

Experimental Study on Thermal Comfort of Fan Air Conditioning Coupling

Shuanghua Cao*, Shiyu Wei and Yue Pu

School of Environment and Architecture, University of Shanghai for Science and Technology, Shanghai 200093, China

Abstract

Taking the room with air conditioner and ceiling fan as the research object, experimental measurements were carried out on three set temperatures of air conditioner and four ceiling fan stalls totaling 12 working conditions by setting measurement points at different locations, the temperature and velocity variations under different working conditions were investigated and the thermal comfort calculations of PMV with PPD were carried out. It provides a basis for optimizing room airflow organization and comfort by coupling fan and air conditioner.

Keywords

Thermocouples; Air Supply Coupling; Temperature Field; Thermal Comfort.

1. Introduction

The traditional indoor temperature control method mainly relies on the air conditioning system, and in some cases, ceiling fans are also used to improve indoor air circulation, which often operate independently. Based on ensuring the comfort of the indoor thermal environment, researchers have started to pay attention to the operation mode of coupled air conditioners and ceiling fans to achieve more energy-saving indoor temperature control effects.

Researchers [1-2] experimentally determined the comfortable wind speed of electric fans under different indoor temperature conditions, and the air flow generated by electric fans can keep subjects comfortable in a temperature background of 28-32°C. Romina et al [3] conducted an experimental study on the comfort of personalized ceiling fans in terms of temperature conditions, air supply direction and activity level of personnel. The research results showed that the use of fans by subjects at a temperature of 31°C can meet their comfort needs, and the air flow direction has no difference in the comfort of subjects at different positions. By appropriately increasing the set temperature of the air conditioner and using an electric fan to improve the indoor air flow velocity, the energy consumption of the air conditioner can be significantly reduced while meeting the thermal comfort requirements [4]. Haslinda et al [5] found that installing fans indoors can reduce the PMV index by 75% to 95% and the PPD index by 87% to 91%.

In this article, experimental measurements are carried out in classrooms equipped with air conditioning and ceiling fans under different working conditions, indoor temperature and velocity fields are analyzed through experimental data, and thermal comfort of different combinations of ceiling fans and air conditioning are studied in order to obtain more suitable air supply parameters for the combination of air conditioning and ceiling fans.

2. Thermal Comfort Experiment

2.1. Experimental Plan

The experiment was conducted in a classroom with fans and air conditioning, with a classroom size of 8.1m × 6.2m × 3.7m. There are two 1m × 0.2m multi-unit supply and return ducts, equipped with four 1.2m diameter fans at a height of 2.8m. During the actual measurement period, the weather was sunny with an average outdoor temperature of 32.6°C. During this period, doors and windows were closed and curtains drawn to prevent the sun's rays from affecting the indoor temperature.

The measurement plan is as follows: the interior plane is a rectangle with a total of five measurement positions on the horizontal plane. The four points are at the four equal points of the two diagonals, and one point is at the intersection of the diagonals, as shown in Figure 1. At each of these five positions in the vertical plane there are four measuring points at 0.1 m, 0.6 m, 1.1 m and 1.7 m. In total there are 20 thermocouple measurement points. The experiment set three air conditioning temperatures of 24, 26 and 28°C, with four fan positions at each temperature: off, low, medium and high. A total of 12 temperature and wind speed tests were performed.

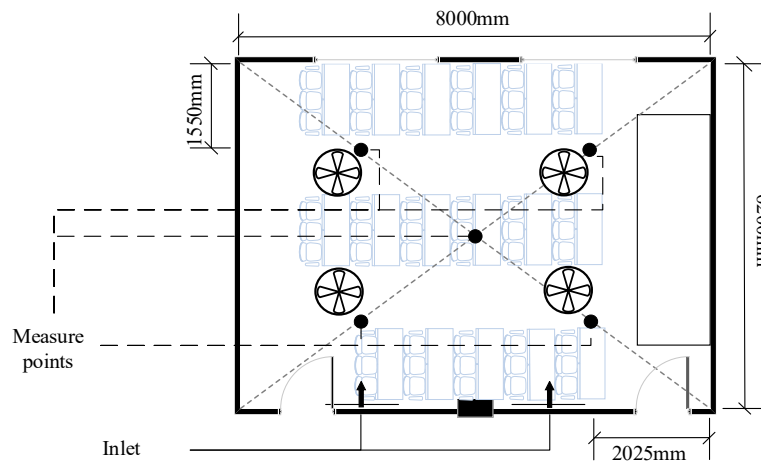


Figure 1. Interior plan

2.2. Comfort Indicator

According to ASHRAE Standard 55-2020, the factors influencing thermal comfort can be divided into subjective and objective factors. The PMV index considers six factors: energy metabolic rate, thermal resistance of clothing, relative humidity, indoor temperature, radiant temperature and air velocity. To eliminate the influence of subjective factors, volunteers are dressed uniformly and remain in a learning state. In a stationary air-conditioned environment, the average radiant temperature is approximately equal to the indoor temperature. The experimental regression equation for PMV is

$$PMV = [0.303 \exp(-0.036M) + 0.0275]TL. \quad (1)$$

$$PPD = 100 - 95 \exp[(0.03353PMV^4 + 0.2179PMV^2)]. \quad (2)$$

M - Human metabolic rate (W);

TL - The difference between the heat generated by the body and the heat emitted by the body to the outside world

3. Experimental Results and Analysis

3.1. Analysis of Wind Speed and Temperature Field

The airflow organisation of a room is determined by the coupling of the airflow from the air handling unit and the ceiling fan. The position of the cold air stream blown from the air conditioner to the floor will also vary for fans with different speeds. Figure 2 shows the average wind speed at each measurement point under different operating conditions. It can be seen that when the fan is not on, the wind speed at each measurement point is relatively low, not exceeding 0.16m/s. When the fan is turned on, the wind speed at each measurement point increases by 0.1-0.2m/s to varying degrees as the fan speed increases. The rate of change of wind speed in the 0.6m~1.1m range is greater than that in the 1.1m~1.7m and 0.1m~0.6m ranges. This is because the tables and chairs in the classroom block the airflow in the 0.6-1.1m range, causing the wind speed to decrease faster. The main reason for the decrease in wind speed in the other two ranges is due to the influence of air resistance. Overall, the measurement point velocity shown in Figure 3 is formed by the different air flow trajectories generated by the air flow velocity of ceiling fans and air conditioners, as well as the arrangement of tables and chairs in the room, air resistance, and different outlet temperatures.

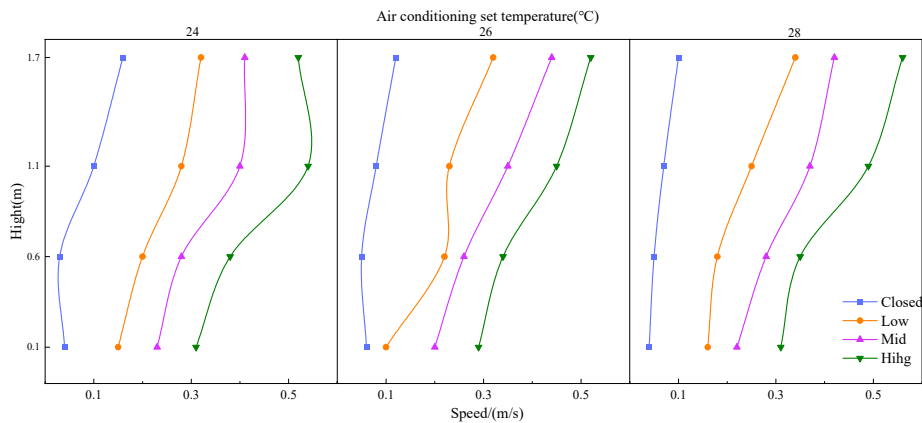


Figure 2. Wind speed height distribution curve under various operating conditions

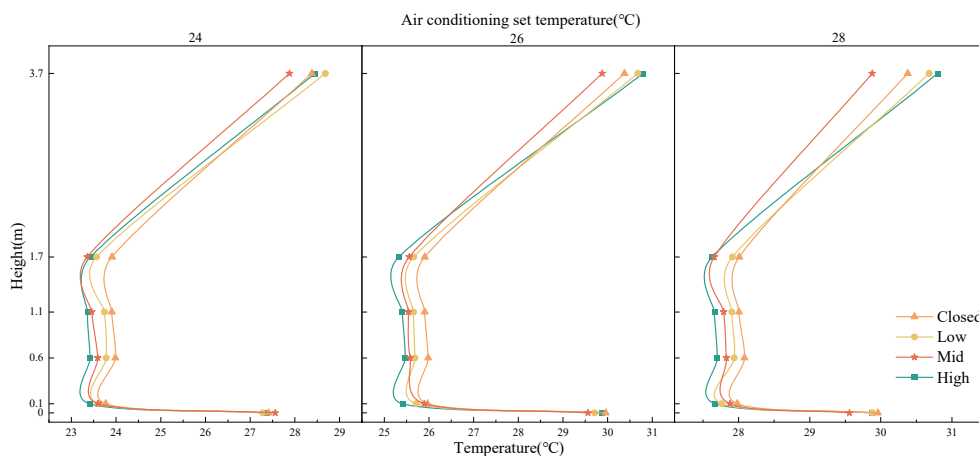


Figure 3. Temperature height distribution curve under various operating conditions

From Figure 3 shows that when the air conditioner alone is running, the average room temperature and the temperature at each measurement point are maintained close to the setpoint of the air conditioner. When the air conditioner and the ceiling fan are running simultaneously, the air flow caused by the swirling flow of the ceiling fan causes the cold air in the upper part of the room to move downwards, and the temperature at the measuring point is lower than when the air conditioner alone is switched on. As the speed of the ceiling fan

increases, the temperature at the same air conditioner setting shows a downward trend. For each increase in the speed of the ceiling fan, the temperature at the measurement point decreases by approximately 0.2°C.

Due to the higher density of cold air, the temperature at measurement points between 0.6m and 1.7m shows an upward trend as the height decreases. By observing the temperature curves of different ceiling fan speeds, it was found that the higher the speed, the more vertical the temperature curve between 0.1m and 1.7m, and the closer the temperature. This suggests that a high wind speed can make the temperature distribution in the room more uniform.

3.2. PMV-PPD Analysis

Using PMV and PPD models for thermal comfort calculation. In the calculation, a comfort standard that complies with ASHRAE standard 55-2020 is set, where the PMV value should be within ± 0.5 and the PPD value should be less than 10%. Assuming a human activity level of 1 met and considering a thermal resistance of 0.5 clo when wearing clothing. [Table 1](#) shows the results of PMV and PPD for different planes.

Table 1. Different height of PMV and PPD under different working conditions

Air conditioning set temperature		24°C				26°C				28°C			
height	Ceiling fan gear	Closed	Low	Mid	High	Closed	Low	Mid	High	Closed	Low	Mid	High
0.1m	PMV	-0.87	-0.85	-1.05	-1.29	-0.1	-0.11	-0.32	-0.55	0.76	0.66	0.3	0.17
0.6m		-0.67	-1.01	-1.31	-1.59	0.11	-0.3	-0.54	-0.76	0.93	0.52	0.26	0.03
1.1m		-0.73	-1.25	-1.61	-1.86	0.02	-0.51	-0.77	-1.02	0.82	0.29	0.04	-0.07
1.7m		-0.72	-1.41	-1.72	-1.9	0.02	-0.59	-0.82	-1.09	0.82	0.21	-0.06	-0.13
0.1m	PPD	21	20	28	40	5	5	7	11	17	14	7	6
0.6m		14	26	41	56	6	7	11	17	23	11	6	5
1.1m		16	38	57	70	5	11	17	26	19	7	5	5
1.7m		16	46	63	72	5	12	19	30	19	6	5	6

The results show the setting temperature of 26°C with the same fan condition, the lower the horizontal height, the closer the PMV is to 0, and the smaller the PPD is, this is mainly due to the fact that the higher the height, the higher the wind speed, and thus the lower horizontal level is more comfortable than the higher horizontal level; at the setting temperature of 28°C, it is the reverse of the situation at 26°C: the higher the horizontal height, the closer the PMV is to 0, and the smaller the PPD is. This is due to the higher setting temperature, only the larger wind speed can offset the discomfort. Overall, the conditions that allowed all four height planes to meet the thermal comfort criteria were: air conditioning 26°C fan off, air conditioning 28°C fan mid-range, and air conditioning 28°C fan high-range.

4. Conclusion

The focus of this paper is to discuss the indoor thermal environment regulation strategy of combining air conditioning and ceiling fans, and to evaluate the effect of the combination of the two on human thermal comfort, with the following conclusions:

- 1) The ceiling fan has a significant effect on improving the thermal environment of the working area. Under the experimental measurement conditions, the temperature decreases by about 0.2°C for every one-speed increase in the ceiling fan.
- 2) PMV is moderate at low air speeds when the temperature setting is relatively low; PMV is moderate at higher air speeds when the temperature setting is relatively high. With

different air conditioning temperature settings, the use of ceiling fans can achieve similar thermal comfort levels for PMV and PPD;

References

- [1] Huang L, Ouyang Q, Zhu Y, et al: A study about the demand for air movement in warm environment. *Building and Environment*, 2013, 61(MAR.),p. 27 -33.
- [2] Y D He, N P Li, N Li, et al: Control behaviors and thermal comfort in a shared room with desk fans and adjustable thermostat [J]. *Building and Environment*, 2018,136,p.213-226.
- [3] Romina R, Marcel S, Andreas: Personalized ceiling fans: Effects of air motion, air direction and personal control on thermal comfort [J]. *Energy and Buildings*, 2021,235:11072.
- [4] S.Atthajariyakul, C.Lertsatittanakorn: Small fan assisted air conditioner for thermal comfort and energy saving in Thailand. *Energy Conversion and Management*, 2008, 49, p. 2499–2504.
- [5] Haslinda Mohamed Kamar, N.B. Kamsah, F.A. Ghaleb, M. Idrus Alhamid: Enhancement of thermal comfort in a large space building[J].*Alexandria Engineering Journal*,2019.
- [6] American Society of Heating, Refrigerating and Air-Conditioning Engineers. ASHRAE Standard 55-2020: Thermal Environmental Conditions for Human Occupancy. 2020.