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Air pollutant dispersion around high-rise buildings under different angles of wind incidence

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ABSTRACT

Gaseous pollutant originated from a building can disperse with ambient air flow and re-enter the same building under different environmental conditions. In our previous studies, it was revealed that the near-wall dispersion characteristics in a windward emission are significantly different from that in leeward emission for a high-rise building due to the effect of the building on the wind flow. Since the atmospheric wind changes constantly in both wind speed and wind direction, such that the wind rarely blows perpendicular to the front or the back of a building, it is important to investigate what occurs under different angles of wind incidence. By means of both physical wind tunnel measurement and simulations using Computational Fluid Dynamics (CFD), we firstly studied the dispersion characteristics around a square-sectioned building. It was found that the building influences on wind flow plays a significant role in the dispersion characteristics and an angle of wind incidence of about 90 degrees is a transition angle for the pollutant dispersion pathway around the building. For angles of wind incidence smaller than 90 degrees, air pollutant will migrate predominantly downward while for angles of wind incidence greater than 90 degrees, the pollutant will migrate predominantly upward. Further tests conducted on a more complicated crucifix-form building model with a re-entry along each building wing showed a similar trend of pollutant dispersion at different angles of wind incidence, with the transition angle shifted to approximately 75–80 degrees. The findings of this study show that building shape and the resultant wind-structure interaction plays a significant role in the pollutant dispersion around a building, thus influencing the air quality at different part of a building.

1. Introduction

In an urban environment, indoor air quality is strongly dependent on urban air pollution. Indoor air quality in a building can be compromised by the re-ingestion of contaminated exhaust air originated from the same building (Gao et al., 2009). Thus the characteristics of gaseous pollutants dispersion around a building are especially important for building design and indoor air evaluation.

Near-field dispersion of air pollutant not only affects general health issues, it may also promote the spreading of communicable diseases (Gao et al., 2009). It has been shown that several emerging and re-emerging respiratory infections including tuberculosis (TB) (Nardell et al., 1991) measles (Riley et al., 1978) and H1N1 influenza (Abd Razak et al., 2013) can be spread by airborne route. Epidemiologic analysis and simulation studies supported the possibility of wind effect enhancing an airborne spread of the SARS virus in a large community outbreak (Brook et al., 2004). The airborne transmission over long distances can also be an important mode of infectious disease transmission (Nardell et al., 1991). These studies have increased the awareness of the scientific and engineering communities to micro-scale pollutant dispersion in the built environment.

Evidently, air ventilation of urban areas by wind flow is an important process in urban pollutant drainage to maintain clean air. In particular, outdoor air quality can be improved by wind flow because wind dilutes and removes pollutants. Urban wind flow is strongly related to urban morphology as a combination of building density, mutual arrangement of buildings and their individual shape and dimensions. Hence, wind-structure interaction, which controls air

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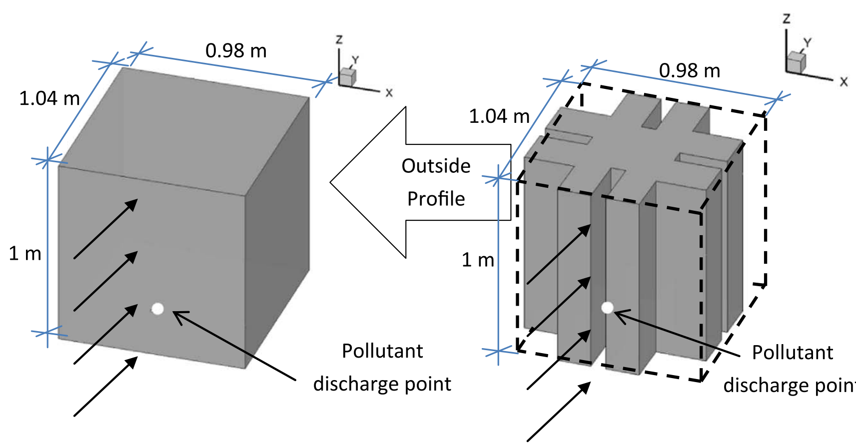
(a) Crucifix-form building model in boundary layer wind tunnel



(b) Simplified square-sectioned building model in a numerical wind tunnel (H:B:D=1:0.98:1.04)

(c) Crucifix-form building model in a numerical wind tunnel (scale 1:30)

Fig. 1. Physical and numerical models.

pollutant dispersion around buildings, needs to be properly considered and the results incorporated in the decision making process for urban development programs.

During the past three decades, a considerable amount of research has been conducted regarding air pollutant dispersion in urban environments by wind action, including field measurements, wind tunnel tests and numerical simulations (Depaul and Sheih, 1985, 1986; Nakamura and Oke, 1988; Meroney et al., 1996; Baik et al., 2000; Lu et al., 2012). Researchers have found that, from a macroscopic point of view, the dispersion of air pollution is generally determined by meteorological factors such as ambient wind speed, wind direction, and atmospheric stability. In addition to these natural factors, urban design, including the arrangement of building arrays and street canyons, also plays an important role in air pollutant dispersion. Yet, in the neighborhood within the local turbulent boundary layer close to the buildings where wind turbulence, vortex formation, exhaust gas emission and natural convection all play a role, the air pollutant dispersion process is far more complex. These neighborhood regions can be crucial as unexpected air flow may result in long residual time for air pollutant close to the residents which further promotes disease spreading. However, which factor amongst natural convection, wind turbulence, and wind-structure interaction plays the most significant role in such areas remains a controversial issue (Niu and Tung, 2008; Yip et al., 2007; Zhou and Jiang, 2004; Li et al., 2005).

In previous work (Liu et al., 2010, 2011; Zhang et al., 2015), we have investigated the wind effect on the pollutant dispersion around a typical Hong Kong high-rise residential (HRR) building with a crucifix platform and a re-entry along each wing. A series of tests using a scaled model was studied in an atmospheric boundary layer wind tunnel (Dimoudi and Nikolopoulou, 2003; Tominaga et al., 2008). Numerical simulations were also performed. The results obtained from both experimental measurement and simulations highlighted the differences in air pollutant dispersion pathway for a windward or leeward emission source, and the dependence on the location of the emission source in relation to the stagnation point. In the following discussion, the releasing point is below the stagnation. In the case of a windward emission, pollutant migrates predominantly downward due to downwash effect and spreads horizontally after reaching the ground. For a leeward emission, air pollutant migrates predominantly upward within the re-entry due to the pressure field and flow recirculation around the building before discharging downstream. Obviously the air pollutant dispersion process is sensitive to the wind direction; hence it is important to investigate how pollutant dispersion pathway responds to a change in the angle of wind incidence from windward (0°) to leeward (180 degrees). Furthermore, the effect of building shape on air pollution dispersion, particularly near-building dispersion remains relatively under-explored.

The objectives of this research were to investigate air pollutant dispersion around high-rise buildings of different shapes under different angles of wind incidence. The emphasis of this research was to

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