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Control behaviors and thermal comfort in a shared room with desk fans and adjustable thermostat

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ABSTRACT

It is well known that fans help maintain thermal comfort in warm environments. Nonetheless, two important questions are unclear: (1) how occupants use fans and control the air conditioner thermostat simultaneously, and (2) how behaviors of occupants interact in a shared room with personal fans. In this study, a series of experiments was conducted with subjects placed in environments having desk fans, with and without the access to controlling indoor temperature. The results show that desk fans significantly reduced warm sensation and improved thermal comfort in the conditions at 28 and 30 °C, while subjects still needed to adjust the indoor temperature until they fully eliminated the warm sensation. Moreover, subjects tended to use desk fans less when they could adjust the indoor temperature. Notably, it was found that insensitive subjects always made concessions to sensitive subjects, and thus the indoor environment was always controlled by sensitive subjects. Moreover, the always-on strategy of desk fans made both sensitive and insensitive subjects choose the higher temperature, and also maintained the same level of thermal comfort as compared with other conditions. This strategy can be regarded as a trade-off between thermal comfort and energy conservation.

1. Introduction

A comfortable environment is important for the well-being and work performance of people in buildings. In the 1970s, Fanger established the predicted mean vote (PMV) model [1], based on the heat balance of the human body, to predict the thermal comfort conditions. This model considered six key parameters, i.e. air temperature, radiant temperature, air velocity, humidity, metabolic rate and clothing insulation. The PMV model was then incorporated in many standards for creating and evaluating building environments, such as ASHRAE Standard 55 [2] and ISO Standard 7730 [3]. However, the PMV model is challenged by the adaptive thermal comfort theory [4], whose authors believe that thermal comfort cannot be determined by only six physical parameters because people have many other ways to adapt to their ambient environments. In a later work, the authors explained that there are three major categories of adaptive methods: physiological, psychological and behavioral adaptation [5]. Specifically, behavioral adaptation refers to people adopting various behaviors to adjust their thermal conditions, including opening windows/doors, changing clothes, using thermostat, using fans/heaters and so on.

As a crucial kind of adaptive behavior, using fans keeps people comfortable in warm environments. Thus it has attracted considerable attention from researchers and several experiments have been performed in artificial chambers. Boerstra et al. [6] carried out a laboratory study and found that personally controlled desk fans effectively maintained thermal comfort in warm environments and improved work performance. Cui et al. [7] tested the influence of constant mechanical wind on human comfort and performance and simulated natural wind. They found that thermal comfort of subjects was improved with personal fans. However, there were no significant changes in their work performance. He et al. [8] also conducted experiments on desk fans in an experimental room at 26, 28 and 30 °C, respectively. They found that allowing subjects to adjust desk fans further improved thermal comfort and energy efficiency in warm environments; however, desk fans also brought about the draft risk. He et al. [9] adopted desk fans to provide additional cooling in a room with a cooled ceiling system. It was found that, although desk fans were highly energy-efficient, they were practical only when the indoor temperature was no higher than 28 °C. Their subsequent experiments on personal cooling systems demonstrated that desk fans were the most energy-efficient way to maintain the neutral thermal sensation but they could not fully eliminate warm discomfort in hot environments [10]. Zhai et al. [11] undertook a series of experiments on ceiling fans and found that subjects (clothing insulation of 0.5 clo) with ceiling fans did not feel too warm even when the indoor temperature reached 30 °C and the metabolic rate was 1.4 met (the highest air velocity was around 1.5 m/s).

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Further, Huang et al. [12] claimed that desk fans significantly reduced warm sensation in the environment at 32 °C. However, the local airflow was strong which may influence normal office work and cause draft discomfort. Yi et al. [13] combined phase-change materials with fans and performed tests on a thermal mannequin with the air temperature at 34 °C. Their findings indicate that fans enhanced the evaporative heat loss which could help reduce heat stress in hot-humid environments. However, this conclusion was not validated by real human being tests.

Although the abovementioned experimental results demonstrate the comfort performance of fans, they do not entirely reflect how occupants use fans in daily life because the experimental environment is not very realistic. Thus, some researchers have conducted field investigations to better understand how people use fans and the corresponding effects. Through a one-year case study, it was observed by Indraganti et al. [14] that 64% of occupants used fans in offices, which helped increase the upper limit of comfortable temperature to 28 °C in summer. In a field study conducted by He et al. [15], it was found that using fans was the second most frequent behavior of university students for adapting to the ambient environment in air-conditioned dormitory buildings (the first most frequent behavior was adjusting the thermostat). Similarly, in a long-term field survey conducted in USA, using fans was the second most frequent behavior, only inferior to drinking cool drinks [16]. On the contrary, Goto et al. [17] claimed that more than 90% of occupants never used personal fans in office buildings in Japan and thus the effect of fans on thermal comfort was negligible. Mustapa et al. [18] also reported that the usage percentages of standing fans were 19.1% and 5.1% in naturally-ventilated and air-conditioned buildings, respectively. Moreover, in a wide field investigation conducted in Malaysia, Indonesia, Singapore, and Japan, the proportion of fan usage in office buildings was usually lower than 10% [19]. In addition, in Australia, the usage frequency of fans in residential buildings was no higher than 40% even when the outdoor temperature reached 40 °C [20].

Undoubtedly, as a kind of adaptive behavior, the use of personal fans is effective to remove warm discomfort. Nevertheless, some important issues have still not been fully explored. Firstly, for people in warm environments with personal fans, the thermal comfort level is not very high and a cooler environment is still desired [7,9–11]. Thus, it is not clear whether personal fans really meet the comfort requirements of occupants. Secondly, in actual buildings, occupants can have access to both personal fans and the thermostat of air conditioning systems [15–19], different from those studies conducted in chambers where the indoor temperature was non-adjustable for subjects. However, little is known about how occupants control the thermostat, especially when they can use fans simultaneously. In addition, adaptive behaviors of a person are not only decided by himself or herself but also by other people around [16]. However, it is not well understood whether there is a behavioral interaction between people in a shared room with personal fans.

To explore the abovementioned issues, a series of experiments in a shared room was carried out. Firstly, subjects were exposed to warm environments with personal fans, and then they were given access to control the indoor temperature so as to determine whether personal fans could meet their thermal comfort requirements. Furthermore, they were also exposed to the environments without personal fans, which helped to identify the effects of personal fans. Subsequently, the results of both subjective responses and control behaviors were further analyzed to understand the behavior characteristics in a shared room.

2. Methodology

2.1. Facilities

In order to create a realistic environment, all experiments were conducted in a real office room (length × width × height = 4.5 m × 3.4 m × 3.4 m) with a split-type air conditioner in a laboratory building at Hunan University, Changsha, China. The layout of the room is shown in Fig. 1. In the room, a split-type air conditioner was installed on the wall, around 2.6 m above the floor. Moreover, a small ventilation fan was installed to supply fresh air from the outdoor environment. A curtain was also used to cover the window during the tests. At the same time, two seats with desk fans (length × width × height = 15 cm × 13 cm × 19 cm) were set up. Each desk fan had a step-less controller which enabled subjects to control the local airflow. The distance between desk fans and subjects was about 40 cm and the local airflow mainly blew on the upper body parts such as head, chest, arms and hands.

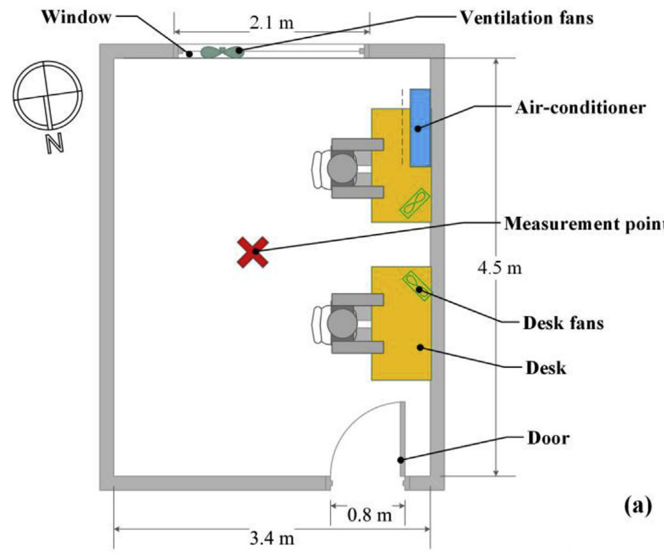

Fig. 1. The layout of the room (a) and the scene photo (b).

2.2. Experimental procedure and conditions

During the tests, subjects were free to read books, surf the internet, listen to music or use mobile phones. However, eating, smoking and walking were not allowed. Each time, two subjects were randomly chosen as a pair and then they entered the shared room simultaneously. Such a setting ensured that the interaction between two subjects was less affected by other factors such as gender, acquaintance, etc. Fig. 2 presents the procedure of each test which lasted 85 min: Firstly, subjects stayed in a preparation room for 15 min, where the indoor temperature was 24–26 °C. Then, subjects entered the experimental room and stayed there for 40 min (Phase 1). During Phase 1, whether they did or did not have desk fans, subjects had no access to controlling the air conditioner. When they had desk fans, subjects were free to control them. Subsequently, during the next 30 min (Phase 2), subjects were offered access to the control over the air conditioner. During the tests, subjects were asked to fill in a questionnaire every 10 min (in Phases 1 and 2) and specify their requirements for changing the indoor