Energy and Buildings 43 (2011) 1051–1056

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Field study of human thermal comfort and thermal adaptability during the summer and winter in Beijing

Bin Cao[a], Yingxin Zhu[a,*], Qin Ouyang[a], Xiang Zhou[b], Li Huang[a]

[a] Department of Building Science, Tsinghua University, Beijing 100084, China
[b] College of Mechanical Engineering, Tongji University, Shanghai 200092, China

ARTICLE INFO

Keywords:
Field study
Thermal comfort
Thermal adaptability
Summer
Winter
Climate
Beijing

ABSTRACT

This study was conducted during the summer and winter in Beijing. Classrooms and offices in a university were used to conduct the survey. The respondents' thermal sensation and thermal adaptability in both seasons were analyzed. During the study, indoor environmental parameters including air temperature, mean radiant temperature, relative humidity, and air velocity were measured. The respondents' thermal sensation was determined by questionnaire.

A relationship between indoor temperature and thermal sensation was found. In the summer study, the "scissors difference" between TSV and PMV was observed in the air-conditioned environments if the temperature was out of the neutral zone. People had higher tolerance in the hot environment than PMV predicted. During winter, the outdoor temperature had a prominent influence on thermal adaptability. The low outdoor temperature made people adapt to the cold environment. When the indoor temperature was heated to a high temperature by space heating facilities, respondents felt uncomfortable since their adaptability to the cold environment was nullified.

Furthermore, the differences in thermal responses between respondents from North and South China showed that the different climates of people's native regions also affected their thermal comfort and adaptability.

1. Introduction

Indoor thermal environments can significantly influence human health and comfort. Since the late 20th century, the PMV (Predicted Mean Vote) model developed by Fanger has been widely used throughout the world. Although the PMV model is based on the database of European and North American subjects, many researchers around the world have conducted experiments in climate chambers and have demonstrated its validity. However, in recent years, an increasing number of surveys have shown that TSV (Thermal Sensation Vote) deviates from PMV in thermal environments which are not neutral, especially in non-air-conditioned environments [1–3]. Fanger and Toftum [4] analyzed thousands of groups of field survey data from Bangkok, Singapore, Athens, and Brisbane within non-air-conditioned environments, and found that there was a prominent "scissors difference" (*a figurative demonstration of the different slopes of the PMV and TSV regression lines*) between TSV and PMV (Fig. 1). Jiang [5] conducted field surveys in non-air-conditioned rooms over one year in Hunan Province in central Southern China, and he reported a similar "scissors difference" between the TSV and PMV regression lines (Fig. 2). All these studies have shown that the occupants' TSVs were much closer to neutral than the PMV prediction in both hot and cold environments. This means that human thermal sensation in non-air-conditioned environment is not as sensitive as predicted by the PMV model.

To explain the "scissors difference", Fanger and Toftum [6] suggested a modified PMV model that includes an expectancy factor *e* which demonstrates people's psychological expectation of the thermal environment. The expectancy factor *e* varies among different places and different people. Brager and de Dear brought forward an Adaptive Model [7,8] which presumes that the human body does not passively accept the environment; rather, physiological adaptability, psychological adaptability, and behavior adaptability are all involved to help people actively adapt to the surrounding environment.

In accordance with the above contributions of former researchers, we conducted a field study with the intent of resolving the following two issues:

(1) Does the "scissors difference" between TSV and PMV exist in all conditions? Is TSV always closer to neutral than the PMV prediction in all seasons?

* Corresponding author. Tel.: +86 10 62782746; fax: +86 10 62773461.
E-mail address: zhuyx@tsinghua.edu.cn (Y. Zhu).

0378-7788/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.enbuild.2010.09.025

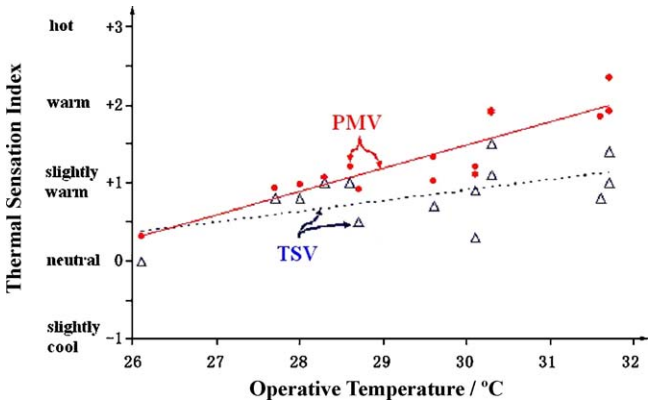

Fig. 1. Field survey results from Bangkok, Singapore, Athens, and Brisbane within non air-conditioned environments [4].

(2) How do people's thermal adaptabilities to cold and hot environments come about? Are there any discrepancies among the adaptations of people from different climate zones?

2. Research methods

2.1. Time and location

The study was conducted during both the summer and winter. The span of the summer study was June–August, 2009 (the range of the daily average outdoor temperature was 24.5–30.0 °C). The winter periods were November–December 2007 and December 2008 (the range of the daily average outdoor temperature was 2.5–12.5 °C). All the studies were conducted in a university in Beijing. During the summer, the indoor temperature was controlled by air conditioning facilities. During the winter, space heating facilities were present in all the investigation rooms, of which there were two types: heating radiators (classrooms) and fan-coil units (office rooms).

2.2. Respondents

The total number of respondents was 206, with 82 in the summer investigation and 124 in the winter studies. All respondents were university students, and over 85% were younger than 25 years old (Table 1). There were more males than females, with a ratio greater than 3:2 (Table 2).

The respondents were classified further according to region. Dividing China's territory into two areas, "North" and "South" with the Yangtze River serving as the dividing line, the respondents were defined as either Northern people or Southern people. The proportions of Northern and Southern respondents are shown in Figs. 3 and 4. In addition, all the respondents in summer had lived in Beijing for more than 2 years, while about 48% of the winter respondents had lived in Beijing for less than 1 year.

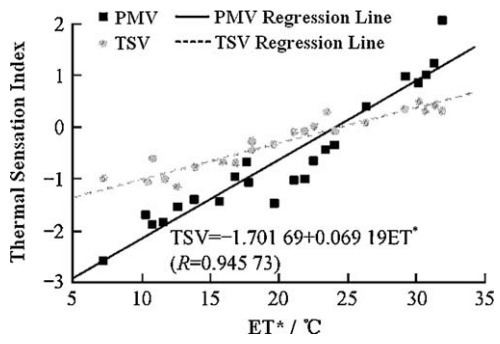

Fig. 2. Field survey results from Hunan province, China [5].

Table 1
Respondents' age distribution.

Season	Age	Amount
Summer (*N* = 82)	17–20	26
	21–25	45
	>25	11
Winter (*N* = 124)	17–20	81
	21–25	38
	>25	5

Table 2
Respondents' sex distribution.

Season	Sex	Amount
Summer (*N* = 82)	Male	60
	Female	22
Winter (*N* = 124)	Male	78
	Female	46

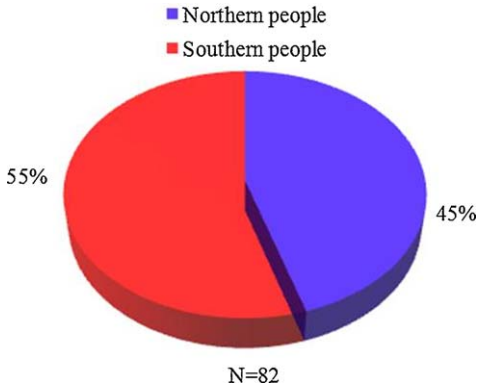

Fig. 3. Proportion of Northern and Southern respondents in the summer study.

2.3. Equipment and questionnaire

This study was comprised of measurements of indoor environmental parameters and investigations of respondents' subjective sensations. These two parts were carried out simultaneously. Indoor environmental parameters including air temperature (T_a), mean radiant temperature ($\bar{T}_r$), relative humidity (RH), and air velocity (v) were measured by an AM-101 PMV and PPD indices meter (Fig. 5). The accuracy of the equipment is shown in Table 3. For the measurements, the sensors were placed beside the respondent, 1.0 m above the floor (Fig. 6).

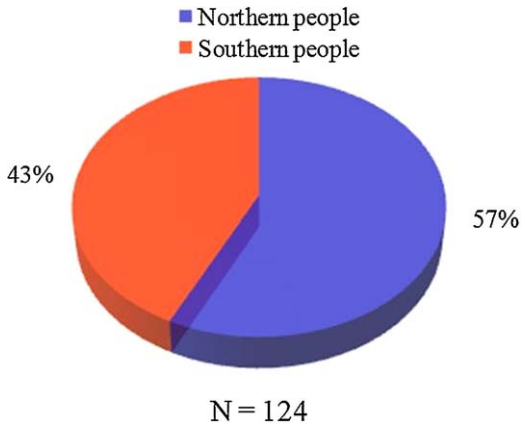

Fig. 4. Proportion of Northern and Southern respondents in the winter studies.