USAGE OF CFD FOR RESEARCH ON LATERAL VENTILATION SYSTEM IN POULTRY HOUSE

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Abstract. Maintaining normalized microclimate in poultry farming is one of the basic factors. It is the quality indicators of the air parameters that ultimately determine the quality of the final product. Keeping poultry requires a lot of effort and technological solutions. In this regard the authors have made improvements of the microclimate system in the air environment of the poultry house by installing exhaust fans on the side wall, in a total of 8 pcs, and 2 pcs. on the end wall. A powerful tool for predicting the airflow patterns in the poultry house is modelling. An alternative to experimental studies is Computational Fluid Dynamics (CFD) with ANSYS Fluent. The CFD model was performed on the Navier-Stokes equations for convective flows. The calculations used the Spalart-Allmaras turbulence model and the Discrete Ordinates radiation model. CFD modeling was performed at an air flow rate of 21.5 kg·s^{-1}. The outside air temperature is assumed to be 2 ºC and the thermal radiation parameter is entered. In poultry houses, the poultry, when kept on the floor, is a source of heat and is + 41 ºC. Heating system is not provided. To remove air, exhaust fans of the Munters EM50 1.5Hp type are used. Fans are mounted on the side wall in the amount of 4 units. and 1 on the end wall. Supply valves Wlotpowietrza 3000-VFG with a total of 80 pcs. Above the valves there are built-in spoilers at an angle of inclination from the vertical 75º. The results of the CFD modelling showed that the valves, located at a height of 210 mm from the ceiling, work efficiently. The pressure drop at the supply valves is 73.565 Pa. The air speed at the inlet of the supply valves is 11.45 m·s^{-1}. The air speed at a height of 0.7 m from the floor level varies within 0.86 m·s^{-1}, the temperature is 14.12 ºC.

Keywords: CFD, system of ventilation, aerodynamics, poultry house, supply valves.

Introduction

Evaluation of the performance of the new ventilation systems may be a difficult task as it is both time-consuming and expensive. As an alternative to the field measurements, there is a possibility to run modelling by means of Computational Fluid Dynamics (CFD), which is a powerful instrument for predicting the airflow patterns, particle and gas concentrations, as well as the thermal environment in the animal houses. The Computational Fluid Dynamics (CFD) has been used to evaluate the efficiency of the existing ventilation systems and new structures [1; 2].

The aim of the authors of [3] was to work out the contemporary level of using CFDs in the indoor broiler environment and their current limitations. It starts from an assumption that the CFD models can provide knowledge about the speed, temperature, distribution of air, gases, and hard particles when the equipment is subject to natural ventilation, mechanical ventilation, and adiabatic evaporative cooling systems.

The authors of [4] analysed the impacts of height (0.4 m, 0.55 m, 0.7 m, 0.85 m and 1 m) and intervals (6 m, 9 m, 12 m, 15 m and 18 m) of deflectors upon the speed and distribution of air in the zones of cages. The research showed that the deflectors can significantly direct the airflow downwards. There was an increase in the speed of air in the cage and passage zones by 0.66 m·s^{-1} and 0.91 m·s^{-1}, respectively, without the use of deflectors; or when the deflectors were 1 m high and installed at 6 m intervals.

The authors in article [5] proposed a new cooling system in the poultry house, using heat exchangers of a special design [6; 7]. In these sources there was carried out CFD modelling of the air flows and the heat and mass exchange in the poultry house. As a coolant, here is used water from underground wells. Recommendations are given for choosing the design of the ventilation systems in poultry houses. In the continuation of these investigations the authors have optimized the height of the exhaust fans. It is shown that it is expedient to install the ventilation equipment at a height of 1.5 m. This reduces the size of the stagnant zones and the uneven distribution of speed near the birds.

A description of the loads of various asynchronous motors of the fans and a combined switching circuit is presented in [8; 9].

The authors [10; 11] have conducted an investigation about the modular keeping of poultry. A design of a module has been worked out. The proposed design is energy efficient and recommended for installation in poultry houses. The microclimate in the module has been analysed. The air temperature near the bird in the module is 18.6 ºC, and the average speed does not exceed 0.75 m·s^{-1}.

This publication is a continuation of scientific and practical research to improve the aerodynamic characteristics of the air in the poultry house [12; 13]. Thus, the purpose of the article is to improve the microclimate system in the poultry house air environment by installing exhaust fans on the side wall in a total of 8 pcs., and 2 pcs. on the end wall.

Materials and methods

According to the purpose of the work, we modify the location of the exhaust fans. The essence is as follows. In the traditional design of the poultry house the exhaust fans are mounted on the rear end wall of the house, but in our case - on the side (Fig. 1), 4 pcs. for each wall, a total of 8 pcs., and 2 on the end wall. The number of poultry is 57971, age 18 months, weight 707 g.

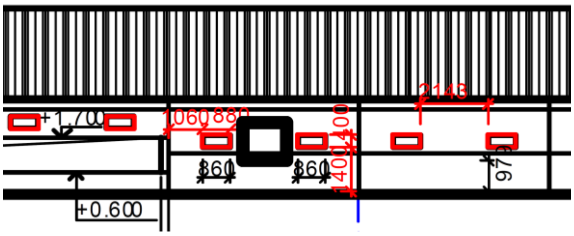


Fig. 1. **Location of the first exhaust fan on the side wall**

Fig. 2 shows the 3D geometry of a poultry house for the CFD modelling. Made on a 100% scale, but only half of the house. The limit condition "symmetry" is set in the centre of the poultry house. The other limit conditions are shown in Fig. 2a. These measures were taken due to insufficient rated power of the computer equipment.

Fig. 2b depicts the constructed grid of the poultry house from the side in the air environment. In the openings of the exhaust fans and the supply valves the mesh is reduced relative to the rest of the wall area. And also near the floor where the poultry are. The mesh is refined for more accurate calculation of hydrodynamics and heat-and-mass transfer by a numerical method.

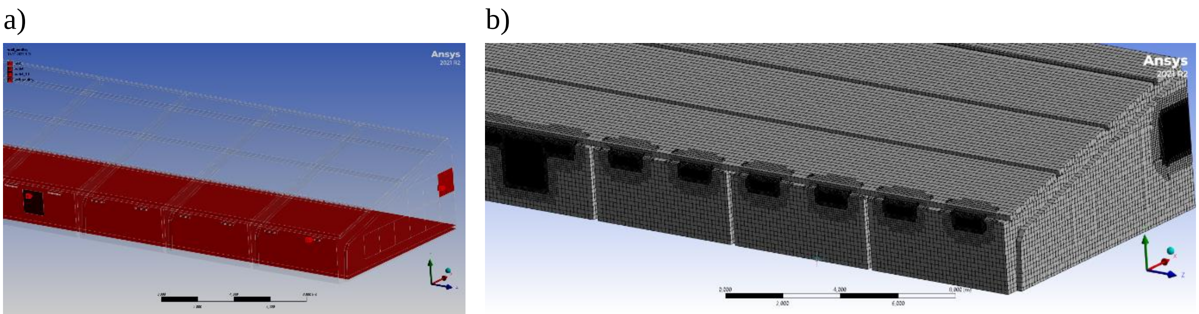


Fig. 2. **3D geometry of the poultry house:** a – with indication of limit conditions; b – mesh with a concrete frame

Using the ANSYS Meshing software, a 3D computational mesh was constructed, using the method of volumetric elements. The CutCell mesh construction method was applied. The quantity of elements reaches 4.3 million. The orthogonal quality index of the mesh is 0.22. The minimum size of the element of the exhaust fan on the side wall of the poultry house is 0.01 m. It is smaller than the size of the inlet valve element by 0.03. This decision was made due to the fact that we are more interested in the behaviour of air in the exhaust fans. We have already studied in publications [12; 13] how air behaves in the supply valves.

CFD modelling was performed at an air flow rate of 21.5 kg·s^{-1}. The outdoor air temperature is assumed to be + 2 ºC, and the thermal radiation parameter is entered. The walls are made of concrete with insulated foam plastic, 35 kg·m^{-3} thick, respectively: 60×100×60 mm. The thermally insulated roof "Izovat" is $Y = 30$ kg·m^{-3}, 100 mm. The floor is thermally insulated with expanded polystyrene 45 kg·m^{-3}, 100 mm thick, 2 m from the wall along the perimeter, the rest of the area is 50 mm. In the poultry houses the poultry, when kept on the floor, is a source of heat, and it is + 41 ºC. The heating system is not intended. To remove air, the exhaust fans of the Munters EM50 1.5Hp type are used. The fans are mounted on the side wall in the amount of 4 units, and 1 on the end wall. The supply valves Wlotpowietrza 3000-VFG with a total of 80 ps. Above the valves there are built-in spoilers at an angle 75º of inclination from the vertical.

In previous investigations [13] the supply valves, ranging from 11 to 40, were located at a height of 0.81 m from the overlap, and the first 10 at a height of 0.21 m. Taking into account the previous recommendations, all the valves are raised to a height of 0.21 m from the ceiling. There was noted also inefficiency of operation of the first supply valves on the right and left sides, which are located at the exhaust fans. The authors decided to close them and exclude the air supply.

The CFD model was executed on the Navier-Stokes equations for convective flows. For calculations there was used the Spalart-Allmaras turbulence model and the Discrete Ordinates radiation model.

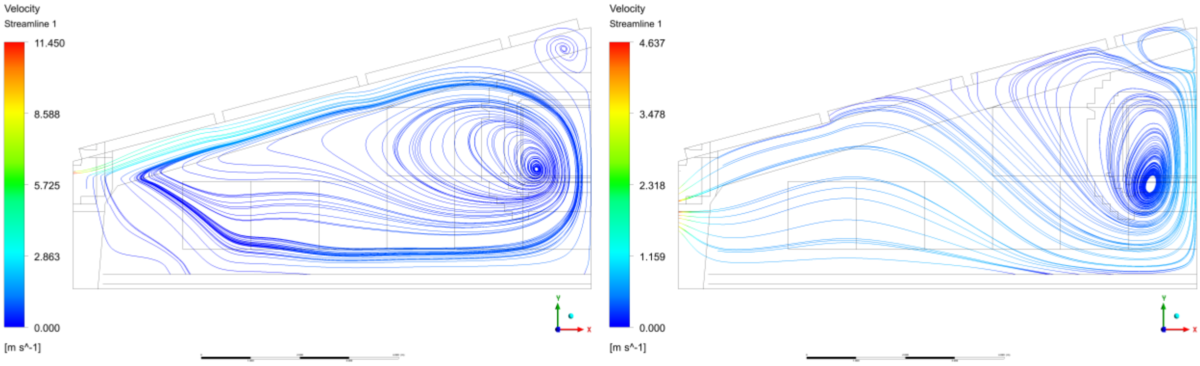
Results and discussion

This section presents the results of the 3D numerical modelling of a poultry house, using ANSYS Fluent. In Fig. 3-4 are shown the results of numerical modelling of a 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 section is the 2nd exhaust fan (between the 17th and 18th supply valves). The third section is in the middle of the 29th supply valve. There are 40 supply valves along the length of the house, on one side.

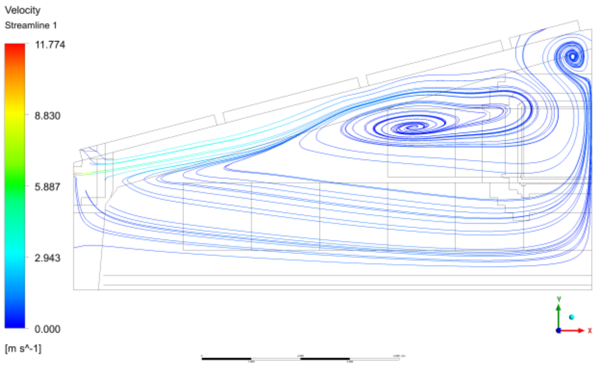
Fig. 3 shows the hydrodynamics of the air flow in the poultry house. As mentioned above, the air flow is directed upwards by tidal valves. Due to sufficient pressures and speeds at the inlet, the air is directed to the centre of the room and it falls down. Air is partly retained by concrete projection in the ceiling. The average speed of air at the inlet at the supply valves is 11.45 m·s^{-1}. At certain points of the poultry house the maximum speed can reach 11.975 m·s^{-1}. In the very centre along the length of the poultry house there arise two vortices at 16.23 m (Fig. 3a). Due to the disturbance at the exhaust fans, along the length of the poultry house of 50.78 m near the ceiling (Fig. 3b), stagnant zones occur. Whirlwind appears in the centre of the house. This is because of the low speeds at the outlet of the fan. In the area of the exhaust fans the average speed ranges from 2.985 to 2.837 m·s^{-1} (Fig. 3b). At a distance of 85.25 m from the front end wall of the house (Fig. 3c) several vortexes form. The air that is pumped through the supply valves, almost reaches the centre of the room. This may be caused by disturbance that occurs due to large volumes of the room. This is also due to the low speed of air, low pressures on these inlet valves and projections in the concrete ceiling.

Results were also obtained of the speeds and temperatures around the plane of the room at a height of 0.7 m from the floor level. These results are most interesting because they will help evaluate the hydrodynamics and heat transfer of air over the birds. The average speed of air is 0.86 m·s^{-1}, and the temperature is 14.12 ºC. In this section, the air speed does not exceed 2 m·s^{-1}. Therefore, the basic mass of the poultry will not experience discomfort. Having analysed the temperature field, we can conclude that the poultry in the transitional period of the year (+2 ºC) are able to heat themselves without additional heating equipment.

In Fig. 4 there is a 3D representation of the poultry house and visualization of the air volume flow in the range from 0 to 2 m·s^{-1}. The results shown indicate that all the valves are located 210 mm from the ceiling and work efficiently. The first valves to the left and right of the exhaust fans are closed and do not work. This gave an opportunity to reduce the air flow disturbance near the exhaust fans and in certain areas of the poultry house. The negative impact of such air disturbance is presented in [13]. One exhaust fan is located on the end wall of the poultry house along the upper line. The authors expected this fan to help create a tunnel effect in the rear part of the poultry house. However, this assumption did not live up to the expectations. We also observe disturbance and excessive turbulence near the end wall, which negatively affects the uniformity of the air flow in the poultry house. In the future the authors do not recommend using the exhaust fans on the end wall, on condition that the fans on the side wall are turned on.



a b



c

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

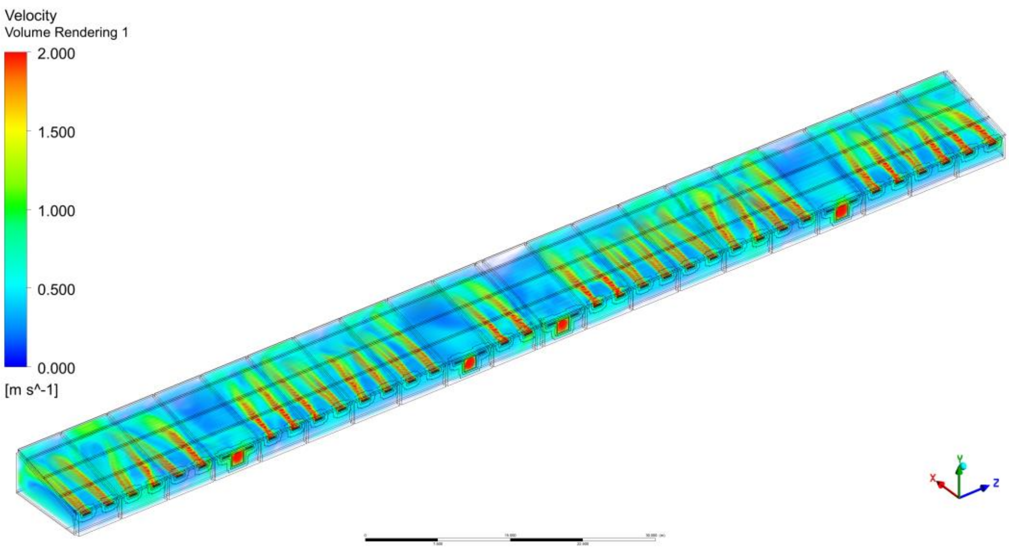


Fig. 4. **Visualization of the volumetric air flow of the poultry house in the range from 0 to 2 m·s^{-1}**

Detailed information about the averaged indicators of the air environment in the poultry house as a result of the numerical modelling is presented in the table.

Table 1

Average(d) indicators of the air environment in the poultry house

Parameters	Dimension	Supply valves	Fans on the side wall	Fan on the end wall
Inlet air consumption for half of the poultry house	$kg \cdot s^{-1}$	21.5	21.5	
Inlet air consumption for half of the poultry house	$m^3 \cdot h^{-1}$	60472	60472	
Inlet air consumption for half of the poultry house	$m^3 \cdot h^{-1}$	120944	120944	
Air pressure	Pa	73.57	–0.27	-0.68
Air temperature	ºC	2.65	22.44	16.08
Air speed	$m \cdot s^{-1}$	11.45	2.98	2.84

With practical experience poultry rearing in traditional poultry houses is divided into 16 uniform zones according to the initial product and the meat quality. Along the perimeter of the zone near the side walls of the poultry house, the quality of the meat is much worse. In the centre of the house, the quality of the product is much better. From the obtained results of the CFD modelling it is evident that due to lower speeds of air over the birds, and more uniform temperatures, the product quality will be higher, compared to the traditional arrangement of exhaust fans. However, the presented results have both positive and negative effects upon the birds, on the whole. The authors have evaluated the pros and cons of the proposed ventilation system and will continue to work on eliminating the shortcomings.

Conclusions

1. The CFD modelling of the heat and mass transfer in the poultry house was carried out. To perform the CFD modelling, a mesh was built, using the volumetric elements of the air environment of the poultry house in 3D. To construct the mesh in the ANSYS Meshing preprocessor, the CutCell method is applied.
2. The results of numerical modelling showed that the valves, located at a height of 210 mm from the ceiling, work efficiently. The pressure drop at the supply valves is 73.57 Pa. The air speed at the inlet of the supply valves is 11.45 $m \cdot s^{-1}$. The inclination angle of the valve relative to the wall is 75°. Valve opening at 49 mm.
3. However, with the proposed location of the exhaust fan on the rear wall of the poultry house, the ventilation system does not work efficiently enough. In the future, the authors do not recommend using the exhaust fans on the rear wall, provided that the fans on the side wall are turned on.

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Author contributions

Conceptualization, V.T.; methodology, V.T., S.I., Y.N. and A.A.; software, V.T.; visualization, V.T., A.A. O.C.; formal analysis, V.T., S.I. Y.I. and Y.N. O.S. All authors have read and agreed to the published version of the manuscript.

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