Thermal Comfort Conditions of Urban Spaces in a Hot-Humid Climate of Chiang Mai City, Thailand

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Abstract: The aim of this study was to investigate thermal sensation for occupants of outdoor and semi-outdoor urban environments in wide range of hot-humid tropical climate conditions of Chiang Mai city. A total of 296 questionnaires were collected in the outdoor and semi-outdoor urban spaces during the survey, which was carried out on days with suitable weather and avoid rainy days. According to survey results, 28.97% and 26.83% of the respondents voted for neutral in outdoor and semi-outdoor urban spaces respectively. The thermal neutrality was derived by solving the simple linear equations for a mean sensation vote of zero, which are determined by analyzing the relationship between the Mean Thermal Sensation Vote (MTSV) and Physiologically Equivalent Temperature (PET) values. The results found that, the neutral sensation PET temperatures (MTSV=0) of outdoor and semi-outdoor spaces were 27.1 °C and 28.5 °C, respectively. And the acceptable thermal conditions ranges were 31.0-23.1°C and 32.0-22.4°C, respectively. Compared with the thermal acceptable range between both spaces was found that the thermal acceptable range in the semi-outdoor environment is much higher than the outdoor environment, indicating that occupants in different spaces have different thermal requirements.

Keywords: Hot and humid climate; human thermal comfort; outdoor urban space; physiologically equivalent temperature (PET)

1. Introduction

Urban spaces are most important to promote liveable cities because they accommodate pedestrians and various outdoor activities which contributing to urban livability and vitality [Chen & Ng, 2012; Oliveira & Andrade, 2007; Nikolopoulou & Steemers, 2003]. Thus, the urban microclimate is an important issue to determining the quality of urban spaces, especially in rapidly growing Asian cities in tropical climates. Moreover, the influence of thermal comfort on outdoor and semi-outdoor activities is a complex issue comprising both climatic and behavioral aspects. The aim of this study was to investigate thermal sensation for occupants of outdoor and semi-outdoor urban environments in wide range of hot-humid tropical climate conditions. Thermal conditions of outdoor and semi-outdoor spaces were evaluated based upon the measurement of major climatic parameters, while the thermal perception of subjects was captured simultaneously using a questionnaire survey. The study concentrated on the shaded outdoor and semi-outdoor spaces within the Chiang Mai urban area whereas the focus was on the local individuals as the respondents of inquiry.

2. Methods

2.1 Study area

During the hot season in Chiang Mai (during February to April), has highest solar intensity, longer sunshine days, the precipitation and cloudiness had the smallest values. So at that time, the urban heat island effects were probably the strongest which could affect a community's environment and quality of life in Chiang Mai city [Srivanit & Hokao, 2012]. Thus, the data obtained from the survey can represent the thermal environment conditions that people may encounter in their daily life in a summer of urban Chiang Mai.

2.2 Field study

The measurement period was conducted during the daytime from 8 am to 4 pm on April within the year 2014, which is the most representative a hottest month of summer in Chiang Mai city (Fig.1a). Thermal environment conditions of two different types of urban spaces were evaluated based upon the measurement of major climatic parameters, while the thermal acceptability of subjects was captured concurrently using a questionnaire survey. The respondents were conducted in a wide range of air temperature (34.8±3.2°C), relative humidity (40.7±7.3%), wind velocity (0.7±0.3m/s) and mean radiant temperature (40.3±8.8°C) for the climatic conditions in summer. The Thermal Sensation Vote (TSV) of the respondents were expressed on a 7-point scale ranging from -3 (very cold) to +3 (very hot), whereas the respondents were asked to rate their overall thermal comfort level (or acceptability) to determine the responses of individuals regarding the outdoor climatic conditions, along with personal

parameters (e.g., age, gender, weight and height) and characteristics (e.g., clothing, activity etc.) of respondents. The summary of data sample is presented in Table 1.

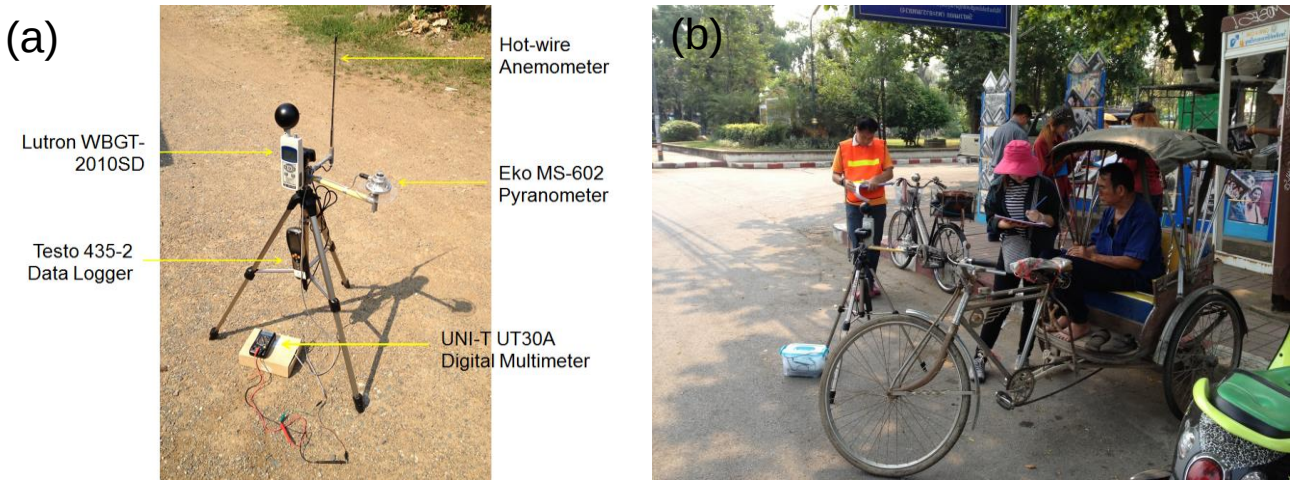

Fig. 1 (a) Microclimatic measuring station used for this study, and (b) Interviewers conducting the questionnaire survey in the outdoor and semi-outdoor spaces on April of summer 2014.

A total of 296 questionnaires were collected in the outdoor (72.3%) and semi-outdoor (27.7%) urban spaces during the survey, which was carried out on days with suitable weather and avoid rainy days (Fig.1b). Metabolic rate and clothing insulation were estimated in accordance with ASHRAE 55-2004. As only respondents who were sitting (1.2 met) and standing (1.4 met) were included during the survey. The average clothing values was found to be 0.55±0.20clo. In the meantime, the evaluation of PET (Physiologically Equivalent Temperature) index using the RayMan model was utilized to calculate the thermal comfort conditions in this study. The majority of the respondents (99.8%) stayed under trees or buildings shaded conditions. The 56.8% of the respondents were males. The average weight and height was 57.7±10.5 kg and 162.6±6.76 cm.

Table.1 Summary of the respondents and their distribution in each urban space.

Personal data		Outdoor	Semi-outdoor	All
Respondent's number		214	82	296
Gender	Male	136	32	168
	Female	78	50	128
Age (year)	Average	35.4	34.9	35.3
	Max.	80	71	80
	Min.	15	15	15
	S.D.	14.7	14.0	14.5
Weight (kg)	Average	57.9	57.1	57.7
	Max	108	95	108
	Min	34	35	34
	S.D.	10.0	11.7	10.5
Height (cm)	Average	163.0	161.6	162.6
	Max.	179	182	182
	Min.	150	149	149
	S.D.	7.0	6.1	6.8
Clothing (clo)	Average	0.56	0.53	0.55
	Max.	1.68	1.05	1.68
	Min.	0.24	0.14	0.14
	S.D.	0.21	0.18	0.20

3. Results and discussions

According to survey results, 28.97% and 26.83% of the respondents voted for neutral (TSV=0) in outdoor and semi-outdoor urban spaces respectively (Fig.2). The thermal neutrality was derived by solving the simple linear equations for a mean sensation vote of zero, which are determined by analyzing the relationship between the Mean Thermal Sensation Vote (MTSV) and PET values.

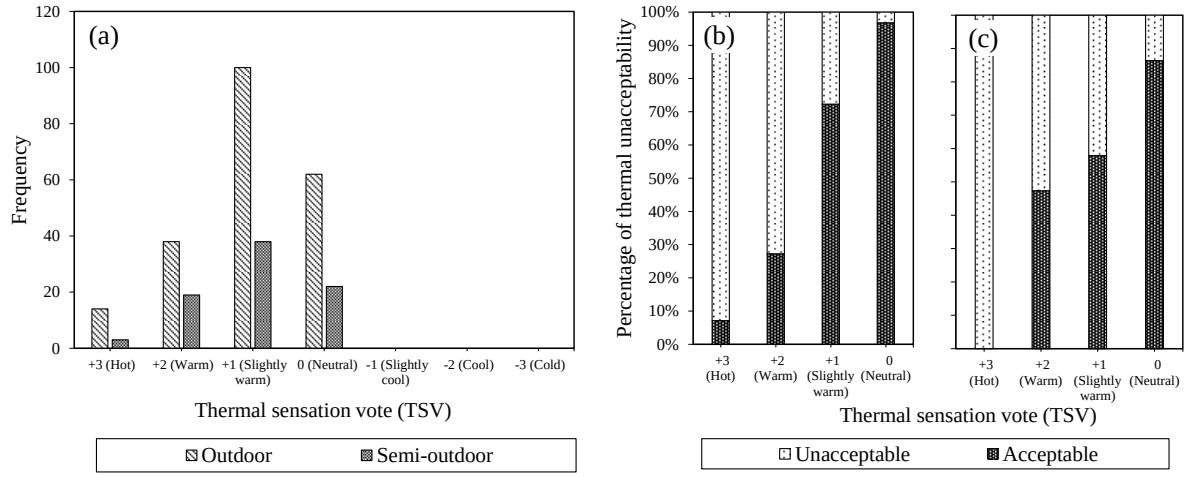

Fig. 2 Frequency distribution of thermal sensation votes in (a) the both outdoor and semi-outdoor spaces and, percentage of thermal unacceptability votes for (b) outdoor and (c) semi-outdoor environments in the summer.

The simple linear regression equations of outdoor and semi-outdoor spaces are presented in Equation [1] and [2], respectively. The results found that, the neutral sensation PET temperatures (MTSV=0) of outdoor and semi-outdoor spaces were 27.1 °C and 28.5 °C, respectively (Fig.3a).

$$MTSV = 0.1079(PET) - 2.9288\,,\ R^2 = 0.8904 \qquad [Eq.1]$$

$$MTSV = 0.1447(PET) - 4.1241\,,\ R^2 = 0.7548 \qquad [Eq.2]$$

And the acceptable thermal conditions (by ASHRAE Standard 55 corresponded with minimum standard of 80% acceptability) ranges were 31.0-23.1°C (difference, 7.9°C) and 32.0-22.4°C (difference, 9.7°C), respectively (Fig.3b). Compared with the thermal acceptable range between both spaces was found that the thermal acceptable range in the semi-outdoor environment is much higher than the outdoor environment, indicating that occupants in different spaces have different thermal requirements. The results of corresponding neutral acceptability temperatures for outdoor and semi-outdoor environments were 27.0°C and 27.2 °C, respectively. Compared with the neutral temperature differentiation in terms of sensations and acceptability temperatures for the both outdoor and semi-outdoor environments were 0.1°C and 1.3 °C, respectively.

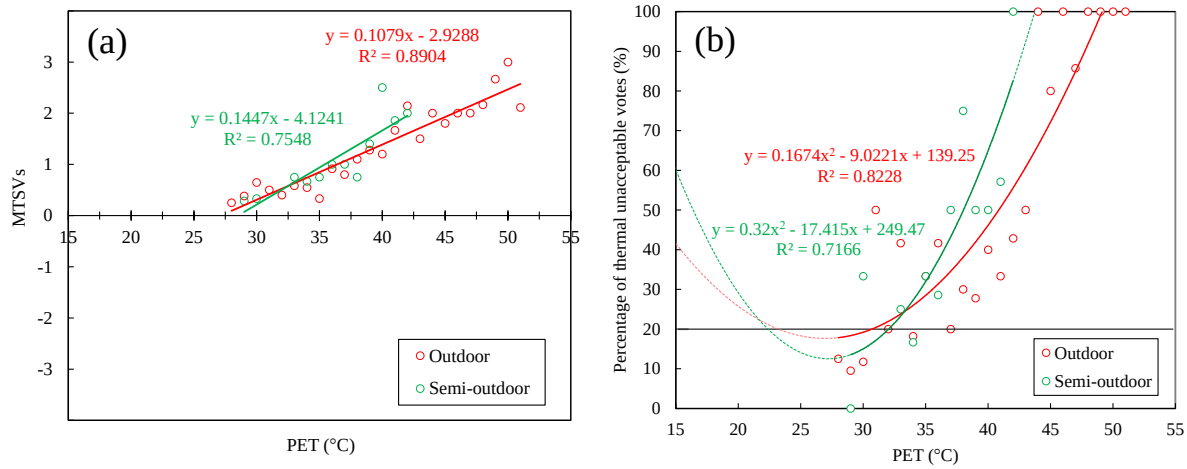

Fig. 3 (a) Comparing linear regressions of thermal sensation and PET and, (b) percentage of thermal acceptable ranges for the respondents voted in different environments.

4. Conclusions

The results demonstrated that occupants of semi-outdoor spaces expect more unacceptable neutral thermal conditions than occupants of outdoor spaces. Thus, the comparison results can be explained that occupants who considered their thermal environments in semi-outdoor environment difficult to control are accepting of thermal environment conditions in summer, even if they are feeling comfort. Based on the results of thermal sensation and acceptability analysis in this study can contributes toward creating and improving comfortable urban spaces in hot-humid contexts to enhance the quality of urban life and achieving a liveable city in tropics such as Chiang Mai. Moreover, these findings reconfirm the other researchers' findings which declared the differences between tolerances of people from different regions. Consequently, it can be concluded that the thermal comfort range for a specific climatic condition may not be applicable to other climates.

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