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Field study on adaptive comfort in air conditioned dormitories of university with hot-humid climate in summer

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ABSTRACT

This study aims to investigate adaptive comfort in air conditioned dormitory rooms in hot-humid climate zone. A field survey was carried out in air conditioned dormitories in Changsha, a big city in south-central China in summer. This survey included indoor environment measurements, questionnaires and interviews. The obtained results indicated that the experience of long-time living in regions with hot-humid climate in summer enhanced subjects' adaptability to higher temperature, which can be explained by psychological and behavioral processes. Such kind of adaptability still existed in air conditioned environment even though it was not as strong as that in naturally ventilated environment due to increased expectation, psychological and behavioral dependencies on air conditioners as well as possible weaker physiological adaptation. Moreover, the experience of long-time living in humid regions also strengthened the adaptation to high humidity, which probably mainly came from psychological adaptation process. Nevertheless, the adaptation process to humidity was slower than that to temperature because less adaptation approaches were available. This paper also provided references for both adaptive comfort researches and application of air conditioners in dormitory environment.

1. Introduction

Thermal comfort is important for both health and performance of occupants. In 1970s, Fanger proposed the PMV (Predicted Mean Vote) model based on heat balance of human body [1], and this model indicated that people's thermal sensation can be estimated by measuring air temperature, relative humidity, air velocity, mean radiant temperature (MRT), clothes insulation and metabolic rate. Nowadays, PMV model has been adopted by ASHRAE Standard and ISO Standard [2,3]. However, PMV model is also challenged by the theory of adaptive comfort which was developed since 1970s [4], because PMV model overestimates or underestimates actual sensation of occupants in the environment deviating from moderate condition, especially in naturally ventilated buildings [5]. In this context, some evaluative methods of adaptive comfort theory were incorporated by ASHRAE Standard and ISO Standard in recent years [2,6].

Adaptation is defined as "the gradual lessening of the human response to repeated environmental stimulation" [7], and mainly consists of three processes: physiological adaptation (adjusting body temperature, sweating, etc.), psychological adaptation (expectation and preference) and behavioral adaptation (adjusting clothes, operating windows, using fans, etc.) [5]. Different from PMV model, adaptive comfort model emphasizes the effect of human, i.e. the interaction between human and the ambient environment, which can help extend comfort range [4], thus it may explain why people could keep moderate sensation in extreme environment. It also exerted energy-saving potential by introducing adaptive model into the control strategy of air condition system [8,9].

Current studies on adaptive comfort mainly focused on naturally ventilated environment. Taki et al. [10] carried out field investigation in 19 buildings in summer during 1997–1998, and the results showed that adaptive model was valid in naturally ventilated buildings and the neutral temperature of occupants was high. Ogbonna and Harris [11] undertook field studies in various places including classrooms, meeting rooms and residential buildings in tropical regions of Africa. It was found that PMV model overestimated actual thermal sensation of local people. In another word, adaptation to hot climate helped reduce warm sensation. Tao and Li [12] conducted field study in classrooms of university campus in sub-tropical region in winter and they reported that PMV model underestimated human's adaptability to cold climate and could not precisely predict comfort condition in non-heating environment. After a long-time investigation in naturally ventilated classrooms in Chongqing, China, Yao et al. [13] pointed out physiological and behavioral adaptations could not fully eliminate discomfort caused by extreme environment, while psychological

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adaptation played a crucial role in decreasing dissatisfaction proportion. Wang et al. [14] reported that thermal comfort in summer could be maintained by opening windows instead of using air conditioners according to a field investigation in residential buildings in Harbin, north of China. That is to say adaptive behavior was enough for eliminating stimulation from outside environment. This conclusion was different from that of Yao et al. [13], because the climate in Chongqing is much more extreme (hot and humid) than that in Harbin in summer. Brager et al. [15] found that in naturally ventilated office rooms, respondents' thermal sensation could be close to neutral if their behaviors were not restricted. This result was consistent with the study of Schweiker et al. [16], however, the results obtained by Goto et al. [17] did not support this point. Nicol and Kessler [18] also thought the opportunity of behavioral adaptation were different for occupants in naturally ventilated buildings, for example, only people close to windows owned opportunity to operate. Similarly, Corgnati et al. [19] stated that adaptive behaviors were restricted by activity style in naturally ventilated environment. For instance, operating windows or adjusting clothes were usually forbidden during class. Yu et al. [20] carried out a series of experiments to study adaptive comfort in both air conditioned and naturally ventilated environment, and the results indicated a stronger thermoregulation ability existed in the latter one. They also found the experience of long-time living in naturally ventilated environment contributed to lowering people's expectation, which was coincident with the viewpoints of Fanger and Toftum [21]. Fanger and Toftum [21] thought that the longer people stay in regions with hot climate, the lower expectation they have, i.e. they would obtain stronger psychological adaptation. Then they proposed an expectancy factor to modify original PMV model. To further explore inner mechanism of adaptive comfort, Brager and de Dear [5] reviewed a large number of previous researches, and found that a much wider comfort range existed in naturally ventilated environment. They thought this result was caused by both expectation and control behavior, i.e. psychological and behavioral adaptation. Nicol and Humphreys [22] expressed the same opinion in their review, and suggested providing more chances of adjustment for occupants to reduce discomfort as well. Moreover, Halawa and Hoof [7] stated that thermal comfort in naturally ventilated buildings could be influenced by people's active effect, while no parameter in current adaptive comfort model can reflect such effect, thus the current model needs to be modified.

Researches on adaptive comfort in naturally ventilated condition have confirmed the existence of adaptation to non-neutral environment. Nevertheless, only a few researches were conducted to explore whether adaptation still existed in air conditioned environment. And it is emphasized by Schweiker et al. [16] and Yang et al. [23] that more studies were quite in need. Luo et al. [24], carried out field research in residential houses with heating devices in winter, and the results demonstrated owning access to control indoor environment (behavioral adaptation) could not only decrease neutral temperature (approximately 2.6 °C), but also make most people feel comfortable. While in the study of Cao et al. [25], spacing heating weakened human's adaptation to cold climate. de Dear et al. [26] analyzed the discrepancy between PMV and AMV (Actual Mean Vote) in air conditioned environment, and concluded that there was only behavioral adaptation. While Humphrey [27] believed that this deviation resulted from physical, physiological and psychological factors. To explore adaptation in air conditioned environment, Yang et al. [23] undertook a series of experiments in well-controlled chamber and found that people who lived long time in regions with hot-humid climate in summer owned physiological adaptation to high temperature, but the effect was not too much significant. They attributed the moderate subjective perception to psychological adaptation process. Brager and de Dear [5] agreed with this point, while Liu et al. [28] insisted that physiological adaptation exerted more influence than the other two process after conducting field researches in both China and U.K. However, the reason resulting in the different results between [23] and [28] remains unknown, because there are no detailed investigation results in [28], and Yang et al. [23] only considered the adjustment of skin temperature as physiological response.

Moreover, some problems of adaptive comfort remain unsolved. According to literature research, most previous studies focused on adaptation to temperature, while none specially concerned about humidity adaptation. Humidity influences both thermal sensation and humidity sensation. Too dry or humid sensation can lead to discomfort as well. Even though no previous research explicitly discussed the adaptation to high humidity, there were some results which hinted the existence of this kind of ability. In literature [29], a large proportion of people in tropical regions still felt dry with humid climate. In Japan, the mean humidity sensation of females went to dry side when indoor relative was lower than 55% and outdoor was over 70% [30]. Dahka et al. [31] found the "ideal humidity" (i.e. neutral relative humidity) was 36% for people in India, where there are dry and rainy seasons (during rainy season relative humidity could be over 90% while it was even lower than 20% during dry season [31]). A reasonable explanation for the difference among [29], [30] and [31] was subjects' experience of exposing to high humidity. Humid period in India [31] is not as long as that in tropical regions [29] and Japan [30]. Long-time and consecutive exposing to humid climate probably strengthened the adaptation. A similar phenomenon was also observed in our previous study [32] that people who acclimatized to hot-humid climate could own neutral humidity sensation at high humidity level (over 60%). Hence, if humidity adaptation exists, i.e. wider comfort humidity range exists, it is possible to reduce energy consumption of air conditioning system by suitably setting higher humidity level.

In addition, current studies were mainly carried out in offices or classrooms, while no study conducted in air conditioned dormitory was found. Environment in dormitory rooms of campus is important for students' health and learning efficiency. Compared with offices and classrooms, dormitories provide more flexibility for occupants to take adaptive behaviors, like adjusting clothes, using fans and operating windows. Since air conditioned dormitories are gaining popularity in China, it is worth studying whether adaptation could still increase occupants' comfort in such condition.

This paper aims to study occupants' adaptation to both temperature and humidity in air conditioned dormitories of university. A field investigation was conducted in dormitory rooms with split-type air conditioners during June to August in 2015 in Changsha, which is located in south of China and characterized by hot-humid climate in summer. In this study, the environment parameters (air temperature, relative humidity, air velocity and black globe temperature) were measured, and questionnaires and interview to occupants were carried out as well. Based on obtained data, adaptation to temperature and humidity was analyzed as well as the reasons behind it. Moreover, the adaptation difference between air conditioned and naturally ventilated environment were discussed by comparison with results in previous literatures. In addition, this paper provides references for both adaptive comfort researches and application of air conditioners in dormitories.

2. Methodology

2.1. Climate and time

In most regions of south China, the climate in summer is characterized by high temperature, and relative humidity remains at high level during whole year (usually higher than 60%). While in