Building and Environment 87 (2015) 154–168

Contents lists available at ScienceDirect

Building and Environment

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

Thermal performance characteristics of unshaded courtyards in hot and humid climates

Amirhosein Ghaffarianhoseini [a], Umberto Berardi [b, *], Ali Ghaffarianhoseini [c]

[a] Department of Geography, Faculty of Arts and Social Science, University of Malaya (UM), Kuala Lumpur, Malaysia
[b] Department of Architectural Science, Ryerson University, 350 Victoria Street, Toronto, Ontario M5B 2K3, Canada
[c] School of Engineering, Faculty of Design and Creative Technologies, AUT University, Auckland, New Zealand

ARTICLE INFO

Article history:
Received 10 November 2014
Received in revised form
17 January 2015
Accepted 1 February 2015
Available online 7 February 2015

Keywords:
Outdoor thermal comfort
Urban microclimate
Hot and humid climate
Courtyard
Urban design

ABSTRACT

In recent years, there has been a growing interest in the design of courtyards for the microclimatic enhancement of outdoor spaces. However, there is still little knowledge regarding the thermal performance characteristics of courtyards, particularly in hot and humid climates. This study evaluates the ability of unshaded courtyards for providing thermally comfortable outdoor spaces according to different design configurations and scenarios, including the orientations, height and albedo of wall enclosure, and use of vegetation. The software ENVI-met was used as a tool for simulating the thermal performance of courtyards in the hot and humid climate of Kuala Lumpur, Malaysia. The PMV and the number of hours per day that a courtyard could be enjoyed once the proposed design suggestions were implemented are assessed. Likewise, the Physiologically Equivalent Temperature (PET) index allowed to further explore the thermal comfort conditions of courtyards. As a result, guidelines are proposed in order to optimize the design of courtyards towards enhancing their thermal performance characteristics. In particular, the study shows that according to design parameters such as the building height ratio, an abundance in the amount vegetation the courtyard can achieve an acceptable level of thermal comfort for the tropics and may be enjoyed by its users for a long duration of daytime even during the noontime. Finally, this paper stresses that only well designed courtyards may represent a valid option for sustainable built environments.

1. Introduction

Modeling the relationship between buildings and the surrounding outdoor environment is a multidisciplinary imperative for urban climate and outdoor thermal comfort [1–3]. In view of the negative impacts of the urban heat island effect, particularly on energy use, air quality and human health [4] and its significant influence on urban comfort [5], meteorological studies which previously focused primarily on the meso-scale (10–40 km) have recently started to focus on the micro-scale (less than 1 km). This is due to the importance of the microclimate of outdoor spaces and urban canopy layers as significant elements of contemporary urban areas [3–5].

Given the growing interest in outdoor thermal comfort and urban life [6], various attempts have been made to study the impacts of courtyards on natural ventilation and thermal comfort [7–9]. In fact, several potential benefits can be achieved by controlling the micro-scale characteristics of outdoor spaces through courtyards.

The impact of courtyards in some climates has been assessed qualitatively and quantitatively by using field measurements and computer modeling [1,10–14] However, there have been very few studies [2,15,16] that focus on the tropical climate where, due to high temperatures and relative humidity levels, the utilization of courtyards merits detailed investigations. In the context of the tropical climate, cooling effects in outdoor spaces can be enhanced by reducing the solar radiation received by the ground [17].

This study aims to evaluate quantitatively the thermal effects of a courtyard in Malaysia and to suggest guidelines to design more sustainable built environments in this climate zone.

2. Thermal effects of courtyards

A courtyard is an enclosed outdoor or semi-outdoor space surrounded by buildings and open to the sky. Courtyards were primarily adopted in vernacular buildings in parts of Asia, the Middle

* Corresponding author. Tel.: +1 416 979 5000x3263; fax: +1 416 979 5153.
E-mail address: uberardi@ryerson.ca (U. Berardi).

http://dx.doi.org/10.1016/j.buildenv.2015.02.001
0360-1323/

East, South America, and the Mediterranean countries [18–20]. Their function was to improve comfort conditions by modifying the microclimate around the building and by enhancing ventilation. Different archetypes have been adopted for courtyards design in different countries (and weathers) through the centuries. Romans and Arabs often included colonnades, especially in convents and important palaces. The history of using courtyards in Malaysia goes back to the era of indigenous architecture where Malay traditional houses in Melaka, Malaysia's oldest city, incorporated enclosed inner courtyards based on the influence of traditional Chinese houses [2,21]. Courtyards were similarly observed in the design of Chinese traditional [22]. The growing interest in the use of courtyards in various types of contemporary architectural projects including residential, educational and healthcare is evident in the Malay context (Fig. 1). Nevertheless, it can be argued that despite the importance of courtyard design in Malaysia, considerably less attention has been paid to the circumstances of enhancing their thermal performance and the development of design guidelines for improving their effectiveness towards achieving outdoor thermal comfort.

Literature related to the performance of courtyards mainly examines inter-courtyard air movements, sun-shadow relations, and formal configurations [24]. One of the first attempts towards analyzing the thermal performance of courtyards is reported by Dunham [25]. Subsequently, the potential of courtyards for ensuring sufficient ventilation and maximized airflow was confirmed through CFD analysis and wind tunnel studies while airflow patterns within a courtyard were illustrated [25–27]. Likewise, shading inherent in courtyards has been reported to be highly contributive to thermal comfort [26]. Meanwhile, the significant roles of courtyards in bringing in daylight, ensuring natural ventilation and optimizing the thermal behavior have been reported by Khan et al. [18] and Acosta et al. [13].

The study by Aldawoud reveals that courtyards are more energy efficient in hot climates than in temperate or cold climates [25]. Al-Masri and Abu-Hijleh identify that a building integrated with courtyard in the hot and humid climate of Dubai consumes 6.9% less energy per year in comparison to a typical building [19].

Courtyards are claimed to be highly efficient in enhancing the ventilation and decreasing the humidity level, as shown by Rajapaksha et al. who also illustrated a strong correlation between courtyard wall surface temperatures and indoor air temperatures [15].

Ernest ascertains that the application of bio-climatic features such as the use of vegetation is highly recommended for improving the performance of courtyards [28]. For instance, in Israel, the utilization of trees and grass in courtyards led to enhanced comfort through their daytime cooling which ranges a PMV between 1.5 and 2.5 based on different landscape treatments [12]. In addition, experimental studies in Saudi Arabia indicated that covering courtyards during the daytime while opening it to the sky during night reduces the outdoor air temperature by 4 °C [29].

The study by Safarzadeh and Bahador show that courtyards alone cannot ensure a high level of thermal comfort in the hot summer hours in Tehran, Iran, although they can decrease the cooling energy load [10]. Muhaisen analyzes the impact of different design configurations of courtyards based on shading simulations [7]. This study found that shading conditions of courtyards are

Fig. 1. Samples of courtyards in different building types in Malaysia; (a) Courtyard in Melaka town houses; (b) Courtyard in a renovated terrace house, Bangsar; (c) Courtyard in a restored 18th century Melaka shop house; (d) Courtyard in British council complex, Kuala Lumpur; (e) Courtyard in the University Putra Malaysia, Serdang [23].