

NUMERICAL INVESTIGATION OF AN AUTONOMOUS AIR COOLING SYSTEM
BASED ON WATER-AIR HEAT EXCHANGE

Kholmatov Faxridin Taxirovich

Independent researcher at Samarkand State

University of Architecture and Construction

Annotatsiya: This paper presents a numerical investigation of the operating performance of an autonomous air cooling system based on water–air heat exchange. The variation of air temperature along the length of a tubular heat exchanger was analyzed as a function of the outdoor air temperature and inlet air velocity. The study was conducted using a physical model developed in COMSOL Multiphysics 6.1. The simulation results show that the cooling efficiency of the system varies significantly when the outdoor air temperature ranges from 30 to 40°C and the inlet air velocity changes from 2.5 to 4.0 m/s. The findings confirm that an increase in inlet air velocity reduces the residence time for heat transfer, leading to higher outlet air temperatures, and demonstrate the necessity of employing a two-loop cooling configuration under high outdoor temperature conditions.

Keywords: air cooling system; water–air heat exchange; tubular heat exchanger; numerical modeling; energy efficiency; autonomous cooling; air temperature distribution

Introduction. At present, climate change, the sharp increase in outdoor air temperatures during the summer season, and the high energy consumption of conventional air-conditioning systems have made the implementation of energy-efficient and environmentally friendly cooling technologies a critical challenge in building cooling applications. This issue is particularly significant in regions with limited electricity supply or where autonomous operation is required, making the development of efficient air cooling systems of great scientific and practical importance. From this perspective, air cooling systems based on water–air heat exchange enable rational utilization of ambient energy sources, reduction of electrical energy consumption during the cooling process, and improvement of indoor thermal comfort. In particular, pre-cooling the supply air by means of a tubular heat exchanger immersed in a water reservoir represents a promising solution for enhancing the overall energy efficiency of buildings. Therefore, numerical modeling of the air cooling process in autonomous air cooling systems, investigation of the effects of inlet air velocity and outdoor air temperature on cooling performance, and determination of optimal operating conditions constitute important and timely research objectives.

Numerical Study and Results of the Air Cooling System. Pre-cooling the supply air delivered to indoor spaces using an autonomous air cooling system represents an effective solution for improving energy efficiency. The air cooling system (ACS) consists of a water reservoir and a water–air heat exchange unit, in which a tubular heat exchanger is immersed in the water basin. The air to be cooled flows through a tube with a diameter of 32 mm, where thermal energy is transferred from the air to the cooling water through the tube wall. The excess heat absorbed by the water is subsequently released to the ambient environment via a fountain-type cooling device. In this study, the outdoor air temperature varied within the range of 30–40°C, while the average temperature of the cooling water was maintained at 20°C. To ensure the required supply airflow rate to the indoor space, the inlet air

velocity to the tube was varied from 2.5 to 4.0 m/s . A physical model of the process was developed using COMSOL Multiphysics 6.1 to numerically investigate the variation of air temperature along the length of the tubular heat exchanger, and an appropriate computational mesh was generated (Fig. 1).

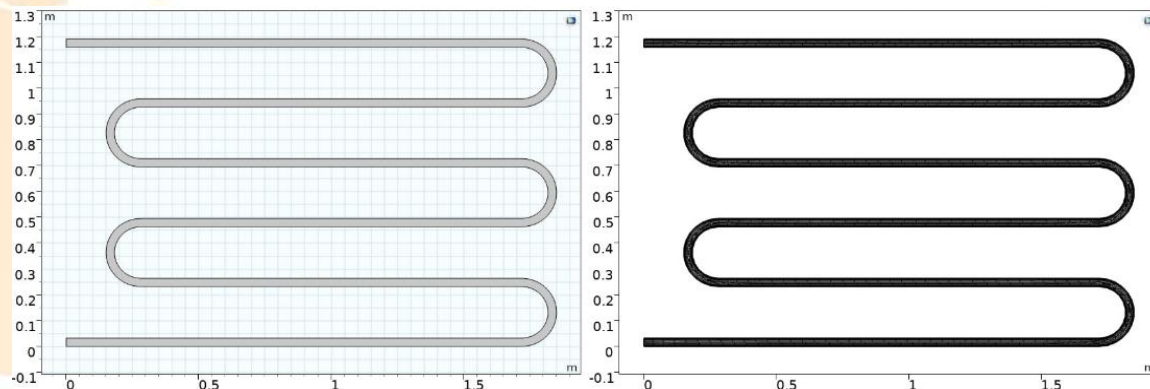


Fig. 1. 2D model of the tubular heat exchanger (a) and computational mesh (b)

When the outdoor air temperature at the tube inlet was 30°C and the inlet air velocity varied from 2.5 to 4.0 m/s , the variation of air temperature along the tube length is presented in Fig. 2. For all inlet velocities, a similar trend was observed, with the air temperature decreasing along the tube. However, as the inlet air velocity increased, the residence time available for heat exchange between the air and the cooling water inside the tube decreased, resulting in relatively higher outlet air temperatures. Specifically, at an inlet velocity of 2.5 m/s , the air temperature decreased from 30°C to 23°C, while outlet temperatures of 23.5°C, 24.1°C, and 25.6°C were obtained at inlet velocities of 3.0, 3.5, and 4.0 m/s , respectively. Therefore, under an outdoor air temperature of 30°C, adjusting the inlet velocity within the range of 2.5-4.0 m/s enables cooling of the air to a temperature range of 23-25.6°C.

When the outdoor air temperature was 40°C and the inlet air velocity varied, the variation of the outlet air temperature along the tube length is shown in Fig. 3.

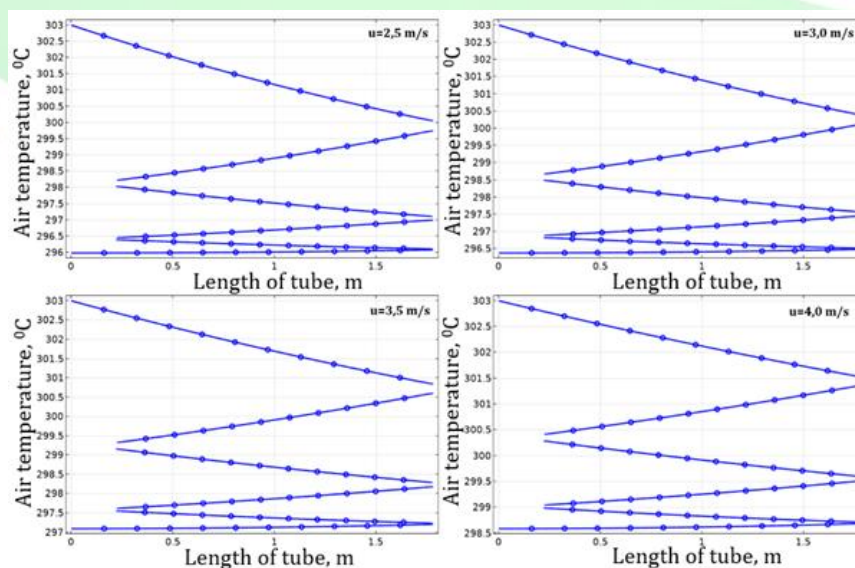


Fig. 2. Variation of air temperature along the tube length ($t_a=30^\circ\text{C}$)

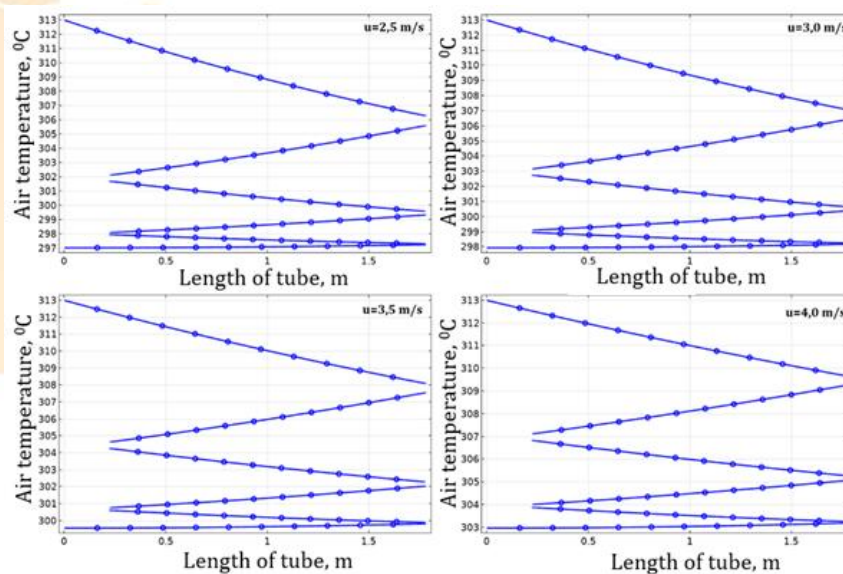


Fig. 3. Variation of air temperature along the tube length ($t_a=40^\circ\text{C}$)

The results indicate that the outlet air temperature increases steadily with increasing inlet air velocity. At an outdoor air temperature of 40°C , outlet air temperatures of 24.1 , 25.0 , 26.5 , and 30°C were obtained at inlet velocities of 2.5 , 3.0 , 3.5 , and 4.0 m/s , respectively. These findings demonstrate that, under an outdoor air temperature of 40°C and an inlet velocity of 4.0 m/s , a single-loop cooling system is unable to cool the air to the required temperature level. Under such conditions, the cooling capacity of the system can be enhanced by employing a second loop in the tubular heat exchanger configuration.

Conclusion. In this study, an autonomous air cooling system based on water–air heat exchange was numerically modeled using COMSOL Multiphysics 6.1. The results show that, at an outdoor air temperature of 30°C , varying the inlet air velocity within the range of 2.5 – 4.0 m/s allows the air to be cooled to 23 – 25.6°C . Under an outdoor air temperature of 40°C , an increase in inlet air velocity leads to higher outlet air temperatures, indicating insufficient performance of a single-loop cooling system. Therefore, the use of a two-loop cooling configuration is recommended to achieve effective cooling under high-temperature conditions.

References.

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