

On the use of wearable face and neck cooling fans to improve occupant thermal comfort in warm indoor environments

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Abstract. Face and neck cooling has been found effective in improving thermal comfort during exercise in the heat despite the fact that the surface area of human face and neck regions accounts for only 5.5% of the entire body. Presently very little documented research has been conducted to investigate cooling the face and neck only to improve indoor thermal comfort. In this study, 16 subjects (8 males and 8 females) used two highly energy efficient wearable face and neck cooling fans to improve occupant thermal comfort in two warm indoor conditions (30 and 32 °C). Results showed that both cooling fans could significantly reduce local skin temperatures at the forehead, face and neck regions. Local thermal sensation votes at the face and neck and the overall thermal sensation votes decreased obviously at 30°C and 32°C. Both cooling fans could raise the acceptable HVAC temperature setpoint to 32.0 °C, which will significantly reduce the energy consumption of HVAC.

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1 Introduction

In recent years, personal thermal management (PTM) has attracted great attention of researchers under the background of saving building energy, and it can effectively improve the thermal comfort of individual occupants [1-3]. Generally speaking, personal thermal management system (PTMS) creates an ideal near-body thermal envelop, which can improve personal thermal comfort. Besides, compared with the traditional HVAC system, the personal thermal management system consumes very little energy [4].

There are two types of PTMS: wearable PTMS and non-wearable PTMS. Non-wearable PTMS may include task ambient conditioning systems, personal comfort devices, and personalized ventilation systems [5-9]. In the past 30 years, extensive research on non-wearable PTMS has clearly shown that: In non-air-conditioned and air-conditioned indoor environments, the use of non-wearable PTMS can improve personal thermal comfort [3]. However, wearable PTMS such as desk fans, ceiling fans and personalized ventilation systems are not suitable for active indoor occupants. Compared with non-wearable PTM, wearable PTM is more suitable for improving the thermal comfort of active indoor people. According to Yang et al. [3], if the intensive conditioning of personal micro-environment is moved closer to human body, individual thermal comfort can be improved. Therefore, it is expected that wearable PTMS will improve personal thermal comfort while consuming little or no energy. At present, there are some researches on wearable PTM based on clothing [10-14]. However, all these researches are conducted under the

condition of thermal neutrality ($< 26.0^{\circ}\text{C}$). Because some clothes are too heavy and accompanied by hygiene problems, it is difficult to guarantee their practicability.

In this study, two wearable cooling fans (face cooling fan and neck cooling fan) with high energy efficiency (power consumption $\leq 4\text{ W}$) were selected to study their actual performance of enhancing thermal comfort of occupant at warm indoor temperature. The effects of these two wearable cooling systems on the whole and local physiological and sensory responses of passengers were thoroughly studied. In addition, the influence of face and neck cooling on thermal comfort is compared and discussed. This study can provide useful guidance for practitioners on how to use wearable personal cooling system to improve personal thermal comfort in warm indoor environment.



Figure 1. Facial cooling fan (a) and neck cooling fan (b).

2 Materials and Methods

Sixteen young college students (8 males and 8 females) participated in the project. All participants were in good health and had no history of heatstroke, lung or cardiovascular diseases. They were told not to drink tea, coffee, alcohol or engage in any strenuous activities at least one day before each experiment. The participants' total clothing thermal insulation on that day was 0.5 clo. Two kinds of neck-hung U-shaped cooling fans were selected: face cooling fan and neck cooling fan (see Figure 1). The battery capacity of the two fans is 2000 mA·h, and

the wind speed can be changed in three stages. The wind speed of the face cooling fan at a distance of 10 cm from the air outlet is 2.5–3.4 m/s, and the rated power is 4 W. The wind speed of the neck cooling fan at a distance of 10cm from the air outlet is 1.3–2.7 m/s, and the rated power is 3.7 W.

Participants were required to wear two kinds of local cooling fans (face cooling fan [FC] and neck cooling fan [NC]) to complete the experiment at two different air temperatures (30 °C and 32 °C). After arriving at the laboratory, participants rest for 20–30 minutes at 26 °C. Then install skin temperature sensors for them. Use wireless skin temperature recorder to measure local skin temperature of forehead, face and

neck (iButton DS1922L, resolution: 0.0625, accuracy: ±0.5 °C). After entering the experimental cabin, participants' perceptual responses were investigated every 10 minutes, including overall and local-body thermal sensation votes (TSVs), overall thermal comfort votes (TCVs), dry eyes and lips. In the first 30 min (stage 1) of the experiment, the participants were required not to wear local cooling fans. In the next 30 min (stage 2), participants should wear local cooling fans and shift the gear to the second gear. In the last 30 minutes, participants can freely adjust the fan gear according to their own thermal requirements. The total experimental time was 90 min.

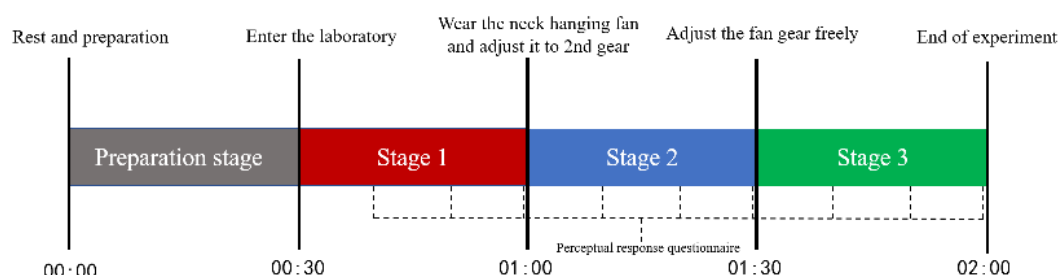


Figure 2. Experimental schedule.

3 Results and Discussion

3.1 Overall thermal sensation vote (TSV) and overall thermal comfort vote (TCV)

Figure 3 shows the overall thermal sensation voting under various operating conditions. When the local cooling fan is not used, the overall thermal sensation vote is +1.7 and +2.3 at 30 °C and 32 °C, respectively. The overall thermal sensation can be reduced below +1.0 by using two local cooling fans. Figure 4 shows the overall thermal comfort voting under various operating conditions. When the local cooling fan is not used, the overall

thermal comfort is maintained at about -1. After using two kinds of local cooling fans, the overall thermal comfort vote is significantly improved, which can reach about -0.5. After allowing free gear control, the overall thermal comfort vote can be further improved to about 0.

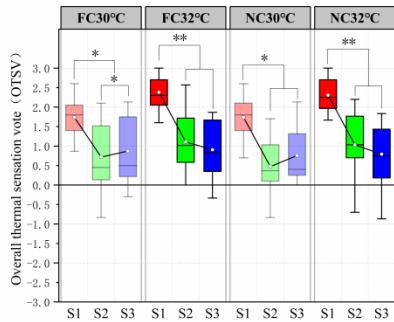


Figure 3. Overall thermal sensation votes (TSVs). *, $p<0.05$; **, $p<0.001$.

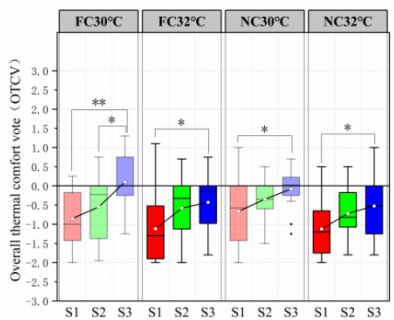


Figure 4. Overall thermal comfort votes (TCVs). *, $p<0.05$; **, $p<0.001$.

3.2 Local skin temperatures at forehead, face and neck

Figure 5 shows the local mean skin temperature of the subject's forehead, face and neck. The results show that, the local mean skin temperature of forehead, face and neck can be significantly reduced by using wearable face and neck cooling fans in both two studied air temperatures (i.e. 30 and 32 °C). It can be seen from Figures 5(a) that the forehead temperature of FC and NC is 0.4–1.0 °C lower than that of no fan. At 30°C, the free control of the fan increases the local skin temperature of the forehead. At 32°C, the average forehead temperature of free control fan is slightly lower than that of fixed second-gear air supply speed. It can be seen from Figure 5(b) that wearing FC can reduce the average skin temperature

of the face by 1.3–1.9°C. Wearing NC can reduce the average skin temperature of face by 0.8–1.0 °C. It can be seen from Figure 5(c) that wearing FC and NC can reduce the forehead temperature by 1.2–1.9°C. At 30°C, the free control of the fan increases the local skin temperature of the forehead by 0.2–0.5°C. At 32°C, the average forehead temperature of the free control of the fan is slightly lower than that of the fixed second-gear air supply speed.

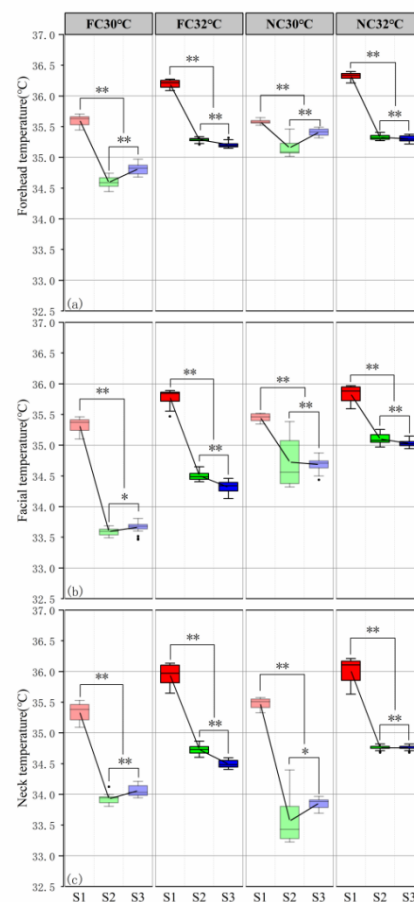


Figure 5. Local mean skin temperatures at the (a) forehead, (b) face and (c). *, $p<0.05$; **, $p<0.001$.

3.3 Dry eye and dry lip syndromes

Figure 6 shows the Ratings of dry eyes and dry lips under various operating conditions. The use of both local cooling fans increased the percentage of

participants who reported dry eye and dry lip symptoms (ratings of -2 and -1). When fans are not used, the percentage of dry eye syndrome is 10–23%, while when two wearable cooling fans are used, the percentage of dry eye syndrome reported as -2 and -1 increases to 52–70%. On the other hand, the dry eye caused by FC is slightly more than that caused by NC. In terms of ratings of dry lip symptoms, the percentage of dry lips does not exceed 21% when there is no local cooling, and the percentage of dry lips increases to 32–46% when the local cooling fan is used. Generally speaking, freely controlling fan gear can effectively improve dry eye and dry lips.

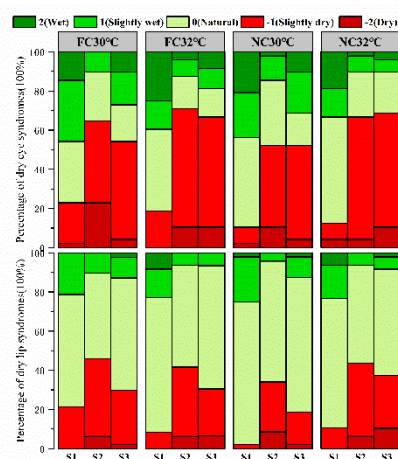


Figure 6. Ratings of dry eye and dry lip symptoms

4 Conclusion

The use of energy efficient wearable face and neck cooling fans can improve the thermal comfort of occupants in warm indoor environment. This study was explored and compared the physiological and perceptual responses of occupants when using two wearable cooling fans. Results showed that both wearable cooling fans can significantly reduce the local skin temperature in forehead, face and neck regions. The overall TSVs

decreased by 1.03–1.14 units at 30 °C and 1.34–1.66 units at 32 °C. This means that both cooling fans can increase the acceptable HVAC temperature setpoint to 32.0 °C, which will save 45.7% energy compared with the baseline HVAC setting of 24.5 °C. Although there are some problems with dry eyes and dry lips, the final conclusion is that the two types of wearable cooling fans can significantly improve the indoor thermal comfort and save the cooling energy of HVAC.

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