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The influence of personally controlled desk fan on comfort and energy consumption in hot and humid environments

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A B S T R A C T

Human beings' comfort is critical for health and work performance of occupants in modern buildings. The main objective of this study was to investigate the influence of a type of energy-efficient desk fan on subjective evaluation of thermal comfort in hot and humid environment. A series of experiments was conducted in an experimental room in Hunan University, China during summer. In total, 24 subjects were invited to participate in the experiments and they experienced the environments which were set at 26, 28, and 30 °C with fixed or free-controlled local airflow by desk fan, respectively. The subjects reported their thermal sensation, thermal comfort, and perceived air quality during the tests. The obtained results indicate that the use of desk fan significantly improved the subjects' thermal comfort and perceived air quality. When subjects were allowed to freely control the desk fan, they considered the hot-humid environment more comfortable; moreover, they thought indoor air was fresher than when they were under the influence of constant local airflow by desk fan. Furthermore, only a little energy was consumed by desk fan (maximum power was merely 3 W) to maintain a comfortable environment for subjects, thus making personally controlled desk fan a very energy-efficient way to deliver comfort in hot-humid environment.

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1. Introduction

With the development of economy and people's living standards, people enjoy the pursuit of high-quality building system, thus people are paying increasing attention to indoor environment as they spend over 80% of their time in buildings [1]. In the 1970s, P. O. Fanger proposed the Predicted Mean Vote (PMV) model which used six parameters (four physical variables and two personal variables) to estimate average thermal sensation of a large group of people [2]. However, when people are exposed to the actual environment without air conditioning systems where they probably feel hot or cold, the PMV model fails to accurately predict the people's thermal sensation, in particular, in naturally ventilated buildings [3]. In contrast, the theory of adaptive comfort which was first proposed in 1970s [4] may be better for explaining the actual thermal comfort in non-neutral environments.

Many researchers [5] and related organizations [6,7] have conducted relevant researches on adaptive thermal comfort, which were based on the data gathered from field studies. The majority of these data are, in particular, related to the environments without air conditioning systems. Based on the results obtained from experimental and field studies, Brager and de Dear [3] found that the process of acclimatization was too slow to actually enhance the thermal adaptation; however, behavioral adjustment and expectation played significant roles in helping people adapt to their ambient environments. A. Auliciems [8], R. de Dear [9], Indraganti et al. [10], and Rijal et al. [11] focused on adaptive behaviors of occupants with respect to thermal comfort, and found that the acceptability to the thermal environment strongly depended on occupant's behaviors. Nicol et al. [12] found that heat exchange calculations could not be applied strictly to all climatic conditions because human beings tend to adapt to their ambient environments. This indicates that people can eliminate the thermal discomfort by adaptive behavior, such as drinking hot or cold beverages, changing clothes, and opening windows or doors. Wang et al. [13] undertook a field investigation in residential buildings in Harbin, northeast of China, and reported that opening windows (instead of running air conditioners) could help subjects to maintain thermal comfort, thus providing a direct evidence that adaptive behavior (increasing air velocity) could effectively offset hot

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stimulation and improve subjects' thermal comfort. This result is consistent with the ASHRAE Standard [6] that stronger air movement extends the upper limit of comfortable temperature in naturally conditioned spaces during summer. Zhai et al. [14] found that with personally controlled air movement, thermal comfort could be maintained when air temperature went up to 30 °C (relative humidity was 60%); moreover discomfort from humidity, air movement, or eye dryness did not occur. Halawa and van Hoof [15] concluded that theoretically, based on the heat balance approach, the cooling effect of increased air velocity could be perceived by the occupants as long as the air temperature was below the mean skin temperature. He et al. [16] carried out a field study on adaptive comfort in air-conditioned dormitory rooms of a university in hot-humid climate zone in summer. They found that various behaviors (such as using fans, opening windows, and so on) were still conducted by students, although there were split-type air conditioners. Moreover, another previous research also proved that people perceive comfort in a large range of environmental thermal conditions [17], which provides an opportunity to save energy in buildings.

However, the above mentioned researches mainly focused on overall air speed mode (i.e. the air movement of the entire indoor space or a large part of it was enhanced); nonetheless, little attention has been paid to local air speed mode (i.e. small ventilation device). Many previous studies used large fan-boxes or personalized ventilation systems; and only a few reported the use of a small-sized desk fans which are easier and cheaper to be applied in buildings. Moreover, desk fan needs very little space for installation. Another unsolved problem is that there are only a few studies focusing on the effects of adaptive behavior in hot-humid environment. J. F. Nicol [18] carried out a meta-analysis on the database of 25 comfort field surveys in hot-humid climate and reported that adaptive comfort temperature was significantly different between hot-humid climate condition and temperate and hot dry climate. In our previous primary study [19], it was proved that strengthened air movement could help reduce warm sensation. However, many other factors, such as thermal acceptability, preference, and perceived air quality were not analyzed. Noteworthy, multiple occupants in a room have different preference for indoor environment. Zhai et al. [14] observed large individual differences among the subjects when they were free to select the air movement, even when they were exposed to the same environment. He et al. [20] also found that the power of personal heating device varied significantly among different subjects, although the indoor temperature was the same. Nevertheless, only a few previous studies have focused on the effect of personalized control and compared it with the condition where people were not able to control. Undeniably, a lot more systematic explorations are demanded to systematically investigate the effect of personalized control.

The main objective of this study was to investigate the occupants' behavioral control over desk fan in hot and humid environment. A series of experiments was conducted to test how people controlled desk fan, and the corresponding effects on both subjective responses and energy consumption in hot and humid environment were also systematically evaluated. During the experiments, the indoor environmental parameters (air temperature, air velocity) were controlled so as to ensure the exposure of the subjects to the preplanned environments. Moreover, questionnaires were delivered to occupants as well. Thus, the research contents of this paper include: (1) examination of the ability of personally controlled desk fan to maintain thermal comfort and perceived air quality in hot-humid environment; and (2) examination of the energy consumption by desk fan under different air movement modes, i.e., the personally controlled and the fixed air velocity.

2. Method

2.1. Experimental facilities

The experiments were conducted in one experimental room (Length × width × height: 3.8 m × 2.7 m × 3 m) in Hunan University, Changsha, China. This room was used as normal office room before the experiment, thus experimental condition could be close to real office environment. The room has one window (1.5 m × 1.8 m) on the north wall; however, it was well shaded by thermal insulation layer (about 40 mm) and thick window curtain during the experiments, which led to a decrease in the influence of outdoor environment. This setting was intended to ensure that the subjects were mainly influenced by indoor factors, such as air temperature and a desk fan. So, it would be helpful to exclude other random factors (like sun radiation). One ventilation device was installed near the window to supply fresh air at low speed. The indoor conditions were controlled by another air-conditioning system which supplied air at low speed during the experiments. Before each test, the air conditioning system was turned on about 1 h ahead. Besides, the outlet air of the air conditioning was not blowing to the subjects directly during the experiments. According to the measurement, the indoor air velocity was very low and similar whatever the condition was. Only one workstation was set up for subjects. Therefore, only one subject experienced the experimental conditions at one time. The workstation included a desk fan, a laptop, and a chair. The desk fan was placed on the table, on the right side of the subject. The indoor layout of experimental room is shown in Fig. 1a and the photo of experimental site is shown in Fig. 1b.

Indoor temperature and relative humidity were measured continuously using TR-72Ui temperature and humidity meters,

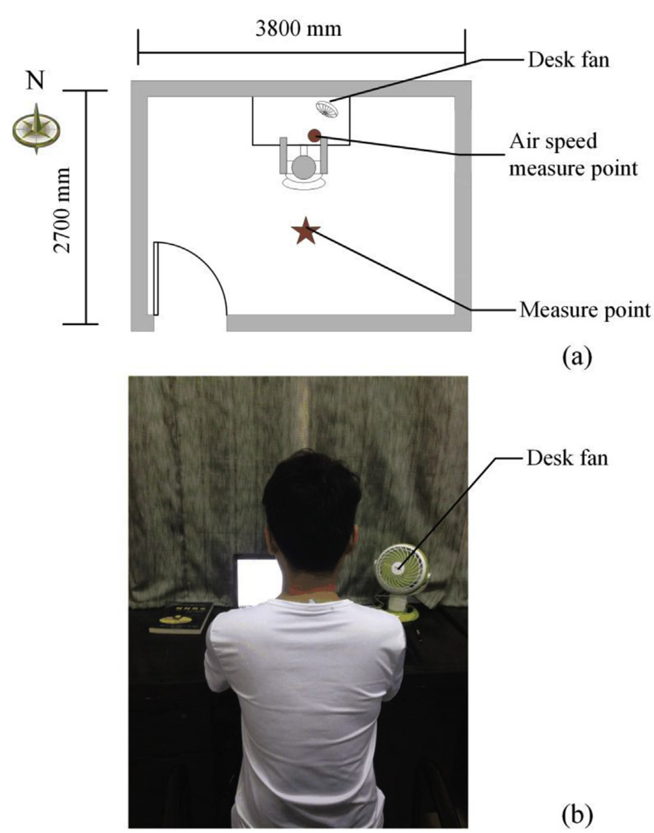

Fig. 1. (a) Layout of experimental room and (b) experimental site.

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