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Exploring the dynamic process of human thermal adaptation: A study in teaching building

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ABSTRACT

In light of growing concerns about climate change and energy conservation, the adaptive thermal comfort theory has become a research focus. However, to date, few about the dynamic process of human thermal adaptation has been explored. In this paper, we ask the question as to whether people accustomed to one indoor climate can readapt to another one? And what about the timescale and difficulty of thermal re-adaptation? A comparative study was conducted in China where wintertime indoor thermal environments remarkably varied between the northern region (with pervasive district heating) and southern region (without district heating). Four college student groups were surveyed in teaching buildings and over 2000 valid responses were collected. The results show that occupants' subjective thermal comfort perception is strongly influenced by their previous thermal experience. People accustomed to indoor climate excellence are able to readapt themselves to environments with lesser quality, however, the adapting process may take some time. The effort of this study shed some light on the dynamic process of human thermal adaptation, which is helpful to shape the future indoor climate.

1. Introduction

Driven largely by climate change and energy saving concerns, building environment researchers are always interested in creating high-quality indoor climate with lower cost. Given the huge amount of energy that has been poured in building HVAC section [1,2], it is essential to get a better understanding on occupants' comfort perception which underpins current indoor thermal environment evaluation standards [3].

1.1. Indoor thermal environment evaluation

Generally, there are two basic philosophies for indoor thermal environment evaluation. One is based on heat balance status of the human body, the other is known as adaptive thermal comfort. The former approach relates occupants' subjective sensation to the heat load of the human body. Among all the heat balance models, PMV is a representative index that has been widely utilized [4]. It believes that the status with zero heat load of the human body (PMV equals to zero) correspondents to the highest satisfaction rate.

As a counterpart to heat balance approach, the adaptive theory emphasizes the role occupants play in maintaining their own thermal comfort state [5]. During the past two decades, the gradual recognition of adaptive comfort theory represent one of the most sweeping shifts in thermal comfort research [6]. The first practical version of adaptive thermal comfort model was that of de Dear and Brager [7] who utilized a quality-assured database of thermal comfort field studies from all major climate zones of the world [8] in the 1990s. After that, models with different coefficients or equations but for the same principle have been established. For instance, Fig. 1 illustrates three example models. It is interesting to see that the slopes of a linear relationship between indoor comfortable temperature and prevailing mean outdoor temperature vary significantly. The Chinese model has a much steeper slope than the other two, which may be caused by variations in climate condition, living habit, and cultural tradition.

1.2. Can people accustomed to one indoor climate readapt to another one?

Although great effort has been made to increase the rigor of the adaptive theory and extend its application scope in different

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Nomenclature

PMV	Predicted mean vote
T_a	Indoor air temperature, °C
T_{out}	Outdoor air temperature, °C
T_g	Black globe temperature, °C
T_{op}	Operative temperature, °C
RH	Relative humidity, %
ν	Air velocity, m/s
CLO	Clothing insulation, Clo
Max.	Maximum
Min.	Minimum

countries, there still remain some issues need further exploration [12,13]. For instance, the current standards simply classify buildings into two categories (i.e., PMV is suitable for air-conditioned buildings and the adaptive model is for naturally ventilated buildings) in a black-and-white way, while the real world can be much more complicated [14,15]. If people moved from one indoor climate to a different one, such as moving from an air-conditioned building to naturally ventilated indoors, what would happen? Can they readapt themselves to the new indoor climate immediately? These simple questions can be expressed in a larger perspective. What about the comfort perception of migrants moving from one climate zone to another, such as migrating from a country with pervasive HVAC services to another country devoid of HVAC services? Can people lived in comfortable thermal environment learn to accept a lower quality indoor climate easily and quickly? All these interesting questions, which can contribute to the knowledge of human thermal comfort, beg for further explanation.

To date, evidence relevant to occupants' thermal re-adaptation has mostly been anecdotal. Here are some related examples. Chun et al. [16] conducted a comparative experiment in South Korea and Japan to compare the comfort perceptions of subjects with different thermal histories. It reported that subjects experienced hotter weather conditions felt cooler than subjects who experienced cooler temperatures. de Dear et al. [17] surveyed thermal comfort in Australia classrooms, and found that students in locations exposed to wider weather variations showing greater thermal adaptability than those in more equable weather districts. Yu [18] and Luo [19] reported that residents who were used to cold indoor climate had a slighter physiological response and better comfort perception than those always lived in neutral-warm indoors when they were exposed to cold temperatures. Humphreys and Nicol [20] found in their large data analyzing that people's optimal thermal sensation moved with the prevailing daily mean indoor temperature. These studies offer some evidence relating to the correlations between indoor thermal experience and thermal adaptation. But direct data that can answer the readapting questions are yet to be produced.

1.3. What about the timescale and difficulty for human thermal adaptation?

Even though people can adapt to different indoor climates, how about its difficulty? Is the adapting process easy or difficult? Quick or slow? The significance of these seemingly simple questions cannot be overstated because it can help developing countries like India and China to shape their future indoor climate. For example, Fig. 2 compares the increasing trend of air conditioner ownership between China and U.S. It can be seen that the air conditioner growing speed in China is shocking. Coincidently, similar increasing trends were also reported in other developing countries with subtropical climate conditions [21]. Under such a circumstance, the

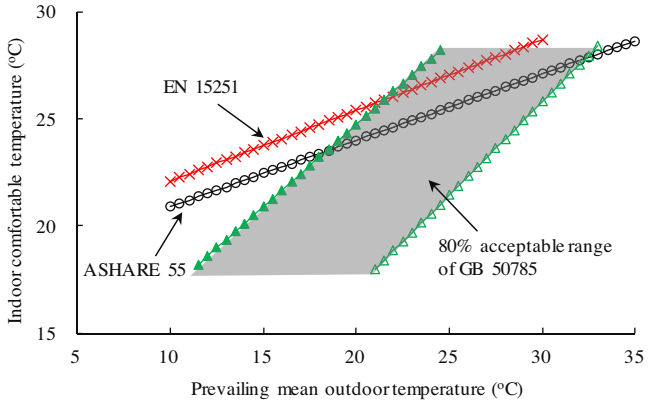

Fig. 1. Adaptive models in ASHRAE 55 [9], EN15251 [10] and GB 50785 [11]. (Note: these three standards may use different running outdoor temperatures. For example, ASHRAE requires it shall be based on no fewer than 7 but no more than 30 sequential days prior to the day in question. GB uses the data in one week.).

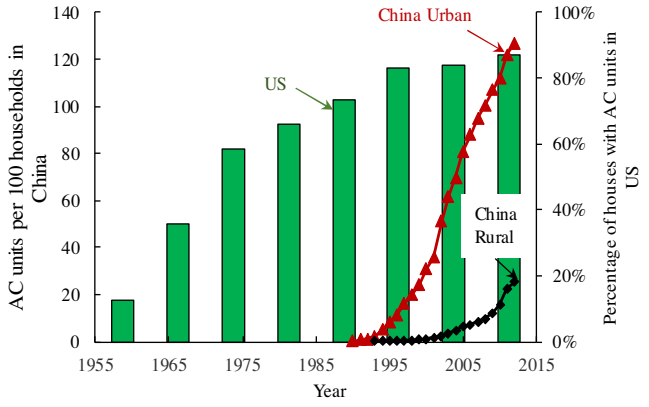

Fig. 2. Increasing trend of Air Conditioning (AC) Units in the US and China.

above theoretical questions can be easily converted into practical one. If people in developing countries like China have adapted to their indoor climate with no air conditioner, why they tend to abandon this kind of adaptation once their economic situation got improved? Is it possible for people accustomed to comfortable indoor thermal environments to lower their comfort expectations and once again re-adapt to poorer, lower-grade indoor climates?

It is true that the existing adaptive thermal comfort studies have offered some insight on how people adapt to indoor thermal environments. However, until now, few about the dynamic adapting process has been known, especially with regard to the timescale and difficulty of adapting process. Actually, one of our former paper [22] in the same series has investigated the evolution of comfort expectation and found that it is easier and quicker for occupants to adapt to improved comfort conditions than it is for 'spoiled' occupants to lower their expectations and readapt to non-neutral indoor climate. But the hypothesis outlined in that paper need to be validated through well-designed field studies and the present study is part of such validation.

1.4. Objective of present study

In this study, we aim to ask the question as to whether people accustomed to one indoor climate can readapt to another one, and explore the timescale and difficulty for people with different thermal experiences to readapt. Besides, as adaptive thoughts and publications are so far made mainly for adaptive processes to warm conditions, this study mainly focus on cold adaptation.