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Study of the Influence of the Arrangement of Exhaust Fans Along the Lower Line on the Aerodynamics of the Poultry House

Abstract. Coverage and outbreaks of diseases lead to considerable losses in large-scale poultry farming. New ventilation systems are essential to ensure a safe and uniform indoor environment in large enterprises, especially in the changing climate of global warming. Thus, it is necessary to improve the design of the poultry house, to search for the most effective way of arranging the supply air valves and to improve the aerodynamic parameters of the internal environment of the poultry house in the most effective way of arranging the supply air valves and improving the aerodynamic parameters of the internal environment of the poultry house. Within the framework of this study, computational hydrodynamics modelling of the lateral ventilation system in the poultry house during the winter period of the year was performed. As a result, the temperature of the 3D field, the current lines, and the pressure in the aviary were detected. Supply air valves located 200 mm above the floor were found to perform better than those conventionally installed at 400 mm. Building walls on the inside of the poultry house frame, as well as reducing the height of the floor, improve the aerodynamics of the poultry house. The practical value of the presented study is targeted at poultry farmers with large productive capacities

Keywords: CFD, aerodynamics, aviary, lateral ventilation system, inlet valves

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INTRODUCTION

The thermal regime of poultry houses is one of the prognostic factors that determine the productivity of the poultry industry. Poultry breeding must follow zootechnical standards [1]. The thermal regime of the poultry house is established as a result of heat exchange processes occurring both indoors and through its outer walls. It is formed under the influence of heating and ventilation systems, depending on the meteorological parameters of the outside air and the structural characteristics of the poultry house. Thus, the normalised microclimate system has a directly proportional effect on poultry farming, and the final product is the yield of meat.

Figure 1 shows the conventional design of the poultry house. The external walls are made of a concrete frame, the ceiling is not lowered. Thus, the purpose of this study was to improve the design of the poultry house, find the most effective way of arranging the supply air valves, and improve the aerodynamic parameters of the poultry house environment using computational fluid dynamics (CFD).

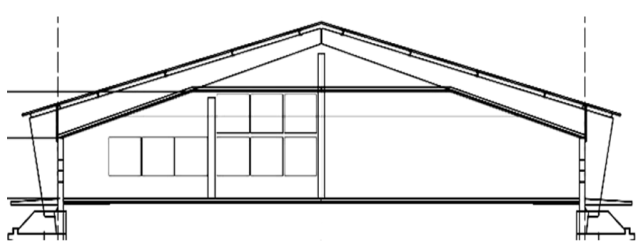

Figure 1. A fragment of the conventional design of the poultry house with inlet valves of the lateral ventilation system

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Thus, the development of improved structural solutions of the lateral ventilation system is an urgent issue that needs to be solved.

LITERATURE REVIEW

The publication [2] analysed the influence 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 on the speed and distribution of air in the cage zones. The study shows that the deflectors can considerably direct the downward airflow, increase the air velocity in the cage and passage area by 0.66 m/s and 0.91 m/s, respectively, compared to no deflectors, if the deflectors are 1 m high at 6 m intervals.

Authors of publications [1; 3; 4] proposed to apply a new cooling system in the poultry house using heat exchangers [5] of a distinctive design [6-8]. CFD modelling of air flows and heat and mass transfer in a poultry house is presented. Here, water from underground wells is used as a coolant. Recommendations for choosing the design of ventilation systems in poultry houses are given. In their further studies [9], the authors optimise the height of the exhaust fan. It is shown that it is advisable to install ventilation equipment at a height of 1.5 m. Here, the area of dead air zones and the uneven distribution of air velocities close to the poultry decrease.

To reduce energy consumption and increase the quality of the air environment while providing the necessary conditions for keeping poultry [10], the authors conducted experimental studies and numerical simulations. During the studies, a reduction in energy consumption was achieved to ensure a microclimate during broiler breeding. The quality of the air environment of poultry farms was improved. It allowed reducing feed costs and poultry losses and, as a result, increasing the economic efficiency of production and the quality of finished products.

The authors of the study [11; 12] consider the methods of the lateral mechanical ventilation system to be more effective compared to other methods. In their article, CFD simulations show a wide range of airflow velocity values. Two main conclusions were made based on the air velocity in the room: 1 – excessive heterogeneity in the area where the animals stay; 2 – air movement is insufficient for thermoregulation of poultry.

CFD solutions for various flow configurations and poultry house shapes are presented in [13]. The effects of transverse and longitudinal ventilation are combined with changes in the directions of incoming air flows, as well as with a different cross-sectional shape obtained using valves. This paper considers the construction of the poultry house in such a way that the walls are located on the outside of the concrete frame. This design worsens the aerodynamics in the middle of the poultry house. There are a lot of stagnant air zones. Due to the high overlap, heat in winter is concentrated above the poultry. This accompanies an increase in energy costs for heating the room.

MATERIALS AND METHODS

According to the terms of reference, an engineering calculation of air exchange in the winter period of the year was performed. To remove carbon dioxide, moisture vapour, and harmful substances, it was necessary to ensure an airflow of about 155 thousand m^3/h at an external temperature of -10°C.

The geometry of the poultry house was built in true size. To reduce the calculation time inside the building, symmetry was applied. That is, modelling was carried out only for half of the poultry house building. The calculation was carried out at an airflow rate of 30 kg/s. The temperature of the outside air was taken as -10°C and the heat release parameters were entered. The walls were concrete and insulated with 35 kg/m^3 foam, 60/150/60 mm thick, respectively. The building was covered with polyurethane with a thickness of 100 mm, 45 kg/m^3. The floor was insulated with polystyrene foam with a thickness of 45 kg/m^3, 100 mm thick on a width of 2 m from the wall along the perimeter of the poultry house, 50 mm on the rest of the area. The length of the poultry house was 120 m, the width was 22.36 m (Fig. 2). The average number of poultry was 41,000, the weight of the poultry was 3.3 kg. The poultry was a source of heat and corresponded to +41°C. Wlotpowietrza 857x337 mm 3000-VFG and Przepustowocs 2900 v^3/h ventilation valves were applied. They were placed on the side walls, a total of 79 pcs. (Fig. 5a). The first ten ventilation valves were installed at a height of 0.2 m from the floor (Fig. 3b, Fig. 5a). The rest of the valves were located at a height of 0.4 m from the floor (Figs. 3a, 4(H5), 5a). One of the design concepts was to install a spoiler at an angle of inclination of 75° from the vertical line above the supply air valves (Fig. 4 (A20)). The length of the spoiler was 0.08 m (L9). Munters EM50 1.5 Hp exhaust fans were used, 18 pcs in total. During winter, 6 pieces were specially prepared (Fig. 5b). As a rule, they are located in the upper row, shifted closer to the centre. Such fans can withstand a maximum long-term load of up to 56 Pa.

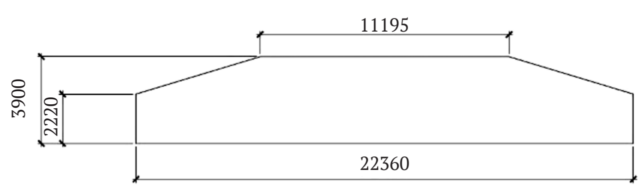
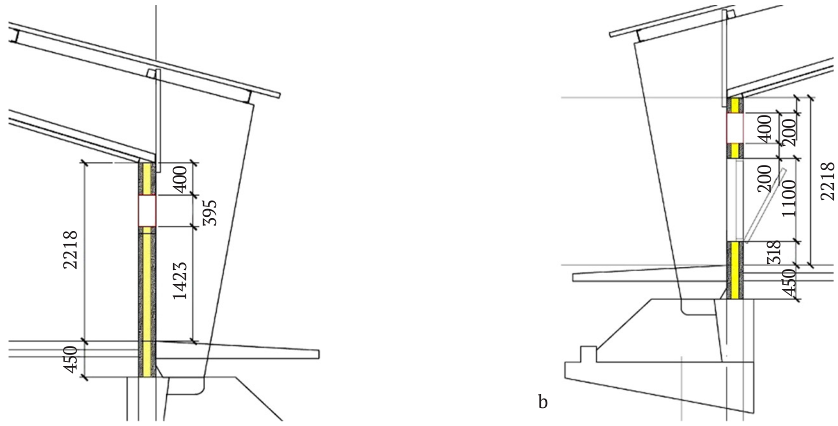


Figure 2. The proposed cross-sectional scheme of the structural dimensions of the poultry house



a b

Figure 3. The proposed cross-sectional scheme of the structural dimensions of the poultry house: a – small valves, b – tunnel ventilation valves

Figure 4 schematically presents the angle of the valve from the side. The ventilation scheme was built in such a way that the airflow in winter reached the centre of the building to normalise the aerodynamic parameters of the poultry house. This method allowed reducing the loss of fresh air pressure in the poultry house. Thus, the following structural changes were made: the width of the building was increased from 21 m to 22.36 m. Figure 4 shows the maximum valve opening of 0.1 m (H16). Numerical simulations were performed at valve openings of 0.1 m, 0.066 m, and 0.049 m, respectively.

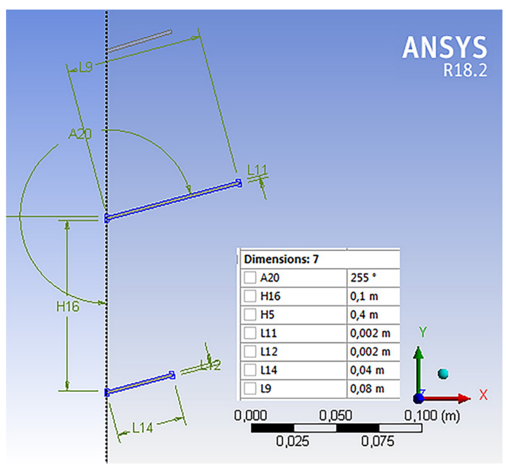


Figure 4. Angles of inclination of intake valves and spoiler

(a)

(b)

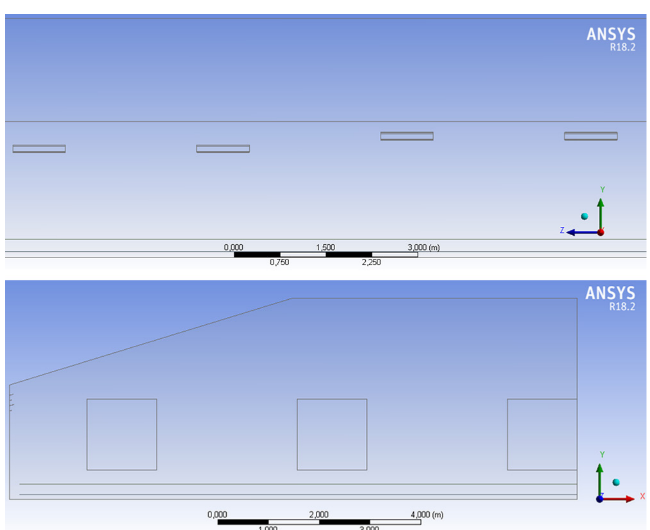


Figure 5. Side (a) and rear (b) walls of the poultry house

The number of elements and faces was quite numerous (Table 1). Given the large dimensions of the building, the size of the element and face was not significantly increased due to limitations of computer performance and design power.

Table 1. Parameters of building a mesh for a poultry house

Configuration options	Indicator
Orthogonal quality indicator	0.24
Number of elements, pcs	3813129
Number of nodes, pcs	4005901
Method	CutCell
Maximum face size, m	0.11
Minimum face size, m	0.0275
Minimum size of the supply valve element, m	0.0276
Minimum element size of exhaust fans, m	0.05

Figure 6 presents the frontal and side views of the formed poultry house mesh, fresh air openings, and entrance gate. The mesh was slightly reduced relative to the rest of the wall area (Table 1). Such measures were applied to obtain a better hydrodynamic calculation. Furthermore, the net was compacted close to the floor, as the poultry was placed there. Using the finite element method, a 3D computational mesh was built in the ANSYS Meshing software complex, aimed at solving the problems of hydrodynamics and heat exchange in the poultry house [2; 4].

(a)

(b)

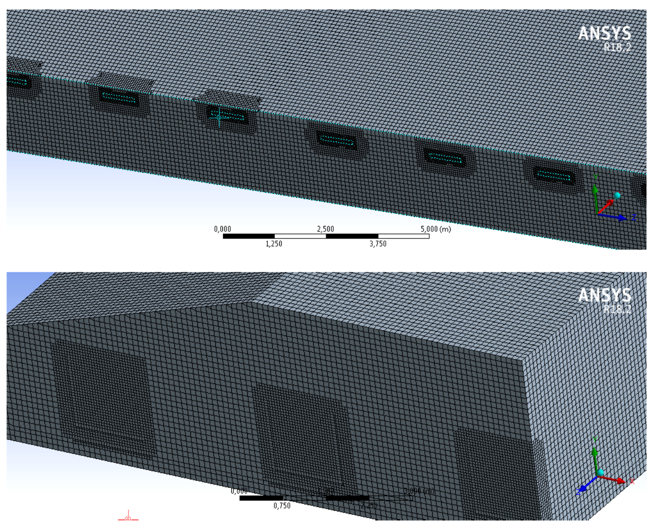


Figure 6. Side view (a) and rear view (b) of the walls of the poultry house

The construction of various meshes for CFD models allowed choosing the optimal and high-quality ones, which allowed obtaining reliable and accurate results of calculating the ventilation of the poultry house. The simulation was carried out without the use of an added heating system.

The flow of a viscous liquid or gas (air) was described by a system of equations that included continuity equations and momentum equations in projections onto the coordinate axis. If the flow of the medium was followed by heat transfer, then the energy conservation equation (heat transfer equation) was added to the aforementioned system of equations.

The mathematical model was based on Navier-Stokes equations [14; 15] and energy transfer equations for convective currents [15-17]. The Spalart-Allmaras turbulence model was used in the calculations [18; 19] and the discrete ordinate radiation model [20; 21].

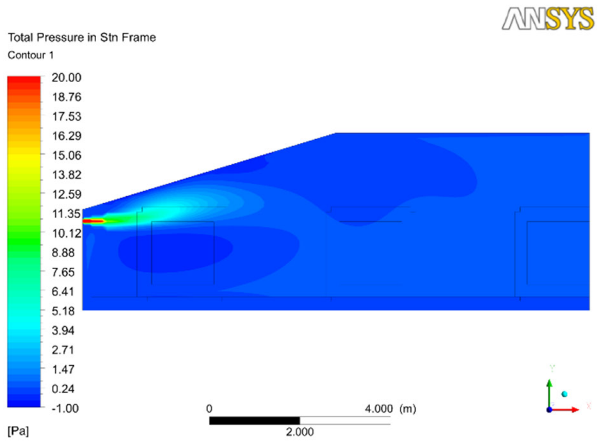
RESULTS AND DISCUSSION

The results of CFD 3D simulation of the poultry house allowed comparing three modifications of the opening of the valves in the case of the lateral ventilation system of the poultry house. Before numerical modelling, a three-dimensional mesh was created using the finite element method [2; 4] in ANSYS Meshing.

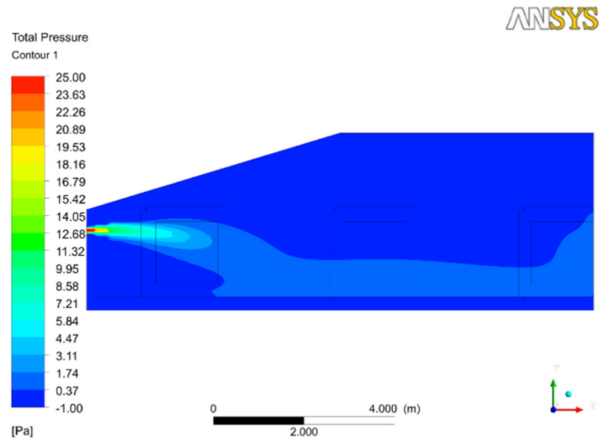
Figures 7-15 show the results of CFD modelling of the poultry house on two sections along the length of the building – 10.3 m and 52.3 m with different valve openings from 0.1 m to 0.049 m.

Figures 7-9 present values of pressure loss in fresh air valves. It is shown that the smallest pressure loss is 24.3 Pa when the valve is opened 0.1 m, and the largest is 55.68 Pa at 0.049 m, respectively.

Figures 10-15 show the hydrodynamics of the airflow in the poultry house.

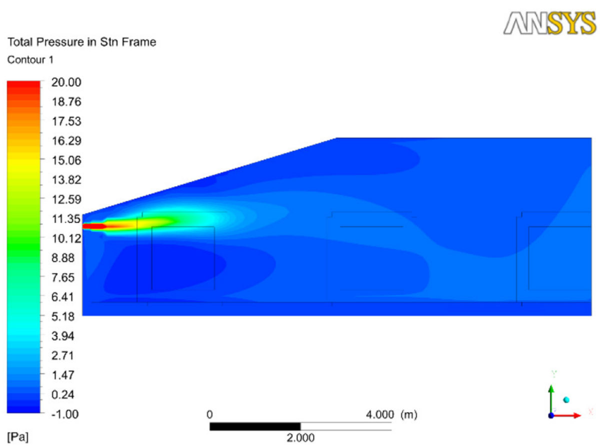


(a)

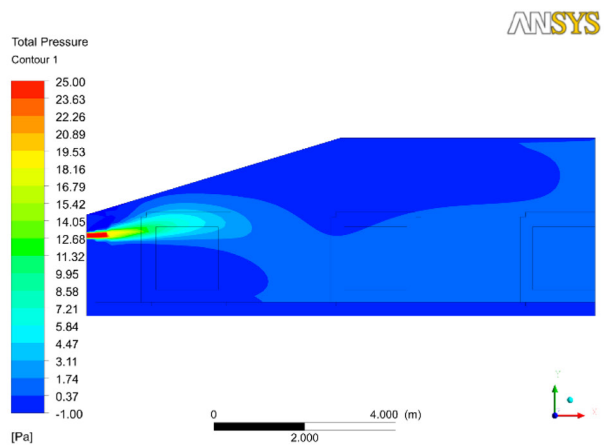


(b)

Figure 7. Pressure loss (Pa) in the fresh air valve of the poultry house when the valve is opened 0.1 m at a distance from the front-end wall: a – 10.3 m; b – 52.3 m

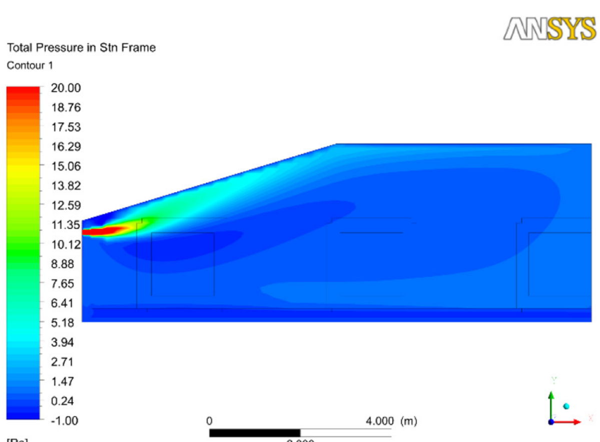


(a)

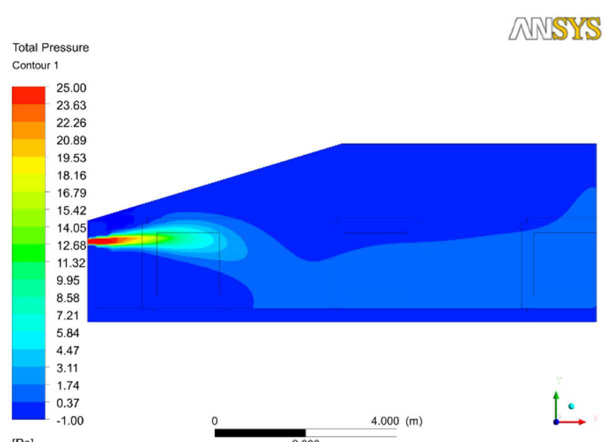


(b)

Figure 8. Pressure loss (Pa) in the fresh air valve of the poultry house when the valve is opened is 0.066 m at a distance from the front-end wall: a – 10.3 m; b – 52.3 m

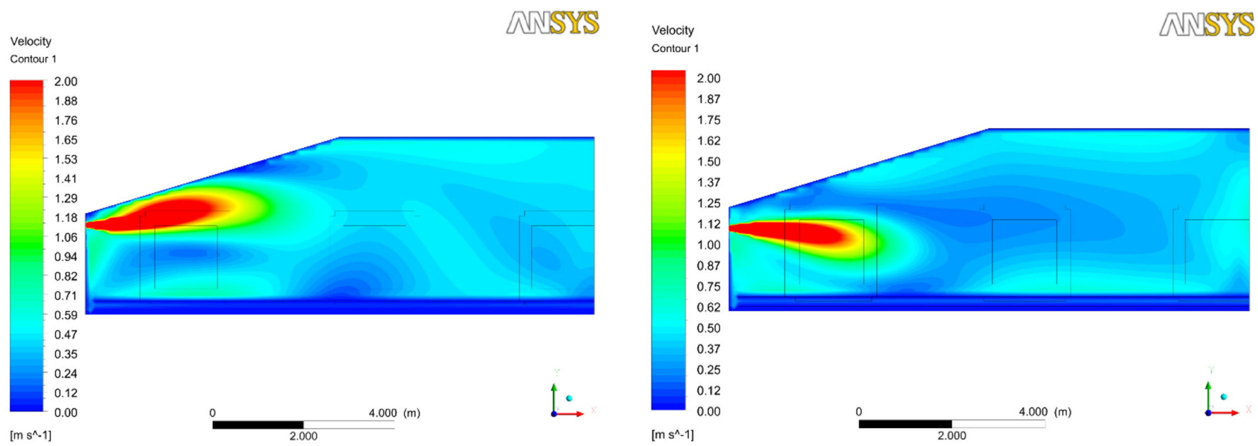


(a)



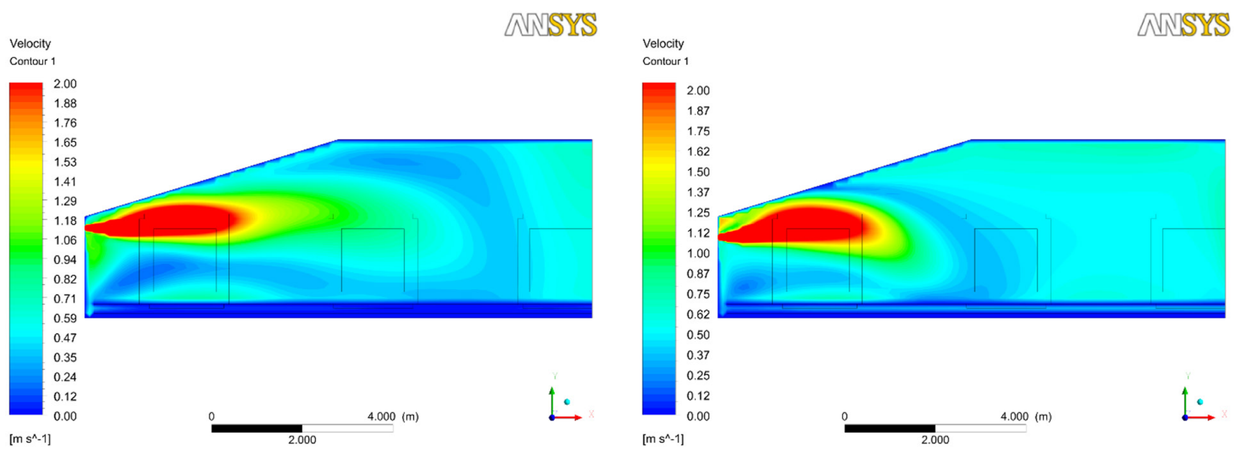
(b)

Figure 9. Pressure loss (Pa) in the fresh air valve of the poultry house when the valve is opened is 0.049 m at a distance from the front-end wall: a – 10.3 m; b – 52.3 m



(a) (b)

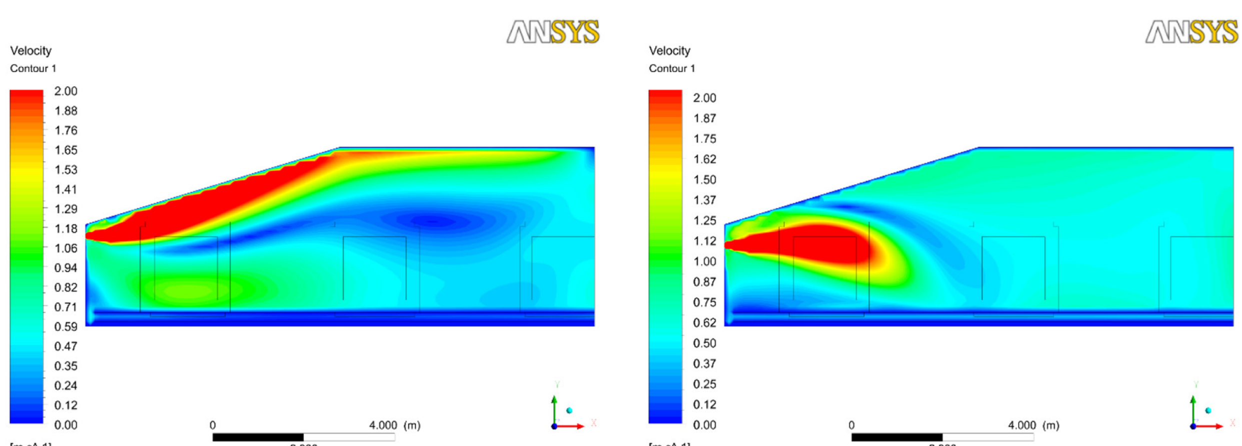
Figure 10. Velocity field (m/s) in the poultry house when the valve is opened 0.1 m at a distance from the front-end wall: a – 10.3 m, b – 52.3 m



(a) (b)

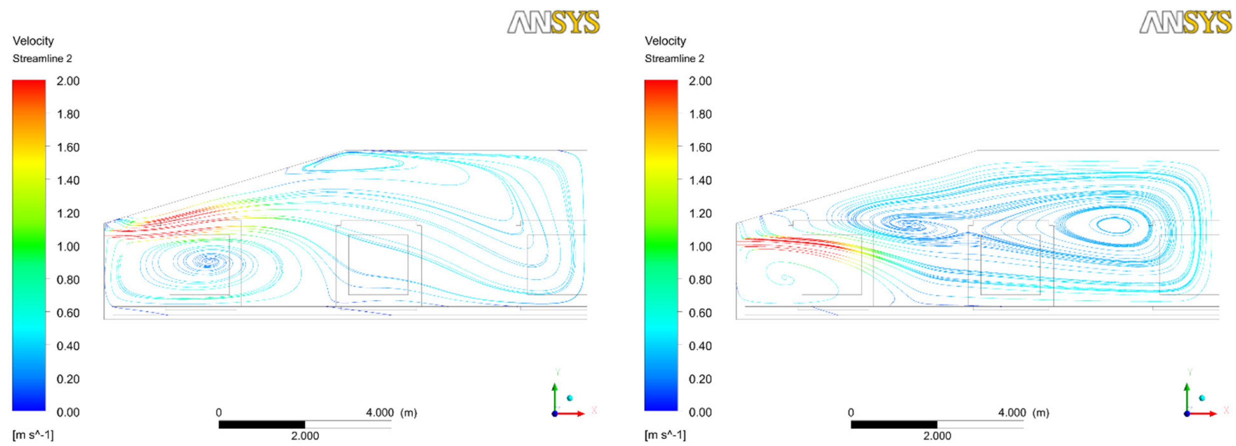
Figure 11. Velocity field (m/s) in the poultry house when the valve is opened 0.066 m at a distance from the front-end wall: a – 10.3 m; b – 52.3 m

As already mentioned, the airflow is directed upwards by fresh air valves. However, due to low pressures and velocities at the entrance, passing a third of the building, the air falls. The valves are located at a height of 200 mm from the floor (Fig. 12a, Fig. 15a). The air moves smoothly close to the floor area and is directed to the centre of the building. Valves found at a height of 400 mm from the floor cannot provide the same effect. This can be caused by disturbance due to the large airspace of the building. The average entry speed for diverse types of air ranges from 6.39 m/s to 9.62 m/s.



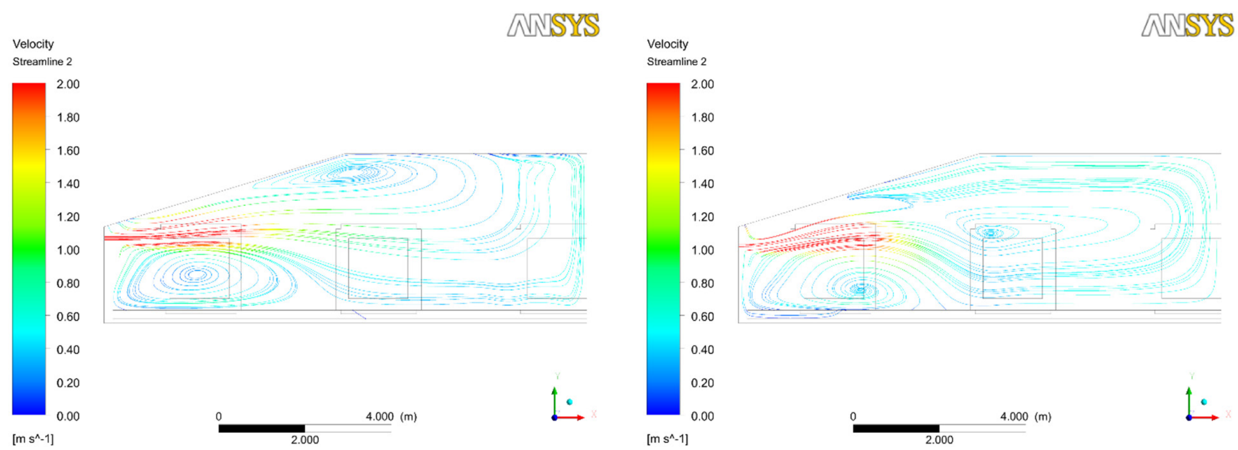
(a) (b)

Figure 12. The field of velocities (m/s) in the poultry house when the valve is opened is 0.049 m at a distance from the front-end wall: a – 10.3 m; b – 52.3 m



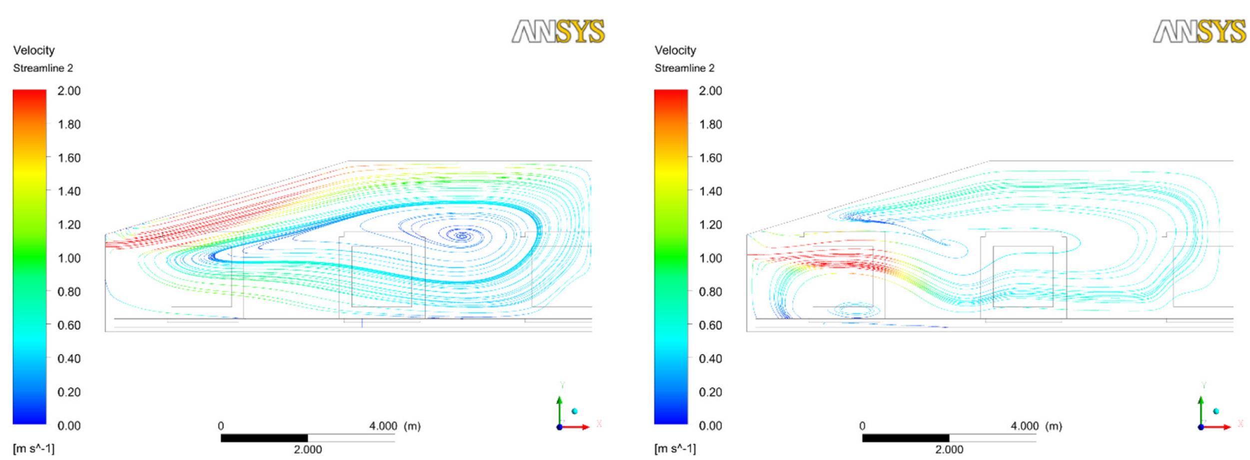
(a) (b)

Figure 13. Stream lines (m/s) in the poultry house when the valve is opened 0.1 m at a distance from the front-end wall: a – 10.3 m; b – 52.3 m



(a) (b)

Figure 14. Stream lines (m/s) in the poultry house when the valve is opened 0.066 m at a distance from the front-end wall: a – 10.3 m; b – 52.3 m



(a) (b)

Figure 15. Stream lines (m/s) in the poultry house when the valve is opened 0.049 m at a distance from the front-end wall: a – 10.3 m; b – 52.3 m

Figure 16 shows the velocity field in the poultry house at a height of 0.7 m from the floor level. These results can help estimate the airspeed over the poultry. The average speed of air movement ranges from 0.54 m/s to 0.66 m/s. Only near the exhaust fans, the speed is slightly higher at 2 m/s. The bulk of the poultry does not feel discomfort. In [9], the authors optimised the height of the exhaust fan. The set height is 1.5 m. However, these studies show that installing exhaust fans at a height of 0.8 m is more effective (Fig. 16).

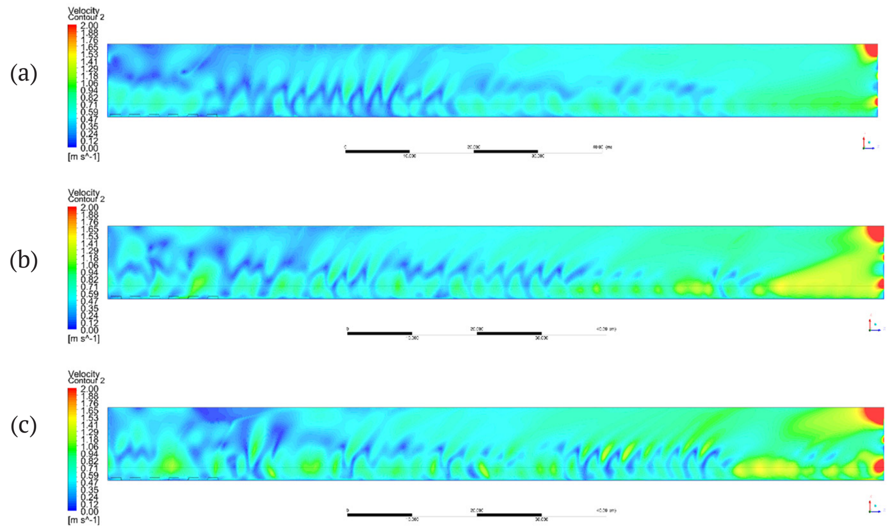


Figure 16. Field of velocities (m/s) in the poultry house at a height of 0.7 m from the floor level when the valve is opened: a – 0.1 m; b – 0.066 m; c – 0.049 m

Figure 17 presents 3D streamlines in the poultry house. The results show that valves that are located at a height of 400 mm are not effective. The middle exhaust fan is practically not used. A large load falls on the side fan, which is arranged close to the wall. The main load is taken by the fan, which is in the centre of the building.

Table 2 presents more detailed information about the CFD simulation results.

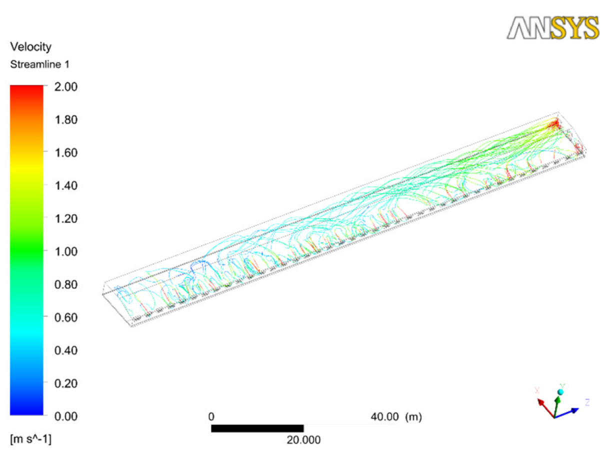


Figure 17. 3D stream lines (m/s) in the poultry house when the valve is opened 0.049 m

Table 2. Average indicators of air in the poultry house

Parameter	Dimensions	Result		
Valve opening distance	m	0.1	0.066	0.049
Consumption of incoming air for half of the poultry house	kg/s	30	30	30
Valve inlet pressure	Pa	24.332	43.41	55.684
Outlet fan pressure	Pa	-1.23	-2.215	-3.132
Air temperature at the valve Inlet	K	263.947	263.927	263.975
Fan outlet air temperature	K	273.778	273.91	273.148
Valve inlet air velocity	m/s	6.388911	8.518548	9.625959
Fan outlet air velocity	m/s	5.904209	7.946565	9.010783
Air velocity at a height of 0.7 m from the floor level	m/s	0.54181	0.63328	0.657591
Air density at the valve Inlet	kg/m^3	1.337423	1.337529	1.337287
Air density at the fan outlet	kg/m^3	1.289433	1.288785	1.292457

In winter, the density of fresh air is higher than in summer. Thus, with a lateral ventilation system, it is difficult to supply air to the centre of the poultry house. The main volume of air is directed to the centre of the room and mixed. Thus, according to studies [11; 12] it is confirmed that the lateral ventilation system is more effective compared to others. As a result of higher quality indicators of the microclimate in the poultry house, the consumption of feed, the loss of the poultry population decreases and, as a result, the economic efficiency of production increases, which is confirmed by the authors [10; 22].

At the next stage of designing the side ventilation system, the authors suggest considering that the supply air valves should be located at a height of at least 200 mm from the ceiling level.

CONCLUSIONS

Based on the conducted research, the project of the poultry house was improved. Spoilers are suggested to be placed above the supply air valves at an angle of 75° from the vertical line; installation of external walls on the inner side of the concrete frame; increasing the width of the poultry house to 22.36 m; lowering the floor height to 3.9 m above the floor level.

Thanks to CFD, the effective arrangement of supply air valves and the improvement of aerodynamic characteristics in the construction of the poultry house were investigated. It was found that the smallest pressure loss is 24.3 Pa when opening the valve 0.1 m, and the largest losses are 55.68 Pa at 0.049 m, respectively.

Conducted studies show that valves located at a height of 200 mm from the floor are much more efficient. Valves that are located at a height of 400 mm from the floor cannot provide the same effect.

The prospect of further research is the inclusion in the model of the cooling and heating system, depending on the season. Thus, the improvement of the microclimate system of the poultry house as a whole. Furthermore, for more efficient air supply, the length of the spoiler will be increased, the overlap model will be more detailed, and other measures will be taken to improve the microclimate in the air environment of the poultry house.

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Дослідження впливу розташування витяжних вентиляторів по нижній лінії на аеродинаміку пташника

Анотація. Охоплення та спалах захворювань призводять до значних втрат у великомасштабному птахівництві. Нові вентиляційні системи необхідні для забезпечення безпечного та однорідного внутрішнього середовища на великих підприємствах, особливо в мінливих кліматичних умовах глобального потепління. Таким чином, необхідно вдосконалити конструкцію пташника, провести пошук найбільш ефективного способу влаштування клапанів припливного повітря та покращити аеродинамічні показники внутрішнього середовища пташника у найбільш ефективного способу влаштування клапанів припливного повітря та покращення аеродинамічних показників внутрішнього середовища пташника. У рамках цього дослідження було проведено моделювання обчислювальної гідродинаміки бічної системи вентиляції в пташнику в зимовий період року. В результаті температура 3D поля, були виявлені поточні лінії та тиск у пташнику. Встановлено, що клапани припливного повітря, розташовані на висоті 200 мм від підлоги, працюють краще, ніж ті, які традиційно встановлюються на висоті 400 мм. Зведення стін з внутрішньої сторони каркаса пташника, а також зменшення висоти підлоги покращують аеродинаміку пташника. Практична цінність представлених досліджень направлена для пташників з великими продуктивними потужностями

Ключові слова: CFD, аеродинаміка, пташник, бокова система вентиляції, припливні клапана