USING CFD SIMULATION TO INVESTIGATE THE IMPACT OF FRESH AIR VALVES ON POULTRY HOUSE AERODYNAMICS IN CASE OF A SIDE VENTILATION SYSTEM
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ВИКОРИСТАННЯ CFD МОДЕЛЮВАННЯ ДЛЯ ОЦІНКИ ВПЛИВУ ПРИПЛИВНОГО КЛАПАНА НА АЕРОДИНАМІКУ ПТАШНИКА ПРИ БОКОВІЙ СИСТЕМІ ВЕНТИЛЯЦІЇ

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ABSTRACT

Exposure and the outbreak of diseases result in significant losses in large scale poultry operation. New ventilation systems are necessary to provide safe and homogenous internal environment at large enterprises, especially under the changeable climatic conditions of global warming. Within the framework of this investigation, computational fluid dynamics (CFD) simulation of a side ventilation system in a poultry house during winter seasons has been conducted. As results, 3D temperature fields, current lines and pressures in a poultry house have been found. It has been determined that fresh air valves arranged at a height of 200 mm from flooring work better than those traditionally arranged at a height of 400 mm. The erection of walls on the inside of a poultry house framework as well as the decrease in the height of flooring improve poultry house aerodynamics.

РЕЗЮМЕ

Переохолодження і спалах хвороби призводять до значних втрат при великомасштабному виробництві птиці. З метою забезпечення безпечного і однорідного внутрішнього середовища для великих виробництв необхідні нові системи вентиляції, особливо в умовах мінливого клімату глобального потепління. В рамках цього дослідження було проведено моделювання обчислення гідродинаміки (CFD) бокової системи вентиляції в пташнику у зимовий період року. В результаті отримано поля швидкостей, ліній току і тисків у пташнику в 3D постановці. Знайдено, що припливні клапана які розміщуються на висоті 200 мм від перекриття працюють значно ефективніше ніж в традиційній постановці на висоті 400 мм. Монтаж стін із внутрішнього боку каркасу пташника, а також зменшення висоти перекриття покращують аеродинаміку в пташнику.

INTRODUCTION

The paper of *Saraz J.A.O. et al., (2012*), was aimed at the development of the modern level of using CFD models in the internal broiler house environment and the investigation of their current limitations. It was based on the assumption that CFD models can provide knowledge about the distribution of velocities, the temperatures of air, gases and solid particles in case of natural ventilation, mechanical ventilation and adiabatic pad-and-fan cooling systems.

The results of the paper written by *Tong, X. J. et al., (2019*) show that an upward airflow displacement ventilation system makes it possible to increase the efficiency of air exchange in cages for 46% -129% as well as to provide more homogenous thermal environment with the heat stress of 9.4% in summer and the cold stress of 68% in winter compared to a tunnel ventilation system.

The paper published by *Cheng Q.Y. et al., (2018),* analyses the influence of the height (0.4 m, 0.55 m, 0.7 m, 0.85 m and 1 m) and the intervals (6 m, 9 m, 12 m, 15 m and 18 m) of deflectors on the velocity and air distribution in cage areas. The investigation shows that deflectors can significantly direct air flow

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downwards, increase air velocity in cage and pass-through areas for 0.66 m/s and 0.91 m/s respectively, compared to the lack of deflectors, in case of deflectors being 1 m tall and with the interval of 6 m.

Some authors' results, suggested a new cooling system to be applied in a poultry house with the use of heat-exchangers of a special design (*Gorobets V.G. et al., 2018; Gorobets V. et al., 2019)*. CFD simulation of air flows and heat-and-mass exchange in a poultry building is presented. Here, water from subterranean wells is used as a cooler. There are recommendations provided for choosing the design of ventilation systems in poultry houses. In their follow-up studies *Gorobets V.G. et al., (2018*), optimize the height of extractor-type fan arrangement. It is shown that it is to the point to arrange ventilation equipment at a height of 1.5 m. Here, the area of dead-air zones and the inequality of air velocity distribution close to poultry decrease.

Aimed at the decrease of energy cost and the increase of quality indices of air environment when providing the necessary conditions for poultry management, some authors conducted experimental research and numerical simulation. In the process of investigation, the decrease of energy expenditures for establishing microclimate during broiler management has been obtained. The quality of air environment in poultry houses has been increased. It makes it possible to decrease the disposal of feeding stuffs and the loss of poultry stock and, as a result, increase the economic efficiency of production and product quality. (*Trokhaniak V.I. et al., 2019*)

Bustamante E. et al., (2017), consider the methods of side mechanical ventilation to be more efficient compared to other methods. Their CFD simulation shows a wide range of the values of air flow velocity. According to the indoor air velocity, two main conclusions have been drawn: 1 – there is excess inhomogeneity in the area of animal presence; and 2 – the movement of air is insufficient to contribute to bird thermoregulation.

Shurub Yu.V. et al., (2018), Shurub Yu. et al., (2019) presented the description of loading of various ventilator engines and a combined connection diagram.

Zajicek M. and Kic P., (2012), Pourvosoghi N. et al., (2018) presented in their paper a CFD solution for various flow configurations and poultry house forms. The effects of cross and longitudinal ventilation are combined with the change of inlet air flow directions as well as various forms of the cross-sectional area obtained with the help of valves. This paper considers the design of a poultry house in such a way that the walls are arranged on the outside of a concrete framework. Such a design makes aerodynamics inside a poultry house worse. There are a lot of dead-air zones. Due to high flooring, warmth during winter season is concentrated above poultry, which results in the increase of energy costs to heat the building.

Fig. 1 presents a traditional poultry house design. The walls are arranged on the outside of a concrete framework. The flooring is not lowered. Thus, the paper is aimed at the improvement of a poultry house design, finding the most effective way to arrange fresh air valves and the improvement of the aerodynamic indices of a poultry house environment with the help of CFD.

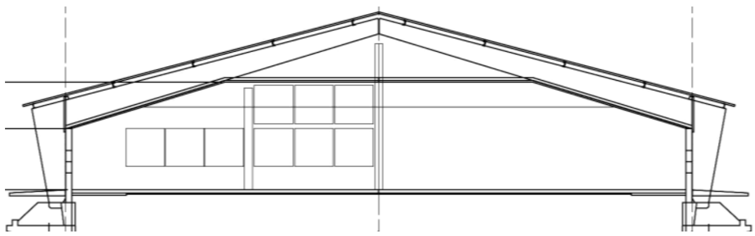


Fig. 1 - Extract of traditional poultry house design with fresh air valves of side ventilation

MATERIALS AND METHODS

According to the set technical task, the engineering calculation of air exchange during winter season was conducted. In order to remove carbon dioxide, moisture vapour and harmful substances, it was necessary to provide air expenditure being about 155 ths m^3/h at the outside temperature being -10^{o}C.

The geometrical pattern was constructed in actual size. In order to decrease the estimate time inside along the building, symmetry was applied. That is to say, simulation was conducted for half of a poultry house building only. The calculation was conducted at the air expenditure being 30 kg/s. Outside air temperature was taken to be equal to -10^{0}C and the parameters of heat emission were introduced. The walls were made of concrete and were insulated by expanded foam being 35 kg/m^3 thick: 60/150/60 mm, respectively. The building was coated by polyurethane being 100 mm thick, 45 kg/m^3. The floor was insulated by expanded polystyrene being 45 kg/m^3 thick, 100 mm for the width of 2 m from the wall around the perimeter of the poultry house, 50 mm for the rest of the area. The length of the poultry house was 120 m, the width was equal to 22.36 m (see Fig. 2). Floor-managed poultry in the building was 41 ths in number, poultry weight was equal to 3.3 kg. It was a heat source and corresponded to +41°C. Ventilation valves Wlotpowietrza 857x337 mm 3000-VFG Przepustowocs 2900 m^3/h were applied. They were arranged on the side walls being 79 pcs in total (Fig. 5a). The first ten ventilation valves were arranged at a height of 0.2 m from flooring (see Fig. 3b, Fig. 5a). The rest of the valves were arranged at a height of 0.4 m from flooring (see Fig. 3a, 4, 5a (H5)). One of the design concepts was to install a spoiler at a slope angle being 75° from a vertical line above fresh air valve (see Fig. 4 (A20)). The length of the spoiler was 0.8 m (L9). Munters EM50 1.5 Hp extraction fans were used, 18 pcs. in total. During winter season 6 pcs were specifically arranged (see Fig. 5b). As a rule, they are arranged in the upper row displaced closer to the centre. Such ventilators can undertake the maximum long-term loading up to 56 Pa.

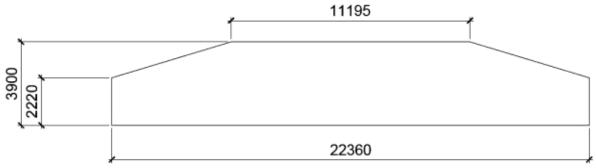
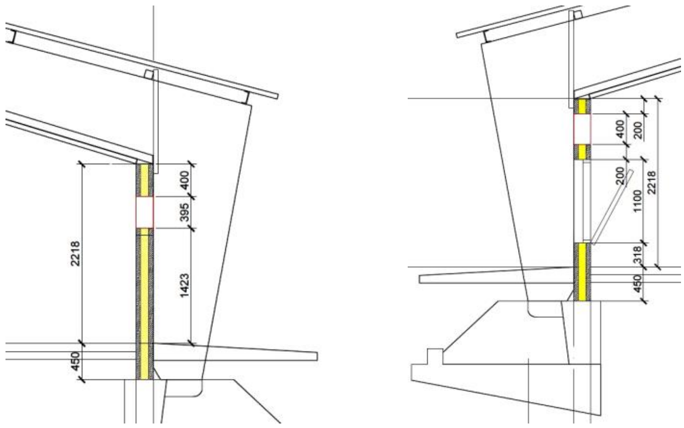


Fig. 2 - Suggested cross sectional diagram of poultry house structural dimensions



a b

Fig. 3 - Arrangement of valves along longitudinal walls

a – small valves, b – tunnel ventilation valves

Fig. 4 schematically presents valve angle side view.

The ventilation scheme was constructed in such a way that air flow reached the centre of the building in winter season in order to normalize the aerodynamic parameters of a poultry house. Such a method made it possible to reduce the loss of fresh air pressure in the poultry building. Thus, the following structural alterations were made: the width of the building was increased from 21 m, which was typical in a traditional design, to 22.36 m in a new design. Fig. 4 presents the maximum valve opening of 0.1 m (H16). Numerical simulation was conducted at valve opening being 0.1 m, 0.066 m and 0.049 m, respectively.

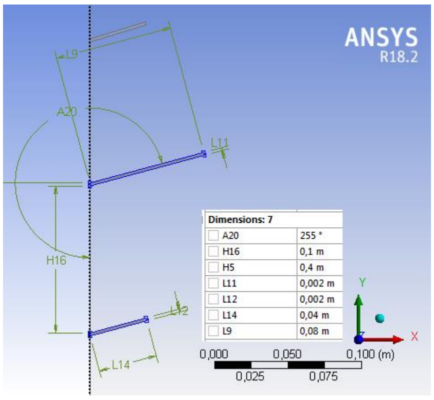
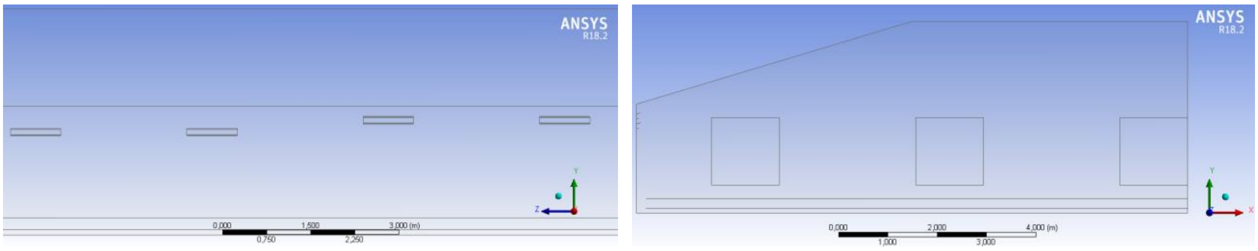


Fig. 4 - Fresh air valves and spoiler angles



a b

Fig. 5 - Side (a) and back end (b) walls of a poultry house

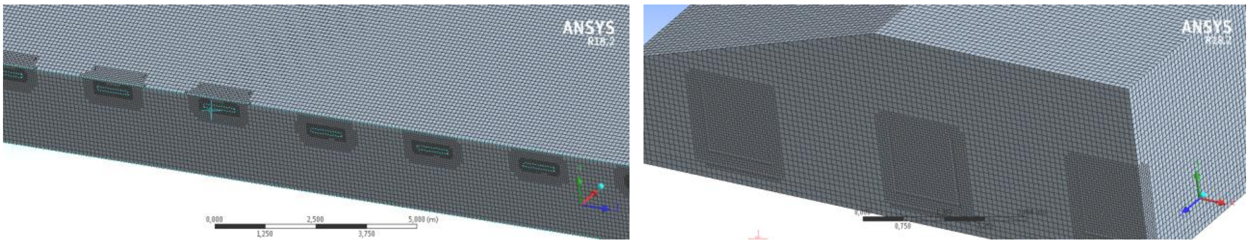
The number of elements and faces was quite numerous (Table 1). Taking into account great building dimensions, the size of an element and a face was not significantly increased because of the limitations of computer productive and design capacity.

Table 1

Parameters of mesh generation for a poultry building.

Settings	Measure units	Measure
Mesh quality index (orthogonal quality)	**–**	0.24
Number of elements	**pcs**	3813129
Number of mesh points	**pcs**	4005901
Method	**–**	CutCell
Maximum face size	**m**	0.11
Minimum face size	**m**	0.0275
Minimum size of fresh air valve element	**m**	0.0276
Minimum size of extraction fan element	**m**	0.05

Fig. 6 presents frontal and side views of the generated mesh of a poultry building, fresh air openings and an entry gate. The mesh was a little decreased relative to the rest of the wall area. Such measures were applied in order to obtain better hydrodynamics calculation. In addition, the mesh was condensed close to the floor, since poultry was placed there.



a) b)

Fig. 6 - Side view (a) and back end view (b) of a poultry house wall

Having applied the finite-element method, 3D computational mesh was constructed in ANSYS Meshing software complex aimed at solving the tasks of hydrodynamics and heat transfer in a poultry house. The construction of various meshes for CFD models resulted in choosing the most optimal and the best-quality ones that made it possible to obtain trustworthy and exact results of the calculation of poultry house ventilation. The simulation was performed without using any additional heating system.

The flow of viscous fluid or gas (air) was described by the system of equations, which included the continuity equation and the momentum equation in the projections on the coordinate axis. If the medium flow was followed by heat transfer, the energy conservation equation (the heat transfer equation) was added to the above-mentioned system of equations.

The mathematical model was based on Navier-Stokes equations (*Khmelnik S.I., 2018; Trokhaniak V. and Klendii O., 2018*) and energy transfer equation for convective currents. Spalart-Allmaras turbulence model (*Allmaras S.R. et al., 2012*) and Discrete Ordinates radiation model (*ANSYS, 2017*) were applied in the calculation.

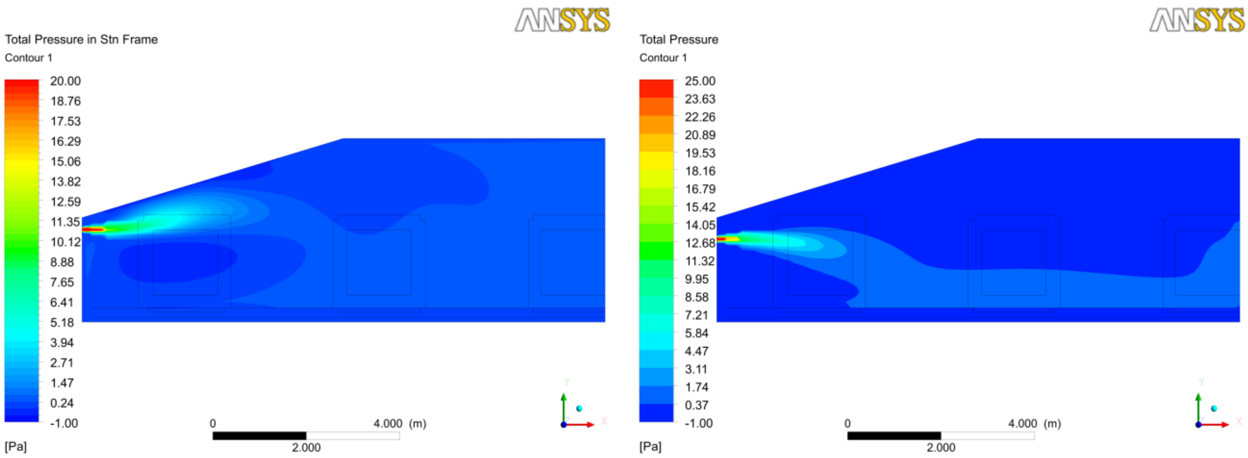
RESULTS

The results of CFD 3D simulation of a poultry house has made it possible to compare three modifications of valve opening in case of side poultry house ventilation system. Prior to conducting numerical simulation, 3D mesh has been generated applying the finite-element method in ANSYS Meshing.

Fig. 7-15 present the results of CFD simulation of a poultry house in two areas along the length of the building – 10.3 m. and 52.3 m. at various valve opening ranging from 0.1m to 0.049 m.

Fig. 7-9 present pressure loss values in fresh air valves. The least pressure loss is shown to be 24.3 Pa at valve opening being 0.1 m and the greatest one – 55.68 Pa at 0.049 m, respectively.

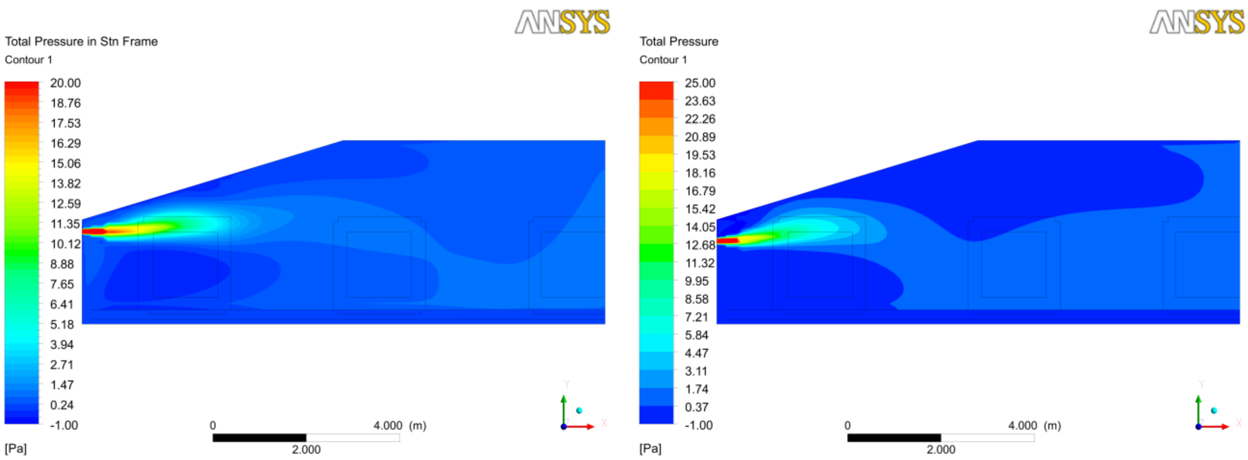
Fig. 10-15 present air flow hydrodynamics in a poultry house. As it has been already mentioned, air flow is directed upwards by fresh air valves. However, due to low entry pressures and velocities, after passing the third of the building the air falls down. The valves are arranged at a height of 200 mm from the flooring (Fig. 12a, Fig, 15a). The air smoothly moves close to the flooring area and is directed to the centre of the building. The valves that are arranged at a height of 400 mm from flooring cannot provide the same impact. This can be caused by perturbation due to large building airspace. The average entry velocity at various air expenditures ranges from 6.39 m/s to 9.62 m/s.



a) b)

Fig. 7 - Pressure loss (Pa) in a fresh air valve of a poultry building at valve opening being 0.1 m at a distance from the front-end wall of:

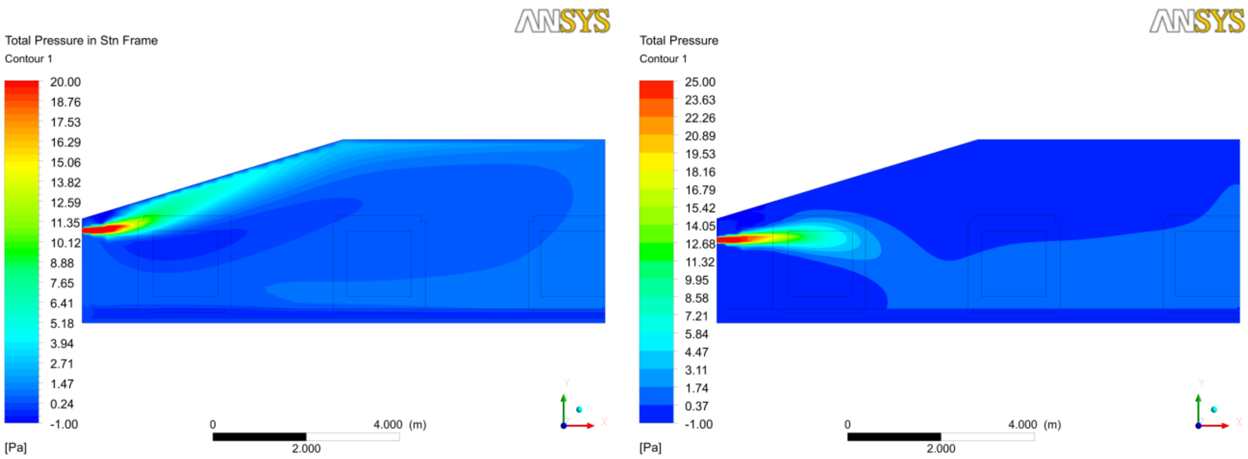
a – 10.3 m; b – 52.3 m



a) b)

Fig. 8 - Pressure loss (Pa) in a fresh air valve of a poultry building at valve opening being 0.066 m at a distance from the front-end wall of:

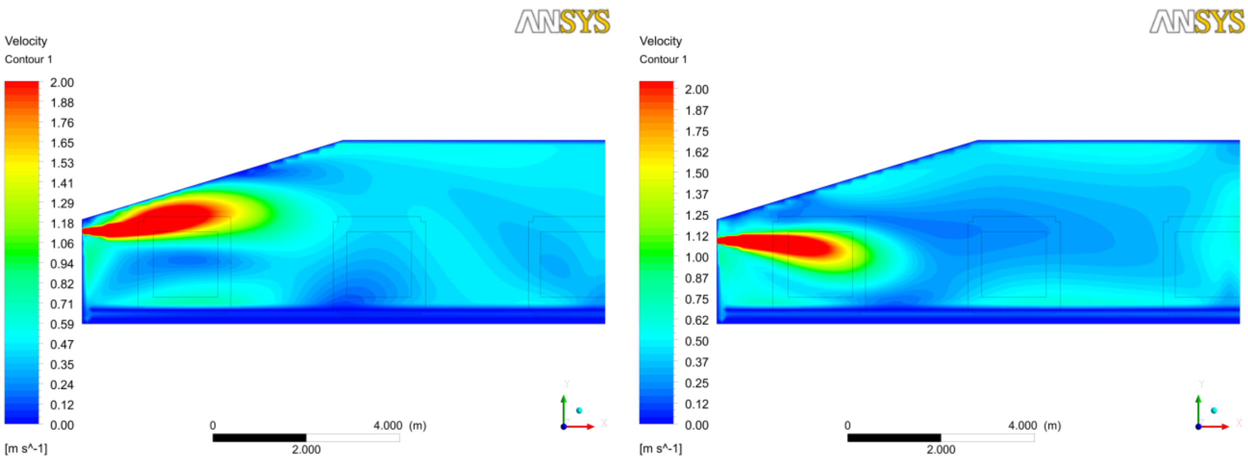
a – 10.3 m; b – 52.3 m



a) b)

Fig. 9 - Pressure loss (Pa) in a fresh air valve of a poultry building at valve opening being 0.049 m at a distance from the front-end wall of:

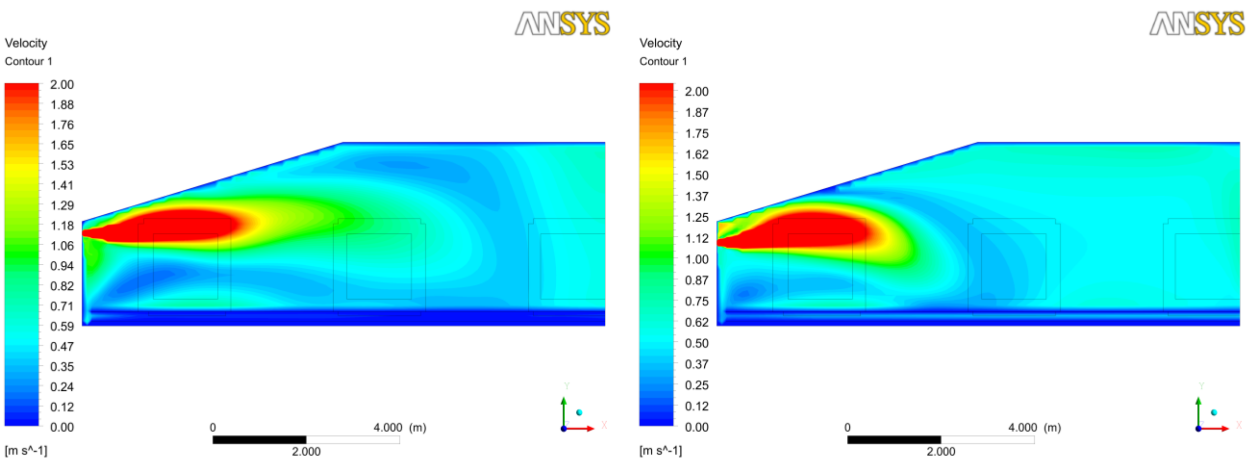
a – 10.3 m; b – 52.3 m



a b

Fig. 10 - Field of velocities (m/s) in a poultry house at valve opening being 0.1 m at a distance from the front-end wall of:

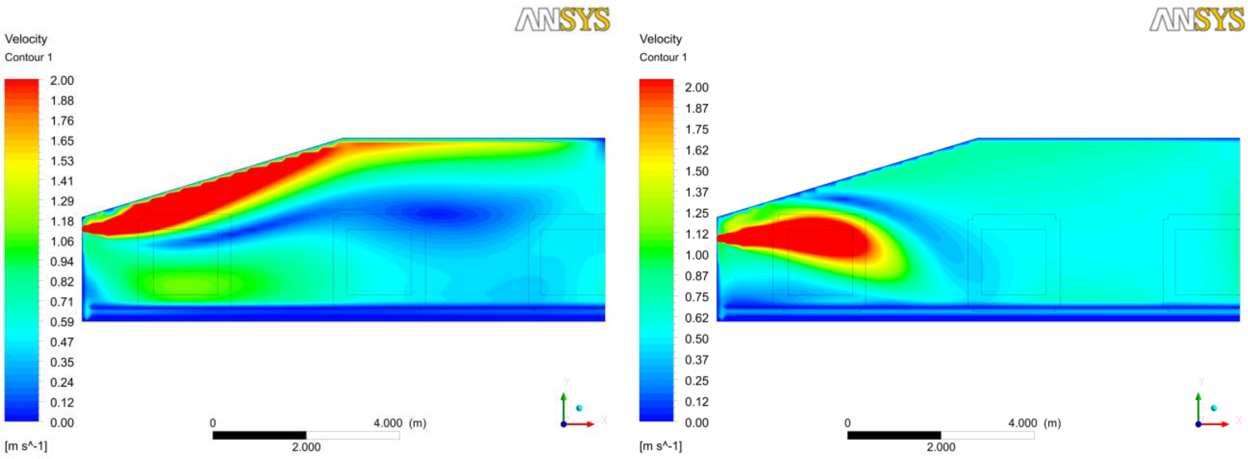
a – 10.3 m, b– 52.3 m



a) b)

Fig. 11 - Field of velocities (m/s) in a poultry house at valve opening being 0.066 m at a distance from the front-end wall of:

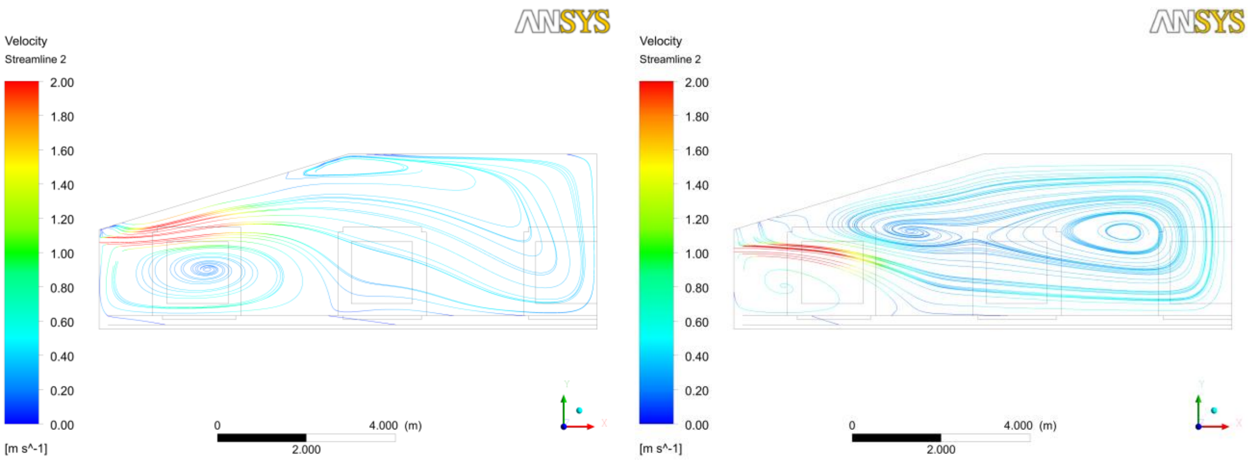
a – 10.3 m; b – 52.3 m



a) b)

Fig. 12 - Field of velocities (m/s) in a poultry house at valve opening being 0.049 m at a distance from the front-end wall of:

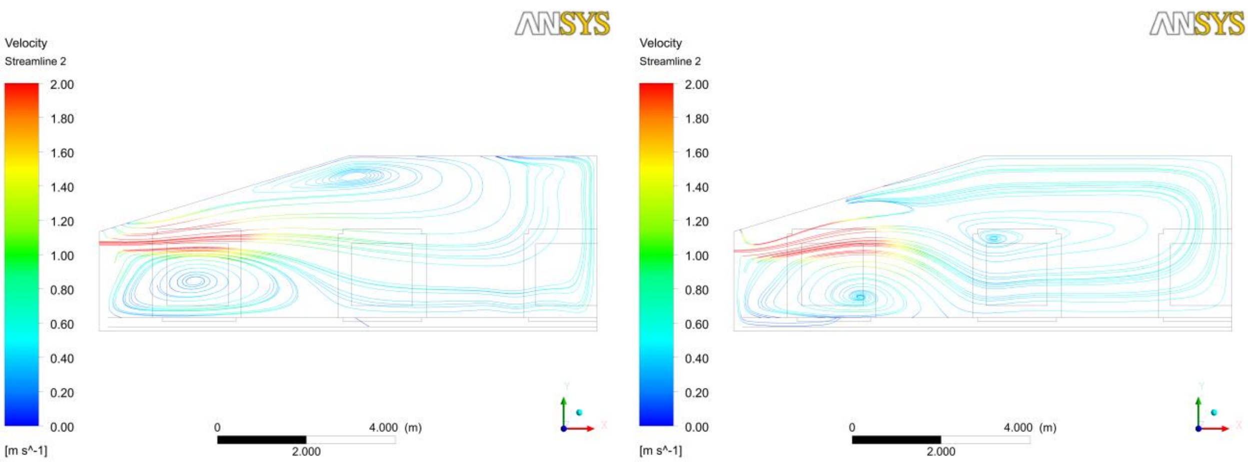
a – 10.3 m; b – 52.3 m



a) b)

Fig. 13 - Stream lines (m/s) in a poultry house at valve opening being 0.1 m at a distance from the front-end wall of:

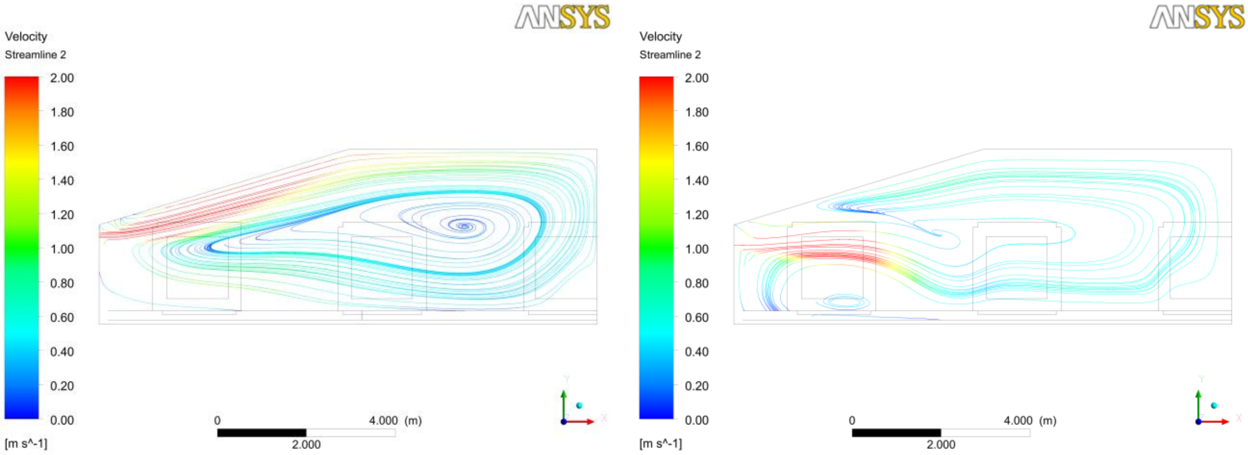
a – 10.3 m; b – 52.3 m



a) b)

Fig. 14 - Stream lines (m/s) in a poultry house at valve opening being 0.066 m at a distance from the front-end wall of:

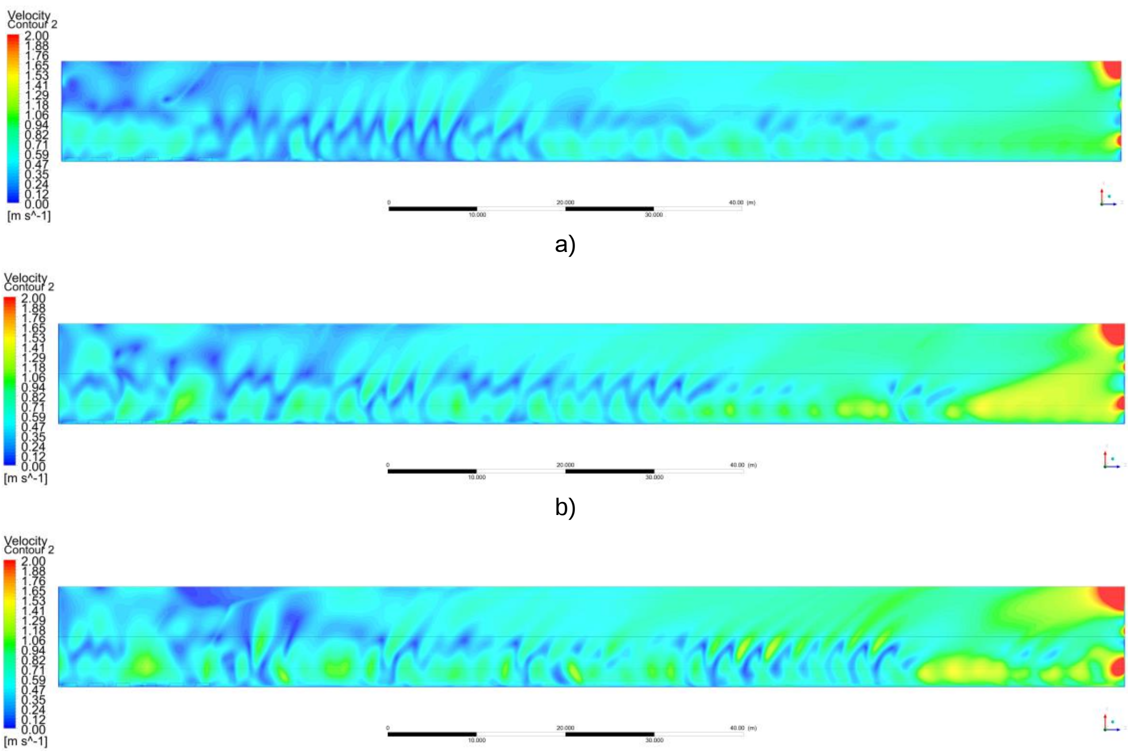
a – 10.3 m; b – 52.3 m



a) b)

Fig. 15 - Stream lines (m/s) in a poultry house at valve opening being 0.049 m at a distance from the front-end wall of:
a – 10.3 m; b – 52.3 m

Fig. 16 presents the field of velocities around the building area at a height of 0.7 m from the floor level. These results can help to estimate air velocity above poultry. The average air velocity ranges from 0.54 m/s to 0.66 m/s. Only close to extraction fans the velocity is a little higher, which is 2 m/s. The main body of poultry does not discomfort.



a)

b)

c)

Fig. 16 - Field of velocities (m/s) in a poultry house at a height of 0.7 m from the floor level at valve opening being:
a – 0.1 m; b – 0.066 m; c – 0.049 m

Fig.17 presents 3D current lines in a poultry house. The results show that the valves, which are arranged at a height of 400 mm are not effective. The middle extractor fan is practically not utilized. A great load is put on the side fan, which is arranged close to the wall. The main load is taken by the fan, which is located in the centre of the building.

In winter seasons, fresh air density is greater than in summer seasons. Thus, in case of side ventilation system, it is difficult to perform air transfer to the centre of a poultry house. At the next stage of designing a side ventilation system, the authors suggest taking into account that fresh air valves should be arranged at a height of not less than 200 mm from the flooring level.

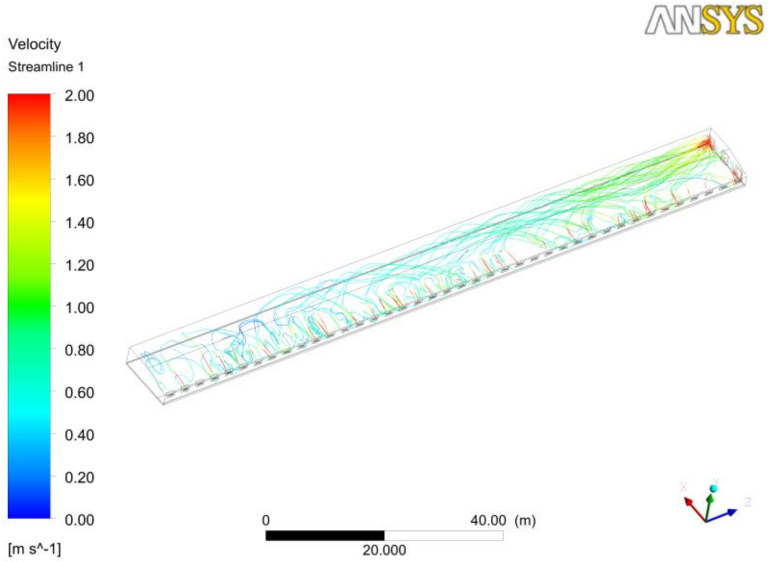


Fig. 17 - 3D stream lines (m/s) in a poultry house at valve opening being 0.049 m

Table 2 presents more detailed information on the results of CFD simulation.

Table 2

Averaged air measures in a poultry house

Parameter	Measure units	Result		
Distance of valve opening	**m**	0.1	0.066	0.049
Entry air expenditure for half of a poultry house	**kg/s**	30	30	30
Valve-inlet pressure	**Pa**	24.332	43.41	55.684
Fan-outlet pressure	**Pa**	-1.23	-2.215	-3.132
Valve-inlet air temperature	**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 flooring level	**m/s**	0.54181	0.63328	0.657591
Valve-inlet air density	**kg/m³**	1.337423	1.337529	1.337287
Fan-outlet air density	**kg/m³**	1.289433	1.288785	1.292457

CONCLUSIONS

The design of a poultry house has been improved. It has been suggested arranging spoilers above fresh air valves at an angle of 75° from a vertical line; mounting outside walls on the inside of a concrete framework; increasing the width of a poultry house up to 22.36 m; decreasing the height of flooring up to 3.9 m above the floor level.

Effective arrangement of fresh air valves and the improvement of aerodynamic characteristics in a poultry house building have been investigated applying CFD. It has been determined that the least pressure loss is 24.3 Pa at valve opening being 0.1 m and the greatest loss is 55.68 Pa at 0.049 m, respectively.

The conducted research shows that the valves, which are arranged at a height of 200 mm from flooring are much more effective. The valves, which are arranged at a height of 400 mm from flooring cannot provide the same impact.

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