Outdoor thermal comfort acceptable range and campus microclimate in hot-humid region

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Abstract

In order to account for occupants' thermal perception under different classification of physiologically equivalent temperature (PET), thermal comfort range for PET are analyzed via outdoor thermal comfort database in Taiwan, with 1644 sets of measurement and questionnaire data in outdoor spaces in five public places. Furthermore, microclimate is measured 12 times through two years in a university campus for the validation of thermal comfort range. RayMan model are applied to calibrate the climate parameter and environment elements, e.g. shelter, ground surface. Mean radiant temperature (Tmrt) and PET are also calculated by the model. The result of thermal comfort range for PET indicate that 26 - 30 °C PET for "neutral" for Taiwanese outdoor occupants, which is much higher than that for Western/middle European occupants, i.e. 18 - 23 °C PET. Furthermore, field experiment indicate that sky view factor (SVF) plays an important role on the thermal environment due to solar radiation is one of the main factor affecting local occupants' outdoor thermal sensation. In hot-humid region as Taiwan, lower SVF value, i.e. more shielding as buildings or trees, provide higher frequencies of thermal comfort period.

1. Introduction

Due to the difficulty of controlling the outdoor thermal environment, such as air temperature, global radiation and wind speed, it is important to provide thermal comfortable condition which meet occupants' expectation. In order to account for occupants' thermal perception under different classification of physiologically equivalent temperature (PET), thermal comfort range for PET are analyzed via outdoor thermal comfort database in Taiwan, with 1644 sets of measurement and questionnaire data in outdoor spaces in five public places. Furthermore, microclimate is measured 12 times through two year in a campus of National Formosa University (NFU) in Taiwan (Figs. 1 and 2) for the validation of thermal comfort range. RayMan model (Matzarakis et al., 2007) are applied to calibrate the climate parameter and environment elements, e.g. shelter, ground surface. Mean radiant temperature (T_{mrt}) and PET are also calculated by the model. Sky view factors (SVF) for each location are also calculated by the model.

2. Outdoor thermal comfort acceptable range

In order to account for tourists' thermal perception under different thermal conditions of PET, it is necessary to define PET ranges in which tourists feel comfortable, i.e. "thermal comfort range" for PET. In addition to the thermo-physiological factor of the human heat balance, thermal sensitivity and thermal comfort ranges vary amongst residents of different regions due to psychological factors, e.g. people who live in tropical region might be more tolerant to high temperature due to their experience. In other words, the thermal comfort range of a particular region may not be applicable for another region.

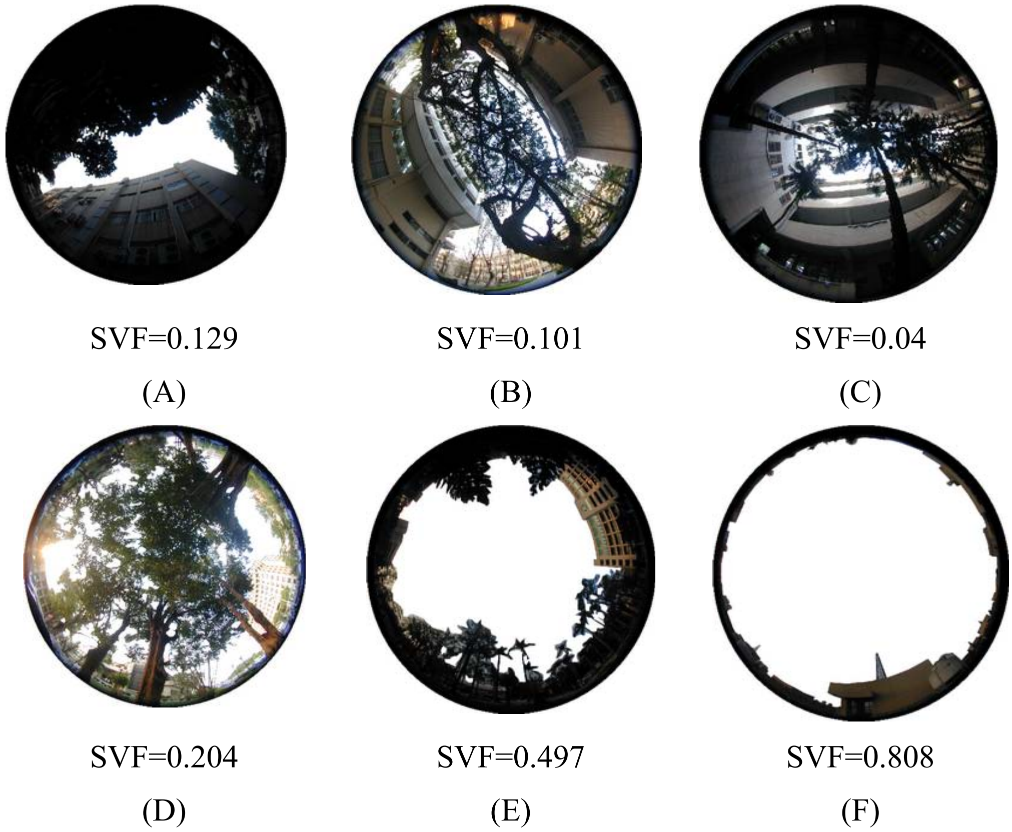


Fig. 1: Fisheye photos and SVF for each measurement location in NFU

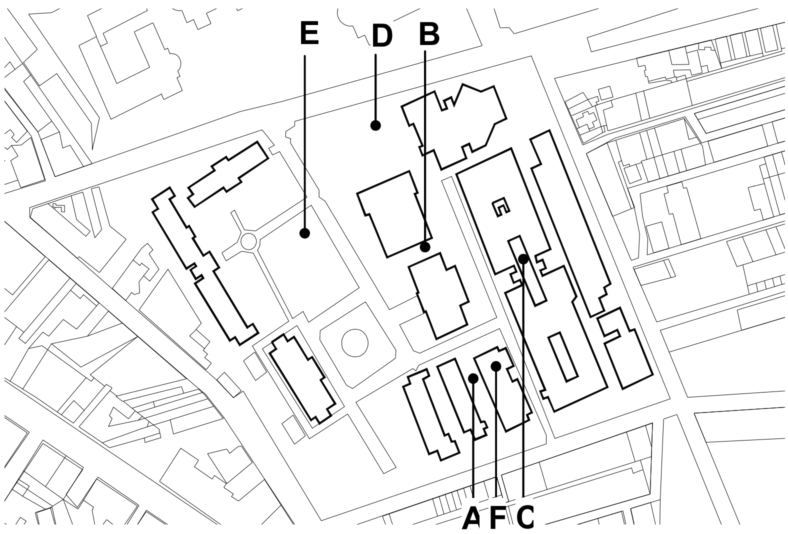


Fig. 2: NFU campus maps and locations of measurement and fisheye photos (see Fig. 1) for each location

In order to calculate the thermal comfort range of tourists in Taiwan, results from a field study based on 1644 interviews in the outdoor environment were used. In the survey (Lin et al., 2005; Hwang and Lin, 2007), basic information on the person's activity level and clothing were obtained. Secondly, objective measurements of ambient air temperature, globe temperature (measured by standard globe), air humidity, air velocity and global radiation were carried out, which were then used together with the activity and clothing level to calculate the PET. Also the interviewed person was asked to subjectively evaluate thermal sensation vote (TSV), thermal preference, and thermal acceptability. TSV ranged from -3 to +3, indicating cold, cool, slightly cool, neutral, slightly warm, warm and hot. Moreover, thermal acceptability indicated whether respondents considered the current thermal environment "acceptable" or "unacceptable".

Fig. 3 shows the percentages of unacceptability obtained by application of the method described in Method section. The 80 % acceptability limits are the intersections of the fitted curve and the 20% unacceptability line, which is 21.6 °C - 35.4 °C. In order to focus precisely on the comfort range and to minimize the data range, the 88 % acceptability limits were chosen for "neutral" the range 26 °C and 30 °C. Correspondingly, the range of feeling "slightly warm", "warm" and "hot" are obtained through a 4 °C increase of the range of "neutral"; and "slightly cool", "cool", "cold" are obtained through a 4 °C decrease of the "neutral" range. Table 1 shows the PET classification for Taiwan (Lin and Matzarakis, 2008) relative to the Western/Central European scale (Matzarakis and Mayer, 1996). The comparison of the two PET thermal scales shows that the neutral temperature scale of Taiwan is higher than that of Western/middle European. Furthermore, the PET range of Taiwan is larger than that of Western/middle European for each thermal sensation scale.

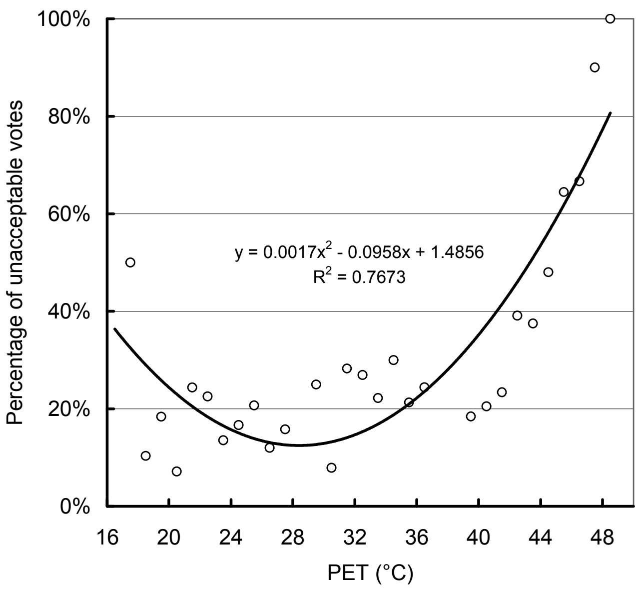


Fig. 3: Thermal comfort range for outdoor environments in Taiwan (Lin and Matzarakis, 2008)

Table 1: Thermal sensation and PET classes for Taiwan and Western/Middle European classes (Lin and Matzarakis, 2008; Matzarakis and Mayer, 1996)

Thermal sensation	PET range for Taiwan[a] (°C PET)	PET range for Western/Central Europe[b] (°C PET)
very cold		
	14	4
cold		
	18	8
cool		
	22	13
slightly cool		
	26	18
neutral		
	30	23
slightly warm		
	34	29
warm		
	38	35
hot		
	42	41
very hot		

3. SVF and thermal comfort

Modelled T_{mrt} for 12 times of campus measurement are significantly correlated with measured data (R^2=0.85). The long-term modeled PET for locations A and F are then calculated and displayed in Fig. 5, revealing that barely shaded point F (SVF=0.808) is very hot during May to October at time period of 10:00-14:00 LST, while highly shaded location A (SVF=0.129) is more comfortable through whole year. To understand the effect of shading on annual thermal comfort, the annual frequency of occurrence for warm or hot condition (PET > 30 °C) and SVF at different points were analyzed as shown in Fig. 4.

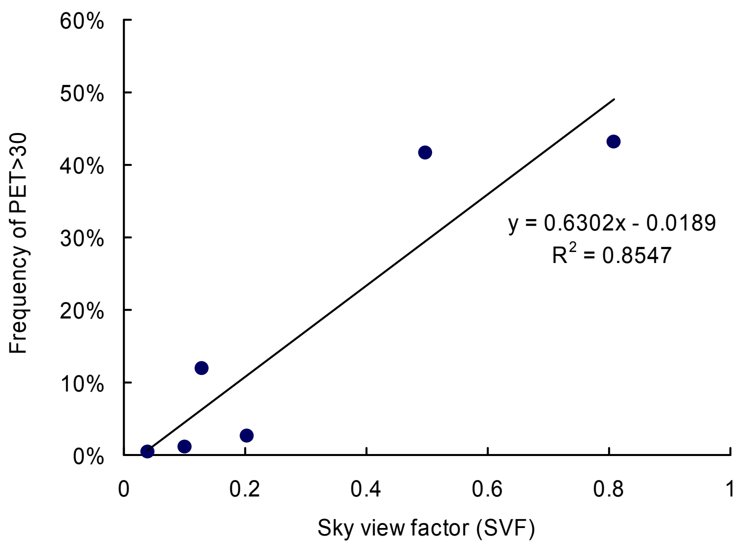
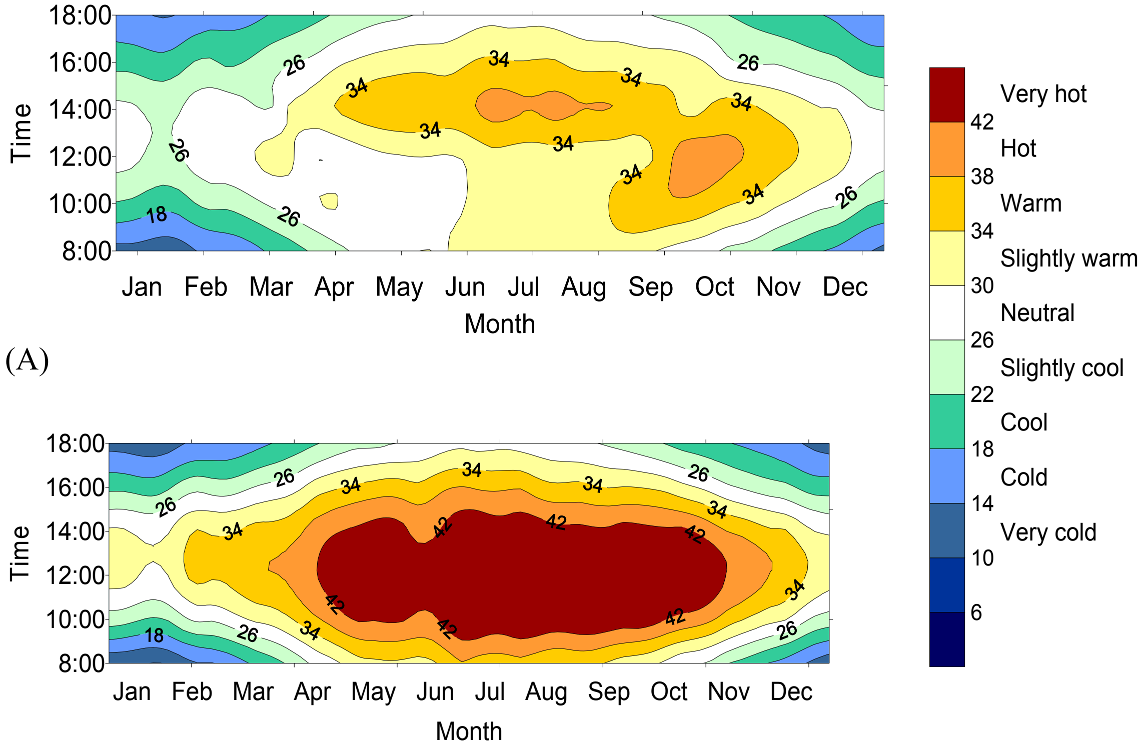


Fig. 4: Correlation of SVF and frequency of PET> 30 °C



(F)

Fig. 5: Modelled PET at location A (SVF=0.129) and F (SVF=0.808) of NFU, 8:00-18:00 LST, period: 1998-2007

The annual frequency of warm or hot condition tends to increase with SVF, due to barely shaded outdoor spaces may increase its long- and short-wave radiation, so the comfort level would decrease in summer.

4. Conclusions

The major contribution of this study is that it proposed a complete framework for analyzing outdoor thermal environment, which incorporates field experiments, simulation, and estimation of annual thermal comfort. The annual thermal comfort index, PET, at different locations of the campus was presented, and the comfort level was presented in frequency distribution whereas discomfort level was displayed in intensity. The results indicated that SVF has a significant relevance on outdoor thermal comfort, and the frequency of high temperature tends to be reduced by the amount of shading. Taiwan is subject to hot summer and mild winter, so sufficient shading should be provided by plants and buildings to improve the thermal comfort in summer. In hot-humid region as Taiwan, lower SVF value, i.e. more shielding as buildings or trees, provide higher frequencies of thermal comfort period.

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