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Results of a Numerical Study of Air Temperature Changes in an Experimental House

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ABSTRACT: Currently, air cooling methods are widely used to ensure comfortable climatic conditions in residential buildings in areas with dry and hot climates. These cooling methods have high energy consumption, and the devices cause a number of inconveniences in operation. Taking into account the above, an easy-to-operate, environmentally friendly and safe air cooling system has been developed, and theoretical studies have been conducted to determine the change in indoor air temperature depending on the height and length of the room when using this system. The results of the theoretical studies conducted are presented in this article.

I. INTRODUCTION

Cooling processes play an important role in ensuring comfortable climatic conditions in residential buildings. Since cooling processes in residential buildings are mainly carried out using electricity obtained from fossil fuels, these processes are also among the processes with high energy consumption. The increase in the population, the improvement of building services and comfort levels, and the increase in the time spent indoors have increased energy consumption in buildings to the level of transport and industry. For example, members of the Organization for Economic Cooperation and Development (OPEC) consume from 15 to 25% of primary energy in the buildings sector, and this figure is even higher in developing countries [1]. It is known that in areas with a dry and hot climate, there is a high need for the use of cooling and air conditioning systems to achieve thermal comfort in rooms and offices. According to the International Refrigeration Institute (IRI), refrigeration and air conditioning systems consume about 20% of the world's electricity [1]. Therefore, in order to reduce energy dependence and greenhouse gas emissions, it is necessary to reduce the energy consumption for cooling loads in the buildings sector. The issue of heat transfer in rooms with air conditioning systems is important, and the comfortable climatic conditions in the room are determined by the sum of the physical variables of the external environment. By knowing these variables, the temperature, velocity and humidity of the air inside the room, it is possible to effectively control the cooling system [2]. The best way to analyze the air movement in rooms with air conditioning systems is a theoretical study, in which the room is considered as a space. The literature contains numerous studies on air movement and heat exchange in a rectangular space with different air flow inlets and outlets, which can be divided into the following: a) a space with air flow entering and exiting in the absence of heat exchange; b) a space with air flow entering and exiting when heat is transferred due to natural and forced convection; c) a space with air flow entering and exiting when heat is transferred due to solar radiation, natural and forced convection.

Posner [3] compared the results of three-dimensional CFD modeling with experimental results obtained in a full-scale test laboratory. The experimental setup consisted of a 1:10 scale model, 91.4 cm long, 45.7 cm wide and 30.5 cm high, with an air inlet opening of 10.1 cm^2. The comparison results were very good, and it was concluded that the model can be fully used. Karava et al. [4] conducted an experimental study of the main characteristics of cross-flow ventilation, which are important for initial data for accurate modeling and design of natural ventilation. The experiments conducted in cross-flow ventilated buildings were based on measurements of particle image velocities to obtain the results in the form of air velocity fields. The results show that the airflow structure in cross-flow ventilated buildings is complex and cannot be represented by models. Rahimi and Arianmehr [5] studied natural ventilation methods in a one-way ventilated experimental room. The ventilation rate through the hole was estimated based on the air flow rate measured at the hole surface area. Based on the experimental results, the effect of vertical air spray on the ventilation rate was studied and a model of the ventilation method was proposed.

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Costa et al. [6] studied the effects of room aspect ratio and maximum return flow velocity in a two-dimensional (2D) space. The authors argue that the ventilation requirements in residential buildings are associated with mixed convection flow, which is characterized by large variations in flow characteristics. Singh and Sharif [7] numerically studied mixed convection in a two-dimensional space with differentially heated walls. The authors sought to optimize the air inlet and outlet positions to determine the most efficient way to remove heat from the space. Raji and Hasnaoui [8] presented results of heat transfer by mixed convection and thermal radiation in a two-dimensional rectangular cavity with a gray surface and heat fluxes on the left and right walls. The authors also studied the radiation effect on the streamline and isotherms. The results showed that the BT configuration (inlet from the bottom and outlet from the top) is the most optimal for reducing the average temperature inside the cavity for the Re number. Radiation ensures a decrease in the temperature gradient, resulting in temperature homogenization, which reduces the average and maximum values in the cavity. Leenknegt et al. [9] studied the effect of modeling options on the development of unsteady flow and convection in a 2D shear of the room with a temperature difference of 3°C between the room and the ventilation air and an air velocity of 0.39 m / s. The investigated modeling options include discretization, pre-wall processing, modeling time step, turbulence model, coupled heat transfer, radiation, as well as inlet and outlet geometry and location. According to the results, the following parameters were found to have a strong influence on the time: inlet and outlet location, window size, and radiation. Taking into account the above, this research paper presents a comprehensive study of a room with an air cooling system. Also, the temperature and total heat fluxes when the air flow is transmitted at different speeds are studied, and the effect of air cooling on the thermal comfort parameter is considered.

II. MATERIALS AND METHODS

The proposed system uses a solar photovoltaic module and a fountain cooler for convective cooling of the indoor air of a living room. Theoretical studies of heat transfer processes in residential buildings with airflow, combined (natural and forced) and radiant heat exchange were conducted in a physical model of an air-cooled experimental house shown in Figure 1.

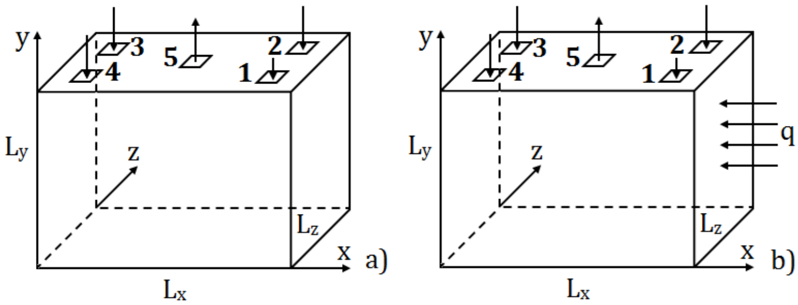

Figure 1. Physical models of an air-cooled experimental house

The dimensions of the experimental house are: L_x=4 m, L_y=2.7 m, L_z=3 m. The air cooling system in the experimental house was studied under two different conditions: a) when there is no heat transfer to the experimental house (all walls are adiabatic); b) a constant heat flux q=300 W/m^2 is transferred to the house through the vertical wall of the experimental house. Air is taken as the working fluid, and the air flow is turbulent. The dimensions of the holes (inlet and outlet) are l_x=0.15 m and l_y=0.15 m. The numerical results were obtained assuming that the wall radiation coefficient is 0.8. The cooling air is supplied to the house at a temperature of 18℃. The inlet air velocity is 0.5, 1.0, 1.5, 2 m/s and it was investigated which of these different velocities provides the maximum efficiency of temperature distribution for the house in question.

A 2D model of the experimental house (Figure 2, a) and a computational mesh (Figure 2, b) were built using the Comsol Multiphysics 6.1 software tool based on the finite element method to solve the basic equations of hydrodynamics and heat transfer.

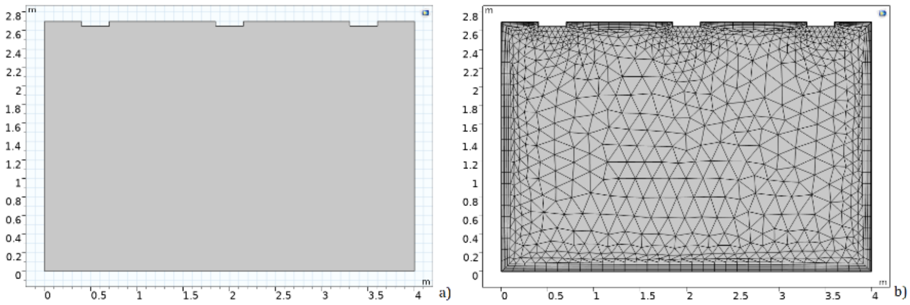

Figure 2. 2D model of an experimental house with an air-cooled system (a) and computational mesh (b)

The geometric characteristics of the computational grid are as follows: the number of grid vertices is 16, the number of boundary elements is 140, the number of elements is 1448, the minimum element quality is 0.5644. The results of the developed numerical model were compared with the results presented in the research work [1]. The dimensions of the research object are L_x=3 m, L_y=2.5 m and L_z=3 m. A constant heat flux of q=300 W/m^2 is transferred to the house through the left vertical wall, and a constant temperature of T_w=298 K is provided on the right vertical wall. The remaining walls are assumed to be adiabatic. Cooling air is supplied from above and discharged from above. When the results of the velocity profile in the research work [1] are compared with the results of the velocity profile in this study, it was found that the results agree well.

III. RESULTS AND DISCUSSION

The variation of the air temperature inside the house along the length and height of the house when the air inlet velocity changes from 0.5 to 2.0 m/s was fully investigated. Initially, the variation of the convective heat flux along the height and length of the house when the air inlet velocity varies was investigated. The distribution of the convective heat flux along the height and length of the house when the air inlet velocity changes from 0.5 to 2.0 m/s is shown in Figure 3.

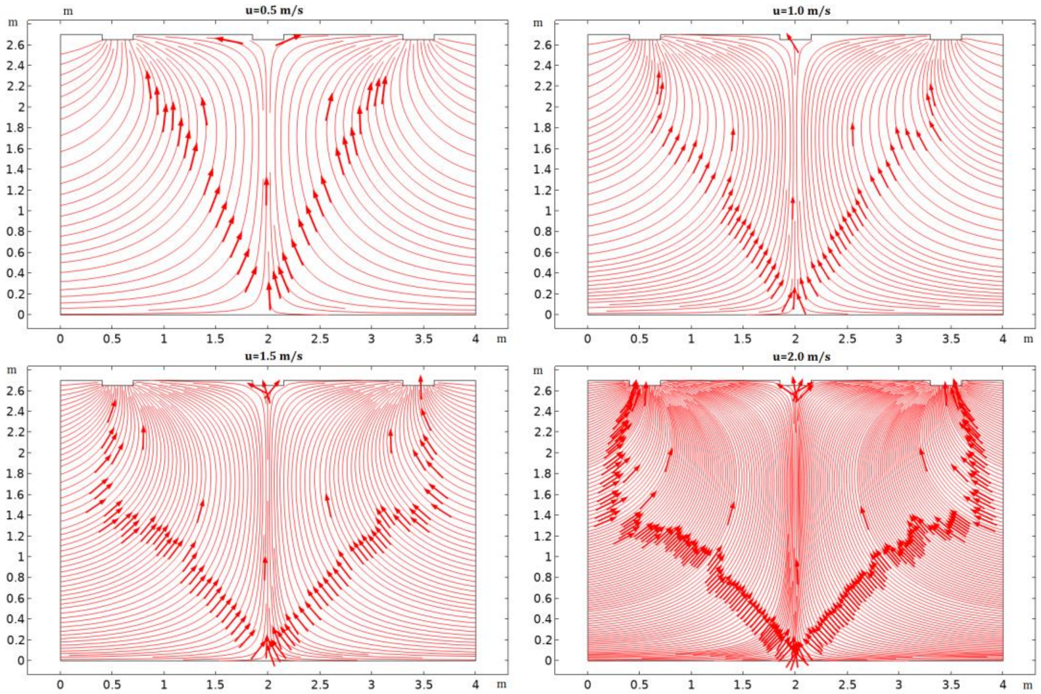

Figure 3. Convective heat flow characteristics in the experimental house

In all cases of air flow velocity, the direction of convective heat flow is almost the same, from the vertical walls of the house to the air outlet. It can be seen that with an increase in the inlet air flow velocity, the distribution of convective heat flow over the volume of the house is also almost the same. The change in air temperature inside the house was

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studied when two different amounts of heat were transferred inside the house. In the first case, the temperature on the vertical walls of the house was assumed to be constant t=25°C. When the temperature of the inner surface of the vertical wall of the house is 25°C and the inlet air flow velocities are different, the change in the air temperature inside the house along the height and length of the house is shown in the diagrams and graphs in Figures 4 and 5.

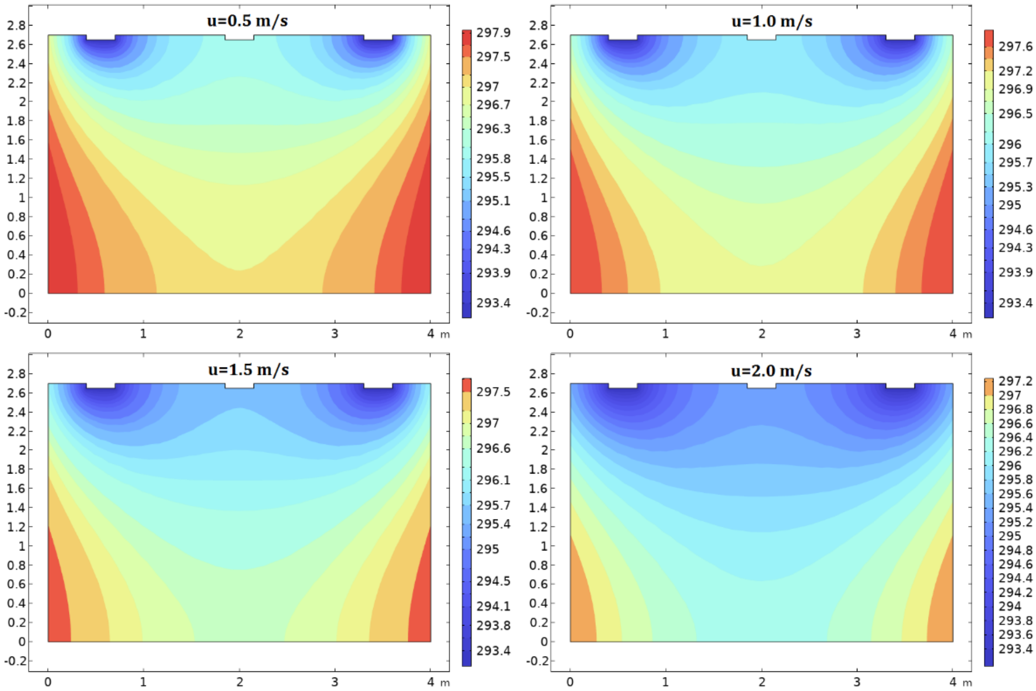

Figure 4. Temperature field for indoor air in the experimental house

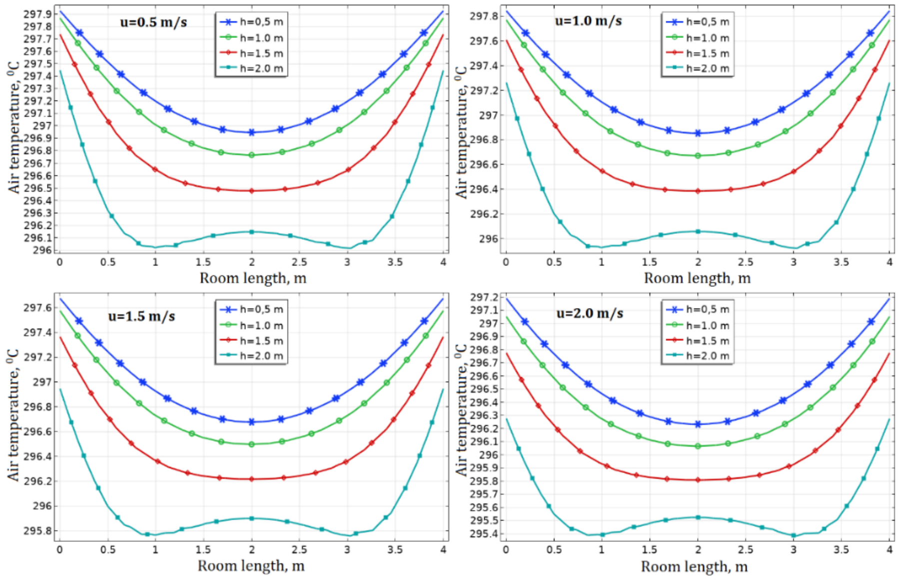

Figure 5. Changes in indoor air temperature in the experimental house

The air temperature change was determined at heights of 0.5, 1.0, 1.5 and 2.0 m above the house. When the air flow velocity changed from 0.5 to 2.0 m/s and the height of the house increased from 0.5 to 2.0 m, the air temperature inside the house decreased. The highest temperature was provided at a height of 0.5 m and the lowest at a height of 2.0 m. The temperature near the surface of the vertical wall of the house decreased as follows when the air flow velocity at the inlet varied: by an average of 0.5°C at a velocity of 0.5 m/s, by 0.6°C at a velocity of 1.0 m/s, by 0.8°C at a velocity of 1.5 m/s and by 1°C at a velocity of 2.0 m/s. The air temperature inside the house was average at the length of the house from 0.5

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to 1.0 m and from 3 to 3.5 m, and the minimum temperature was provided at the length of 1.5 to 2.5 m. When the air flow velocity at the inlet was 0.5 m/s, the average temperature in the house was 23.6℃, when the velocity was 1 m/s, it was 23.4℃, when the velocity was 1.5 m/s, it was 23.1℃, and when the velocity was 2.0 m/s, it was 22.9℃. Thus, it was found that when the air flow velocity at the inlet changed from 0.5 to 2 m/s, the average air temperature inside the house could be provided from 22.9 to 23.6℃.

The next research work was aimed at determining the effect of air inlet velocity on the change in air temperature inside the house when the temperature on the inner surface of the vertical wall of the house is 25℃ and the solar radiation energy of 300 W/m^2 is transmitted to the entire vertical wall. The change in air temperature inside the house along the height and length of the house when the solar radiation energy of 300 W/m^2 is transmitted to the vertical wall of the house is shown in the form of diagrams and graphs in Figures 6 and 7.

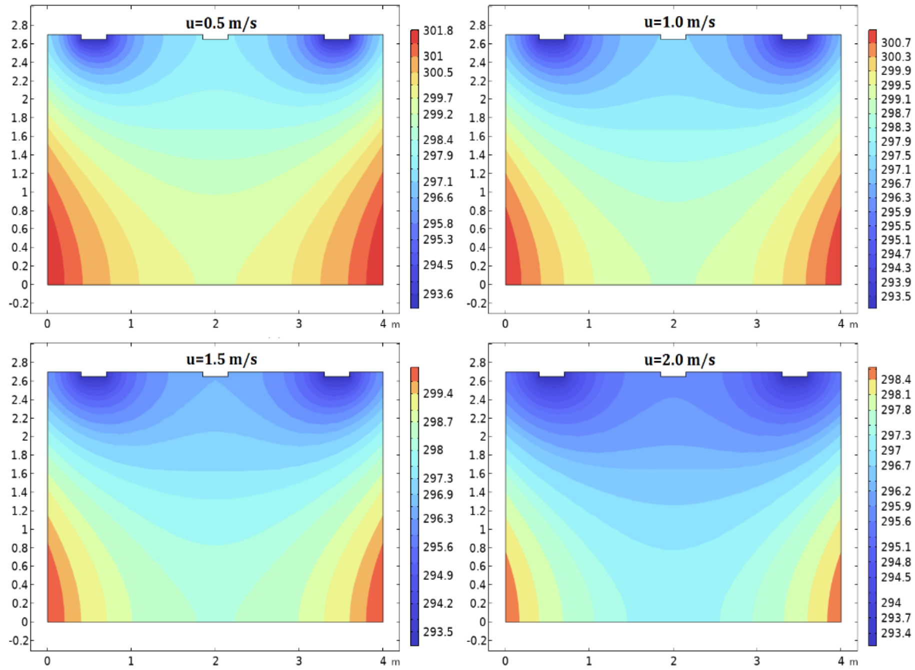

Figure 6. Temperature field for indoor air in the experimental house

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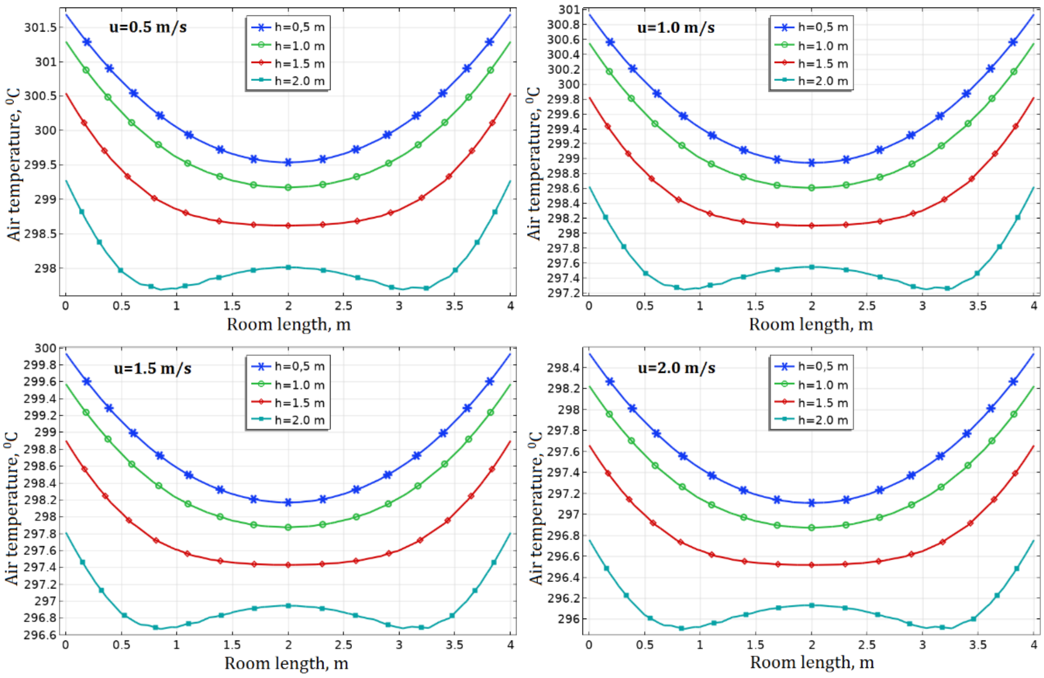

Figure 7. Changes in indoor air temperature in the experimental house

When the air flow velocity at the inlet is different, the temperature change pattern inside the house is almost the same, and when the height of the house increases from 0.5 to 2.0 m, the air temperature inside the house decreases. When 300 W/m^2 of solar radiation energy is transmitted to the vertical wall of the house, the temperature on the inner surface of the vertical wall of the house is 33℃. The temperature on the inner surface of the vertical wall of the house decreases with increasing air velocity at the inlet. The temperature decrease on the vertical surface of the house is as follows: at a speed of 0.5 m/s, it decreases to an average of 27.7℃, at a speed of 1.0 m/s, it decreases to 26.8℃, at a speed of 1.5 m/s, it decreases to 25.9℃, and at a speed of 2.0 m/s, it decreases to 24.6℃. It was found that the temperature is the lowest in the range of 1.5 to 2.5 m of the length of the house. When the air flow velocity at the inlet was different, the average temperature inside the house was as follows: at a speed of 0.5 m/s, it was 25.5℃, at a speed of 1.0 m/s, it was 25.1℃, at a speed of 1.5 m/s, and it was 23.5℃ at a speed of 2.0 m/s. Therefore, it is clear from the results of the above study that when the surface temperature of the vertical wall of the house is 25℃ and 300 W/m^2 of solar radiation energy is transmitted to the vertical wall of the house, if air with a temperature of 18℃ is introduced into the house, it is possible to ensure thermal comfort inside the house.

IV. CONCLUSION

Physical models of an experimental house with an air-cooled system were developed and thermal-technical parameters were described. A mathematical model was developed that allows determining the characteristics of air flow in the experimental house and the change in air temperature along the height and length of the house.

When the temperature on the surface of the vertical wall of the experimental house was 25℃, the air inlet temperature was 18℃, and the air inlet velocities were different, the change in the air temperature inside the house was determined. According to the results, the average temperature in the house was 23.6℃ when the air flow velocity was 0.5 m/s, 23.4℃ when the velocity was 1.0 m/s, 23.1℃ when the velocity was 1.5 m/s, and 22.9℃ when the velocity was 2.0 m/s.

The temperature on the surface of the vertical wall of the experimental house was 25℃, the air inlet temperature was 18℃, the solar radiation energy was transmitted to the wall at 300 W/m^2, and the air inlet velocities were different. The changes in the air temperature inside the house were determined. According to the results, the average temperature in the house was 25.5℃ when the air flow velocity was 0.5 m/s, 25.1℃ when the velocity was 1.0 m/s, 24.5℃ when the velocity was 1.5 m/s, and 23.5℃ when the velocity was 2.0 m/s.

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