DISCUSSION ON THE VOTING SCALES RELATED TO THERMAL SENSATION IN THE FIELD SURVEY OF HOUSES DURING WINTER IN JAPAN

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ABSTRACT

Knowledge of thermal comfort is useful for guiding the design of buildings and other enclosed environments, for achieving energy savings. Several scales have been used in the laboratory and field studies to know the thermal sensation or comfort sensation of occupants. The most common are the 7-point ASHRAE scales, related to thermal sensation, comfort and acceptability. However, what kind of scales we should use to survey has received little attention. It is important to save energy and cost in the design of buildings and their mechanical systems. The purpose of this study is to clarify the significance of the votes on each scale from the comparison between scales.This study investigates thermal environment and comfort of residences in Hyogo, Japan. A total of 52 occupants and 21 residences provided thermal perception data in the winter of 2006. The main results are a more than 75% of the total number respondents (136 of 179) fell outside the standard's comfort zone requirements, a vote of "slightly cooler (warmer)" on the thermal preference scale is sometimes considered to be comfortable or acceptable, and thermal comfort zone was included in acceptable range. To put it another way, acceptable range has comfort zone and slightly discomfort zone.

Keywords: Thermal sensation, Thermal acceptability, Thermal Comfort, Thermal preference, Japan

1. INTRODUCTION

There is currently a necessity to achieve energy savings and reduce the potential harm to the environment which can result from use of energy. Unnecessarily high heating or cooling causes an increase in CO_2 from combustion, which produces more global warming and acid rain, and will also reduce dwindling fuel resources. Such environmental issues will also incur an economic drain on the building owner. Knowledge of thermal comfort is useful for guiding the design of buildings and other enclosed environments, for achieving energy savings.

Several scales have been used in the laboratory and field studies to know the thermal sensation or comfort sensation of occupants. The most common are the 7-point ASHRAE scales, related to thermal sensation, comfort and acceptability. Researchers use those scales to reveal a neutral temperature, comfort zone or acceptable range. Cena, Ladd and Spotila (1990) reported mean indoor winter temperatures of approximately 21 °C in homes and the mean comfort vote was neutral in the environments. Forwood et al. (2001) have also looked at subjective thermal comfort in Sydney, and found that the majority of people

report being "comfortable" between mean radiant temperatures of 24 °C and 30 °C. Nicol et al. (1999) found Pakistani office workers reported temperatures varied with climate and season.

Some research has confirmed the differences of the desirable conditions from each scale (Larry, 1979, Nicol et al., 1994, de Dear et al., 1997). However, what kind of scales we should use to survey has received little attention. It is important to save energy and cost in the design of buildings and their mechanical systems. The purpose of this study is to clarify the significance of the votes on each scale from the comparison between scales.

2. METHOD

2.1 The climate of Japan

The climate in most major area, including Hyogo, is temperate to sub-tropic and consists of four seasons. The survey in this study was performed in the winter of 2006.The range of daily mean temperatures and relative humidity are shown in Figure 1. The mean daily temperature was in the range of 0.8-12.0°C from January to February. Meanwhile, the mean daily relative humidity(RH) was in the range of 45-91%.

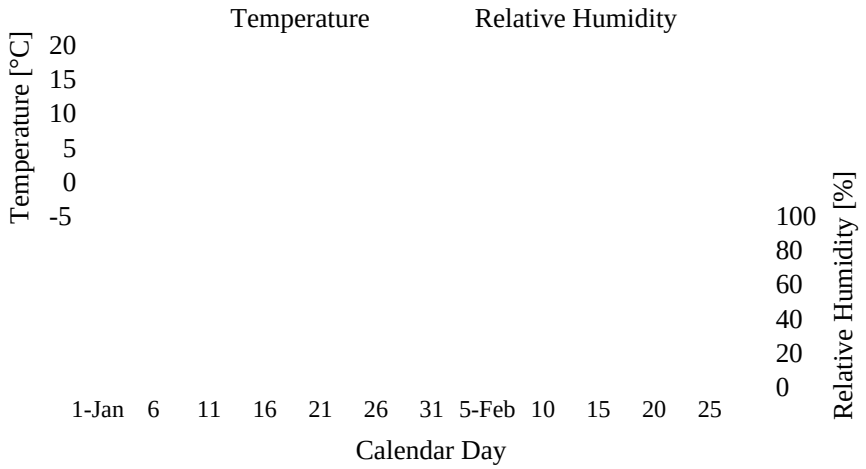

Figure 1: Daily outdoor minimum, maximum, and mean temperatures and humidity.

2.2 Subjects

Fifty-two subjects in 21 different residences in the Hyogo were collected in the survey and field measurement. Twenty-four males and 28 females responded the Questionnaire. Their age ranged from 15 to 82 years (x=49.0, σ=18.2).

2.3 Physical Measurements

Micro-meteorological sensors were selected in accordance with the specifications outlined in ASHRAE's Handbook of Fundamentals. Micro-meteorological measurements were selected four basic environmental parameters known to influence thermal comfort namely temperature, humidity, radiant environment and wind speed, could be accurately measured. Air temperature, the humidity, the globe temperature, and air velocity were measured at a height of 0.6m above the floor in the living-room. Mean radiant temperature was calculated with the globe temperature from the following equation:

$$Tr = \left[\frac{6.32\, D^{-0.4} V^{0.5}}{\sigma \varepsilon} (Tg - Ta) + Tg^4 \right]^{0.25}$$

where

D = diameter of the globe(m)
ε = emissivity of globe
σ = Stephan-Boltzmann constant ($5.67 \cdot 10^8$ W/m^{2}K^4)
Ta = air temperature (K)
Tg = globe temperature (K)
Tr = mean radiant temperature (K)
V = air velocity (m/s).

2.4 Questionnaire

The specific scales that will be analyzed in this paper are shown in Figure 2. The ASHRAE thermal sensation scale is labeled "cold"(1), "cool"(2), "slightly cool"(3), "neutral"(4), "slightly warm"(5), "warm"(6), "hot"(7). It has been noted that the thermal comfort equation is based on the ASHRAE scale which is strictly a measure of thermal sensation rather than thermal comfort, but it is generally accepted that the central three points represent thermal comfort.

(a)ASHRAE Thermal Sensation Scale

□Hot
□Warm
□Slightly warm
□Neutral
□Slightly cool
□Cool
□Cold

(b)Thermal Preference Scale

I would like to be:
□warmer
□slightly warmer
□no change
□slightly cooler
□cooler

(c)Thermal comfort Scale

□Very comfortable
□Moderately comfortable
□Slightly comfortable
□Slightly uncomfortable
□Moderately uncomfortable
□Very uncomfortable

(d)Thermal Acceptability Scale

□Acceptable
□Slightly acceptable
□Slightly unacceptable
□Unacceptable

Figure 1: Scales used in this study.

The subjects were also asked their preference on a 5-point scale. A scale of thermal preference indicates whether people would prefer a warmer or cooler condition, and so it may be used to locate more precisely where within in the comfort zone the optimum point might be. Commonly, a vote of "no change" on the thermal preference scale is considered "acceptable". A comfort questions asked subjects to rate the comfort of living-room, ranging from "very comfortable" to "very uncomfortable". A direct acceptability question asked subjects to reply "acceptable" or "unacceptable" about their current thermal conditions.

3. RESULTS

3.1 Indoor climate

Table 1 shows the statistical summaries of the indoor measurements for 21 homes. Air and radiant temperatures were 17.3 and 17.0°C, respectively, in the living room. Relative humidity was 59.6%. Collected temperature and humidity data are plotted on a psychrometric chart and are compared with the

criteria specified by ASHRAE Standard55 in Figure 2. More than 75% of the total number respondents (136 of 179) fell outside the standard's comfort zone requirements.

Table 1: Statistical summary of indoor climatic date

Parameter	Mean	S.D.	N	Max	Min
Air temperature(°C)	17.3	4.1	173	26.2	6.5
MRT(°C)	17.0	4.0	173	25.5	6.3
Relative humidity(%)	59.6	15.3	173	91.3	27.0
Operative temperature(°C)	17.1	4.1	173	25.79	6.37

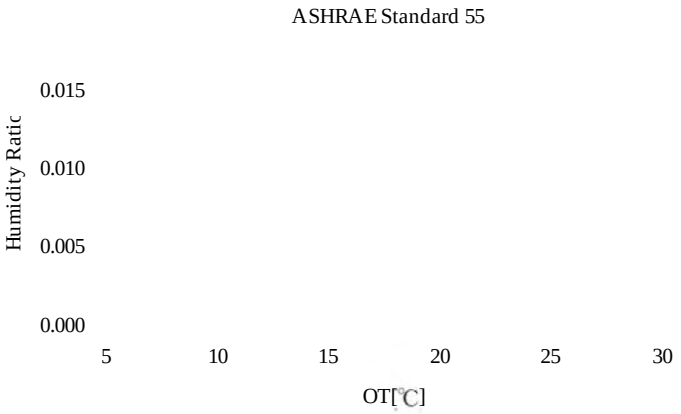

Figure 2: Indoor climatic conditions on Standard 55

3.2 Thermal Assessment

Figure 3 shows the distribution of subjective assessments of indoor climates. The distribution of votes on the ASHRAE thermal sensation scale (Figure 3a) showed a skewing towards the "warm" end of the scale, as expected. The air temperature preference votes (Figure 3b) showed that 68% of the sample wanted "no change" of the air temperature. The distribution of frequency for thermal comfort responses is given, see Figure 3c. The results for thermal acceptability (Figure 3d) showed that more than half of the sample voted "acceptable".

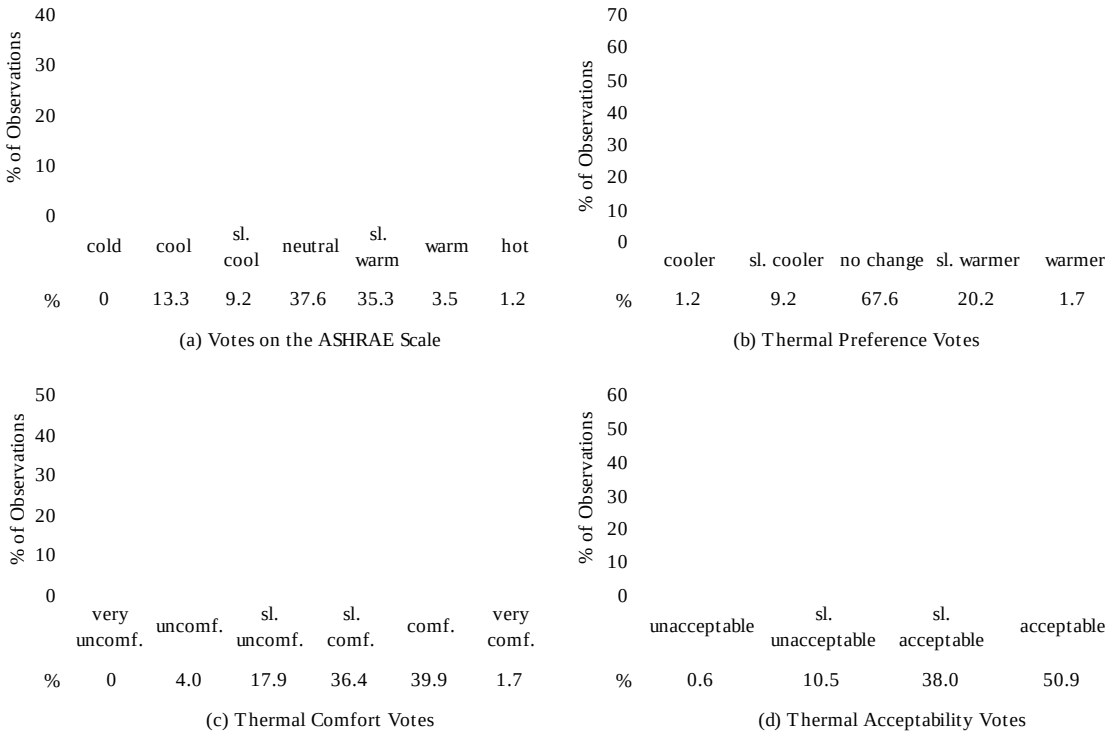

Figure 3: Frequency distributions of questionnaire responses.

4. DISCUSSION

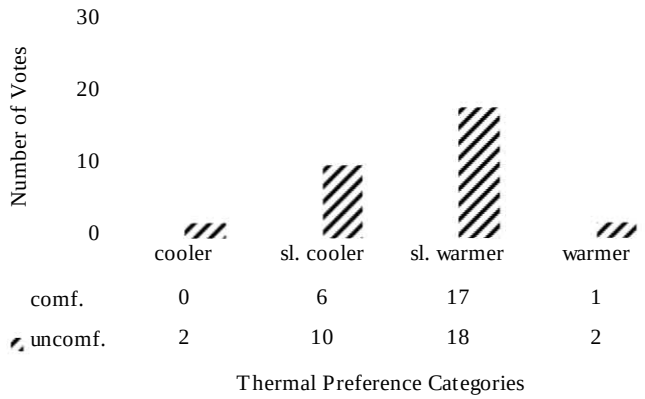

Figure 4: Comfort versus thermal preference scale expected "no change".

Figure 4 compares the thermal preference and the thermal comfort. The x-axis represents the preference scale and each bar is based on the group of people voting on the thermal preference scale. The height of the bar, the y-axis, represents the number of votes on the thermal comfort scale divided into 2 groups: "slightly comfortable" or better and "slightly uncomfortable" or worse. The data shows that defining acceptability using the comfort scale results.

Looking first at the group of people voting "slightly" cooler or warmer of the thermal preference scale, these votes on the thermal preference scale admit of two interpretations. The first, when people votes "slightly uncomfortable" or worse on the thermal comfort scale as well as voting "slightly cooler (warmer)" on the thermal preference scale, they wanted to relieve thermal discomfort. The second, when

they votes “slightly comfortable” or better as well as voting “slightly cooler (warmer)”, the people wanted to pursue thermal comfort.

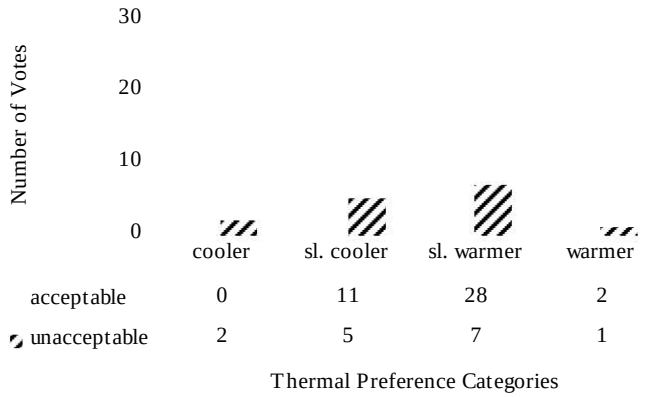

Figure 5: Acceptability versus thermal preference scale expected “no change”.

Although Figure 5 is similar to Figure 3, Figure 4 compares the thermal acceptability and the thermal preference. Looking first at the group of people voting “slightly” cooler or warmer of the thermal preference scale, this graph can be compared with the previous one. The height of the bar, the y-axis, represents the number of votes on the thermal acceptability scale divided into 2 groups: “slightly acceptable” or better and “slightly unacceptable” or worse. The ratio of acceptable votes defined by thermal acceptability scale is higher than that of the acceptable votes defined by the thermal comfort scale.

As shown in Figure 4 and 6, these results indicate that “slightly cooler (warmer)” on the thermal preference scale is sometimes considered to be comfortable or acceptable.

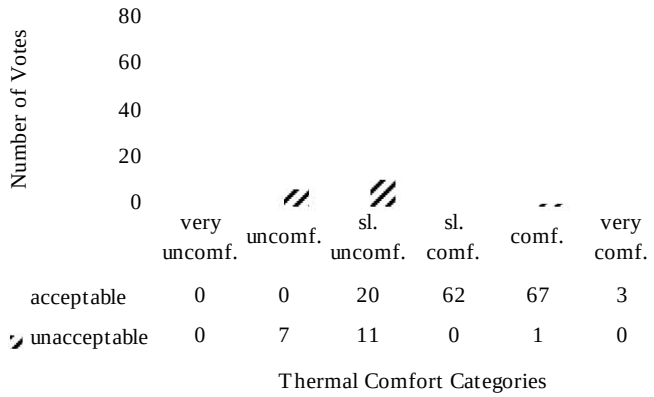

Figure 6: Acceptability versus thermal comfort scale.

Figure 6 compares the thermal comfort and the thermal acceptability. The x-axis represents the thermal comfort scale and each bar is based on the group of people voting on the thermal acceptability scale. In general, “slightly comfortable or better” on the thermal comfort scale are considered to be acceptable, and “slightly uncomfortable or worse” are considered to be unacceptable.

Looking first at the group of people voting “slightly comfortable or better” categories, most of them found the conditions acceptable. Those who voted “uncomfortable” found the conditions unacceptable. Whereas these results satisfied the above assumption, some subjects who voting “slightly uncomfortable” didn’t satisfied it. When subjects vote “slightly uncomfortable”, they are in discomfort conditions and feel

some stresses. So votes of "slightly uncomfortable" are considered to be unacceptable. However, Figure 6 shows that there are the people who voted "slightly uncomfortable" on the thermal comfort scale as well as voting "acceptable" on thermal acceptability scale. This means that thermal comfort zone was included in acceptable range. To put it another way, acceptable range has comfort zone and slightly discomfort zone.

5. CONCLUSION

This study investigates thermal environment and comfort of residences in Hyogo, Japan. A total of 52 occupants and 21 residences provided thermal perception data in the winter of 2006. The main results are as follows;

1) More than 75% of the total number respondents (136 of 179) fell outside the standard's comfort zone requirements.
2) A vote of "slightly cooler (warmer)" on the thermal preference scale is sometimes considered to be comfortable or acceptable.
3) Thermal comfort zone was included in acceptable range. To put it another way, acceptable range has comfort zone and slightly discomfort zone.

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