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Research Article

Investigating Thermal Comfort and User Behaviors in Outdoor Spaces: A Seasonal and Spatial Perspective

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Numerous studies have examined the correlation between the number of attendants in a given outdoor environment and thermal indices to understand how the environmental planning has an impact on the users. However, extensive observations should be conducted to examine the detailed static and dynamic behavior patterns of users. We conducted dynamic observations at a stepped plaza to perform on-site measurements of the physical environment and observations of users behaviors, including their resting positions, movements, and stay durations. The results indicated that more people rested on the steps during the cool season than hot season. Compared to neutral temperatures, people demonstrated higher heat tolerance to the hot season. The results indicated that more than 75% of users preferred to remain in shaded areas and stayed longer than in the sunlight. The people tended to engage in static activities in environments that exhibit sufficient shading. The shaded areas were conducive to static activities as the summer grew hotter. The results verified that the people of Taiwan would avoid sunlight and desire shaded spaces based on their previous climate experiences and expectations, which can serve as a reference for outdoor space design to improve the usability and quality of open urban spaces.

1. Introduction

Requiring leisure and recreation space, people in urban environments use public outdoor spaces, such as parks and plazas, for their activities; this directly exposes them to the external climate. Thermal comfort, which is governed by temperature, humidity, wind speed, and radiation, closely relates to perceptions and preferences towards the way people use outdoor spaces. Because the success of a public space can be judged by the number of people using it [1], numerous studies have examined the number of people using specific spaces and how this variable relates to the thermal indices of the environment. Such studies have investigated locations in diverse countries and climate zones, such as Canada [2], UK [3], Sweden [4, 5], Japan [6], Taiwan [7, 8], Greece [9], Hungary [10], and Netherland [11]. These findings indicate a significant relation between the number of people using a space and the thermal environment of that space, depending on the climate conditions.

Studies have analyzed and compared the numbers of people and the thermal environments in locations that exhibit distinct spatial patterns (e.g., various degrees of shading) within a surveyed area. The results indicate that environmental design, for example, shading levels, would influence the thermal environments and the number of people gathering in outdoors [12, 13].

However, the number of people using a space alone cannot detail how that space is being used. Therefore, detailed observations should be conducted to examine user behavioral patterns and describe how the thermal environment affects space usage. These observations assess the personal attributes of users (e.g., age, sex, purpose, and clothing), their resting positions (in the shaded or unshaded area), staying characteristics (location selection, movement, and stay duration), and behavior patterns (e.g., reading, discussing, or resting).

To obtain detailed information regarding users' behavior patterns for verifying the relation between behavior and the thermal environment, researchers must firstly determine appropriate observation methods and select an appropriate site. Regarding observational methods, similar studies in the past focused on numbers of attendants and the distributions of their locations. Therefore, researchers typically use visual methods to count the number of attendants and record their locations by using static photographs as supplementary information sources during analyzing.

However, to document users' behavior patterns in detail, long-term observation is needed. It is often done by means of scrutinizing continuous dynamic images filming from video camera. For example, Gómez-Martín and Martínez-Ibarra [14] used webcams to observe the number of people on beaches, employing quantitative visual estimation to determine the number and the density of people at various regions and timeframes. In their study, only users' location distribution and the density were analyzed due to the limitation of webcam's footage resolution; therefore, the behavior patterns of users were not assessed. Regarding the site selection, actual measurements must be conducted in spaces that are able to demonstrate diversifying thermal environments to further analyse the association between the thermal environment and the user behavior patterns. When using dynamic video recording, the locations of positioning recording device should be carefully selected to ensure that an unobstructed full view of the space is captured.

Digital video camera was used for dynamic observations toward a stepped square situated at the outdoor public recreational garden of National Museum of Natural Science (NMNS) in Taichung City, Taiwan. The chosen square exhibits diversifying thermal environments, which is partially shrouded by various thicknesses of tree canopies and partially sky open, and is considered an ideal place to perform on-site thermal measurements and observations. The objectives of this study are as follows:

(a) to observe the number of space users during various seasons and determine the histogram of the number of users against various temperature ranges;

(b) to investigate the user's prior selection of activity locations and the amount of time that people remained at their chosen locations;

(c) to analyze the relation between the thermal environment characteristics and the user behavior patterns.

The findings elucidated space use behaviors in response to thermal environments, which would help facilitate decision determining of outdoor space planning and design in the future.

2. Methods

2.1. Observational Subjects. As previously mentioned, the observation location requires a varied thermal environment that comprises unobstructed observation spots for placing video camera to elucidate how microclimates would influence the usage of recreation spaces, thermal comfort, and adaptive behaviors. Therefore, a stepped plaza at the outdoor garden of the NMNS was chosen for long-term observation. Figure 1 shows that the stepped plaza is located at 24°08′ N, 120°40′ E with an altitude of 26 m. The area is approximately 12.5 m in width, 4 m in depth, and the observational height range of the space is approximately 2.7 m. The area comprises four levels of steps. A lawn is positioned at the front of the steps with the two sides being turf and shading trees. The primary users of the space arrive after visiting the museum or attend the NMNS park for walking or resting. Most people remain in the plaza for less than 30 minutes. People use the plaza with various behaviors, including movements, talking, and reading.

Taichung City exhibits a hot and humid climate. The average observed climate data from 1991–2010 recorded by the Central Weather Bureau of Taiwan indicated that the monthly mean air temperature is highest in July at 28.5°C and lowest in January at 16.2°C. Furthermore, the mean monthly relative humidity is held constantly around 80% all the year, suggesting a humid climate. Since cool air temperature only exists from December to February, this research defines this period as the "cool season" and the remaining months (March to November) as the "hot season," which is in accordance with the definition of previous local studies [7, 12, 15, 16].

2.2. Shading Characteristics of the Stepped Plaza. The shading characteristics of an outdoor space would affect the thermal environment [15, 16]. Therefore, the shading characteristics of the evaluated stepped plaza must be quantitatively described. Because trees are mainly located at the south and north sides of the steps, the degree of shade varies along the steps. The sky view factor (SVF) was introduced herein to represent the shading level in an outdoor environment. The SVF can be defined as the percentage of free sky at specific location with the value ranging from totally obstructed (SVF = 0) to totally free spaces (SVF = 1) [17, 18].

A small SVF value indicates that a high amount of shade is present and the range of the visible sky is limited. Figure 2 shows fisheye photos shot in cool season 15:00 of the external appearance of the stepped plaza and the 10 corresponding positions. The SVF distribution ranged from position B1, which exhibited a high level of shade (SVF = 0.09), to A4, which was relatively open (SVF = 0.57). This indicates that various locations within the stepped plaza demonstrated distinct levels of solar insolation depending on the season, and the plaza exhibited varying thermal environmental characteristics. The SVF values of each location are similar whether in hot or cool season due to the surrounding evergreen trees planted in the stepped plaza.

2.3. Data Obtainment. Thermal environment measurements and user behavior observations were performed simultaneously. Physical quantities of microclimatic parameters measurements including the air temperature, relative humidity, globe temperature, and wind speed were measured with two identical sets of instruments with which one was placed

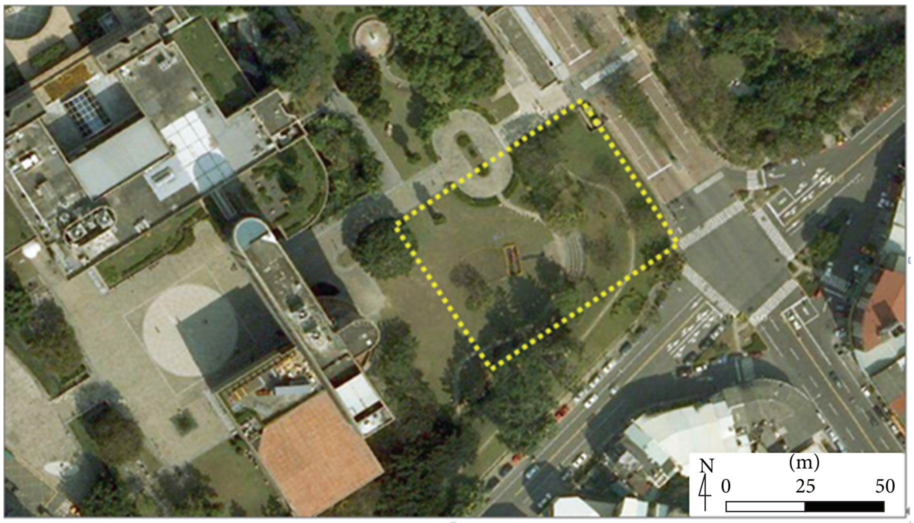


Figure 1: Aerial photograph of the NMNS location.

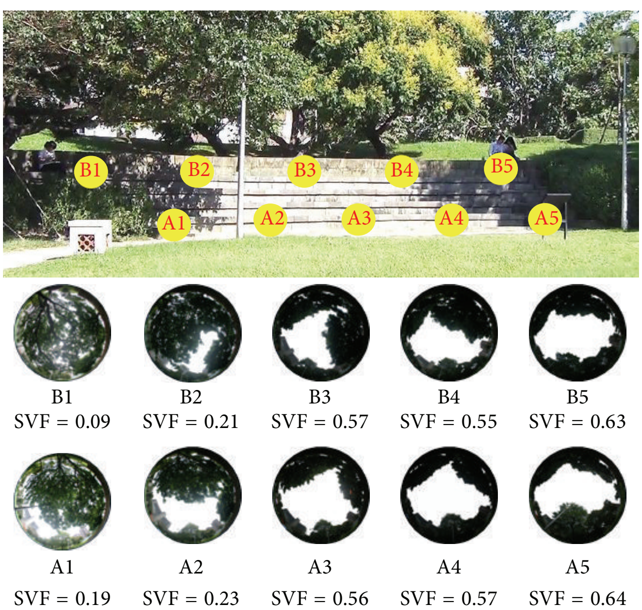


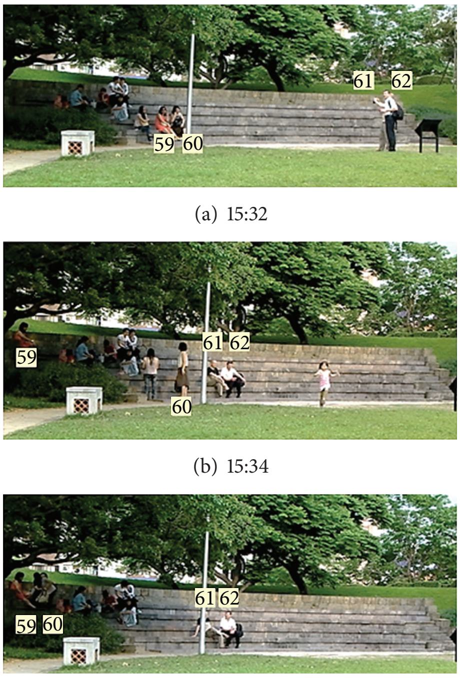
Figure 2: Panorama of the steps and fisheye diagrams of the measuring points. (Cool season 15:00).

under the tree shaded area and the other was placed totally unshaded as counterpart. A location with a dense tree canopy was considered a "shaded" location, whereas a location without shading from nearby buildings or trees was considered as an "unshaded" location. The resolution and accuracy of the instruments for each parameter are 0.1°C and ±0.3°C for air temperature and globe temperature, 0.1% and ±2.5% for relative humidity, and 0.01 m/s and ±0.2 m/s for wind speed. Both instruments were mounted on tripods that were 1.1 m above the ground and the parameters were automatically recorded once per minute from 1400 to 1700 hours simultaneously on the day the instruments were deployed.

The shaded and unshaded locations where the two sets of instruments were placed would vary day by day according to the position of the sun, resulting in various degrees of shading levels for each duration of time, and are dependent on seasons. The "shaded" and "unshaded" locations were not fixed and could vary according to the sun's movement. Nevertheless, the sunlight in the "shaded" locations by definition must be fully blocked, whereas the "unshaded" locations must be exposed to direct sunlight at all times without obstructions. The method of selecting shaded and unshaded measurement locations was similar to that used in a previous park study in Taiwan [12]. The hourly meteorological observations, such as the wind direction, horizontal solar insolation, and the amount of cloud, were obtained from the nearby Taichung Park weather station.

To record the basic characteristics and behaviors of users in the observation area, a high-resolution digital video camera was deployed approximately 25 m away from the steps and 1 m above ground to conduct nonstop snapshots. The time of appearance and departure, movements, and adaptive behaviors of the users were documented by scrutinizing the recorded footage. Although children were present in the observation area, we did not include them in the analysis because their activities/behaviors would possibly be restricted by their guarding parents.

2.4. Thermal Comfort Index Calculation. This study applied physiologically equivalent temperature (PET) to evaluate the thermal environment objectively. PET is defined as the air temperature at which, in a typical indoor setting (air temperature = mean radiant temperature; vapor pressure = 12 hPa; wind velocity = 0.1 m/s), the heat budget of the human body is in equilibrium, with the same core and skin temperatures as those under complex outdoor conditions [19–21]. To calculate PET, this study adopted the RayMan model [22, 23]. The value of mean radiant temperature was calculated from the measured globe temperature using formulas proposed by ISO



(a) 15:32

(b) 15:34

(c) 15:35

Figure 3: Image sample from the video.

standard 7726 [24] initially and subsequently corrected by the parallel measurements of both the globe thermometer and the six-direction short- and long-wave radiation flux measurement system previously conducted in Taiwan [25].

2.5. Video Image Interpretation and Encoding. To establish an observation record table for facilitating analysis, the dynamic digital image recordings were interpreted and encoded. First, we encoded the observed subjects, assigning a number to each individual (e.g., 001 and 002). Second, we visually interpreted the basic characteristics (gender, age, number of companions, and amount of wearing clothing) and behavioral characteristics of the subjects (primary activity, choice of sunny or shaded area, number of people within an area, the amount of time between arriving to and departing from an area, total time spent within an area, and other thermal related adaptive behaviors) to facilitate subsequent quantitative statistical analyses. One specific researcher interpreted all the images to ensure consistency. Finally, we linked the thermal environmental measurements (each physical parameter and the integrated thermal comfort index PET) to each of subjects, establishing a complete database containing records of the subject codes, basic and behavioral characteristics, and thermal environmental parameters.

An example of how the video image is interpreted and encoded is expounded as follows. Figure 3 shows that subjects numbers 59–62 formed a four-member group. Their staying and moving patterns can be divided into three periods. (a) Subjects numbers 59 and 60 were women; at 15:32, they walked into the semishaded area on the left side of the steps and sat down. Subjects numbers 61 and 62 were men; they stood and talked on the lawn approximately 2 m from the stairs. (b) After 2 min, at 15:34, subjects numbers 61 and 62 walked to the steps and sat in the sunlight. At the same time, subjects numbers 59 and 60 stood up and considered sitting in a position covered by dense shade. (c) After 1 min, at 15:35, subjects numbers 59 and 60 moved toward the shade and sat. Subjects numbers 61 and 62 remained sitting and talking in their original position.

In this way, we were able to track the users through each image footage, enabling us to establish a complete database of the association between user behavioral characteristics and the thermal environment to facilitate subsequent analyses.

2.6. Measurement Process. This study performed a total of 19 measurements and observations from April of 2012 to February of 2013. All measurements were conducted between 13:00 and 18:00 on Saturday or Sunday, which is the most visited period for local users. The observation days were divided into two seasons, hot seasons (March to November) and cool seasons (December to February), based on Taiwan's climate characteristics, as stated in Section 2.1.

To prevent the observation from influencing users' behavior, we carefully installed the instruments in inconspicuous locations instead of intervening in the user activities by conducting questionnaires or interviews. Before the measurements were conducted, the consent from the NMNS authority was acquired. The privacy of the filmed people during identification, analysis, and processing was also ensured.

3. Results

3.1. Number of Users. As the number of users is the most basic information regarding the space use, the number of subjects accompanied with their corresponding PET thermal index measurements from the 19 observations was illustrated. The mean air temperature was 32.9°C during the hot season and 24.1°C during the cool season. The mean radiant temperature was 39.6°C during the hot season and 30.6°C during the cool season. The PET was 36.7°C during the hot season and 27.1°C during the cool season. The relation between PET and the number of participants is shown in Figure 4. In June and July (hot season), the PET was as high as approximately 45°C, and the number of users was consistently less than 10. In November and December (cool season), the PET decreased to approximately 20°C and the number of users was as high as 59. This indicates that, during the hot season, the number of users decreased as the PET increased. During the cool season, the number of users increased as the temperature increased. These data are consistent with the results of similar study previously conducted in Taiwan, addressing the relation between the thermal comfort range and number of users. As Taiwan is located in a subtropical hot-and-humid climate zone, the temperatures during the hot season are inversely proportional to the number of plaza users [7].

To elucidate the relation between the use of the stepped plaza and the PET variation in outdoor thermal environment, the number of users observed from all 19 observations was lumped and grouped against each PET range based on

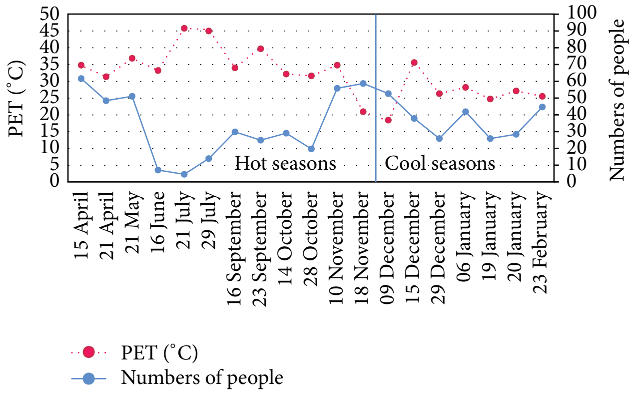


Figure 4: Relation between the PET and number of participants.

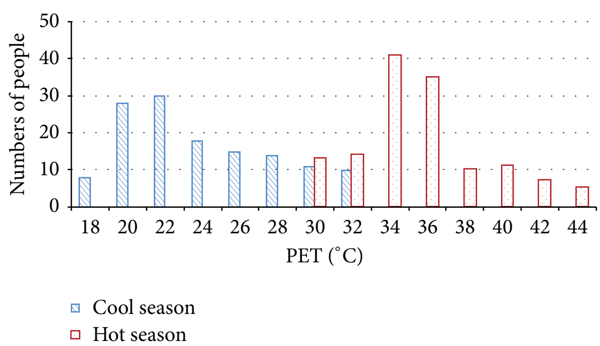


Figure 5: Relation between the annual PET and mean number of participants.

a temperature increment of 2°C PET, as illustrated in Figure 5. During the hot season, the results indicate that the mean number of space users was the highest (41 people) when the PET was 34°C. The number of people decreased as temperatures increased, and only 5 users were present when the PET reached 44°C. During the cool season, the mean number of space users was the highest (30 people) when the PET was 22°C. The number of people decreased to 10 as temperature increased.

3.2. Location Selection and Movement. When engaging in outdoor activities, people choose a staying location based on their past experiences of the current or a similar location/space from thermal perspective. When people feel thermally dissatisfied with their first location choice, they may move. These choices may be closely associated with microclimate perception, experiences, and expectations. For example, Kántor and Unger [10] examined microclimate perception regarding plazas in Netherlands; the results indicated that people do not go to a location only after determining that the climate is suitable. Instead, they use their past experiences and awareness to judge the current environment and decide. For example, when users observe shade under trees, they may speculate that the shaded area is cooler based on their past experiences and move to this location. Therefore, first choices of location are psychological representations of environmental experiences. Subsequent movements are responses caused by the combination of physiological exposure and psychological expectations. In other words, people exhibit appropriate adaptive behaviors based on their microclimate expectations and preferences, in addition to changes in physiological heat balance caused by exposure to the microclimate. Thus, people move to other locations because their perceptions of the heat level differ from their psychological experiences and expectations.

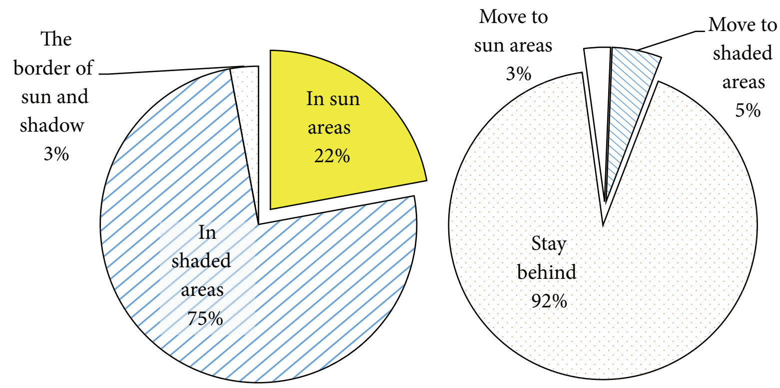
To explore this phenomenon, we recorded the first locations chosen by users when interpreting and encoding the images. These locations reflected differences in the thermal environment, comprising (a) sunny areas, (b) shaded areas, and (c) boundaries between the two. The time at which users arrived at and departed from these locations was recorded. The location types and the arrival and departure time for the first and second movements of users were also recorded in the same fashion. Thus, the stay duration for each location type of every user movement could be calculated and recorded.

This section addresses staying and moving location types (the stay duration is addressed in Section 3.3). We calculated the number and percentage of people who stayed in various types of locations (sunny area, shaded area, and the boundary area between the two) within the stepped plaza during the hot and cool seasons (Figure 6). During the hot season, 74% of users first chose shaded areas, whereas 22% first chose sunny areas. Subsequently, 5% moved to shaded areas and 3% moved to sunny areas, indicating that most people first chose shaded areas as resting locations during the hot season. Only a minority selected sunny areas as their resting locations. Most who initially chose shaded areas remained in their original locations, whereas some who firstly chose sunny areas moved to shaded areas.

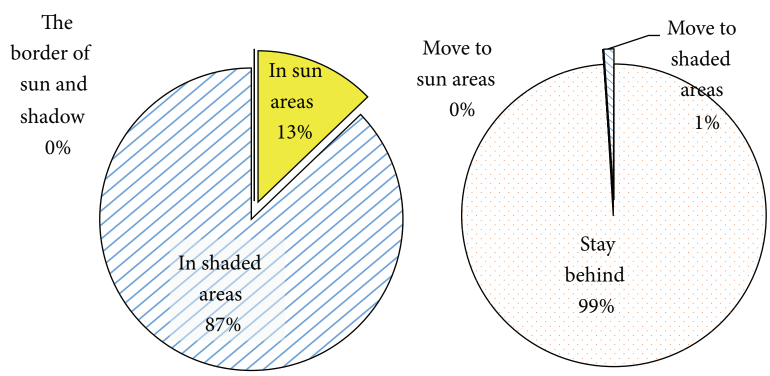
During the cool season, 87% of users first selected shaded areas, whereas 13% selected sunny areas. Subsequently, 1% moved to shaded areas and none moved to sunny areas, indicating that most people initially chose shaded areas for resting during the cool season. Likewise in hot seasons, only a minority selected sunny areas for resting. In a statistics regarding the second movement, 99% of people stayed in their original positions and only 1% moved to shaded areas.

In both the hot and cool seasons, users tended to select shaded areas as their first choices. This indicates that people prefer to engage in outdoor leisure activities in areas containing shade-providing trees or canopies, avoiding direct exposure to intense solar irradiance. As previously described, most people perceived that shaded areas would exhibit relatively low temperatures based on their past experiences and expectations and considered these places would be more comfortable. As a result, most people preferred engaging in activities in shaded areas. Few people had made their second movement, indicating that few people were affected by increased physiological heat loads. Thus, people relied on their experiences, expectations, and other psychological factors rather than on physiological factors when displaying thermal adaptive behaviors.

3.3. Stay Duration. The amount of time that users spend on activities in outdoor spaces can reflect their satisfaction



(a) Hot season



(b) Cool season

FIGURE 6: User choices of resting locations and movements during the hot and cool seasons.

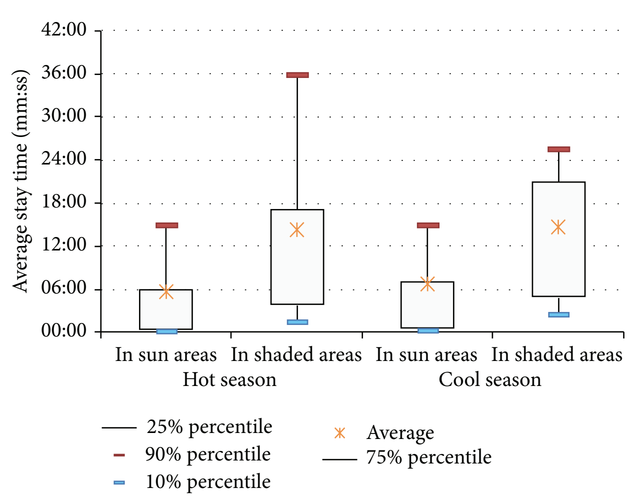


FIGURE 7: User time spent in sunny and shaded areas during the cool and hot seasons.

with the environment. When encoding the images, we recorded the location types, arrival and departure time for the first location choices, and the subsequent movements. This enabled calculating the amount of time users spent in sunny and shaded areas. The box plot shown in Figure 7 reveals the distribution of the duration that users spent in sunny and shaded areas, and the differences between the two. The results indicate that the mean stay duration during the hot season was 5 min, 41 s in sunny areas and 14 min, 18 s in shaded areas. During the cool season, the mean stay duration was 6 min, 45 s in sunny areas and 14 min, 41 s in shaded areas.

Figure 7 apparently indicates that the stay duration was longer in shaded areas than it was in sunny areas during both seasons. Despite the low air temperatures during the cool season, people did not move to sunny areas for enhancing their thermal comfort but rather tended to avoid solar insolation, showing a likewise preference for shaded and cool areas as in hot seasons. The classical physiological thermal balance failed to explain these behavioral patterns.

It is worthy to mention that the 90th percentile of stay duration in shaded areas was 35 min, 55 s during the summer. Few users spent approximately half an hour, which is longer than that in the cool season, in shaded areas during the hot season. It suggests that users would be willing to increase their stay duration in open spaces if shaded recreation areas were provided in hot outdoor environments.

To elaborate the variations in stay duration under various thermal comfort conditions, cases observed in the hot season were used as an example to calculate changes in mean stay durations under sunny and shaded areas at fixed intervals against the PET thermal comfort index (e.g., 2°C PET). Figure 8 shows that users in shaded areas stayed longest (17 min 7 s) when the PET was 31°C. The stay duration

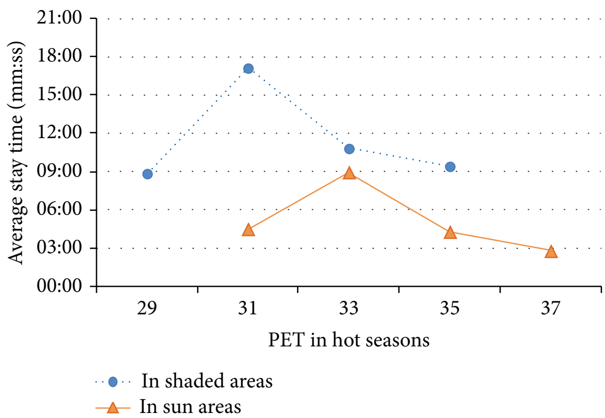


FIGURE 8: Changes in the mean user time spent in sunny and shaded areas during the hot and cool seasons.

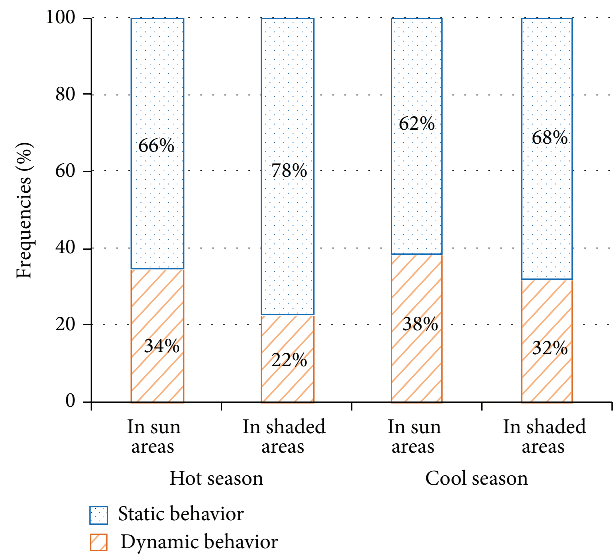


FIGURE 9: Ratio of dynamic to static behaviors in the sunny and shaded areas during the cool and hot seasons.

decreased as temperatures increased or decreased. Users in sunny areas stayed longest when the PET was 33°C, but it still exhibits lower stay duration in comparison to shaded areas in all PET ranges. Moreover, the association between temperature changes and stay duration in the sunny areas had similar variation trend to that in the shaded areas. The temperature at which people stayed longest in the shaded areas (31°C PET) was lower compared with that of the sunny areas (33°C PET) because people hoped for decreased temperatures based on their expectations of thermal comfort in shaded environments.

3.4. Behavior Patterns. To some extent, behavioral patterns indirectly reflect how users interact with microclimate environments. A previous study of microclimate and the exploratory behaviors of lions and tigers in zoos [26] recorded the activity patterns of animals, dividing animal behaviors into two categories: comfort (e.g., lying down, sitting, and being in water) and movement behaviors (e.g., standing, walking, and running). Similarly, in the current study, we observed the detailed behaviors of users from the images, dividing them into static (e.g., sitting, talking, eating and drinking, and reading) and dynamic behaviors (e.g., standing and walking). The frequencies of static and dynamic behaviors were calculated based on the season (hot and cool) and location (sunny and shaded areas). It is assumed that a high frequency of static activity indicated that people felt stable and comfortable. To some degree, this indicates that the microclimate of the environment is considered comfortable.

Figure 9 indicates that, during both seasons, more users engaged in static behaviors compared with dynamic behaviors in the stepped plaza. During the hot season, more users adopted static behaviors than in the cool season. The primary reason for this is that metabolic rates are decreased when sitting compared with standing or walking [27]. In the attached table from the American Society of Heating, Refrigerating, and Air-Conditioning Engineers [28], metabolic rates were approximately 60 W/m^2 when sitting and reading and approximately 80–100 W/m^2 when standing or slow walking. Therefore, people tend to adopt static activities during the hot season, producing decreased metabolic heat inside the body to increase comfort.

Comparing behavior patterns in spaces that demonstrate varied shade indicates that users in sunny areas were more likely to adopt dynamic behaviors than users in shaded areas were. This can be explained based on the stay durations addressed in the previous section. Figures 7 and 8 indicate that users stayed in sunny areas for less duration than they stayed in shaded areas. In other words, compared with people in shaded areas, those in sunny areas were more likely to adopt dynamic behaviors such as leaving the plaza or moving to locations. By contrast, when people were in shaded areas that provided relatively comfortable thermal environments, their calm moods facilitated adopting static activities, such as sitting, talking, and reading.

4. Discussion: Verification through Thermal Adaptation Theory

To provide an objective discussion of the association between user behaviors and the environment, thermal comfort theory and previous investigations are referenced to describe and verify the close relation between the behavior and the thermal environment.

4.1. Thermal Adaptation Theory. The ASHRAE defined thermal comfort as "a state of mind expressing satisfaction toward the thermal environment (temperature, humidity, wind speed, and radiation) assessed through subjective evaluation" [28]. In the field of thermal comfort, scholars have attempted to combine temperature, humidity, wind speed, radiation, amount of clothing, and metabolic rates to represent thermal comfort as a single index. The ASHRAE guidelines highlight that thermal comfort is a psychological condition; thus, subjective perceptions cannot be interpreted using a physiological index based on body heat balances. Because psychological factors influence perceptions, the subjective perceptions of people within environments that exhibit identical thermal comfort indices can differ substantially based on their experiences, expectations, exposure durations, cultural characteristics, perceived control, and other factors. This refers to "thermal adaptability," which numerous studies have discussed and validated [29–35].

Seasonal changes are the most obvious experience factor. For example, people distinctly perceive summer and winter temperatures. Spatial types (e.g., shaded or open) are also relevant to expectations (e.g., people anticipate disparate feelings when they are exposed to the shade or hot sun). Accordingly, the obtained behavioral observations were explored in detail based on the above two factors (seasonal and spatial behavioral differences) as follows. The results were also validated with previous studies conducted in Taiwan.

4.2. Verification of Seasonal Behavioral Differences. Lin [7] used subjective questionnaires and objective physical environmental measurements in Taiwan to analyze neutral temperature (T_n) and preferred temperature (T_p). T_n is a temperature that is perceived as neither cold nor hot; thus, it can be considered a comfortable temperature. T_p is a temperature that people prefer; at this temperature they do not seek to become cooler or warmer. Thus, the T_p can be considered the expected temperature. In this study, the T_n was 23.7°C and 25.6°C during the cool and hot seasons, respectively. The T_p was 23°C and 24.5°C during the cool and hot seasons, respectively.

In this study, our observations regarding the numbers of participants in the PET groups (Section 3.1) indicate that the thermal index ranges in which the most people appeared during the cool and hot seasons were 20°C PET–22°C PET and 34°C PET–36°C PET, respectively. Comparing these values with the on-site measurements, the 20°C PET–22°C PET range, in which the most people appeared during the cool season, was close to the T_n and T_p values of the cool season. However, the 34°C PET–36°C PET range, in which the most people appeared during the hot season, was nearly 10°C PET higher compared with the T_p (25.6°C) of the hot season.

We can view the difference between these temperatures as the gap between psychological feelings (T_n or T_p) and actual behaviors (the temperatures at which people attend an area). This difference was not clear during the cool season, but it was obvious during the hot season, indicating that although people psychologically preferred low temperatures during the hot season, they continued to move to the observed site when temperatures were high. People demonstrated a high tolerance to increased summer temperatures, indicating their adaptability to the local climate.

4.3. Verification of Spatial Behavioral Differences. The constructed environment strongly influences the thermal conditions to which people are exposed in outdoor spaces [36–41]. Among several environmental attributes of the outdoors, shading can block solar radiation and has been proven to influence outdoor thermal environments significantly. Certain studies have examined street orientation and height-to-width ratios for representing the shading factors [42–48]. Other studies have used SVF to represent the degree of shading [49–52]. Previous on-site measurements in Taiwan [15, 16] proved that areas exhibiting high levels of shading would provide superior long-term comfort. Lin [7] used questionnaires to determine that people prefer taking shade under trees or other shelters when exhibiting adaptive behaviors to relieve increases in outdoor temperatures. This explains why more than 75% of users in this study preferred shaded areas and remained in these areas longer in comparison with those who chose sunny areas.

It could be logically assumed that users prefer direct insolation to ameliorate coldness during the cool season; however, Figure 6 indicates that users were more likely to go to and stayed in shaded areas during the cool season than they were during the hot season. The phenomenon that people tended to stay in shaded areas during the cool season can be elucidated based on a study performed in Taiwan. Lin et al. [53] examined four factors in the physical environment that influenced outdoor thermal comfort in Taiwan: the air temperature, air humidity, solar radiation level, and wind speed. The analysis indicated that air temperature was the critical factor (64.3%) during the hot season, followed by radiation (34.3%). During the cool season, solar radiation contributed considerably more (58.3%) to the thermal comfort level than the air temperature did (38.7%) because air temperatures are moderate during the cool season in Taiwan. When the subjects were exposed to comfortable environments, the intensity of the sun insolation flexibly represented perceptions of heat or cold (radiation could improve comfort). Therefore, the solar radiation influenced thermal perceptions more than the air temperatures did and, as a result, people continued to prefer conducting their activities in shaded areas during the cool season.

5. Conclusion

In this study, physical microclimate measurements, image recordings, and dynamic behavior observations of users in a stepped plaza at the outdoor garden of the NMNS in Taichung City, Taiwan, were performed. We discussed whether and how the resting location choices, stay durations, and dynamic or static activities were associated with the thermal environment in seasonal and spatial type perspectives of a recreational field that coexist with both shaded and unshaded areas.

The dynamic image recordings and user behavior observations were novel for use in this field. This method enabled recording all user behaviors within the observational range and comparing the images with physical measurements of the thermal environment to determine how microclimates affect occupant's adaptive behaviors. The disadvantage of this method was that we could not interfere with the users (e.g., conducting interviews or providing questionnaires) to precisely determine their microclimate feelings and preferences. In addition to recording videos, subsequent studies can design questionnaires to investigate user feelings toward the thermal environment; however, care must be taken not to interfere with the subjects. The primary findings of this study are as follows.

(1) More people rested on the stepped plaza during the cool season compared with the hot season. The number of people present during the hot season decreased as temperatures increased. The temperature ranges at which most people were present were 34°C PET–36°C PET during the hot season and 20°C PET–22°C PET during the cool season.

(2) More than 75% of users preferred shaded areas. Users also stayed longer in shaded areas than they did in sunny areas.

(3) In highly shaded environments, people preferred static activities. The shaded areas were ideal for static activities, particularly during the hot season.

We also referenced thermal comfort theory and previous local on-site investigations to describe and verify the relation between behavior and the thermal environment. It is proved that the observed subjects demonstrated an extremely high tolerance to increased summer temperatures despite their psychological preferences for lower temperatures. This was reflected in the attendance and behavior during the hot season, demonstrating human adaptability toward the local climate. We confirmed that people psychologically disliked high levels of outdoor insolation; this was evidenced by their spatial use behaviors. People substantially preferred to conduct activities in shaded areas even during the cool season.

This study elucidates the association between the thermal environment and adaptive behaviors of users. It differs from past studies, which investigated only participant numbers, and extends to assess user stay locations, stay durations, and behavior patterns. The findings prove that the people of Taiwan, which are living in a hot and humid region, avoid sunlight and desire shaded spaces based on their previous microclimate experiences and expectations. This is distinct from the trends observed in countries in the temperate zone. In addition, the findings proved that people often use their past experiences to determine whether to move to a space after observing the sun and shade conditions to ensure their thermal comfort. Because people rarely make second move after choosing a location, designing spaces that include sufficient trees or shading shelters could facilitate users' recognition of thermal comfort. Furthermore, by integrating user climate experiences and awareness to outdoor environmental planning and design, a successful outdoor space that is attractive to the public could be achieved.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

[1] M. Carmona, T. Heath, T. Oc, and S. Tiesdell, *Public Places-Urban Spaces: The Dimensions of Urban Design*, Architectural Press, Elsevier, Burlington, NJ, USA, 2003.

[2] J. Zacharias, T. Stathopoulos, and H. Wu, "Microclimate and downtown open space activity," *Environment and Behavior*, vol. 33, no. 2, pp. 296–315, 2001.

[3] M. Nikolopoulou, N. Baker, and K. Steemers, "Thermal comfort in outdoor urban spaces: understanding the human parameter," *Solar Energy*, vol. 70, no. 3, pp. 227–235, 2001.

[4] S. Thorsson, M. Lindqvist, and S. Lindqvist, "Thermal bioclimatic conditions and patterns of behaviour in an urban park in Göteborg, Sweden," *International Journal of Biometeorology*, vol. 48, no. 3, pp. 149–156, 2004.

[5] I. Eliasson, I. Knez, U. Westerberg, S. Thorsson, and F. Lindberg, "Climate and behaviour in a Nordic city," *Landscape and Urban Planning*, vol. 82, no. 1-2, pp. 72–84, 2007.

[6] S. Thorsson, T. Honjo, F. Lindberg, I. Eliasson, and E.-M. Lim, "Thermal comfort and outdoor activity in Japanese urban public places," *Environment and Behavior*, vol. 39, no. 5, pp. 660–684, 2007.

[7] T.-P. Lin, "Thermal perception, adaptation and attendance in a public square in hot and humid regions," *Building and Environment*, vol. 44, no. 10, pp. 2017–2026, 2009.

[8] C. H. Lin, T. P. Lin, and R. L. Hwang, "Thermal comfort for urban parks in subtropics: understanding visitor's perceptions, behavior and attendance," *Advances in Meteorology*, vol. 2013, Article ID 640473, 8 pages, 2013.

[9] M. Nikolopoulou and S. Lykoudis, "Use of outdoor spaces and microclimate in a Mediterranean urban area," *Building and Environment*, vol. 42, no. 10, pp. 3691–3707, 2007.

[10] N. Kántor and J. Unger, "Benefits and opportunities of adopting GIS in thermal comfort studies in resting places: an urban park as an example," *Landscape and Urban Planning*, vol. 98, no. 1, pp. 36–46, 2010.

[11] S. Lenzholzer and J. Koh, "Immersed in microclimatic space: microclimate experience and perception of spatial configurations in Dutch squares," *Landscape and Urban Planning*, vol. 95, no. 1-2, pp. 1–15, 2010.

[12] T. P. Lin, K. T. Tsai, R. L. Hwang, and A. Matzarakis, "Quantification of the effect of thermal indices and sky view factor on park attendance," *Landscape and Urban Planning*, vol. 107, no. 2, pp. 137–146, 2012.

[13] T.-P. Lin, K.-T. Tsai, C.-C. Liao, and Y.-C. Huang, "Effects of thermal comfort and adaptation on park attendance regarding different shading levels and activity types," *Building and Environment*, vol. 59, pp. 599–611, 2013.

[14] M. B. Gómez-Martín and E. Martínez-Ibarra, "Tourism demand and atmospheric parameters: non-intrusive observation techniques," *Climate Research*, vol. 51, no. 2, pp. 135–145, 2012.

[15] R.-L. Hwang, T.-P. Lin, and A. Matzarakis, "Seasonal effects of urban street shading on long-term outdoor thermal comfort," *Building and Environment*, vol. 46, no. 4, pp. 863–870, 2011.

[16] T.-P. Lin, A. Matzarakis, and R.-L. Hwang, "Shading effect on long-term outdoor thermal comfort," *Building and Environment*, vol. 45, no. 1, pp. 213–221, 2010.

[17] T. R. Oke, "Canyon geometry and the nocturnal urban heat island: comparison of scale model and field observations," *Journal of Climatology*, vol. 1, no. 3, pp. 237–254, 1981.

[18] T. R. Oke, *Boundary Layer Climates*, Metheun, London, UK, 1987.

[19] VDI, *Methods for the Human Biometeorological Evaluation of Climate and Air Quality for the Urban and Regional Planning. Part I: Climate. VDI Guideline 3787. Part 2*, Beuth, Berlin, Germany, 1998.

[20] H. Mayer and P. Höppe, "Thermal comfort of man in different urban environments," *Theoretical and Applied Climatology*, vol. 38, no. 1, pp. 43–49, 1987.

[21] P. Höppe, "The physiological equivalent temperature—a universal index for the biometeorological assessment of the thermal environment," *International Journal of Biometeorology*, vol. 43, no. 2, pp. 71–75, 1999.

[22] A. Matzarakis, F. Rutz, and H. Mayer, "Modelling radiation fluxes in simple and complex environments—application of the RayMan model," *International Journal of Biometeorology*, vol. 51, no. 4, pp. 323–334, 2007.

[23] A. Matzarakis, F. Rutz, and H. Mayer, "Modelling radiation fluxes in simple and complex environments: basics of the RayMan model," *International Journal of Biometeorology*, vol. 54, no. 2, pp. 131–139, 2010.

[24] ISO, "Thermal environment-instruments and method for measuring physical quantities," International Standard 7726, International Standard Organization, Geneva, Switzerland, 1998.

[25] T. P. Lin and A. Matzarakis, "Estimation of outdoor mean radiant temperature by filed experiment and modelling for human-biometeorology use," in *Proceedings of the 11th Annual Meeting of the European Meteorological Society*, EMS2011-89, Berlin, Germany, 2011.

[26] T. Young, E. Finegan, and R. D. Brown, "Effects of summer microclimates on behavior of lions and tigers in zoos," *International Journal of Biometeorology*, vol. 57, no. 3, pp. 381–390, 2013.

[27] P. O. Fanger, *Thermal Comfort*, McGraw Hill, New York, NY, USA, 1972.

[28] ASHRAE, *ASHRAE Standard 55-2010, Thermal Environmental Conditions for Human Occupancy*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Ga, USA, 2010.

[29] Y. Fan, S. Lang, and W. Xu, "Field study on acceptable thermal conditions for residential buildings in transition zone of China," in *Proceedings of the 6th International Conference on Indoor Air Quality and limate (Indoor Air '93)*, J. J. K. Jaakkola, R. Ilmarinen, and O. Seppänen, Eds., Helsinki, Finland, July 1993.

[30] R.-L. Hwang and T.-P. Lin, "Thermal comfort requirements for occupants of semi-outdoor and outdoor environments in hot-humid regions," *Architectural Science Review*, vol. 50, no. 4, pp. 357–364, 2007.

[31] D. A. McIntyre, *Indoor Climate*, Applied Science Publishers, London, UK, 1980.

[32] M. Paciuk, "The role of personal control of the environment in thermal comfort and satisfaction at the workplace," in *Coming of Age*, R. Selby, K. Anthony, J. Choi, and B. Orland, Eds., Environment Design Research Association, Edmond, Okla, USA, 1990.

[33] G. S. Brager, G. Paliaga, R. de Dear et al., "Operable windows, personal control, and occupant comfort," *ASHRAE Transactions*, vol. 110, pp. 17–35, 2004.

[34] B. Givoni, *Climate Considerations in Building and Urban Design*, Van Nostrand Reinhold, New York, NY, USA, 1997.

[35] A. Malama, S. Sharples, A. C. Pitts, and K. Jitkhajornwanich, "Investigation of the thermal comfort adaptive model in a tropical upland climate," in *Proceedings of the 1998 ASHRAE Winter Meeting*, pp. 1194–1206, January 1998.

[36] T. P. Lin, Y. F. Ho, and Y. S. Huang, "Seasonal effect of pavement on outdoor thermal environments in subtropical Taiwan," *Building and Environment*, vol. 42, no. 12, pp. 4124–4131, 2007.

[37] S.-A. Tan and T.-F. Fwa, "Influence of pavement materials on the thermal environment of outdoor spaces," *Building and Environment*, vol. 27, no. 3, pp. 289–295, 1992.

[38] H. Taha, "Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat," *Energy and Buildings*, vol. 25, no. 2, pp. 99–103, 1997.

[39] T. Asaeda and V. T. Ca, "Characteristics of permeable pavement during hot summer weather and impact on the thermal environment," *Building and Environment*, vol. 35, no. 4, pp. 363–375, 2000.

[40] N. H. Wong, S. K. Jusuf, A. A. la Win, H. K. Thu, T. S. Negara, and X. C. Wu, "Environmental study of the impact of greenery in an institutional campus in the tropics," *Building and Environment*, vol. 42, no. 8, pp. 2949–2970, 2007.

[41] T. Ichinose, K. Shimodozono, and K. Hanaki, "Impact of anthropogenic heat on urban climate in Tokyo," *Atmospheric Environment*, vol. 33, no. 24-25, pp. 3897–3909, 1999.

[42] E. Johansson, "Influence of urban geometry on outdoor thermal comfort in a hot dry climate: a study in Fez, Morocco," *Building and Environment*, vol. 41, no. 10, pp. 1326–1338, 2006.

[43] E. Johansson and R. Emmanuel, "The influence of urban design on outdoor thermal comfort in the hot, humid city of Colombo, Sri Lanka," *International Journal of Biometeorology*, vol. 51, no. 2, pp. 119–133, 2006.

[44] R. Emmanuel and E. Johansson, "Influence of urban morphology and sea breeze on hot humid microclimate: the case of Colombo, Sri Lanka," *Climate Research*, vol. 30, no. 3, pp. 189–200, 2006.

[45] F. Ali-Toudert and H. Mayer, "Thermal comfort in an east-west oriented street canyon in Freiburg (Germany) under hot summer conditions," *Theoretical and Applied Climatology*, vol. 87, no. 1–4, pp. 223–237, 2007.

[46] F. Ali-Toudert and H. Mayer, "Numerical study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot and dry climate," *Building and Environment*, vol. 41, no. 2, pp. 94–108, 2006.

[47] F. Ali-Toudert and H. Mayer, "Effects of asymmetry, galleries, overhanging façades and vegetation on thermal comfort in urban street canyons," *Solar Energy*, vol. 81, no. 6, pp. 742–754, 2007.

[48] R. Emmanuel, H. Rosenlund, and E. Johansson, "Urban shading—a design option for the tropics? A study in Colombo, Sri Lanka," *International Journal of Climatology*, vol. 27, no. 14, pp. 1995–2004, 2007.

[49] R. Giridharan, S. S. Y. Lau, and S. Ganesan, "Nocturnal heat island effect in urban residential developments of Hong Kong," *Energy and Buildings*, vol. 37, no. 9, pp. 964–971, 2005.

[50] Z. Bottyán and J. Unger, "A multiple linear statistical model for estimating the mean maximum urban heat island," *Theoretical and Applied Climatology*, vol. 75, no. 3-4, pp. 233–243, 2003.

[51] R. Hamdi and G. Schayes, "Sensitivity study of the urban heat island intensity to urban characteristics," *International Journal of Climatology*, vol. 28, no. 7, pp. 973–982, 2008.

[52] R. Giridharan, S. S. Y. Lau, S. Ganesan, and B. Givoni, "Urban design factors influencing heat island intensity in high-rise high-density environments of Hong Kong," *Building and Environment*, vol. 42, no. 10, pp. 3669–3684, 2007.

[53] T.-P. Lin, R. de Dear, and R.-L. Hwang, "Effect of thermal adaptation on seasonal outdoor thermal comfort," *International Journal of Climatology*, vol. 31, no. 2, pp. 302–312, 2011.