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# Improving pedestrian level low wind velocity environment in high-density cities: A general framework and case study

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ABSTRACT

An acceptable pedestrian level wind environment is essential to maintain an enjoyable outdoor space for city residents. Low wind velocity environment can lead to uncomfortable outdoor thermal experience in hot and humid summer, and it is unable to remove the pollutants out of city canyons. However, the average wind velocity at pedestrian level is significantly lowered by closely spaced tall buildings in modern megacities. To improve the low wind velocity environment at pedestrian level in high-density cities, a general framework and detailed guidelines are needed. This study is the first time to develop such a framework, and provide detailed guidelines for improving pedestrian level low wind velocity environment in high-density cities. Additionally, a detailed review and summarisation of evaluation criteria and improvement measures are presented in this paper, which provide additional options for urban planners. To investigate the performance of the framework, the Hong Kong Polytechnic University campus was utilised as a case study. Results showed that pedestrian level wind comfort was greatly improved with the developed framework. The outcomes of this study can assist city planners to improve the low wind velocity environment, and can help policy makers to establish sustainable urban planning policies.

## 1. Introduction

Outdoor spaces are considered vital constituents of urban environments because they can host entertainment activities that are fundamental to the character of a city and the quality of life of city residents (Chen & Ng, 2012). In particular, outdoor human comfort is extremely important in city planning because it can not only improve the physical and mental health of city residents, but also can help reduce power consumption in residential buildings (Amindeldar, Heidari, & Khalili, 2017; Chatzidimitriou & Yannas, 2016; Elnabawi, Hamza, & Dudek, 2016; Kong et al., 2017; Li, Huang, Wu, & Xu, 2018). Actually, an enjoyable outdoor thermal comfort can encourage city residents to spend more time in outdoor spaces (Chen & Ng, 2012; Du, Mak, Huang, & Niu, 2017). However, congested airflow at the pedestrian level has become a major concern in the high-density cities because it is the driving force for the transfer of pollutant, heat, and water vapour (Ai & Mak, 2015; Chatzidimitriou & Yannas, 2017; Ignatius, Wong, & Jusuf, 2015). This problem is more serious in densely built cities at low or mid latitudes, such as Hong Kong and Singapore, which suffer from urban heat island and global warming (Du, Mak, Kwok et al., 2017; Kong et al., 2017; Ng, 2009; O'Malley, Piroozfar, Farr, & Pomponi, 2015; Yang, Wong, & Jusuf, 2013). Therefore, improving pedestrian level wind environment in high-density cities has become a pressing issue for the establishment of comfortable, healthy, and sustainable cities.

A strong relationship between low wind velocity environments at pedestrian level and unfavourable outdoor living environments has been widely identified in high-density cities (Ignatius et al., 2015). For sub-tropical and densely built cities, such as Hong Kong, the wind speed and radiant temperature are the most influencing factors of pedestrian thermal comfort in hot and humid summers (Niu et al., 2015). In particular, Cheng, Ng, Chan, and Givoni (2012) reported that even in shaded environments, the thermal sensation of respondents was not neutral when wind velocity was below 0.9 m/s during the hot and humid summer of Hong Kong. The cooling effect of wind flow can contribute to the reduction of heat stress in urban cities (Memon, Leung, & Liu, 2010; Priyadarsini, Hien, & Wai David, 2008; Yang & Li, 2011). It was identified that a wind speed of 1 m/s to 1.5 m/s could lower the air temperature by nearly 2 °C (Erell, Pearlmutter, & Williamson, 2012). Thus, low wind velocity environment has a negative effect on outdoor thermal comfort, particularly in hot and humid summers. In addition, the dispersion and dilution of airborne pollutants in the urban environment depend strongly on wind flow because it can help remove pollutants to external surroundings (Ai & Mak, 2014a,b, 2016; Hang & Li, 2011; Kim & Baik, 2004; N'riain, Fisher, Martin, &

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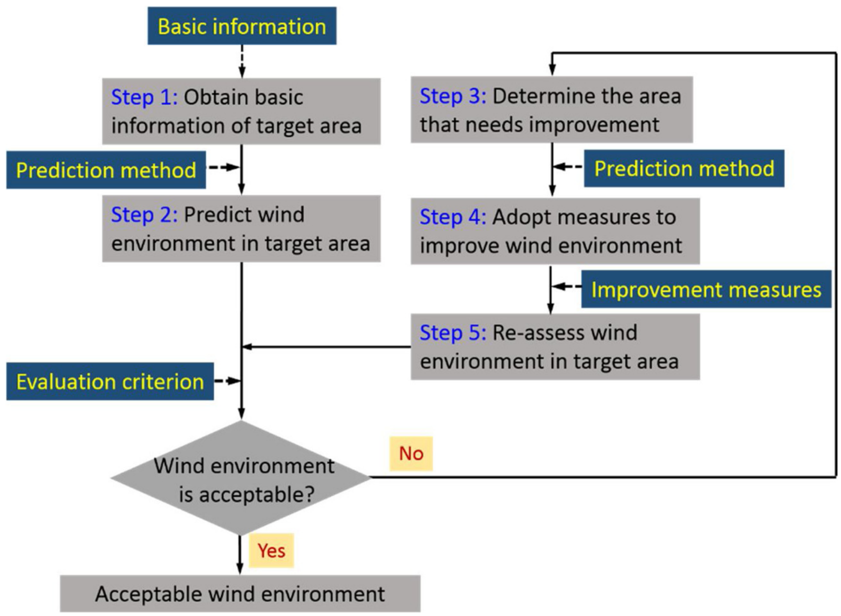


**Fig. 1.** Design framework for improving pedestrian level low wind velocity environment in high-density city.

Littler, 1998). The outbreak of severe acute respiratory syndrome (SARS) in Hong Kong urged the officials and city residents to consider the pollutant dispersion in their living environment (Li, Duan, Yu, & Wong, 2005). By analysing the results from field measurements, Jones, Fisher, Gonzalez-Flesca, and Sokhi (2000) indicated that traffic pollutants could not be properly dispersed or diluted with weak wind conditions in urban areas. Moreover, low wind velocity environments in the street canyons could not form the coupling process to remove the pollutants from the street canyons to the upper atmosphere (Jones et al., 2000; Vignati, Berkowicz, & Hertel, 1996).

There have been a substantial investigations into the improvement of pedestrian level wind environment in the past few decades (Blocken, Stathopoulos, & van Beeck, 2016; Du, Mak, Huang et al., 2017, 2017c; Hang, Sandberg, & Li, 2009; Hang, Li, Sandberg, Buccolieri, & Di Sabatino, 2012; Kubota, Miura, Tominaga, & Mochida, 2008; Liu, Niu, & Xia, 2016; Mirzaei & Haghighat, 2010). Tsang, Kwok, and Hitchcock, (2012) conducted wind tunnel tests to investigate the influence of building dimensions, separations, and podiums on pedestrian level wind environment. Their results indicated that wide buildings with podiums should be discouraged in building designs in high-rise cities, for resulting in large areas of low wind velocity environment around buildings. In the study of Kubota et al. (2008), the relationship between the gross building coverage ratio and the wind environment at pedestrian level from actual Japanese city was quantitatively studied using wind tunnel tests. The results showed that a small gross coverage ratio should be adopted in city planning because a high gross coverage ratio results in low wind velocity at pedestrian level, especially for the detached houses. Niu et al. (2015) conducted field measurements in a university campus in Hong Kong, and their findings indicated that local wind amplification could be achieved by utilising an innovative building design (lift-up design). Hang, Li, Sandberg et al. (2012) numerically studied the wind environment in idealized high-rise urban areas, and reported that building height variation could improve pedestrian level wind environment. Apart from the above mentioned measures, the Hong Kong government has issued the air ventilation assessment (AVA) scheme to enhance wind flow movement at pedestrian level (Ng, 2009). Later, new wind comfort criteria were proposed by Du, Mak, Kwok et al. (2017), which were aimed at assessing wind comfort in low wind velocity environments. However, no general framework that provides detailed application procedure has been presented. Therefore, a general framework that can be applied to improve pedestrian level wind environment is in urgent needed.

In this study, a general framework for improving low wind velocity environment at pedestrian level was developed, and this paper provides detailed guidelines for the framework. Moreover, measures that have been utilised in improving the low wind velocity environment in high-density cities were thoroughly reviewed. Meanwhile, the evaluation criteria aimed at assessing low wind velocity environment at the city scale are summarized in this paper. A case study of the Hong Kong Polytechnic University (HKPolyU) campus model was used to elaborate this framework and demonstrate its performance. The remainder of this paper is structured as follows: Section 2 describes the general design framework for improving the low wind velocity environment and describes its detailed guidelines. Sections 3 and 4 summarise the evaluation criteria and improvement measures. The performance of the design framework was investigated with a case study of HKPolyU campus, which is presented in Section 5. Concluding remarks are given in Section 6.

## 2. Design framework and guidelines

This section describes the design framework and guidelines in detail. Note that the present study only concerns the improvement of low wind velocity environments in high-density cities. However, the general framework developed in this study can also be used to mitigate the nuisance caused by strong wind conditions. In doing so, the improvement measures and evaluation criteria need to be re-determined. A flow chart of the design framework for improving the pedestrian level low wind velocity environment in a high-density city is shown in Fig. 1. Meanwhile, the basic parameters for the design framework are summarized in Fig. 2. Based on Figs. 1 and 2, the detailed guidelines for the improvement of pedestrian level low wind velocity environment are presented as follows:

- Step 1: basic information on the target area should be collected before evaluating the wind environment at pedestrian level. This includes the target area, surrounding area, local wind climate, building information, and geomorphological information. It is well known that urban wind flow is very complex and is closely related to the urban morphology, especially in high-density cities. Thus, for scaled models, accurate reproduction of the buildings and geomorphological features of the target area are very important. These