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Effects of thermal comfort and adaptation on park attendance regarding different shading levels and activity types

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Outdoor thermal environments influence thermal adaptation, thereby affecting the utilization of space. To determine the effects of thermal comfort and adaptation on attendance regarding different shading levels and activity types, this study conducted field investigations at a public park located in southern Taiwan, using micrometeorological measurements, estimations of park attendance, and questionnaire surveys on thermal comfort. The results indicate that participants' acceptable range of thermal comfort leads to substantial changes in overall park attendance during different seasons, whereas characteristics of thermal adaptations influence the individual differences of utilization in various ways within diverse spaces. In addition, this study reveals that in unshaded areas within parks, the number of visitors increases following rising thermal conditions during cool seasons, whereas the number of visitors decreases during hot seasons. However, the number of visitors to shaded areas increases with rising thermal conditions in both cool and hot seasons. Because of the possibility and effectiveness of personal behavior adjustments (e.g., decreases in the amount of clothing worn, the wearing of hats, or carrying of an umbrella) in decreasing thermal discomfort, people choose to seek adjustments in external environments. That is, they move from unshaded to shaded areas to relieve their perception of thermal discomfort. The results of this study reveal the importance of shading facilities within parks in the hot climate zone of Taiwan, and can be used as references in future park designs.

1. Introduction

Previous studies have investigated outdoor thermal environments, human thermal adaptation, and the utilization of outdoor space (such as in plazas and at parks) in various nations and climate zones, including: Montreal, Canada [1]; Cambridge, the UK [2]; Gothenburg, Sweden [3,4]; Matsudo, Japan [5]; Taichung, Taiwan [6]; Huwei, Taiwan [7]; Athens, Greece [8]; Szeged, Hungary [9]; the Hague, Eindhoven, and Groningen, the Netherlands [10]. These studies have revealed the relationship between thermal environments and the number of users within environmental spaces, user distributions, and behavioral modes.

Concerning previous studies in hot and humid regions, Lin [6] conducted field surveys on thermal environment and attendance in an unshaded public square in Taiwan. Lin found that the number of people visiting the square increased as the thermal index value increased during the cool season. However, the number of people frequenting the square decreased as the thermal index increased during the hot season. Moreover, Lin et al. [7] applied the similar method but focused on a park which is highly shaded by trees. They indicated that thermal indices contribute more attendances in cool season but fewer attendances in hot season. The correlation analysis between area-averaged sky view factor (SVFa) and attendance also revealed that areas with more shading have higher utilization intensity in the park.

In analyzing the attendance and conditions of people at parks and in plazas, some of these studies have used single-climate parameters, such as air temperature (T_a), wind speed (v), cloud cover (Cd), and globe temperature (T_g), to serve as indicators of the thermal environment; whereas other studies have further considered compound indicators, such as mean radiant temperature (T_{mrt}), physiologically equivalent temperature (PET) [11,12], and standard effective temperature (SET) [13]. However, thermal physiological indicators based on energy balances in the human

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body (such as PET and SET) and used to describe thermal environments where people are exposed remain insufficient to understand completely the attendance and conditions of people at parks and in plazas. Whether people feel comfortable outdoors is directly influenced by their experiences and expectations in thermal environments. For example, at 28 °C PET, people living in temperate zones may feel hotter than those in tropical zones do. Furthermore, physiological, psychological, and behavioral "thermal adaptation" factors [14], such as seasonal preferences, purpose in coming to a space, autonomy of activity, perceived control, and adjustments to clothing, can influence a person's thermal perception when outdoors. Thus, the first crucial topic of this study is whether these thermal comfort and psychological adaptation characteristics are reflected by attendance in outdoor spaces.

In addition, the majority of previous research in this field has investigated only unshaded sites in single locations. Although some previous studies (e.g., Ref. [7]) have examined shading, they have not investigated unshaded and shaded spaces simultaneously; thus, comparing levels of shading within the same site has been difficult. Numerous studies have indicated that shading is an important factor and contributes to microclimate because it blocks sunlight, mitigating the thermal uncomfortableness that is caused by short-wave radiation. Furthermore, shadows on the ground decrease surface temperatures, reducing long-wave radiation [15–19]. In addition, studies in (sub)tropical Taiwan have revealed that local people prefer shading to reduce their radiation exposure outdoors. These studies were based on the characteristics of local peoples' thermal comfort and adaptations [20–22]. Furthermore, participants' thermal adaptations may also be determined by the activities in which they engage. Therefore, in combination with the first topic, the second topic of importance is whether thermal comfort and adaptation have different effects on the aggregate number of people, their methods in choosing locations, and their behavioral adjustments in shaded and unshaded spaces when engaging in different activities.

In summary, this study investigated the influence of different shading levels and activity types on park attendance from the perspectives of thermal comfort and adaptation. To accomplish this, a suitable location was determined, exhibiting a variety of usage frequencies and space shading. In the shaded and unshaded areas, the thermal comfort and adaptation of users were investigated, and their usage conditions were also observed. Simultaneously examining these aspects facilitated understanding of the influence of user thermal comfort and adaptation on aggregate models and usage behavior. These results will be extremely beneficial in future outdoor space planning, particularly regarding vegetation and facility design, as well as creating spaces based on the perspective of thermal adaptation.

2. Method

2.1. Investigation site

Three principles were followed in selecting the site for this study. First, there should be a high density of usage and excellent availability for better observation results. Second, because the amount of short-wave radiation is an important factor for the outdoor thermal environment, and as shading conditions are crucial factors in determining the short-wave radiation, there should be several different types of shading at the site, e.g., vegetation and buildings, to create a diverse thermal environment. Finally, diversified functions and activities in each space are required to investigate the thermal adaptations resulting from differences in psychological characteristics during different spatial activities, which will benefit for further interpreting the aggregation phenomena of the whole site.

Chung Cheng Park of Chiayi City (120°27′ N, 23°29′ E), located in southern Taiwan, was selected in this study (Fig. 1). This is an urban park with excellent availability that is used by numerous people, providing many uses for the metropolitan area. In addition, it has many different shading levels and a variety of activity types. It is thus suitable as the subject of this study.

Chiayi City has the characteristics of a subtropical/tropical transition zone. According to data from the Central Weather Bureau of Taiwan, January is the coldest month in Chiayi City, with an average air temperature of 16.5 °C and a low of 12.5 °C. The hottest month during the summer is July, with an average air temperature of 25.2 °C and a high of 33.1 °C. The yearly average relative humidity is between 75% and 85%. These data indicate that Chiayi City is humid year-round, with cool winters and hot summers. Because distinctly low temperatures appear only between December and February, this study designated these months as Chiayi's cool season. The other months with higher temperatures, from March to November, were defined as the hot season.

According to the research purpose of this study, the park was divided into nine areas designated A–I during observation. Each area was differentiated by characteristics of shading levels and activity types. Because spatial segmentation was also considered (e.g., having the same elevation and pavement type), some of the areas were assigned irregular boundaries, as shown in Fig. 1. Shading was assessed using the sky view factor (SVF), representing the open area over a location as a ratio of the entire overhead view. Locations with higher SVFs have lower shading rates, whereas those with lower SVFs have higher shading rates. Sky view factor (SVF) is measured from 0 to 1, ranging from "entirely shaded" to "entirely unshaded". This study measured SVF by photographing upward from a height of 1.1 m at a representative location of each area using a fisheye lens. Photographs were entered into the RayMan model [23,24] to calculate the ratio of open area. Table 1 indicates that areas with high shading ($SVF < 0.1$) included the tree-shaded trails (Area A) and tree-shaded activity zone (Area B). Areas with moderate shading ($0.1 < SVF < 0.6$) included the wood deck square (Area E), southern side of the activity center (Area F), eastern side of the activity center (Area H), and open trails (Area G). Areas with low shading ($SVF > 0.6$) included the amphitheater (Area C), central plaza (Area D), and children's playground (Area I).

2.2. Micrometeorological measurement

In measuring thermal environmental parameters, a total of nine thermometers were used to measure the T_a, T_g, and relative humidity (RH) of each area. In addition, one non-directional anemometer was placed at the center of unshaded Area D to measure the wind speed (v). The resolution and accuracy of the instruments for each parameter were 0.1 °C and ±0.3 °C for T_a and T_g, 0.1% and ±2.5% for RH, and 0.01 m/s and ±0.2 m/s for v. All instruments, which are compliant with the ASHRAE 55 [25] and ISO 7726 [26] standard, were placed on tripods 1.1 m above the ground. Fig. 1 indicates the exact positions of the instrument installations at Areas A–I. The T_{mrt} was calculated using T_a, T_g, and v based on ISO standard 7726 [26] and 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 [27]. In addition, the v for each area was transferred from the measured value in Area D by correcting for height and surface roughness.