NUMERICAL ANALYSES OF AIR VELOCITY AND TEMPERATURE DISTRIBUTION IN POULTRY HOUSE USING COMPUTATIONAL FLUID DYNAMICS

آنالیز عددی توزیع سرعت و دما در مرغداری با استفاده از دینامیک سیالات محاسباتی

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ABSTRACT

Experimental analysis of air velocity and temperature distribution in poultry houses is laborious, especially for large scale houses. Enhanced broiler yield can be obtained when the house is suitably ventilated. Therefore, efficient prediction tools would be vital. Computational fluid dynamics (CFD) provides detailed data on indoor flow patterns, air velocity and temperature distribution in poultry houses giving promising outlooks as an efficient and cost-effective tool to establish optimum ventilation systems. This work focused on evaluation and numerical analysis of the influence of differential pressure (20, 30 and 40 Pa) and fan activation scenarios on indoor air velocity and temperature distribution in a poultry house. Results showed that air velocity tends to be maximum toward the centre of the cross-section of the house and minimum near the floor next to the side walls. Furthermore, it is elucidated that considerable thermal discomfort for chickens is likely due to temperature variation at the proximity to the exhaust fans. Based on the evaluations of pressure variation on the air velocity distribution, quick estimation of the air velocity can be obtained in the zones occupied by chickens. Generally speaking, numerical computation of the equations dominating the poultry house leads to desirable control model of the ventilation and aeration. This would be vital in decision making and economical management of the house.

خلاصة

تجزیه و تحلیل تجربی توزیع سرعت هوا و دما در مرغداری‌ها، بخصوص در مرغداری‌های بزرگ، بسیار دشوار است. بیشترین و بهترین عملکرد مرغداری‌ها موقعی حاصل می‌شود که سالن به‌خوبی تهویه شود. بنابراین نیاز به ابزار پیش‌بینیموثری، حیاتی است. دینامیک سیال محاسباتی (CFD) اطلاعات دقیقاز الگوی جریانهوا،نحوه توزیع سرعت هوا و دما در مرغداری‌ها فراهم می‌کند که به عنوان یک ابزار کارآمد و مقرون به صرفه، برای ایجاد سیستم‌های تهویه مطلوب چشم‌اندازهای امیدوار کننده‌ای ارائه می‌دهد. اینمطالعهبه ارزیابی و تجزیه و تحلیل عددی، تاثیر اختلاف فشار (20، 30 و 40پاسکال)و کارکرد هواکش‌ها بر توزیعسرعت هوا و دمای سالن در مرغداری، متمرکز شده است. نتایج نشان داد که سرعت هوا به حداکثر مقدار خود درخط مرکزی مرغداری و حداقل مقدار خود در نزدیکی کف و کنار دیوارهای جانبیمی‌رسد. به‌علاوه، مشخص است که شرایط نامساعد قابل توجهی برای جوجه‌ها در مجاورت هواکش‌ها،به علت تغییرات دما،وجود دارد. بر اساس ارزیابی‌ها تاثیر تغییرات فشار در توزیع سرعت هوا، می توان برآورد سریع سرعت هوا در مناطق اشغال شده توسط جوجه‌ها رابه‌دست آورد. به طور کلی، محاسبه عددیمعادلات غالب در مرغداری، منجر به یافتن مدل کنترلی مطلوب برای تهویه و هوادهی می شود. اینموضوع در تصمیم گیری و مدیریت اقتصادیمرغداری بسیار حیاتی است.

Nomenclature			
P	Pressure, Pa	**AH**	total chicken heat, W
ρ	Density, kg m^{-3}	**AHS**	sensible heat from chicken, W
S_h	Total entropy, J K^{-1}	**AHL**	latent heat from chicken, W
τ	Stress tensor, Pa	**m**	mass of chicken, kg
E	Total energy, J	**Ti**	indoor temperature, °C
k_{eff}	Heat transmission coefficient	**Sm**	Mass source, kg m^{-3}
h	Specific enthalpy, J kg^{-1}	**J**	Component of diffusion flux, kg m^{-2}s^{-1}

INTRODUCTION

Meat production in poultry is a crucial and economical industry in the world *(Mostafa et al., 2012).* Controlling poultry conditions is an increasingly important issue in rearing processes. Environmental control systems in poultry houses include heating, ventilation and cooling which in turn are featured by temperature, air velocity, relative humidity, concentration of oxygen, ammonia, carbon dioxide, dust and microbial contamination *(Blanes-Vidal et al., 2007).* Ventilation in poultry houses is an action that prepares required air and oxygen, thermal comfort and reduces polluted gas concentration of chickens. The most common system

in poultry houses is forced ventilation based on negative-pressure. Velocity range at the animal level, rate of air exchange and air distribution are three basic principles for ventilation design (*MWPS., 1990; ASAE EP270.5., 2009*; *Pedersen., 1999*). Operational factors such as fan operation, adjustment of air inlet openings and pressure drop are essential to define an optimal ventilation system (*Bustamante et al., 2012*).
Among ventilation systems, tunnel ventilation is extensively used in most poultry houses in order to remove extra heat and to simultaneously prepare the required amount of fresh air during hot seasons (*Kwon et al., 2015*). A significant distinction between tunnel ventilation and conventional poultry housing is the uniformity of air movement. The uniform air movement results in increased cooling for the birds throughout the house. In ventilation systems, poultry breeders usually control the internal environment by changing the amount of slot opening inlets and the activity of fans. These changes are performed by automatisms that cause changes in the differential pressure and air velocity values (*Bustamante et al., 2013*). Air flow rate in the zone occupied by the birds is one of the main parameters affecting the creation of an appropriate indoor environment (*Zajíček and Kic, 2013*). When the ambiance climate is hot and humid, temperature inside the poultry house rises above the recommended levels. As a result, air flow rate strongly affects convective animal heat losses and plays a vital role in animal welfare. However, experimental measurement of air velocities in poultry houses has obstacles such as lack of comprehensive details of interior air velocity in various parts of the building, high cost of measuring devices and finally sensitivity of some electronic devices to environmental parameters which distort the output data (*Blanes-Vidal et al., 2008*).

In the last few years there has been a growing interest in using computational fluid dynamics (CFD) in order to remove experimental measurement limitations and get careful results (*Lee et al., 2007;Seo et al., 2009*). This method has several benefits for setting the experimental conditions within poultry houses, enabling airflow predictions. Hence, CFD has been widely used for ventilation of concentrated agricultural systems, such as greenhouse (*Bartzanas et al., 2002; Campen and Bot, 2003; Campen, 2005; Fatnassi et al., 2006; OuldKhaoua et al., 2006; Baeza et al., 2008; Bournet et al., 2007*), poultry houses (*Norton et al., 2010; Li, 2012; Zajicek and Kic, 2012; El Mogharbel et al., 2013; Rojano et al., 2015; Bustamante et al., 2015*), livestock houses (*Bjerg et al., 2013; Wu et al., 2012*) and storage (*Ghoreishi-Madiseh et al., 2015; Tseng et al., 2016*). CFD has been considered as a strong and versatile tool for analyzing complex phenomena, such as turbulent flow or heat transfer, according to various environmental conditions (*Kwon et al., 2015*). CFD could also save the cost, time and effort associated with field experiments to establish the optimum system (*Lee et al., 2009*). Another effective parameter inside the poultry house is static pressure. Indeed when the exhaust fan is active, it pulls air out of the house. Air from outside the house moves into the house to replace the air removed by the exhaust fan. Theoretically, when the fans are active, they could pull all the air out of the house and creating a vacuum (*Czarick et al., 2002*). The higher static pressure the harder the fans have to work. As the level of static pressure increases, the amount of air moved by a fan decreases and power usage increases (*Czarick et al., 2010*).

In this work, we study a poultry house equipped with tunnel ventilation, using a powerful numerical method, CFD, to characterize the accurate internal environment. Thermohydraulic parameters governing the house ventilation and hence optimum management are quantified. The impact of static pressure and number of active fans on the air velocity and temperature distribution in the zone occupied by the birds (0.2 m above of floor) are argued.

MATERIALS AND METHODS

Simulated broiler house

The poultry house simulated in this study was typical of that popularly used in Iran. It was located in the city of Nooshin Shahr (latitude: 37°, 43', longitude: 45°, 3' and 1320 m above sea level). Fundamental geometric dimensions of the hall are as follows: length, 80 m; width, 15.80 m; side-wall height, 2.7 m, and the maximum distance from floor to ceiling, 3.6 m. This broiler house uses a mechanically ventilated tunnel system by negative pressure with multiple tunnel fans during the summer and a mechanically cross-ventilated system using a number of inlets in the winter. The house was provided with 10 side-wall inlets, each 120 cm wide and 100 cm high, whose central horizontal axis was located 1.1 m above the floor, and seven fans located at the end wall with a diameter of 0.65 m. Brick was the main material used in all the walls and polystyrene as insulation between bricks and sandwich panels with a thickness of 4 cm used for roof (Fig. 1).

The actual arrangement of the house is given in Fig 2. Characteristic of poultry house used in simulation are indicated in Table 1.

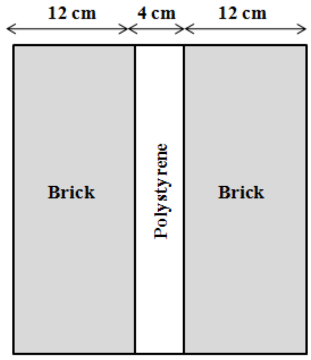

Fig. 1 -Structure of poultry houses walls

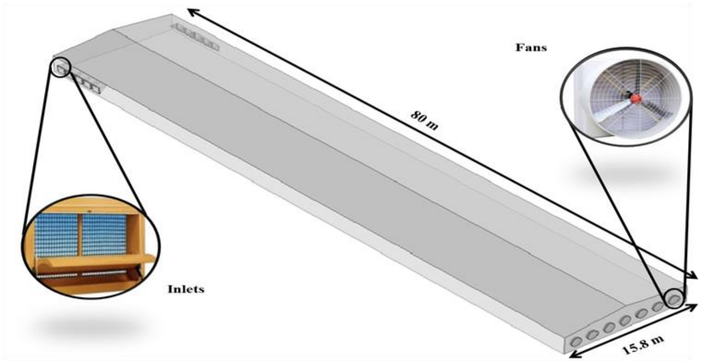

Fig. 2 -Schematic and dimensions of poultry house

Table 1

Characteristic of poultry house used in simulation

Poultry house dimensions	
Length	80 m
Width	15.8 m
Height	2.7 m
Ceiling height	3.6 m
Chicken number	19000
Chicken density	15 chickens per m^2
Chicken age	3 weeks
Number of exhaust fans	7 (diameter 1.3 m)
Number of air inlets	10 (1.20 * 1.00 m)

Numerical model

Numerical methods for calculating air velocity and temperature distribution of poultry house are attractive in terms of time and costs given the difficulty to experimentally determining the flow and temperature field. In this study, three-dimensional CFD models were generated by COMSOL Multiphysics (ver. 5.1) software. Fine and dense meshes were used to improve the accuracy of the CFD model. The standard k-ω model was used to simulate the air velocity and temperature in the summer (high ventilation rate) conditions and simulations were carried out under steady-state conditions. This model performs excellent near the wall, as a result of its simple low Reynolds number formulation and its ability to accurately compute flows with weak adverse pressure gradients (*Yang, 2004*).

Governing equations

CFD indeed acts as a powerful alternative for implementation of sensors and massive experimentation. The fundamental theory behind all CFD methods is the resolution of a set of nonlinear partial differential equations where the equations correspond to conversation of mass (Eq. (1)) or continuity, momentum (Eq. (2)) or Navier-Stoke's law and energy (Eq. (3)) (*Shivkumar, 2014; Mostafa et al., 2012 ; Seo et al., 2009; El Mogharbel et al., 2013*).

$$\frac{\partial P}{\partial t} + \nabla.(\rho\vec{v}) = S_m \tag{1}$$

$$\frac{\partial}{\partial t}(\rho\vec{v}) + \nabla.(\rho\vec{v}\vec{v}) = -\nabla P + \nabla.(\bar{\tau}) + \rho\vec{g} + \vec{F} \tag{2}$$

$$\frac{\partial}{\partial t}(\rho E) + \nabla.\left(\vec{v}(\rho E + P)\right) = \nabla.\left(k_{eff}\nabla T - \sum_j h_j\vec{J}_j + (\bar{\tau}\vec{v})\right) + S_h \tag{3}$$

Boundary condition

Boundary conditions for air inlets and outlet fans, differential pressure was chosen. The differential pressure variable was set at 20, 30 and 40 Pa. At each pressure level, two groups of fans worked: first stage 5 fans active and second stage 7 fans active. Average ambient temperature for summer conditions in western Azerbaijan was chosen 25°C and heat flux boundary condition for the floor, instead of the heat generated by the hens, determined with Eq. (4), was applied. Also for heat exchange with the exterior, heat flux boundary condition were considered. Eq. (5) and Eq. (6) compute the produced sensible and latent heat, respectively (*CIGR, 2002*).

$$AH = 10.62\, m^{0.75} \times \left(1 + \frac{20(20 - T_i)}{1000}\right) \tag{4}$$

$$AH_s = 0.61\ \times AH - \left(\frac{0.228}{1000}\right) \times T_i^2 \tag{5}$$

$$AH_L = AH - AH_S \tag{6}$$

RESULTS

The main objective of this article is to show effect of differential pressure between inlet and outlet on air velocity and temperature distribution in the zone occupied by the birds by CFD methods. A comparison of velocity profiles and temperature profiles at various differential pressure and fans activation was done.

Air velocity variation

Fig. 3 illustrates the air velocity distribution of the poultry house at 20 Pa differential pressure and 5 fans active conditions. The results, as seen in fig. 3, indicate that maximum value for air velocity obtained in centerline of the house and the region near the inlets. In half end of house distribution of air velocity is approximately uniform. It can be seen infig. 3 that air velocity tends to be highest toward the center of the house cross-section and lowest near the floor next to the side walls. There are similarities in the distribution of velocities between the present study and (*Blanes-Vidal et al., 2007; Czarick et al., 2015*) study. Variation of air velocity at 30 and 40 Pa differential pressure and 5 fans active condition are shown in figures 4 and 5, respectively.

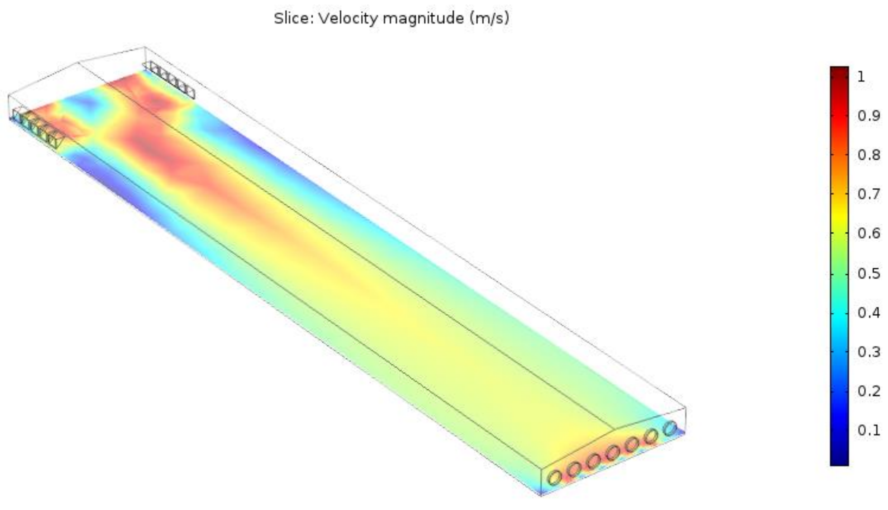

Fig. 3 - Variation of air velocity at 20 Pa differential pressure and 5 fans active condition

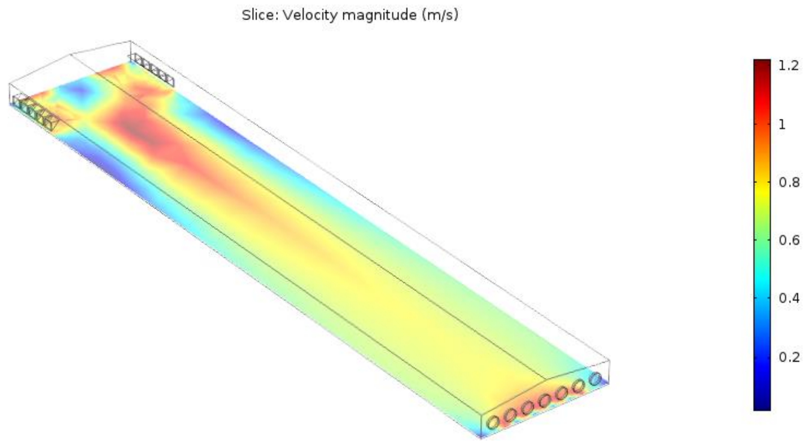

Fig. 4 - Variation of air velocity at 30 Pa differential pressure and 5 fans active condition

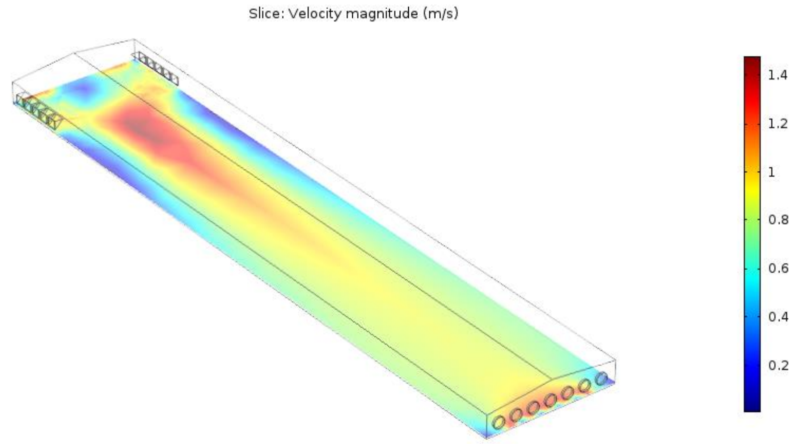

Fig. 5 - Variation of air velocity at 40 Pa differential pressure and 5 fans active condition

Fig. 6, 7 and 8 present the distribution of air velocity within the poultry house at various differential pressures (20, 30 and 40 Pa) and 7 fans active condition, respectively. The maximum value for air velocity in the centerline of the house at 20, 30 and 40 Pa differential pressures is 1.2, 1.8 and 2 m/s, respectively. Proper air velocity in the poultry house is essential for ensuring thermal homogeneity in the zone occupied by the chickens. Also sufficient air velocity is required to keep the litter inside the house dry. When ambient temperatures are above that in the chicken zone, air velocity must be kept relatively high to reduce bird body heat (*Mostafa et al., 2012*). According to (*Bustamante et al., 2015*) high air velocity values (~2 m/s) in the poultry house can help for chicken thermoregulation by increasing the convective flux heat of them and therefore decrease their thermal stress and reduce mortality. Also this finding corresponded to (*Czarick et al., 2010*) who indicate that with increasing static pressure, speed increases. This result is shown in figure 9.

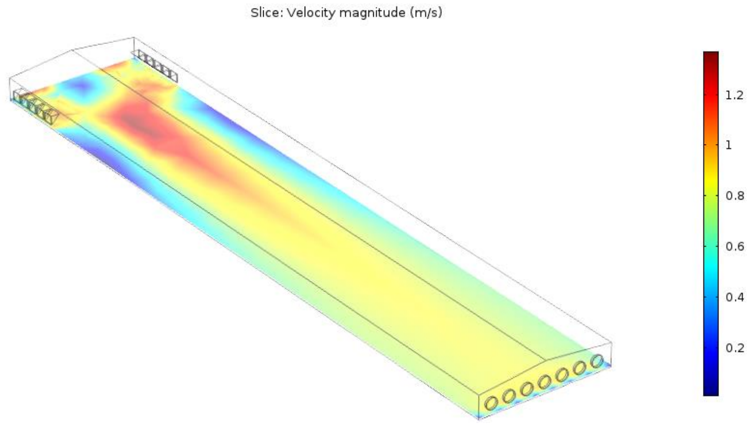

Fig. 6 - Variation of air velocity at 20 Pa differential pressure and 7 fans active condition

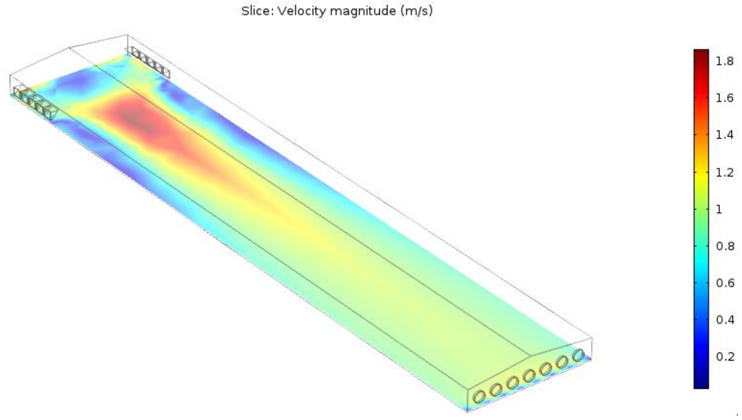

Fig. 7 - Variation of air velocity at 30 Pa differential pressure and 7 fans active condition

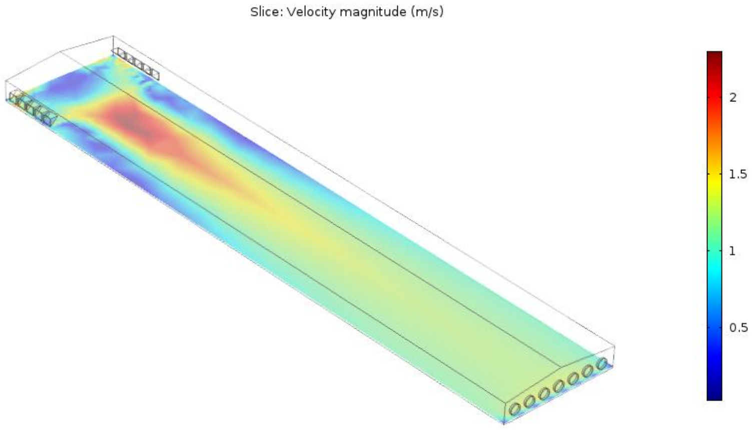

Fig. 8 - Variation of air velocity at 40 Pa differential pressure and 7 fans active condition

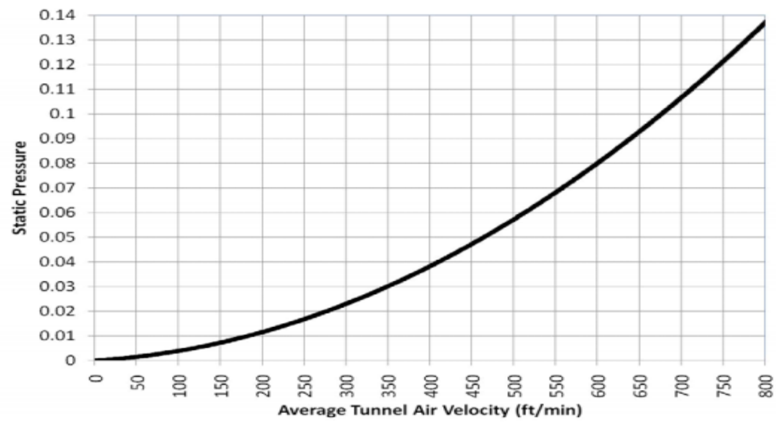

Fig. 9 - Relationship between air velocity and the static pressure in tunnel-ventilated houses
(Czarick et al., 2010)

Temperature variation

Figures 10-12 describe the monitored thermal distribution along the zone occupied by the chickens (0.2 m above the floor) according to the variables of differential pressure (20, 30 and 40 Pa) and 5 fans active, respectively. It is shown in figure 10 that air temperature increases when it moves through the poultry house length. When entering air temperature was 25°C, the CFD model predicted an increase in air temperature in the order of 4 or 5°C at the outlets; This increase is due to heat production by animal. Therefore, additional heat is transported from the inlet towards the outlet. This result has best agreement with (*Lee et al., 2007; Osorio et al., 2011; Rocha et al., 2014*) searches. Also this temperature increasing for figures 11 and 12 observable, but value of output temperature reduces due to increasing air velocity.

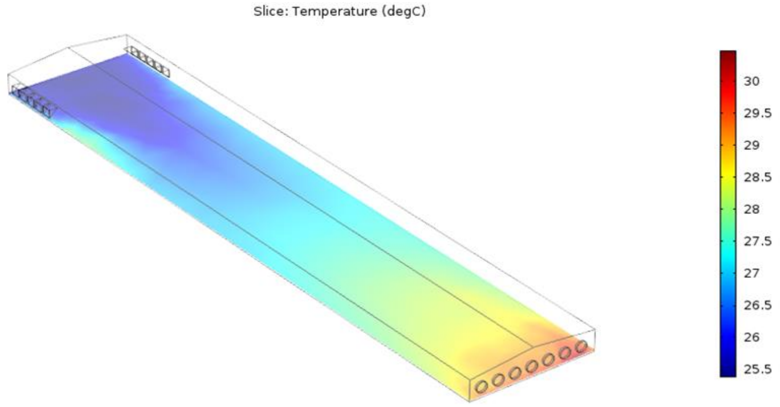

Fig. 10 - Distribution of temperature at 20 Pa differential pressure and 5 fans active condition

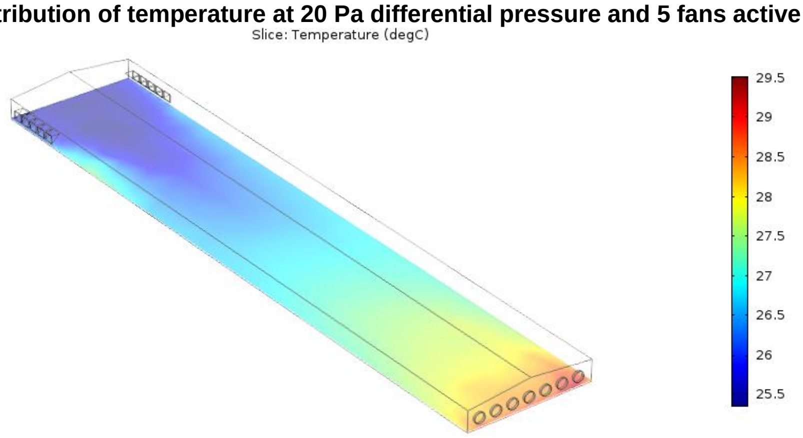

Fig. 11 - Distribution of temperature at 30 Pa differential pressure and 5 fans active condition

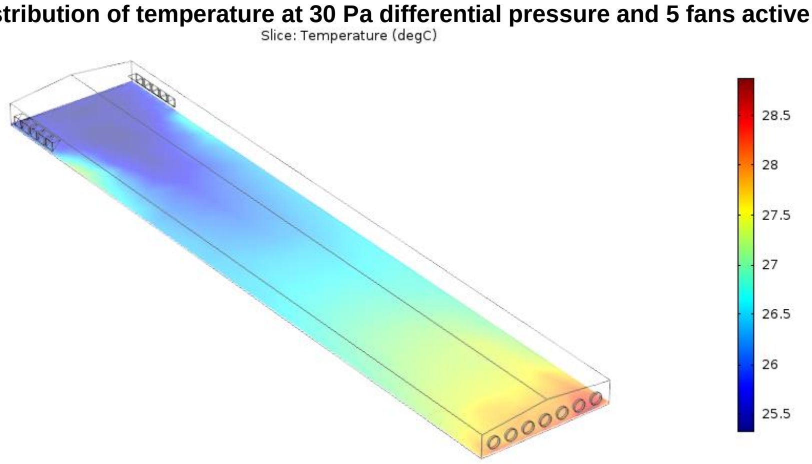

Fig. 12 - Distribution of temperature at 40 Pa differential pressure and 5 fans active condition

The maximum temperature in the zone occupied by the chickens by CFD in the poultry house is 33, 28 and 27.5ºC which is shown in fig. 13, 14 and 15 respectively. These figures show that temperature gradient variation proximity to the exhaust fans causes thermal discomfort for chickens. For ventilation with 20 Pa differential pressure (fig.13), temperature at the bird's height varied between 26 and 33°C. The lower efficiency of this system may be explained by the fact that this system generates a low velocity which prevents the convective transport of heat produced by the chickens (*Osorio et al., 2013*). Increasing air velocity makes the animals increase the heat loss and causes thermal comfort. According to (*Simmons et al., 1994*) for chickens in fifth week of age with outside temperature of 29ºC and air velocity increasing from 1.01 to 3.05 m.s-1, the loss of heat increases from 1.19 to 2.09 W kg-1 and in the sixth week of age from 1.30 to 2.33 W kg-1. The result obtained from figures 14 and 15 indicated that increasing differential pressure from 30 Pa to 40 Pa has no significant effect on outlet air temperature. Considering the previous results, it was concluded that the suggested CFD simulation can be used to sufficiently characterize the air velocity and temperature distribution inside poultry houses.

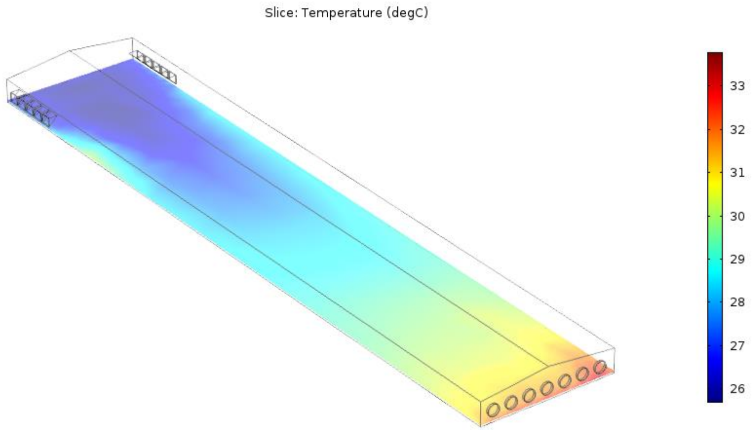

Fig. 13 - Distribution of temperature at 20 Pa differential pressure and 7 fans active condition

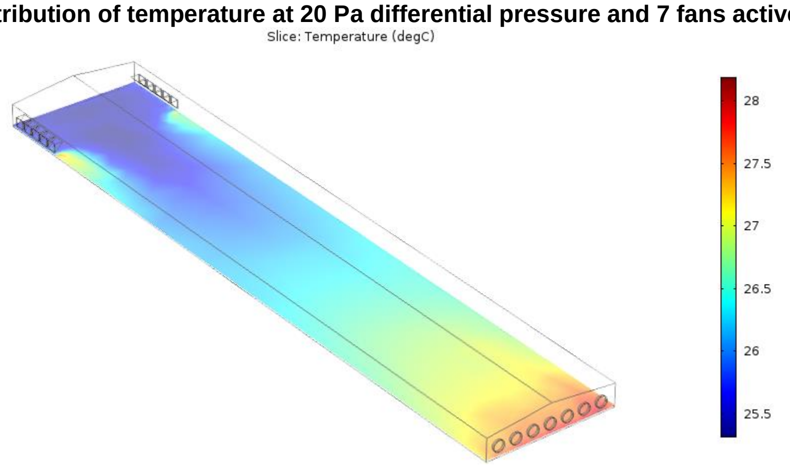

Fig. 14 - Distribution of temperature at 30 Pa differential pressure and 7 fans active condition

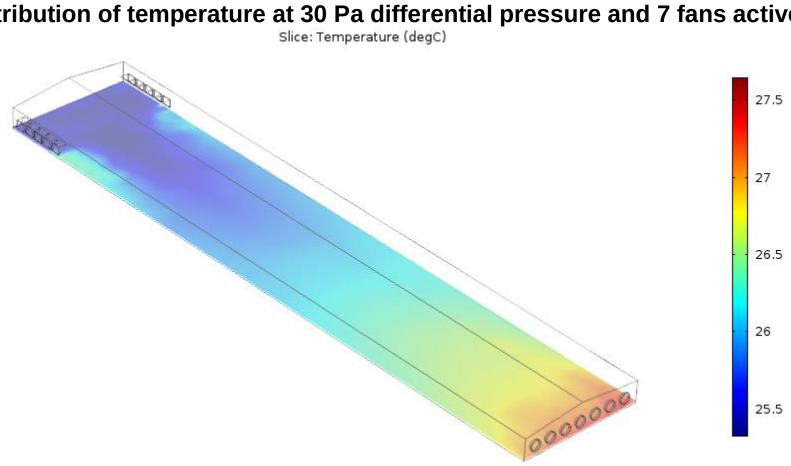

Fig. 15 - Distribution of temperature at 40 Pa differential pressure and 7 fans active condition

CONCLUSIONS

The present work demonstrates the advantages of using the numerical method (CFD) modelling in the environmental control process of a poultry house. Commercial CFD software (COMSOL Multiphysics) was used to conduct the numerical simulations. Differential pressure (20, 30 and 40 Pa) and fans activation (5 fans active and 7 fans active) are main variable parameters in poultry simulation. This simulation is useful for investigating the effect of differential pressure and fan activation on the parameters of comfort (air velocity and temperature distribution). The result showed that in differential pressure variation (20, 30 and 40 Pa) and 7 fans active condition the maximum value for air velocity in the poultry house centreline is 1.2, 1.8 and 2 m/s, respectively. Also it results for all conditions that air temperature increases when it moves through the poultry house length and additional heat is transported from the inlet towards the outlets. The generated model can be used to help enhancing poultry design, in terms of enhancing the efficiency of the ventilation system.

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