Building and Environment 125 (2017) 261–272

Contents lists available at ScienceDirect

Building and Environment

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

Towards an integrated method to assess effects of lift-up design on outdoor thermal comfort in Hong Kong

Yaxing Du [a], Cheuk Ming Mak [a,*], Taiyang Huang [a], Jianlei Niu [a,b]

[a] Department of Building Services Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong
[b] Faculty of Architecture, Design and Planning, The University of Sydney, Australia

ARTICLE INFO

Article history:
Received 6 June 2017
Received in revised form
2 September 2017
Accepted 2 September 2017
Available online 5 September 2017

Keywords:
Lift-up design
Thermal comfort
Integrated method
Wind tunnel test
On-site monitoring

ABSTRACT

City residents wish to have pleasant experience in outdoor space, which are often impeded by thermally uncomfortable conditions, particularly in hot and humid summer. Lift-up design can provide comfortable microclimate in summer but the effects of lift-up design on thermal comfort in a built-up environment have not been systematically studied. This paper aims to investigate the effects of lift-up design on outdoor thermal comfort comprehensively, as well as the effects on pedestrian level wind environment. The thermal comfort assessments are carried out by using a proposed integrated method, which combines wind tunnel tests and on-site monitoring to calculate Physiologically Equivalent Temperature (PET) values. The Hong Kong Polytechnic University (HKPolyU) campus is selected as study area. The investigation mainly focuses on summer and winter seasons. Four typical days in a year were chosen to carry out on-site monitoring for obtaining environmental parameters. This study demonstrates that the proposed integrated method can be used to predict outdoor thermal comfort. Results also show that lift-up design can effectively improve pedestrian level wind environment and thermal comfort. Moreover, lift-up design can provide a comfortable microclimate in summer while not cause strong cold stress in winter. These findings provide solid evidence bases to city planners and architects of available options for creating pleasant outdoor microclimate in precinct planning.

1. Introduction

Comfortable outdoor environments can encourage people to go outside and enjoy leisure activities, such as walking, jogging and cycling. Besides, outdoor activities can also help efficiently reduce building energy consumption that constitutes more than 60% of energy needs in Hong Kong in 2016 [1]. However, outdoor thermal comfort is often impeded by uncomfortable conditions, like intense solar radiation, unfavourable wind environment, high temperature and so on [2–8]. Meanwhile, recent studies have demonstrated that the average temperature of Hong Kong shows a rising trend and the unbearable hot and humid period has become remarkably longer than the past century [9]. Moreover, future projections have indicated that the period will continue in the 21st century and extreme high temperature events in Hong Kong will notably increase in the future [10]. Apart from high temperature problem, the stagnant air at pedestrian level also causes thermally uncomfortable environment in the hot and humid summer [11]. Therefore, against the background of global climate change and rapid urbanization, the creation of a thermally comfortable microclimate is very much desired in hot and humid Hong Kong [11–14].

A considerable amount of investigations have been carried out to improve microclimate thermal comfort in urban context. Two common approaches that have been used to create pleasant microclimate in hot and humid areas are wind amplification and shading techniques [11,13,15–18]. It has been confirmed in previous studies that the wind velocity made great difference in thermal comfort, especially in hot and humid regions [11]. The Hong Kong SAR government has established the Air Ventilation Assessment (AVA) scheme with the purpose of enhancing wind velocity at pedestrian level [18]. Hang [16] investigated wind conditions in high-rise long street in a city scale, and the results indicated that tall buildings with wide streets can enhance the city ventilation and remove heat stress. As for shading techniques, Gehl [19] studied the effect of shading on the popularity of sensitive bench in public places. Lin [20] indicated that sufficient shading should be guaranteed for providing thermally comfortable environment in

* Corresponding author.
E-mail address: cheuk-ming.mak@polyu.edu.hk (C.M. Mak).

http://dx.doi.org/10.1016/j.buildenv.2017.09.001
0360-1323/

Taiwan. Johansson and Emmanuel [21] clearly stated that shading played an important role in outdoor thermal comfort in tropical cities.

Among numerous techniques that can improve thermal comfort in hot and humid regions, lift-up design that “lifted off” the buildings from ground with modern pillars has become more and more popular in hot and humid cities. This can be attributed to its prominent feature of providing local cooling spot in hot and humid summer due to wind amplification and shading effect, which has been indicated in our previous researches [11,13,15,17,22]. Niu et al. [11] conducted on-site measurement in the lift-up and podium areas of HKPolyU campus. Xia et al. [22] and Tse et al. [17] both carried out wind tunnel tests to study the effects of lift-up design on pedestrian level wind environment. Du et al. [15] performed numerical simulation to investigate the effects of lift-up design in different building shapes on pedestrian level wind environment. Liu and Niu [13] combined numerical results and on-site monitoring parameters to predict thermal comfort around an isolated building with lift-up design. Previous studies have shown that for the isolated buildings, even though the lift-up design can significantly amplify wind velocity at pedestrian level, the amplification effect is limited to neighbouring areas around the buildings [13,15,17,22]. Besides, the lift-up design in the HKPolyU campus can provide local cooling spot in hot and humid summer [11]. However, the aforementioned studies are mostly focused on isolated buildings and the on-site measurements were only conducted for two summer days. Therefore, there is a lack of systematic study to quantitatively evaluate the potential benefits of lift-up design on pedestrian level wind environment and thermal comfort in a complex urban environment for long term (summer and winter seasons, respectively), which is genuinely needed for fully understanding of the effects of lift-up design on pedestrian level wind environment and thermal comfort.

In the past decades, on-site monitoring approach was used as the main method for evaluating outdoor thermal comfort [7,8,12,23–32]. For instance, Ng and Cheng [12] conducted an outdoor thermal comfort study in Hong Kong by using on-site monitoring approach. The results showed that the meteorological parameters, including air temperature, wind speed and solar radiation intensity, were important for outdoor thermal sensation. Ali-Toudert et al. [26] carried out on-site monitoring approach in an urban street canyon in Germany. They found that the street geometry and orientation had a great impact on the heat stress gained by people under hot conditions. Hwang et al. [28] studied the thermal comfort in workplaces and residences in Taiwan using on-site monitoring approach. The findings revealed that the thermal adaption behaviour of people can be affected by the used thermal adaptation method. Nikolopoulou et al. [29,30] conducted on-site monitoring in UK, and the findings enriched the understanding of microclimatic characteristics in outdoor urban spaces. However, these studies were merely elucidated thermal comfort characteristics of a particular day and cannot be used to represent long-term thermal conditions [20]. In order to acquire local wind statistics at pedestrian level, wind tunnel test has been intensively utilized [33–36]. The data obtained from wind tunnel tests are usually used to either analyse the local wind environment or utilized as benchmark data for further numerical validation [15,33,37]. Kubota et al. [35] employed wind tunnel techniques to study the relationship between building density and pedestrian level wind velocity. Tsang et al. [36] investigated the effects of building dimensions, separations and podium on pedestrian level wind environment. To the best knowledge of the authors, there are few studies that combines these two techniques to predict outdoor thermal comfort for a local precinct.

In this paper, the effects of lift-up design on thermal comfort in a complex environment are investigated by using a proposed integrated method which combines wind tunnel test techniques and on-site monitoring approach. Meanwhile, the effects of lift-up design on pedestrian level wind environment are also systematically studied. In addition, PET is adopted in this paper as thermal comfort index, which is typically and frequently used for evaluating outdoor environment [3,20,21,38]. The study of the HKPolyU campus, which is located in the midtown of Hong Kong, is presented in this study to illustrate the proposed method. The wind tunnel tests of the campus model were conducted correspondingly. The environmental parameters of four typical days were obtained by on-site monitoring techniques: one cloudy day in summer, one sunny day in summer, one cloudy in winter and one sunny day in winter.

The rest of this paper is organised as follows: after introduction, the methodology for obtaining parameters is presented in Section 2. Section 3 describes data analysis method for this study. The effects of lift-up design on pedestrian level wind environment are discussed in Section 4.1 and the effects of lift-up design on thermal comfort are presented in Section 4.2. Finally, Section 5 concludes the paper.

2. Methodology

2.1. On-site monitoring

The environmental parameters which were perceived as influencing parameters for thermal comfort were continuously monitored for four typical days: one cloudy day in summer (Jul. 15, 2016), one sunny day in summer (Aug. 22, 2016), one cloudy day in winter (Dec.6, 2016), and one sunny day in winter (Dec. 12, 2016). Meanwhile, data loggings of the environmental parameters were taken continually from 09:00 a.m. to 18:00 p.m. for the four typical days. Two sites were selected in the campus as monitoring locations, as shown in the photos of Fig. 1: Site 1 was on the podium area of the Ho lu Kong and Kow Pui Chun Square (Fig. 1(a)) and Site 2 was in the lift-up area underneath the Chow Yei Ching building (Fig. 1(b)). As a matter of fact, this lift-up area is often used for outdoor activities, such as dancing, practicing martial arts and formal exhibitions. On the contrary, the open square is seldom used for holding outdoor activities because of the direct subjection to solar radiation, especially in the hot and humid Hong Kong summer.

The mini weather stations were used to measure the environmental parameters in the four sample days at these two selected sites. The monitored environmental parameters were: air temperature (T_a, °C), relative humidity (RH, %), short-wave and long-wave radiation (K_i and K_i (W/m^2), $i = 6$ means six directions perpendicular to each other). It should be mentioned that all the instruments were complied with ISO 7726 standard [39]. The photos of the mini weather station are shown in Fig. 2 and the specifications of measuring instruments are illustrated in Table 1. The data logging was taken 10s intervals during the tests for all the monitored environmental parameters. Besides, all the instruments were carefully pre-tested and calibrated before each on-site monitoring. Noted that only measurement results of net radiometer instrument and T_a & RH sensor, which are specified in Fig. 2, are used in this study.

2.2. Wind tunnel tests

The pedestrian level wind velocity was obtained from wind tunnel tests of the HKPolyU campus model. The wind tunnel tests were conducted in the low-speed section of CLP Power Wind/Wave Tunnel Facility (WWTF) at Hong Kong University of Science and