EXPERIMENTAL RESEARCH AND CFD MODELING OF MODULAR POULTRY BREEDING
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ЕКСПЕРИМЕНТАЛЬНЕ ДОСЛІДЖЕННЯ ТА CFD МОДЕЛЮВАННЯ МОДУЛЬНОГО ВИРОЩУВАННЯ ПТИЦІ

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ABSTRACT
For high-quality and simultaneous breeding of different ages of poultry a modular keeping is proposed. The heating system of the module is a panel infrared heater. It is intended for local heating of technological area. Design dimensions of the module were determined for reasons of qualitative course of technological process, namely the stocking density of poultry. Experimental studies of the temperature regime of poultry breeding area were carried out. Body temperature of the poultry was within acceptable limits, up to 41.5ºC. In addition, the surface temperature of the feathers did not exceed 29.1ºC, which fully complies with sanitary and hygienic standards. For a better representation of temperature regime in the module, CFD modeling was performed. Fields of velocities, pressures and temperatures were obtained. The air temperature near poultry in the module reached 18.6ºC, and the average velocity did not exceed 0.75m/s.

РЕЗЮМЕ
Для якісного і одночасного різновікового вирощування птиці запропоновано модульне утримання. Системою теплозабезпечення модуля служить панельний інфрачервоний нагрівач. Він призначений для локального нагріву технологічної зони. Конструктивні розміри модуля визначалися з міркувань якісного перебігу технологічного процесу, а саме щільності посадки птиці. Проведено експериментальні дослідження температурного режиму зони вирощування птиці. Температура тіла птиці знаходилася в допустимих межах, до 41,5ºС. А температура поверхні пір'я не перевищувала 29,1ºС, що повністю відповідає санітарно-гігієнічним нормам. Для отримання більш якісного представлення температурного режиму в модулі проведено CFD моделювання. Отримано поля швидкостей, тисків і температур. Температура повітря поблизу птиці у модулі сягала 18,6 ºС, а середня швидкість не перевищувала 0,75 м/с.

INTRODUCTION
Intensive poultry farming in industrial conditions is carried out mainly in limited livestock facilities, equipped with mechanical ventilation systems. Frequency of heat stress of the body is constantly increasing due to poor regulation of microclimate parameters. This in turn affects the productivity of the poultry, namely, daily weight fluctuation, mortality, feed conversion rate and others (*Vitt R. et al., 2017*).

Traditional heating systems are not able to fully satisfy the temperature parameters in the poultry`s location area at the same time providing a dynamic thermal regime. Alternative to them may be local heating systems, such as infrared heating systems.

With the correct placing of infrared emitters, heating occurs only in the area where the poultry is located. This feature allows to avoid the necessity to heat the entire volume of the poultry house. In addition, the heaters are easy in adjusting and provide the required air temperature, which changes with the growth of poultry. With additional application of the automation kit, together with the infrared heating system, significant economic effect can be obtained (*Voznyak O. et al., 2021*).

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From a sanitary and hygienic point of view, infrared radiation has a positive effect on the physiological condition of poultry, especially on young stock. Radiation heat transfer occurs at the absence of intermediate environment between two surfaces at different temperatures. Thus, nature of the surface coating plays an important role in the absorption of infrared rays (*Amanowicz Ł. and Wojtkowiak J., 2018*).

Diffuse nature of the radiation heat transfer is shown *Brown K.J. et al., (2016),* where the example of infrared heater with a power of 600 W describes a method of studying the heat flow distribution. It is indicated that efficiency of the emitter raises up with initial increase of electric power and stabilizes at 52%. It is also proved that the uniformity of the radiant heat flow distribution improves with distance from the heater.

Linhoss J.E. et al., (2017) presents in his paper the results of a study of radiant heat flow at the heights of heater from 1.22 to 1.98 m above the measuring plane. Authors *Ermolaev A.N. et al., (2018)* presented the results of studies of a light infrared emitter. This heater has wide range of capacities and it is located at heights from 4 to 10 m. Numerous studies in this direction prove that the choice of infrared heater`s type depends directly on geometric dimensions of the room, geometric location of equipment, heat sources, size of irradiation area (*Kuznetsov G.V. et al., 2018; Semenov B.A. et al., 2018*). These facts confirm the influence of many factors on the formation of temperature regime in the irradiation area.

Sufficient attention is paid to the design of heater. Additional reflectors will increase the efficiency of radiation. *Lee E.H. and Yang D.Y. (2015)* made an experimental-numerical analysis of a parabolic reflector with a radiant heat source and different input widths, the effects of which on the temperature distribution are presented. In the paper *Maznoy A. et al., (2020)* is proposed a heater with using an annular cylindrical radiant burner mounted inside a stainless steel conical reflector. The item not only refocuses the directed radiant flow of the burner, but also participates in heat exchange with the flue gases and emits additional radiation flux. All these features show effectiveness of the application of infrared emitters in agriculture, in particular in poultry houses.

Authors *Gorobets V.G. et al., (2018b)* proposed a new cooling system in the poultry house using heat exchangers of special design (*Gorobets V.G. et al., 2018a)*. They performed CFD modeling of air flows and heat and mass transfer in the poultry house, using water from underground wells as a cooler. In addition, recommendations for the choice of ventilation systems in poultry houses are given. In continuation of these studies (*Gorobets V.G. et al., 2018c)*, authors optimized the height of the exhaust fans. It was shown that the ventilation equipment should be installed at a height of 1.5 m. This reduces the sizes of stagnant areas and the uneven distribution of air velocity near the poultry.

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

In the paper *Trokhaniak V.I. et al., (2020)*, the construction of the poultry house was modernized. CFD modeling was performed and the effective location of supply valves for the side ventilation system was found. Authors noted that the supply valves should be installed not lower than at a height of 200 mm from the floor level. Scientists recommended that this be further taken into account at the design stage of the side ventilation system.

Authors *Kiktev N. et al., (2021), Lysenko V. et al., (2019), Korobiichuk I. et al., (2017)* investigated the feasibility of using IoT technology in agricultural production and developing an energy-efficient method of controlling a modular electrical complex.

MATERIALS AND METHODS

Based on the principle of sectional poultry breeding, modular keeping of broiler chickens is proposed. The heating system of the module is a panel infrared heater, designed for a local heating of the technological area. To ensure a constant supply of fresh air and assimilation of hazards is provided a supply and exhaust ventilation system in the module.

This method of poultry breeding has a number of advantages. First of all, it is possible to use modules both in industrial breeding and within individual farms. The industrial method of poultry breeding involves the accumulation of large number of it in one poultry house, so the emergence and rapid spread of infectious diseases is possible. Due to the local microclimate, provided in the module, this negative phenomenon can be prevented. In addition, it is possible to keep different age groups of poultry in one poultry house, changing the temperature regime with the growth of poultry.

Infrared heating and ventilation systems provide normalized air temperature in the irradiation area when the air temperature in the module changes from +16 to +35 ºC, air velocity - from 0.2 to 0.3 m/s and there is quality regulation of these parameters (*Spodyniuk N. and Lis A., 2021*). At the same time, the required temperature conditions change while the poultry is growing.

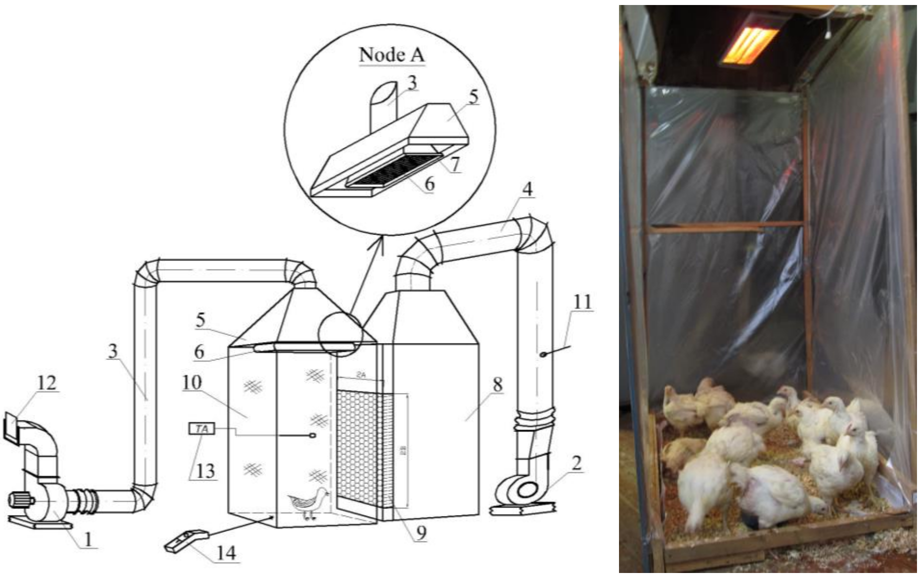
Design dimensions of the module were determined for reasons of qualitative course of technological process, namely, ensuring maximum indexes of production yield in the poultry house, taking into account normalized stocking density of poultry n_{norm} = 0.035 m^2 per 1 head and normalized intensity of floor irradiation q_{norm} = 174… 290 W/m^2 (*DSTD-AIC-04.05, 2005*).

Table 1 shows the results of solving the problem of choosing rational parameters of the module for poultry breeding.

Rational geometric parameters of the module **Table 1**

Module area *F*, m^2	Module length *a*, m	Module width *b*, m	Module height *H,* m	Dimensions of the infrared heater a_{heat}xb_{heat}, m	Irradiation area F_{irrad}, m^2
0.96	1.2	0.8	1.5	0.1x0.54	3.26

On the basis of defined rational parameters of the module for poultry breeding, experimental installation in full size, shown in Fig. 1, was mounted.



a) b)

Fig. 1 – Scheme (a) and a photo (b) of experimental installation for studying the temperature regime of technological area of module for poultry breeding

1 – exhaust fan; 2 – supply fan; 3 – exhaust air duct; 4 – supply air duct; 5 – exhaust outlet; 6 – infrared heater QH 1500; 7 – reflector; 8 – static pressure chamber; 9 – uniform air distributor; 10 – module for poultry breeding; 11, 12 – dampers; 13 – thermoanemometer ATT - 1004; 14 – pyrometer "Nimbus-530/1"

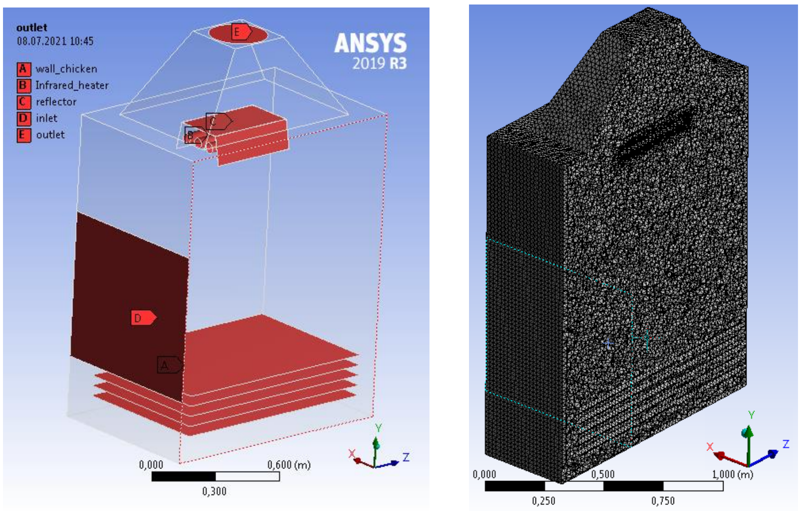
The experimental installation was built for reasons of quality provision the microclimate parameters in module and was represented as a complex of heating and ventilation system. Study of the temperature regime was carried out as follows. Poultry was located in the module in accordance with sanitary and hygienic standards of stocking density. The infrared heater *6* was intended for local heating of technological area of the module. Through the uniform air distributor *9* and the static pressure chamber *8*, fresh air was supplied to technological area of the module. Exhaust outlet *5* removed polluted air from the module. Air flow was regulated with the dampers *11* and *12*. The temperature in the module was measured with a thermoanemometer ATT – 1004 13. The surface temperature on the poultry's feathers was measured with a pyrometer "Nimbus-530/1" 14.

For a better assessment of thermal state in the module and microclimate in general, numerical simulations were performed. To save computer calculation time, numerical simulations were performed only in module for poultry breeding 10. Prepared geometric model with the selected boundary conditions is presented in fig. 2 a.

Mathematical model is based on the Navier-Stokes equations (*Gorobets V.G. et al., 2018b; Khmelnik S.I., 2018*), the energy transfer equations for convective flows and the continuity equations. The Spalarta-Allmarasa turbulence model (*Allmaras S.R. et al., 2012*) and the Discrete Ordinates radiation model (*ANSYS, 2017*) were used in the calculations.

Air consumption of supply and exhaust air was 800 m^3/h (0.02722 kg/s). Irradiation intensity of the infrared heater was 7238 W/m^2. Blackness degree of the heater surface was 0.7. Temperature of the poultry was 41°C.

Numerical model of hydrodynamics and heat and mass transfer used the finite element method. The method of local grid control was used in construction of grid for the module area (Fig. 2 b). The quality index of the Orthogonal Quality grid corresponds to about 0.274. The minimum size of the element was 0.005 m, the maximum - 0.02 m. Number of elements - 1747410, number of nodes - 2381752. The protruding grid is clearly visible in the section, thus it is possible to estimate better quality and shortcomings of the grid. In addition, it can be noticed a thickening of the grid near infrared heater.



a) b)

Fig. 2 – Geometric model (a) and a grid (b) of area of the module for poultry breeding

RESULTS

Temperature regime is a complex phenomenon that combines air temperature and ambient surface temperature. As it is known that the main parameters that affect its formation in module are power of infrared heater and height of its installation, that is, these values were chosen as input and variable factors. The thermal power Q_{heat} varied from 500 to 1500 W, and the installation height of the heater H was chosen as the most optimal for the module - 1.5 m. Temperature regime in the module also depended on background temperature in the room, and this value was also taken into account. In the cold period of the year, indoor air temperature was 15 - 18 ºC.

Research results of the temperature regime of module for poultry breeding were compared with the normalized values, according to sanitary and hygienic standards [20] and numerical simulations (Table 2).

The air in the module was heated due to convective heat transfer between the heated surface of the poultry's body, other surrounding surfaces and the surrounding air. Therefore, air temperature in the module was the resulting temperature and it took into account temperatures of all surfaces, feather surface temperature and indoor air temperature.

For a more thorough study of the effects of infrared radiation on poultry's body, which was placed under the heater for a long time, the body temperature of poultry was determined. As can be seen from the table, body temperature is within acceptable limits, according to sanitary and hygienic standards (*DSTD-AIC-04.05, 2005*), therefore, the body does not overheat and infrared radiation has a positive effect on young animals.

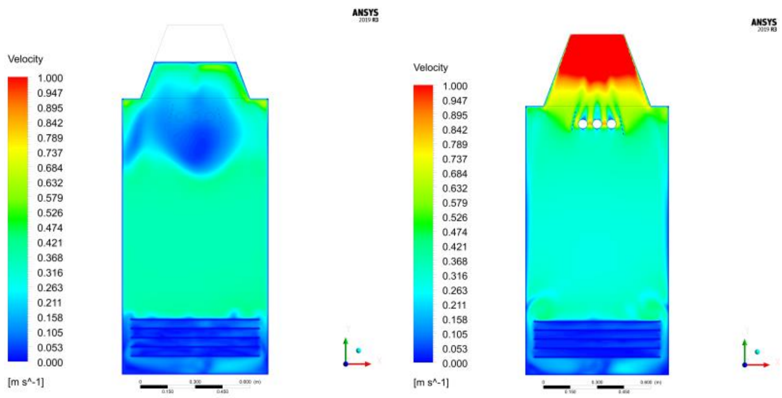
Therefore, in a comprehensive experimental study obtained the total air temperature in the module for poultry breeding, which was changed with increasing of infrared heater's power. The obtained temperature values satisfied the internal microclimate parameters in poultry's location areas. The use of heating and ventilation system made it possible to change air temperature in the module quickly and dynamically by adjusting the power of heater. Changing the power by one position allowed increasing the air temperature in poultry's location area by 7.2%.

Figures 3-9 show the results of numerical simulations. Figures 3-4 show the velocity field in the module for poultry breeding. Maximum velocity in the boundary area "exit" reaches 10.427 m/s (Fig. 3b). Average air velocity near the poultry is 0.75 m/s, which fully complies with the standards of poultry farming. Velocity at the boundary area "entrance" is 0.2 m/s. In figure 4, flow turbulence can be observed in the upper part of module. The air flow is slowly directed to the end wall, opposite the boundary area "entrance" and rises up.

Table 2

Results of experimental research and numerical modeling of the temperature regime of module for poultry breeding

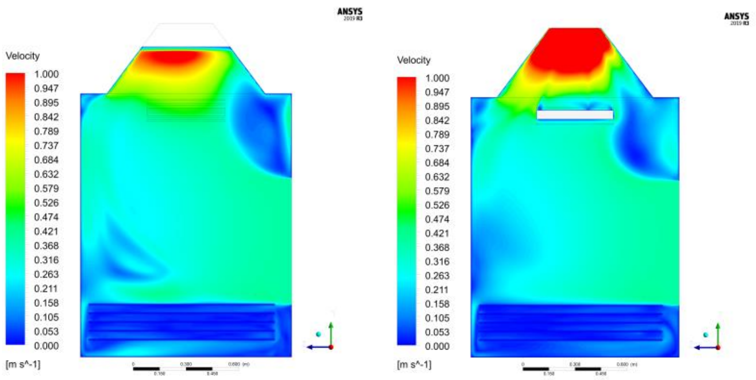
Results	Thermal power of the heater Q_{heat}, W	Installation height of the heater H, m	Indoor air temperature t_{in}, °C	Body temperature of the poultry t_{body}, °C	Feather surface temperature t_{feath}, °C	Air temperature in module t_{mod}, °C
Experiment	500	1.5	15	40.9	26.1	19.5
	1000	1.5	15	41.0	27.4	20.7
	1500	1.5	15	41.5	29.1	22.3
CFD	1000	1.5	15	41.0	-	19.124
Standards for poultry breeding (*DSTD-AIC-04.05, 2005*)	400…1500	1…1.7	15…18	40…42	23…35	16…35



a) b)

Fig. 3 – Velocity field (m/s) in the module for poultry breeding on the axis *xy*

a – 0.3 m from the wall; b – 0.6 m from the wall



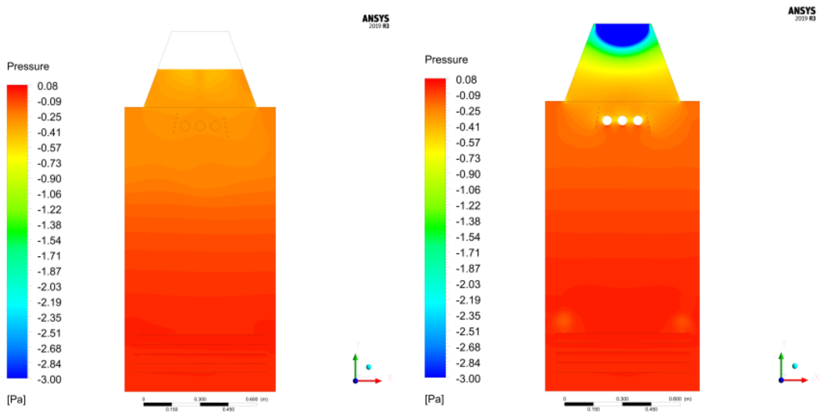
a) b)

Fig. 4 – Velocity field (m/s) in the module for poultry breeding on the axis *zy*

a – 0.2 m from the wall; b – 0.4 m from the wall

Figures 5-6 showed the pressure field in the module. The maximum pressure drop reaches 10 Pa. At the boundary area "output", a slight vacuum of up to 5 Pa is created in the module. Observed phenomenon is insignificant and does not affect the poultry breeding as a whole.

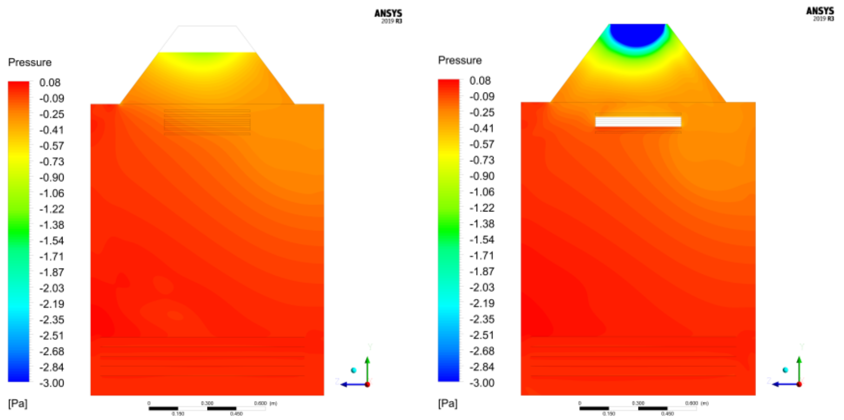
Figures 7-8 show the temperature field in the module. The maximum temperature is observed near the infrared heater - 154 ºC. An infrared emitter heats the poultry of modular breeding. At the same time, air flow passes around the poultry in the module. The heat is extracted from the surface of poultry's body and moves up. Average temperature in the module is 18.6ºC, which fully meets the standards of poultry farming.



a) b)

Fig. 5 – Pressure field (Pa) in the module for poultry breeding on the axis *xy*

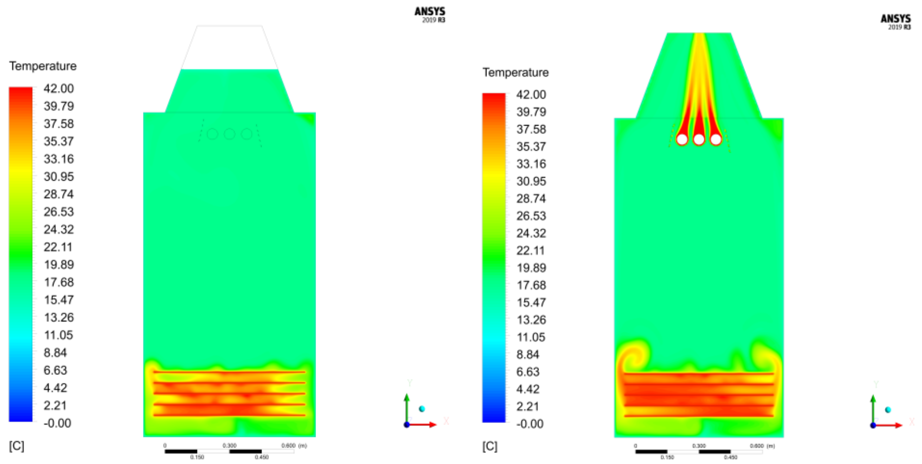
a – 0.3 m from the wall; b – 0.6 m from the wall



a) b)

Fig. 6 – Pressure field (Pa) in the module for poultry breeding on the axis *zy*

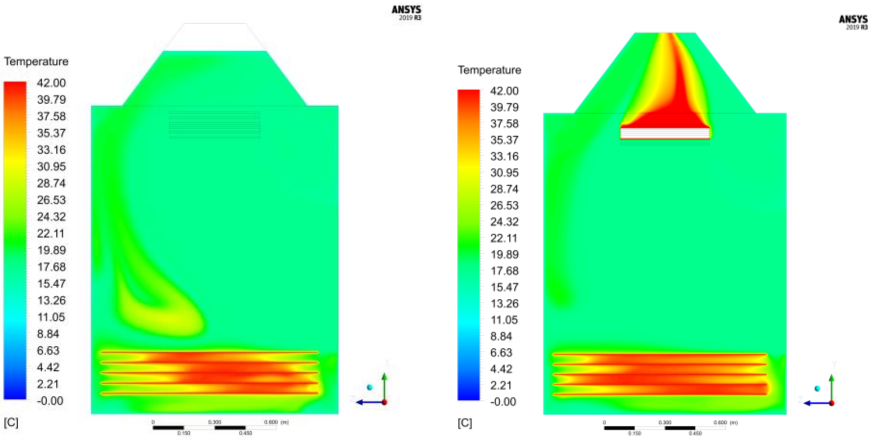
a – 0.2 m from the wall; b – 0.4 m from the wall



a) b)

Fig. 7 – Temperature field (ºC) in the module for poultry breeding on the axis *xy*

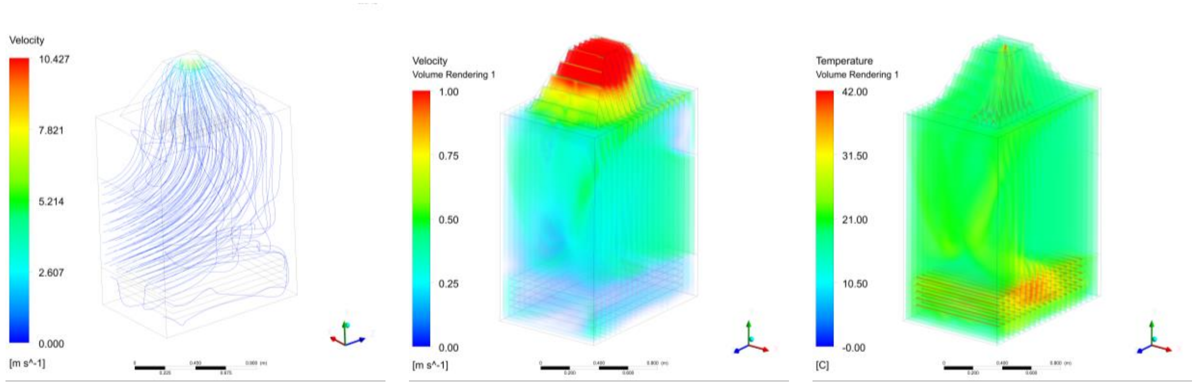
a – 0.3 m from the wall; b – 0.6 m from the wall



a) b)

Fig. 8 – Temperature field (ºC) in the module for poultry breeding on the axis *zy*
a – 0.2 m from the wall; b – 0.4 m from the wall

Below are the current lines, m/s (Fig. 9 a), air velocities, m/s (Fig. 9 b) and air temperatures, ºC (Fig.9c) in the module for poultry breeding in 3D display. From these images, it is possible to estimate in more detail and qualitatively the formation of a microclimate in the module and its influence on the poultry's organism.



a) b) c)

Fig. 9 –Current lines, m/s (a), air velocities, m/s (b) and air temperatures, ^{o}C (c) in module for poultry breeding in 3D display

CONCLUSIONS

Based on the principle of sectional poultry breeding, modular keeping of broiler chickens is proposed. Design of a module for poultry breeding with an infrared heater has been developed. The proposed design is energy efficient and it is recommended for installation in poultry houses.

Experimental researches of a temperature regime in the module at change of thermal power of the heater were carried out. Air temperature in the module, as well as the thermal state of the poultry's organism were within acceptable values, according to sanitary standards of poultry farming. The use of infrared heater allows changing the air temperature in module dynamically according to the technological process.

Numerical modeling of the module for poultry breeding was carried out. Fields of velocities, pressures and temperatures were obtained. The microclimate in the module was analyzed. The air temperature near the poultry in the module reached 18.6ºC, and the average velocity did not exceed 0.75m/s.

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