Prediction of thermal acceptability in hot-humid outdoor environments in Taiwan

Tzu-Ping Lin*,†, Richard de Dear**, Andreas Matzarakis***, Ruey-Lung Hwang****
*Department of Leisure Planning, National Formosa University, Taiwan
**Faculty of Architecture, Design and Planning, University of Sydney, Australia
***Meteorological Institute, Albert-Ludwigs University of Freiburg, Germany
****Department of Architecture, National United University, Taiwan

Abstract

Thermal comfort assessments have usually been performed with thermal indices based on the human heat balance. However, we know that contextual factors induce thermal expectations that are specific to each setting, so heat-balance indices may not necessarily work as well across all contexts. Therefore, people may well have divergent thermal perceptions when they are exposed to different contexts despite them having identical values of thermal comfort indices. This study focused on 1644 subjects in outdoor thermal comfort surveys in hot-humid Taiwan. The results of this research indicate the thermal requirement, i.e. neutral temperature, preferred temperature, are variant in different season, demonstrating that thermal adaptation factors, such as long term experience and expectation, are important for human's thermal comfort in outdoor environment. Furthermore, even exposed in the same thermal comfort range (e.g. the same SET*), people have different preferences on each thermal parameter in different seasons.

Key words: outdoor thermal comfort, hot-humid regions, thermal adaptation

1. INTRODUCTION

Due to the need for leisure and recreation, people are often directly exposed to weather in outdoor spaces. Therefore, a comfortable thermal environment is extremely important to people in outdoors. Some studies have found that thermal perceptions and preferences for outdoor people can not sorely explained by energy balance of human's body, it is significantly affected by the psychological and behavioral factors such as experience, expectation, perceived control, cultural reasons, time of exposure, etc (Brager and de Dear 1998; Nikolopoulou et al. 2001; Nikolopoulou and Steemers 2003; Spagnolo and de Dear 2003; Hwang and Lin 2007), which is so called thermal adaptation. The variance of thermal comfort in different season is a significant example for thermal adaptation effect, which include the issues of long term experiences and expectations factors for thermal comfort of outdoor people. For example, people in winter may prefer lower air temperature than in summer, and can tolerate higher temperature in summer than in winter.
Thermal indices based on human energy balance and integrated air temperature, air humidity, mean radiant temperature and wind speed used to evaluate people's thermal perceptions in a easy and objectively manner. However, we know that contextual factors induce thermal expectations that are specific to each setting, so heat-balance indices may not necessarily work as well across all contexts. Therefore, people may well have divergent thermal perceptions when they are exposed to different contexts despite them having identical values of thermal comfort indices.
Therefore, this research applied the outdoor thermal comfort survey database in Taiwan, firstly focusing on the thermal comfort requirement in different season. Secondly, the subjects are divided into different temperature bin to examine people's preferences to the four meteorological parameters, which can validate the effect of thermal adaptation on thermal comfort.

2. METHOD

2.1 Physical measurements

This study measured air temperature, relative humidity, global radiation, wind speed and globe temperature. All instruments are compliant with ISO 7726 (ISO 1998) and placed at a height of 1.1 m on tripods in the middle of the square. On the measurement day, the data were collected at 1-minute intervals. Mean radiant temperature is estimated by the RayMan model (Matzarakis et al. 2007).

2.2 Questionnaire survey

A questionnaire survey was administered during field measurements. The first part of the questionnaire collected demographic information (e.g., age and sex) and data for activity level, clothing worn. The second section asked subjects to rate their current thermal comfort. Thermal comfort was rated on ASHRAE 7-point thermal sensation vote (TSV) scale (i.e., −3, cold; −2, cool; −1, slightly cool; 0, neutral; 1, slightly warm; 2, warm; and 3, hot). The

† Corresponding author: 64 Wen-hua Rd, Huwei, Yunlin 632, Taiwan, E-mail: tplin@nfu.edu.tw

McIntyre preference scales (Right now I want to be “cooler, “ “no change“ or warmer”), directly assessed thermal acceptability (acceptable or unacceptable) (ISO 1998). Furthermore, subjects were asked to indicate their level of thermal sensation and preference for wind and sun. The ratings for wind/sun sensation were on a 7-point scale raging from −3 for “very weak” to 3 for “very strong” (0=“neutral”), and the preference ratings were on a 3-point scale with “I prefer wind/sun to be weaker,” “no change” and “I prefer wind/sun to be stronger.” Sensations and preferences for air humidity were also measured in a similar manner.

2.3 Thermal comfort indices

Several indices integrating thermal environmental factors and the energy balance of the human body were applied to assess outdoor thermal comfort, e.g., predicted mean vote (PMV) (Fanger 1972), effective temperature (ET*), standard effective temperature (SET*) (Gagge et al. 1986), OUT_SET* (Pickup and de Dear 2000; Spagnolo and de Dear 2003) and physiologically equivalent temperature (PET). The SET*, which is defined as the air temperature at which an individual in a reference environment (Ta = Tmrt, RH = 50 %, v= 0.15 m/s) wearing 0.6 clo with a metabolic rate of 1.2 mets has the same mean skin temperature and skin wettedness as the individual in the complex environment (Gagge et al. 1986), is applied in this research.

3. RESULTS

This study collected 1644 effective questionnaires in outdoor environment in Central Taiwan. The comparison of thermal requirement for subjects in cool and hot season are discussed below.

3.1 Clothing

Fig. 1 shows the relation between subjects’ clothing and current air temperature in hot and cool season. The results indicate that the amount of clothing worn by the subjects decrease with the air temperature rising. In hot season, the clothing amount drops dramatically while the air temperature reaches 28°C with the 0.5clo levels. In cool season, clothing amount raise to 0.8 clo while the air temperature lower than 18°C. The overlapped range of clothing in hot and cool season, i.e. SET*=22–28°C, indicated that people wear a little more in cool season than in hot season while expose to the same thermal condition in the range.

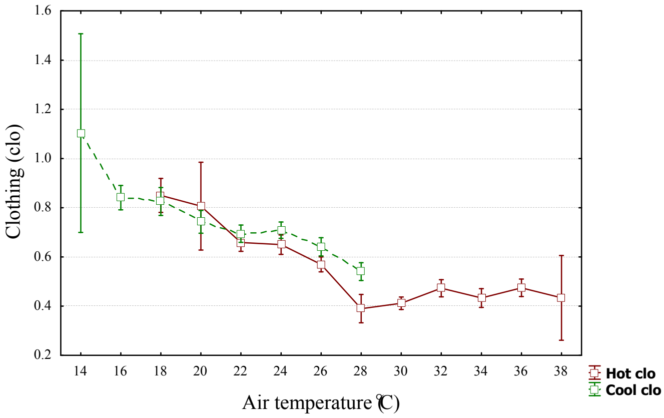


Fig. 1. Clothing worn by subjects under different SET* segments. The box represents the average value and the whiskers indicate the 95% confidence interval

3.2 Neutral temperature

According to the method suggested by (de Dear and Fountain 1994), the mean TSV (MTSV) in each temperature interval (in SET*) is calculated and fitted with regression line both in hot and cool seasons (fig 2). By substituting MTSV=0 into both regression model, the neutral temperatures for hot and cool season could be obtained, and are 29.3°C and 28.0°C SET*, respectively.

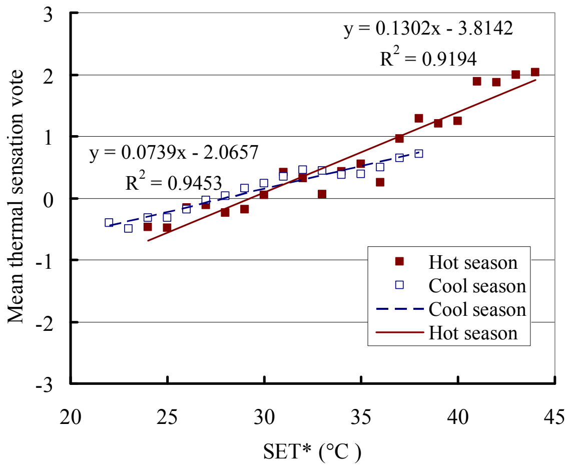


Fig. 2. Correlation between the mean thermal sensation vote (MTSVs) and SET* in the hot and cool seasons

3.3 Preferred temperature

Thermal comfort also can be defined as a condition in which individuals prefer neither warmer nor cooler temperatures, i.e., the preferred temperature. While neutral temperature is the temperature at which people feel comfortable, preferred temperature is the temperature people want. Therefore, this study derived preferred temperatures for both seasons based on preference votes in questionnaires, thereby confirming the impact of expectations on thermal comfort. Probit analysis (Ballantyne et al. 1977) is applied to calculate preferred temperature based on preference votes, i.e., votes for warmer want cooler temperatures. These preferences are divided into groups for each 2° C PET intervals, and the percentage of each preference is calculated within each groups and fitted with the probit model separately. The point at which both models intersect is the temperature at which individuals did not prefer either a cooler or warmer temperature, which we assume is the preferred temperature (de Dear and Fountain 1994). The preferred temperatures in the hot and cool seasons were 28.9° C and 25.4° C SET*, respectively (Fig. 3)

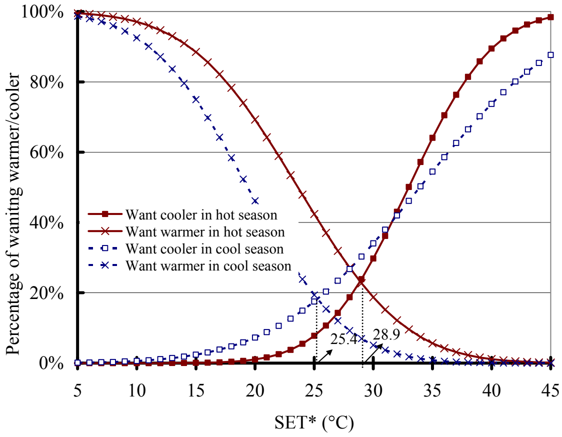
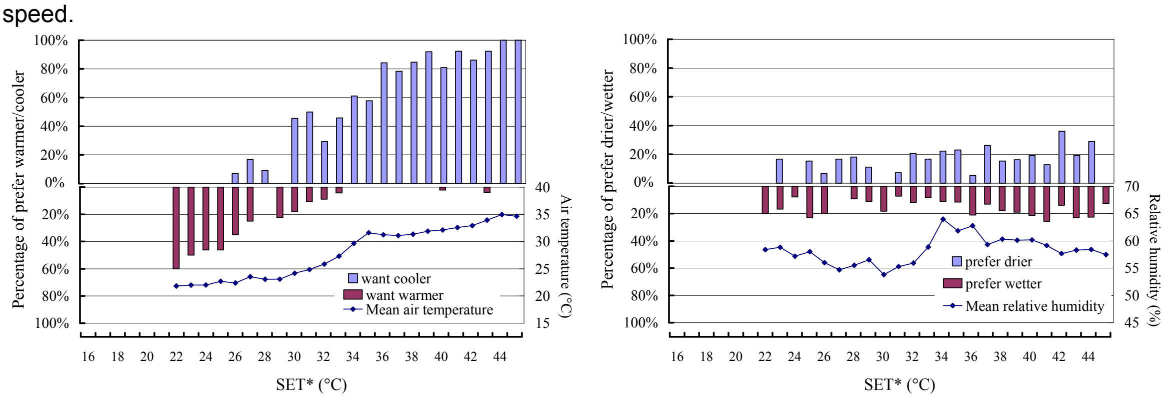


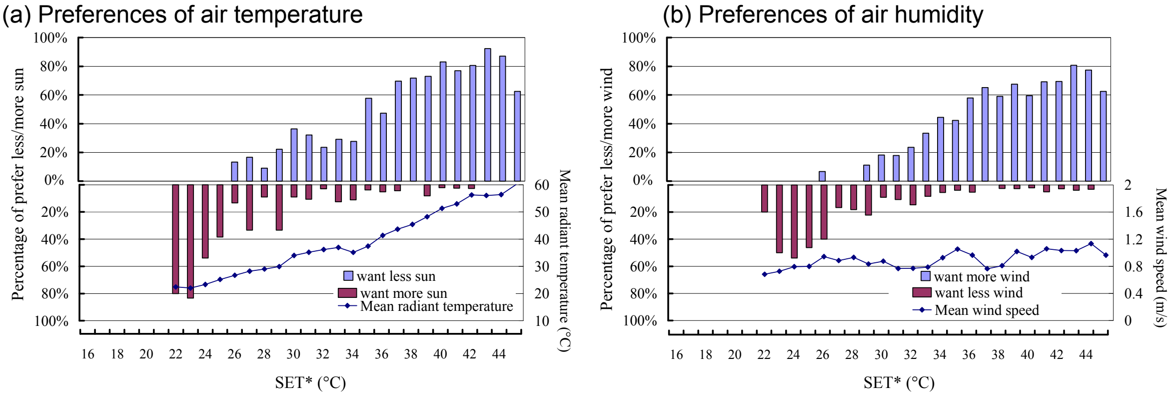
Fig. 3. Preferred temperatures in cool and hot seasons

4. DISCUSSION

This section will further discuss weather people will express the preferences of each factor (i.e. air temperature, relative humidity, mean radiant temperature, wind speed) according with the variant with thermal index SET*. The percentage of preferences of subjects, i.e. want warmer/cooler, drier/wetter, less/more sun and wind, are calculated with 1 ° C SET* bin both in hot and cool season. The average values of physical measurement data are also displayed in each figure for comparison.
Fig. 4 is the subjects' preference versus thermal index SET* and physical data in hot season. For the temperature (a), people prefer warmer when in low SET* and want cooler when in high SET*. Their thermal preferences also variant with the air temperature. The similar phenomena also occur for the preferences of mean radiant temperature (c). For the air humidity, there are no correlation among the subjects' preference, thermal index SET* and physical data, people don't express the difference of preference on humidity due to the variant of SET* or relative humidity. For the wind speed, although lots of people report high preferences on higher wind speed while the SET* increasing, wind speed is not actually decrease in high SET*. The results indicate that people want to eliminate thermal uncomfortable (caused by high air temperature or mean radiant temperature) through high wind speed.



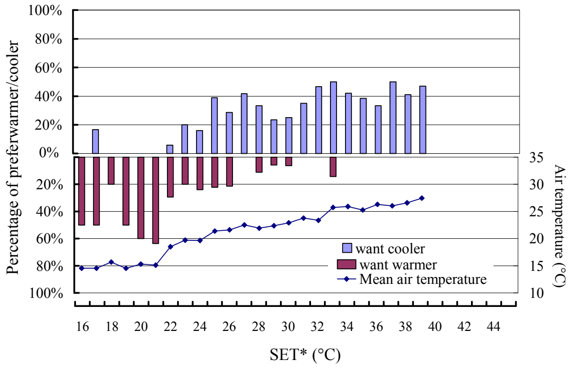
(a) Preferences of air temperature (b) Preferences of air humidity



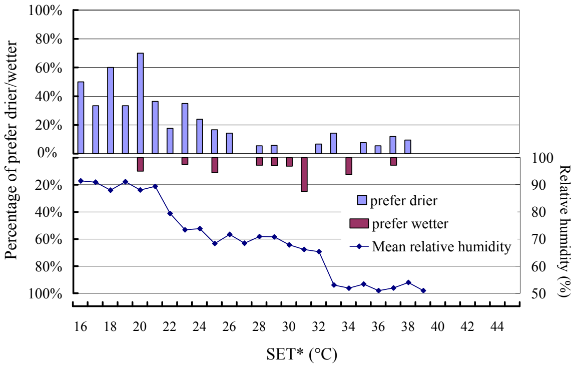
(c) Preferences of mean radiant temperature (d) Preferences of wind speed

Fig. 4. Subjects' preferences versus thermal index SET* and physical data in the hot season.

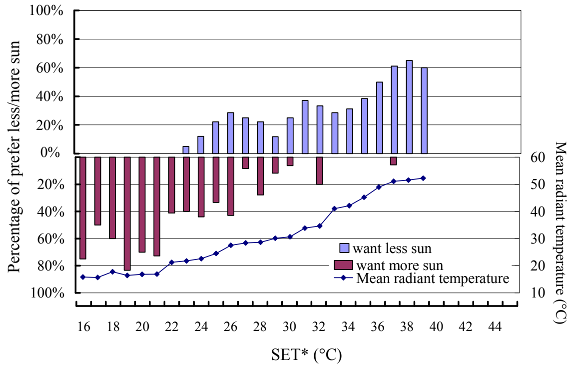
Fig 5 is the preferences analysis in cool season. For the temperature (a), compared to hot season, the trend of preference to SET* and air temperature are similar in cool season, but less people report "want cooler" in high SET. The similar phenomena also occur for the preferences of mean radiant temperature (c). For the air humidity, more people prefer drier in low SET*, which is also reflect the high value of relative humidity in low SET*, revealing that people are sensitive to high relative humidity in cool season. For the wind speed, the results are similar to that in hot season, but less people report more wind while exposing to high SET* in cool season than that in hot season.



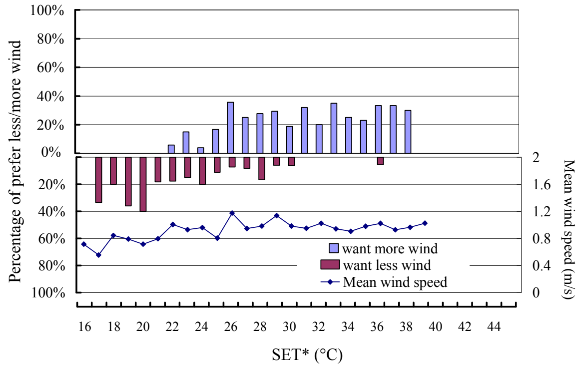
(a) Preferences of air temperature



(b) Preferences of air humidity



(c) Preferences of mean radiant temperature



(d) Preferences of wind speed

Fig. 5. Subjects' preferences versus thermal index SET* and physical data in the cool season.

5. CONCLUSIONS

The results of this research indicate the thermal requirement are variant in different season, demonstrating that thermal adaptation factors, such as long term experience and expectation, are important for human's thermal comfort in outdoor environment. The further discussion indicate that people's preferences of air temperature and sun significantly reflect the variant of SET*, which is also affected by air temperature and mean radiant temperature. However, people's preferences on humidity is only significantly related to SET* in cool season. Furthermore, subjects' preferences on wind in high SET* are based more on their perception of air temperature and mean radiant temperature, rather than on the current wind speed. Generally speaking, even exposed in the same SET*, people have different preferences on each thermal parameter in different seasons.

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