Study on the role of vegetation towards thermal comfort in outdoor urban areas

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Abstract

Urban heat islands have a direct impact on the areas where people are suffering from heat stress during the hot climatic conditions. In order to get relief from heat stress, many researchers have explored various strategies that have given more importance to green spaces i.e. vegetation. Urban greenery such as parks, gardens, and street trees helps to improve outdoor thermal comfort. Several research in different countries have given approaches to vegetation as improving methods for outdoor thermal comfort of urban open spaces. The main goal of this study is to analyze the human perceptions of outdoor conditions in Ratna-park, Kathmandu, Nepal through field survey and to establish the relationship between meteorological parameters. 78% of the visitors voted for neutral which shows that they are highly satisfied with the park. Additionally, the mean comfort temperature was found to be 29.1°C. People are well adapted to the thermal environment of the urban park, and thus the comfort temperature was significantly high in summer.

Keywords - Outdoor thermal comfort, Field survey, Urban Park, Comfort temperature, Griffiths' method

1. Introduction

Thermal comfort is the state of mind that expresses satisfaction with the surrounding environment [1]. Occupants these days are more aware of urban issues due to the worsening urban climate. This compels the researcher to concentrate more on outdoor thermal comfort studies. Other than that, the effects of urbanization also contributed to the rise of studies that focus on outdoor thermal comfort. In the same way, open space can improve residents' social, environmental, and healthy lives [2]. However, comfort in urban space is governed by different factors, which include meteorological factors and personal factors.

With a focus on quality of life, people prioritize outdoor space thermal comfort levels. The topic of outdoor thermal comfort has gained significant attention in recent years, promoting a large number of studies to examine and explore the topic through field studies [3-5]. According to the IPCC assessment by 2100, the global surface temperatures are expected to have increased by 0.3-4.8 °C [6]. According to research, being in a hot environment might make one feel exhausted and breathless, and increase in heart rate [7]. Comparably, green spaces improve mental health by lowering stress and raising satisfaction, which in turn raises comfort [2]. Additionally, it aids in air pollution filtering, which improves outdoor comfort and air quality.

Scientific evidence indicates that the impact of global warming is significantly high [8]. Up to 70,000 people died across Europe in 2003 as a result of heat waves [9]. Summertime research conducted in the Netherlands by Klemn et al. [10] found a 0.8K drop in air temperature between the city center and the park. Similar findings were made by Karimi et al. [11] who replaced the summertime vegetation in Iran with pine trees and found a 0.3K drop in air temperature. Furthermore, in Japan, it is found that people living in an urban area with green space extend their life expectancy [12]. Similarly, comparing a shady region to a sunny site in an open space, found a 6.9K drop in air temperature in Portugal [13]. In a 3.5 hectare park, Zoich et al. [14] measured a maximum air temperature of 32.1 °C with a 1K air temperature drop in an area covered by trees.

Xu et al. [15] investigated the outdoor thermal benchmark of shaded spaces in an urban park in China by conducting field measurement and survey during winter and summer. Martinelli et al.

[16] investigated the impact of vegetation during the summer months in Italy. The prior study was limited to a specific country. More research is necessary because results from one city, country, or season may not be applicable to another. The main objective of this paper is to investigate the thermal sensation vote and thermal preference of the visitors in the urban park of Kathmandu, and to estimate the comfort temperature of the visitors.

2. Methodology

2.1. Study Area

The study area is located in Ratna-park, Kathmandu, Nepal. Kathmandu is approximately 1,400 meters above sea level, surrounded by the mountain to the north (Figure 1). Kathmandu lies in the temperate climate of Nepal. The mean outdoor air temperature in summer and winter are 20.5 °C and 9.2 °C [17,18]. The mean outdoor relative humidity was 73% and 79% in summer and winter [17,18].

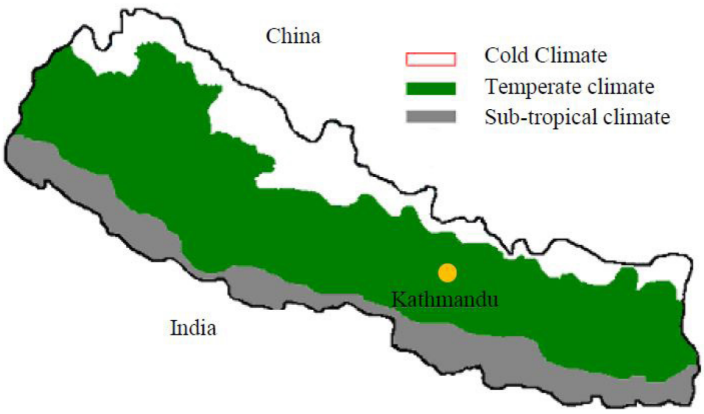

Figure 1: Location of the study area

2.2. Thermal Measurement

The field survey was conducted from 8th July to 12th August 2023 from 11:00 to 15:00. During the field survey period, the air temperature, relative humidity, wind speed, globe temperature, and radiant temperature were measured by instruments (Table 1). The instrument was set up at 1.5 m height from the ground level. If there was the presence of direct solar radiation, then the instrument was set up about 3 m away from the people. The data was recorded 15 minutes after the set up of the instruments.

Figure 2: Field survey in Ratna-park

Table 1: Details of instruments used

Measured variables	Instruments name	Accuracy
Air temperature, Relative humidity (RH)	TR-76Ui	±0.5°C, ±5%RH
Wind speed	TSI 9535-Anemometer	3% reading or ±3 ft/min whichever is greater
Globe temperature	Thermo Recorder TR-52i	±0.3 °C, (-20 to 80 °C)

2.3. *Thermal Comfort Survey*

The survey ensured that it included the majority of the park visitors, and the measuring time was chosen when people were using the park. First, a group of respondents was chosen in the study area. The questionnaire sheet consists of two sections. The first section contains the background of people like name, age, gender, etc. The second section consists of 16 questionnaires consisting of thermal sensation, thermal preference, clothing insulation, and park features. The seven-point thermal sensation scale, five-point thermal preference scale, and six-point overall comfort scale were used (Table 2). A total of 121 votes were gathered from 49 males and 72 females.

Table 2: Thermal sensation, thermal preference, and overall comfort scale

Scale	Thermal sensation scale	Thermal preference scale	Overall comfort
1	Very cold	Much warmer	Very discomfort
2	Cold	A bit warmer	Discomfort
3	Slightly cold	No change	Slightly discomfort
4	Neutral	A bit cooler	Slightly comfort
5	Slightly hot	Much cooler	Comfort
6	Hot	-	Very comfort
7	Very hot	-	-

3. Results and discussion

3.1. *Thermal environment during voting*

During the survey period, the physical parameters were measured to evaluate the thermal comfort of visitors. Table 3 presents the physical parameters of the investigated park. The mean air temperature, globe temperature, relative humidity, and wind speed were 28.4 °C, 29.3 °C, 61%, and 0.68 m/s respectively.

Table 3: Physical parameters during voting

Air temperature, T_a (°C)			Globe temperature, T_g (°C)			Relative humidity, *RH* (%)			Wind velocity, *V* (m/s)		
Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
28.4	31.8	26	29.3	32.7	24.1	61	72	48	0.68	1.5	0.1

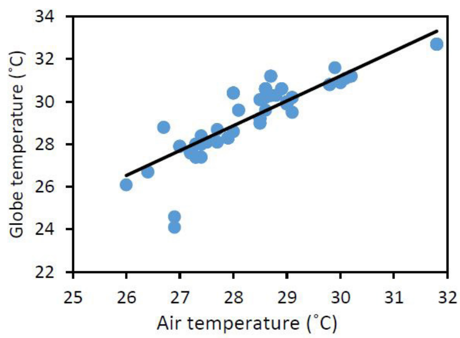

Figure 3: Relationship between globe temperature and air temperature

Figure 3 shows the relationship between globe temperature and air temperature. When air temperature increases the globe temperature also increases (R2 = 0.78). The regression equation obtained from Figure 3 is shown below. Due to the high correlation between air temperature and globe temperature, globe temperature is used for further analysis.

$$T_g = 1.1T_a - 3.8 \text{ (N = 121, } R^2 = 0.78) \quad (1)$$

Where T_g: Globe temperature (°C), T_a: Air temperature (°C), N: Number of samples, R^2: Coefficient of determination

3.2. Thermal Responses

Figure 4 shows the distribution of the thermal sensation and thermal preference vote from the visitors of the park. Most of the respondents (78%) voted for "4. Neutral". The second highest number of respondents (17%) reported feeling "5. Slightly hot". 5% of the respondents voted for "3. Slightly cold". This result was consistent with Zhang et al. [19] as they found that 60% of the respondents voted for "Neutral" during the field study which was conducted in Chengdu Park, China during the summer. The vegetation coverage of this park is high. On the other hand, from the thermal preference vote, 59% of respondents preferred "3. No change" as they are satisfied with the existing environment of the park, while 41% preferred "4. A bit cooler" in the investigated park. Canan et al. [20] also found that 43% of respondents preferred "No change" in the existing thermal environment in Turkey during summer.

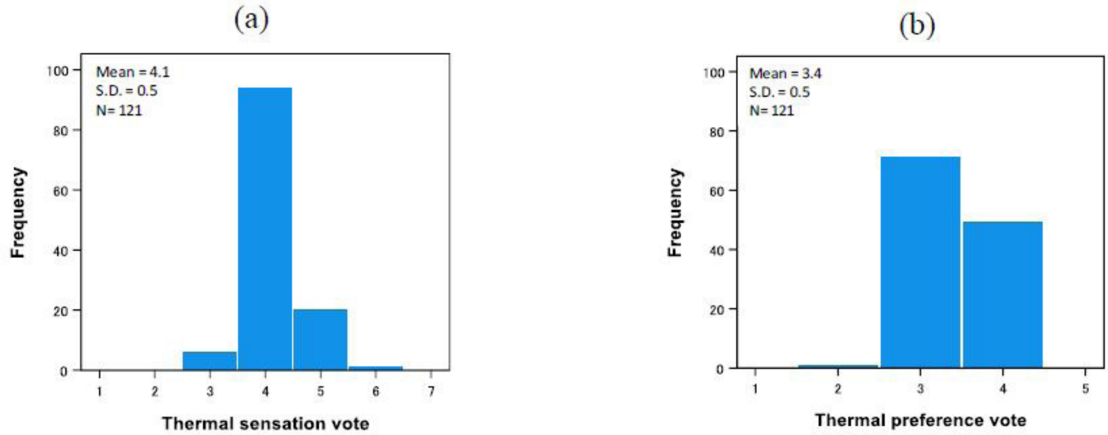

Figure 4: Distribution of thermal sensation and thermal preference vote

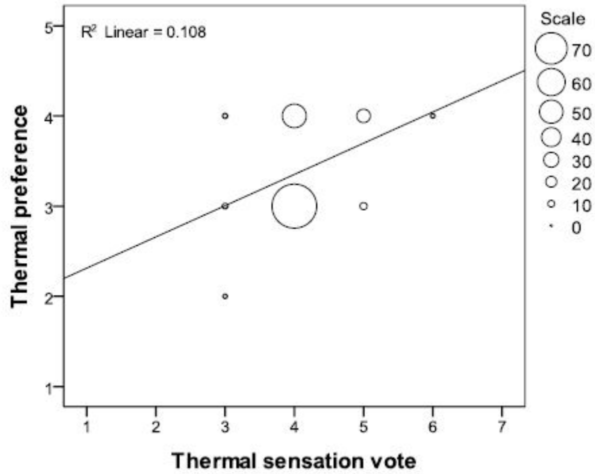

Figure 5: Relation between thermal preference vote and thermal sensation vote

Figure 5 shows that most of the respondents voted for "Neutral" thermal sensation and they preferred "No change" in thermal preference. Similarly, when occupants voted for a "Slightly hot" sensation, they preferred "4. A bit cooler" condition. The regression coefficient between thermal sensation and thermal preference is 0.34. The following regression equation from Figure 5 was obtained:

$$TP = 0.34TSV + 1.96 \ (\mathrm{N} = 121, \ \mathrm{R}^2 = 0.11, \ \mathrm{P} < 0.001) \quad (2)$$

Where TP: Thermal preference vote, TSV: Thermal sensation vote, N: number of the sample, P: significant level of regression coefficient.

The overall comfort of people in the park is shown in Figure 6. The majority of the respondents (65%) voted for "5. Comfort". 25% of the visitors voted for "4. Slightly comfort" and 9% of respondents voted for "6. Very comfort" in the park. The result shows that a high number of park visitors feel comfortable during the stay period at the park. This result was similar to Zhang et al. [19] that 82% of the respondents voted "Comfortable" in Chengdu Park during the summer season.

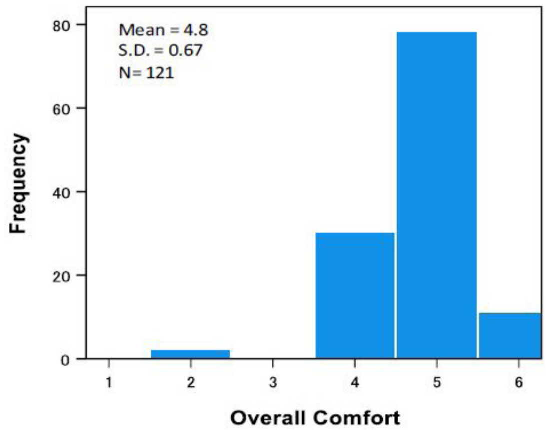

Figure 6: Distribution of overall comfort

3.3. *Prediction of Comfort Temperature*

Finding the comfort temperature is one of the objectives of this study. The linear relationship between thermal sensation votes and globe temperature was conducted to predict the comfort temperature as shown in Figure 7. The linear regression equation derived from Figure 7 is given below.

$$TSV = 0.075T_g + 1.9 \ (\mathrm{N} = 121, \ \mathrm{R}^2 = 0.06) \quad (3)$$

Where, *TSV*: Thermal sensation vote, T_g: Globe temperature (°C), N: number of samples, R^2: Coefficient of determination

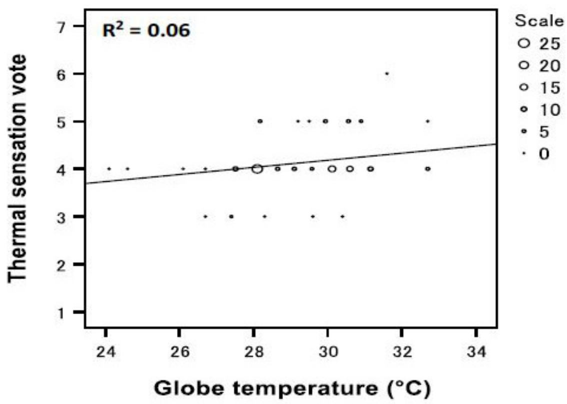

Figure 7: Relationship between thermal sensation vote and globe temperature

From equation 3 the regression coefficient is 0.075 i.e. 13.3 °C (= 1/0.075) is required to shift one thermal sensation vote. This seems to be unreliable. This could be because of insufficient data and a short period of survey. Therefore, Griffiths' method was applied to estimate the comfort temperature. This method is appropriate when there is a small number of data to calculate the comfort temperature. Griffiths' comfort temperature is calculated by the following equation.

$$T_c = T_g + (4\text{-}TSV)/\mathrm{a} \qquad (4)$$

Where, T_c: Comfort temperature (°C), a: Griffiths' constant (0.5)

For each comfort vote, Griffiths' comfort temperature was calculated. The mean comfort temperature is 29.1 °C. The result of this study has been compared with other studies in outdoor spaces as shown in Table 4. Nikolopoulou and Nikolopoulou & Lykoudis [3] found a slightly lower value of comfort temperature in Europe. Givoni et al. [21] found a comfort temperature of 29.7 °C in Israel which is similar to our study.

Table 4: Comfort temperature found in various studies for outdoor spaces

References	Country	Comfort temperature (°C)
Nikolopoulou & Lykoudis [3]	Europe	26.7
Givoni et al. [21]	Israel	29.7
Lin & Matzarakis [22]	Taiwan	27.2

4. Conclusions

An outdoor thermal comfort survey was conducted and comfort temperatures were predicted by Griffiths' method. The following conclusions can be drawn from this study.

1. The occupants are highly satisfied with the park, as most of their thermal sensation votes (78%) were "Neutral". 65% of the occupants voted "Comfort" while staying in the park.

2. The mean comfort temperature is 29.1 °C. People are well adapted to the thermal environment of the urban park, and thus the comfort temperature was significantly high in summer.

5. Acknowledgements

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6. References

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