data to evaluate the effectiveness of the model for predicting temperature and humidity gradients. The simulated field velocity was then used to calculate the ventilation intensity.

To maximise the benefits of weather conditions, the authors [11] analyse the influence of natural ventilation on the dynamics of the internal climate of the poultry house, with an emphasis on the role of external climatic parameters, in addition to wind direction. According to experimental data, seven periods with a stable wind direction of at least 4 hours were identified with a predominant

Suggested Citation:
Trokhaniak, V.I. (2022). Investigation of the lateral ventilation system in a poultry house using CFD. *Machinery & Energetics,* 13(3), 81-91.

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north-easterly wind direction. Three of these periods were selected as typical examples and used to test a three-dimensional CFD model for integrating the main elements, internal climate: animal heat generation and water vapour, radiation heat transfer, and ventilation. The predictions of the three-dimensional CFD model were then analysed using the concept of air residence time to estimate the ventilation rate and to investigate explicit and latent heat exchange.

In the study [12], the authors developed a 3D CFD model for modelling air velocity, air temperature, humidity, and heat stress in a commercial laying hen house. The model was successfully confirmed by field measurements during the warm, transitional, and cold periods of the year. Heat stress was detected in 69.1%, 78.0%, and 18.4% of kindergartens in summer, autumn, and winter according to the temperature and humidity indicator at the incoming air temperature of 26.0°C, 15.0°C, and 2.5°C with ventilation intensity of 85.8, 15.5, and 11.7 air exchange per hour, respectively. As a continuation of the study [13], the authors developed a new ventilation system, an upward airflow displacement (UAD) ventilation system, which allows fresh air to enter the poultry house through air ducts located at the bottom of the cages, move upwards due to thermal buoyancy caused by chickens and the static pressure difference caused by exhaust fans, and eventually exit the housing through fans installed on the roof. The results showed that the UAD system resulted in a 46-129% increase in the efficiency of air exchange in cages 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 conventional system.

The paper [14] presents the results of a study of intelligent control systems for biotechnological objects on the example of a greenhouse. A measurement system has been developed to effectively study solar radiation and predict possible information violations. Neural networks were used as a mathematical tool for predicting temperature time series. Subsequently, in [15; 16], a software and hardware subsystem of phytomonitoring was created in a modern greenhouse building, which is provided using LabVIEW software and Arduino equipment, which is tested directly in production. To conduct experiments, the authors of [17] developed a mobile robot for monitoring the state of the atmosphere and phyto status in protected ground objects to form control strategies that maximise production profits. As the final stage, the authors [18] developed an energy-efficient control system for the electrical engineering complex of an industrial greenhouse. Evaluation of the quality of plant products based on the use of Harington desirability function. This allows determining the parameters of the microclimate (plant temperature, temperature, and humidity), maximising the profit of products. All these methods that were used to create, analyse, and predict the microclimate in greenhouses can be used to a large extent for poultry houses.

The authors [19; 20] conducted a study of modular poultry maintenance. The design of a module for raising poultry with an infrared heater has been developed. The proposed design is energy efficient and is recommended for installation in poultry houses. The microclimate in the module is analysed. The air temperature near the bird in the module reaches 18.6°C, and the average speed does not exceed 0.75 m/s.

This paper is a continuation of scientific and practical research on improving the aerodynamic characteristics of the air environment in poultry housing [21]. Thus, *the purpose of the study* is to improve the microclimate system in the air environment of the poultry house by installing exhaust fans on the side wall in a total of 8 units. The scientific component is the investigation of hydrodynamics and heat exchange processes in the air environment of the poultry house with the improvement of the location of exhaust ventilation equipment.

MATERIALS AND METHODS

According to the purpose of the study, the authors modify the location of exhaust fans. The bottom line is as follows: in the conventional design of the poultry housing (Figs. 1, 2) exhaust fans are mounted not on the rear end wall of the poultry house, but on the side (Fig. 3.). 4 units for each wall, a total of 8 units. Current indicators in the poultry house can be seen in Table 1.

Table 1. Current indicators in the poultry house premises

Current indicators	Livestock	Cross	Age/Weight, g	Density units/m^2	Density kg/m^2	External temperature, C	Internal humidity, %	External humidity, %
	57,971	Ross	18/707	24.15	15.46	2	72	92

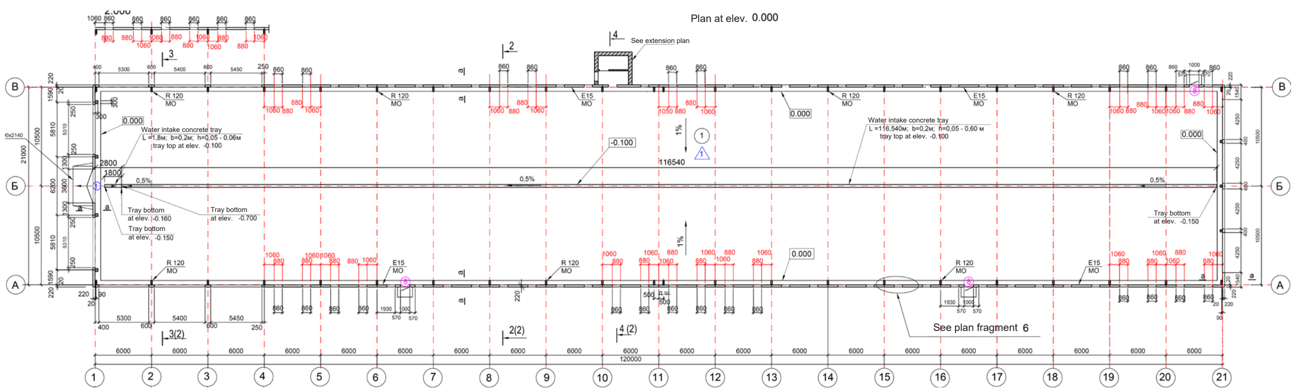

Figure 1. Valve arrangement plan

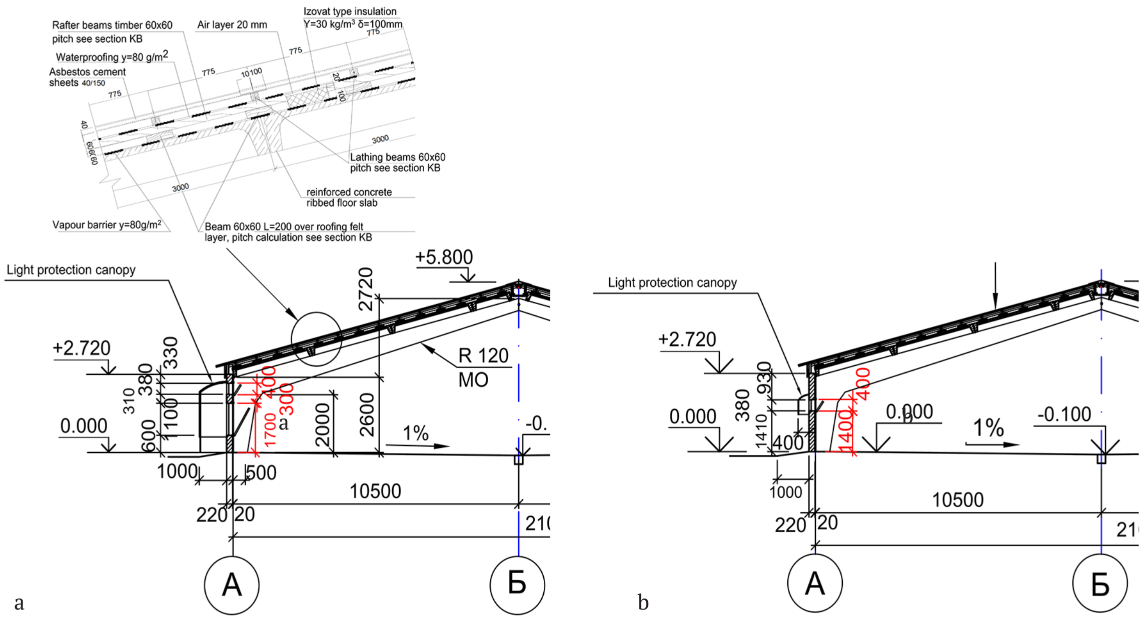

Figure 2. Fragment of a plan with side ventilation inlets: a – 1-6 valve, b – 7-40

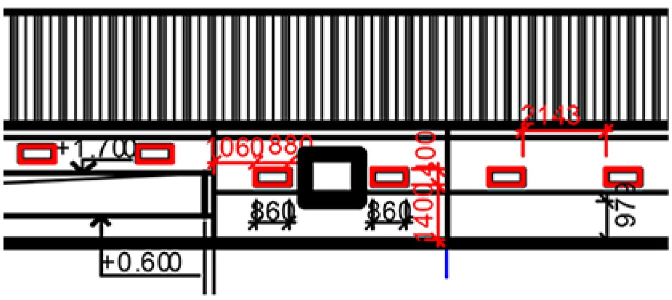

Figure 3. Location of the first exhaust fan on the side wall

Figure 4 shows the 3D geometry of a poultry house for CFD modelling made in 100% scale, but only half of the poultry house. The boundary condition "symmetry" is set in the centre of the poultry house. The remaining boundary conditions are shown in Figure 4a. These measures were carried out due to insufficient power of computer equipment. Figure 4b clearly shows concrete frame (stick).

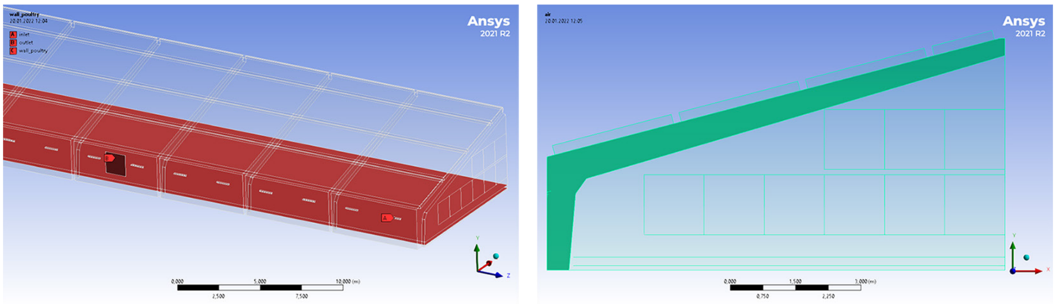

Figure 4. 3D poultry house geometry: a – with indication of boundary conditions; b – with selection of concrete frame

Figure 5a shows 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 form (Fig. 5b). In the openings of exhaust fans and supply valves, the mesh is reduced relative to the rest of the wall area. In addition near the floor where the bird was located, mesh grinding was performed for a more accurate calculation of hydrodynamics, and heat and mass transfer by numerical method.

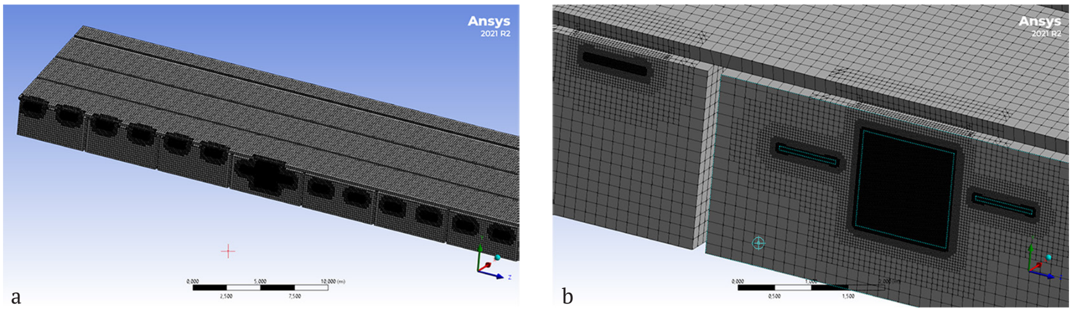

Figure 5. Mesh in the air environment of the poultry house: a – remotely, b – close

Table 2 shows the parameters for building a mesh in the air environment of a poultry house. Using the ANSYS Meshing software, a 3D calculation mesh is constructed using the 3D element method. The CutCell mesh construction method was applied. The number of elements reaches 4.3 million. The Orthogonal Quality mesh indicator is 0.22. The minimum size of the exhaust fan element on the side wall of the poultry house is 0.01 m. It is smaller than the size of the supply valve element by 0.03. This decision was made due to the fact that the authors of this study are more interested in the behaviour of air in exhaust fans. Air behaviour in supply valves has already been investigated [21].

Table 2. Parameters for building a mesh for a poultry room

Configuration options	Indicator	Size
Mesh quality indicator (orthogonal quality)	0.22	–
Number of elements	4,291,613	units
Number of nodes	4,849,379	units
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 exhaust fan element	0.01	m

Calculations were made at an air flow rate of 21.5 kg/s. The outside air temperature is assumed to be +2°C and the parameters of thermal radiation are entered. The walls are made of concrete and insulated with foam 35 kg/m^3 thickness, respectively: 60/100/60 mm. Insulated roof "Izovat" Y=30 kg/m^3, 100 mm. For more information, see Figure 2. The floor is insulated with expanded polystyrene 45 kg/m^3 with a thickness of 100 mm and a width of 2 m from the wall around the perimeter, the rest of the area is 50 mm. In poultry premises, poultry is a source of heat when kept on the floor and the temperature is +41°C. The heating system is not provided. For air removal, Munters EM50 1.5 Hp exhaust fans are used in the amount of 4 units. Wlotpowietrza 3000-VFG supply valves with a total number of 79 units. Spoilers are mounted above the valves at an angle of inclination from the vertical of 75°C. The remaining design parameters of the poultry house can be obtained from Figure 1-3.

The CFD model was performed using the Navier-Stokes equations for convective flows [22-24]. The calculations use the Spalart-Allmaras turbulence model [25; 26] and the Discrete Ordinates radiation model [9; 27].

RESULTS AND DISCUSSION

This section presents the results of the numerical modelling of a poultry house in 3D using ANSYS Fluent. This allows assessing the hydrodynamic air flows in the poultry house. To perform numerical modelling, a 3D grid is previously constructed using the 3D element method in ANSYS Meshing.

Figure 6-14 show the results of numerical modelling of the poultry house in three sections along the length of the room – 16.23 m, 50.78 m, and 85.25 m. The first section is the middle of the 6th supply valve. The second is the 2nd exhaust fan (between the 17th and 18th supply valves). The third section is located in the middle of the 29th supply valve. There are 40 supply valves along the length of the poultry house.

Figure 6 and 12 show the temperature field in different parts of the poultry house. At a constant air flow rate of 77,402 m³/h and the inlet air temperature of +2°C. The upper layers of air near the ceiling and near the side wall are slightly higher in temperature. This is accompanied by the radiation of the sun and ranges from +22 to +24°C. Since the bird is a source of heat, and in combination with radiation, the air in the room is partially heated. In the centre of the room, the temperature reaches +16°C along the entire height. Cool air with a temperature of +2°C is directed to the centre of the room and washes the bird. In the area where the supply air is actively mixed with the air that is in the poultry house, the air temperature does not exceed +9.85°C (Fig. 6a, 6b). Figure 6b shows how the exhaust fan draws some of the heat from the bird. Which is unacceptable. The average air temperature on exhaust fans is +8.5349°C.

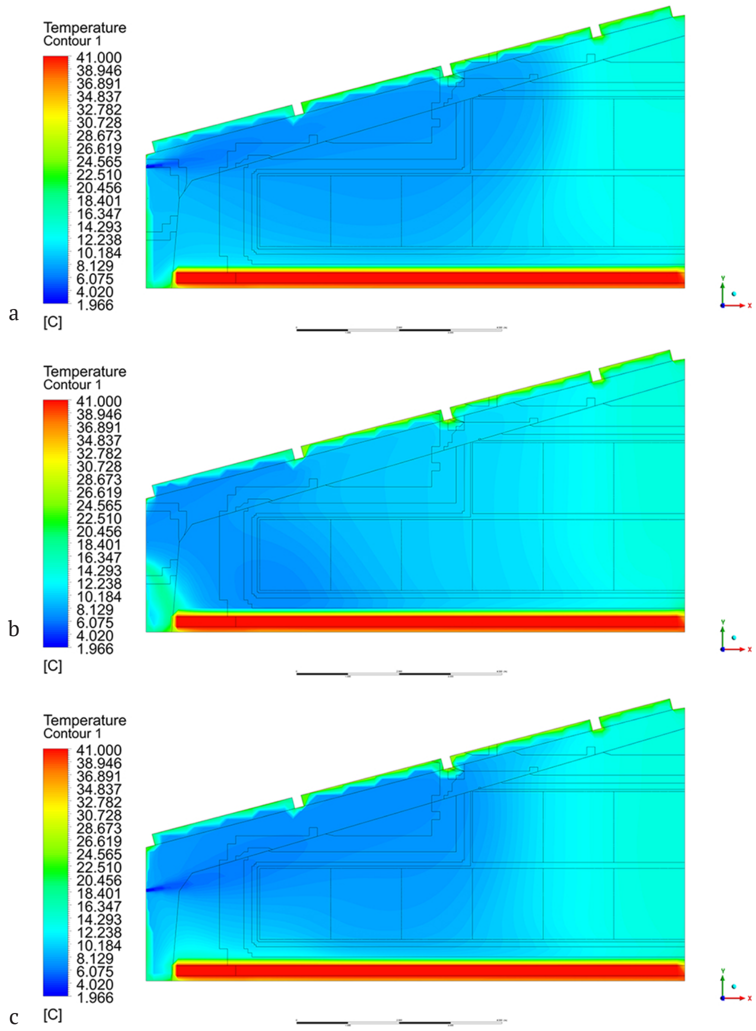

Figure 6. Mesh in the air environment of the poultry house: a – remotely, b – close

Figure 7 shows the pressure field in the poultry house. At the inlet on the supply valves, the pressure is 45.846271 Pa (Fig. 7a, 7b). On the exhaust fans, a certain vacuum is observed – -8.4171922 Pa (Fig. 7b). At certain points, the maximum pressure reaches 54.505 Pa.

Figure 8-9 show the hydrodynamics of air flow in the poultry house. As mentioned above, the air flow is directed upwards by supply valves. However, due to the low pressure and speed at the inlet, the air after passing a third of the room falls down. Only valves that are located at a height of 330 mm from the ceiling (Fig. 8a, 8b, Fig. 9a, 9b) pass smoothly near the ceiling surface. Air is partially retained due to the concrete protrusions of the ceiling (Fig. 2a). After that, it is sent to the centre of the room. But it reaches a third of the room. The average air velocity at the inlet of the supply valves is 9.166368 m/s. At certain points in the poultry house, the maximum speed can reach up to 9.871124 m/s. In the very centre, two vortices are formed along the length of the poultry house by 16.23 m (Fig. 9a). Due to disturbances near the exhaust fans, along the length of the poultry house by 50.78 m (Fig. 9b), stagnant zones occur near the ceiling. A vortex forms at a distance of 4.15 m from the side wall. This is conditioned by the low speed at the fan outlet. On the exhaust fan section, the average speed is 3.4614946 m/s (Fig. 8b, 9b). At a distance of 85.25 m from the front end wall of the poultry house (Fig. 8b, 9b) several vortices are formed. The air that is pumped through the supply valves at a height of 810 mm from the ceiling does not reach the centre of the room. They do not give a sufficient effect this can be caused by a disturbance that occurs due to large volumes of the room. It is also caused by low air velocity, low pressure on these supply valves, and protrusions in the concrete floor.

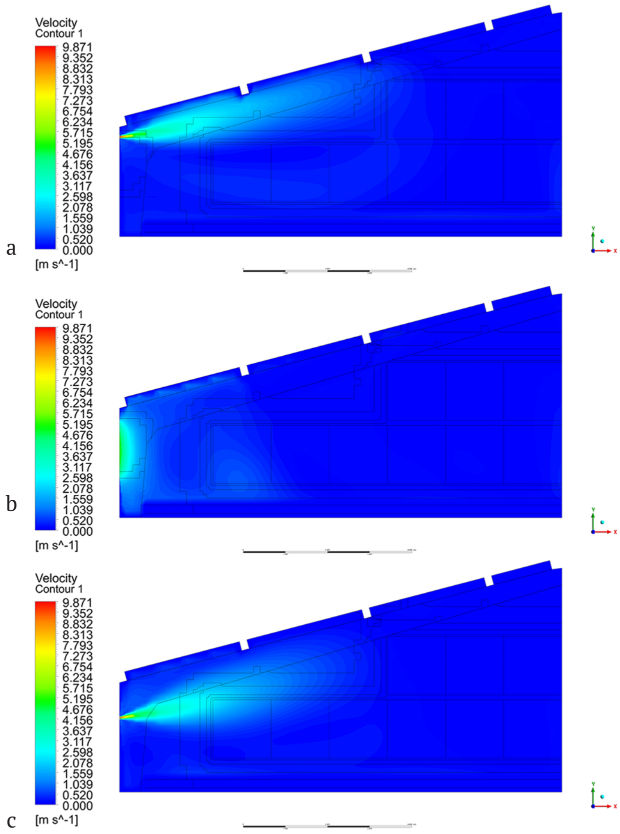

Figure 8. Velocity field (m/s) in the poultry house at a distance from the front end wall at: a – 16.23 m; b – 50.78 m; c – 85.25 m

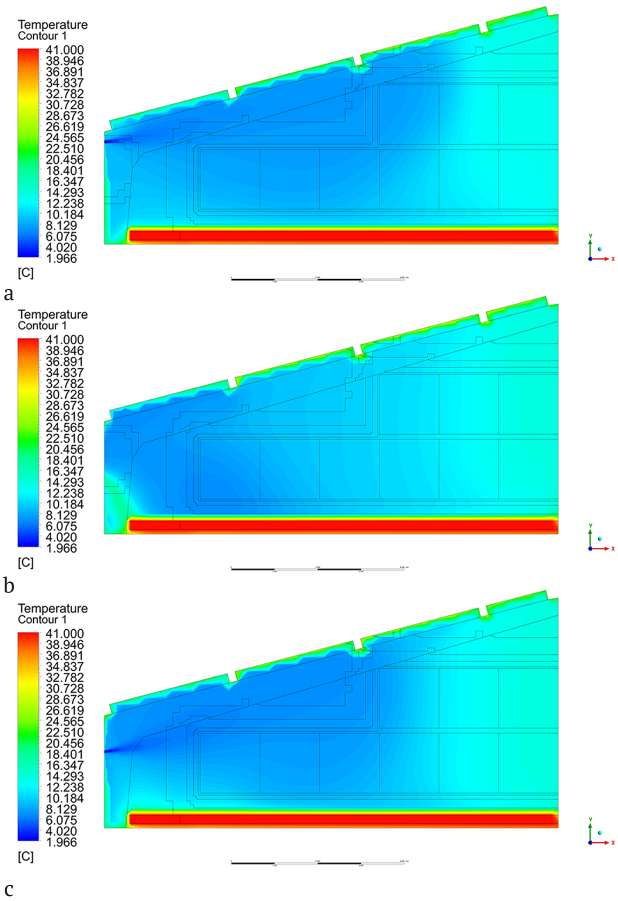

Figure 7. Pressure losses (Pa) in the poultry house at a distance from the front end wall at: a – 16.23 m; b – 50.78 m; c – 85.25 m

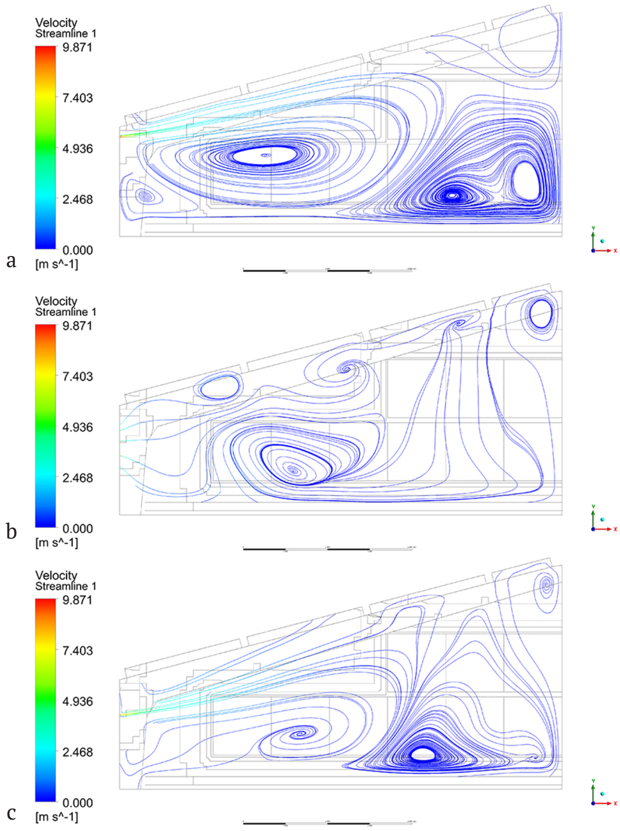

Figure 9. Current lines (m/s) in the poultry house at a distance from the front end wall at: a – 16.23 m; b – 50.78 m; c – 85.25 m

Figure 10 shows the field of velocities and temperatures along the room plane at a height of 0.7 m from the floor level. These results are the most interesting, which would help assess the hydrodynamics and heat exchange of air above the bird. The average air velocity is 0.57 m/s, the temperature is 9.91°C. Only at some points the speed is slightly higher than 2 m/s. The main array of birds will not experience any discomfort.

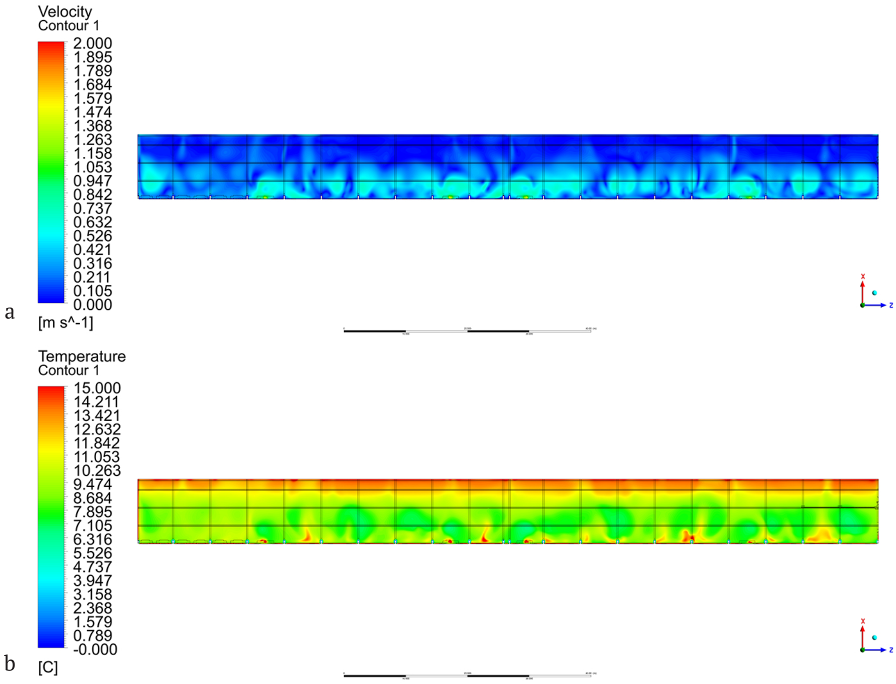

Figure 10. Velocity field, m/s (a), and temperature field, oC (b) in the poultry house at a height of 0.7 m from the floor level

Due to disturbances and stagnant zones in the centre of the poultry house, the air velocity reaches about 0.32156 m/s. It was indicated above that the temperature reaches +16°C over the entire altitude. In the study [28-29], exhaust fans are located on the upper line of the rear end wall. This arrangement accompanies the creation of a tunnel effect in the centre of the poultry house. In this regard, in the future, the authors suggest installing two exhaust fans on the rear end wall in addition to the existing ones. This would increase the air velocity in the centre of the poultry house.

Figure 11-14 show current lines and visualisation of the volume flow rate in the range from 0 to 2 m/s for a poultry house in 3D. The results show that the valves located at 810 mm from the ceiling do not work effectively. Valves located at 210 mm are slightly better. The first valves that are located to the right and left of the exhaust fans practically do not work. All air that enters through them immediately enters the exhaust fan. The authors suggest that these 8 valves should be closed and not used. Thus, there will not be such a large disturbance in certain areas of the poultry house. And also the speed of the remaining valves will rise to 0.1-0.2 m/s.

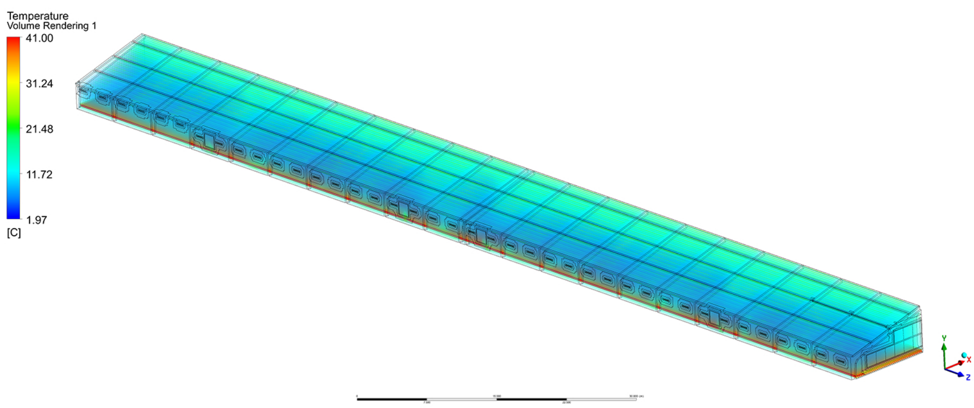

Figure 11. Visualisation of the volumetric temperature flow rate of the poultry house air environment, oC

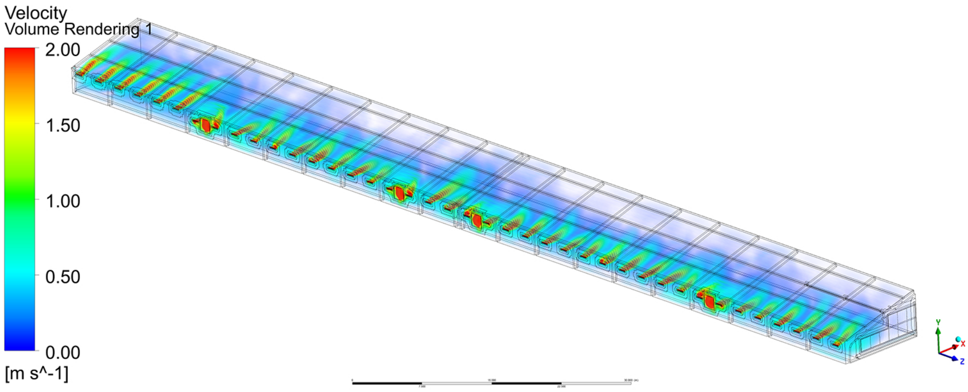

Figure 12. Visualisation of the volume air flow rate of the poultry house in the range from 0 to 2 m/s

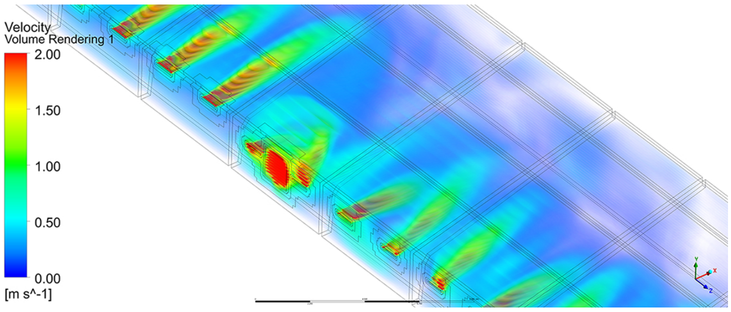

Figure 13. Visualisation of the volumetric air flow rate of the poultry house in the convergence of the first exhaust fan in the range from 0 to 2 m/s

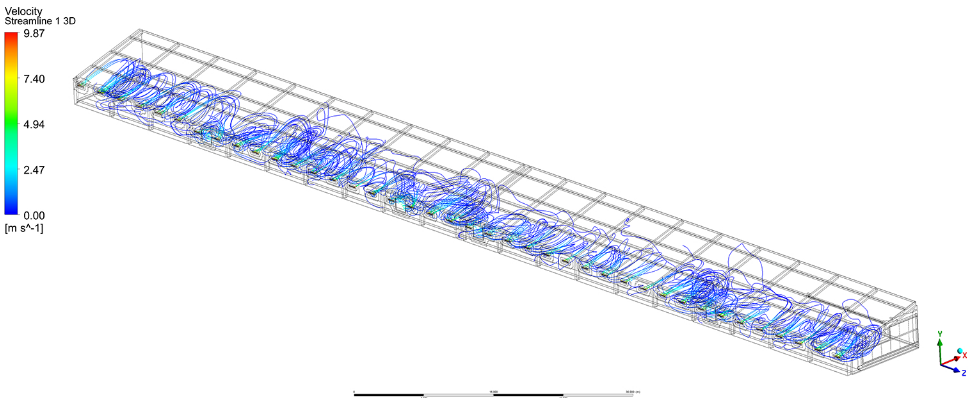

Figure 14. 3D current lines (m/s) in the poultry house

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

Table 3. Average indicators of the air environment in the poultry house

Parameter	Dimension	Supply valves (inlet)	Exhaust fans (outlet)
Inlet air consumption for half of the poultry house	kg/s	21.5	21.5
Inlet air consumption for half of the poultry house	m^3/h	77,402	77,402
Inlet air consumption for a full poultry house	m^3/h	154,804	154,804
Air pressure	Pa	45.846271	-8.4171922
Air temperature	°C	2.0757952	8.5349084
Air velocity	m/s	9.166368	3.4614946
Air density	kg/m^3	1.2816432	1.2532063
Coefficient of thermal conductivity of air	W/m·K	0.024559	0.025
Kinematic air viscosity	kg/m·s	$1.68137 \cdot 10^{-5}$	$1.71239 \cdot 10^{-5}$

With practical experience, raising poultry in conventional poultry houses is divided into 16 uniform zones in terms of output and meat quality. Along the perimeter of the area near the side walls of the poultry house, the quality of meat is much worse. In the centre of the poultry house, the output of product quality is much better. From the results of CFD modelling, it can be seen that due to lower speeds over the bird, and more uniform temperatures, the product quality, compared to the conventional location of exhaust fans, will be higher. However, the presented results have both positive and negative effects on the bird in general. The authors evaluated all the pros and cons of the proposed ventilation system and will continue to work on the elimination of shortcomings.

CONCLUSIONS

CFD modelling of heat and mass transfer in the poultry house premises was performed. For CFD modelling, a mesh was built by the method of volumetric elements of the air environment of the poultry house in 3D. The CutCell method is used to build a mesh in the ANSYS Meshing pre-processor. The maximum mesh face size is 0.16 m. The number of elements is about 4.3 million. The mesh quality index Orthogonal Quality is 0.22.

The results of numerical modelling have shown that the most efficient valves are those located at a height of 330 mm from the ceiling. The pressure drop of the supply 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 – 9.91°C. The angle of inclination of the valve relative to the wall is 75°. Opening of the valve by 4 mm. However, with the proposed location of exhaust fans on the side wall of the poultry house, the ventilation system does not work efficiently enough. The authors recommend not using two supply valves (total 8 units) located to the right and left of the exhaust fans. This would increase the speed of the remaining valves to 0.1-0.2 m/s. In addition, two additional fans on the rear end wall of the house along the top line should be included. This would create a tunnel effect in the centre of the poultry house. And this is accompanied by an increase in air speed. At the same time, it reduces disturbances in the air environment of the poultry house.

ACKNOWLEDGEMENTS

The study was conducted with the support of topic 4/81 commissioned by the branch "Poultry Complex" of Vinnytsia Poultry Farm LLC and topic No. 110/1m-pr-2022 by Order of the Ministry of Education and Science of Ukraine.

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Дослідження бокової системи вентиляції в пташнику за допомогою CFD

Анотація. Підтримання нормованого мікроклімату у птахівничому приміщенні це один із основних факторів. Саме від якісних показників параметрів повітря в кінцевому результаті залежить якість виходу продукції. Птиця при її утриманні вимагає значних зусиль і технологічних рішень. В зв'язку з цим метою дослідження є вдосконалення системи мікроклімату у пташнику шляхом встановлення вентиляційного обладнання на боковій стінці. Потужним інструментом прогнозування схеми повітряного потоку в пташнику є моделювання обчислювальної гідродинаміки (Computational Fluid Dynamics (CFD)) за допомогою ANSYS Fluent. Це є як альтернатива експериментальним дослідженням. Результати CFD моделювання показали, як практичну цінність в тому, що най ефективніше клапани працюють які розташовані на висоті 330 мм. від перекриття. Перепад тиску у припливних клапанів становить 45,85 Па. Швидкість повітря на вході припливних клапанів 9,17 м/с. Швидкість повітря на висоті 0,7 м. від рівня підлоги коливається в межах 0,57 м/с, температура – 9,91 °C

Ключові слова: обчислювальна гідродинаміка, мікроклімат, аеродинаміка, птахівниче приміщення, припливні клапана