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A comparative analysis of urban and rural residential thermal comfort under natural ventilation environment

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ABSTRACT

The paper presents a field study of occupants' thermal comfort and residential thermal environment conducted in an urban and a rural area in Hunan province, which is located in central southern China. The study was performed during the cold winter 2006. Twenty-eight naturally ventilated urban residences and 30 also naturally ventilated rural residences were investigated. A comparative analysis was performed on results from urban and rural residences. The mean thermal sensation vote of rural residences is approximately 0.4 higher than that of urban residences at the same operative temperature. Thermal sensation votes calculated by Fanger's PMV model did not agree with these obtained directly from the questionnaire data. The neutral operative temperature of urban and rural residences is 14.0 and 11.5 °C, respectively. Percentage of acceptable votes of rural occupants is higher than that of urban occupants at the same operative temperature. It suggests that rural occupants may have higher cold tolerance than urban occupants for their physiological acclimatization, or have relative lower thermal expectation than urban occupants because of few air-conditioners used in the rural area. The research will be instrumental to researchers to formulate thermal standards for naturally ventilated buildings in rural areas.

1. Introduction

In recent years, many researchers studied residential thermal environment and occupant comfort in urban residences of different climatic zones [1–7]. Specifically, in China, such field studies have been conducted in large cities, such as Beijing, Harbin, Shanghai, Changsha, Xi'an, Hong Kong, Guangzhou and Shenzhen [8–15]. However, China is a developing country, the majority of Chinese live in rural areas rather than in urban areas. In order to improve people's living conditions in rural areas, the Chinese government is now promoting new rural constructions all over the country. This study seeks responses to the following questions: what is the difference of occupants' thermal comfort between urban and rural residences, and should we provide the same residential thermal environment for rural and urban residences? It is well known that the lifestyle and economic status of individuals in rural areas are different from those in urban areas in China. For example, air-conditioning in rural areas is less popular than in urban areas, which leads to occupants living in rural areas to expect less thermal comfort than those living in urban areas. Fanger and Toftum [16] have introduced an expectancy factor to explain the difference between non-air-conditioned buildings in regions where the weather is warm only during the summer where there are none or few buildings with air-conditioning and regions with same or similar environmental conditions but widespread use of air-conditioning. The expectancy factor is 0.7–0.8 with few air-conditioned buildings and 0.8–0.9 where there are many air-conditioned buildings. Moreover, thermal adaptive theory indicates that behavioral adjustment, past thermal history and expectation influence occupants' thermal comfort [17].

It is evident that there are many differences between urban and rural occupants' comfort because of their different economic condition, lifestyle, context factors, physiological acclimatization and expectation. However, to the best of our knowledge, there is little information available concerning the occupant's comfort and residential thermal environment in the rural area. Thus, two purposes of this study were proposed, firstly this paper provides the information of occupant's thermal comfort and residential thermal environment in the rural area through field studies, secondly, a comparative and statistical analysis of urban and rural occupants' thermal comfort was conducted, which will be assistant

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to recommend the sustainable thermal standards for buildings in the rural area in China in the future.

2. Research methods

2.1. Building types, envelop characteristics and possible use of heating

Changsha, which represents conditions of typical hot summer and cold winter zone of central southern China, is the capital of Hunan province. Changsha was selected as the urban area site for our study. Yuping, a village about 150 km away from Changsha, was selected as the rural area site. The outdoor meteorological conditions of the two areas are very similar: cold winters and hot summers. The surveys were performed in both Changsha and Yuping in the cold winter of 2006.

There are two common types of buildings in the rural area: earth and brick-masonry buildings. The envelopes of earth buildings are rammed earth walls made of yellow earth and sand. The envelopes of brick-masonry buildings are cavity walls made of brick and cement mortar. Reinforced-concrete buildings are usually in the urban area. The envelopes of reinforced-concrete buildings are filled wall which are made of aerated concrete block or hollow brick. During the winter months, occupants of naturally ventilated buildings without heating and cooling systems warm themselves using basins in which charcoal is burnt, while urban occupants warm themselves using electric heaters. In summer, the majority of rural and urban occupants make use of oscillating fans for cooling occupied areas of naturally ventilated buildings. All residences both in the rural and the urban areas were investigated by this study without installing central HVAC systems or any mechanical ventilated systems. The size of rural residences is usually larger than urban residences.

2.2. Subjects

A sample size of 103 subjects in 58 different residences of the urban and rural areas participated in the study, occupants of 28 residences in urban Changsha and 30 in rural Yuping responded to the winter surveys. The subjects participating in the survey were composed of 51 females (49.5%) and 52 males (50.5%). The average age of all respondents is 37.5 years old, ranging from 10 to 70. The questionnaire covered several areas including demographics (sex, gender, height, weight, age, etc.), years of living in their current places, economic condition, educational level and measures for improving residential thermal environment and advancing occupants' thermal comfort level. The questionnaire also includes the traditional scales of thermal sensation and thermal preference, current clothing garment and metabolic activity checklists. The thermal sensation scale was the ASHRAE seven-point scale of warmth ranging from cold (−3) to hot (+3) with neutral (0) in the middle. The thermal preference scale is a three-point scale with the following options: (1) "want warmer", (2) "no change" and (3) "want cooler". Intrinsic clothing insulations were estimated using the garment values published in ISO 7730. Metabolic rates were assessed by a checklist of residential activities databases published in ASHRAE Standard 55-1992. Summary of the background characteristic of the subjects are represented in Table 1.

2.3. Measurement of indoor climate

Swema 3000, multi-purpose test system for professional measurements in indoor climate, was utilized in this study. The multi-purpose Swema 3000 is ideal in a broad range of applications, including indoor climate, thermal comfort, air-conditioning and ventilation. Moreover, Swema 3000 incorporates powerful built-in calculation and documentation features that vastly simplify field study. Three probes are equipped with Swema 3000, Swa03 probe measures air velocity and temperature with sensory accuracy of ±0.3 m/s, ±0.3 °C, respectively. Hygroclip S probe measures relative humidity (RH) and temperature with sensory accuracy of ±1.6%, ±0.3 °C, respectively. SWAT probe measures globe temperature with sensor accuracy of ±0.3 °C. The test system is shown in Fig. 1.

Three points were measured in a room along the diagonal. The field investigator measured thermal comfort variables (ambient air temperature, relative humidity, velocity and globe temperature) at the 0.1, 0.6 and 1.1 m heights while each respondent filled in the questionnaire. Operative temperature (T_0) was calculated as the average of air temperature and mean radiant temperature.

Table 1
Summary of the subjects of residential occupants and personal thermal variables

Place	Urban area	Rural area
Sample size (male/female)	53 (21/32)	50 (31/19)
Mean age (year)		
Mean, standard deviation	34.8, 15.6	40.1, 13.9
Minimum, maximum	10, 67	12, 70
Mean height (m)		
Mean, standard deviation	1.63, 8.6	1.60, 0.09
Minimum, maximum	1.35, 1.78	1.25, 1.76
Mean weight (kg)		
Mean, standard deviation	59.3, 12.9	54.3, 11.2
Minimum, maximum	32, 90	25, 76
Mean years living in local address		
Mean, standard deviation	7, 8.6	30.6, 19.6
Minimum, maximum	0.5, 50	3, 70
Mean metabolism (met) (58.2 W/m^2 = 1 met)		
Mean, standard deviation	1.25, 0.43	1.53, 0.5
Minimum, maximum	1, 2	1, 2
Mean clothing insulation		
Mean, standard deviation	2.0, 0.48	2.15, 0.46
Minimum, maximum	0.92, 2.86	1.16, 2.89

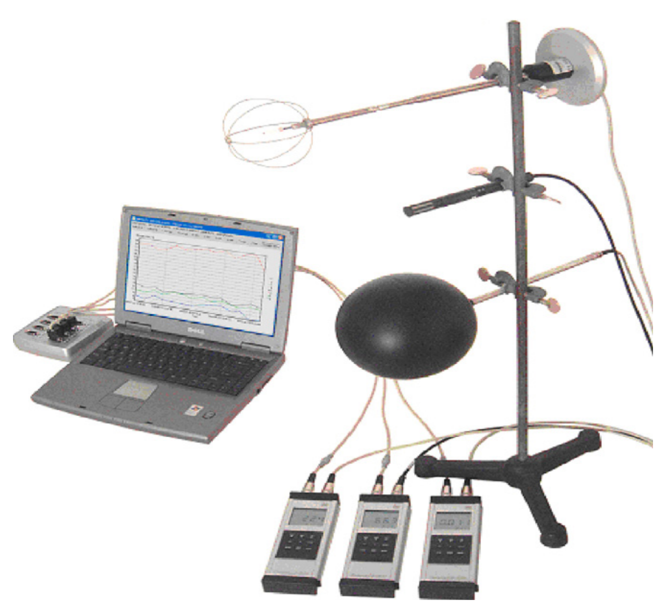

Fig. 1. Swema 3000 test system.