Topic A7: Thermal comfort

Gender differences in thermal comfort in a hot-humid climate

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SUMMARY

Thirty female and 30 male college students, who had naturally acclimatized to hot-humid climate, were exposed to seven temperature/humidity combinations in a climate chamber, and they were surveyed all year long at their classrooms and dormitories. They dressed in 0.5 clo in the chamber tests, while their subjective and physiological responses were collected. In the field study the subjects were surveyed while the thermal parameters around their body were measured. Results show no significant differences in thermal sensitivity to temperature changes or in neutral temperatures, based on our chamber and field studies with the same group of subjects. Both genders were equally satisfied with temperatures, although females tended to be more dissatisfied in cool temperatures, and males tended to be more dissatisfied in warm temperatures in the chamber tests; however the differences disappeared when they can adjust their clothing in the field.

INTRODUCTION

Classical thermal comfort chamber studies of Nevins and Fanger have found no significant gender difference in neutral temperature with American and Danish subjects (Nevins et al. 1966, Fanger 1970), however females were more sensitive to temperatures deviate from neutral. These results were confirmed by chamber studies in other climate zones (Tanabe 1988, Chung et al. 1990, Lan et al 2008).

Field studies have found that although gender had no significant effect on neutral temperatures, however females tended to be more dissatisfied in real buildings (de Dear and Fountain 1994, Donnini et al 1997, Cena et al 1999, Choi et al 2010). Recently, Karjalainen came to the same conclusion by conducting a meta-analysis on thermal comfort and gender with a mixed of chamber and field studies (Karjalainen 2012).

The current study presents a unique dataset with a mixed study design, which used the same group of subjects in both chamber and field studies. The objective is to investigate gender differences in thermal comfort in a testing chamber and in real buildings contexts in subtropical Guangzhou, China.

METHODOLOGIES

A mixed design was employed in this study, in which subject were exposed to test conditions in a test climate chamber and were survived in the buildings that they experienced every day.

Guangzhou climate

Guangzhou is located at latitude 23°08'N and longitude 113°19'E, which is a typical city in hot-humid area of China. Summer is hot and humid and winter is cool. The mean monthly outdoor air temperatures are 28.8 °C in July and 13.9 °C in January, while the mean monthly relative humidity are 82% in July and 74% in January (China Meteorological Bureau 2005).

Subjects

Sixty healthy college-age subjects (30 men and 30 women) participated in the present study. The basic information of the subjects is shown in Table 1.

Table 1 Anthropometric data for the subjects

Sex	Number	Age	Height (cm)	Weight (kg)	BMI* (kg/m2)
Male	30	22.2±0.7#	170.5±5.6	60.9±7.2	20.9±1.6
Female	30	21.7±0.8	160.9±3.9	48.7±2.9	18.8±0.8

*Body mass index, BMI = weight/stature2, normally between 18 and 25.
#Standard deviation.

Chamber tests

Five air temperatures were tested at 50% RH, which were 20, 23, 26, 29, and 32°C. Two temperatures (29 and 32°C) were tested at 70% RH to represent the hot-humid conditions.

Each subject participated in all the test conditions and the total time was 9 hours for each subject in the chamber. The sequence was balanced for the subjects using Latin squares to avoid the effects of learning, increased familiarity and over-familiarity (boredom).

Subjects dressed in standard uniforms, which included cotton short sleeves shirts, long pants, socks, slippers and their own underwear (bra and briefs for females and briefs for male). The clothing insulation was estimated to be 0.5clo.

The chamber tests were conducted in the controlled test chambers in South China University of Technology, which consists two adjacent chambers placed in a hall with the same dimension of 3.45×3.25×3.35 m. The conditioned air is supplied from the ceiling and returned through the floor, achieving a uniform distribution of thermal environment inside the chambers. Air temperature can be controlled in 10-40ºC with ±0.2°C accuracy, and humidity can be controlled 40-90% with ±5% precision. Air velocity was maintained less than 0.1 m/s and mean radiant temperature (MRT) was equal to air temperature during all the experiments.

A questionnaire consisted of subjective rating on scales of thermal sensation, comfort and acceptability was used in the present study to obtain the most important thermal responses of subjects. A 9-point thermal sensation scale is used by adding very cold (-4) and very hot (4) to the ASHRAE 7-point scale. The acceptability scale is a split scale with votes from 0.01 to 1 considered as "acceptable" and votes from -0.01 to 1 counted as "unacceptable".

Upon arrival, subjects were instructed to change into the test uniforms before entering the pre-conditioning chamber, which was controlled always at 26°C, 50%RH. Then they seated for half an hour, during which the skin temperature sensors were attached and one questionnaire was asked to report. The subjects then entered the other chamber which was controlled at target temperatures mentioned before and seated for 1 hour. Figure 1 shows the experimental procedure.

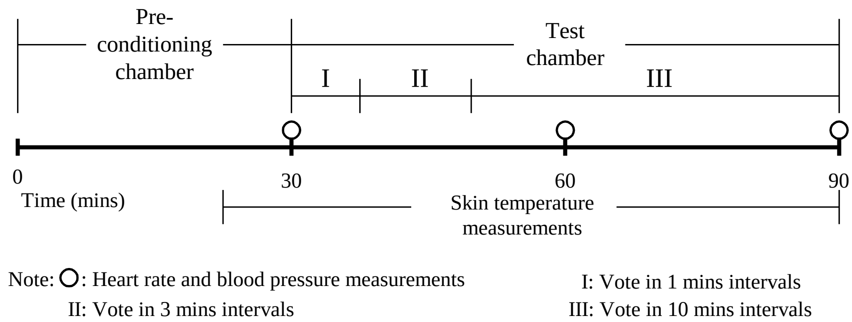

Figure 1 Experimental procedure

Field tests

The same 60 subjects were surveyed twice a week either at classrooms or at their dormitories. During each survey, the subjects completed a subjective questionnaire while ambient environments were measured by the investigators at three heights (0.1, 0.6 and 1.1 m) above floor. Detailed method can be seen from Zhang et al (2010).

The year-long field survey generated 1200 sets of raw data in 33 weeks for males, and 1094 sets of data for females.

Statistical analysis

Analysis of covariate (ANCOVA) was performed to compare the slopes and intercepts of regression lines. Fisher's exact test was used to compare the percentage dissatisfied for both genders. All differences were accepted as significant at the 0.05 level. All the analyses were carried out with GraphPad Prism statistical software.

RESULTS AND DISCUSSION

Chamber tests

Thermal sensation (TS)

We conducted linear regression TS votes against $ET^*$for the males and females subjects (Figure 2), and compared the slopes and intercepts of the regression lines with ANCOVA. Results show that the slopes of TS against ET^* are not significantly different (F=0.38 p=0.54), nor are the intercepts (F=3.09, p=0.08). The pooled regression line for both genders is

$$TS_{chamber}=0.29ET^*-7.88\ (R^2=0.73,\ p<0.0001)$$

which yields a neutral temperature of 26.9°C for all the subjects.

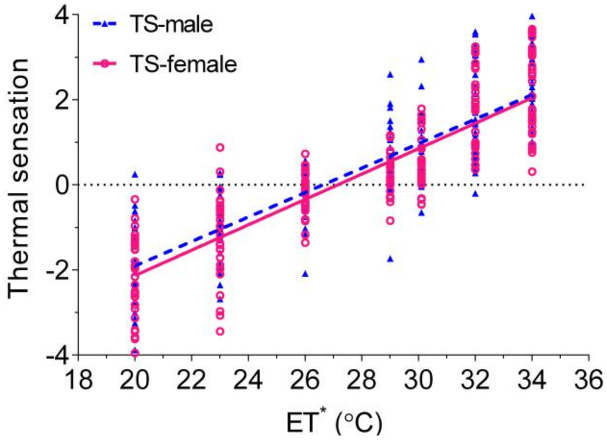

Figure 2 Thermal sensation against ET*

Thermal acceptability

The percentage of dissatisfied (PD) was calculated by counting minus value of thermal acceptability votes (-1 to -0.01) as "dissatisfied", and divided by the sample size of the subjects of both genders. Figure 4 shows the PD at each ET*. Fisher's exact test was used to compare the differences. No significant differences were found at any test conditions. However there was a trend that females tended to be more dissatisfied in cool temperatures (20 and 23°C ET*), while males tended to be more dissatisfied in warm temperatures (32°C ET*). Overall, the 80% acceptable range for the subjects was 23°C to 30°C in the current chamber studies.

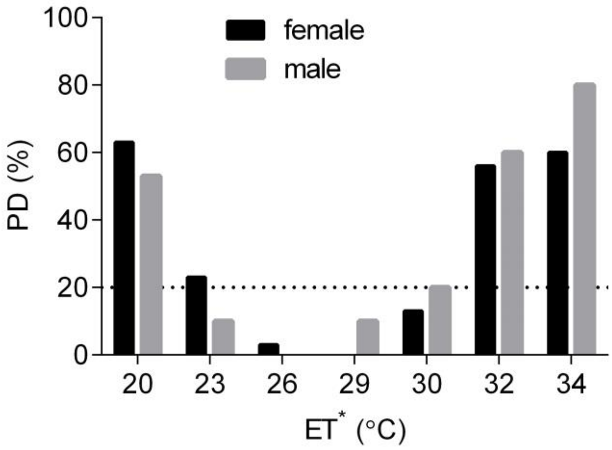

Figure 3 PD at each ET*

Field results

Neutral temperature and temperature sensitivity

Figure 5 shows the thermal sensation votes from the field studies as a function of ET*. Regression lines of both genders show no significant difference in the slopes ($F=1.87$, $p=0.17$) nor the intercepts ($F=2.58$, $p=0.09$). Based on the pooled slope and intercept the regression equation for both genders is

$TS_{field}=0.22ET^*-5.68$ ($R^2=0.44$, $p<0.0001$),

which yields a neutral temperature of 26.2°C ET*.

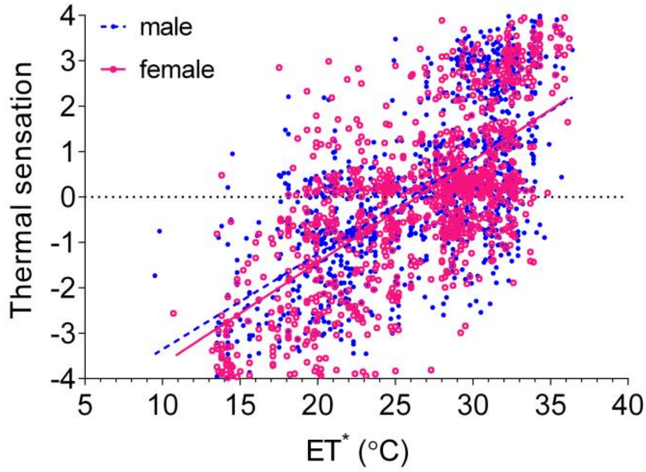

Figure 4 Field thermal sensation votes against ET*

Clothing levels

Clothing adjustment is one of the most important adaptive means in daily life. The clothing levels obtain in the field was regressed against ET* (Figure 5). Results show that females changed their clothing more than males (0.04 vs. 0.03 in slopes) as temperature changed (F=24.28, p<0.0001). Females also tended to dress more than males in cool temperatures. Both genders dressed more or less the same in warm temperatures.

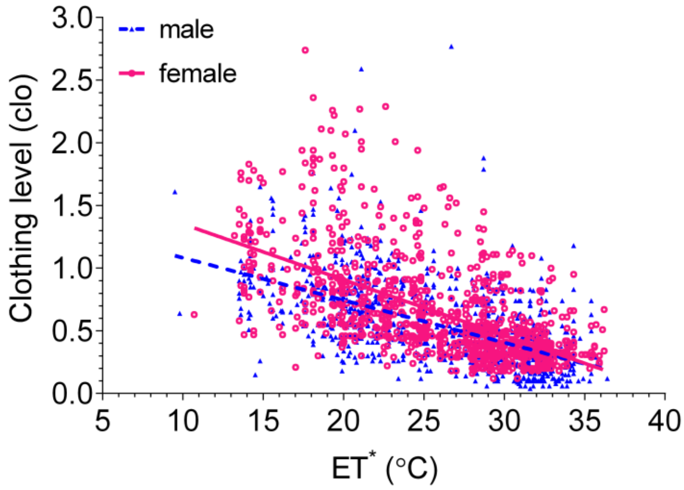

Figure 5 Field clothing levels against ET*

Thermal acceptability

Over the temperatures experienced by both genders in the current field study, it was found that they were equally satisfied with the thermal environment (Figure 6). Since the subjects had many adaptive means that could improve their satisfactions, the acceptable range was very wide, from 18°C to 32°C ET*.

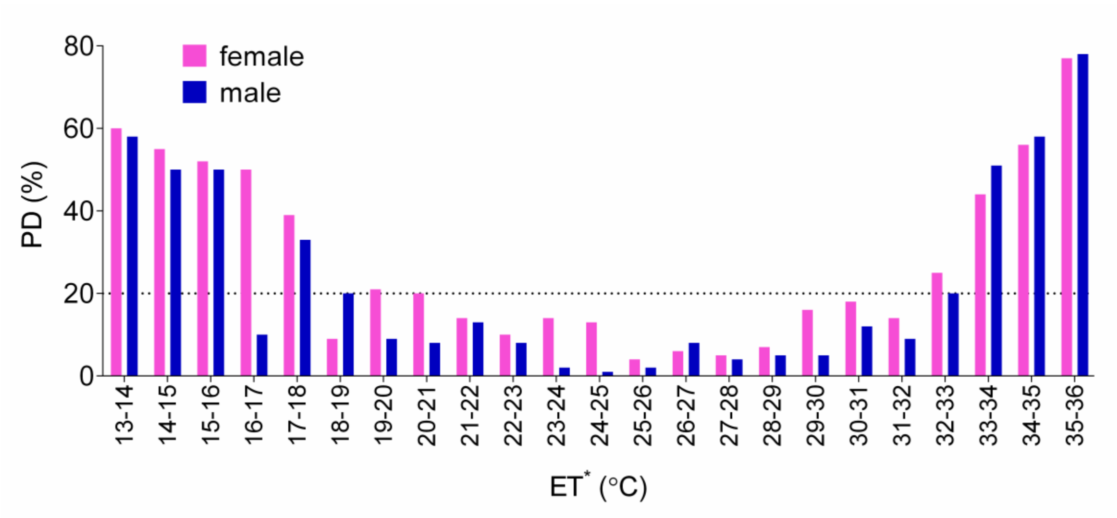

Figure 6 Percentage dissatisfied in field studies
(only number of votes higher than 20 is included)

CONCLUSIONS

There were no significant differences in thermal sensitivity to temperature changes, or in neutral temperatures, based on our chamber and filed studies with the same group of subjects.

Both genders were equally satisfied with temperature, although females tended to be more dissatisfied in cool temperatures, and males tended to be more dissatisfied in warm temperatures; however the differences disappeared when the subjects were able to adjust their clothing in real buildings.

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