Building and Environment 46 (2011) 863–870

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Seasonal effects of urban street shading on long-term outdoor thermal comfort

Ruey-Lung Hwang [a], Tzu-Ping Lin [b,*], Andreas Matzarakis [c]

[a] Department of Architecture, National United University, 1 Lien Da, Miaoli 360, Taiwan
[b] Department of Leisure Planning, National Formosa University, 64 Wen-Hua Rd, Huwei, Yunlin 632, Taiwan
[c] Meteorological Institute, Albert-Ludwigs-University Freiburg, Werthmannstr. 10, D-79085 Freiburg, Germany

ARTICLE INFO

Article history:
Received 20 July 2010
Received in revised form
12 October 2010
Accepted 16 October 2010

Keywords:
Shading effect
Urban streets
Outdoor thermal comfort
Sky view factor

ABSTRACT

As shading, an important factor in urban environments, affects thermal environments and long-term thermal comfort, this study conducted several field experiments to analyze the outdoor thermal conditions on urban streets in central Taiwan. The RayMan model was utilized for predicting long-term thermal comfort using meteorological data for a 10-year period. Analytical results indicate that slightly shaded areas typically have highly frequent hot conditions during summer, particularly at noon. However, highly shaded locations generally have a low physiologically equivalent temperature (PET) during winter. Correlation analysis reveals that thermal comfort is best when a location is shaded during spring, summer, and autumn. During winter, low-shade conditions may contribute to the increase in solar radiation; thus, thermal comfort is improved when a location has little shade in winter. We suggest that a certain shading level is best for urban streets, and trees or shade devices should be used to improve the original thermal environment.

1. Introduction

Outdoor thermal comfort of people are affected by thermal environment, moreover, people's usage of outdoors are affected by their perception of outdoor thermal conditions[1–4]. Furthermore, outdoor thermal environments are significantly affected by the design of built environment [5–10]. Since shadings can block direct solar radiation, numerous studies examine the effects of shading on outdoor thermal environments. For instance, previous studies [11–18] 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 as representative of shading levels [19–23].

Ali-Toudert and Mayer, who simulated microclimatic changes by applying the ENVI-met model to an urban environment in Ghardaia, Algeria [15,16], determined that the spatial distribution of physiologically equivalent temperature (PET) at the street level depended strongly on the H/W ratio of urban streets. Emmanuel et al. [13] conducted field experiments at five locations during spring in the city of Colombo, Sri Lanka. They calculated the mean radiant temperature (Tmrt) and PET using the RayMan model [24], and found that deep street canyons (i.e., highly shaded streets) improved the outdoor thermal comfort of pedestrians. Lin et al. [25] indicated that studies with few field experiments can elucidate characteristics measured (or simulated) on a particular day and likely do not represent annual thermal conditions. Therefore, they conducted several field experiments to analyze outdoor thermal conditions at a university campus in central Taiwan, and employed the RayMan model for predicting long-term thermal comfort using meteorological data for a 10-year period. The thermal comfort range of PETs of Taiwanese residents obtained in a previous study [26] was also applied as the criterion for determining whether a thermal environment is comfortable or uncomfortable.

However, some issues related to shading on urban streets need further clarification. First, previous studies have not discussed the relationship between shading and thermal comfort in different seasons. Since a thermal environment may be comfortable in summer and cold in winter under the same amount of shade, the thermal comfort of a location must be addressed in different seasons. Furthermore, thermal comfort may vary at different times of the day (e.g. hot at noon and cool in the morning); thus, one must also determine the thermal comfort distribution during a given day to elucidate the thermal conditions at different times.

Buildings on Taiwan's traditional streets are mostly residential and commercial, i.e., the first floor is rented by stores and all other floors are residential. If these buildings are not designed with an arcade on the ground floor and lack shading, people must walk beside the street while shopping, and are exposed to the outdoor climate. Thus, people may not be satisfied with their shopping experiences when they feel uncomfortable in an outdoor thermal environment, adversely affecting store revenue and reducing rental

* Corresponding author. Tel.: +886 5 631 5890; fax: +886 5 631 5887.
E-mail address: tplin@nfu.edu.tw (T.-P. Lin).

0360-1323/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.buildenv.2010.10.017