INVESTIGATION OF THE INFLUENCE OF EXHAUST FANS` LOCATION ON THE UPPER LINE ON POULTRY HOUSE AERODYNAMICS WITH THE USE OF CFD
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ДОСЛІДЖЕННЯ ВПЛИВУ РОЗТАШУВАННЯ ВИТЯЖНИХ ВЕНТИЛЯТОРІВ ПО ВЕРХНІЙ ЛІНІЇ НА АЕРОДИНАМІКУ ПТАШНИКА З ВИКОРИСТАННЯМ CFD

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ABSTRACT
The aerodynamic air ducts in the poultry house significantly affect the poultry keeping and ensure air quality. Stagnant zones ultimately worsen the quality of output and many other factors that contribute to this. To improve the aerodynamics in the poultry house, authors proposed to install exhaust ventilation equipment on the upper line – 2.18 m above floor level. New scientific and practical results of CFD modeling show improved aerodynamic characteristics near exhaust fans. On the plane of the room at a height of 0.7 m from the floor level, the average air velocity is 0.696 m/s. In certain areas the air velocity is kept at 1.5 m/s. When the exhaust fans are located on the upper line, the so-called "tunnel effect" is created, which allows, in the warm period of the year, not to use additional equipment of the microclimate system to create a tunnel ventilation system.

РЕЗЮМЕ
Аеродинамічні протоки повітря в пташнику значною мірою впливають на утримання птиці та забезпечують якість повітря. Застійні зони, погіршують в кінцевому результаті, якість виходу продукції та безліч інших чинників які на це вливають. Для покращення аеродинаміки в пташнику, автори запропонували встановлювати витяжне вентиляційне обладнання по верхній лінії – 2.18 м над рівнем підлоги. Нові отримані науково-практичні результати CFD моделювання показують покращені аеродинамічні характеристики поблизу витяжних вентиляторів. По площині приміщення на висоті 0.7 м. від рівня підлоги середня швидкість повітря – 0.696 м/с. У певних ділянках швидкість повітря тримається на відмітці 1.5 м/с. При розташуванні витяжних вентиляторів по верхній лінії створюється так званий, «тунельний ефект», який дозволяє, у теплий період року, не застосовувати додаткового обладнання системою мікроклімату для створення тунельної системи вентиляції.

INTRODUCTION
Results of the publication of *Tong, X.J. et al., (2019*), showed that the upward airflow displacement ventilation system (UADV) has increased the efficiency of air exchange in cages by 46 -129%. This system also provided more homogeneous thermal environment with thermal stress by 9.4% in summer and cold stress by 68% in winter compared to the tunnel ventilation system.

Authors *Cheng, Q.Y. et al.,* (*2018*), analyzed the effects 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 velocity and distribution of air in areas of cages. Research has shown that deflectors can significantly direct airflow downward. They can also increase the air velocity in the cage and passage areas by 0.66 m/s and 0.91 m/s, respectively, than without deflectors, when the deflectors were 1 m high with an interval of 6 m.

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The study of *Küçüktopcu E. and Cemek B., (2019*), evaluated three k-ε turbulence models, standard k-ε, RNG k-ε, and realizable k-ε for assessing the indoor environment of a poultry house based on temperature and airspeed measurements. The goal of this research was to determine which turbulence model best reproduced the experimental results using CFD. Choosing an appropriate turbulence model is important, as it can significantly affect results. In this study, the RNG k-ε model fitted best with the measurements of air velocity and temperature, and thus, its use and typical parameters is recommended for simulating the indoor environment of poultry buildings.

The authors conducted CFD modeling of air flows and heat and mass transfer in the poultry house. They use water from underground wells as a cooler. A heat exchanger of special design was used as a cooling equipment in the poultry house (*Gorobets V.G. et al., 2018b)*. Recommendations for choosing the design of ventilation systems in poultry houses are given. In continuation of these studies (*Gorobets V.G. et al., 2018a)*, the authors optimized the height of exhaust fans. It is shown that it is advisable to install ventilation equipment at a height of 1.5 m. This reduces the size of stagnant zones and the uneven distribution of air velocity near the poultry.

In order to reduce energy consumption and improve the quality of the air environment while providing the necessary conditions for poultry keeping (*Trokhaniak V.I. et al., 2019*), authors conducted experimental studies and numerical simulations. In the process of research, a reduction in energy consumption to ensure the microclimate during broiler farming was achieved. At the same time, the air quality of poultry houses has improved. This, in turn, made it possible to reduce feed costs and poultry losses and, as a result, increase the economic efficiency of the production and the quality of finished products.

Authors *Bustamante E. et al.,* (*2017*), consider that the method of lateral mechanical ventilation system is more effective than other methods. CFD simulations have shown a wide range of air flow rate values. Regarding the velocity of indoor air, two main conclusions were drawn: 1 - excessive heterogeneity in the plane where the poultry were located; and 2 - insufficient air movement to contribute to the thermoregulation of the poultry.

In other study by authors *Park G. et al.* (*2018*), a new formula was developed to estimate the total ventilation rate for mechanically ventilated broiler farms using the number of operating fans and the slot-opening rate, both of which are relatively easy to measure in practice. The suggested formula was derived from the in-situ fan performance curve and the discharge coefficient, which represent the ventilation characteristics of the exhaust fans and slot openings respectively. This was evaluated through a field experiment and a computational fluid dynamics (CFD) simulation. The measured ventilation rate was 24.1–26.6% lower than the desired ventilation rate showing that the in-situ fan performance curve was 33.7 Pa lower on average than the designed fan performance curve provided by the manufacturer. The distribution of static pressure in the broiler farm was analyzed using CFD models and it was found that the new formula could be applied to broiler farms having different lengths.

The presented theoretical and experimental studies on improving the microclimate parameters in livestock buildings were carried out using an innovative air curtain system (*Kiktev N. et al., 2021a; Kiktev N. et al., 2021b*). Its power is calculated based on the dimensions of the room, and the flow rate of warm air near the floor level is three times lower than at the installation site. The use of air curtains reduces consumption of thermal energy needed to maintain an optimal microclimate for livestock by 10–15%.

Figure 1 shows an improved design of the poultry house (*Trokhaniak V.I. et al., 2020*). Exhaust ventilation equipment is located in the lower line at a height of 0.8 m above floor level. In these studies, it was found that the supply valves located at a height of 200 mm from flooring work much more efficiently than in the traditional setting at a height of 400 mm. Installation of walls on the inside of the poultry house framework, as well as reducing the height of the flooring improve the aerodynamics in the poultry house. Thus, the aim of this article is to improve the aerodynamics of the air environment in the poultry house with CFD based on the modernization of the location of exhaust fans.

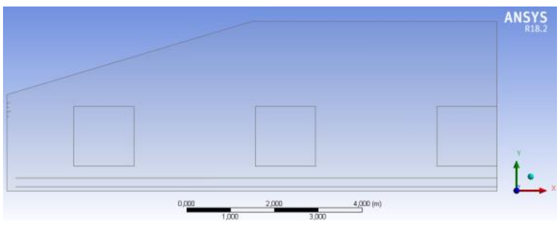
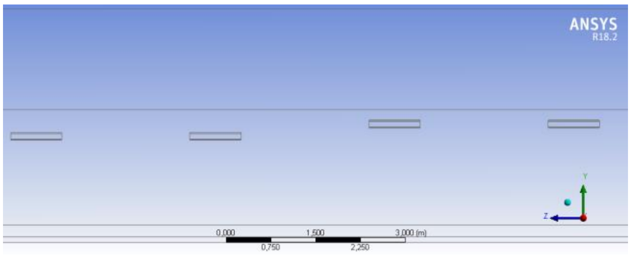


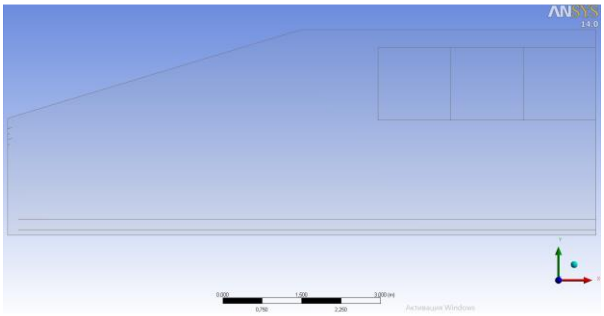
Fig. 1 – Fragment of the rear end wall with the location of the exhaust fans on the lower line
(*Trokhaniak V.I. et al., 2020*)

MATERIALS AND METHODS

This publication is a continuation of scientific and practical research on improving the aerodynamic characteristics of the air environment in poultry house. In previous studies, *Trokhaniak V.I. et al., (2020*), placed the exhaust ventilation equipment in the bottom line (Fig. 1). In this study, design solutions for the poultry house modernization, supply valves and installation of a spoiler over them (see Fig. 2a) remain unchanged. To improve the aerodynamics in the poultry house, authors suggested to install exhaust ventilation equipment on the upper line – 2.18 m above floor level (see Fig. 2b).



a)



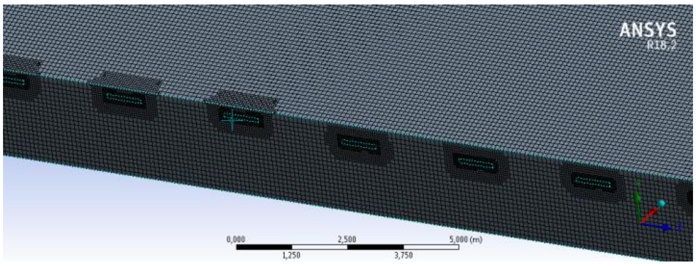
b)

Fig. 2 – Lateral (a) and rear end (b) walls of the poultry house.

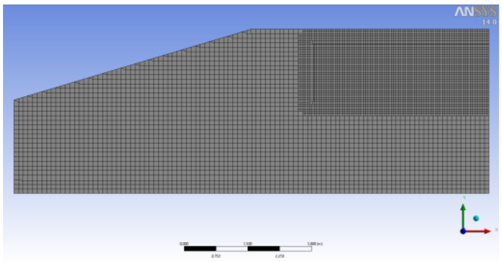
Geometry is built in real size. Symmetry is used to reduce the estimated time in the middle along the room length. That is, the simulation was performed only for half of the poultry house. Calculations were performed at an air flow rate of 45.2 kg/s. The outside air temperature is assumed to be -10 ºC and thermal radiation parameters are introduced. The first 6 ventilation valves were located at a height of 0.2 m from the floor. The other valves were located at a height of 0.4 m from the floor (see Fig. 2a).

In winter period of the year, 6 fans are used (see Fig. 2b), they are placed in the upper row and are shifted closer to the center. These fans can withstand a maximum long-term load of up to 56 Pa.

Figure 3 shows the constructed mesh of poultry house on the front and side, as well as openings of the supply air and the entrance gate. Mesh is slightly reduced relative to the rest of the wall area. These measures are used to improve the hydrodynamics calculation. The floor netting was also thickened due to the location of poultry on it.



a)



b)

Fig. 3 – Net of poultry house on the side (a) and on the rear end (b)

The number of elements and planes is quite large (Table 1). Due to the large size of the room, the size of the element and the plane is not increased much due to limited production and design power of the computer.

Table 1

Construction parameters of a grid for a poultry house

Settings parameters	Dimensionality	Indicator
Mesh quality indicator (orthogonal quality)	-	0.234
Number of elements	pcs	3812864
Number of nodes	pcs	4005172
Method	-	CutCell
Maximum plane size	m	0.11
Minimum plane size	m	0.0275
Minimum size of the element of supply valves	m	0.0276
Minimum size of the element of exhaust fans	m	0.05

The finite element method is used to build a 3D computing mesh in the ANSYS Meshing software package to solve problems of hydrodynamics and heat transfer in poultry house. As a result of construction of various mesh for numerical modeling the most optimum and qualitative of them were chosen. They allow to obtain reliable and accurate results of calculation of aerodynamic flows in the air environment of poultry house. The simulation was performed without an additional heating system.

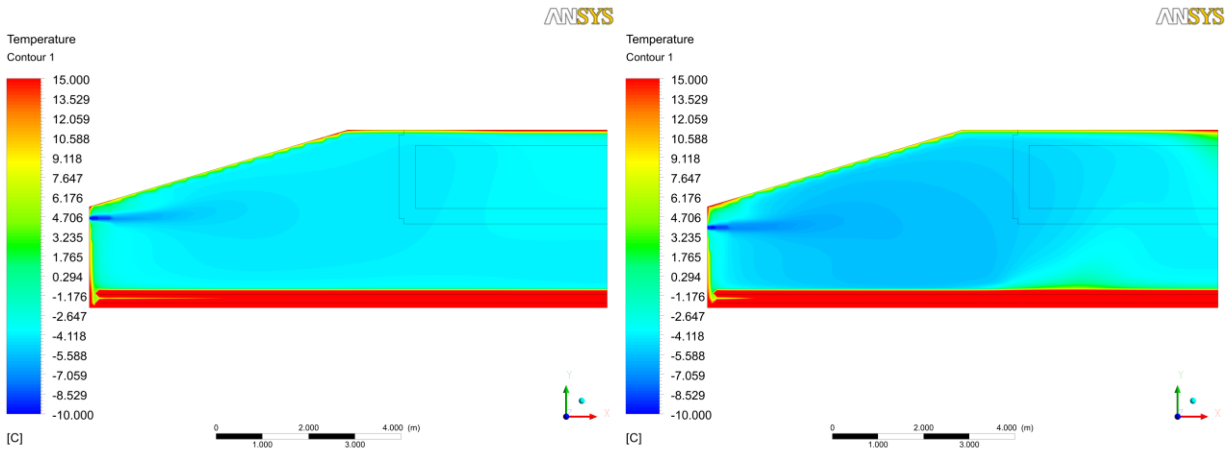
Motion of a viscous liquid or gas (air) is described by a system of equations that includes the equation of continuity and the equation of conservation of momentum in projections on coordinate axis. If the motion of medium is accompanied by heat transfer, then the energy conservation equation (heat exchange equation) is added to the system of these equations.

Mathematical model is based on the Navier-Stokes equations (*Khmelnik S.I., 2018; Trokhaniak V. and Klendii O., 2018*) and the energy transfer equations for convective flows. Spalart-Allmaras turbulence model (*Allmaras S.R. et al., 2012*) and Discrete Ordinates radiation model (*ANSYS, 2017*) were used in the calculations.

RESULTS

Figures 4-10 show the results of numerical modeling of the poultry house in two sections along the room length - 10.3 m and 52.3 m, with an air flow rate of 45.2 kg/s.

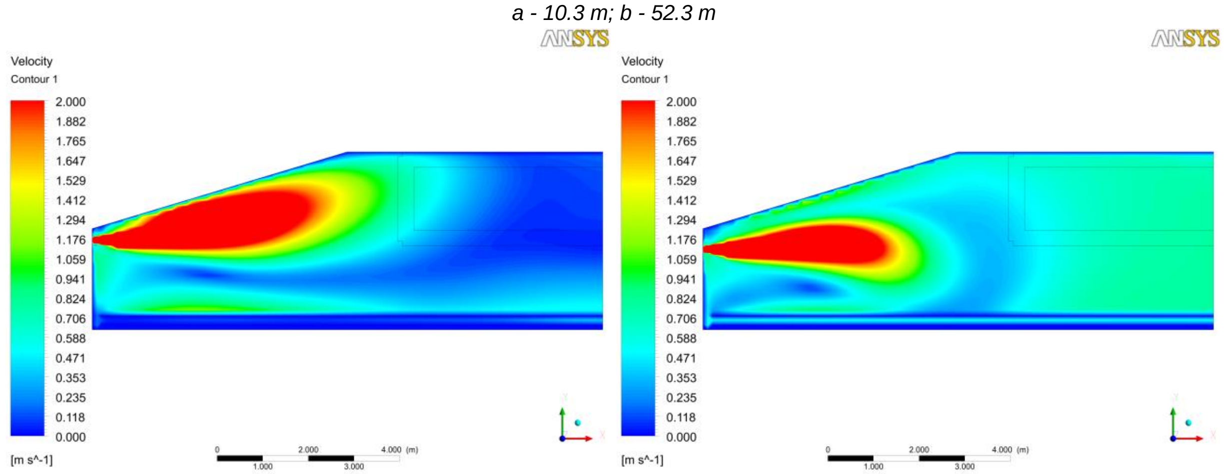
Figure 4 shows the temperature field in poultry house at a distance of 10.3 m (Fig. 4a). Cold air entering the room flows smoothly to the room center and passes the majority of poultry. At a distance of 52.3 m (Fig. 4b) along the room length this type of picture is not observed. Cold air with a temperature of -5 to -2°C goes to the center of the room and runs along the placement of the poultry.



a) b)

Fig. 4 – Temperature field (ºC) in the poultry house at an air flow rate of 45.2 kg/s at a distance from the front end wall:

a - 10.3 m; b - 52.3 m



a) b)

Fig. 5 – Field of velocities (m/s) in the poultry house with an air flow rate of 45.2 kg/s at a distance from the front-end wall

a - 10.3 m; b - 52.3 m

Figures 5-6 show the hydrodynamics of the flow in the air environment of poultry house. As mentioned above, the air flow is directed upwards due to the supply valves. However, due to low velocities and pressures at the inlet, the air after passing a third part of the room, goes down. Only location of the valves at a height of 200 mm from the floor (Fig. 5a, Fig. 6a) ensures that the air passes smoothly near the floor surface and moves to the room center. Valves located at a height of 400 mm from the floor do not give a qualitative effect. This can be caused by disturbance due to the large amount of space in the poultry house. The average air velocity at the inlet is 9.63 m/s.

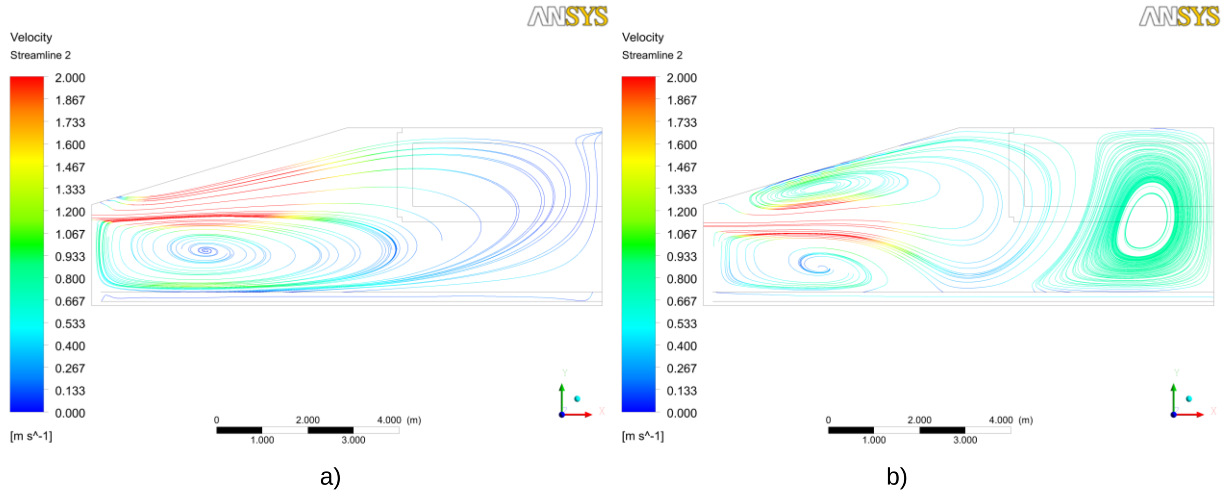


Fig. 6 – Current lines (m/s) in the poultry house at an air flow rate of 45.2 kg/s at a distance from the front-end wall

a - 10.3 m; b - 52.3 m

Figure 7 shows the pressure loss in the supply valves. Inlet pressure of the supply valves is 56.807 Pa - at 45.2 kg/s.

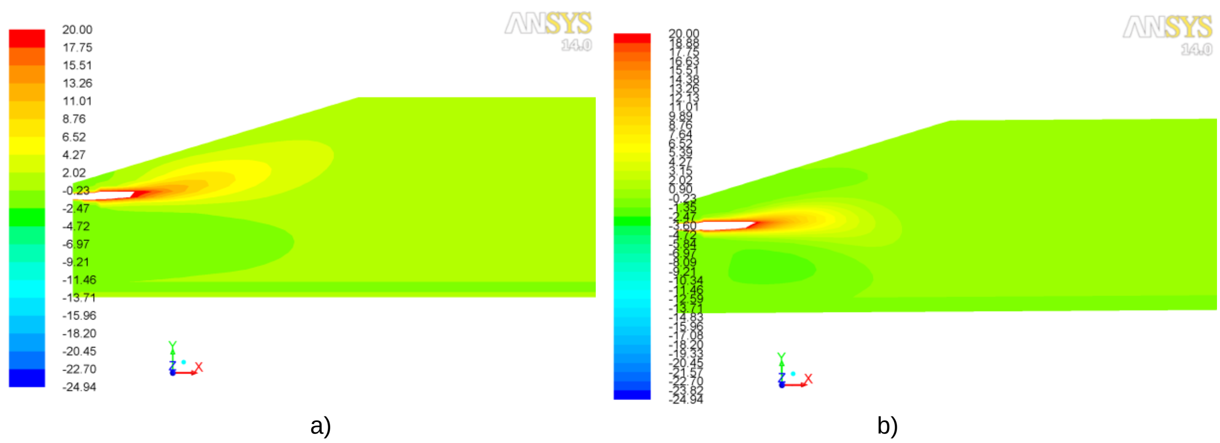
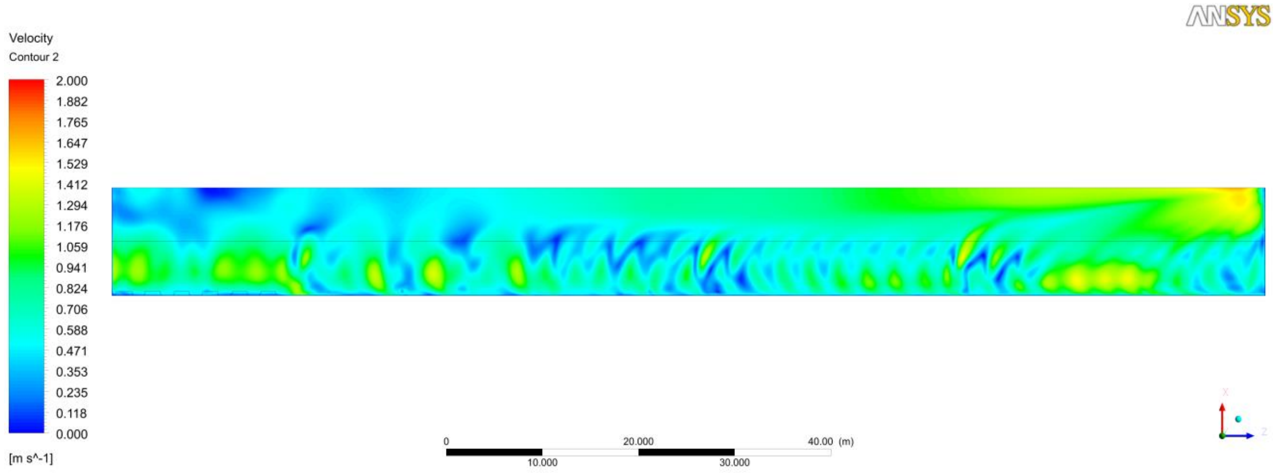


Fig. 7 – Loss of pressure (Pa) in the supply valve in the poultry house at an air flow rate of 45.2 kg/s at a distance from the front-end wall

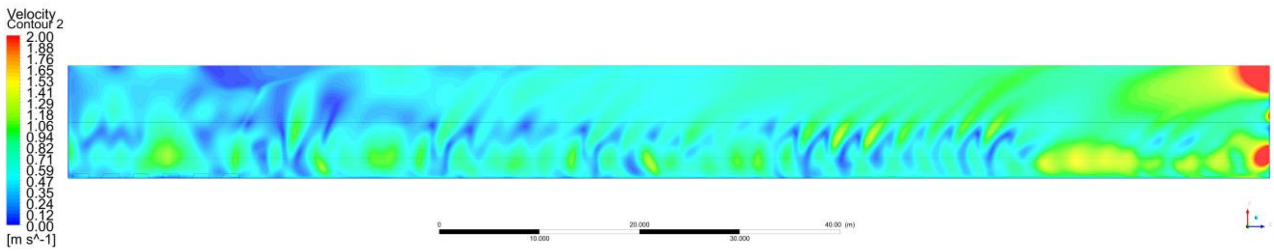
a - 10.3 m; b - 52.3 m

Figure 8 shows velocity field along the plane of the room at a height of 0.7 m from the floor level. Location on the upper line of exhaust fans gave a certain effect in the hydrodynamic currents above the poultry. The average air velocity is 0.696 m/s, which meets the standards of technical design. Only at some points near the exhaust fans (Fig. 8a) velocity is slightly higher - 2 m/s. In certain areas the air velocity is kept at 1.5 m/s. The main body of poultry will not feel discomfort. In a previous study (*Trokhaniak V.I. et al., 2020*), as can be seen in Fig. 8b air velocity, at a height of 0.7 m above floor level, is uniform. Only near exhaust fans it is higher than 2 m/s. Therefore, the new scientific and practical results of CFD modeling show improved aerodynamic characteristics near exhaust fans.

Figures 9-10 show the current and volumetric air flow lines for the poultry house in 3D. Results show that the valves, which are located at 400 mm from the flooring, do not work effectively. Given this arrangement of exhaust fans, the air is directed through the room in turbulent mode, creating a so-called "tunnel effect". This phenomenon showed an unexpected/unpredictable result for the authors. Tunnel effect begins to form about 22 m from the front-end wall. After that, the air is formed into a homogeneous flow and goes outside. It is possible to observe the flow in more detail in Fig. 6b.



a



b

Fig. 8 – Field of velocities (m/s) in the poultry house at a height of 0.7 m from the floor level at the location of exhaust ventilation equipment on

a - the top line; b - lower line (Trokhaniak V.I. et al., 2020)

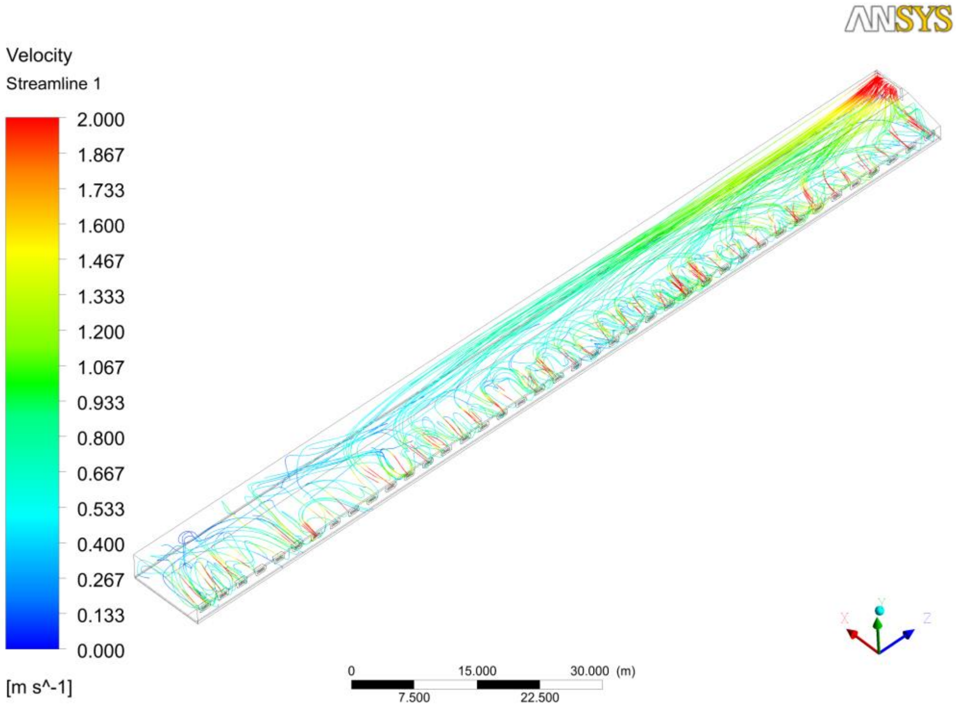


Fig. 9 – 3D current lines (m/s) in the poultry house at an air flow rate of 45.2 kg/s

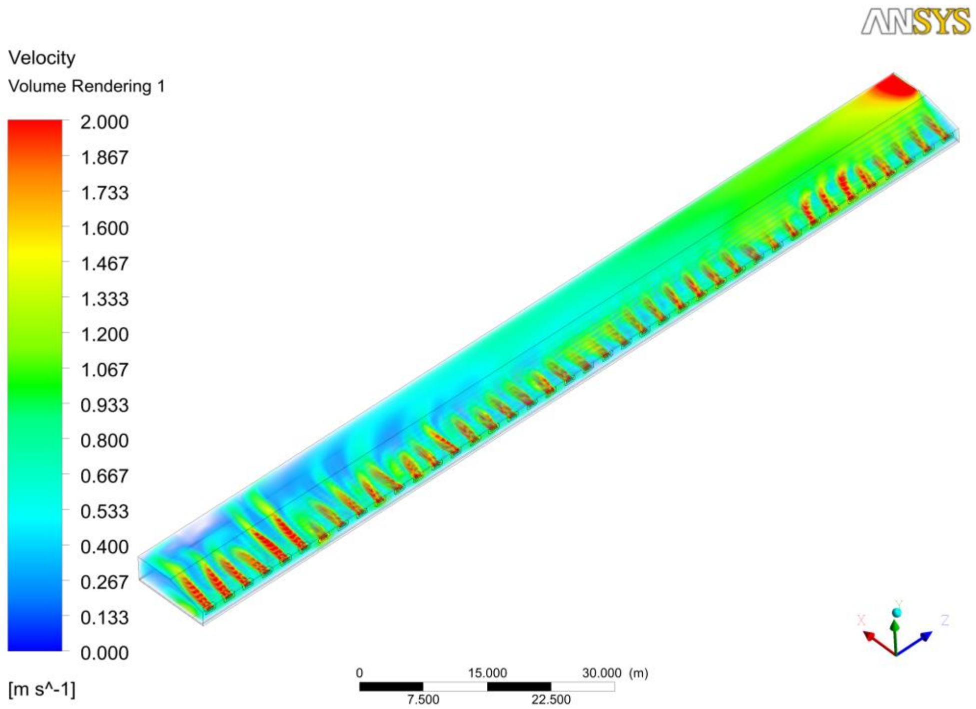


Fig. 10 – Visualization of air volume flow of poultry house in the range from 0 to 2 m/s

Table 2 presents more detailed information on the results of numerical simulations.

Table 2

Average indicators of the air in the poultry house

Parameters	Dimensionality	Result
Inlet air consumption for half of the poultry house	kg/s	45.2
Pressure at the inlet to the valve	Pa	56.80748
Pressure at the outlet of the fan	Pa	-3.9018
Air temperature at the inlet to the valve	K	263.961
Air temperature at the outlet of the fan	K	272.241
Air velocity at the inlet to the valve	m/s	9.633385
Air velocity at the outlet of the fan	m/s	9.010783
Velocity at a height of 0.7 m above floor level	m/s	0.696554
Density of air at the inlet of the valve	kg/m^3	1.337779
Density of air at the outlet of the fan	kg/m^3	1.296898

Authors proved once again, both in this and in the previous study (*Trokhaniak V.I. et al., 2020*) that location of supply valves at a height of 200 mm from the floor is more effective than at a height of 400 mm. The "tunnel effect" has both positive and negative aspects. For warm period of the year at a temperature of +35 ºC and above use a tunnel ventilation system. Thus, with the "tunnel effect" it is not necessary to use additional equipment in the ventilation system. However, in the cold and transitional periods of the year, this is somewhat unacceptable. One third of the poultry house will be at high velocities.

CONCLUSIONS

Placement of exhaust fans on the rear end wall along the upper line has been modernized. Other innovations remained unchanged: height of the flooring was reduced to 3.9 m; installation of a spoiler over the supply valve.

New scientific and practical results of CFD modeling show improved aerodynamic characteristics near exhaust fans. Average air velocity on the plane of the room at a height of 0.7 m from the floor level is 0.696 m/s. In certain areas air velocity is kept at 1.5 m/s. The main body of poultry will not feel discomfort.

Due to location of the exhaust fans on the upper line, so-called "tunnel effect" is created. It allows, in the warm period of the year, not to use additional equipment of the microclimate system to create a tunnel ventilation system.

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