NUMERICAL SIMULATION OF AIR COOLING PROCESSES IN A POULTRY HOUSE WITH A TUNNEL-SIDE VENTILATION SYSTEM

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ABSTRACT

During the warm season, when ambient temperatures exceed +28 °C, the tunnel ventilation system is predominantly used in poultry facilities. This system effectively removes excess heat from the environment. However, under conditions of high ambient temperatures and high humidity, specialized systems were required to cool the incoming air and create a controlled microclimate within the poultry house. In ventilation systems, various types of cooling methods are employed to reduce the temperature of incoming air during the summer. Most commonly, these involve water spray systems. The core objective of this study is to conduct theoretical research on regulating heat and mass transfer processes in poultry houses, considering both internal dynamics and interactions through external barriers. This study proposes an innovative approach to cooling incoming air in poultry house ventilation systems. The method utilized water sourced from underground wells and heat exchangers-recovery units (recuperators) to efficiently cool the incoming air. As a result of the numerical modeling, the temperature distribution within the service zone of the poultry house was determined. When heat exchangers were used, the inlet air temperature in the facility was maintained at +20 °C. The temperature increase along the length of the facility was clearly observed in the provided diagrams. The outlet temperature of the cooled air is +27.89 °C, which was attributed to heat generated by the poultry and the warming of the poultry house walls by external air. Thus, the air temperature within this cooling system did not exceed permissible limits. Analyzing the numerical modeling results at a height of 0.7 m from the floor level, it was concluded that no more than 2% of the poultry would experience discomfort under the proposed cooling system. The average air velocity was 0.83 m·s $^{-1}$, and the air temperature was +23.64 °C.

INTRODUCTION

A conventional method for maintaining a regulated microclimate in poultry houses is direct evaporative cooling (DEC) using cassette-type systems (*Hoff, 2018; Liang et al., 2020; Boltyanska et al., 2022*). However, this method has significant drawbacks, such as high aerodynamic resistance and installation costs. Another disadvantage is the clogging of cassette channels with dust during operation (Hui et al., 2018). Notably, mold formation on the clogged cassette surfaces can introduce harmful components into the incoming air, which, under high humidity conditions, may lead to various poultry diseases (Kim et al., 2008).

Direct evaporative cooling is a typical ventilation system used in poultry houses in hot climates (*James, 2012; Czarick & Fairchild, 2014*). As mentioned earlier, this cooling method becomes ineffective in conditions of relatively high humidity, resulting in reduced thermal comfort and degraded air quality for poultry.

Studies have examined two advanced ventilation systems designed for hot and humid climates to improve poultry housing conditions (*Harrouz et al., 2021; Rozenboim et al., 2007*). System I integrates a conventional direct evaporative cooler with an adsorption dehumidifier containing a packed bed, while System II combines a dew point indirect evaporative cooler with a packed-bed dehumidifier. These models were optimized using a genetic algorithm to evaluate and compare their performance. The findings revealed that System II met the heat and air quality requirements of poultry houses with 35% lower operational costs compared to System I over the entire cooling season.

One of the modern cooling systems that has gained attention in recent years and has proven to be a successful replacement for DEC is the indirect evaporative dew point cooler (IDPC) (*Mahmood et al., 2016*). The IDPC is capable of significantly cooling the incoming air to its dew point without adding moisture (*Tariq et al., 2017*). Many studies have examined the performance of IDPCs with various configurations of working airflow (in wet channels) and product airflow (in dry channels). They found that the crossflow IDPC has the lowest pressure drop, the lowest investment cost, and the highest energy efficiency ratio (*Zhan et al., 2011; Pandelidis et al., 2019*).

Al-Assaad et al. (*2021*) compared the performance of two cooling systems combining DEC or crossflow IDPC with tunnel ventilation for a poultry house in the hot and semi-arid climate of the Bekaa Valley in Lebanon. They demonstrated that the IDPC better met heat and air quality constraints while reducing system costs by 6.8%. This is due to the IDPC's ability to provide a lower supply air temperature, which reduces water consumption and, consequently, water and electricity usage.

All of the aforementioned cooling systems have their drawbacks, which ultimately lead to reduced productivity in poultry farms. Thus, the development of new and improved cooling systems for poultry houses remains a relevant issue. The aim of this study is to explore new ways to improve the poultry house cooling system by installing heat exchange equipment with evaporative cooling cassettes, as well as by implementing a non-traditional placement of exhaust fans on the side wall of the poultry house.

MATERIALS AND METHODS

A tunnel cooling system is proposed for poultry facilities during the hot season when the outside air temperature reaches +40 °C. The poultry house has dimensions of 120×21 meters and a height of 5.3 meters, the total volume of the poultry house is 5,234.4 m^3. On the side walls, where evaporative cooling cassettes are typically located near the front end wall, heat exchange units are installed instead. The number of units is 3 pcs, each with dimensions of 5.3 × 1.0 m and a total capacity of 35.52 m^3·s^{-1} (42.8 kg·s^{-1}) for half of the poultry house. The heat exchangers for this system were developed in the study by Trokhaniak et al. (2023a). They ensure an outlet air temperature of +20 °C when the inlet air temperature is +40 °C. The warm outside air is cooled using water from underground wells.

Additionally, considering the authors' previous studies (*Trokhaniak et al., 2023b*), exhaust fans are installed: 4 pcs on the side wall and 1 on the rear end wall, with a total capacity of 35.52 m^3·s^{-1} (42.8 kg·s^{-1}). This airflow volume is sufficient to remove excess heat from the poultry house.

The floor is made of concrete with a thickness of 0.1 m on the top and bottom, separated by a 0.05 m layer of polystyrene insulation. In areas 2 m from the walls, the thickness of the insulating material is increased to 0.1 m. The assumed temperature for the floor is +10 °C. The walls are constructed as three-layered structures, with concrete layers 0.06 m thick on both sides and a 0.1 m polystyrene layer in between. For simplification, the ceiling is modeled as a three-layer structure with concrete layers on both sides and an insulating material, Izovat 30, in between with a thickness of 0.1 m. For all external walls and the ceiling, third-kind boundary conditions (Fig. 1) were applied, with an external temperature of +40 °C and a heat transfer coefficient of 10 W·(m^2·K)$^{-1}$, assuming low wind speeds were observed at the poultry house location.

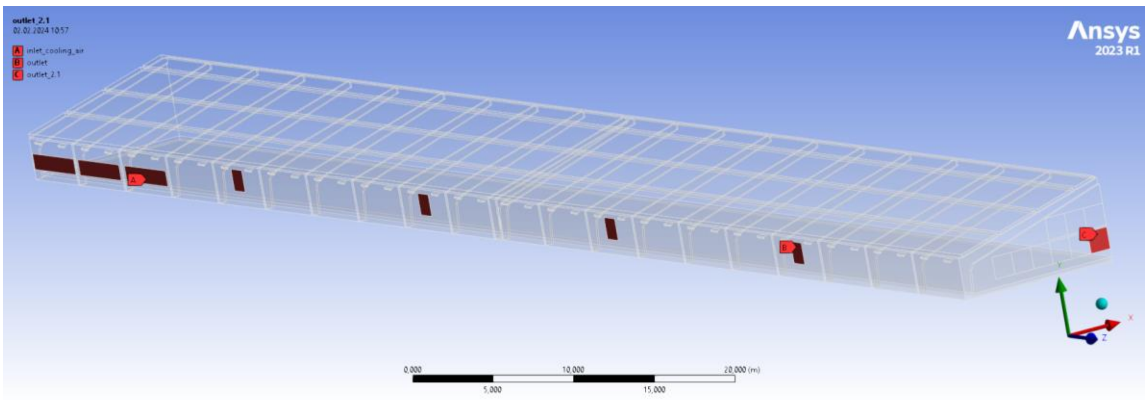


Fig.1 - 3D model of poultry house

The geometry of the poultry house was created using ANSYS Design Modeler 2023 R1, with boundary conditions applied. The geometry was then transferred to ANSYS Meshing 2023 R1 for mesh generation. The mesh was constructed using the CutCell method. The minimum face size was set to 0.015 m, and the maximum face size to 0.12 m. For the supply air inlets and exhaust fans, the mesh was refined with minimum element sizes of 0.01 m and 0.04 m, respectively. This refinement was implemented to achieve more accurate simulation results at the poultry house's inlet and outlet. As a result, the mesh quality indicator, orthogonal quality, was 0.214. The total number of elements was 4,485,116 pcs, and the total number of nodes was 4,854,992 pcs.

The numerical modeling was carried out directly in ANSYS Fluent 2023 R1. The model used the Navier-Stokes equations (*Schneiderbauer & Krieger, 2014*), the standard k-ε turbulence model, and the Discrete Ordinates radiation model (ANSYS, 2023). The tunnel effect of turbulent flows is also discussed in detail in *Azhar et al., (2022*). The development of mathematical models in the technical field of crop and livestock farming is the focus of works by *Bulgakov et al., (2017, 2020a, 2020b), Ivanovs et al., (2020*). Specific aspects of the methodology presented in these works were used in the current study.

RESULTS AND DISCUSSION

In Fig. 2–3, the results of numerical modeling of the poultry house are shown at four locations along the length of the room: 10.25 m, 43.25 m, 74.75 m, and 109.25 m along the xy axis. The first location is the outlet of the second heat exchanger. The third is the third exhaust fan. The second and fourth are the third section of the poultry house and the end, respectively.

Fig. 2 shows the airflow lines in the poultry house at different locations. The airflow, exiting from the heat exchangers (2.24 m·s^{-1}, 3.080 Pa), covers a quarter of the poultry house's width and, due to heating, rises sharply upwards (Fig. 2a). Flowing over the ceiling, it meets the neighboring flow from the opposite side of the poultry house and descends towards the birds. A large air vortex is formed, which moves deeper into the poultry house. Such a gas-dynamic flow can be observed in Fig. 2b and 2d. As seen, the tunnel effect is formed. A similar phenomenon, but with more turbulent flows, can be seen in (*Raza et al. 2020; Trokhaniak et al., 2023b*). In the middle at the top near the ceiling, a small stagnant air zone is formed. The average velocity in the poultry house is 0.58 m·s^{-1}.

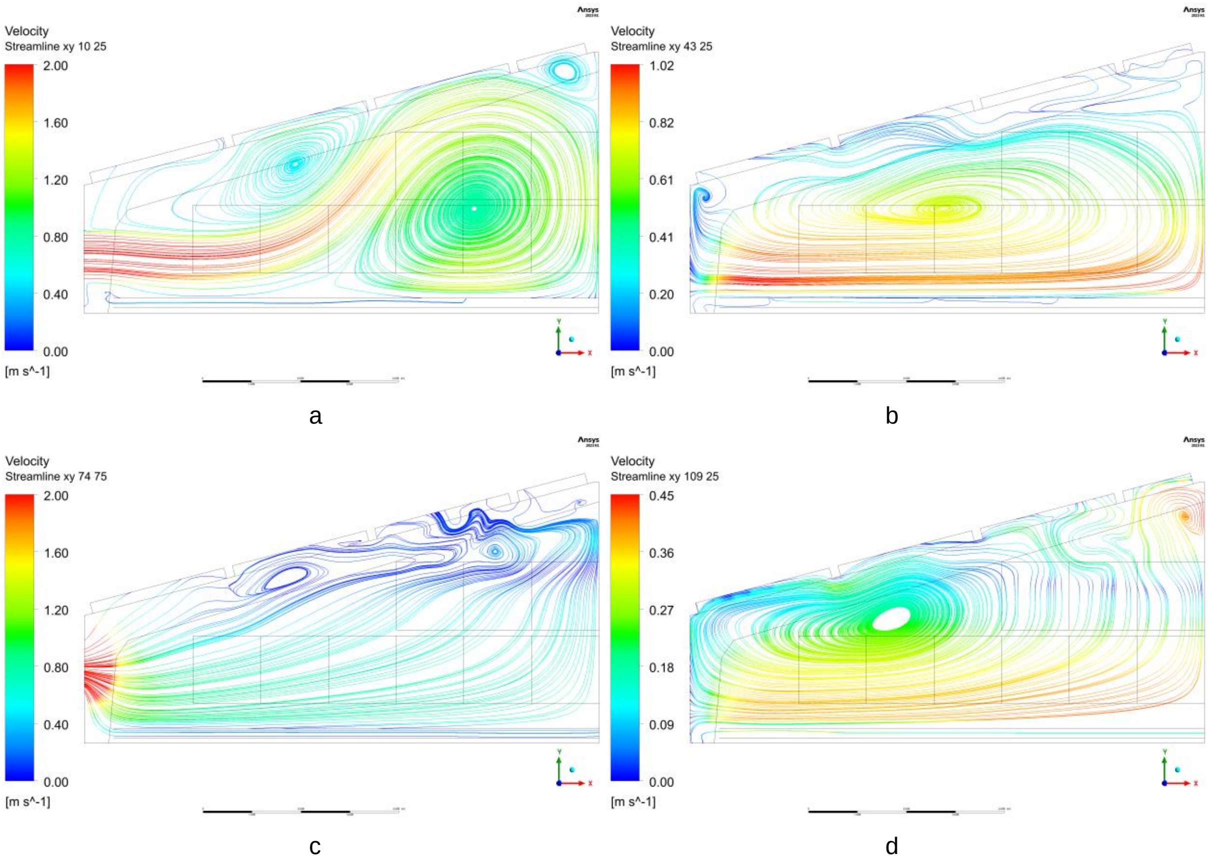
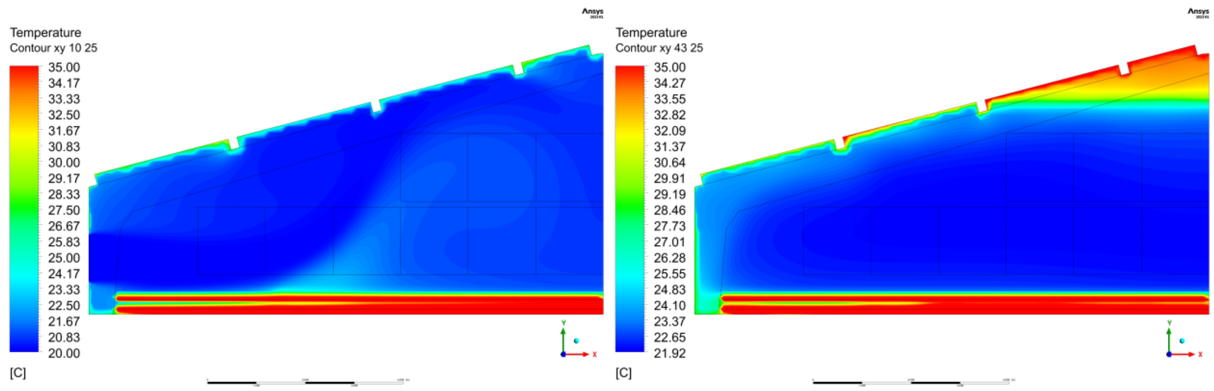


Fig. 2 - The air flow lines (m·s^{-1}) in the poultry house along the xy axis at different distances from the front end wall

a – 10.25 m; b – 43.25 m; c – 74.75 m; d – 109.25 m

In turn, at the exhaust fans (Fig. 2c), located on the side wall, the air speed is 5.11 m·s⁻¹. The air is evenly removed from the poultry house. The pressure at the outlet is – 2.72 Pa. The fan on the rear end wall showed the following results: speed – 5.06 m·s⁻¹; pressure – 2.27 Pa.

Fig. 3 shows the temperature distribution in different sections of the poultry house. As seen, the cooled air from the heat exchangers, with a temperature of +20 °C (Fig. 3a), enters the poultry house. After passing about 3.5 m and absorbing heat from the birds, the air heats up and rises. The average temperature in this section ranges from +20 °C to +22 °C. Through the stagnant zones of the air flow at the top of the poultry house, the temperature increases, but as it approaches the birds, it cools down (Fig. 3b-3d). This thermal barrier has a size from 1.3 m to 1.6 m, with temperatures ranging from +40 °C to +24.1 °C. Fig. 3c shows the temperature field at the level of the third exhaust fan. The temperature in this section is slightly higher, ranging from +24.17 °C to +25.83 °C. This is due to the intense air mixing and high turbulence. The heated air enters the fan's exhaust field, where the temperature at the outlet is +25.74 °C.



a b

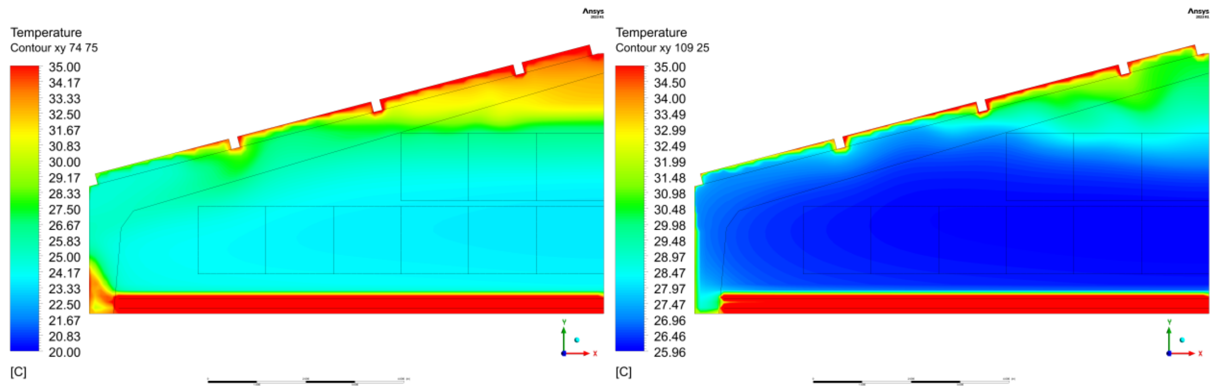


Fig. 3 - The air temperature field (°C) in the poultry house along the xy axis at different distances from the front end wall

a – 10.25 m; b – 43.25 m; c – 74.75 m; d – 109.25 m

Fig. 4 shows the velocity field (Fig. 4a) and temperature field (Fig. 4b) at a height of 0.7 m from the floor level. These results are the most interesting and important, as the birds are kept on the floor. According to the technical norms for poultry housing, the air velocity near the birds should not exceed 2 m·s⁻¹. As seen in Fig. 2a, the airflow from the heat exchangers enters the poultry house. It is slightly above 2 m·s⁻¹, but this affects only 0.25% of the birds near the heat exchangers. An obvious and simultaneously interesting turbulent flow created by the first exhaust fan is also observed. Between the third heat exchanger and the first exhaust fan, a stagnant zone is observed (Fig. 4a). Due to this zone, an increase in temperature levels near the wall is noticeable (Fig. 4b). The model assumes that the birds are not placed within 0.5 m of the wall. Therefore, the birds will not experience discomfort. The average air velocity at a height of 0.7 m from the floor (Fig. 4a) is 0.83 m·s⁻¹, and the pressure is 0.430 Pa.

The air temperature near the birds during the hot period of the year should not exceed +28 °C. Considering the results of the numerical simulation (Fig. 4b), the air temperature exceeding +28 °C occupies no more than 2% of the area. This indicates the sufficient effectiveness of the poultry house cooling system. On the rear side of the poultry house, where the exhaust fan is located, slightly higher air temperatures are observed, approaching +28 °C. This is due to the stagnant zone from the fourth exhaust fan on the side wall to the rear side of the poultry house. The average temperature across the entire area of the poultry house at a height of 0.7 m from the floor level is +23.64 °C.

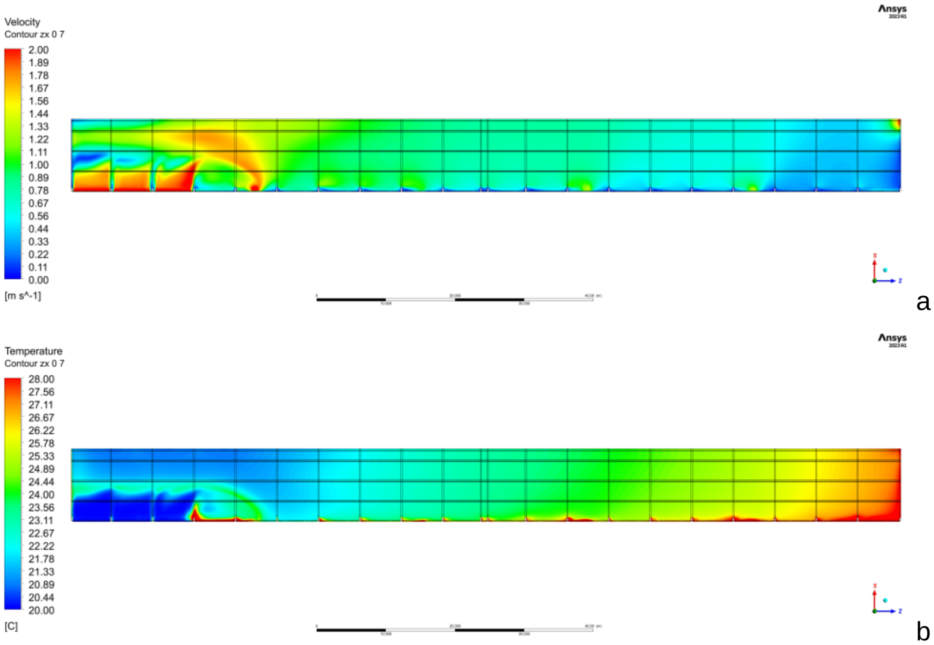


Fig. 4 - The air velocity field, m·s^{-1} (a), and temperature field, °C (b), in the poultry house along the zx axis at a height of 0.7 m from the floor level

Fig. 5 shows the distribution of air temperature in the 3D poultry house, ranging from +20 °C to +35 °C. It can be seen that in the center of the poultry house, near the ceiling, the air temperatures are higher. With the tunnel-side ventilation system, the air gradually heats up along its length. As the air moves through the poultry house, part of it reaches the exhaust fan on the rear end wall with a temperature of +27.89 °C.

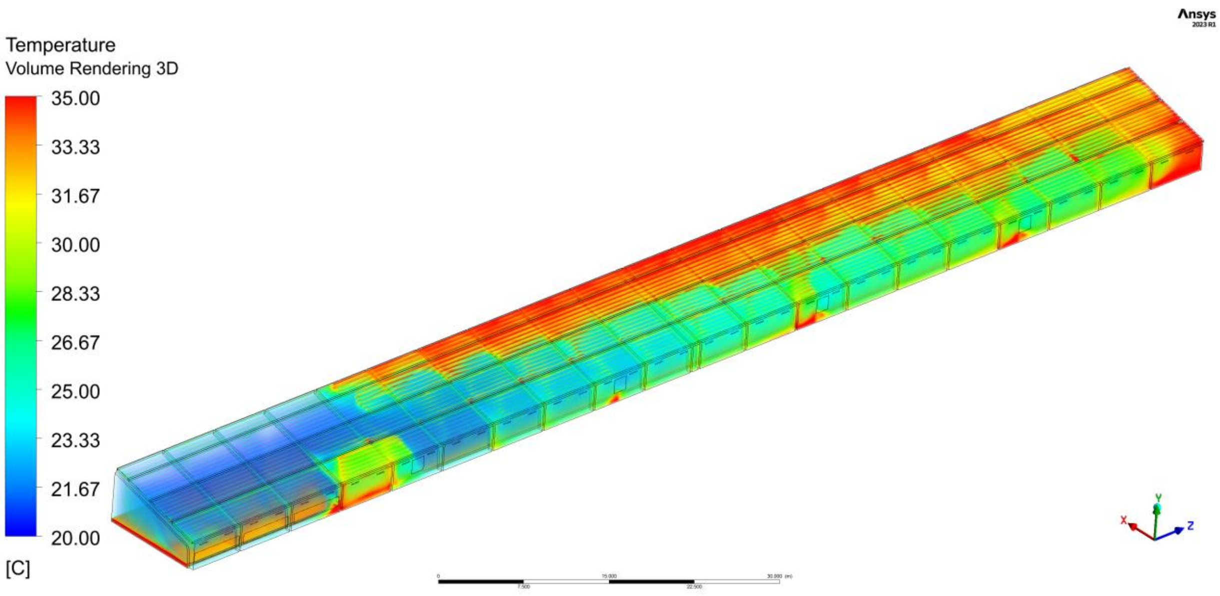


Fig. 5 - The visualization of the air temperature in the poultry house ranges from 20°C to 35°C

Considering Fig. 6, it can be concluded that due to the tunnel effect and the decrease in air velocity near the ceiling (Fig. 6a), the temperature rises in this area (Fig. 6b). To avoid such heat and mass transfer processes, the authors recommend relocating the exhaust fan on the rear wall of the poultry house, with its center positioned 4.45 m from the side wall. This would prevent stagnant airflow and thermal zones within the poultry house.

In the study by *Trokhaniak et al. (2024)*, the use of heat exchange equipment achieved a lower air temperature at the outlet (20 °C). However, this approach may require significant energy costs and the use of groundwater, which limits the applicability of this technology. In contrast, the system proposed in this article is less energy-intensive, ensuring uniform temperature and air velocity distribution with minimal discomfort for the poultry, though in some areas the temperature may slightly exceed 28 °C. Both studies confirm the effectiveness of the proposed cooling systems for poultry houses during the hot period of the year, but the approaches to implementing cooling are different.

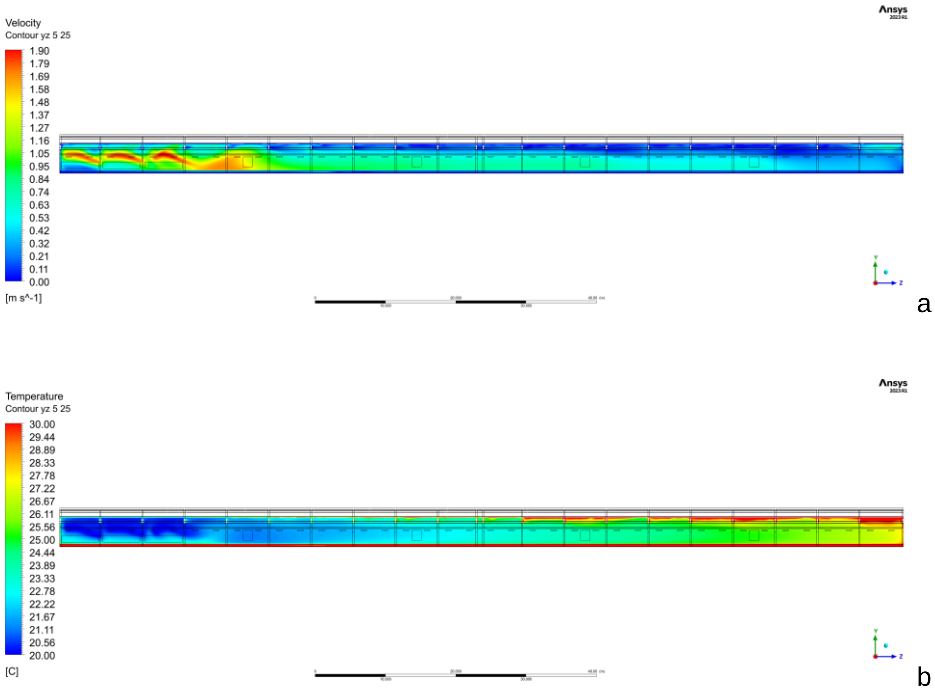


Fig. 6 - The air velocity field, m·s^{-1} (a), and temperature field, °C (b), in the poultry house along the zy axis at 5.25 m from the side wall

Additionally, the study by *Trokhaniak et al. (2024)* demonstrated that with an air velocity of 14.36 m·s^{-1} at the outlet of the ventilation openings, the airflow effectively reached the center of the room, ensuring uniform temperature distribution. In this case, the average air temperature in the poultry housing area was 26.56 °C, exceeding 28 °C only in certain locations. Discomfort was experienced by no more than 7.8% of the birds at an average air velocity of 0.74 m·s^{-1}. In this article, it is shown that the airflow velocity ensured uniform temperature distribution within a range that did not exceed critical values. Thermal comfort was achieved through the optimal placement of ventilation openings and the use of spoilers.

According to the numerical modeling results in the study by *Trokhaniak et al. (2024),* the use of heat exchange equipment with groundwater as the cooling medium reduced the air temperature from 30 °C to 20 °C at the system outlet. This result demonstrates the high efficiency of the proposed cooling technology. In this article, the maximum temperature inside the poultry house did not exceed 28 °C, and the average temperature was within the range of 24.44–27.35 °C. These values confirm that the proposed cooling system also successfully maintains comfortable conditions for poultry during the hot period of the year. However, the cooling system relies on a combination of ventilation openings and directional elements (spoilers), which may require less energy compared to active heat exchange.

CONCLUSIONS

1. Using numerical modeling, the cooling system for the hot season with an outdoor air temperature of +40°C was investigated in 3D for half of the poultry house. A new cooling system for poultry houses is proposed, utilizing heat exchange equipment, with an outlet temperature of +20°C. Groundwater from underground wells is suggested as the cooling agent.
2. Air velocity fields were obtained at various sections of the poultry house. The effectiveness of the placement of heat exchange units and exhaust fans was demonstrated. The fresh air flow, exiting the heat exchangers with a speed of 2.24 $m \cdot s^{-1}$ and a pressure of 3.08 Pa, passes a quarter of the width of the poultry house and, due to heating, rises sharply. The temperature in these sections averages from +20°C to +27.9°C, not exceeding the standard of +28°C during the hot season. Analyzing the results of numerical modeling at a height of 0.7 m from the floor level, it was concluded that no more than 2% of the birds would experience discomfort with the proposed cooling system. The average velocity is 0.83 $m \cdot s^{-1}$, and the air temperature is +23.64°C.
3. To avoid the decrease in air velocities near the ceiling where the temperature rises, and similar heat and mass transfer processes, the authors recommend relocating the exhaust fan to the rear wall of the poultry house, with its center positioned 4.45 m from the side wall. This will prevent stagnant airflow and thermal zones in the poultry house.

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REFERENCES

[1] Al Assaad D.K., Orabi M.S., Ghaddar N.K., Ghali, K.F., Salam, D.A., Ouahrani D. (2021). A sustainable localised air distribution system for enhancing thermal environment and indoor air quality of poultry house for semiarid region. *Biosyst Eng*, 203,70–92.

[2] ANSYS, (2023). *ANSYS Fluent Theory Guide*. Release 2023R1, Published in the USA, 1066 p.

[3] Azhar Muhd & Ikegaya Naoki & Mohamad Mohd. (2022). Stochastic and statistical characteristics of artificially generated turbulent flow following Karman spectrum in a wind-tunnel experiment. *Journal of Wind Engineering and Industrial Aerodynamics*, 229, 105148. https://doi.org/10.1016/j.jweia.2022.105148

[4] Boltyanska N., Podashevskaya H., Skliar O., Sklyar R., Boltianskyi O. (2022). Problems of implementation of digital technologies in animal husbandry. *CEUR Workshop Proceedings*, 3109, pp.75–82.

[5] Bulgakov V., Adamchuk V., Ivanovs S., Ihnatiev Y. (2017). Theoretical investigation of aggregation of top removal machine frontally mounted on wheeled tractor. *Engineering for Rural Development*, 16, 273–280.

[6] Bulgakov V., Nikolaenko S., Holovach I., Boris A., Kiurchev S., Ihnatiev Y., Olt J. (2020a). Theory of motion of grain mixture particle in the process of aspiration separation. *Agronomy Research*, 18 (Special Issue 2), pp. 1177–1188.

[7] Bulgakov V., Sevostianov I., Kaletnik G., Babyn I., Svanovs S., Holovach I., Ihnatiev Y. (2020b). Theoretical Studies of the Vibration Process of the Dryer for Waste of Food. *Rural Sustainability Research*, 44(339), pp. 32–45.

[8] Czarick M., Fairchild B. (2014). Plastic cooling pads are found to be less efficient comparing to paper cool pads. Poultry Housing Tips 24(8), College of Agricultural and Environmental Sciences, Georgia, USA, 64–69.

[9] Harrouz J.P., Katramiz E., Ghali K., Ouahrani D., Ghaddar N. (2021). Comparative analysis of sustainable desiccant – Evaporative based ventilation systems for a typical Qatari poultry house. *Energy Conversion and Management*, 245, 114556. https://doi.org/10.1016/j.enconman.2021.114556

[10] Hoff S.J. (2018). HVAC System. *InTech*. https://doi.org/10.5772/intechopen.78785.

[11] 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* 11(1), Beijing, China, 66–73. https://doi.org/10.25165/j.ijabe.20181101.2479

[12] Ivanovs S., Bulgakov V., Nadykto V., Ihnatiev Ye., Smolinskyi S., Kiernicki Z. (2020). Experimental study of the movement controllability of a machine-and-tractor aggregate of the modular type. *INMATEH – Agricultural Engineering*, 61(2), 9–16. https://doi.org/10.35633/inmateh-61-01

[13] James, O. Donald. (2012). *Technology of microclimate of broiler house*. Aviagen Brands. p.24, Huntsville, USA,.

[14] 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*, 100(2), San Diego, USA, 245–255.

[15] Liang Y., Tabler G.T., Dridi S. (2020). Sprinkler technology improves broiler production sustainability: from stress alleviation to water usage conservation: A mini review. *Front Veterinary Sci*, 7, 689.

[16] Mahmood M.H., Sultan M., Miyazaki T., Koyama S., Maisotsenko V.S. (2016). Overview of the Maisotsenko cycle – A way towards dew point evaporative cooling. *Renew Sustain Energy Rev*, 66, 537–555. https://doi.org/10.1016/j.rser.2016.08.022

[17] Pandelidis D., Cichoń A., Pacak A., Anisimov S., Drąg P. (2019). Performance comparison between counter-and cross-flow indirect evaporative coolers for heat recovery in air conditioning systems in the presence of condensation in the product air channels. *Int J Heat Mass Transf*, 130, 757–777.

[18] Raza H.M.U., Ashraf H., Shahzad K., Sultan M., Miyazaki T., Usman M. (2020). Investigating applicability of evaporative cooling systems for thermal comfort of poultry birds in Pakistan. *Appl Sci*., 10(13), 4445. https://doi.org/10.3390/app10134445

[19] Rozenboim I., Tako E., Gal-Garber O., Proudman J.A., Uni Z. (2007). The effect of heat stress on ovarian function of laying hens. *Poult Sci*., 86 (8), 1760–1765.

[20] Tariq R., Benarab F.Z. (2017). Mathematical Modelling and Numerical Simulation of Maisotsenko Cycle. *19th International Conference on Fluid Mechanics, Heat Transfer and Thermodynamics (ICFMHTT)*.

[21] Schneiderbauer S., Krieger M. (2014). What do the Navier-Stokes equations mean?. European *Journal of Physics*, 35. 015020. 10.1088/0143-0807/35/1/015020.

[22] Trokhaniak V., Ivanovs S., Nasieka Yu., Chernysh O., Aboltins A., Ihnatiev Y., Synyavskiy O. (2023). Usage of CFD for research on lateral ventilation system in poultry house. *Engineering for Rural Development*, 22, 582-587. https://doi.org/10.22616/ERDev.2023.22.TF120

[23] Trokhaniak V., Nasieka Y., Ihnatiev Ye., Synyavskiy O., Skliar O., Olt J. (2024) Study of heat exchange processes in the cooling system of a poultry house with side ventilation. *Agronomy Research*, 22(2), 1016–1025. https://doi.org/10.15159/AR.24.084

[24] Trokhaniak V., Gorobets V., Shelimanova O., Balitsky A. (2023). Research of thermal and hydrodynamic flows of heat exchangers for different air cooling systems in poultry houses. *Machinery & Energetics*, 14(1), 68-78. https://doi.org/10.31548/machinery/1.2023.68

[25] Zhan C., Duan Z., Zhao X., Smith S., Jin H., Riffat S. (2011). Comparative study of the performance of the M-cycle counter-flow and cross-flow heat exchangers for indirect evaporative cooling–paving the path toward sustainable cooling of buildings. *Energy*, 36 (12), 6790–6805.