347: An analysis of the effects of shading factors on human bioclimate in an evolving urban context

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This study analyzes the results of field experiments on the effects of outdoor thermal conditions on urban streets in Central Taiwan and considers long-term thermal comfort based on meteorological data. Results indicate that areas with slight amounts of shade typically experience frequent hot conditions during summer, particularly at noon. However, highly shaded locations generally show a low physiologically equivalent temperature (PET) during winter. Correlation analysis shows that thermal comfort is greater when a location is shaded during spring, summer, and autumn. Furthermore, historical data and current observations of the evolution of urban context in Taiwan show that the formation of current unpleasant thermal environments of urban street patterns in old townships of Taiwan has an historical legacy that affects opportunities for street businesses. We suggest that a specific shading level is ideal for urban streets, and trees or shade devices should be employed to improve the existing thermal environment.

Keywords: thermal comfort, bioclimate, urban context

1. Introduction

The outdoor thermal comfort of people is affected by the thermal environment. Moreover, their use of outdoor environments is affected by their perception of outdoor thermal conditions [1-5]. Furthermore, outdoor thermal environments are affected significantly by the design of urbanised environments [6]. Because shading can block direct solar radiation, numerous studies have examined the effects of shading on outdoor thermal environments. For example, previous studies [7-11] quantified the height/width (H/W) ratio of urban streets to assess shading levels, whereas the sky view factor (SVF) was used in other studies to represent shading levels [12, 13]

Buildings on Taiwan's traditional streets are mostly a combination of residential and commercial (i.e., the first floor is rented by stores and the upper floors are residential). Buildings that are not designed to include an arcade on the ground floor result in insufficient shading, and people are forced to walk beside the street when shopping, thereby exposing them to the outdoor climate. Thus, people may be dissatisfied with their shopping experiences when they feel uncomfortable in an outdoor thermal environment, adversely affecting store revenue and reducing rental prices. Therefore, investigating thermal comfort on urban blocks is essential to the economy. The objectives of this study are to (1) conduct a field experiment in traditional urban streets in Taiwan; (2) establish a prediction model for thermal environments based on the long-term meteorological data; (3) evaluate the long-term thermal comfort frequencies based on the local thermal comfort criteria; and (4) examine the seasonal effects of urban street shading on long-term outdoor thermal comfort.

2. Method

2.1 Outdoor thermal comfort indices

Physiologically equivalent temperature (PET) is defined as air temperature (Ta) that, in a typical indoor setting (Ta = Tmrt; vapor pressure (Vp)=12 hpa; and wind speed (v) = 0.1 m/s), balances with the heat budget of the human body (i.e., identical core and skin temperature as those under complex outdoor conditions [14, 15]. In this study, PET is applied as the main thermal comfort index because it can be estimated using the RayMan model and has been used in developed urban areas to generate predictions of thermal comfort in outdoor environments [16-19]Additionally, the sky view factor (SVF) (i.e. the ratio of free sky spaces to the entire fisheye view) at a specific location can also be calculated using the RayMan model for subsequent analyses.

2.2 Local thermal comfort criterion for PET

Previous studies examining thermal adaptation indicated that occupant thermal sensations and preferences vary considerably because of differences in behavioural adjustment, physiological acclimatization, and psychological habituation or expectations [20] All of these factors may contribute to different thermal comfort ranges (i.e., the range of thermal indices at which people feel comfortable). Therefore, the thermal comfort range for a particular region may be inapplicable to other regions. In this study, the thermal comfort range is obtained from a field survey of 1,644 participants in Taiwan [21]. In this survey, the following PET values were associated with specific sensations: 26–30 °C was perceived as "neutral" , 18–22 °C was considered "slightly cool," 14–18 °C was "cool," and <14 °C was "cold." Furthermore, participants identified 30–34 °C as "slightly warm," 34–38 °C as "warm," 38–42 °C as "hot," and >42 °C was considered "very hot." Because these thermal comfort ranges have been applied specifically to Taiwan (a hot and humid country [22]), these thermal comfort ranges are applied as criteria in this study to determine whether a thermal environment is comfortable or uncomfortable for local Taiwanese residents.

2.3 The field experiment

Specific streets selected for thermal measurement in this study are primarily walking spaces with many commercial businesses (e.g., restaurants and stores) that are generally unaffected by traffic or large air conditioners. Therefore, a traditional Taiwanese street in Huwei Township (23°43'N, 120°26'E, 20 m above sea level) was selected. Figure 1 shows the surveyed area. Measurements points A–F are outdoor spaces frequented by local residents and are characterized by various shading levels. Point K, a reference for points A–F, is located on the roof of a 10-m high building with no shade.

Fig 1. Studied area and measurement points in Huwei Township

Table 1 shows fisheye and street photographs and the SVF of each measurement location. Among the six measurement locations, the SVF ranges from highly shaded (point A, SVF=0.236) to slightly shaded (point F, SVF=0.616).

To measure physical thermal parameters, survey instruments were placed on a tripod at 1.1 m above ground level at locations A–F and K to measure Ta, RH, and globe temperature (Tg). At location K, v and Gr were also measured simultaneously. Measurements were recorded automatically at 1-min intervals from 8:00 AM to 6:00 PM because this is the period when shoppers are outdoors most; thus, this period is also the period used in the subsequent analyses. Four field experiments were conducted, one in each season, to ensure data representativeness of climate characteristics for each season.

Table 1 Fisheye and street photographs and the SVF of each measurement location

	Fisheye photo	Street photo	SVF
A			0.236
B			0.309
C			0.326
D			0.348
E			0.555
F			0.616
K			0.879

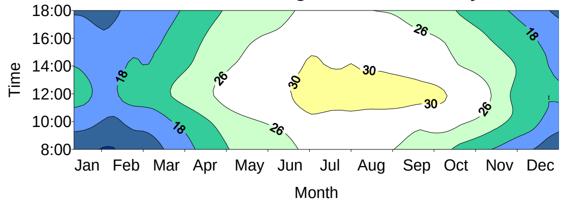
2.4 Validation of RayMan model

The RayMan model must be validated by comparing field measurements and model simulation results to fit the local climate and urban context. Because Tmrt is an integrated thermal index representing the combination of Ta, v, and short- and long-wave radiation fluxes, and can be determined using both measurements and simulations, the consistency between measured and modelled Tmrt was used as a criterion for model validation. The measured Tmrt was calculated using Ta, Tg, and v based on ISO standard 7726 [23]. The mean convection coefficient was corrected using the method developed by Thorsson et al. [24]. The modelled Tmrt was calculated using the RayMan model by importing the same factors used in calculating the PET. According to the method applied in Lin et al. [22], Tmrt for each location is estimated by Gr, cloud cover, fisheye photographs, and other climatic and environmental factors during the experiments.

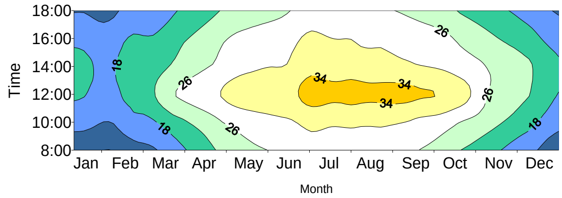
3. Mean thermal sensations at different periods in a day

Figure 5 shows a PET isotherm (x-coordinate is the month, y-coordinate is the time of day). We calculated PET averages for different times for each 10-d period using PET data from 2000 to 2009. For example, PET at 8:00 AM on January 1 to January 10 was the average of 100 climate data (10 y × 10 d) at 8:00 AM from January 1 to January 10 from 2000 to 2009. Based on this principle, we calculated PET and generated the PET isotherm using the Kriging algorithm from the Surfer® software package.

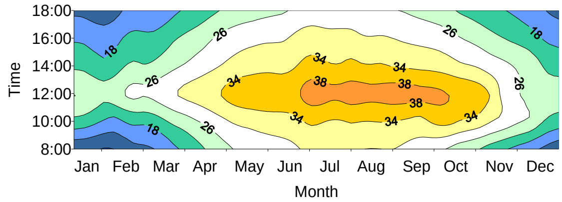
We selected 3 locations with different levels of shading to determine their PET isotherm (i.e., highly shaded point A, SVF=0.236; moderately shaded point E, SVF=0.555; and slightly shaded point F, SVF=0.616). For point A (Fig. 5(a)), the thermal comfort period (white) was from July to September except at noon, and at noon during May, June, and October. "Slightly warm" (PET>30 °C) was measured at noon during July to September. "Slightly cool" (PET<26 °C) was distributed from November to April. For point E (Fig. 5(b)), the "thermal comfort" period was shorter and the "slightly warm" period was longer than those at point A. "Slightly warm" was distributed from May to October, and "warm" occurred from July to September. For the slightly shaded point F (Fig. 5(c)), "slightly warm" was widely distributed during March to November, almost reaching "hot" at noon during July to September. Therefore, the thermal sensation distribution varied at different periods in a day, showing that the slightly shaded areas are hot at noon in summer, whereas highly shaded areas are more comfortable throughout the whole year.



(a) Point A (SVF=0.236)



(b) Point E (SVF=0.555)



(c) Point F (SVF=0.616)

Fig. 5. Predicted PET isotherm for points A(a), E(b), and F(c), 2000 to 2009

4. Human bioclimate in the urban context

In this section, it is necessary for us to further discuss two critical issues related to the current uncomfortable urban street patterns at Taiwan, First, we need to trace some historical data back to Japanese colonial period, when the modern urban planning project was introduced into Taiwan, in order to investigate the reasons for such an unpleasant urban street pattern design. Furthermore, we would discuss how such a thermal uncomfortable urban street design affects the commercial activities at Taiwan.

In 1895, the worst enemy Japanese army had faced when they seized Taiwan were not just Taiwanese people but the epidemic disease. After the Japanese colonial authority gradually controlled Taiwan, they began to discover the Chinese village style street structure at Taiwan, which was narrow and circle, was unsuitable for the development of transportation infrastructure.. Therefore, the Japanese colonial government began the urban reform policy in 1898 to construct a sewerage system and alter the design of streets and housing to receive more sunshine in order to eliminate the infection germs that caused epidemics. The Japanese colonial government issued the housing built regulations that requested to install large area window for lighting, and the withdraw of the line of building frontage from street in order to provide enough sun lighting on the open sewerage system etc. [25]. These design regulations reflects what Anthony King indicates to be the major force behind the installation of the urban planning system in the colonial society– the so-called "sanitation syndrome" [26]. This design principle hence resulted in the current thermal urban environment in traditional Taiwanese townships. Therefore, at Taiwan, we witness numerous illegal annexes and attachments are onto the original buildings that reduce the heat from directly sunlight and also provide areas of shades for the streets. Hence, it might reduce the street temperature and improve comfort.

Further, with such an uncomfortable thermal urban street pattern, we observed that the evolution of wider urban streets result in less commercial functionality. Furthermore, wider streets result in less safety for people wishing to cross. Ultimately, it forces existing shops to transform themselves into speciality shops such as luxury goods retailers or local community shops that provide small goods for local residents. Furthermore, people who are less likely to feel comfortable stay on wider streets because of tropical and subtropical weather in Taiwan. Therefore, it could be argued that the installation of arcades in Taiwan since the Japanese colonial period can be associated with the adaptation of Western-style architecture in Taiwan.

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7. References

1.Nikolopoulou, M., N. Baker and K. Steemers, (2001). Thermal comfort in outdoor urban spaces: understanding the human parameter. *Solar Energy*, 70:227-35

2.Thorsson, S., M. Lindqvist and S. Lindqvist, (2004). Thermal bioclimatic conditions and patterns of behaviour in an urban park in Goteborg, Sweden. *International Journal of Biometeorology*, 48:149-56.

3.Eliasson, I., I. Knez, U. Westerberg, S. Thorsson and F. Lindberg, (2007). Climate and behaviour in a Nordic city. *Landscape and Urban Planning*, 82:72-84.

4.Lin, T.P., (2009). Thermal perception, adaptation and attendance in a public square in hot and humid regions. *Building and Environment*, 44:2017-26.

5.Lin, T.P., R.J. de Dear and R.L. Hwang, Effect of thermal adaptation on seasonal outdoor thermal comfort. *International Journal of Climatology (in press, DOI: 10.1002/joc.2120)*.

6.Lin, T.P., Y.F. Ho and Y.S. Huang, (2007). Seasonal effect of pavement on outdoor thermal environments in subtropical Taiwan. *Building and Environment*, 42:4124-31.

7.Johansson, E., (2006). Influence of urban geometry on outdoor thermal comfort in a hot dry climate: A study in Fez, Morocco. *Building and Environment*, 41:1326-38.

8.Emmanuel, R. and E. Johansson, (2006). Influence of urban morphology and sea breeze on hot humid microclimate: the case of Colombo, Sri Lanka. *Climate Research*, 30:189-200.

9.Ali-Toudert, F. and H. Mayer, (2007). Thermal comfort in an east-west oriented street canyon in Freiburg (Germany) under hot summer conditions. *Theoretical and Applied Climatology*, 87:223-37.

10.Emmanuel, R., H. Rosenlund and E. Johansson, (2007). Urban shading - a design option for the tropics? A study in Colombo, Sri Lanka. *International Journal of Climatology*, 27:1995-2004.

11.Shashua-Bar, L., D. Pearlmutter and E. Erell, The influence of trees and grass on outdoor thermal comfort in a hot-arid environment. *International Journal of Climatology (in press, doi: 10.1002/joc.2177)*.

12.Giridharan, R., S.S.Y. Lau and S. Ganesan, (2005). Nocturnal heat island effect in urban residential developments of Hong Kong. *Energy and Buildings*, 37:964-71.

13.Bottyan, Z. and J. Unger, (2003). A multiple linear statistical model for estimating the mean maximum urban heat island. *Theoretical and Applied Climatology*, 75:233-43.

14.Höppe, P., (1999). The physiological equivalent temperature - a universal index for the biometeorological assessment of the thermal environment. *International Journal of Biometeorology*, 43:71-75.

15.Mayer, H. and P. Höppe, (1987). Thermal comfort of man in different urban environments. *Theoretical and Applied Climatology*, 38:43-49.

16.Gulyas, A., J. Unger and A. Matzarakis, (2006). Assessment of the microclimatic and human comfort conditions in a complex urban environment: Modelling and measurements. *Building and Environment*, 41:1713-22.

17.Lin, T.P., A. Matzarakis and J.J. Huang. Thermal comfort and passive design of bus shelters. Proceedings of 23rd Conference on Passive and Low Energy Architecture (PLEA2006), Geneva, 2006.

18.Matzarakis, A., F. Rutz and H. Mayer, (2007). Modelling radiation fluxes in simple and complex environments - Application of the RayMan model. *International Journal of Biometeorology*, 51:323-34.

19.Matzarakis, A., F. Rutz and H. Mayer, (2010). Modelling radiation fluxes in simple and complex environments: basics of the RayMan model. *International Journal of Biometeorology*, 54:131-39.

20.Brager, G.S. and R.J. de Dear, (1998). Thermal adaptation in the built environment: a literature review. *Energy and Buildings*, 27:83-96.

21.Lin, T.P. and A. Matzarakis, (2008). Tourism climate and thermal comfort in Sun Moon Lake, Taiwan. *International Journal of Biometeorology*, 52:281-90.

22.Lin, T.P., A. Matzarakis and R.L. Hwang, (2010). Shading effect on long-term outdoor thermal comfort. *Building and Environment*, 45:213-21.

23.ISO. International Standard 7726, Thermal environment-instruments and method for measuring physical quantities. Geneva: International Standard Organization; 1998.

24.Thorsson, S., F. Lindberg, I. Eliasson and B. Holmer, (2007). Different methods for estimating the mean radiant temperature in an outdoor urban setting. *International Journal of Climatology*, 27:1983-93.

25.Chang, J.S. Modern Taiwan Urban Planning – A Political Economic Historical Study: 1895-1988. Unpublished Dissertation. National Taiwan University, 1991.

26.King, A.D. Urbanism, Colonialism, and the World-Economy: Cultural and Spatial Foundations of the World Urban System. London and New York: Routledge; 1990.