INTERNATIONAL SCIENTIFIC JOURNAL

MECHANIZATION IN AGRICULTURE & CONSERVING OF THE RESOURCES

Issue 5
2023

Year LXIX, ISSN print:2603-3704, ISSN web 2603-3712

SCIENTIFIC TECHNICAL UNION OF MECHANICAL ENGINEERING
BULGARIAN ASSOCIATION OF MECHANIZATION IN AGRICULTURE

PUBLISHERS

SCIENTIFIC-TECHNICAL UNION OF MECHANICAL ENGINEERING "INDUSTRY-4.0"
BUGLARINA ASSOTIOATION OF AGRICULTURAL MACHINERY

ISSN (PRINT) 2603-3704, ISSN (ONLINE) 2603-3712

YEAR LXIX ISSUE 5 / 2023

The journal "MECHANIZATION IN AGRICULTURE & CONSERVING OF THE RESOURCES " is continuer of the journals "Mechanized farming" (1948-1957), "Mechanization and electrification of agriculture" (1959-1980) and "Mechanization of agriculture " (1981-1991)

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C O N T E N T S

MECHANIZATION IN AGRICULTURE

CONSERVING OF THE RESOURCES

Investigation of the side ventilation system in the poultry house using CFD

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Abstract. Maintaining a standardized microclimate in the poultry house is one of the main factors. It is the quality of the air parameters that ultimately determines the quality of the product output. Poultry at its maintenance requires great efforts and technological solutions. In this regard, the study is to improve the system of microclimate in the air environment of the poultry house by including exhaust fans on the rear end wall in a non-traditional way. Computational Fluid Dynamics (CFD) using ANSYS Fluent is a powerful tool for predicting the microclimate system in the poultry house as an alternative to experimental studies. According to the results of CFD modeling of hydrodynamics and heat and mass transfer processes, it was concluded that changing the spoiler angle by 73° allows to supply air to the center of the house. At the same time the pressure drop at the inlet valves is 70.48 Pa, which allows to fully provide the exhaust fan. The air velocity at the inlet of the supply valves is 11.57 m·s^{-1}. The average air velocity at a height of 0.7 m from floor level is 0.46 m·s^{-1}and the temperature is 15.94 ℃. Thus, the presented scientific research can be used in the future in the development of new ventilation systems of poultry houses.

***KEYWORDS**: HOUSE, LATERAL VENTILATION SYSTEM, CFD, AIR INLET VALVE, AERODYNAMICS.*

1. Introduction

Development of new technologies in the energy industry, transition to a new level of energy supply of facilities, including ventilation systems of poultry complexes, is characterized by accelerated growth rates of all quantitative and qualitative indicators of product output, as well as improvement of the entire structure of poultry production.

Assessing the performance of new ventilation systems can be a difficult task because it is time-consuming and quite expensive [1]. As an alternative to field measurements, Computational Fluid Dynamics (CFD) modeling is a powerful tool for predicting airflow patterns, particle and gas concentrations, and thermal environment in livestock buildings [2]. It has also been used to evaluate the performance of existing ventilation systems and new constructions [3].

In a study [4], three k-ε turbulence models were evaluated: standard k-ε, RNG k-ε, and realisable k-ε to estimate the internal environment of a bird based on temperature and air velocity measurements. The purpose of this study was to determine which turbulence model best reproduces experimental results using CFD. In this study, the k-ε RNG model agreed best with air velocity and temperature measurements, so its use and typical parameters are recommended for modeling the indoor environment of poultry houses.

In [5], the construction of air inlet devices for this typical broiler house in a cold region under cross ventilation was optimized based on two influencing factors: the length of the flow direction device and the direction of air flow. The optimized air inlet devices helped to improve the air flow in the broiler room, thereby modifying environmental factors such as internal temperature distribution, wind speed distribution, and carbon dioxide distribution.

The aim of this work [6] is to create a 3D model using CFD capable of reproducing real operating conditions inside a poultry house. The improvement consists in integrating the main explicit and hidden heat sources following the procedure described in [7], previously applied to a 2D CFD model. In order to investigate the typical cooling and heating processes observed in a poultry house, the typical cooling and heating processes were identified and considered for modeling. The model results were initially validated against experimental data to evaluate the performance of the model for predicting temperature and humidity gradients.

The authors [8, 9] conducted a study of modular poultry housing. The construction of a module for poultry rearing with an infrared heater was developed. The proposed construction is energy efficient and is recommended for installation in poultry houses. The microclimate in the module is analyzed. The air temperature near the birds in the module is 18.6 ℃, and the average velocity does not exceed 0.75 m·s^{-1}.

This publication is a continuation of scientific and practical research on improvement of aerodynamic characteristics of the air environment in the poultry house [10, 11].

Thus, the purpose of the article is to improve the microclimate system in the air environment of the poultry house by mounting exhaust fans on the side wall in total number of 8 pcs. As a scientific component is the research of processes of hydrodynamics and heat exchange in the air environment of the poultry house with improvement of location of both exhaust ventilation equipment and spoilers over the inlet valves.

2. Materials and Methods

According to the purpose of the work we modify the arrangement of exhaust fans. The essence of it is as follows. In the traditional construction of the poultry house exhaust fans are not mounted on the rear end wall of the poultry house, but in our case on the side wall (Fig. 1). 4 pcs. for each wall, for a total of 8 pcs.

Fig. 1 shows the 3D geometry of the poultry house for CFD modeling. It is made in 100% scale, but only half of the house. The boundary condition "symmetry" is set at the center of the house. Other boundary conditions are shown in Fig. 1. These measures were performed due to insufficient capacity of computer equipment.

Calculations are made at air flow rate of 21.5 kg·s^{-1}. The outside air temperature is assumed to be +2 ℃ and the heat radiation parameter is introduced. The walls are made of two sides of concrete 60 mm thick and insulated foam 35 kg·m^{-3} between them 100 mm thick. The roof is insulated with material "Izovat" $Y = 30$ kg·m^{-3},
100 mm. The floor is insulated with polystyrene foam 45 kg·m^{-3} 100 mm thick on the width of 2 m from the perimeter wall, all other area – 50 mm. In the poultry rooms, poultry in floor housing is a source of heat, which is +41 ℃. No heating system is provided. For air removal, exhaust fans type Munters EM50 1.5 HP with a total number of 6 pcs are used. Supply valves Wlotpowietrza 3000-VFG with a total of 64 pcs, which are placed at a height of 0.21 m from the ceiling for 1-6 valves and 0.81 m for 7-40 valves. Spoilers are embedded above the valves at an angle of inclination from the vertical of 73º and their length is 0.2 m for 1-6 valve and 0.25 m for 7-40 valve. From the recommendations of previous works of the authors [12], the near valves near the exhaust fans are not involved, namely 7-8, 17-18, 21-22 and 33-34. Other constructive parameters of poultry house ventilation can be obtained from Table 1.

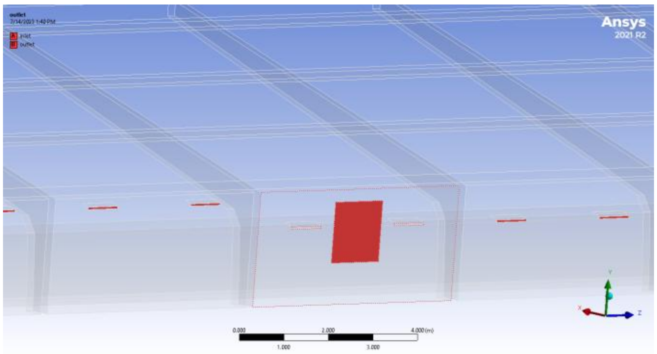


Figure 1. *3D poultry house geometry with boundary conditions and location of the first exhaust fan on the side wall*

Table 1. *Constructive parameters of poultry house air supply ventilation*

Parameters	1-6 valves	7-40 valves
Valve width, m	0.86	0.86
Valve opening height, m	0.049	0.049
Spoiler length, m	0.2	0.25
Spoiler tilt angle, deg.	73	73
The height of the valve location from the slab level, m	0.21	0.81
Valve shank length, m	0.04	0.04
Number of valves used for half of the house, pcs.	6	26

A mesh was constructed in the air environment of the poultry house from the side of the house. At the openings of the 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. Grid reduction is carried out for more accurate calculation of hydrodynamics and heat and mass transfer by numerical method.

Using ANSYS Meshing software, a 3D calculation mesh was constructed by the method of volumetric elements. CutCell mesh construction method was applied. The number of elements reaches 4.6 million. The index of quality of the mesh orthogonal quality is equal to 0.263. The minimum size of the element of exhaust fans and inlet valves on the side wall of the poultry house is 0.01 m.

The CFD model was performed on the Navier-Stokes equations for convective flows [13]. The Discrete Ordinates radiation model [6] and the Spalart-Allmaras turbulence model [14] were applied in the calculations.

3. Results and discussions

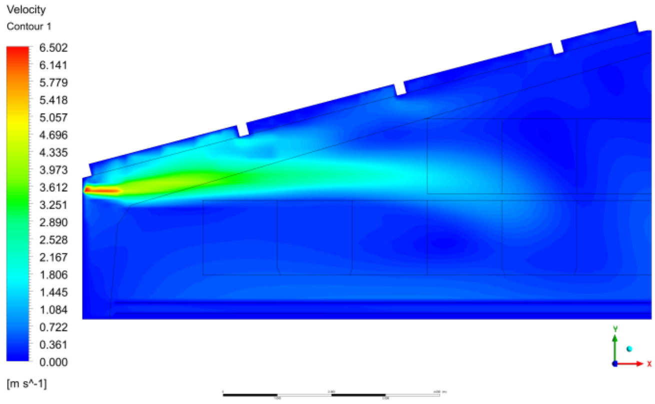
In this section we present the results of numerical modeling of the poultry house in 3D using ANSYS Fluent. This allows to estimate the hydrodynamic air flows in the house. To perform numerical modeling, the 3D mesh construction by the volumetric element method in ANSYS Meshing is preliminary carried out.

Fig. 2-5. shows the results of numerical modeling of the poultry house at three sections along the length of the room – 16.23 m, 50.78 m and 85.25 m. The first plot is the middle of the 6th tidal vent. The second is the 2nd exhaust fan (between the 17th and 18th tidal valve). The third site is in the middle of the 29th tidal valve. There are 40 inlets valves along the length of the house.

At constant air flow rate 77402 $m^3 \cdot h^{-1}$ and inlet air temperature +3 ℃. The upper air layers near the slab and near the side wall temperature is slightly higher. It is accompanied due to radiation emission from the sun and ranges from +21.5 to +24.5 ℃. Since the bird is a source of heat, and in conjunction with radiation emission, the air in the room is partially heated. In the center of the room the temperature reaches +15-17 ℃ throughout the whole height. Cool air with a temperature of +3 ℃ is directed to the center of the room and washes over the bird. In the area where the supply air actively mixes with the air in the house, the air temperature does not exceed +10.28 ℃. From the results of modeling we observe that the exhaust fan extracts part of the heat from the poultry. That is unacceptable. The average air temperature at the exhaust fans is +17.512945 °C.

At the inlet at the supply valves the pressure is 70.476332 Pa. At the exhaust fans there is a certain rarefaction – –0.58615902 Pa. At certain points the maximum pressure reaches 73.364712 Pa.

Fig. 2-3 shows the hydrodynamics of air flow in the poultry house. As mentioned above, the air flow is directed uphill by the tidal valves. However, due to insufficient inlet pressures and velocities, after passing almost the entire width of the house, the air is distributed downward and uphill. Only the valves located at a height of 210 mm. from the slab (Fig. 2a, 2c, Fig. 3a, 3c) are smoothly directed towards the center of the house. The air is partially trapped by the concrete overhangs of the slab. The average inlet air velocity at the inlet valves is 11.5657 $m \cdot s^{-1}$. At certain points in the supply valves of the house, the maximum velocity can reach 12.01243 $m \cdot s^{-1}$. One large vortex is formed at the very center across the width of the house (Fig. 3a). Due to the disturbance at the exhaust fans, along the length of the house at 50.78 m (Fig. 3b), near the slab, the air is partially trapped and directed towards the fans. At the exhaust fan site, the average velocity is 3.2801507 $m \cdot s^{-1}$ (Fig. 2b, 3b). At a distance of 85.25 m from the front end wall of the house (Fig. 2c, 3c), two large vortices are formed. The air that is pumped through the supply valves at 810 mm reaches the center of the room due to the upper vortex. This can be caused by a disturbance due to the large volume of the room. The separation into two opposite vortices is due to the high air velocity, sufficient pressures at these supply valves.



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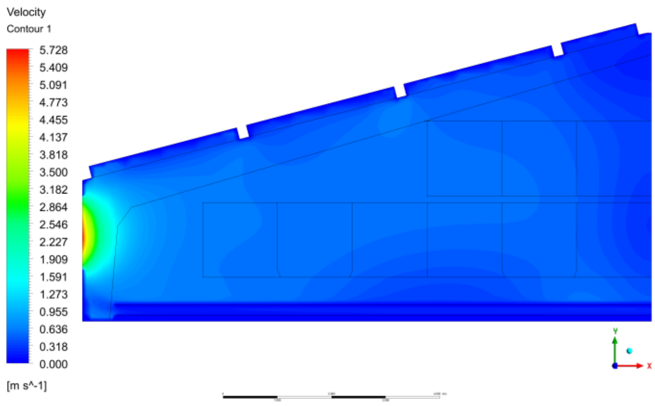

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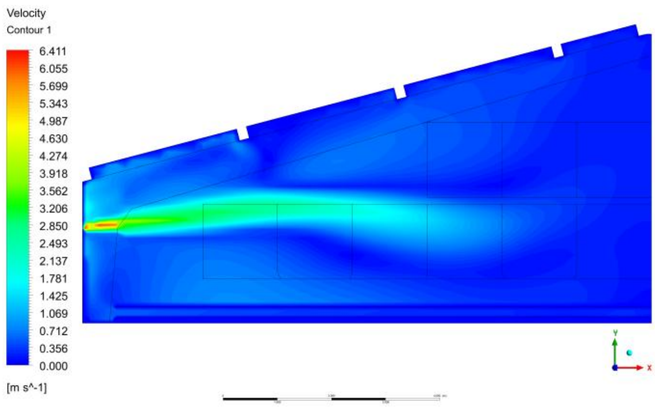

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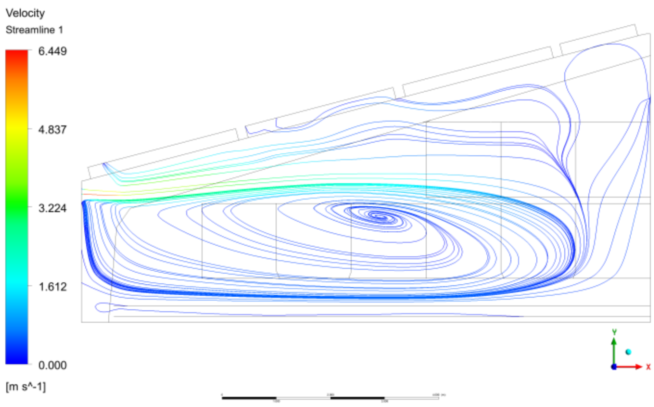
Figure 2. *Velocity field ($m \cdot s^{-1}$ in the poultry house at a distance from the front end wall on the:*
a – 16.23 m; b – 50.78 m; c – 85.25 m



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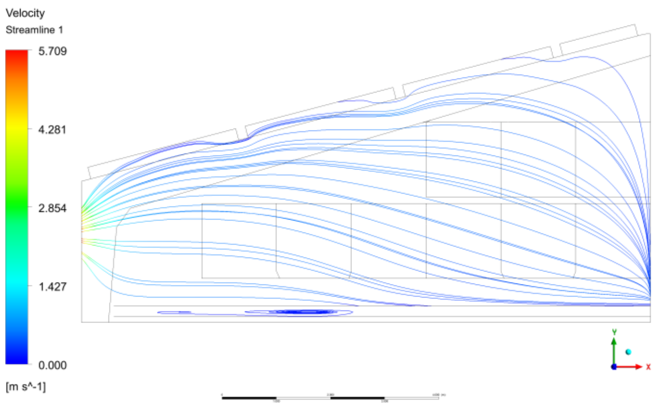

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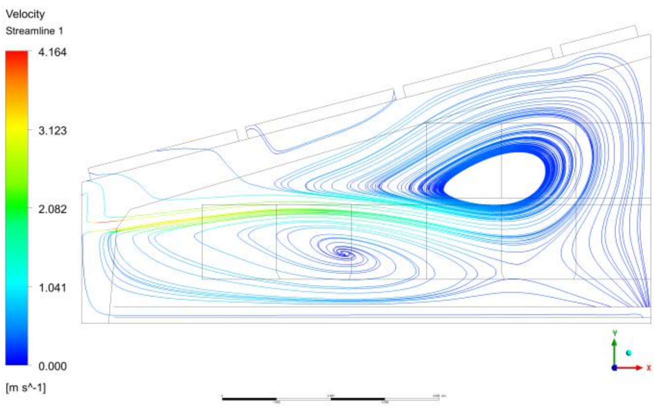
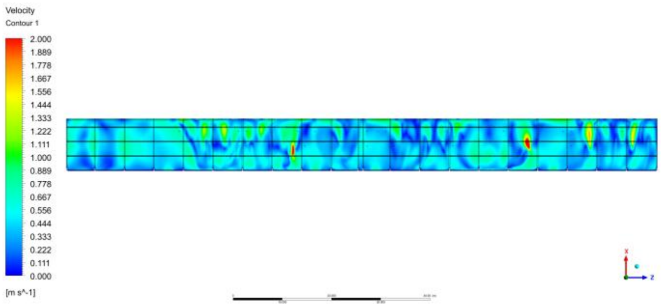


c

Figure 3. *Flow lines ($m{\cdot}s^{-1}$) in the house at a distance from the front end wall at the:*
a – 16.23 m; b – 50.78 m; c – 85.25 m

Fig. 4 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 most interesting, which will help to evaluate the hydrodynamics and heat exchange of the air above the bird. The average air velocity is 0.45958 $m{\cdot}s^{-1}$, and the temperature is – 15.94015 ℃. Only at some points is the velocity slightly greater than 2 $m{\cdot}s^{-1}$. The main body of birds will not experience discomfort.



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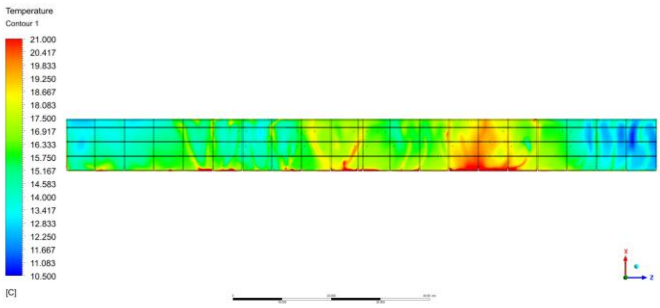

b

Figure 4. *Velocity field, $m{\cdot}s^{-1}$ (a) and temperature field, °C (b) in the poultry house at a height of 0.7 m from floor level*

Fig. 5 shows a 3D visualization of the volumetric air flow rate between 0 and 2 $m{\cdot}s^{-1}$ for the poultry house. The results show that valves located at 810 mm. from the overlap are not effective enough. Valves located at 210 mm achieve their goal.

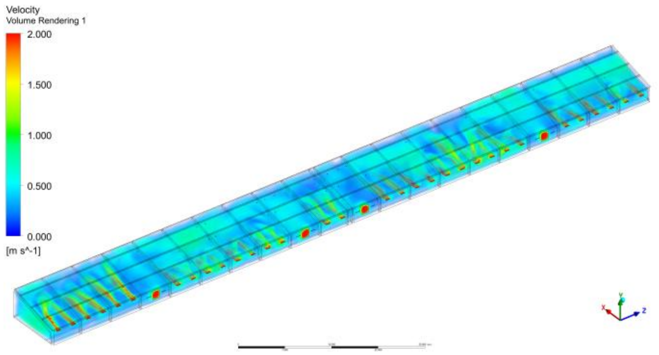

Figure 5*. Visualization of the volumetric air flow rate of the poultry house in the range from 0 to 2 $m{\cdot}s^{-1}$*

Detailed information of the averaged air environment parameters in the poultry house as a result of numerical modeling is presented in Table 2.

Table 2. Average indicators of the air environment in the poultry house

Parameter	Supply valves (inlet)	Exhaust fans (outlet)
Inlet air flow rate for half of the house, $kg{\cdot}s^{-1}$	21.5	21.5
Inlet air flow rate for half of the poultry house, $m^3{\cdot}h^{-1}$	77402	77402
Inlet air flow rate for a full poultry house, $m^3{\cdot}h^{-1}$	154804	154804
Air pressure, Pa	70.476332	–0.58615902
Air temperature, ℃	2.9241463	17.512945
Air velocity, $m{\cdot}s^{-1}$	11.5657	3.2801507
Air density, $kg{\cdot}m^{-3}$	1.2740213	1.2144894
Heat transfer coefficient of air, $W{\cdot}(m{\cdot}{}^{o}K)^{-1}$	0.02467469	0.025701037
Kinematic viscosity of air, $kg{\cdot}(m{\cdot}s)^{-1}$	$1.689621{\cdot}10^{-5}$	$1.750194{\cdot}10^{-5}$

From the CFD modeling results, it can be seen that due to lower velocities over the birds and more uniform temperatures, product quality will be higher compared to the traditional exhaust fan arrangement. However, the results presented have both positive and negative effects on the poultry as a whole. The authors have analyzed all the positive and negative aspects of the proposed ventilation system and will work on eliminating the disadvantages in the future.

4. Conclusion

CFD modeling of heat and mass transfer in the poultry house was carried out. To carry out CFD modeling, a grid was constructed by the method of volumetric elements of the air environment of the poultry house in 3D. CutCell method was used for mesh construction in ANSYS Meshing preprocessor. The maximum size of the mesh face is 0.16 m. The number of elements is about 4.6 million. The mesh Orthogonal Quality index is 0.263.

The results of numerical modeling showed that the most efficient valves are located at a height of 210 mm from the overlap. The air velocity at the inlet of the supply valves is 11.57 $m \cdot s^{-1}$. The average air velocity at a height of 0.7 m from the floor level is 0.46 $m \cdot s^{-1}$, temperature – 15.94 °C. Taking into account the choice of fan, the pressure drop at the supply valves is 70.48 Pa, which is fully provided by air pumping. The angle of inclination of the valve in relation to the wall is 73°. The opening of the valve is 49 mm. However, with the proposed location of exhaust fans on the side wall of the poultry house, the ventilation system works quite effectively.

The scientific results obtained in the work can be used in the development of new ventilation systems to maintain a normalized microclimate in poultry houses, which allows increasing the productivity of poultry farms.

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