THE NUMERICAL SIMULATION OF HYDRODYNAMICS AND MASS TRANSFER PROCESSES FOR VENTILATING SYSTEM EFFECTIVE LOCATION
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ЧИСЕЛЬНЕ ДОСЛІДЖЕННЯ ГІДРОДИНАМІКИ І ТЕПЛОПЕРЕНОСУ У ПТАШНИКУ ДЛЯ ЕФЕКТИВНОГО РОЗМІЩЕННЯ ВЕНТИЛЯЦІЙНОГО ОБЛАДНАННЯ

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ABSTRACT
In this paper the numerical evaluation for heat and mass transfer during the air ventilation in poultry houses' premises was provided. The analysis of the proposed conditions for heat and mass transfer in poultry houses depends on the ventilators location in the poultry house's altitude. The efficiency of this equipment's location was determined. The observed climate-control supporting system for poultry-houses is based on the external air cooling by water from underground wells. The simulation was made for 2D computational fluid dynamics (CFD) analyses by ANSYS Fluent software. The CFD analysis for the air flow analysis scheme CFD and heat condition inside the poultry house was proposed. The geometrical ventilation equipment and the best ways of its location in the poultry house were found by the results of numerical simulation.

РЕЗЮМЕ
У роботі проведено чисельне моделювання процесів тепло- і масопереносу при вентиляції повітря в птахівничих приміщеннях. Проведений аналіз умов тепло- і масопереносу у пташнику в залежності від розміщення вентиляторів по висоті пташника та визначена ефективність розташування такого обладнання. Система підтримання мікроклімату в пташниках розглядалась при наявності системи охолодження зовнішнього повітря водою з підземних сверловин. Моделювання проведено для 2D CFD моделей за допомогою програмного забезпечення ANSYS Fluent. Представлені результати CFD аналізу схеми потоку повітря і теплового стану всередині пташника. В результаті чисельних досліджень знайдено геометрію розташування вентиляційного обладнання, при якій умови вентилювання птахівничих приміщень будуть найкращими.

INTRODUCTION
There are some ventilating equipment systems that depend on the air vent and exhaust ventilator location *(Campbell J. et al., 2007)*. The present analysis showed that the most energy efficient ventilation system is the tunnel ventilation. This system would be chosen as the base during the modulation and numerical simulation of heat and mass transfer in poultry houses premises *(Curi T. et al. 2017)*.

A paper *(Zajicek M., Kic P., 2013)* researched the influence of maximum air exchange and intensive cooling of poultry by the high air velocities during the poultry houses ventilation in the summer period of the year. The air exchange numerical simulation in different configurations of ventilating systems inlet and outlet holes were executed by ANSYS Fluent software. The dimensions and forms of inlet holes and their locations on the poultry houses' walls were changed during the stimulation of heat and mass transfer in poultry houses premises.

The CFD simulation of airflow and heat and mass transfer in poultry houses premises are provided in the paper. The side ventilation system is used in this process. The authors *(Blanes-Vidal V. et. al., 2008; Bustamante E. et. al., 2017)* considered that the method of side mechanical ventilation system is the most effective in comparison with other methods. It allows decreasing the heat stress and poultry productivity increase during the summer period of the year. The results of numerical simulation were compared with the data of experimental researches. The deviation was of 12%. The authors *(Blanes-Vidal V. et. al., 2008;*

Bustamante E. et al., 2017) have concluded that the non-enough air velocity and the absence of the cooling system resulted in productivity decrease during the poultry growing. This absence favours the non-homogeneity of air flow and the existence of stagnation zone decreases the conditions for poultry's thermal regulation.

Another paper *(Zajicek M. and Kic P., 2012)* presents the CFD solution of miscellaneously improved cases for the various flow and shape configurations of the poultry house. Effects of the transversal and longitudinal ventilation are combined with the changes of inlet air streams directions and also with the different cross-section shaping obtained using curtains.

This paper is the next stage of researches for supporting the climate-control systems in poultry houses *(Gorobets V.G. et al. 2018)*. The cooling system for external air by special construction heat exchanger is observed. The underground wells' water is used as cooling medium in these heat exchangers.

MATERIALS AND METHODS

In this paper is observed the effective location of exhausting ventilation equipment in poultry-house's altitude. The measures are directed for the ventilating system improving and microclimate enhancement. The observed air cooling system is based on the water usage from underground well and heat exchanger recuperators. *(Gorobets V.G. et al., 2018)*. The specified technique allows decreasing the external air temperature without increasing their relative humidity comparing with the cooling system of water spraying. The paper's aim is to propose theoretical researches connecting with the heat and mass transfer in poultry houses. These processes run inside the house and run through its walls, by the geometry ventilators location change.

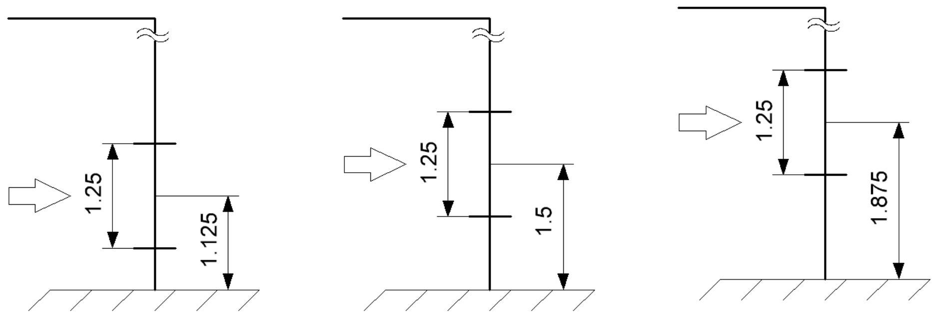
The poultry house of standard type has the following main characteristics:

- Building's data – 90x20x5m
- External barriers are made of claydite – concrete with thickness of 0.2 m.
- External air temperature in the summer period +40°C.
- Building's volume 7200 m^3.
- Internal air temperature as per norm +17°C

The research of heat exchange and mass transfer in poultry houses is the basic aim of the present paper. The height of the ventilating equipment has important value for decreasing the stagnation zones dimension. These zones are characterized by the high temperature of heated air in poultry houses and by the decrease of growing poultry productivity. These researches allow to evaluate the hydrodynamic and heat conditions for supporting a normalized microclimate and to determine the efficiency of present ventilation system operating. The air velocity in the poultry house is within: 2.58 through 1.64 m/s with average temperature +27°C *(Gorobets V.G. et al., 2018)* according to the standards. The evaluated average value is 1.97 m/s and it is at the border «Inlet_2D» (see fig.2a). The views of rear and lateral surfaces in 2-D mode are showed schematically in Figure 1. This line runs through the centreline of separate ventilators.

The poultry is kept in the floor storage mode. Poultry is the source of heat generation. The general quantity of poultry is 1000 heads. The distance between the poultry and the ventilating equipment should not be less than 3 m. The barrier is installed on the border with the poultry. It is designed for avoiding the poultry entrance into the ventilators. These barriers protect the equipment against poultry break. The barrier influence was not considered on the hydrodynamics and heat transfer for the simplifying model. The safe distance was chosen for the poultry and ventilators in spite of it. The poultry's average temperature was accepted +41°C. The poultry's high concentration was considered and accepted 7 heads per 1m^2. The present source of heat generation around the floor was accepted at +41°C (fig.2b). The exhausting ventilating equipment of the present system was supplied with an accepted diameter of the wheel of 1.25 m. The ventilators were located at the height of 1.125, 1.5 and 1.875 m to the centre line of ventilators (see fig.1).

The proposed poultry houses' hydrodynamic flow and thermal fields' analysis *(Gorobets V.G., et. al., 2018)* showed the best conditions for vertical areas. These flows run through the ventilator's centre. These flows slightly changed independently from the ventilator's location toward to lateral walls. Some differences were only observed for extreme ventilators. They didn't influence on the general view of flow and temperature separation in the whole poultry. The 2D model may be used during the modeling. This way facilitates the numerical simulation without influence on the physical data of heat exchange and mass transfer in poultry houses premises. The calculations were done from the centreline through the poultry house length. *(Gorobets V.G. et al. 2018)*. The air velocity alignment was observed through all cross sections of premises and it became the same on the first approximation through the whole section.



a) *b)* *c)*

Fig. 1 - The ventilator location configuration from centreline to the floor in terms of height:
a – 1,125 m; b – 1,5 m; c – 1,875 m

Numerical mathematical simulation of hydrodynamic and heat and mass transfer processes in an industrial greenhouse was conducted. For this purpose, computer-generated simulation method based on ANSYS Fluent software was used. Navier-Stokes equations *(Khmelnik S.I., 2018)* and energy-transfer equations for convective currents are the basis for this mathematical model.

Navier-Stokes equation:

$$\left.\begin{aligned} \rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial z^2}\right),\\ \rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial z^2}\right),\end{aligned}\right\} \tag{1}$$

where ρ – medium density, [kg/m^3]; μ – medium dynamic viscosity, [Pa•s]; p - pressure, [Pa];
u, w – velocity field of vectors; *t* – time, [s].

A continuity equation:

$$\frac{\partial u}{\partial x}+\frac{\partial w}{\partial z}=0 \tag{2}$$

An energy-conservation equation:

$$\rho\cdot C_p\left(V_x\frac{\partial T}{\partial x}+V_z\frac{\partial T}{\partial z}\right)=\frac{\partial}{\partial x}\left(\lambda\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial z}\left(\lambda\frac{\partial T}{\partial z}\right) \tag{3}$$

where *T* – point temperature, [^{o}K]; λ – coefficient of medium heat transfer capacity, [W/m ^{o}K];
C_p – specific heat capacity of a medium, [J/kg ^{o}K].

Boundary Conditions

- by inlet on poultry houses centreline (fig.2a):

$$x=0;\ 0\le z\le z_{1ch};\ z_{2ch}\le z\le H_i;\ W=W_{inlet\_2D};\ T=T_{inlet\_2D};\ i=1,2,...,7; \tag{4}$$

where z_{1ch}, z_{2ch} are vertical coordinates of the heat generation source.

It was produced by poultry arrangement during the floor storage;

H-is the distance from the floor to the roof in terms of poultry house altitude for *i*-ventilator.

So the number of installed ventilators equals 7, $W_{inlet\_2D}, T_{inlet\_2D}$ is the velocity and temperature of air flow on inlet to poultry house centreline:

- on outlet vent doors, which locate ventilation on the rear and wall (fig, 2a):

$$x=L;\quad z_{1v}\le z\le z_{2v};\ W=W_{outlet\_2D};\ T=T_{outlet\_2D}; \tag{5}$$

- conditions for the absorption of heat and air temperature at the back of the poultry house (fig.2b):

$$x=L;\quad 0\le z\le z_{1v};\ z_{2v}\le z\le H;\ W=0;\ T=T_{wall\_2D}; \tag{7}$$

- pollution terms and roof temperature (fig.2b):

$$z=H_i;\ 0\le x\le L;\ W=0;\ T=T_{wall\_roof\_2D}; \tag{8}$$

- pollution terms and floor temperature (fig.2b):

$$z = 0;\ 0 \le x \le L;\ W = 0;\ T = T_{wall\_floor\_2D};\tag{9}$$

- pollution terms of heat generation on surface source, which is formed by poultry (fig.2b):

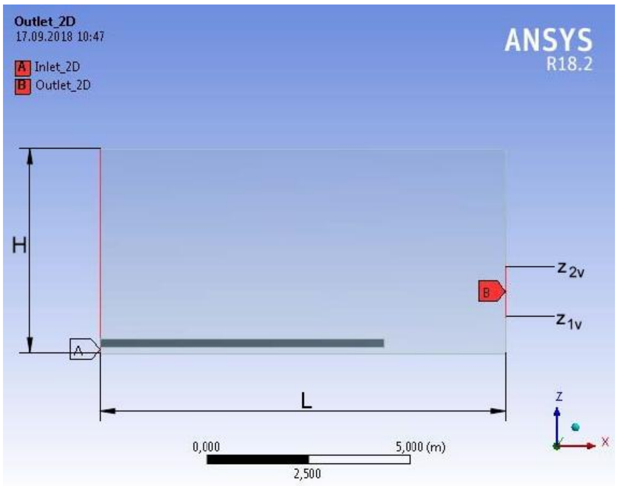
$$z_{1ch} \le z \le z_{2ch};\ 0 \le x \le L_{ch};\ W = 0;\ T = T_{wall\_chichen\_2D}.\tag{10}$$

Where:

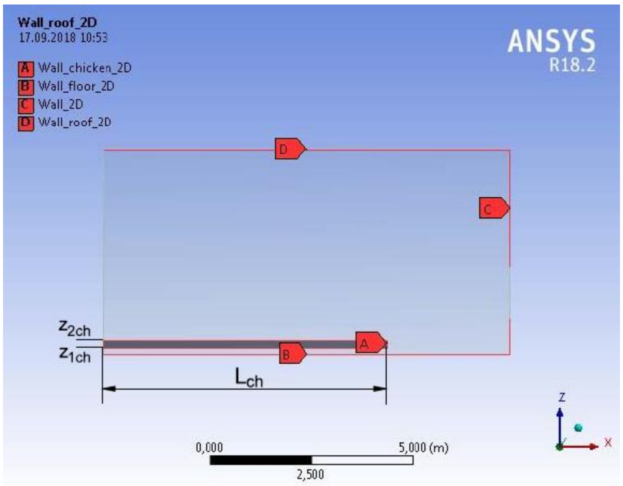
L – poultry house length from centreline to rear wall, [m];

L_{ch} – the length of the area of the poultry house on which the birds are located [m];

T_{wall_2D}, $T_{wall\_roof\_2D}$, $T_{wall\_floor\_2D}$, $T_{wall\_chichen\_2D}$ ceiling wall temperature poultry house, on the floor, roof, surface source of heat generation, respectively [^oC]



a



b

Fig. 2 - The poultry house projection view in 2 D cross-section which runs by the ventilator's centre line by the poultry house's length

a-boundary conditions at the inlet and outlet of air exchange system in the poultry house; b- boundary conditions on the surface of the interaction of the heat source with the plane of the poultry house on which the birds are located; H-poultry house's terms of height, m; L- poultry house's length, m; L_{ch} – the length of the location on which the birds are located in the poultry house, m.

The turbulence model by Spalarta-Allmarasa *(Spalart P.R. and Rumsey C.L., 2007; Allmaras S.R. et.al., 2012; Bailly C. and Comte-Bello G., 2015)* and Discrete Ordinates (DO) radiation model *(ANSYS, 2017)* were used in design. The cooling system of enforced air by water from underground wells in heat exchanger – recuperators *(Gorobets V.G., et.al., 2018)* designs were provided.

RESULTS

The finite element method was used for the numerical simulation of hydrodynamics and heat and mass transfer. The mesh building was made in the ANSYS Meshing mesh generator. The method of local mesh control was used for mesh building. The index of Orthogonal Quality is 1. The mesh building of poultry houses premises runs through the centreline of separate ventilator through the premises. This mesh is in fig.3.

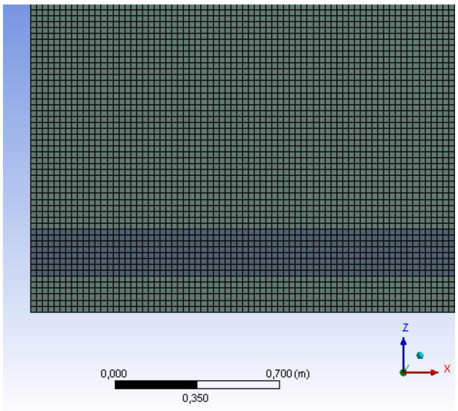
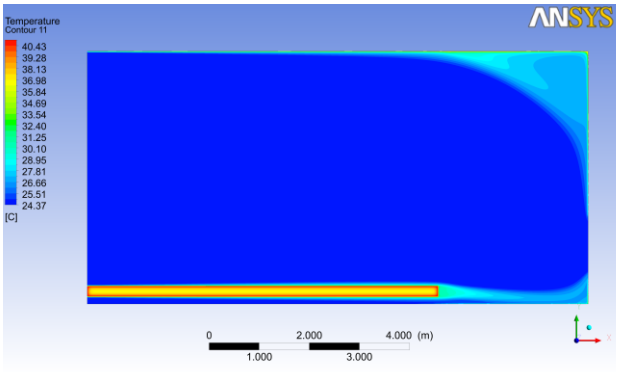


Fig. 3 - The building of mathematical mesh of centreline through ventilator centreline by the premises length

The calculation results of computer mathematical simulation for poultry house were provided in figures 4-7.



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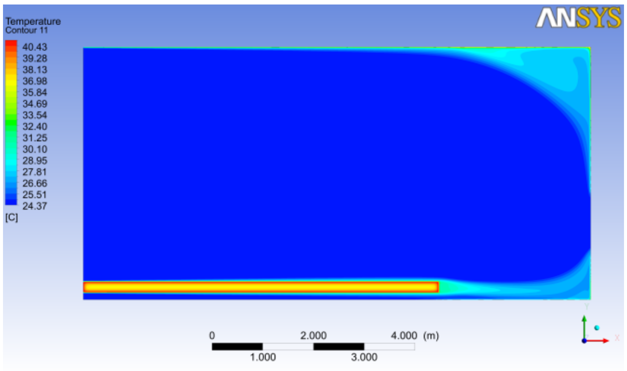

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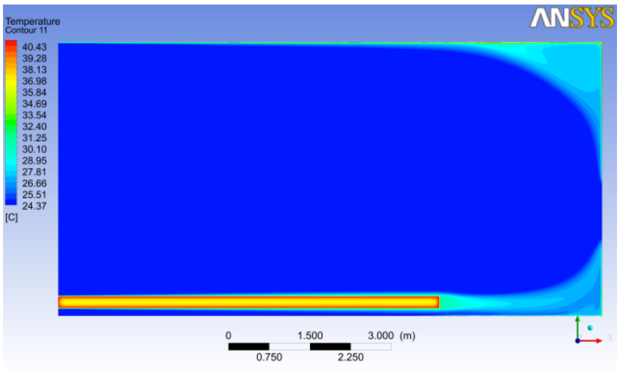
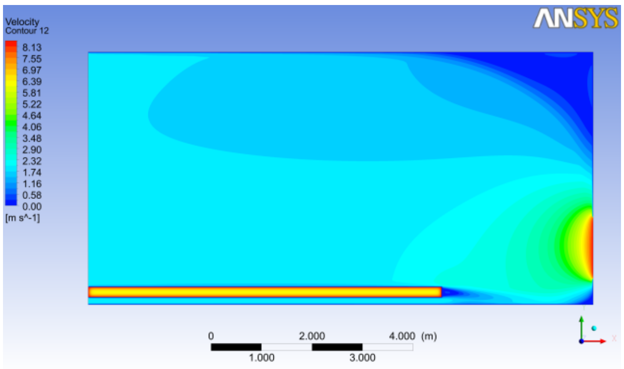


c

Fig. 4 - Thermal fields (^{o}C) in longitudinal section of premises by the ventilator centreline on coordinates *0x* from ventilators location from centreline to floor on height:
a – 1.125 m; b – 1.5 m; c – 1.875 m

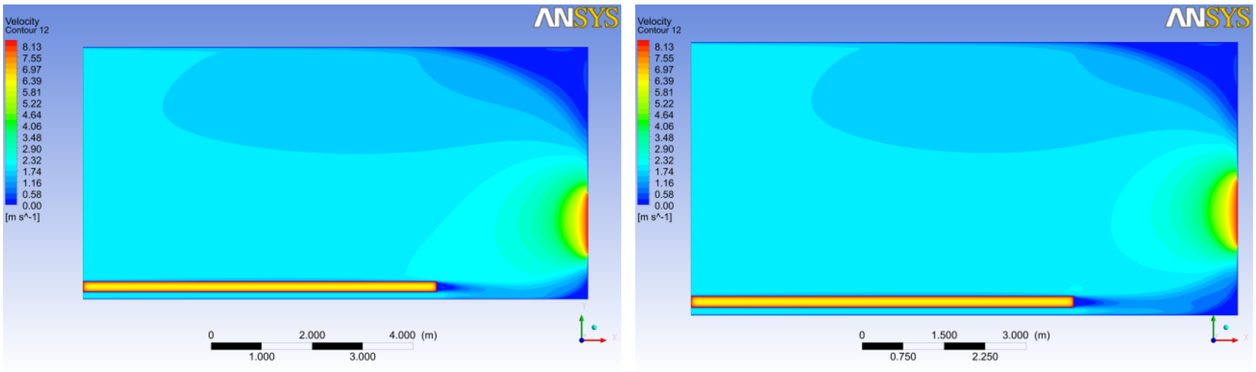
The thermal fields by the premises height in longitudinal section by the ventilator centreline on coordinate *0x* for all ventilators' location on the poultry house rear wall are shown in fig. 4. The air inlet temperature +27^{o}C cools the poultry. It locates in the lowest part of the poultry house. The air's external temperature and radiation background were considered. The increased air temperature is observed around the ceiling. The heated air has a temperature +30^{o}C. It is caused by the heat release from poultry heads. The heated air runs to the exhausting ventilating units after the poultry cooling.

The poultry house air velocity data, especially around the poultry is located. Is one of the important data for poultry keeping. The velocity field by the poultry house premises' height and length is shown in fig 5-7. Maximum velocity on the poultry house inlet and outlet areas doesn't surpass 2 m/s. The air velocity equals zero, especially in stagnant areas of some premises places. But the average velocity around the poultry, for the height of 0.5 m from the floor, was considered 1.97 m/s in spite of high turbulence and flow non-homogeneity. The air velocity on ventilator's outlet is considered nearly 8.4 m/s (fig. 5-7) independently from ventilators' location.



a)

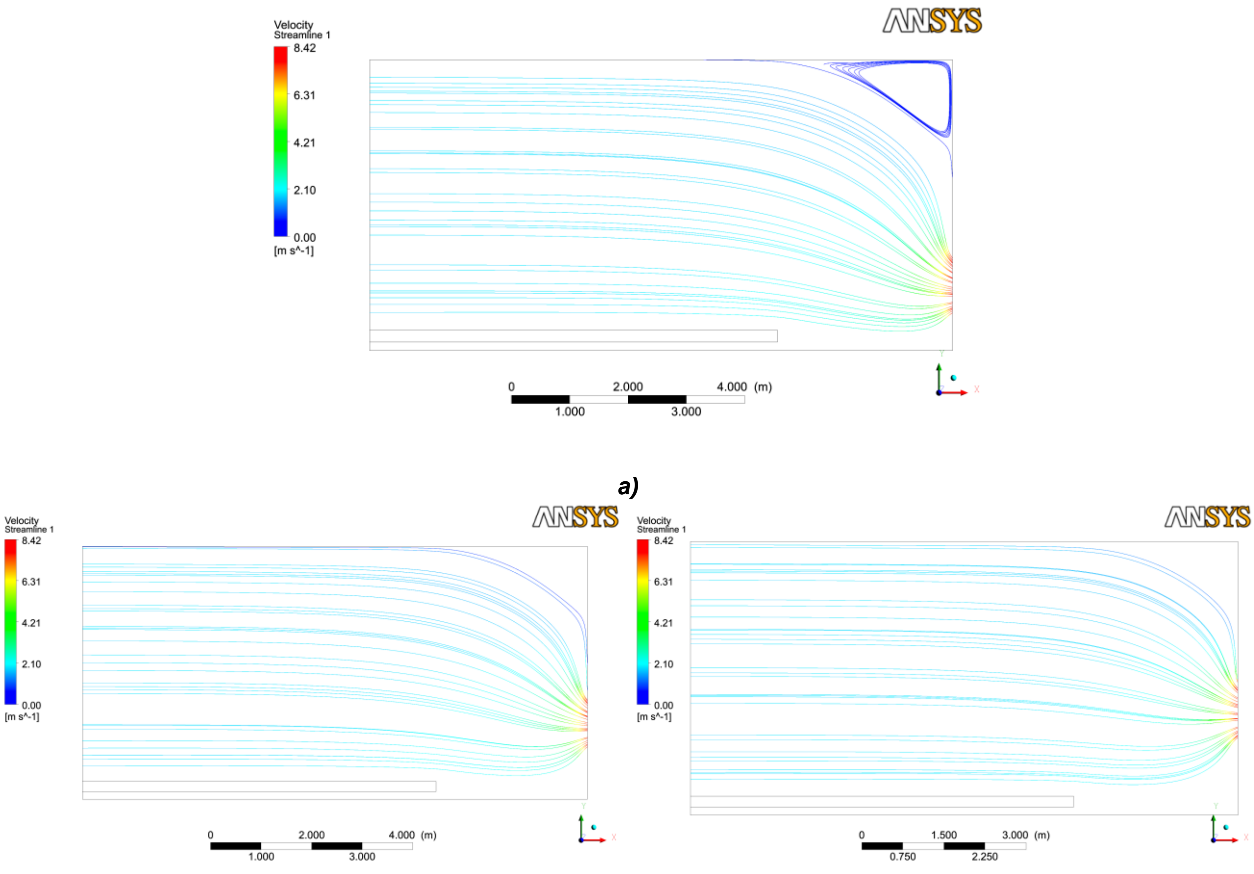
Fig. 5 a – Field of velocities (m/s) in premises' cross-section by coordinate Ox with ventilator's location from centre line to floor in terms of height *a – 1.125 m*



b) *c)*

Fig. 5 b,c – Field of velocities (m/s) in premises' cross-section by coordinate Ox with ventilator's location from centre line to floor in terms of height: *b – 1.5 m; c – 1.875 m*

The vortex zones are observed in the form of elliptical region in the upper part of the poultry house. The air velocity decreases to 1.65 m/s (fig. 5-7). The excessive stagnation area is observed in the upper angle area in fig. 5a-7a. The vortex appears in the lower part of the premises in fig. 5b-7b. The ventilator's location at the height of 1.5 m makes the vortex minimizing the stagnation areas in the angle parts of the poultry house (fig. 5b- 7b).



a)

b) *c)*

Fig. 6 - Streamlines (m/s) in premises' longitudinal section by the ventilator centreline by coordinate *0x* with ventilators location from centreline to floor in terms of height:
a – 1.125 m; b – 1.5 m; c – 1.875 m

The stagnation area may be observed in the premises' upper part in fig. 6a. The ventilators streamlines and air rate velocity (fig. 6a and 7a) direct downside. That is why the air velocity around the poultry increases. It may cause the excessive poultry cooling. The decrease in poultry's temperature may cause poultry disease. It will have a negative impact on the poultry farms operation indexes.

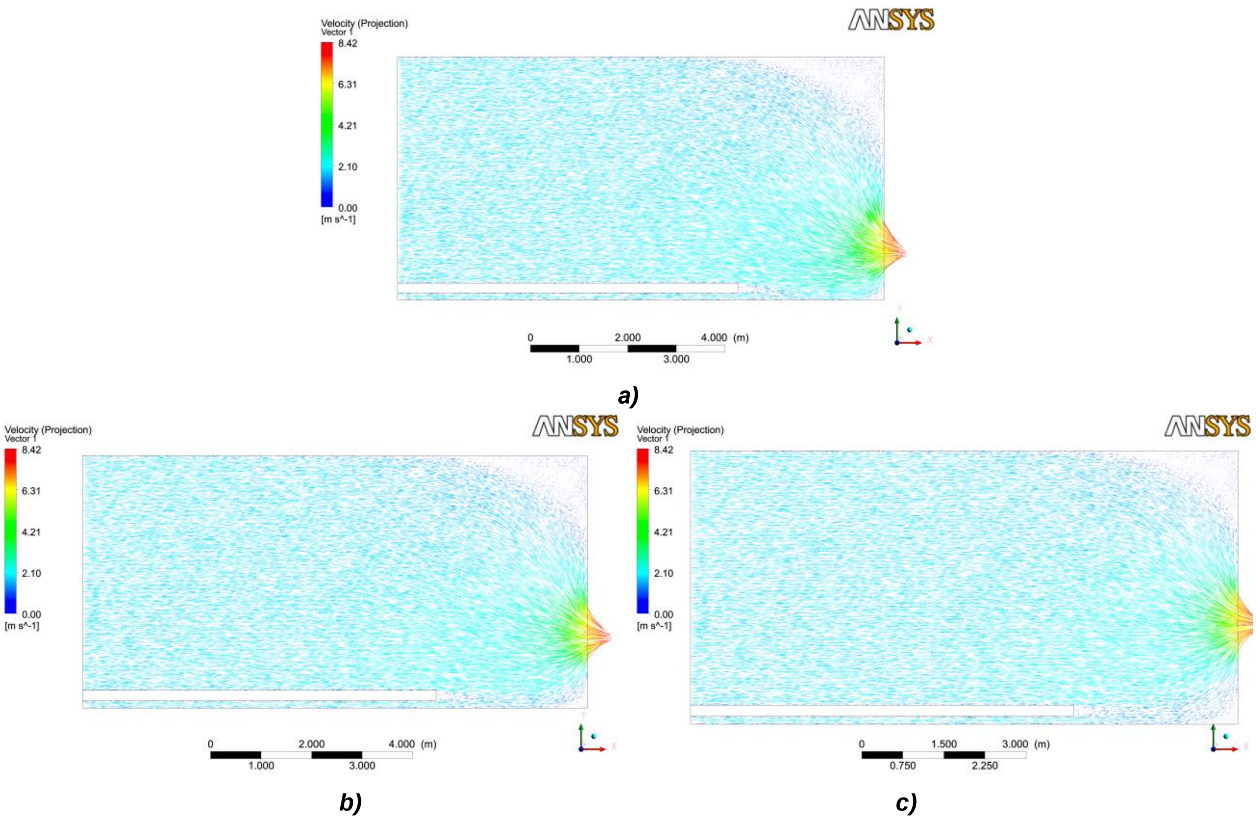


Fig. 7 - The velocity vector (m/s) in premises longitudinal section by the ventilator by coordinate *0x* with ventilators location from centreline to floor in terms of height:
a – 1.125 m; b – 1.5 m; c – 1.875 m

CONCLUSIONS

The numerical simulation of poultry's heat exchange and mass transfer were provided. The velocity and temperature distribution were received by the centreline of separate ventilator by the longitudinal section. The velocity field analysis showed the presence of stagnation areas in poultry houses' angle regions. The multiple calculations of mass transfer and heat exchange during the different geometry of ventilating equipment location on the rear wall were provided with the aim to minimize the stagnation areas, air flow aligning and temperature indexes increasing. It is necessary to install the ventilating equipment at the height of 1.5 m. It allows decreasing the dimension of stagnation areas and non-equality distribution of air velocity around the poultry. Such ventilators location allows equalizing flow considering the poultry house`s terms of height. It will not cause the excessive poultry cooling. The average air temperature for such conditions is 1.97 m/s. The poultry house's outlet air temperature is +27^{o}C. Such mode favours the productivity increase during the poultry farming.

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