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Thermal comfort and thermal adaptive behaviours in traditional dwellings: A case study in Nanjing, China

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ABSTRACT

Adaptive thermal comfort is the predominant model used for studying thermal comfort in naturally ventilated buildings. However, current international thermal comfort standards do not represent the people living in all the different types of Chinese buildings, especially in old and traditional dwellings. Much of China's urban and rural populations live in traditional dwellings; their indoor thermal comfort and characteristics differ from those of people who reside in modern dwellings because of their unique thermal experiences and adaptive behaviours. To improve upon the thermal comfort database for energy-saving transformation of traditional dwellings, such as installation of heating or cooling devices and systems for residents, we conducted a field study of thermal comfort and thermal adaptive behaviours of residents in a traditional residential settlement in Nanjing in summer and winter. The results show that traditional dwellers are more tolerant to harsh environments, and their thermal neutral temperature and thermal sensitivity are lower in winter and higher in summer, than those of the people that reside in modern dwellings. Residents of traditional homes employ a series of thermal adaptive behaviours to expand their thermal comfort zone. We demonstrate a significant difference in human thermal comfort, which provides a basis for heating systems design for traditional dwellings and for further research on thermal comfort in different kinds of dwellings and regions.

1. Introduction

In recent years, architects and construction specialists have been faced with the crucial task of creating suitable indoor environments in buildings while saving energy [1,2]. Modern buildings are becoming increasingly high technology, unconventionally shaped, and higher quality, which has increased the energy consumption of the building sector, raising the stakes of energy savings in buildings [3]. Buildings consume up to 40% of the total energy used in developed countries, with related emissions of 40% of total greenhouse gas emissions [4]. Furthermore, a considerable amount of this energy is used to provide a suitable indoor environment, and it is responsible for a significant portion of consumption within a country's nonindustrial energy usage [5,6]. In developed countries, 30–60% of building energy consumption is used for improving the indoor thermal environment [7].

In China, building energy consumption has increased by 45% in the last two decades [8]. The country's economic development and urbanization continues to accelerate this increase in building energy consumption [9–11]. However, ensuring a comfortable and healthy indoor environment is critical for occupants, as it affects their well-being, productivity, and efficiency. Many civil organizations and governments have recently begun working to improve the living environment of residents in China, especially for those living in traditional-style dwellings. With the growing awareness of the importance of protecting traditional dwellings, the government has also ceased its previous practice of demolishing old buildings and relocating residents to new residential buildings; though simpler, this practice had a high economic cost and led to legal disputes. In contrast, optimizing traditional dwellings based on the existing building settlements involves practices such as installing central heating systems and adding thermal insulation to exterior walls to improve the living environment in cold winter weather. However, installing central heating systems involves setting a reasonable indoor temperature for thermal comfort. In most cases, a better thermal environment increases a building's energy consumption. Thus, it is a challenge to balance energy conservation and thermal comfort improvement in building environments in China [12].

To achieve this goal, it is necessary to carry out field studies of occupants' thermal comfort and adaptive behaviours in traditional dwellings. There are some international thermal comfort standards, including ASHRAE 55-2004 [13] and ISO7730 [14]. In ASHRAE 55-

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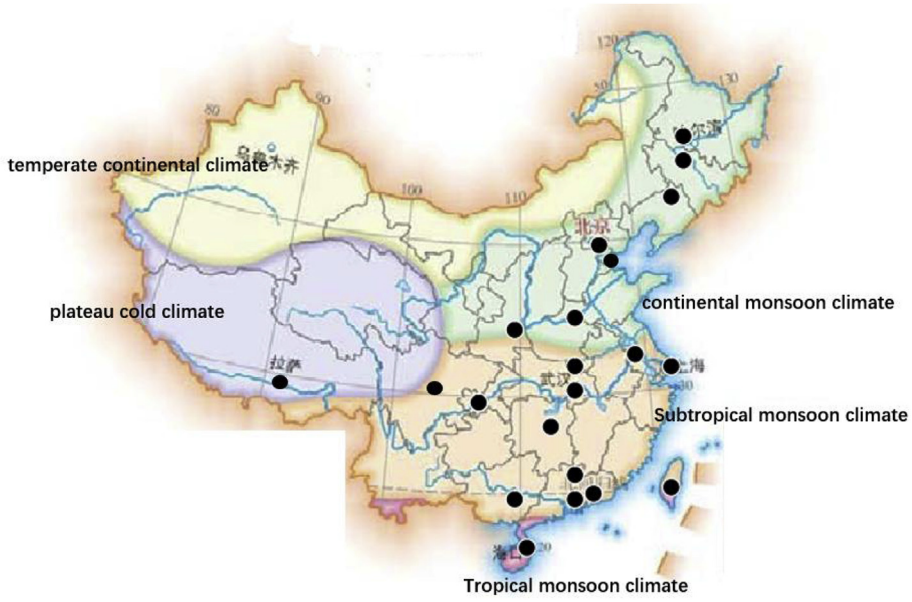

Fig. 1. Field study of thermal comfort in China.

2004, for example, the comfort temperature range is between 23 °C and 26 °C and the comfort humidity range is between 30% and 60%. In ISO7730, the values of predicted mean vote (PMV) and predicted percentage dissatisfied (PPD) are used; herein, the thermal comfort range corresponds to a PMV between −0.5 and + 0.5 for PPD of less than 10%, when the indoor air speed v_a is less than 0.25 m/s. These standards are based on laboratory studies in which the environmental parameters are maintained as constant; the human body passively accepts the thermal environment stimulation. Further, differences in architectural types, adaptive behaviours, and thermal experiences are not accounted for, which makes these standards unsuitable for free-running buildings. Additionally, Chinese buildings were not included in the worldwide comfort surveys conducted by de Dear and Brager in 1996, and no field studies in China were carried out for the Project RP-844.

In past decades, many Chinese researchers have conducted studies on indoor thermal comfort in various types of buildings nationwide, which have provided useful and common knowledge for the study of building design, energy savings, and thermal comfort [15–24], as shown in Fig. 1. However, most of these studies were aimed at modern urban residential and public buildings [11,12,15,16,25,26].

Unlike residents of modern architectures, the living habits and thermal experiences of residents in traditional dwellings exhibit strong regional characteristics, which are commonly considered as important factors affecting the thermal comfort [27]. At the same time, the economic conditions of residents living in modern urban buildings are generally superior to those of residents in traditional dwellings [28], and so, the possibility of obtaining devices for improvement in living environments is different between the two, which may lead to significant differences in their thermal experiences and living habits. In the official Chinese government documents, traditional urban dwellings are known as “shanty towns”. From 1978 to 2005, the gap between the per capita income of residents of modern metropolitan areas and that of residents of shanty towns increased from 2.57 times to 3.22 times. These values do not yet incorporate the effect of government subsidies enjoyed by urban residents, such as the inexpensive central heating service in winters. Different thermal experiences lead to different thermal expectations, especially between residents living in modern and traditional dwellings. Therefore, thermal comfort heavily depends not only on environmental factors but also on physical, physiological, psychological, and even socio-economic aspects [29–31]. Thus, the database of thermal comfort for traditional architecture in China is not complete and needs to be improved, especially for winter conditions in the hot summer and cold winter (HSCW) zone.

Therefore, this study considers traditional dwellings in Nanjing, China as an example to perfect and improve partially the database of thermal comfort, and explore the thermal adaptive behaviours of the residents of traditional dwellings in Nanjing, in order to help define guidelines for reconstruction (such as installing central heating systems for winters) of more comfortable traditional buildings. A field study focused on thermal comfort and thermal adaptive behaviours of residents in an old residential settlement was carried out; the indoor and outdoor environment parameters were also measured at the same time. Background information concerning the analysed site and dwellings is provided in section 2. Section 3 describes the methodology including the measuring methods, instruments, and survey questionnaire used. The results of the analysis of thermal comfort and thermal adaptive behaviours are presented in section 4. The results and conclusions of this study, presented in section 5, could provide a reference for energy policymakers to develop the required climate-resident-responsive design standards for different types of residential buildings in China.

2. Background information

2.1. Chinese climatic zones

Climatic divisions for building design divide China into five zones: Severe Cold, Cold, HSCW, Hot Summer and Warm Winter, and Mild [32]. As shown in Fig. 2, the HSCW zone is located in the south of China, where many important and large cities are located, such as Shanghai, Nanjing, Hangzhou, Wuhan, and Chongqing. This region is economically and culturally prosperous and densely populated, especially in the Yangtze River Delta region, which contains Shanghai, Nanjing and Hangzhou. In summer, region is hot and humid; in winter, it is a cold and humid. Social habits, added to severe climatic conditions, lead to much greater energy demands and consumption in buildings compared to other regions of China [33–40]. The unique local climate characteristics of the HSCW zone has impacted both indoor thermal environments and traditional building design.

2.2. Analysed city: Nanjing

Nanjing is the former capital of the Republic of China (on the