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OUTDOOR THERMAL COMFORT IN UNIVERSITY CAMPUS IN HOT-HUMID REGIONS

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Abstract

Due to the difficulty of controlling the outdoor thermal environment, it is important to provide thermal comfortable conditions which meet occupants' expectation. In order to realize the long-term thermal comfort in outdoor environment, the microclimate in a university campus in Taiwan is measured 12 times through two years. RayMan model are applied to calibrate the climate parameters and environment elements, e.g. shelter, ground surface. The results of modeled Tmrt for 12 times of campus measurement are significantly correlated with measured data. Sky view factor (SVF) plays an important role on the thermal environment due to solar radiation fluxes and is one of the main factors affecting local occupants' outdoor thermal sensation. In hot-humid region as Taiwan, highly shaded area (i.e. lower SVF value) may provide cooler environment which contribute longer thermal comfort period for the entire year. However, since the local people are poorly cold-tolerant, overly shaded areas may induce extreme discomfort in winter due to low air temperatures, indicating that thermal adaptation characteristics of local people and local climate should be considered thoroughly in outdoor shading and urban planning.

Key words: outdoor thermal comfort, hot-humid regions, sky view factor

1. INTRODUCTION

The outdoor thermal environment is impacted by the built environment, e.g. anthropogenic heat (Ichinose et al. 1999), ground surface covering (Lin et al. 2007), evaporation and evapotranspiration of plants (Robitu et al. 2006), and shading by trees and man-made objects (Lin et al. 2009). As shade can block incident solar radiation, some studies have discussed shading effect on thermal environments. For example, street orientation and the height/width (H/W) ratio have been measured to asses the shading levels is some studies (Ali-Toudert and Mayer 2006; Emmanuel and Johansson 2006; Johansson 2006; Johansson and Emmanuel 2006; Ali-Toudert and Mayer 2007b; Ali-Toudert and Mayer 2007a; Emmanuel et al. 2007), whereas the sky view factor (SVF) represents the shading levels in others (Bottyan and Unger 2003; Dimoudi and Nikolopoulou 2003; Giridharan et al. 2005; Giridharan et al. 2007; Hamdi and Schayes 2007).

Previous studies have generally performed field experiments on only a few days to investigate how shade improves thermal comfort. However, such experimental results merely elucidate the characteristic measured (or simulated) on a particular day and may not represent annual thermal conditions. On the other hand, tolerance of outdoor thermal environments also varies for people in different climates, that is, they would not feel the same given the same thermal environment (Givoni et al. 2003; Cheng and Ng 2006; Nikolopoulou and Lykoudis 2006; Lin and Matzarakis 2008). Therefore, one must discuss long-term thermal comfort based on the thermal requirements and characteristics of local residents. Since Taiwan's residents are accustomed to its hot and humid climate and relatively less tolerant of cold temperatures; thermal comfort in winter is a significant concern for use of outdoor spaces.

This study analyzed the shading effect on the long-term thermal environment based on the comfort range of local residents. Meteorological data for 10 years are utilized. Rather than extremely hot or cold weather events, this study analyzes the annual microclimate distribution, such that thermal discomfort intensity and thermal comfort potential in different seasons can be evaluated objectively.

2. METHOD

To determine the shading effect on long-term thermal comfort, this study first conducted field experiments at several locations with different shading levels. Measurements of thermal environment were obtained in different months to elucidate the variations in thermal conditions in different seasons. Second, measurement results for each location and each day were compared with simulation results to validate the accuracy of the RayMan model (Matzarakis et al. 1999; Matzarakis et al. 2007). The optimal setting for the model that fits the local climate and environment is then obtained. Finally, meteorological data for a 10-year period were imported into RayMan model to simulate the long-term thermal environment and thermal indices needed to assess the shading effect on annual thermal comfort.

The field experiment was performed at the National Formosa University (NFU) campus to eliminate interference from anthropogenic heat generated by traffic and large air conditioners. The NFU campus is situated

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in Huwei Township, central Taiwan (23°42' N, 120°26' E), at an elevation of 23m above sea level. Six measurement locations were distributed throughout the campus. Figure 1 presents descriptions of each measurement location. Measurement locations A–E, which are the outdoor spaces most frequently used by students, are characterized by different shading levels. Point F, a reference for locations A–E, is located on the roof of a four-story building and no shade.

Figure 1 also shows fisheye photographs of each measurement location. Among the six measurement locations, SVF ranges from highly shaded—point C (SVF=0.04)—to the barely shaded—point F (SVF=0.808) (Table 2). Notably, the trees around the measured locations are evergreens, thus the fisheye photographs and SVF values are roughly the same in different seasons.To measure physical parameters, instruments were placed 1.1m above ground level on a tripod at locations A–F to measure air temperature (Ta), relative humidity (RH), and globe temperature (Tg). At location F, wind speed (v) and global radiation (Gr) were also measured simultaneously. Measurements were recorded at 1-min intervals automatically from 08:00 to 18:00, as this is the period when the students are outdoors most; thus, this period is also the period for further analysis.

PET can be estimated using free software packages RayMan, which has been used in urban built-up area with complex shading patterns and generated accurate predictions of thermal environments (Gulyas et al. 2006; Lin et al. 2006). Meanwhile, when calculating PET, fisheye photographs of the sky taken from the measurement location are imported into the RayMan model to include the shading effect while calculating short- and long-wave radiation fluxes. Moreover, the ratio of free sky spaces to the entire fisheye view, the SVF, can be calculated by the RayMan model. The SVF is a dimensionless measure ranging between 0 and 1, representing totally obstructed and totally free spaces, respectively.

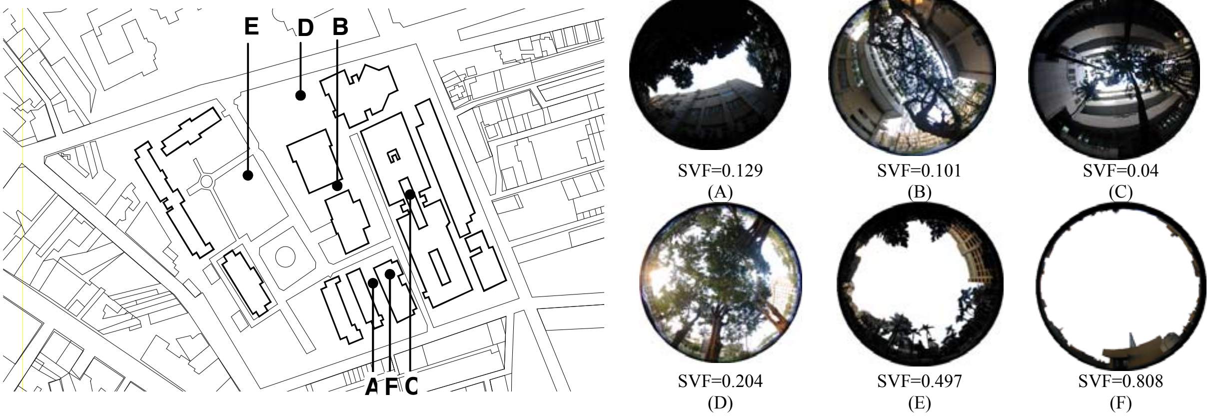
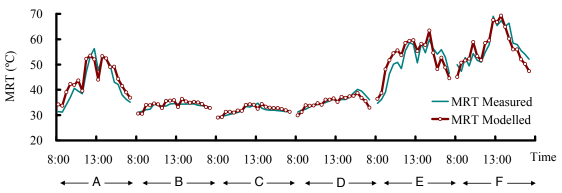


Fig. 1. NFU campus maps and locations of measurement and fisheye photos for each location

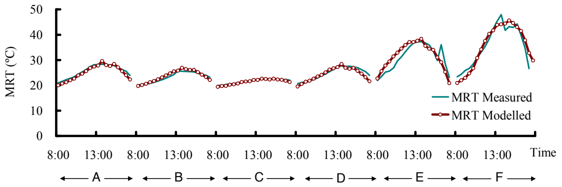
3. RESULTS

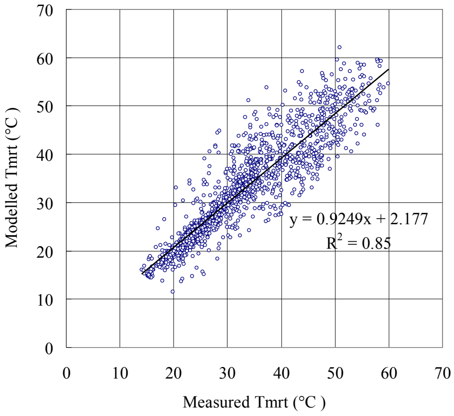
3.1 Model validation results

Figure 2 shows the variation in both measured and modelled mean radiant temperature (Tmrt) for cases selected to represent the summer (2006/8/15) and winter (2008/1/8). As shown, the modelled Tmrt and measured Tmrt have similar trends and values; the only difference was at a high Tmrt. The measured Tmrt and modelled Tmrt were strongly correlated (R^2=0.85, P<0.001), demonstrating that the model is accurate in predicting Tmrt. Therefore, the model can provide accurate estimates for PET, the primary thermal comfort index in this study.



(a) summer





(b) Winter

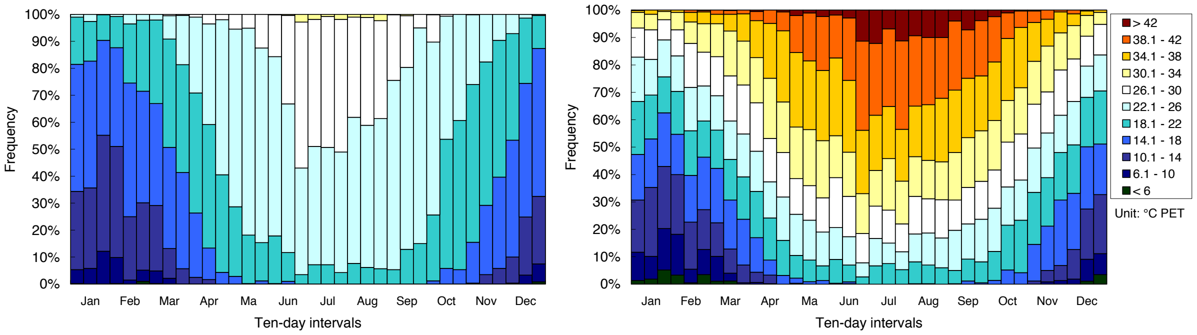
(c) correlation of measured and modelled Tmrt

Fig. 2. measured and modelled Tmrt at (a) summer 2006/08/15 and (b) winter 2008/01/08. (c) represent the correlation of measured and modelled Tmrt

3.2 Frequencies of thermal perceptions

Average climate data (e.g., mean Ta and RH) are frequently used to describe outdoor thermal environments in previous studies; however, deriving a relatively more concrete picture for the frequency distribution of each factor and thermal comfort is difficult. Therefore, the PET, a thermal comfort index, was used in this study at 10-day intervals (36 intervals/year) to increase data resolution. The frequency of various thermal sensation classification was calculated based on the thermal comfort range in Taiwan, i.e., 26°C–30°C PET. Figures 3 (a) and (b) show modelled PET frequency distribution graphs for locations C (Engineering building atrium) and F (roof) in the daytime (08:00–18:00) during 1998–2007 at 10-day intervals, respectively.

In summer (June–August), the probability of PET>30°C (slightly warm) at highly shaded location C is very low, whereas the probability of PET>42°C (very hot) exceeds 10% in the daytime at barely shaded location F. In winter, PET was always <22°C (cool) at location C, and the probability of PET<22°C was only 70% in the daytime at location F. In terms of the thermal comfort range (26–30°C PET), the thermal comfort duration at location C in summer (July and August) was 50% of time, whereas that at location F was constantly below 20% all year. Comparison results reveal that different shading levels contribute to variation in the thermal perception distribution.



(a) location C

(b) locations F

Fig. 3. PET frequencies at location C and location F of NFU, 8:00-18:00, 1998-2007

3.3 Effect of SVF on annual thermal comfort

This study has focused on determining the number of discomfort hours; however, a simple indicator to interpret long-term simulation results would prove helpful. This, thermal comfort ratio (TCR) is defined in this study as the ratio of thermal comfort hours (hours that thermal condition is in the range of 26°C<PET<30°C) over 10 days to the total hours in 10 days (10 days*10 hours/day(08:00–18:00)=100hours) for a specific location. This research then used TCR=20% (upper limit of TCR for barely shaded locations E and F for the entire year) as the criterion, and defined the period each location had a TCR>20% as the "thermal comfort period". A percentage of the thermal comfort period (PTCP) is then defined as the ratio of the thermal comfort period to time for the entire year, representing annual thermal comfort levels for each location. Thermal comfort for the entire year increased when the PTCP value increased. With location A as an example (Fig. 4), the PTCP of location A was 53%, which was calculated based the thermal comfort period form late April to the end of October (194 days) divided by one year (365 days), i.e., 194/365=53%.

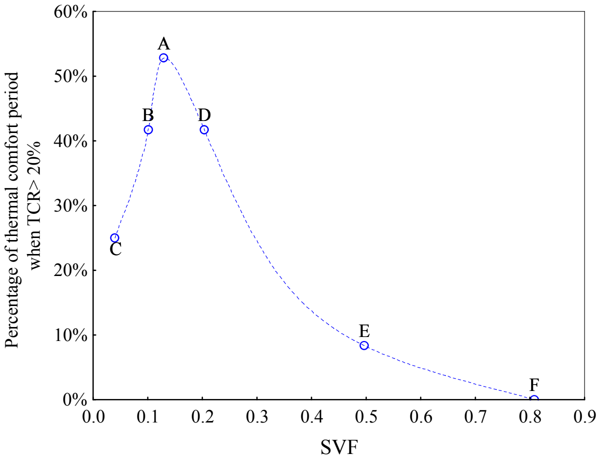


Fig. 4. Correlation of SVF and percentage of thermal comfort period (PTCP) when thermal comfort ratio (TCR) >20%

To determine the shading effect on annual thermal comfort, the correlations between PTCP and SVF at various locations were analyzed (Fig. 4). Location A (SVF=0.129) had the highest PTCP value (53%) among all measurement locations; that is, the thermal comfort ratio was high for over 50% of the year. When the measurement locations have SVFs >0.129, the PTCP value decreased as the SVF increases, and reaches 0 when SVF=0.808 (location F). Conversely, when the SVF of measurement locations is <0.129, the PTCP value decreases as the SVF decreases, and reached 25% at SVF=0.04 (location C). Analytical results indicate that a high SVF (barely shaded) causes discomfort in summer and a low SVF (highly shaded) causes discomfort in winter; both conditions reduce the duration of the annual thermal comfort period.

4. CONCLUSIONS

This study focused on a university campus in central Taiwan, and discussed the shading effect on long-term outdoor thermal comfort. This study had three stages. In the first stage, 12 field experiments were conducted; in the second stage, the RayMan model was validated for use for thermal comfort assessment; and in the third stage, long-term thermal comfort prediction was based on meteorological data covering a 10-year period. In terms of the thermal comfort index selection and result presentation, the PET was selected and presented at 10-day intervals based on its applicability to outdoor environments. The thermal comfort range of Taiwanese residents obtained in a previous survey was applied as the criterion to determine whether a thermal environment is comfortable or uncomfortable.

Validation results demonstrate that the Tmrt modelled by RayMan was close to the measured Tmrt, indicating that RayMan is accurate in predicting long-term thermal comfort. Analytical results show that the barely shaded (high SVFs) locations were uncomfortable in summer and highly shaded locations (low SVFs) were uncomfortable in winter. The median shading levels (SVF=0.129, location A) contributed to the longest thermal comfort period in an entire year. Spaces with little or excessive shading have short thermal comfort periods. As Taiwan has hot summers and mild winters, sufficient shading should be provided by trees and buildings to improve thermal comfort in summer. However, since the Taiwanese have poor tolerance of cold temperature, based on the theory of thermal adaptation and according to previous studies of the local thermal comfort range, outdoor space planning should avoid creating areas with excessive shading. For outdoor space design, multiple shading types and different shading levels are recommended to allow users to choose their preferred thermal comfort conditions.

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