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Air Pollutant Dispersion around High-Rise Buildings due to Roof Emission

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ABSTRACT

The current COVID-19 pandemic heightens our awareness of the impact of high-rise buildings on the dispersion of air-borne contaminant. Evidently, wind-structure interaction plays a key role to facilitate the air pollutant spread. This paper presents the dispersion results of pollutant discharged from roof vent pipe around a cubic building model using computational fluid dynamics (CFD). The results show that the air pollutant dispersion is dominated by wind-structure interaction, and is influenced by a number of parameters including the angle of wind incidence and the location and height of the vent pipe. The results demonstrate that, for a cubic building model, the air pollutant discharged from the vent pipe only disperses effectively in high floor area. When the wind incidence angle reaches 90°, air pollutant affects occupancy at the high floor on the building side face. Increasing the vent pipe height and adjusting the vent pipe position close to the downstream edge of the roof significantly reduce the area adversely affected by the air pollutant.

1. Introduction

In the past four decades, many researchers studied air pollutant dispersion (e.g. Cermak, 1978, Snyder *et al.*, 1981, Heinsohn and Cimbala, 2003 and others), with recent interest focuses on the effect on human health, especially air pollutant dispersion around high-rise buildings with high-density occupancy. The deadly SARS outbreak in a residential estate Amoy Garden in Hong Kong in 2002 highlighted the role played by wind-structure interaction to potentially facilitate the spread of air-borne diseases. The suspected pathology of the disease spread in residential areas is illustrated in Figure 1. It can be seen that the bio-contaminant is released from toilet and/or waste pipe to the connected vent system. Though the vent system the contaminant is finally discharged from the vent pipe located on the building roof. Obviously, the pathway of air pollutant dispersion from the vent pipe to the residential areas is driven by air flow generated by wind-structure interaction. Since 2002, a number of valuable works have been done that improved our understanding of disease spread and the vital role played by wind-structure interaction.

Computational fluid dynamics (CFD) based numerical models have been increasingly used to investigate the spread of pollutant in urban areas. For obtaining reasonable simulation results, Blocken and Carmeliet (2004) indicated that it is particularly important to select appropriate turbulence models and boundary conditions. Reynolds Averaged Navier–Stokes (RANS) models were broadly accepted for the simulation of pollutant dispersions in urban areas (Salim *et al.*, 2001). Tominaga *et al*. (2018) discussed the influence of different turbulence models on the simulation results of pollutant dispersion with different plume buoyancies. Jeong *et al.* (2018) investigated the effect of atmospheric stability on near-field pollutant dispersion from rooftop emissions of a single cubic building. Keshavarzian *et al.* (2017) and Baghlad *et al.* (2018) found that different aspect ratios, heights, and building types have a significant impact on the spread of air pollutant in a built environment. Besides building configurations, the pollutant discharging locations also have a significant impact on the pollutant dispersion. Zhang *et al.* (2015) found that for the case with windward pollutant emission, the pollutant migrates downwards due to the downwash created by the wind. In contrast, for the case with leeward pollution emission, dispersion is dominated by intense turbulent mixing in the near wake and characterized by the upward migration of the pollutant in the leeward. In particular, when the angle of wind incidence is about90°, pollutant will not disperse either upward or downward but remains suspended around the discharge position.

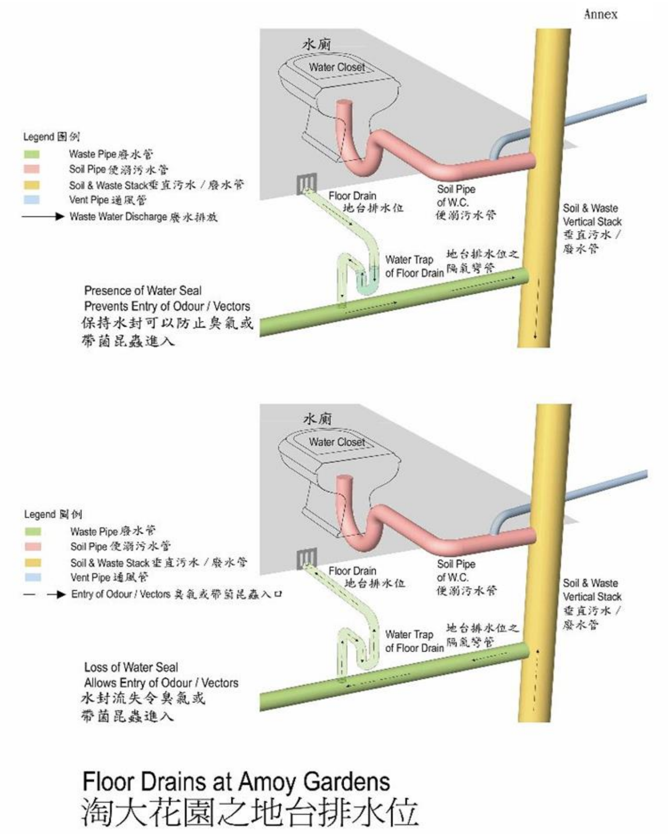

Figure 2. The transmission of SARS in sanitary channels in Amoy Garden (SARS Expert Committee - Reports (sars-expertcom.gov.hk)).

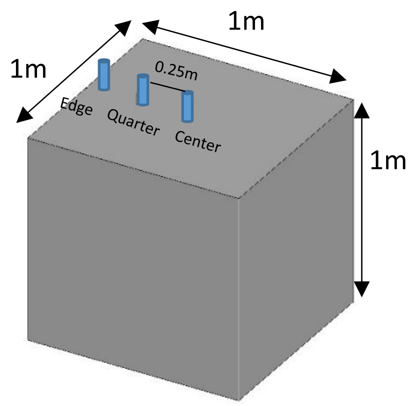

Figure 1. Cube building model and location of the vent pipes

Our previous work, Keshavarzian *et al.* (2020), Yu *et al.* (2017) and Zhang *et al.* (2015), investigated in details the scenarios of air pollutant discharging from residential rooms. However, the air pollutant discharged from roof vent pipe may play an equally important role in air pollutant dispersion and disease spread, particularly for those residents who are living in top floors near the discharging position. The objective of this study is to investigate the effects of angle of wind incidence and the location and height of the roof vent pipe to the air pollutant dispersion.

2. Method

A generic 30m cubic building model is scaled down 1: 30 for CFD simulations, as shown in Figure 2. Three air pollutant discharging locations on the roof were considered. They are at the building roof edge, at the building roof center, and at a quarter position between the building roof edge and roof center, as shown in Figure 2. Three vent pipe heights were tested, they are 0m, 1.5m and 3m with respect to the building roof. ANSYS Fluent CFD Software Package (version19.0) was used for CFD simulations. Grid arrangement, sensitivity and convergence have been tested and confirmed previously by Yu *et al.* (2017).

3. Results

In this study, we tested the cases of five wind incidence angles: 0°, 45°, 90°, 135°, and 180°. The modification of wind incidence angles can be readily achieved by rotating the building model numerically in the CFD code.

The cases with 0m vent pipe height are presented in Figure 3, where **Case 1** represents air pollutant discharged from the roof edge, **Case 2** represents air pollutant discharged from the quarter position, while **Case 3** represents air pollutant discharged from the center position.

For **Case 1**, when the wind incidence angle is 0°, the air pollutant only affects the roof area. As the angle of wind incidence increases, the dispersion plume progressively shifts to the corner of the roof and the affected areas gradually reduces. When the wind incidence angle reaches 90°, part of the roof flow is entrained over the roof edge onto the side face surface of the building and the air pollutant starts to affect the high floors close to the roof. When the wind incidence angle is at 135° and 180°, air pollutant continues to be entrained and affect the higher floors.

For **Case 2,** when the wind incidence angle is 0°, the air pollutant only affects the roof area but the affected area is noticeably smaller compared with **Case 1**. As the angle of wind incidence increases, air pollutant disperses changes with wind incidence. At wind incidence angles 90° and greater, i.e. 90° 135° and 180°, the roof area is clearly affected by the dispersing air pollutant while only relatively small areas at the high floors on the building side face and leeward face are affected by the dispersing air pollutant.

For **Case 3,** the pathway of air pollutant dispersion is similar to that found in **Case 2**, with dispersing air pollutant affecting mostly the roof area. The side face and leeward face of the building are minimally affected by the dispersing air pollutant.

A comparison of **Cases 1, 2, 3** reveals that wind incidence angle and discharging position play a significant role in air pollutant dispersion. The results suggest that the dispersing air pollutant mostly affects the roof area. Although a high air pollutant concentration on the roof may not pose a direct hazard as the roof is not treated as a habitable area, re-ingestion of vent exhaust into an air-conditioning system can potentially be a serious health hazard. Of particular importance is **Case 1** with wind incidence angle greater than 90° when flow entrainment apparently causes the dispersing air pollutant to migrate towards the high floors of the side face and leeward face of the building, thus potentially impacting on occupants. Therefore we further investigate the effects of increasing the vent pipe height from 0m to 1.5m and 3m to whether increasing the vent pipe helps to reduce the pollutant affected area.

Fig. 4 shows the results of air pollutant dispersion for air pollutant discharged from the roof edge at vent height at 0m (**Case 1**), 1.5m (**Case 4**) and 3m (**Case 5**) for wind incidence angles 90°, 135° and 180°. At a wind incidence angle of 90° and a vent pipe height of 1.5m with respect to the building roof, the area on the side face of the building affected by the dispersing air pollutant is significantly reduced compared to the affected area for a vent pipe height of 0m. Increasing the vent pipe height to 3m can further reduce the affected area to only a small region on the side face of the building. When the wind incidence angle reaches 135° and 180°, increasing the vent pipe to 1.5m and 3m can completely eliminate the air pollutant affected area on the side face and leeward face of the building.

4. Conclusion

CFD simulations were performed to study the effect of angle of wind incidence, vent pipe position and height on the air pollutant dispersion around a cubic building model. It was found that for roof vent emission, the dispersing air pollutant mostly affects the roof area. The residential areas on the high floors on the side face of the building are the most susceptible to the dispersing air pollutant when the vent pipe is at the roof edge. Relocating the vent pipe position downstream of the windward roof can significantly reduce the affected area on the side and leeward faces of the building. Furthermore, increasing the vent pipe height above the roof can substantially reduce the impact of the dispersing air pollutant. Increasing the vent pipe height to 1.5m and above can almost entirely eliminate the adverse influence of the dispersing air pollutant, except at a wind incidence angle of 90^{o} where a relatively small area at the high floors on the side face of the building remains affected by the dispersing air pollutant.

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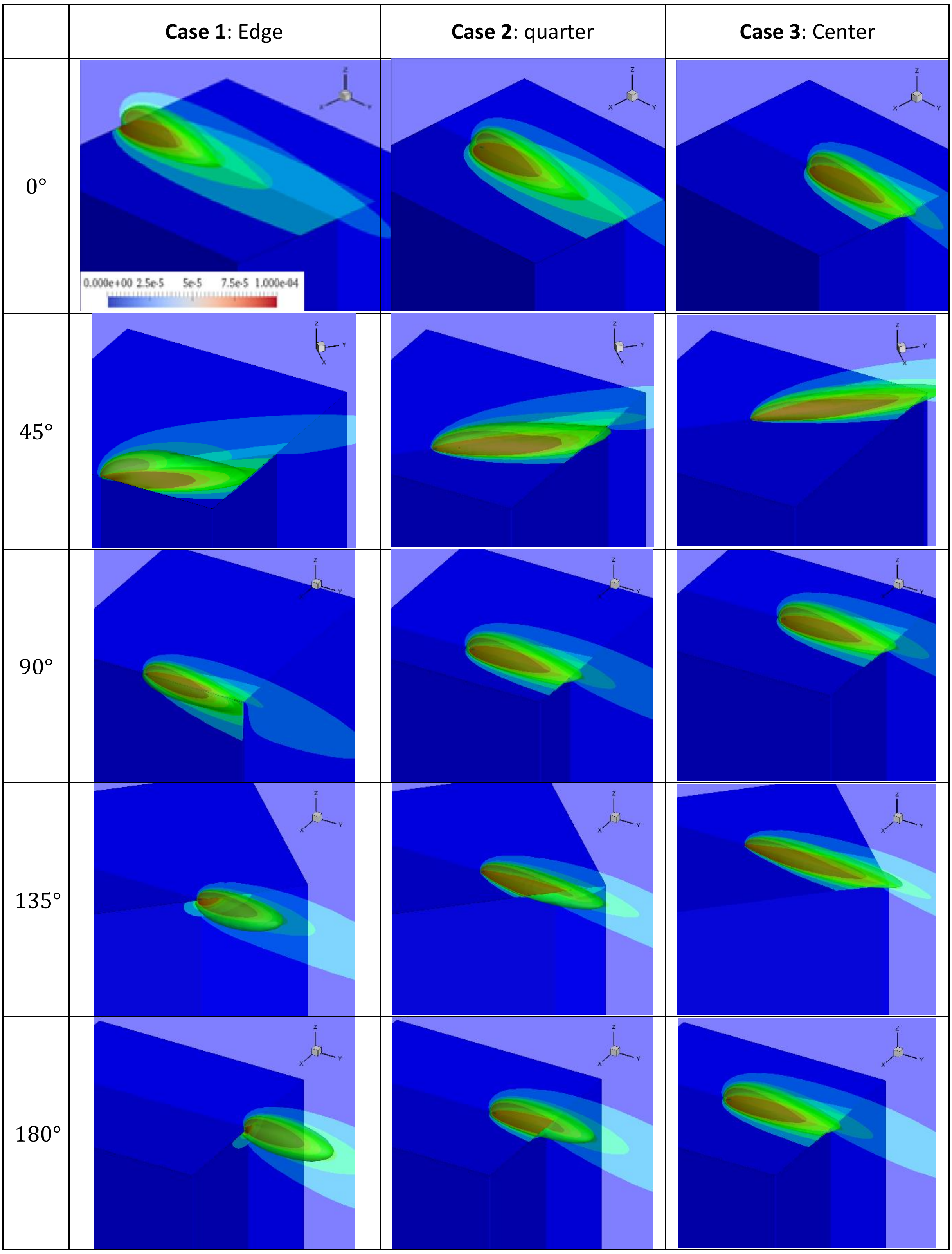

Figure 3. Air pollutant dispersion around cubic building model for three installation positions at height 0m for different wind incidence angles

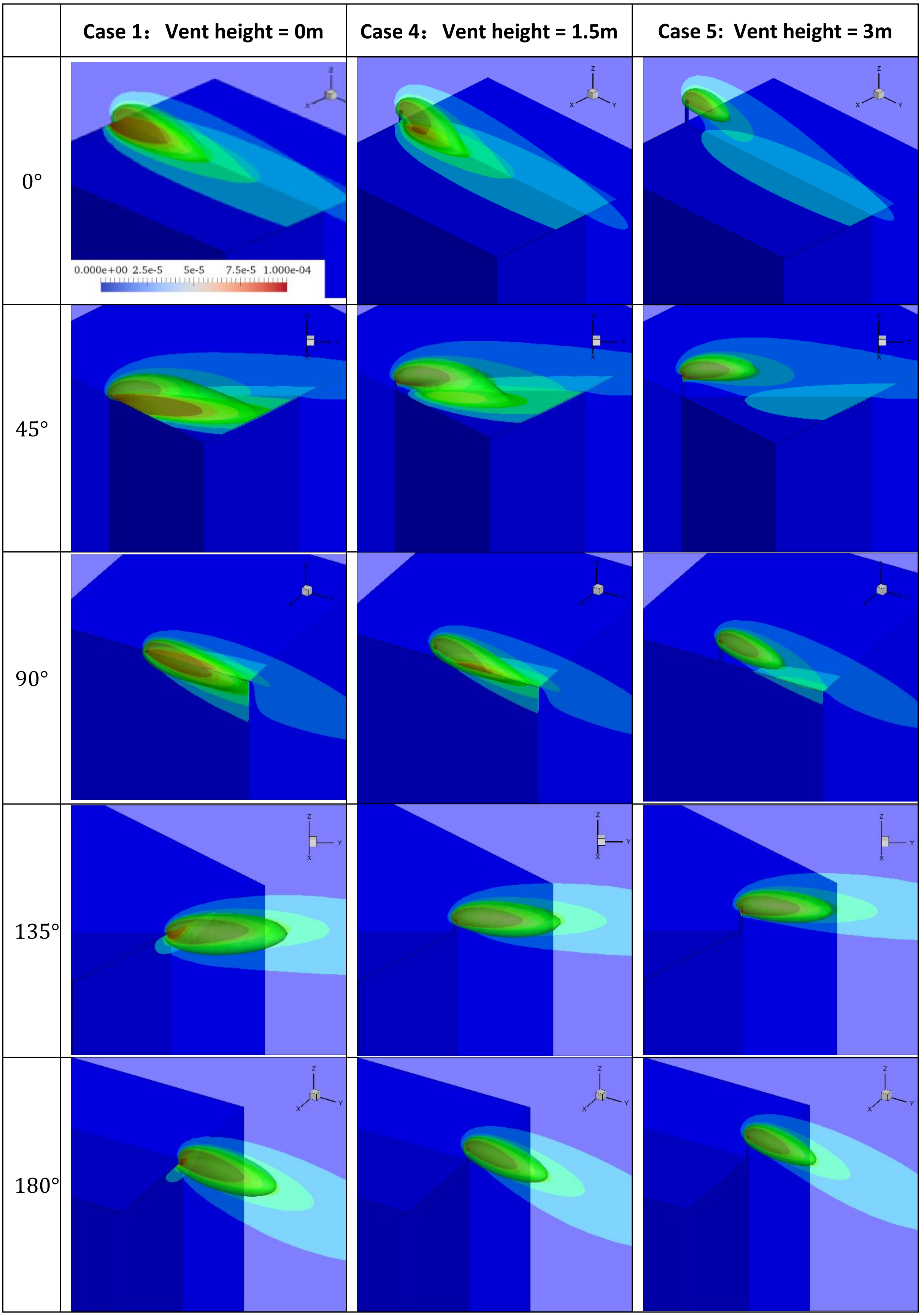

Figure 4. Air pollutant dispersion around cubic building model for emission location at edge at three emission heights 0m, 1.5m, 3m, for different wind incidence angles.