THE NUMERICAL SIMULATION OF HEAT AND MASS TRANSFER PROCESSES IN TUNNELING AIR VENTILATION SYSTEM IN POULTRY HOUSES
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ЧИСЕЛЬНЕ МОДЕЛЮВАННЯ ПРОЦЕСІВ ТЕПЛО- І МАСООБМІНУ ПРИ ТУНЕЛЬНІЙ СИСТЕМІ ВЕНТИЛЯЦІЇ ПОВІТРЯ У ПТАШНИКАХ

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ABSTRACT

The mathematical modeling was provided for heat and mass transfer during the air ventilation in poultry houses. Air ventilation systems based on the injectors or moisture pads is well known. Our system is different from the existing ones by using special construction heat exchangers. The cooling medium in heat exchangers special construction is the water from the underground wells. The ANSYS Fluent software is used for receiving numerical simulation velocity fields, temperature and pressure in poultry house. The recommendations are made for the choice of poultry house's air ventilating system.

РЕЗЮМЕ

Проведено математичне моделювання процесів тепло- і масопереносу при вентиляції повітря в птахівничих приміщеннях. На відміну від існуючих систем охолодження припливного повітря, що базуються на використанні форсунок або зволожуючих касет, запропоновано нову систему охолодження з використанням теплообмінних апаратів спеціальної конструкції, в яких в якості охолоджувача використовується вода підземних свердловин. В результаті чисельного моделювання отримані поля швидкостей, температур і тисків у пташнику використовуючи програмний продукт ANSYS Fluent. Дано рекомендації по вибору конструкції систем вентиляції в пташниках.

INTRODUCTION

The modern cooling systems for supplying air in poultry houses *(Donald O.J., 2012; Czarick M. and Fairchild B., 2014; Hui, X., 2018)* are based on the usage of spraying or evaporating systems. The principle of adiabatic cooling is a base for both systems *(Kim K. et.al., 2008)*, when water transfers from liquid into gaseous state through the free evaporating. This process allows decreasing the external heated air temperature in poultry house.

The aerosol or spray appears in systems with injectors or disc sprayers. This spray consists of water drops of small diameter (*Vyshnevskyi E.P., 2004*). The injectors may be of two types: lower or high pressure. When used for air cooling, the injectors' method requires the presence of a special system of water treatment – cleaning, filtering, etc., because contamination of nozzles quickly disables the operation of injectors. Besides, the operation of such system needs high power consumption.

The pad usage is necessary for steam forced cooling. The air enters through the channels system with humid walls. Such pad's working principles were described in detail *(Hulzebosch J., 2005)*. The cooling pads are used in the terms of high temperature for external air, which increases +37^{o}C. The pad method is the most effective in the modern time. The cooling process for supplied air in the moisture pads was described in detail in *Campbell J. et.al. (2007)* works. The aerodynamic resistance and the high price of the units are the main lacks for this method. The contamination of pad's channel by dusts during the operation process is one of the lacks for the present method. It is necessary to talk about the mould formation on the contaminated surfaces. This mould adds components into supplied air. These components favour the poultry diseases at the high temperature. The algae may appear on the pad's surface in the case of non-time cleaning. The indicated factors encourage the frequent replacement of pads in the first year of operation. The maximum life of the pads does not exceed 10 years and depends on the quality of water, preventive work and special operating conditions. The effectiveness of pad cooling to a large extent also depends on the tightness of the poultry house.

There are some systems for air ventilating equipment. It depends upon the location of vent door and air exhauster *(Donald O.J., 2012)*. The tunnel ventilation is the most energetically effective as per analysis among the existing systems. The tunnel system was chosen as the basic during the modeling and providing the numerical simulation process for heat exchanging and mass transfer in the poultry houses *(Chui E.H. and Raithby G.D. 2013)*.

The CFD simulation was provided in the works *(Blanes-Vidal V. et. al., 2008; Bustamante E., et. al., 2008)* about the poultry houses with the side ventilation system. The authors *(Blanes-Vidal V., et. al., 2008; Bustamante E., et.al., 2008)* considered the method of side mechanical ventilation system as the most effective in comparison with other methods. It allows decreasing the heat stress and increasing poultry productivity during the summer period. The velocities distribution pressures and temperature for air flow for side ventilating systems were obtained from the results of numerical simulation. The results of numerical simulation were compared with the data of experimental researches, with a difference of 12 %.

The conclusion was drawn in the results of authors' researches *(Blanes-Vidal V. et. al., 2008; Bustamante E. et.al., 2008)* namely that the lack of air and the absence of cooling system generate the poultry's heat stress. It is accompanied by the productivity decrease during the poultry growing. The air-flow non-homogeneity and stagnation zone existence in the areas with poultries decrease the terms of poultry's thermal regulation.

The influence of maximal air exchange and intensity for poultry cooling through the air high velocities in the poultry houses during the summer period of the year was researched in the paper *(Zajicek M. and Kic P., 2013).* The Ansys Fluent software was used for the numerical simulation in poultry house in different configurations of air ventilating system's inlet and outlet holes. The dimensions and forms of inlet holes and their locations on poultry houses wall were changed during the simulation. The influence of these factors on the basic data of air exchange was analyzed. The data were put as per technical standards for keeping poultry. The recommendations were proposed for the choice of the most effective configuration of inlet velocity profile form and optimal temperature for internal area of poultry house by the researches results.

The analysis of the existing researches for numerical simulation of heat and mass transfer during the ventilation of poultry houses in the summer period have showed the direction for improving the existing ventilation system. It is necessary to develop new air ventilating systems. These systems differ from the traditional system of air supply with injectors and moisture pads usage.

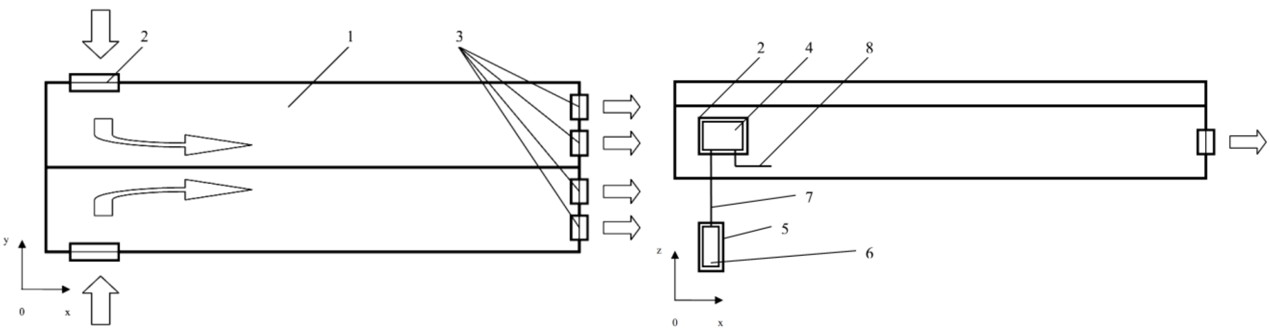
MATERIALS AND METHODS

The new technique for the cooling of external air in poultry houses' ventilating system was proposed in this paper. This technique is based on the water usage from the underground well with use of heat exchangers - recuperators. Heat exchangers, smooth-tube or finned shell-and-tube heat exchangers, as well as plate heat exchangers with water-air heat carriers, can be used, taking into account the conditions under which they operate *(Gorobets, V.G., 2006)*. This technique makes it possible to reduce the temperature of the outside air without increasing its relative humidity, in contrast, for example, with cooling systems with water spraying. The aim of this paper is to propose theoretical researches on the heat and mass transfer in poultry houses. These processes run inside the accommodation and run through the external barrier. The proposed system can be used to keep a normalized microclimate in a poultry house and, for example, to grow broiler chickens with floor-keeping (10 thousand heads).

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

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

The schematic top view is shown in Fig. 1 a, Fig. 1 b side view by shown stall space of poultry house with ventilating equipment. The proposed air ventilating system works in the following way. The heated air runs from the external medium into the house *1* through heat exchangers *4*. They are installed on the vent holes *2*. Air runs through all heat exchangers sections *4*; after that, cooled air enters into the house. The waste air removes through the individual ventilating units *3*. The movement of air in the accommodation *1* is due to the difference in atmospheric pressure at the inlet to the heat exchanger *4* and the ventilation units *3* at the outlet of them. The cold water runs from the well *5* through pipeline *7* by the pump *6* to heat exchanger *4*. The heated water is removed through the outlet nozzle *8*. The heated water can be used for the internal needs.



a) ***b)***

Fig. 1 - Scheme of air-running in poultry house

a) top view; b) side view

1 – poultry house building; 2 – vent doors; 3 – air exhausters; 4 – heat exchanger recuperator; 5 – well; 6 – pump; 7 – pipeline; 8 – outlet nozzle

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. Spalarta-Allmarasa turbulence model *(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, 2011)* were used for the calculations. The computation was conducted using heating and ventilating systems in buildings during winter time, taking into account solar radiation.

Navier-Stokes equation:

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

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

A continuity equation:

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

An energy-conservation equation:

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

where T – point temperature, °K; λ – coefficient of medium heat transfer capacity, W / m • °K; C_p – specific heat capacity of a medium, J/kg • °K.

Boundary Conditions

Let us set boundary conditions (see Fig. 2 a) for ventilation openings on the front end wall:

$$y'_{Si}\le y\le y''_{Si};\; z'_{Si}\le z\le z''_{Si};\; i=1,2...6;\; S_i(y=\pm M/2,x,z); \tag{4}$$

$$W=W_{inlet};\; T=T_{env.}.$$

For ventilation openings on the sidewalls (see Fig. 2 b):

$$y'_{\varphi i}(z) \le y \le y''_{\varphi i}(z);\ z'_{\varphi i}(y) \le z \le z''_{\varphi i}(y);\ i = 1,2...7;\ \varphi_i(x = L, y, z);$$
$$W = W_{outlet};\ \left.\frac{\partial T}{\partial x}\right|_{x=L} = 0. \qquad (5)$$

For ventilation openings on the back end wall, where fans are located (see Fig. 2 c):

$$x'_{Si} \le x \le x''_{Si};\ z'_{Si} \le z \le z''_{Si};\ i = 7,8...10;\ S_i(y = \pm M/2, x, z);$$
$$W = W_{inlet};\ T = T_{env.}. \qquad (6)$$

Attachment conditions for heat carrying air on the front end wall (see Fig. 2 a):

$$-M/2 \le y \le M/2;\ 0 \le z \le H + h(y);\ 0 \le h(y) \le h_{max};$$
$$y \notin S_i(x = 0, y, z);\ i = 1,2...6;\ W = 0;\ T = T_{wall}. \qquad (7)$$

Attachment conditions on the back end wall (see Fig. 2 b):

$$-M/2 \le y \le M/2;\ 0 \le z \le H + h(y);\ 0 \le h(y) \le h_{max};$$
$$y \notin \varphi_i(x = L, y, z);\ i = 1,2...7;\ W = 0;\ T = T_{wall}. \qquad (8)$$

Attachment conditions on the sidewalls and the roof wall (see Fig. 2 c):

$$y = \pm M/2;\ 0 \le x \le L;\ 0 \le z \le H + h(y);\ y \notin S_i(y = \pm M/2, x, z);$$
$$z \notin S_i(y = \pm M/2, x, z);\ i = 7,8...10;\ W = 0;\ T = T_{wall}. \qquad (9)$$

where $S_i(x \le 0, y, z)$ − the function that describes the boundaries of air inlet openings; $\varphi_i(x=L,y,z)$ − the function that describes the boundaries of air outlet openings; L – the length of greenhouse sidewalls, m; M – the width of the front and the back end wall, m; H – the height of the greenhouse, m; $h(y)$ – the function of roof wall height in section 0y, m; T_{wall} – wall temperature, °C; $T_{env.}$ – environment temperature, °C; W_{inlet} – inlet air velocity when entering the greenhouse, m/s; W_{outlet} – outlet air velocity when leaving the greenhouse, m/s.

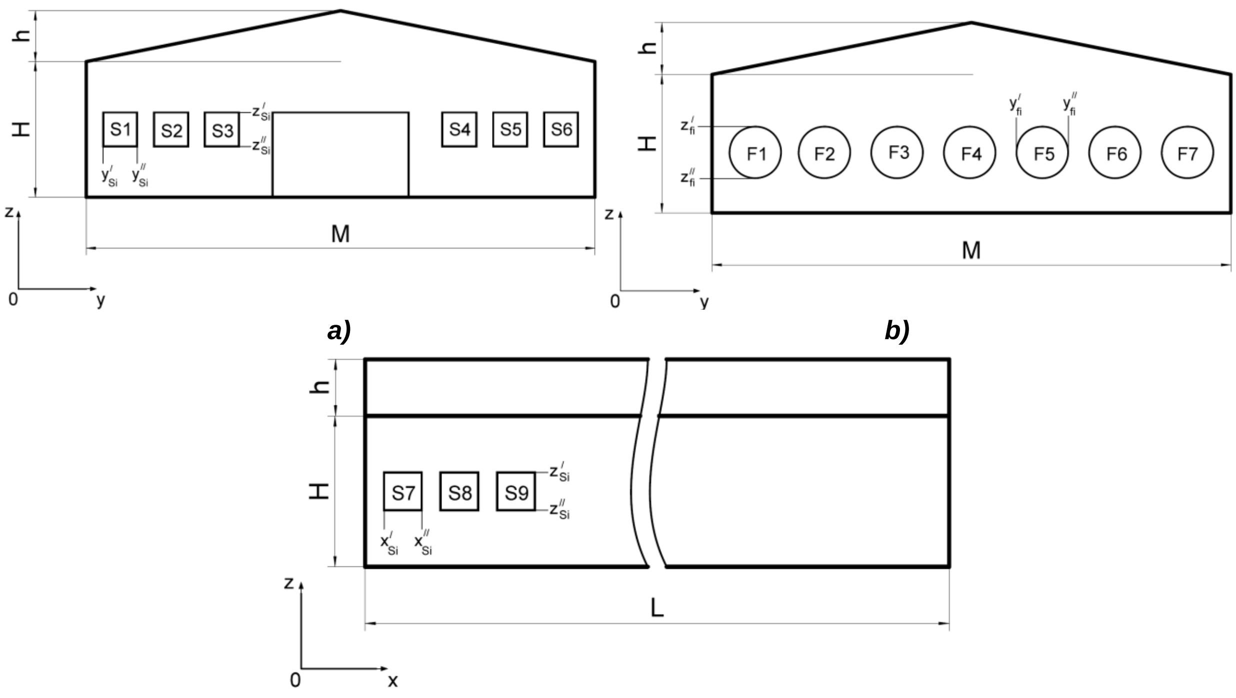


Fig. 2 - General view of poultry houses walls projection

a – front end wall; b – back end wall; c – side wall

Spalarta-Allmarasa turbulence model:

The transported variable in the Spalart-Allmaras model, ṽ, is identical to the turbulent kinematic viscosity except in the near-wall (viscosity-affected) region. The transport equation for the modified turbulent viscosity ṽ is:

$$\frac{\partial}{\partial t}(\rho\tilde{v})+\frac{\partial}{\partial x_i}(\rho\tilde{v}u_i)=G_v+\frac{1}{\sigma_{\tilde{v}}}\left[\frac{\partial}{\partial x_i}\left\{(\mu+\rho\tilde{v})\frac{\partial\tilde{v}}{\partial x_i}\right\}+C_{b2\rho}\left(\frac{\partial\tilde{v}}{\partial x_i}\right)^2\right]-Y_v+S_{\tilde{v}} \quad (10)$$

where G_v is the production of turbulent viscosity and Y_v is the destruction of turbulent viscosity that occurs in the near-wall region due to wall blocking and viscous damping. $\sigma_{\tilde{v}}$ and C_{b2} are the constants and v is the molecular kinematic viscosity. $S_{\tilde{v}}$ is a user-defined source term.

Discrete Ordinates radiation model:

The radiative transfer equation for an absorbing, emitting, and scattering medium at position $\vec{r}$ in the direction $\vec{s}$ is

$$\frac{dI(\vec{r},\vec{s})}{ds}+(a+\sigma_s)I(\vec{r},\vec{s})=an^2\frac{\sigma T^4}{\pi}+\frac{\sigma_s}{4\pi}\int_0^{4\pi}I(\vec{r},\vec{s}\,')\Phi(\vec{s}\cdot\vec{s}\,')d\Omega', \quad (11)$$

where $\vec{r}$ – position vector, $\vec{s}$ – direction vector, $\vec{s}\,'$ – scattering direction vector, s – path length, α – absorption coefficient, n – refractive index, σ_s – scattering coefficient, σ – Stefan-Boltzmann constant (5,669·10^{-8} W/m^2·K^4), I – radiation intensity, which depends on position $(\vec{r})$ and direction $(\vec{s})$, Φ – phase function, Ω' – solid angle, $(\alpha+\sigma_s)s$ is the optical thickness or opacity of the medium. The refractive index n is important when considering radiation in semi-transparent media.

The discrete ordinates radiation model solves the radiative transfer equation (RTE) for a finite number of discrete solid angles, each associated with a vector direction fixed in the global Cartesian system *(x, y, z)*. The uncoupled implementation is sequential in nature and uses a conservative variant of the DO model called the finite-volume scheme *(Chui E.H. and Raithby G.D., 2013; Hassanzadeh P. et.al., 2008)*, and its extension to unstructured meshes *(Murthy J.Y. and Mathur S.R., 1998)*. In the uncoupled case, the equations for the energy and radiation intensities are solved one by one, assuming prevailing values for other variables.

The discrete ordinates model considers the radiative transfer equation in the direction $\vec{s}$ as a field equation.

Thus, equation 11 is written as:

$$\nabla\cdot(I(\vec{r},\vec{s})\vec{s})+(a+\sigma_s)I(\vec{r},\vec{s})=an^2\frac{\sigma T^4}{\pi}+\frac{\sigma_s}{4\pi}\int_0^{4\pi}I(\vec{r},\vec{s}\,')\Phi(\vec{s}\cdot\vec{s}\,')d\Omega'. \quad (12)$$

ANSYS Fluent also allows the modeling of non-gray radiation using a gray-band model. The RTE for the spectral intensity $I_\lambda(\vec{r},\vec{s})$ can be written as *(Modest M.F., 2013)*

$$\nabla\cdot(I_\lambda(\vec{r},\vec{s})\vec{s})+(a_\lambda+\sigma_s)I_\lambda(\vec{r},\vec{s})=a_\lambda I_{b\lambda}+\frac{\sigma_s}{4\pi}\int_0^{4\pi}I_\lambda(\vec{r},\vec{s}\,')\Phi(\vec{s}\cdot\vec{s}\,')d\Omega'. \quad (13)$$

Here λ is the wavelength, α_λ is the spectral absorption coefficient, and $I_{b\lambda}$ is the black body intensity given by the Planck function. The scattering coefficient, the scattering phase function, and the refractive index n are assumed independent of wavelength.

The non-gray DO implementation divides the radiation spectrum into N wavelength bands, which need not be contiguous or equal in extent. The wavelength intervals are supplied by you and correspond to values in vacuum (n=1). The RTE is integrated over each wavelength interval, resulting in transport equations for the quantity $I_\lambda\Delta\lambda$, the radiant energy contained in the wavelength band $\Delta\lambda$.

The behaviour in each band is assumed gray. The black body emission in the wavelength band per unit solid angle is written as:

$$[F(0\to n\lambda_2 T)-F(0\to n\lambda_1 T)]n^2\frac{\sigma T^4}{\pi}, \quad (14)$$

where $F(0\to n\lambda T)$ is the fraction of radiant energy emitted by a black body *(Modest M.F., 2013)* in the wavelength interval from 0 to λ at temperature T in a medium of refractive index n.λ_2. and λ_1 are the wavelength boundaries of the band.

The total intensity $I(\vec{r},\vec{s})$ in each direction $\vec{s}$ at position $\vec{r}$ is computed using

$$I(\vec{r},\vec{s}) = \sum_k I_{\lambda_k}(\vec{r},\vec{s})\Delta\lambda_k, \tag{15}$$

where the summation is over the wavelength bands.

Boundary conditions for the non-gray DO model are applied on a band basis. The treatment within a band is the same as that for the gray DO model.

RESULTS

The finite element method is used for the numerical simulation of hydrodynamics and heat and mass transfer. The principle of this method is based on the approximate method for solving definition of a variational task. The notional of functional is used for the formulation of this task. The operator *I[f (x)]* is called a functional which was given on some set of functions f(x), if for each function *f(x)* it corresponds to a certain rule or law a certain numerical value *I=I[f (x)] (Dulnev G.N., 1990).*

The mesh building is made in the ANSYS Meshing mesh generator on the base platform Workbench. The method of local mesh control was used for the mesh building. The index of Orthogonal Quality *(Trokhanyak V.I. and Bogdan Yu.O., 2015)* equalled nearly 0.45. Minimum dimension of bound was 2.3×10^{-2} m.

The data of heat and mass transfer in the mesh of ANSYS Meshing were put in Table 1. They will be needed for the further calculation of heat exchange and mass transfer. The geometry was built in real dimensions. The quantity of elements and bounds are rather big during the mesh building. Considering big dimensions of the building, element's dimensions and bounds are not much increased through the limits of productive and design computer's capacity.

Table 1

The data for the building mesh of poultry house

Setting data	Poultry house
Indexes for mesh orthogonal quality	0.45
Element's quantity, pcs	1628712
Joints number, pcs	9303422
Angles curvature, grad	45
Method	Triangle
Element's maximum dimension, m	2.3
Bound's maximum dimension, m	4.6
Bound's minimal dimension, m	2.3×10^{-2}

Fig. 3 shows a constructed poultry house mesh from the frontal side. The mesh is slightly reduced (concentrated) near the holes of the inflow air relative to the rest of the wall area. These measures are applied for the improved calculation of hydrodynamics. In the section (Fig. 4), a mesh is clearly visible, so you can better assess the quality and disadvantages of the mesh itself. We also notice concentration of the mesh near the floor due to the location of the poultry on it.

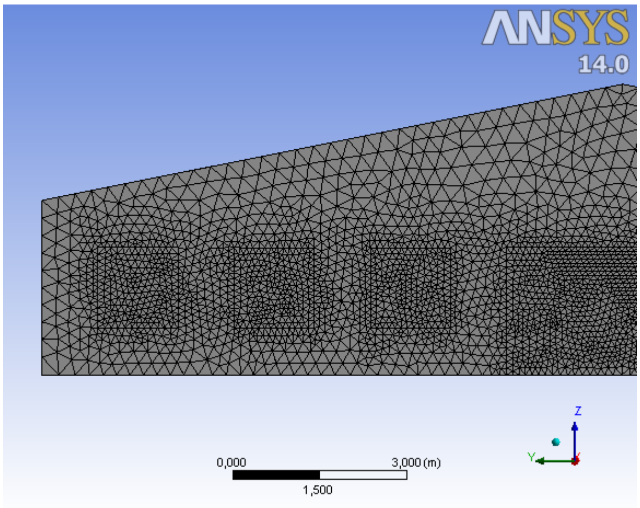


Fig. 3 - Front end wall

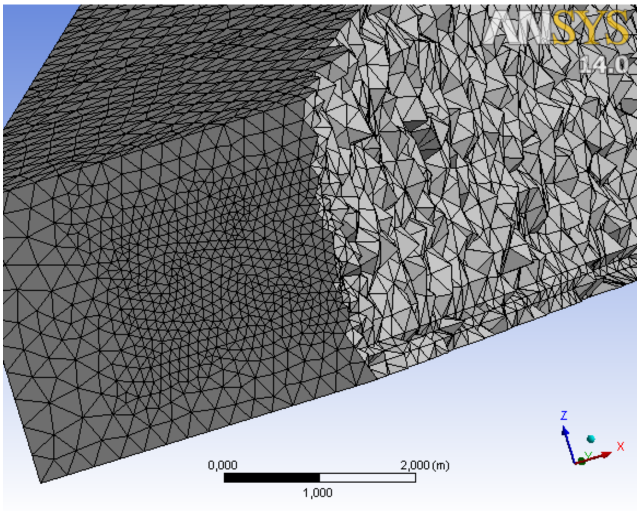


Fig. 4 - Back end wall's poultry house in section

The calculations' results of computer mathematic simulation for poultry house were given in Fig. 5-11.

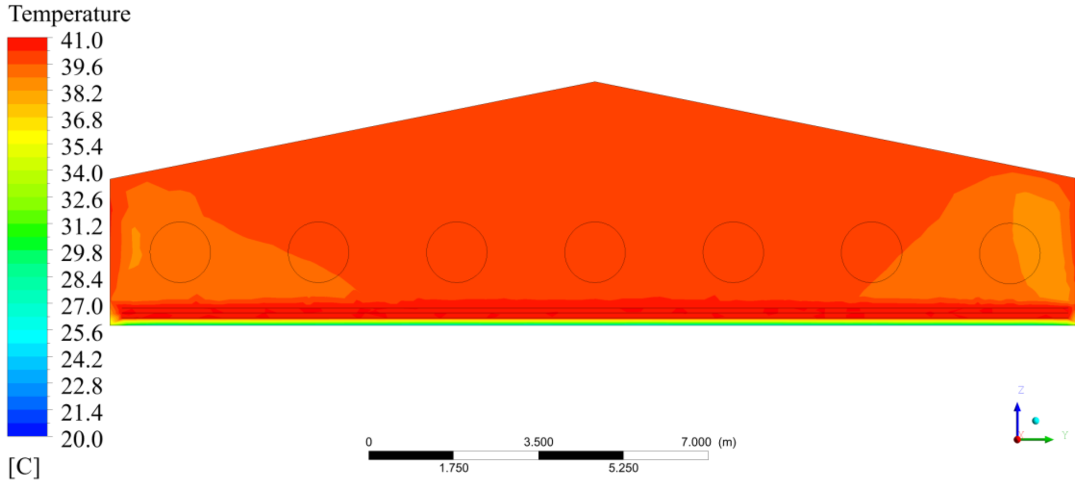


Fig. 5 - Temperature field in poultry houses of transverse section by centreline Oy on the distance 30 m from inlet, °C

All calculations were made on the mass rate of 170 kg/s. Walls and floor are produced from claydite-concrete with 0.2 m thickness. The calculation was made twice without or with air cooling systems usage of water from the underground cells in heat exchangers recuperators. The external air and water are chosen as a medium in heat exchanger recuperator The temperature of the external air at the inlet to the heat exchanger is +40°C. Heat capacity of the heat exchanger is selected in such a way that at the outlet the temperature of the air is + 20°C. The cooling water coming from underground wells has a temperature of +10°C. The poultry locates in floor holding. It is a source for the heat output with the temperature +41°C.

The high temperature without air cooling system has negative influence on poultry holding. You may decrease the temperature by ±2°C using the high productive vents in the poultry houses. These terms cannot reach the standard microclimate in poultry-farm. The temperature field distribution with inlet external air temperature +40°C is shown in Fig. 3, without heat exchanger recuperators' usage as air cooling system elements. The maximum temperature area is in the place of poultry floor holding as shown in Fig. 5.

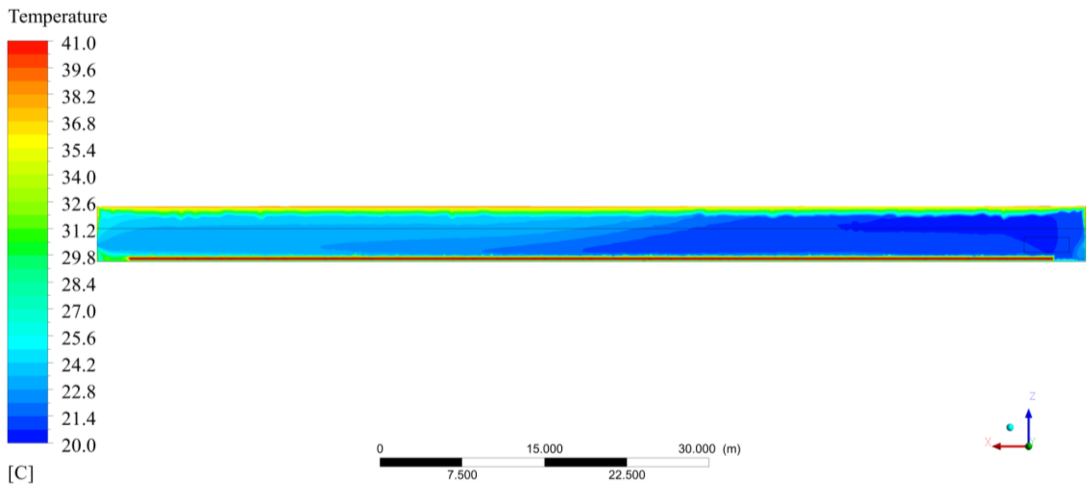


Fig. 6 - The change of temperature fields in longitudinal section of the building by centreline on the 6 m distance from the wall, °C

The temperature distribution was shown in Fig. 6-9 in the service area of cooling water usage from underground walls. The internal temperature was considered +20°C during the heat exchanger recuperator usage. The air temperature growing through the whole house was clearly observed in Fig. 7-8. The outlet temperature of cooled air was nearly +27°C. It is caused by poultry's heat output and the external poultry houses' walls by external air. So, the air supply did not increase the allowable norms in the present air ventilating system. The poultry house's temperature field has not homogenous character and oscillates in the range from +20 to +40ºC. The highest temperature was observed near the wall. It was caused by the heat exchange between the external and internal air cooling through barriers system considered the convective and radioactive components of heat exchanging. The heating air areas locate far from poultry floor holding. It did not affect the cooling.

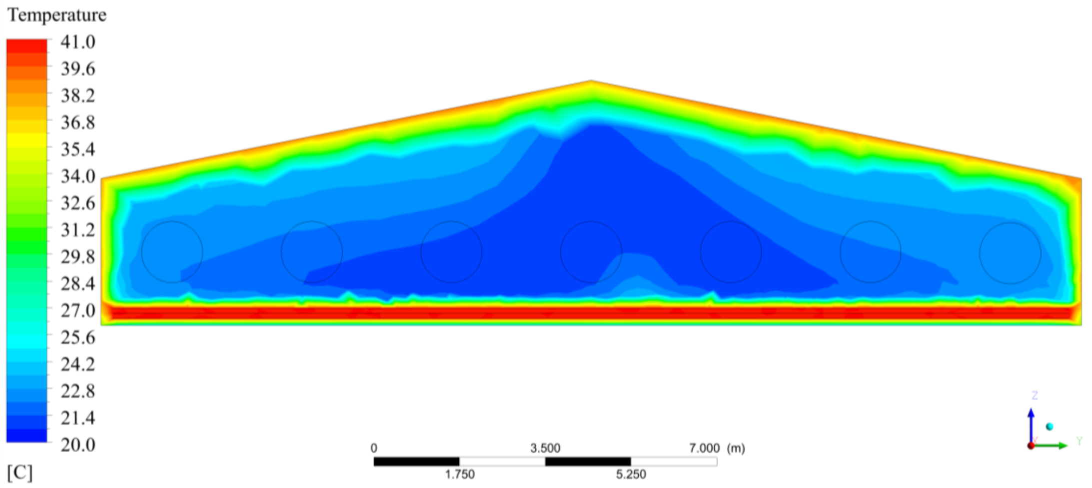


Fig. 7 - The temperature fields in the transverse section by axis 0y on the 30 m distance from inlet, ºC

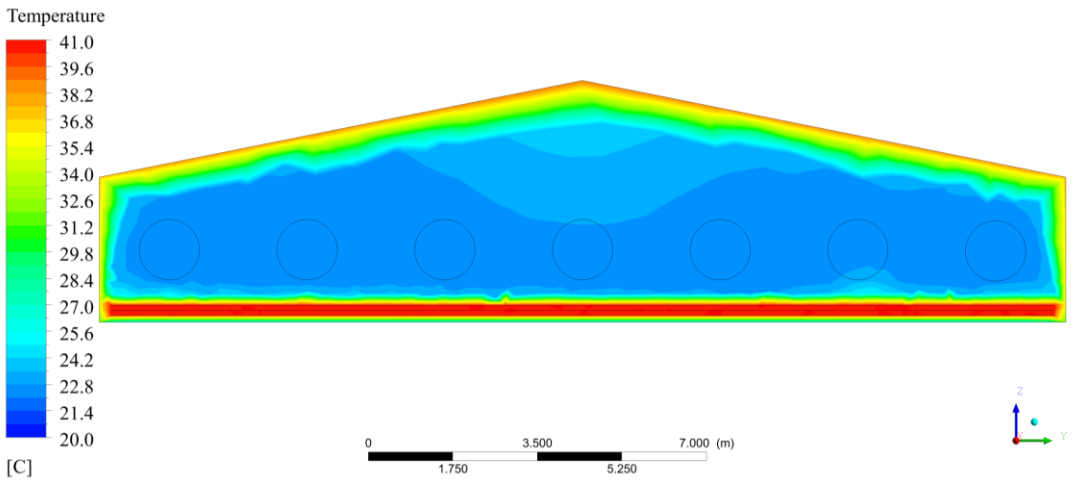


Fig. 8 - Temperature fields in poultry house in transversal section by axis 0y on the 60 m distance from inlet, ºC

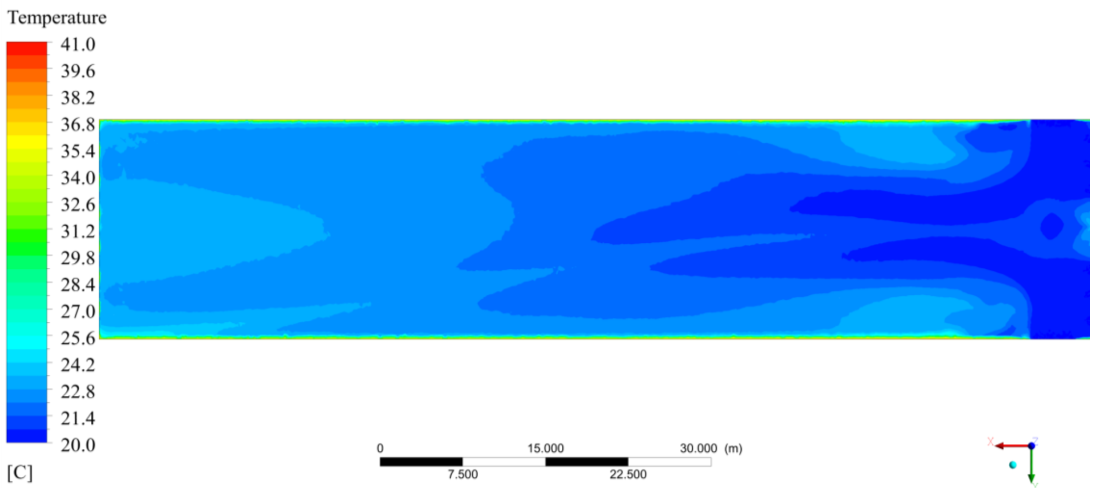


Fig. 9 - Temperature fields in poultry house in transversal section by axis *0z* on the 1.3 m height from the floor ºC

The air velocity of the poultry houses is the most important data for the poultry holding, especially near the poultry. The poultry houses velocity field is on the 0.5 height from the floor as shown in Fig. 10. The maximum velocity is not increased at 2.5 m/s. It is observed near the inlet and outlet parts of the poultry house. The air velocity reaches zero in the stagnation area. The average air velocity at the 0.5 m height is 1.97 m/s in spite of the high turbulence and non-homogenous flow. The air streamlines are shown in 3D image. The building's internal air motion has rectilinear character. As we have mentioned before, the stream non-uniformity and the stagnation area presence is near the side walls.

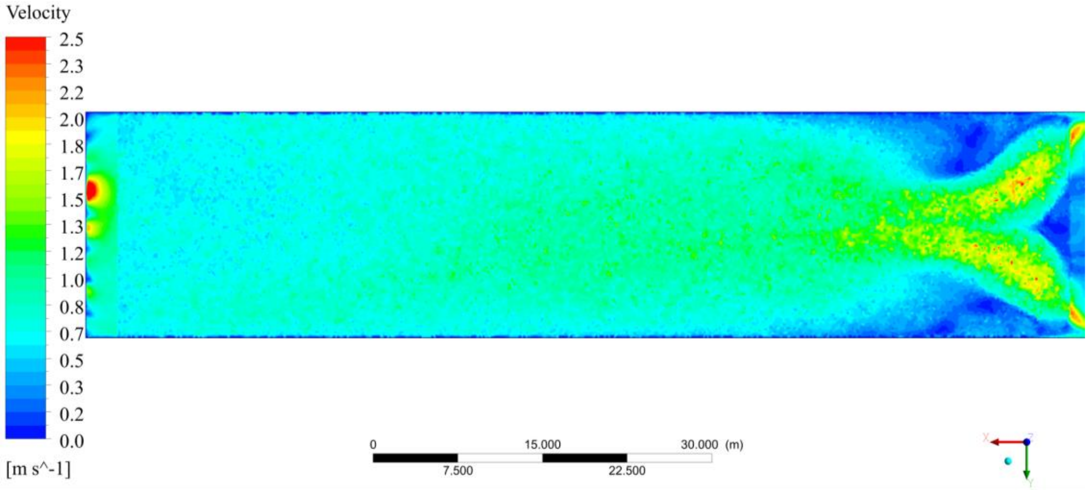


Fig. 10 - The velocity fields in poultry house in transverse section by axis *Oz* at 0.5 m height from the floor, m/s

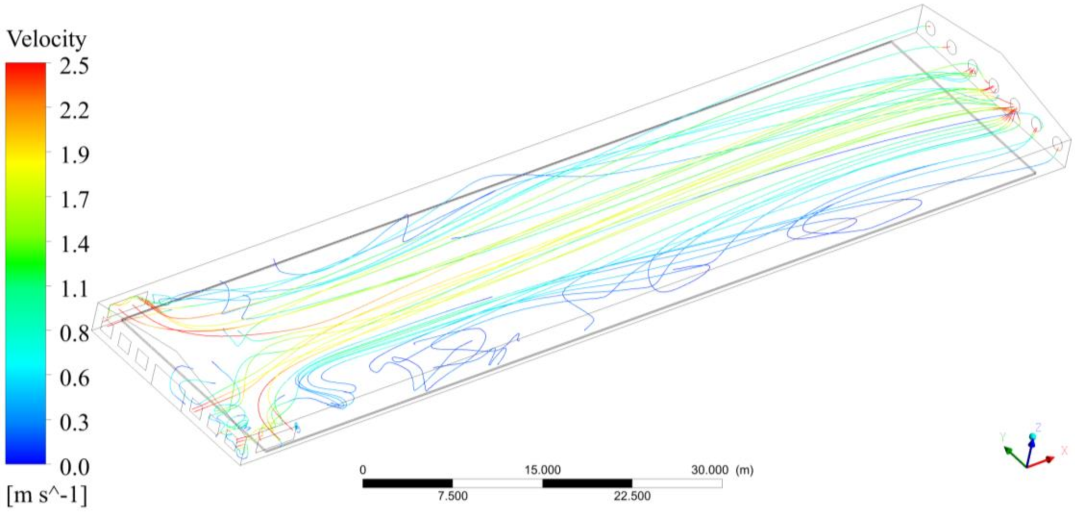


Fig. 11 - The air streamlines of poultry house in 3D image, m/s

CONCLUSIONS

The new air cooling system with heat exchangers recuperators was proposed. Heat exchangers were used for the water cooling from underground wells. It allows decreasing the poultry houses temperature to +20°C without increasing its relative humidity. The numerical simulation for the heat and mass transfer of ventilating air in poultry houses with or without cooling heat exchangers for air supply was provided. The velocity field, temperature and pressure were received using ANSYS Fluent software.

REFERENCES

[1] Allmaras S.R., Johnson F.T., Spalart P.R., (2012), Modifications and Clarifications for the Implementation of the Spalart-Allmaras Turbulence Model, *7th International Conference on Computational Fluid Dynamics*, pp. 9-13, Big Island/Hawaii;

[2] ANSYS (2011), ANSYS Fluent Theory Guide. Release, *Published in the USA*, 794 p.;

[3] Bailly C., Comte-Bello G., (2015), Turbulence. Series: Experimental Fluid Mechanics, *Springer International Publishing*, 360 p., Heidelberg/Germany;

[4] Blanes-Vidal V., Guijarro E., Balasch S., Torres A.G., (2008), Application of computational fluid dynamics to the prediction of airflow in a mechanically ventilated commercial poultry building. *Biosystems Engineering,* vol.100, no.1, pp. 105-116, San Diego/USA;
[5] Bustamante E., Calvet S., Estelles F., Torres A.G., Hospitaler A., (2017), Measurement and numerical simulation of single-sided mechanical ventilation in broiler houses, *Biosystems Engineering,* vol.160, pp. 55-68, San Diego/USA;
[6] Campbell J., Donald J., Simpson G. and other, (2007), Keeping birds cool costs down in summertime heat, *Auburn University in association with the US poultry and egg association*, no.48, pp. 12-15;
[7] Chui E.H., Raithby G.D., (2013), Computation of radiant heat transfer on a non-orthogonal mesh using the finite-volume method, *Numerical Heat Transfer*, vol.23, part B, pp. 269–288;
[8] Curi T., de Moura D.J., Massari J.M., Mesquita M., Pereira D.F., (2017), Computational fluid dynamics (CFD) application for ventilation studies in broiler houses, *Engenharia Agricola,* vol.37, no.1, pp. 1-12, Jaboticabal/Spain;
[9] Czarick M., Fairchild B., (2014), Plastic cooling pads are found to be less efficient comparing to paper cool pads, *Poultry Housing Tips. College of Agricultural and Environmental Sciences. The University of Georgia*, vol. 24, no.8, pp. 64-69, Georgia/USA;
[10] Dulnev G.N., Parfenov V.H., Sihalov A.V., (1990), Application of an EC for solving heat exchange problems (Применение ЭВМ для решения задач теплообмена), *by publishing in "High school" (опубліковано у видавництві «Вища школа»)*, 207 p., Moscow/Russia;
[11] Gorobets, V.G., (2006), Influence of nonisothermicity on the heat transfer from a bank of finned tubes in the presence of coating on the outside surface. *Heat Transfer Research,* vol. 37, no 2, pp. 93-102, Redding/USA;
[12] Hassanzadeh P., Raithby G.D., Chui E.H., (2008), Efficient calculation of radiation heat transfer in participating media, *Journal of Thermophysics and Heat Transfer,* vol. *22*, no 2, pp. 129-139, doi:10.2514/1.33271, Reston/USA;
[13] Hui X., Li B.M., Xin H.W., Zheng W.C., Shi Z.X., Yang X., Zhao S.M., (2018), New control strategy against temperature sudden-drop in the initial stage of pad cooling process in poultry houses, *International Journal of Agricultural and Biological Engineering,* vol.11, no.1, pp.66-73, doi:10.25165/j.ijabe.20181101.2479, Beijing/China;
[14] Hulzebosch J., (2005), How to keep your birds cool, *World Poultry Climate*, vol.21, no.6, pp. 32-34;
[15] Donald O.James, (2012), Technology of microclimate of broiler house, *by publishing in Aviagen Brands*, 44 p., Huntsville/USA;
[16] Khmelnik S.I., (2018), Navier-Stokes equations. On the existence and the search method for global solutions, Mathematics in Computers – MiC, 134 p., Bene-Ayish/Israel;
[17] Kim K., Yoon J. Y. Kwon H.J., Han J.H., Son J.E., Nam S.W., Lee I.B., (2008), 3-D CFD analysis of relative humidity distribution in greenhouse with a fog cooling system and refrigerative dehumidifiers, *Biosystems Engineering,* vol.100, no.2, pp. 245-255, San Diego/USA;
[18] Modest M.F., (2013), Radiative Heat Transfer (Third Edition), *Publishing in: Academic Press*, 897 p.;
[19] Murthy J.Y., Mathur S.R., (1998), Finite volume method for radiative heat transfer using unstructured meshes, *Journal of Thermophysics and Heat Transfer*, vol.12, no.3, pp. 313-321;
[20] Seo I.H., Lee I.B., Moon O.K., Kim H.T., Hwang H.S., Hong S.W., Han J.W., (2009), Improvement of the ventilation system of a naturally ventilated broiler house in the cold season using computational simulations, *Biosystems Engineering,* vol.104, no.1, pp. 106-117, San Diego/USA;
[21] Spalart P.R., Rumsey C.L., (2007), Effective inflow conditions for turbulence models in aerodynamic calculations, *Aiaa Journal,* vol. *45,* no. 10, pp. 2544-2553 doi:10.2514/1.29373, Reston/USA;
[22] Trokhanyak V.I., Bogdan Yu.O., (2015), The finite element method in making up meshes in ANSYS Meshing for CFD models (Застосування методу кінцевих елементів при побудові сітки в Ansys Meshing для CFD моделей), *Bulletin of Pryazovslyi State Technical University*, vol. 30, no. 2, pp. 181–189., Mariupol/Ukraine;
[23] Vyshnevskyi E.P., (2004), Comparative analysis of adiabatic humidification systems (Сравнительный анализ систем адиабатического увлажнения воздуха), *Plumbing, Heating, Air conditioning (*Сантехника, Отопление, Кондиционирование*)*, no. 8, pp. 76-83, Moscow/Russia;
[24] Zajicek M., Kic P., (2013), Longitudinal ventilation of broiler house – sumulation of variants, *12th International Scientific Conference Engineering for Rural Development*, pp. 198-202, Jelgava/Latvia.