RESEARCH ON GAS DYNAMIC FLOWS IN POULTRY HOUSE LATERAL VENTILATION SYSTEM USING CFD MODELLING

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Abstract. Maintaining a good microclimate in the poultry house is one of the most important factors in poultry breeding. It is the quality of the air parameters that ultimately determines the quality of the yield. Poultry keeping requires a lot of effort and technological solutions. Therefore, the study is aimed to improve the microclimate system in the air environment of the poultry house by incorporating exhaust fans on the rear end wall in a non-traditional way. Computational Fluid Dynamics (CFD) with ANSYS Fluent is a powerful tool for predicting the climate system in the poultry house, as an alternative to experimental studies. CFD modelling of the gas-dynamics and heat-mass exchange processes has led to the conclusion that raising the valves to a height of 210 mm from the slab, and changing the spoiler cut-out by 73 ºallows air to be conveyed to the centre of the poultry house. At the same time, the pressure drop of the supply valves is 47.18 Pa, which makes it possible to fully supply the exhaust fan. The air velocity at the inlet of the supply valves is 9.16 $m \cdot s^{-1}$. The average air speed at 0.7 m above the floor level is 0.71 $m \cdot s^{-1}$, and the temperature is 14.83 ºC. Thus, the research presented can be used to develop new ventilation systems for poultry houses in the future.

Keywords: poultry house, side ventilation system, aerodynamics, air inlet valve, CFD modelling.

Statement of the problem

The development of new technologies in the energy sector, the transition to a new level of energy supply of facilities, including ventilation systems of poultry farms, are characterised by an accelerated growth rate of all quantitative and qualitative output indicators, as well as improvements in the whole structure in poultry farming.

Increasing the productivity of poultry farms is linked to the need to create a standardised microclimate in the poultry houses. An important task here is to find new approaches and principles to solve the problem of supply air in the centre of the poultry house, thereby ensuring the necessary air quality. This problem is particularly important due to the decreasing productivity of poultry farms, which is due to the inadequacy of existing microclimate systems. It should be noted that existing energy supply systems for poultry houses require large amounts of energy and resources to maintain the microclimate in the poultry houses. New research into improving the microclimate systems in poultry houses is therefore a prerequisite for conserving resources in this area.

Evaluating the performance of new ventilation systems can be a complex task, as it is time-consuming and quite expensive [1]. As an alternative to field measurements, Computational Fluid Dynamics (CFD) modelling is a powerful tool for predicting airflow patterns, particle and gas concentrations and the thermal environment in livestock buildings [2-4]. It has also been used to assess the effectiveness of existing ventilation systems and new designs [5; 6].

The study [7] evaluated three turbulence models k-ε: standard k-ε, RNG k-ε and realisable k-ε to assess the bird internal environment based on measurements of the temperature and air velocity. The aim of this study, however, is to determine which turbulence model best reproduces experimental results using CFD. The choice of an appropriate turbulence model is important, as it can significantly affect the results. In this study, the model k-ε RNG best matched with air velocity and temperature measurements, so its use and generic parameters are recommended for modelling the poultry house interior environment.

In [8], the design of air intake devices for this typical poultry house in a cold region was optimised for cross ventilation based on two factors affecting: the length of the flow direction device and the direction of the airflow. Optimised air supply devices have helped improve the air flow in the poultry house, thereby changing environmental factors such as internal temperature distribution, wind speed distribution and carbon dioxide distribution. The length of the ideal flow directional device should be approximately 1 m and no more than 2 m.

DOI: 10.22616/ERDev.2023.22.TF164

The aim of [9] was to create a 3D model using CFD that could reproduce real operating conditions inside the poultry house. The improvement consists in integrating the main explicit and latent heat sources according to the procedure described in [10], previously applied to the 2D CFD model. In order to investigate the typical cooling and heating processes observed in a poultry house, the following were identified and considered for modelling. The model results were initially validated with experimental data to assess the effectiveness of the model for predicting temperature and humidity gradients. The modelled field speed was then used to calculate the ventilation intensity.

A study on modular poultry keeping was carried out by the authors of [11]. A poultry rearing module design with an infrared heater was developed. The proposed design is energy efficient and recommended for installation in poultry houses. The microclimate in the module has been analysed. The air temperature in the vicinity of the birds in the module is 18.6 ºC, and the average speed does not exceed 0.75 $m \cdot s^{-1}$.

This study is a continuation of scientific and practical research on improving the aerodynamic characteristics of the air environment in the poultry house [12; 13]. Therefore, the aim of the article is to improve the microclimate system in the poultry house environment by incorporating exhaust fans on the rear end wall in total of 6 pieces. As a scientific component, we provide the study of hydrodynamics and heat exchange processes in the air environment of the poultry house with improvements in the layout of both the exhaust ventilation equipment and the spoilers above the inlet valves.

Materials and methods

According to the purpose of the work, the authors modified the positioning of the extractor fans. The idea is as follows: in the traditional barn design (Fig. 1) the exhaust fans are not mounted on the rear end wall of the barn, but on the side wall, 4 pcs. per wall, for a total of 8 pcs.

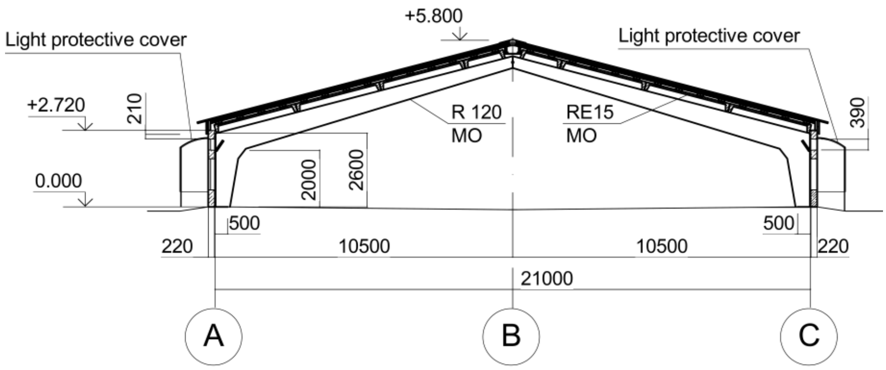

Fig. 1. **Fragment plan diagram of a poultry house with air inlets**

Fig. 2 shows the 3D geometry of the poultry house for modelling CFD. It is made to 100% scale, but is only for half of the poultry house. A “symmetry” boundary condition is set at the centre of the poultry house. The remaining boundary conditions are shown in Fig. 3a. In Fig. 3b the concrete frame (hockey stick) is clearly shown.

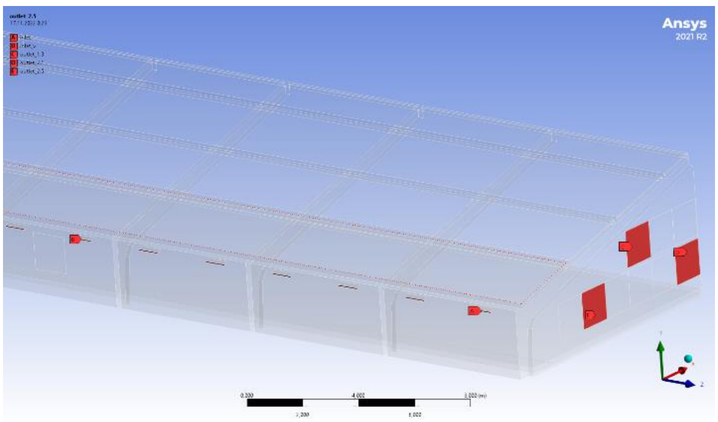

Fig. 2. **Geometry of a 3D poultry house indicating boundary conditions**

Calculations were made with the air flow rate 21.5 kg·s^{-1}. The outside air temperature is assumed to be + 2 ºC and a thermal radiation parameter is introduced. The walls are made of two sides of 60 mm thick concrete and insulated with foam 35 kg·m^{-3} between them with a thickness of 100 mm. The roof is insulated with "Izovat" Y = 30 kg·m^{-3}, 100 mm. See Fig. 2 for more details. The floor is insulated with polystyrene foam 45 kg·m^{-3} 100 mm thick and 2 m wide from the perimeter wall and the remaining area – 50 mm. In poultry houses, floor housing is a source of heat, which amounts to +41 ºC. No heating system provided. Exhaust fans such as Munters EM50 1.5 HP in total 6 pcs are used for air extraction. Supply valves Wlotpowietrza 3000-VFG with a total of 80 pcs, which are placed 0.21 m above the slab. Above the flaps are integrated spoilers angled away from the vertical 73º, and their length is 0.2 m. The rest of the design parameters for the ventilation of the hen house can be obtained from Fig. 1-2 and Table 1.

Table 1

Design parameters for inlet ventilation in the poultry house

Parameters	Index
Valve width, m	0.86
Valve opening height, m	0.049
Spoiler length, m	0.2
Spoiler tilt angle, deg.	73
Height of the valve from the slab level, m	0.21
Valve shank length, m	0.04
Number of valves involved for half the poultry house, pcs.	40

Using ANSYS Meshing software, a 3D calculation grid is constructed using the volumetric element method. The grid method used was CutCell. The number of elements is more than 3.3 million. The orthogonal quality index is 0.11. The minimum element size of the exhaust fans on the side wall of the poultry house is 0.01 m. In turn, the minimum size of the inlet flap element is 0.04 m. The maximum face size for the general model of the poultry house is 0.16 m.

The CFD model has been run on the Navier-Stokes equations for convective flows [14-16]. The calculations use the discrete ordinates radiation model [9; 17] and the Spalart-Allmaras turbulence model [18; 19].

Results

This section presents the results of a 3D numerical simulation of the poultry house using ANSYS Fluent. This allows the hydrodynamic air flows in the poultry house to be estimated. To perform numerical simulations, a 3D mesh is first constructed using the volumetric element method in ANSYS Meshing.

Fig. 3-5 shows the results of the numerical simulation of the poultry house in three sections along the length of the poultry house – 16.23 m, 50.78 m and 85.25 m. The first section is the middle of the 6th inlet valve. The second is between the 17th and 18th inlet valves. The third section is in the middle of the 29th inlet valve. There are 40 inlet valves along the length of the poultry house. Figure 3 shows the pressure field in the poultry house. At the inlet on the inlet valves, the average pressure amounts to 47.176882 Pa (Fig. 3a, 3c). There is a certain amount of vacuum on the rear end wall where the exhaust fans are located – 0.85900323 Pa. At certain points at the inlet of the valves, the maximum pressure reaches 54.151 Pa. Fig. 4 shows the gas dynamics of the air flow in the poultry house. The air flow is directed upward by the inlet valves. By raising the inlet valves to a height of 0.21 m from the slab and changing the spoiler cuttings to 73 ºC, as recommended by the authors [20], the air in the poultry house flows smoothly near the slab surface (Fig. 4a, 4c). The air is partially trapped by the concrete slab protrusions. It is then routed to the centre of the room. Average inlet air velocity at the inlet valves is 9.16 m·s^{-1}. At certain points in the poultry house inlet valves, the maximum speed can be as high as 9.88 m·s^{-1}. At the very centre along the length of the poultry house at 16.23 m a vortex is formed near the top of the house (Fig. 4a). Due to perturbation along the length of the poultry house by 50.78 m (Fig. 4b), stagnant zones occur near the overlap. Two vortices form at a distance of 5.2 m from the side wall. This can be caused by perturbation and low velocities due to large room volumes. In the exhaust fan section, on the end wall, the average speed is 3.119 m·s^{-1} (Fig. 4b). At the distance from the front-end wall of the poultry house 85.25 m (Fig. 4c) several swirls are formed. The air that is pumped through the supply valves at a height of 210 mm from the slab reaches the centre of the room. The velocity field and flow lines (see Fig. 4a) almost follow the gas-dynamic flows as in Fig. 4c.

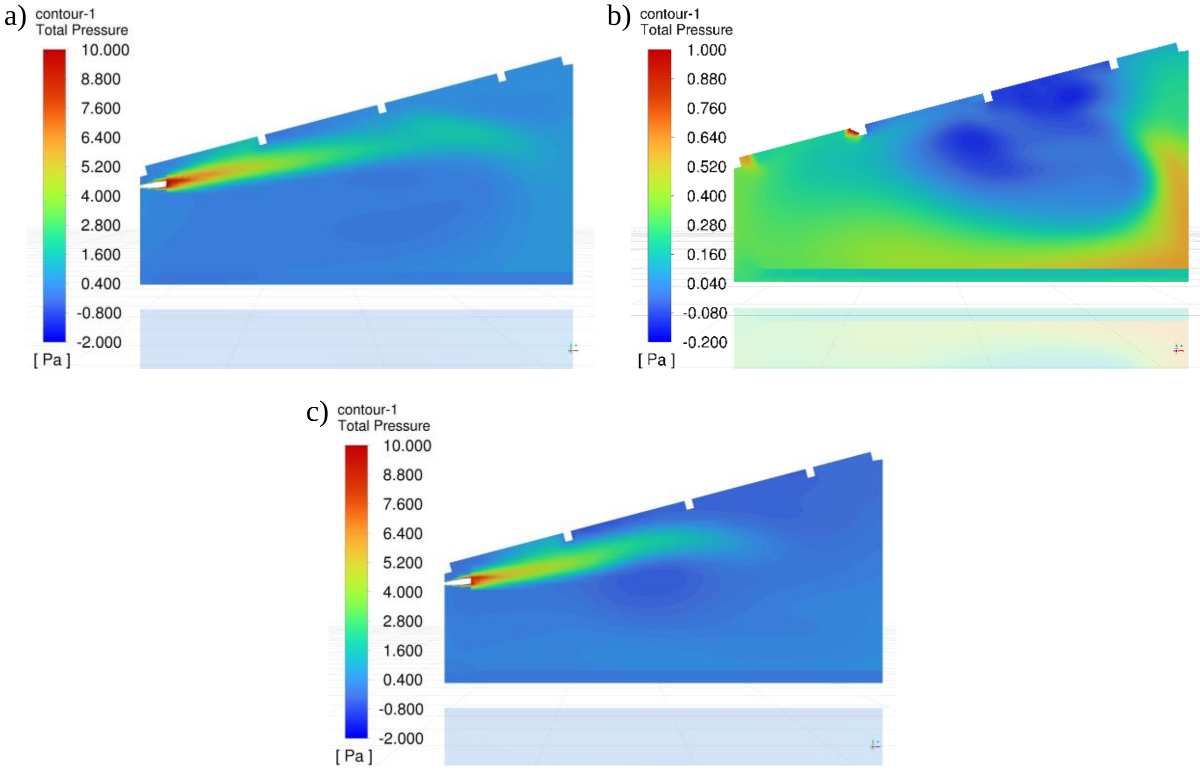

Fig. 3. **Pressure drop (Pa) in the poultry house at the distance from the front-end wall of:** a – 16.23 m; b – 50.78 m; c – 85.25 m

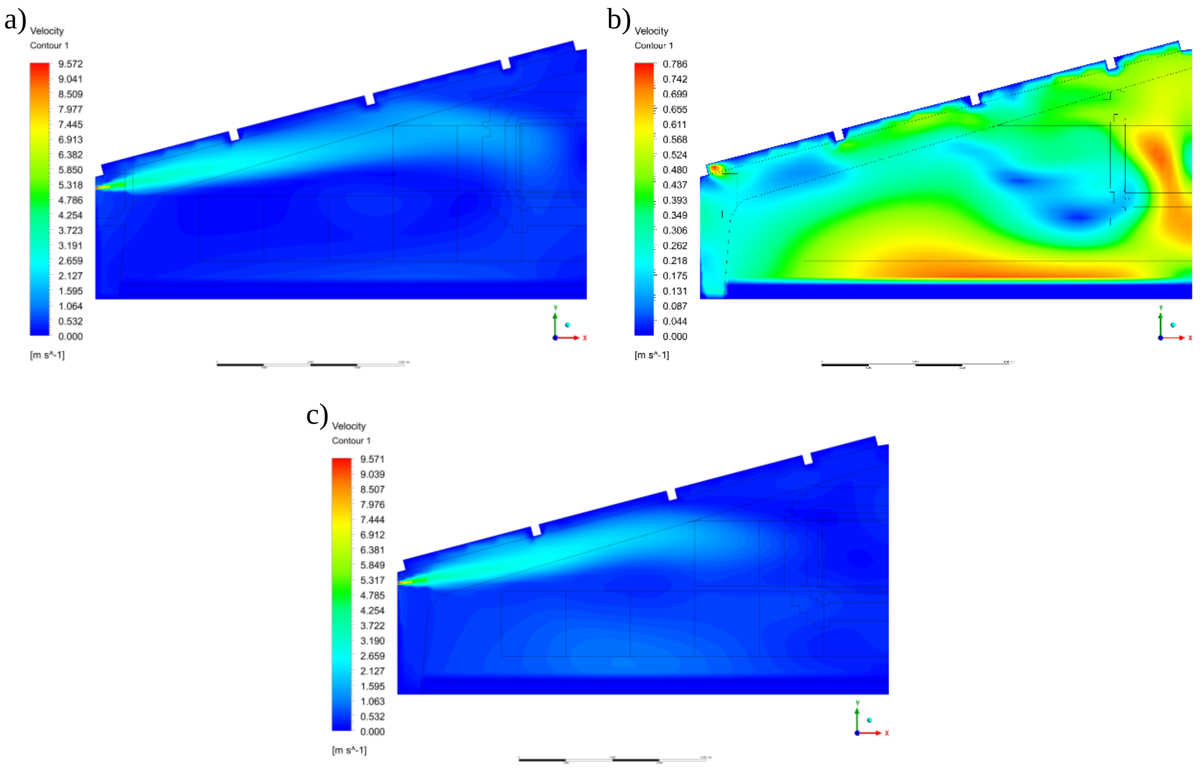

Fig. 4. **Speed field (m·s^{-1}) in the poultry house premises at a distance from the front-end of:** a – 16.23 m; b – 50.78 m; c – 85.25 m

Figure 5 shows the velocity and temperature field across the plane of the poultry house interior at 0.7m above the floor level. These results are most interesting, as they will help evaluate gas dynamics and heat exchange in the air above the birds. The average velocity at this plane is 0.71 m·s^{-1} (see Fig. 5a), and the temperature is 14.83 ºC (see Fig. 5b). There are only a few points where the air velocity reaches 1.6 m·s^{-1}. The main body of birds will not be uncomfortable as the maximum air velocity near the birds does not exceed 2 m·s^{-1}. On the other hand, at the end wall opposite the fans, the temperature is quite high and reaches + 23 ºC. As the air in the poultry house wobbles, the temperature decreases. Approximately 45% of the house is within acceptable limits: +16 to +18 ºC.

However, the remaining area is below the permissible standard and the minimum value reaches +13.3 ºC, which is not permissible for keeping poultry. The heating system must therefore be activated.

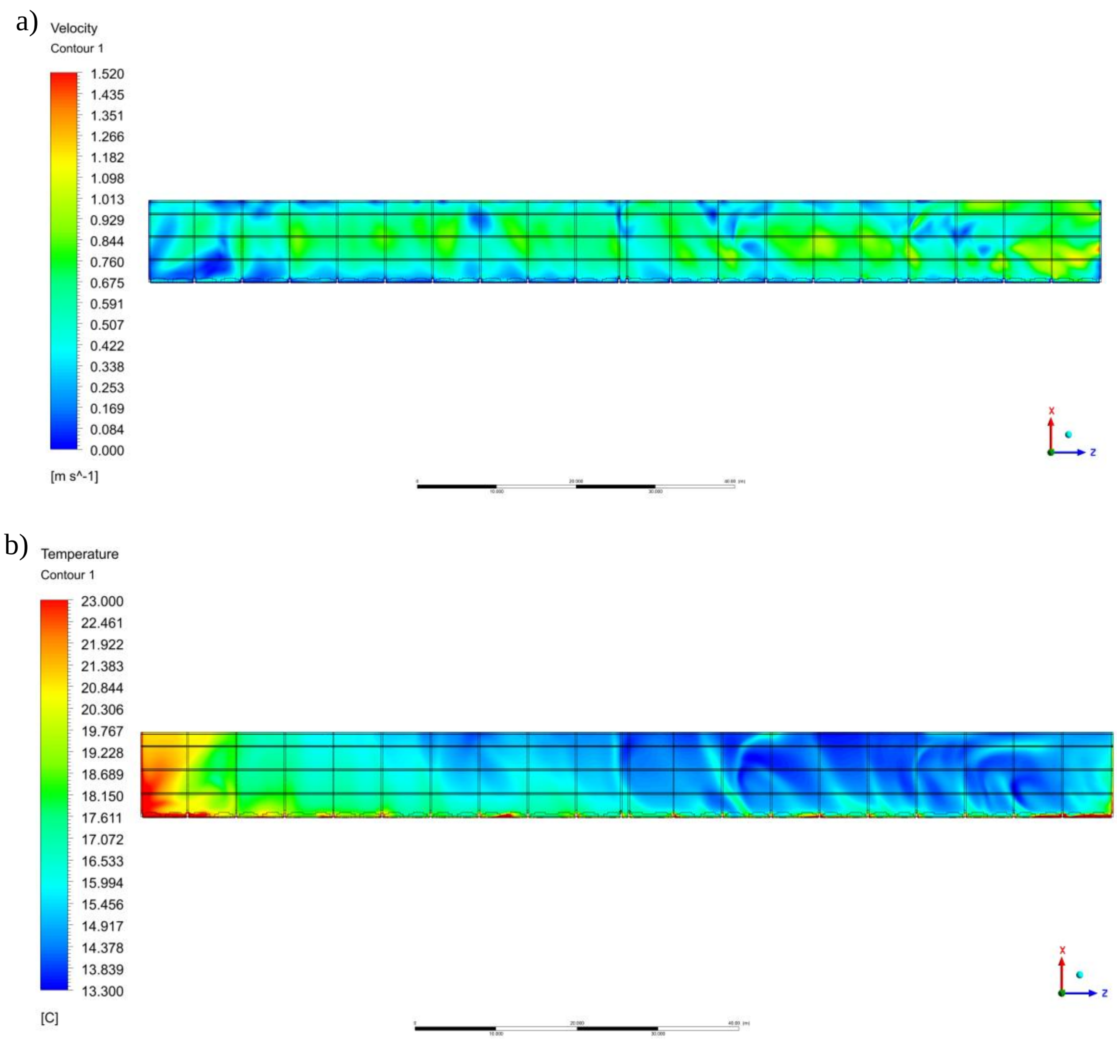

Fig. 5. **Velocity field, m·s^{-1} (a) and temperature field, °C (b) in the poultry house at 0.7 m above the floor level**

The given results show that the valves located at 210 mm from the shut-off work efficiently. The numerical simulation of such a house is presented in detail in [20]. In this case, however, we observe a damping down of the intensive air supply through the valves towards the centre of the house. This phenomenon starts 90 m from the front-end wall. This is due to the location of the fans on the rear end wall, and is accompanied by turbulent flow through the air intake intensity, by the same fans.

Details of the averaged air environment in the poultry house as a result of the numerical modelling carried out are shown in Table 2.

Table 2

Averages of the air environment in the poultry house

Parameters	Dimensions	Inlet valves	Exhaust fan
Mass inlet airflow for half of the poultry house	$kg \cdot s^{-1}$	21.5	21.5
Volumetric inlet airflow for half of the poultry house	$m^3 \cdot h^{-1}$	77402	77402
Volumetric inlet airflow for full poultry house	$m^3 \cdot h^{-1}$	154804	154804
Air pressure	Pa	47.18	-0.86
Air temperature	ºC	1.99	16.15
Air velocity	$m \cdot s^{-1}$	9.16	3.12

Based on practical experience, rearing poultry in traditional poultry houses is divided into 16 equal zones in terms of initial productivity and meat quality. The perimeter zones located at the side walls of the hen house have significantly lower meat quality. In the centre of the poultry house, the yield of quality is much better. From the results of the CFD modelling it can be seen that due to lower speeds over the birds, and more uniform temperatures, the product quality will be higher compared to the traditional positioning of the exhaust fans. It is worth reminding that in traditional poultry houses, all overhead fans are always activated. In our study, however, a different kind of fan operation is proposed (see Fig. 3). However, the results presented have both positive and negative effects on poultry in general.

Conclusions

Based on the results of CFD simulations of gas dynamics and heat and mass transfer processes, it is proposed to change the structure of the microclimate system and the layout of its components in the poultry house. Specifically, changing the spoiler angle from 75 ºto 73 ºand raising the inlet dampers to a height of 210 mm from the floor level. This allows air to be supplied to the centre of the barn, providing the right climate conditions.

The average air velocity at 0.7 m above the floor level is 0.71 $m \cdot s^{-1}$, temperature – 14.83 ºC. The main body of birds will not experience any discomfort as the maximum air speed allowed near the birds does not exceed 2 $m \cdot s^{-1}$. In terms of temperature, a heating system should be applied.

Given the choice of the fan, the pressure drop of the supply valves is 47.18 Pa, which is fully ensured by pumping air. The average air velocity at the inlet of the supply valves is 9.16 $m \cdot s^{-1}$.

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

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