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Pedestrian level wind environment assessment around group of high-rise cross-shaped buildings: Effect of building shape, separation and orientation

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ABSTRACT

Blockage of air circulation caused by the mutual sheltering effect of high-rise buildings in built-up areas in dense cities causes various health- and comfort-related problems. The combined effect of neighborhood geometry (e.g., re-entrant corners, wind incident angle, passage angle, and building separation) on wind flow at the pedestrian level is an active field of research. This study investigates the influence of the wind incident angle and passage width on the wind flow characteristics at the re-entrant corners of cross-shaped high-rise buildings. This study also examines the influence of stagnant zones and wake regions on ventilation potential and wind comfort around the case study arrangements at various wind incident directions. An investigation was performed from 16 wind directions using the standard $k-\varepsilon$ turbulence model with revised closure coefficients. A wind tunnel experiment was conducted to validate the results, which revealed that wind circulation at re-entrant corners was substantially affected by the building orientations and separation. The wind catchment effect within the re-entrant corners and the sheltering effect of buildings at various wind incident directions and building separations are also discussed. Unstable vortices were formed in oblique wind directions; these vortices facilitate contaminant dispersion and wind comfort at re-entrant corners and near buildings.

1. Introduction

Wind flow assessments around high-rise buildings, particularly in built-up areas in megacities, are essential for pollution dispersion and ensuring human health and thermal comfort at the pedestrian level [1–3]. Wind flow modeling in urban areas has recently received considerable attention due to an increase in urbanization and high-rise buildings, which directly affect wind flow patterns and urban environments [4]. Urban air quality is a major concern [1]. Dense areas have formed due to the blockage effect from high-rise buildings [5]. Outdoor wind comfort analyses are currently included in building design processes [6]. The majority of building design authorities worldwide recommend an outdoor wind comfort analysis prior to new building construction [6,7]. To estimate the wind-flow patterns around high-rise buildings within canopies and at the pedestrian level, various numerical techniques have been employed [8,9]. Due to advancements in modeling techniques, building parameters such as building orientations and separation are analyzed based on the wind flow patterns in the respective area during the design stage. These parameters directly affect the wind flow patterns in the respective area, which alter the surrounding wind environment.

Numerous researchers have conducted outdoor investigations to create comfortable wind environments around buildings, especially at the pedestrian level. For example, Stathopoulos [10] examined all existing outdoor comfort criteria, especially wind speed, air temperature, and relative humidity, to ensure thermal comfort around various buildings. Blocken et al. [11] provided a comprehensive review of pedestrian-level wind environment assessments from 1960 onwards. With advancements in computational power, computational fluid dynamics (CFD) marked a breakthrough in wind engineering [12]. Blocken [8,12] discussed the detailed contributions of CFD in wind engineering over the last 50 years and provided guidelines for accurate CFD simulation. In addition to wind assessments, few researchers, such as Yang et al.

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[13] who described an approach to establishing a total comfort index, have focused on comfort criteria. Stathopoulos et al. [14] proposed pedestrian-level wind comfort criteria and discussed a knowledge-based approach to building design. Blocken et al. [15] proposed a modification to existing pedestrian-level wind assessment criteria. The majority of previous studies have been limited to wind flow analysis around conventional buildings. For irregularly shaped buildings, previous studies have been limited to wind load and pollution dispersion within the re-entrant bay [16,17]. Chow et al. [18] investigated wind flow through a re-entrant bay at a building's midlevel. In a similar manner, Cheng et al. [19] examined pollution dispersion and flow through a re-entrant bay. Cook [20] provided an overview of wind flow in the re-entrant corner and bay of various arrangements; however, he did not provide details on wind flow patterns. In addition to wind comfort analysis, this study examines the influence of various wind incident directions and building separations on wind flow within the re-entrant corners of cross-shaped residential building blocks.

This study analyzed common cross-shaped residential building blocks, which are referred to as ‘harmony blocks’, in Hong Kong (Fig. 1). A ‘harmony block’ is a cross-shaped type of high-rise building block with 18 residential flats per floor. According to the Council on Tall Buildings and Urban Habitat, buildings taller than 50 m are referred to as high-rises [21]. Currently, harmony blocks are a mainstream, standard design for public rental housing in Hong Kong. Hong Kong is a densely populated city of more than 7 million people [22]. Compared with other Asian cities, Hong Kong has a unique urban morphology and humid weather. In 2003, the severe acute respiratory syndrome (SARS) virus spread in Hong Kong, which caused nearly 300 deaths. An investigation found that fatalities occurred in a high-rise cluster of buildings name “Amoy Garden”. More than 200 casualties were reported above the ninth floor of the buildings, whereas no casualties were reported below the ninth floor. After the investigation, medical professionals reported that the SARS virus may have originated in the 16th-floor bathroom of an infected unit and spread throughout the air-flow path of the building re-entrant bay to other units [23]. Mao et al. [24] recently discussed pollution dispersion and the transmission of infection among congested high-rise buildings in various locations. These incidents highlighted the importance of the orientations of re-entrant corners and bay for proper air ventilation. Studies have suggested that stagnant air reduces pollution dispersion and increases discomfort around buildings, which increases the risk of SARS-like events. Based on this brief review, the influence of wind incident directions on wind circulation within the re-entrant corners has not been established. Appropriate layout pattern and building orientation is very important for proper wind circulation and outdoor wind comfort [25,26]. In this study, a detailed investigation of wind circulation at the re-entrants corners of cross-shaped buildings from various wind directions at the pedestrian level was performed. This study determines the optimum arrangement for a comfortable outdoor environment based on the wind circulation at the re-entrant corners. The remainder of the paper is organized as follows: Section 2 discusses a wind tunnel experiment, the numerical setup of the case study buildings, and the revised closure coefficients. The results of the case study building arrangements are presented in Section 3. Section 3 also details influence of the wind incident directions and passage width (building separation) on wind circulation and wind comfort. Section 4 presents the study's conclusions.

2. Methodology

2.1. Experimental setup

For cross-shaped elements, an experiment was performed in a closed-circuit, subsonic boundary-layer wind tunnel facility at the City University of Hong Kong. The inside view, velocity sensor arrangements on the test board and the dimensions of the wind tunnel are shown in Fig. 2. The models were mounted on a circular table with a diameter of 2 m (Fig. 2(c)).

The schematic arrangements of the four tested configurations are shown in Fig. 3. The building models were fabricated at a scale of 1:280. The Hong Kong building department recommends a minimum building separation between high-rise buildings of 15 m for proper ventilation [28]. This study examines three building separations of 0.054 m, 0.107 m and 0.142 m (15 m, 30 m and 40 m, respectively, in full scale). The case study buildings are residential building blocks. Additional building separations (30 m and 40 m) were considered for greening and other recreational activities. However, this study only conducts a wind flow analysis. In three cases of building separation, the aspect ratio (H/W) was greater than two. The influence of various aspect ratios and flow regimes of the street canyon on flow parameters is well documented in Refs. [29,30]. An aspect ratio (H/W) > 2 is considered to be a deep street canyon [30]. In this study, however, buildings were distinctly arranged; in all cases, H/W > 2.

Fig. 4 shows all four scenarios, which are also listed in Table 1.

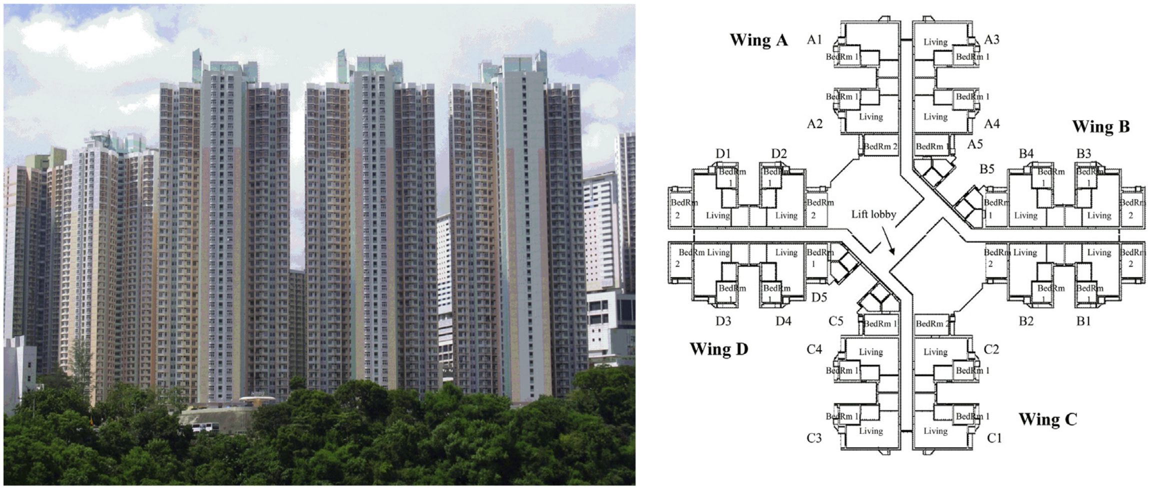

Fig. 1. Harmony blocks in an actual urban area and layout with wings locations [27].