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Design criteria of built thermal environment for Hot Summer & Warm Winter zone of China

Yufeng Zhang*

State Key Laboratory of Subtropical Building Science, Department of Architecture, South China University of Technology, Wushan, Guangzhou 510640, PR China

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ABSTRACT

Driven by guiding passive architectural design and HVAC system design, the present study is aimed to propose design criteria of built thermal environment for Hot Summer & Warm Winter zone of China. During the four years from 2008 to 2012, thermal comfort field studies were conducted on 32 urban buildings and 270 rural buildings, more than 500 persons were involved and 3894 sets of raw data that contain thermal acceptability, thermal behaviors and physical parameters were collected. Data of using split air-conditioners was also collected in living rooms, bedrooms and dorms. Based on the data, the acceptable range was determined for environments of naturally ventilation, using fans and using air-conditioners respectively, and accordingly the design criteria of built thermal environment were proposed. The 80% acceptable range of indoor air temperature for naturally ventilated spaces was specified as 18.0–29.5 °C for urban buildings and ≤29.5 °C for rural buildings under the air speed conditions provided by opening windows and using fans. The upper limit of the range can be raised by 1–2 °C by effectively improving indoor humidity and radiation conditions through architectural design. The setting conditions for air-conditioned spaces were obtained as indoor air temperature of 24–28 °C and relatively humidity of 50–70%. The proposed criteria provide solid and essential bases for passive and active designs of built thermal environment in Hot Summer and Warm Winter zone of China.

1. Introduction

Built thermal environment is constructed by both passive architectural design and active HVAC system, and design criteria of built thermal environment provide essential bases for design and operation of buildings and their systems. Hot Summer & Warm Winter zone of China (abbreviated as HSWW zone) locates in south part of China and contains Guangdong, Fujian and Hong Kong (see Fig. 1). Summer is long, hot and humid, winter is short and warm, and it is more important to prevent heat in summer than cold in winter. With the fast-developed economy, a large number of buildings have been built and a great amount of energy is annually consumed on summer cooling of buildings in HSWW zone, and therefore it is necessary and important to appropriately determine design criteria of built thermal environment for HSWW zone to achieve its energy conservation and sustainable development.

There are some Chinese standards making provisions on design criteria of built thermal environment for HSWW zone. The design standards for energy efficiency of buildings GB 50189-2005 [1] and JGJ 75-2012 [2] provide such criteria in aspects of energy efficient calculation and design. Indoor air temperature of 25 °C, air speed of 0.15–0.30 m/s and relative humidity of 40–60% are specified for public buildings and indoor air temperature of 26 °C is specified for residential buildings under their air-conditioned conditions. The design code for HVAC of civil buildings GB 50736-2012 [3] provides criteria for HVAC design and operation. Two categories of thermal environments are specified for long-occupied air-conditioned spaces, in which air temperature of 24–26 °C, humidity of 40–60% and air speed not greater than 0.25 m/s are specified for category I, and air temperature of 26–28 °C, humidity not higher than 70% and air speed not greater than 0.3 m/s are specified for category II. It can be known that the above standards provide criteria only for HVAC system design and operation, and no criteria for architectural design are provided.

Only few standards provide criteria of built thermal environment for architectural design, for instance ASHRAE standard 55 [4],

* Corresponding author. Tel.: +86 18664866529; fax: +86 2087110164.
E-mail address: zhanguf@scut.edu.cn.

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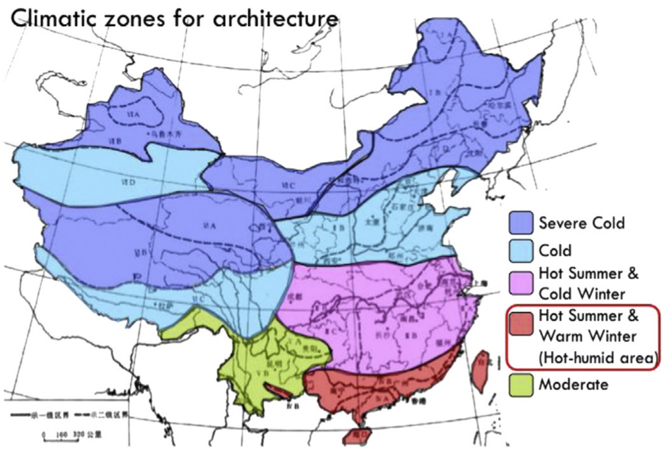

Fig. 1. Hot Summer & Warm Winter zone of China.

European standard EN 15251 [5] and Chinese standard GB/T 50785 [6]. These standards specify acceptable thermal environments for naturally ventilated spaces based on thermal adaptive models. Humphreys is the first to systematically collect thermal comfort data from field studies and suggest an adaptive model to explain the differences between field and chamber studies [7]. Thermal adaptive model was then proposed in a more systematic form by Brager and de Dear [8]. A global database of thermal comfort field studies was established in 1998 [9], based on which an adaptive model of thermal comfort was proposed [10] and cited in ASHRAE 55 to guide design of natural ventilated spaces. In the EU-funded project SCATs, McCartney and Nicol [11] collected raw data of thermal comfort field studies in Europe and obtained a European adaptive control algorithm, which is used in EN 15251 to guide design of buildings without mechanical cooling systems. Taking Guangzhou, a city in HSWW zone, as an example (monthly mean outdoor air temperature is 28.4 °C in July and 13.3 °C in January), its acceptable ranges of built thermal environments were obtained according to the standards as Table 1 shows.

It can be seen that the upper limit for naturally ventilated spaces is much higher than that for air-conditioned spaces. It is thus necessary to provide specific design criteria of built thermal environment for naturally ventilated spaces to achieve significant contributions of passive architectural design on building energy conservation.

To directly apply the above standards to HSWW zone is not reasonable and sufficient. One reason is that they lack of local field studies and data to support. The criteria for air-conditioned spaces are proposed based on the PMV model. The model is derived from the experimental results of American and Danish people and its applicability to Chinese people still remains unknown [12–14]. The standards ASHRAE 55 and EN 15251 are established on ASHRAE and European databases, in which no Chinese data are included. Many field studied have been conducted for the Chinese standard GB/T 50785, however, only few data are collected from HSWW zone [15,16].

Another reason is that the current criteria for naturally ventilated spaces lack of key parameters to be specified. Not only air and radiant temperatures, but also relative humidity and air speed have impacts on human thermal comfort. Passive architectural designs in HSWW zone, regardless traditional or modern, affect not only indoor air temperature, but also indoor air speed (by natural ventilation), radiation (by shading and thermal mass) and humidity (by moisture absorption finishing). Current standards are only focused on indoor operative temperatures, and therefore insufficient to guide passive architectural design of HSWW zone.

Table 1
Acceptable range of indoor operative temperature for naturally ventilated spaces of buildings in Guangzhou.

Standard	Acceptability	Lower limit (°C)	Upper limit (°C)
ASHRAE 55	80%	18.6	30.2
EN 15251	80%	20.5	31.2
GB/T 50785	75%	16.0	30.0

The author and his research group [17–25] had previously conducted several thermal comfort field studies on urban and rural buildings of HSWW zone, and preliminarily revealed the adaptive characteristics of local people to their built thermal environments. Based on our previous studies, we aim the present study to investigate relationships between subjective responses and environmental parameters and find acceptable ranges for both naturally ventilated and air-conditioned environments, and propose design criteria of built thermal environment in HSWW zone for both architectural design and HVAC system design.

2. Research methods

2.1. Climate and buildings

The field studies were conducted in Guangzhou city and Chaoshan area, the representative urban and rural areas in HSWW zone. The climates of two areas are similar on their hot-humid and long summer, plentiful rainfall, and warm and short winter. The monthly mean is 28.4 °C and 82% in July and 13.3 °C in January for Guangzhou, and 28.3 °C and 83% in July and 14.4 °C in January for Chaoshan.

Thirty-two urban buildings were investigated in Guangzhou, including 13 naturally ventilated dormitory and teaching buildings (Fig. 2a, abbreviated as NV buildings), and 19 residential, dormitory and teaching buildings that installed with split air-conditioners (Fig. 2b, abbreviated as SAC buildings). The buildings are mostly built in last century and constructed by 180 mm thick brick walls, reinforced concrete roofs, aluminum alloy windows and heat absorbing glasses. Two hundred and seventy rural buildings (abbreviated as rural buildings) were investigated in Chaoshan area. They are all in brick–concrete structures and naturally ventilated (Fig. 2c). The main thermal behaviors of residents in the urban and rural buildings are adjusting clothing, opening windows and doors, using electrical fans and using split air-conditioners (Fig. 2d).

2.2. Subjects

Longitudinal design was adopted in the urban studies. Each subject was surveyed twice a week and the survey lasted for whole summer or a year. Totally 92 college students were recruited as subjects, half male and half female (Table 2). They were all born in and grew up in HSWW zone and have been living in the investigated buildings for more than one year, which well guarantees the natural acclimatization to local climate and long experience with the investigated buildings of the subjects.

Cross-section design was adopted in the rural studies. Each subject was surveyed only once. Totally 446 people were investigated, 234 male and 212 female, and their ages change from 12 to 75. They all have lived in the rural areas for several generations and they are representative in aspects of climatic adaptation and built environmental experience.