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Occupants' adaptive responses and perception of thermal environment in naturally conditioned university classrooms

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ABSTRACT

A year-long field study of the thermal environment in university classrooms was conducted from March 2005 to May 2006 in Chongqing, China. This paper presents the occupants' thermal sensation votes and discusses the occupants' adaptive response and perception of the thermal environment in a naturally conditioned space. Comparisons between the Actual Mean Vote (AMV) and Predicted Mean Vote (PMV) have been made as well as between the Actual Percentage of Dissatisfied (APD) and Predicted Percentage of Dissatisfied (PPD). The adaptive thermal comfort zone for the naturally conditioned space for Chongqing, which has hot summer and cold winter climatic characteristics, has been proposed based on the field study results. The Chongqing adaptive comfort range is broader than that of the ASHRAE Standard 55-2004 in general, but in the extreme cold and hot months, it is narrower. The thermal conditions in classrooms in Chongqing in summer and winter are severe. Behavioural adaptation such as changing clothing, adjusting indoor air velocity, taking hot/cold drinks, etc., as well as psychological adaptation, has played a role in adapting to the thermal environment.

1. Introduction

The interaction between building environment and occupants is complex. People adjust themselves to maintain and improve their wellbeing through physiological, psychological and behavioural reactions to environmental stimuli [1]. It is crucial to understand building occupants' perceptions of their indoor environment and their adaptive behaviour towards it.

The adaptive theory assumes that people consciously or unconsciously respond to a given thermal environment to which they are exposed in order to restore their own thermal comfort [2]. The recent development of the adaptive theory of thermal comfort explains occupants' thermal comfort in different environmental contexts, particularly in naturally conditioned (NC) buildings, from the point of view of the adaptive approach [3]. Occupants in a given environment can achieve thermal comfort through adjustments to their personal environmental conditions in the form of taking on/off clothing, drinking hot/chilled water, opening/closing windows, shifting the sun shadow and switching on/off fans, heating or air-conditioners, etc. [4].

Chongqing is a typical hot summer and cold winter city in China. The averages outside temperatures for the hottest and coldest months are 0–10 °C and 25–30 °C, respectively [5]. The city is traditionally called "stove city" which implies the extreme hot summer climate. The classrooms of universities in Chongqing are designed as naturally conditioned spaces without air-conditioners and heating systems. Therefore, occupants' adaptive responses will play a significant and positive role in the procedure to maintain the indoor environmental parameters at an acceptable thermal environment level or adjust themselves to adapt to the ambient environment. The climatic characteristics in Chongqing provide a great opportunity to examine the effects of the adaptive responses of subjects in NC university classrooms.

The main objectives of this field study are as follows:

- To reveal the real conditions of the thermal environment in NC university classrooms in Chongqing.
- To determine whether the thermal conditions are in the comfort zones specified by ASHRAE Standard 55-2004 [6].
- To reveal subjects' thermal perceptions in NC classrooms.
- To verify the effects of occupants' adaptive responses to the hot summer and cold winter weather in NC classrooms in Chongqing.

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Nomenclature

PMV	Predicted Mean Vote	T_{out}	monthly mean outdoor temperature (°C)
PPD	Predicted Percentage of Dissatisfied	T_c	comfort temperature (°C)
AMV	Actual Mean Vote	C	Bedford Comfort votes
APD	Actual Percentage of Dissatisfied	Clo	clothing insulation, 1 clo = 0.15 m^2 K/W
NC	naturally conditioned		
T_i	indoor air temperature (°C)		

2. Brief literature review

The existing thermal comfort standards, such as ASHRAE 55 [14] and ISO 7730 [7], are base on theoretical analysis of the human body heat exchange with the environment as well as experiments conducted in the climate-controlled chamber with 'paid college-age subjects' [8], which predict the thermal environment and thermal comfort of human body in air-conditioned (AC) context [4]. The application of such standards in the naturally ventilated (NV) buildings has been challenged by filed investigations worldwide. For example, most recently, Ogbonna et al. [9], reported the field study results carried out in sub-Saharan Africa in summer and revealed that the PMV determined neutrality is much higher than the actual votes. It is suggested that future research is required over longer periods, covering all seasons across different climatic-zones within the same country. Corgnati et al. [10] carried out a field study in Italian classroom and suggested an interesting hypothesis of the thermal preference trend as a function of the season. Becker et al. [11] carried out field study in residential buildings in winter and summer in Israel and indicated that thermal responses in real-world relate not only to actual thermal conditions but also to the processes by which the indoor environment is controlled, perceived, experienced, and interacted with. Bouden et al. [12] carried out a pilot field survey in two different climate zones in Tunisia over a year aimed at study the thermal comfort standard adaptation to the Tunisian context. It is a common concern that the international thermal comfort standards are expected to be verified in the local context. The Chinese professional society has recognised the importance of thermal comfort standard in terms of energy efficiency. A new thermal comfort standard is expected to be set up and the field studies are essential.

3. Method

Field measurements and an onsite questionnaire survey have been conducted in this research project. Beginning in April 2005, the survey and experiments were carried out monthly during a complete year in Chongqing, except August due to the summer vacation. Five university lecture buildings located in campuses A and B of Chongqing University have been selected for the study. These were called Lecture Building No. 5 and Lecture Building No. 8 in campus A and Lecture Building No. 1 and Lecture Building No. 2 and Lecture Building No. 3 in campus B, respectively. Most of them were of a masonry structure except No. 2, which was a steel-framed concrete structure. The window frames in all investigated buildings were quite different but all of them were single-glazed windows. All the rooms were not equipped with heating and air-conditioning equipment during the survey periods. Table 1 shows the general profiles of the investigated buildings. The field studies were taken for 3–4 days per month. The simultaneous subjective survey and environmental data monitoring were conducted four times per experimental day, twice in the morning and twice in the afternoon. The subjects were free to open/close windows, take hot/cold drinks and use hand-warmer bags in winter and ceiling fans in summer.

Chongqing is geographically bordered by hills to the southeast and mountain ridges to the south which contribute to climate characteristics of long hot summers and long cold–humid winters. The year-long field study was conducted from April 2005 to April 2006. Both physical measurements and subjective questionnaires were carried out in this investigation, which involved over 3000 participants. The information about the participants is summarised in Table2.

3.1. Subjective survey

In this investigation, a questionnaire was designed to quantify respondents' personal information and thermal perceptions. The main contents of the questionnaire included personal information (such as gender, age), subjects' activity level, clothing insulation, and their perceptions of the thermal environment in terms of air temperature, relative humidity and air velocity.

The metabolic rate was quantified by the level of activity of respondents and estimated to be 1.1 met in this survey, which cor-

Table 1
Structural information of the investigated buildings.

Building name	Orientation	Structure	Number of floors	Windows
Lecture Building No. 1	South–north	Masonry	8	Plastic steel single-layer window
Lecture Building No. 2	South–north	Steel-framed concrete	18	Aluminium alloy single-layer window
Lecture Building No. 3	South–north	Masonry	5	Aluminium alloy single-layer window
Lecture Building No. 5	South–north	Masonry	3	Wooden single-layer window
Lecture Building No. 8	South–north	Masonry	8	Wooden single-layer window

Table 2
Background information of the subjects in the survey.

Sample	3621	
Gender	Male	2302 (63.6%)
	Female	1319 (36.4%)
Age	Max.	40
	Min.	16
	Mean	21.6
	SD	2.05
Activity	Reading and writing (sedentary)	