

## Research Article

# Thermal Comfort for Urban Parks in Subtropics: Understanding Visitor's Perceptions, Behavior and Attendance

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The paper is an effort toward thermal comfort assessment for urban parks under the climatic conditions of Taiwan to help architects achieve better climatic design. Field interviews, observations, and micrometeorological measurements were conducted in this study. The WBGT was used as the thermophysiological index to investigate the effects of thermal conditions on visitor's thermal perception and adaptive behavior in outdoor urban spaces. In this study, behavioral adaptations used by visitors as a means of achieving comfort were evaluated. Observational results showed that the overall attendance was influenced by sun and thermal conditions. There was a robust relationship between thermal sensation votes, as well as thermal acceptability, and thermal environment, in terms of WBGT. The upper and lower limits of 80% acceptability are 26°C WBGT and 20°C WBGT, respectively.

## 1. Introduction

Ensuring acceptable thermal comfort conditions in outdoor spaces is always one of the considerations of landscape design, since thermal environmental conditions greatly affect individual moods and activities in the outdoors as well as the usage of the outdoor spaces. In densely populated cities, with the continuously growing emphasis on the importance of quality of life, the public attaches greater value to the quality of thermal comfort in outdoor urban spaces. At the same time, with the expansion of cities, the urban heat island effect is increasingly significant, and the trend of urban microclimate change is not optimistic. Hence, the architects or landscape designers must seriously consider the actions required for outdoor space design to support comfortable conditions. In recent years, the thermal comfort of outdoor spaces has become an important issue, attracting a considerable number of articles to analyze and discuss outdoor thermal comfort through field surveys, for example, Spagnolo and de Dear in Australia [1], Ahmed in Bangladesh [2], Nakano and Tanabe in Japan [3], Nikolopoulou and Lykoudis in European countries [4], Oliveira and Andrade [5] and Andrade et al. [6] in Portugal, Cheng et al. in Hong Kong

[7], Kariminia et al. in Iran [8], and Lin [9], Hwang et al. [10], and Lin et al. [11] in Taiwan.

Many of the research studies have generally used a thermophysiological index in outdoor thermal condition analysis. Some of the indices, for example, physiological equivalent temperature (PET), standard new effective temperature (SET\*), universal thermal climate index (UTCI), and so forth, are based on comprehensive energy-balance models for the human body to describe outdoor thermal conditions. The outdoor thermal comfort investigations conducted in Taiwan [9–12] found that the thermal comfort characteristics of a population adapted to hot and humid climate were different from residents living in temperate climates. Meanwhile, it was also found that thermo-physiological indices, based on energy-balance model, cannot fully explain subjective perceptions or preferences of people due to the impacts of their personal psychological and behavioral adjustments [12]. In addition, thermo-physiological indices based on energy-balance model are general complex in calculation and result in difficulties in application for those architects or landscape designers who are unfamiliar with energy-balance modeling. In this sense, our research question is, can simpler and directly measurable indices, which correlate well with human



FIGURE 1: Photograph of investigated Wen-Xin Park in Taichung, Taiwan.

responses and thus enable reliable predictions to be made, be used to replace such complex indicators to help architects achieve better climatic design? Thus, the objectives of this study were to select a thermo-physiological index that can be determined from simple readings to analyze outdoor thermal comfort and to discuss the relationship between the public's outdoor adaptive behaviors and the selected index.

## 2. Materials and Methods

*2.1. Description of Study Park.* This study was based on questionnaire surveys and weather measurements performed simultaneously in Taichung City, the third largest city of Taiwan (longitude 120°40'E; latitude 24°09'N), which is located in central Taiwan and has approximately 1,200,000 inhabitants. The city has a hot and humid climate, with mild winters and hot and humid summers.

The field investigations were conducted in the open area of Wen-Xin Park (see Figure 1), which is one of the three metropolitan parks in downtown Taichung City. This park is used for leisure and sport activities, such as lying, sitting, promenading, jogging, and kite flying, particularly during weekends and holidays. The surveyed area has paved sidewalks and green areas, with about 80% of the total area covered by grass. There are a few benches facing the green areas along the sidewalks; however, most people use the grass areas. The trees that provide shade are around the sidewalk in the middle of the surveyed area and cover about 20% of the area.

*2.2. Instrumentations and Microclimatic Measurements.* A combination of portable equipment, which complies with the requirements of instruments for measuring physical quantities in ISO 7726 [13], was assembled to allow monitoring of the microclimate during questionnaire interviews. Data Logger Center 314 was used to collect measurements of dry-bulb temperature, globe temperature, and relative humidity. The globe thermometer is a standard black-painted matte globe. The dry-bulb temperature and relative humidity sensor

were shielded from radiation by a highly reflective aluminized top film but were subject to free-flowing ventilation. Air speed was monitored with a separate data logger, the omnidirectional anemometers Delta HD 2103. Metabolic rate and the insulation of clothing [14] were estimated based on the answers to the questionnaire. The thermo-physiological index WBGT was calculated in order to evaluate the combined effects of atmospheric variables on thermal sensation votes (TSV). The wet-bulb temperature was obtained by substituting the measured dry-bulb temperature and relative humidity into the equations in the Chapter of Psychometrics, ASHRAE Handbook of Fundamentals [15]. Besides the measurements of condition nearby the respondents, two sets of instruments were installed in sunlit and tree-shaded area for continuous measurements on fieldwork days. Meteorological data were also obtained from a nearby local official weather station, which is located in another downtown metropolitan park about 4 km away from the study park.

*2.3. Questionnaire Interviews and Observation.* A team of three research assistants performed the questionnaire interviews and observations every fieldwork day: two of them were responsible for questionnaire interviews, and the remaining assistant for observations. The interviews were performed in Chinese and required 15 minutes to complete. The questionnaires used in this study were created by modifying those deployed in earlier studies [9–11], divided into two parts, namely, BACKGROUND and PERCEPTION.

BACKGROUND covered questions regarding demographics, current clothing garments, metabolic activities, living or working in the neighborhood of park, the reason for being in the park, and the frequency and duration of time spent in the park.

PERCEPTION had questions concerning the subject's assessment of their immediate thermal environment at that point in time. The subjects were asked to report their sensations of thermal environment through a 7-point scale and of air movement through a 5-point scale. The thermal sensation scale was the ASHRAE 7-point scale, ranging from cold (−3) to hot (+3), with neutral (0) in the middle. The subjects assessed the wind sensation on a 5-point scale: still (−2), weak (−1), moderate (0), strong (+1), and very strong (+2). The final question in the PERCEPTION part asked subjects whether, or not, they considered the weather of the fieldwork day suitable for leisure outdoor activities. The protocol for each interview was as follows: (1) two research assistants approach subject, ask if time is convenient, and present the questionnaire; (2) one of them gives the subject a brief explanation about the aim and the context of questionnaire, while the other settles the instrumentations nearby to measure thermal environmental variables; (3) subject completes questionnaire survey; (4) during the survey, a 15-minute sample of the thermal environment is made; and (5) subject leaves and the assistants seek the next subject. 60–120 subjects were surveyed daily on fieldwork days.

The number of visitors and their activities within the study area were investigated by observations on fieldwork days. Observations on each day were performed every 30

TABLE 1: Climatic characterization of fieldwork days.

Fieldwork date	Daily average values				Maximum DB temperature °C	$\Delta T_{\max}^{\dagger}$ °C
	DB °C	RH %	Wind speed m/s	Solar radiation MW/m <sup>2</sup>		
Sep. 19	27.4	74.5	1.3	1.56	31.2	-2.8
Sep. 26	28.1	76.0	1.0	1.65	32.4	-1.6
Oct. 03	28.1	75.5	1.5	1.22	30.7	-1.9
Oct. 10	28.2	71.4	0.8	1.38	32.1	-0.5
Oct. 17	27.9	69.1	1.0	1.44	32.3	-0.3
Oct. 24	27.1	73.3	1.1	1.58	30.8	-1.8
Oct. 31	21.2	61.4	2.6	1.83	26.2	-6.4
Nov. 07	24.4	77.3	2.0	1.30	28.0	-0.1
Nov. 28	21.5	68.0	0.8	1.42	26.4	-1.7
Dec. 05	23.1	67.3	1.0	1.34	28.4	0.0
Dec. 12	19.7	72.4	0.9	1.36	27.0	-1.4
Dec. 19	18.2	65.5	0.6	1.39	24.3	-4.1
Jan. 09	16.6	73.6	2.9	1.34	20.0	-2.9
Jan. 16	10.3	68.5	2.8	0.55	11.5	-11.4

<sup>†</sup>Difference between daily maximum temperature on fieldwork day and monthly maximum temperature.

minutes from 10:00 am to 5:00 pm, for a daily total of 15 observations. The numbers of people in different subspaces were observed according to the observation protocol. Field investigations were conducted on Saturday or Sunday from September 2010 to January 2011. All fieldwork days were sunny and no festival celebrations held in the park.

### 3. Results of Key Survey Questions

**3.1. Descriptions of the Weather on Fieldwork Days.** Table 1 summarizes the weather conditions on the fieldwork days. The data in Table 1 are from the local weather station. The differences between maximum air temperatures of fieldwork days and monthly maximum temperature are also shown for comparison. The mean dry-bulb temperature varies between 10.3°C and 28.2°C. Mean relative humidity and mean wind speeds are in the ranges of 61.4–77.3% and 0.6–2.9 m/s, respectively.

**3.2. Characterization of Subjects.** The fieldwork team invited 759 visitors to take part in the questionnaires. Of the questionnaire responses, 43% were from male visitors of the park and 57% were from female visitors. Of the respondents, 51% live or work in neighborhood of the park, and 49% are from other regions. The profile of subjects' age is 20% teenagers, 75% in the range of 20–50 years, and 5% older than 50 years.

The result of the question regarding how often the subjects visit this park shows 9% visit more than 10 times, 17% visit 5–10 times, and 35% visit 1–5 times per month, respectively. There are 27% of subjects seldom visiting this park and 13% visiting this park for the first time. Regarding the question "How long are you going to spend in this park?" 37% answered more than two hours, 33% answered 1–2 hours, 23% answered 0.5–1 hour, and the remaining 7% answered less than 0.5 hour. Regarding the question "For what purpose

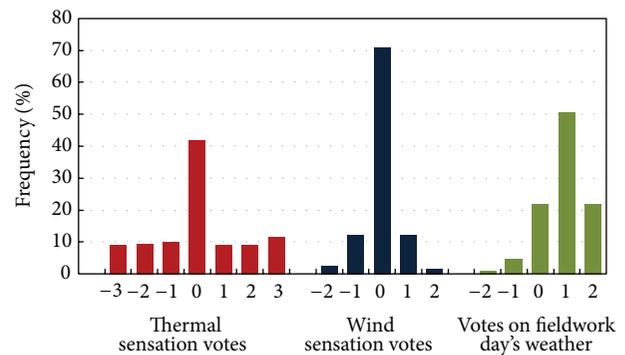


FIGURE 2

do you visit this park?" and 69% said for the special reason of sport, relaxing, or meeting other(s), 31% said for other reasons, such as being on the way to other places. Based on the results of observations, the frequency distribution of visitors' activities shows that 32% of the visitors observed were engaged in light activities, such as seating relaxed, reading, sun bathing, and picnicking; 39% were taking a walk; 16% were jogging; and 14% were playing ball, flying a Frisbee, flying a kite, and so forth. In addition, it was observed that visitors prefer to use this park after 3:00 pm, as the solar radiation at that time would not annoy them.

**3.3. Assessment of the Thermal Environment.** The subjects were asked to report their thermal and wind sensations according to a 7-point and a 5-point scale, respectively. Figure 2 shows, the relative frequency distribution for thermal sensation votes while being surveyed; 42% of the subjects felt the thermal conditions to be thermal neutral; 28% felt slightly cool, cool, and cold; and 30% felt slightly warm, warm, and hot. Figure 2 also shows the distribution for wind

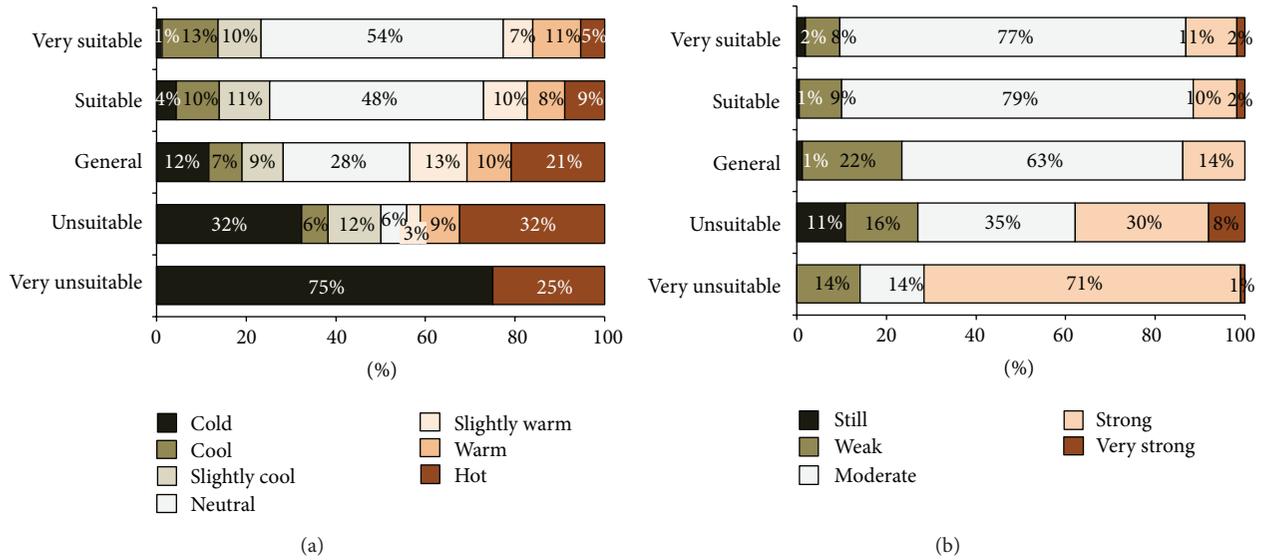


FIGURE 3: (a) Thermal sensation votes versus votes on fieldwork day's weather, (b) wind sensation votes versus votes on fieldwork day's weather.

sensation votes. In wind assessment, the majority of subjects (72%) assessed the wind conditions as being moderate; 14% as still or weak, and 14% as strong or very strong. As shown in Figure 2, the majority of subjects considered the weather of fieldwork days as suitable for outdoor leisure activities; 22% chose very suitable, 51% suitable, 22% general, 5% unsuitable, and 1% as very unsuitable.

Patterns of thermal or wind sensation votes, versus fieldwork day weather, are examined in more detail in Figure 3. As shown in Figure 3(a), when feeling the weather as suitable or very suitable for outdoor leisure activity, about 70% of subjects were also satisfied with the thermal conditions at the site, with their votes falling in the three central categories ( $TSV = -1, 0$  and  $+1$ ) of the thermal sensation scale, whereas 30% were unsatisfied by voting extreme thermal sensations ( $TSV = \pm 2, \pm 3$ ). Of the people feeling unsuitable or very unsuitable, 80% to 100% were not satisfied with the thermal conditions at the site. In Figure 3(b), the distributions of cross-examinations between wind sensation and votes on the weather fieldwork days revealed the same trend; however, when subjects felt "unsuitable" or "very unsuitable," 35% and 14% felt the wind was moderate, respectively.

## 4. Thermal Perception Analysis

**4.1. Thermal Sensation versus Thermal Environment.** The relationship between thermal sensation and thermal environment was examined using linear regressions between thermal sensation votes and the thermo-physiological index. WBGT was selected as the thermal index in this study. Provided in ISO 7243 [16], as a simplified version of  $ET^*$  for the assessment of hot environments, the WBGT for outdoor environments with solar radiation is determined from three single readings, namely, wet-bulb temperature, globe temperature, and dry bulb temperature. As explained in the introduction, the WBGT seems suitable for practical use

by those unskilled in energy-balance modeling of the human body, which is the reason this study decided to test WBGT as the basis for all subsequent analyses. The WBGT index combines temperature, humidity, radiation, and wind into a single index, which is determined as follows:

$$WBGT = 0.7 \times t_{wb} + 0.2 \times t_g + 0.1 \times t_a, \quad (1)$$

where  $t_{wb}$  is normal meteorological wet bulb temperature shown by a wet bulb thermometer;  $t_a$  is dry bulb temperature; and  $t_g$  is 150 mm diameter black globe temperature.

In the regression analysis, the mean thermal sensation votes in each temperature interval were used, rather than actual individual votes, in order to eliminate the influence of individual differences. Thus, all thermal sensation votes of the subjects were sorted in ascending order according to WBGT and are binned into  $1.0^\circ\text{C}$  intervals of WBGT. The  $R^2$  of the model can be interpreted as an index of goodness of fit. The regression of the mean thermal sensation vote against WBGT is shown in Figure 4. Thermal sensation votes correlate strongly with WBGT; thus, the WBGT index is considered by this study as a suitable index without elaborate procedures of calculations.

**4.2. Thermal Acceptability.** Generally, the votes equal to "slightly cool," "neutral," and "slightly warm" are considered to be of those who consider the thermal conditions surrounding them acceptable. Thus, for each  $1^\circ\text{C}$  interval of the WBGT, the percentage of thermal acceptability could be determined from counting the total number of votes and the number of votes falling into the three categories of "slightly cool," "neutral," and "slightly warm." Figure 5 shows the histogram of the distribution of the acceptable votes as well as the percentage of unacceptability, due to coldness or hotness. The percentage of hot unacceptability in each interval of the WBGT is derived from dividing the number of votes falling into the categories of "warm" and "hot" by the total

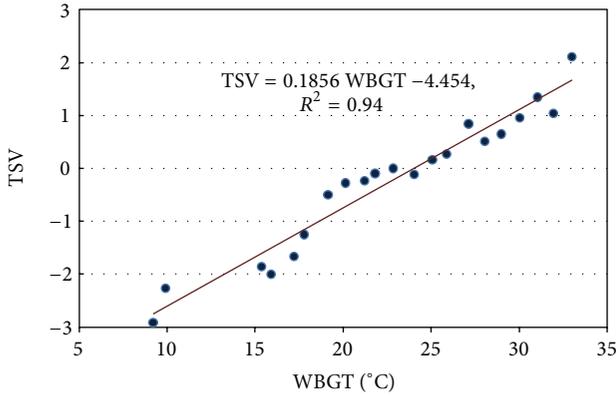


FIGURE 4

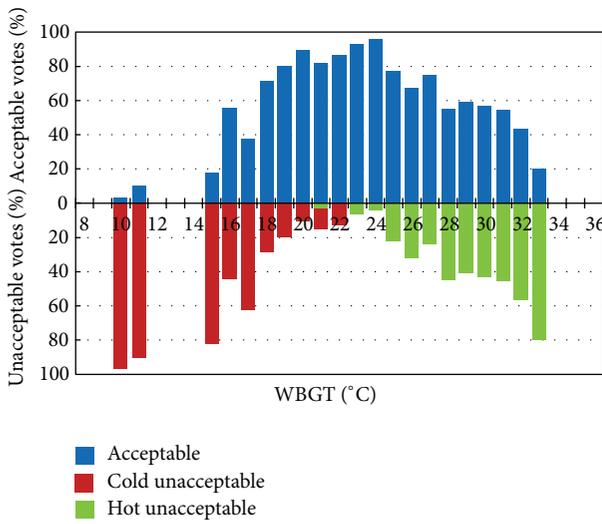


FIGURE 5

number of votes, while the percentage of cold unacceptability is derived from dividing the number of votes falling into the categories of “cool” and “cold” by the total number of votes. It appears that the distribution of thermal acceptability rate and the distribution of thermal unacceptability rate depend on WBGT.

The sigmoid distribution of unacceptability rates due to hotness or coldness suggests that the resulting percentages within each interval could be subjected to the probit analysis [17, 18]. The resulting models are depicted in Figure 6. The maximum likelihood probit models for the percentages of unacceptability due hotness and coldness are given in (2) and (3), respectively.

For hotness,

$$\text{probit } p_{\text{hot}} = 4.38 \times \text{WBGT} + 29.2R^2 = 0.89. \quad (2)$$

For coldness,

$$\text{probit } p_{\text{cold}} = -4.11 \times \text{WBGT} + 16.6R^2 = 0.93. \quad (3)$$

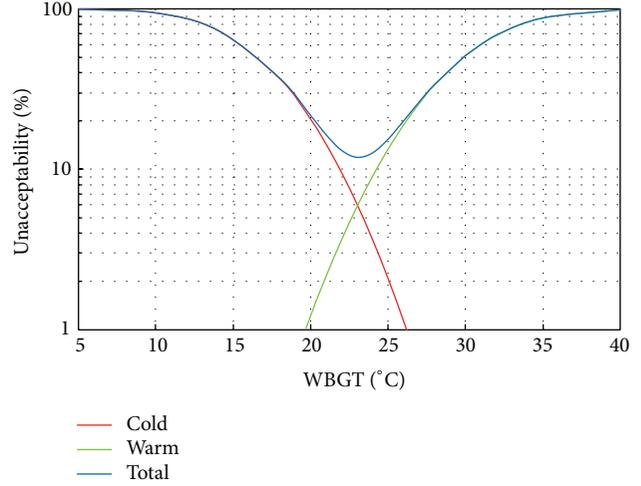


FIGURE 6

Then, the sum of the probabilities of unacceptability due to hotness and coldness is the total percentage of unacceptability, with respect to a specific WBGT. By inspecting the curve of total unacceptability, it can be noticed that the distribution of thermal unacceptability is approximately symmetrical around the ideal comfort temperature. For WBGT between 20°C and 26.0°C, there are less than 20% of subjects voting unacceptable, that is, more than 80% of subjects voting acceptable. An ideal comfort condition, at which the minimum value of thermal unacceptability occurs, is at the point of 23.2°C WBGT.

## 5. Behavioral Adaptation

According to the adaptive principle, “If a change occurs, and produces discomfort, people react in ways that tend to restore their comfort” [19]. For the case of this study, the behavioral adaptations of clothing adjustments and metabolic rates were evaluated. The air velocity and attendance of visitors were used as means to measure the methods subjects used to achieve comfort.

**5.1. Clothing Level.** Adjusting clothing is the most important personal behavioral adaptation to restore thermal comfort at different temperatures. By plotting the value of clothing insulation worn by the subjects, it is easy to determine the correlation between the clo value and the outdoor thermal condition. Figure 7 shows how the clo value varies among the fieldwork days. The scattered clo value was observed from a minimum of 0.3 clo on hot days to a maximum of 1.5 clo on cold days. The regression in (4) shows that the correlation between average clothing insulation and average WBGT on a fieldwork days is robust:

$$\text{clo} = -0.039 \times \text{WBGT} + 1.54R^2 = 0.96. \quad (4)$$

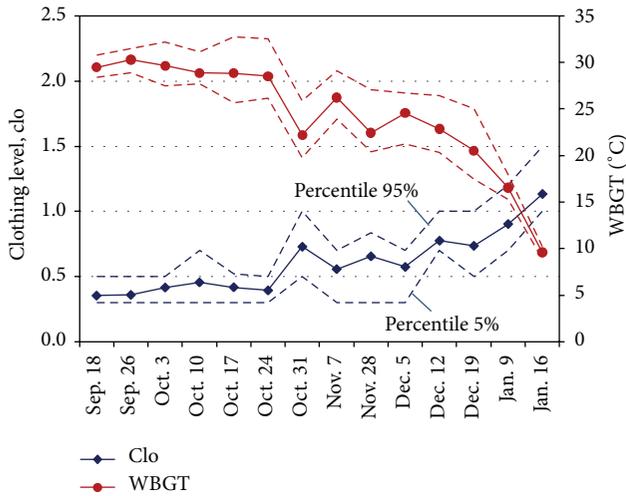


FIGURE 7

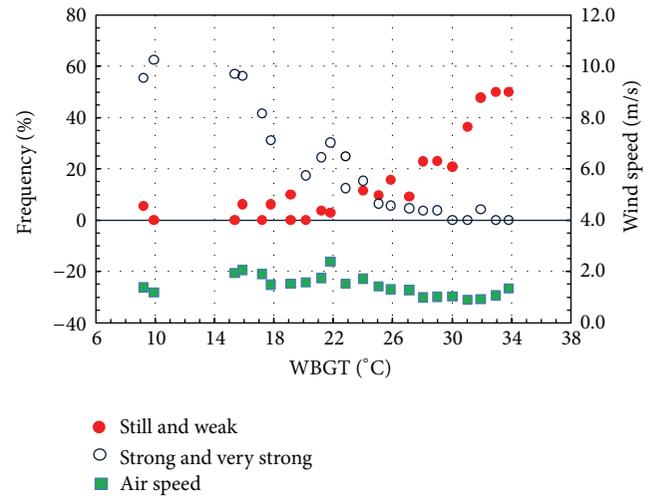


FIGURE 9

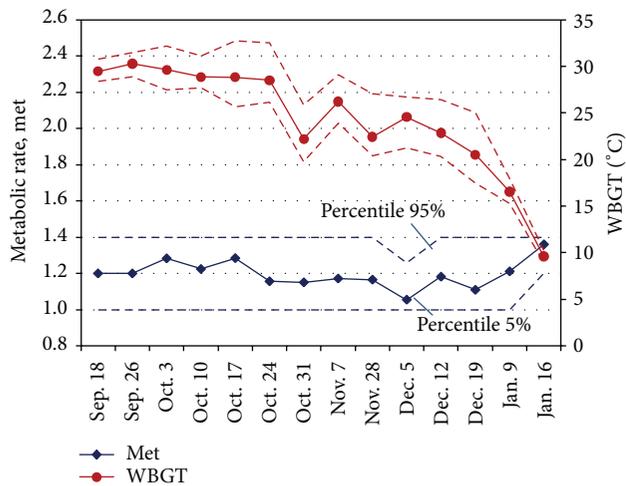


FIGURE 8

A similar regression was conducted between the clothing and the instantaneous WBGT during interviews. The linear regression gives

$$\text{clo} = -0.031 \times \text{WBGT} + 1.50R^2 = 0.93. \quad (5)$$

Results from the field studies demonstrate that individuals use changes in clothing levels to try and achieve comfort and that a correlation exists between the clothing and the WBGT.

**5.2. Activity Level.** The plot of the activity levels of visitors on fieldwork days shows that the corresponding metabolic rate is nearly horizontal, between 1.0 and 1.5 met, Figure 8. This indicates that the visitor's activity level is independent of the value of the WBGT.

**5.3. Air Movement.** Figure 9 shows the average wind speed and percentage of wind sensation votes in “still” and “weak”

categories or “strong” and “very strong” categories as a function of WBGT. In warmer-than-neutral conditions ( $\text{WBGT} \geq 24.0^\circ\text{C}$ ), the percentage of subjects feeling the wind speed to be “still” or “weak” increases dramatically from 10% at  $24.0^\circ\text{C}$  WBGT to 52% at  $34.0^\circ\text{C}$  WBGT, even though the mean air speed varies in a narrow range of 0.9–1.5 m/s. A possible explanation is that subjects who exposed to high WBGT perceived the wind to be weak based on their experience that lower wind speed may contribute to hot condition. That is, they think stronger wind may release their uncomfortable feeling so they might vote the wind speed as “still” and “weak” to reflect their subconscious uncomfortable perception. The sharp rise in wind discomfort votes without a significant change in wind speed and in accordance with the respective thermal conditions indicates that wind is actually perceived as a component of the thermal environment rather than as a separate environmental factor. It should be noted that the wind speed measured in this park is not strong due to the high density urban forms in Taiwan and tall buildings surrounding. The subjects may express a reasonable perception equivalent to actual wind speed once the wind speed is relatively high (e.g.,  $>10$  m/s).

**5.4. Avoidance of the Sun.** Thorsson et al. [20] conducted a fieldwork study in Japan, where the ideal beauty is fair skin, and found that 80% of the visitors in the urban public places sought shade at temperatures higher than  $20^\circ\text{C}$ . A counterpart study done in Sweden [21], where the ideal beauty includes a suntan, showed that only 14% of park visitors sought shade at temperatures higher than  $20^\circ\text{C}$ . With respect to attitudes toward the sun, this study demonstrates the relationship between the thermal environment, in terms of the temperature difference ( $t_g - t_a$ ) between globe temperature and dry-bulb temperature, and the usage as shown Figure 10. Rather than the percentage of visitors in shade, total attendance is used in Figure 10, which results from the limited amount of shade in the park. As shown in Figure 10, the maximum of people in the park was observed at a situation

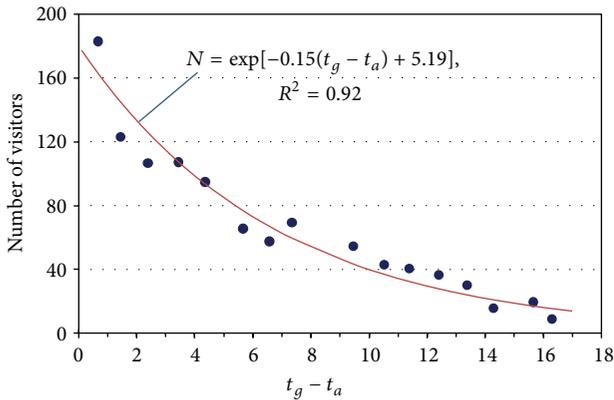


FIGURE 10

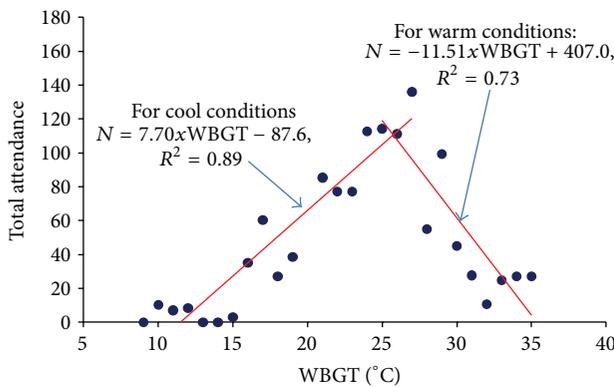


FIGURE 11

where the temperature difference was less than  $1.0^{\circ}\text{C}$ . As the  $t_g - t_a$  increases, the total attendance presents an exponential decay. The best-fitted regression equation is superposed in Figure 10. The  $R^2 = 0.92$  indicates a robust relation exists. This demonstrates that strong solar radiation intensity result in people in Taiwan, where the ideal beauty is also fair skin, tends to avoid the sun to a notable extent.

**5.5. Relation between Total Attendance and Thermal Conditions.** Figure 11 shows the relation between thermal environments in terms of WBGT and the average total attendance. This distribution of total attendance against WBGT is a single peak model. When the park's thermal condition is moderate, there are more than 120 people remaining in the study area of the park, and the total attendance in the park decreases considerably, to a level of less than 20 people staying in the study area. The number of people decreases more rapidly with WBGT in hot conditions than in cool conditions. Linear regression analysis is used to fit the relation between thermal conditions and total attendance, as shown in Figure 11. The relation is found to be significant, which indicates that the more comfortable the perceived thermal environment is, the higher the usage rate of the park will be.

## 6. Conclusions

Urban outdoor thermal environmental evaluation is of great significance in guiding the public's outdoor activities, the design of comfortable outdoor environments, and the improvement of urban climate. Based on the data from field surveys, this study used the WBGT as the thermo-physiological index to analyze outdoor thermal comfort. The major achievements of this study are as follows.

According to the respondents' thermal perceptions, WBGT, as an index of the outdoor thermal conditions, has statistical significance relationship with the thermal perception of the respondents. This suggested the reliability of its application for analyzing outdoor thermal comfort. According to that relationship, the lower and upper limits of comfort acceptability for 80% of acceptability were  $20^{\circ}\text{C}$  WBGT and  $26^{\circ}\text{C}$  WBGT. This study also found that the temperature, corresponding to the lowest thermal unacceptable value, is  $23.2^{\circ}\text{C}$  WBGT.

The results regarding the adjustment behaviors and thermal environments suggested that the amount of clothing was significantly correlated to WBGT. However, the activity was not significantly correlated to WBGT. When the WBGT increases, expectations for high wind speed rise rapidly. When the WBGT decreases, expectations for low wind speed rise rapidly. The research found that Taiwan's residents had the apparent characteristics of avoiding sunlight. With rising or falling of WBGT, the number of visitors in the park would decline accordingly. The WBGT range of most visitors was approximately consistent with the outdoor thermal comfortable zone.

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