# Some interesting phenomena on air pollutant dispersion in urban street canyons

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## 1 Introduction

With increased concern over urban air pollution problems, many studies have been conducted in recent years related to the wind flow and pollutant dispersion characteristics in street canyon. Oke (1988) and Hunter et al. (1992) categorised the flow regimes into isolated roughness flow, wake interference flow, and skimming flow. Meroney et al. (1996) studied the line source characteristics at different street canyon widths. Pavageau and Schatzmann (1999) examined the pollutant concentration distribution in street canyon in a wind tunnel with urban roughness. However, many wind tunnel experiments were based on perfect arrangement of identical buildings, which may not be realistic.

A number of operational numerical models, for example, the Canyon Plume Box (CPB) model (Yamartino and Wiegand, 1986), the Operational Street Pollution Model (OSPM) (Berkowicz et al., 1997), and the Street Level Air Quality (SLAQ) model (Micallef and Colls, 1999), have been used for simulating pollutant dispersion in street canyons. One common feature of these models is that the approaching flow at rooftop of the target street canyon is usually assumed parallel to the ground based on the findings from wind tunnel experiments. However, this is found not always the case due to the irregular height of the upstream buildings. Even in a two-building case the wind direction at the rooftop is changed due to the flow separation. This can dramatically change the pollutant dispersion behaviour in street canyons.

In this study, the physical process of pollutant dispersion in street canyons was simulated using computational fluid dynamics (CFD) techniques. The wind field was first computed from the time dependent imcompressible Navier-Stokes equations and the continuity equation based on finite element method (Xia and Leung, 2001a). The dispersion process was simulated by discharging a large number of particles into the computation domain while the time dependent wind field data were obtained. Trajectories of the released particles were predicted using a Lagrangian particle model (Xia and Leung, 2001b).

## 2 Numerical comparison

Simulation is conducted to demonstrate the quality of the present numerical models. The geometry for comparison is shown in Figure 1a. The target street canyon is composed of two 60 × 60 mm squares with 60 mm in canyon width. Three and two urban roughness buildings are placed upstream and downstream of the canyon, respectively. The pollutant source is set at midway of the target canyon at ground level. The inflow velocity $U_0$ is set to 2.0 m/s, as Meroney et al. (1996) did. The numbering and the location of the sampling points for concentration comparison in the target street canyon are set the same as those in Meroney et al. (1996).

Comparison between the wind tunnel data from Meroney et al. (1996) and the computed pollutant concentration, which are both normalised by the concentration at the sampling point 7 ($C_0$) to facilitate comparison, is shown in Figure 1b. Due to the effect of upstream roughness buildings, wind that approaches the target street canyon is almost parallel to the ground. The reverse flow is greatly reduced at rooftop of the upstream square building. A quantitative comparison at the 14 sampling points between the experimental data of Meroney et al. (1996) and the computed data is shown in Figure 1c. As expected, very low concentration is experienced at rooftop of the building B01 (sampling points 1, 2, and 3). The concentration at the leeward side of B01 (sampling points 4, 5, 6, and 7) is higher than those at the windward side of B02 (sampling points 11, 12, 13, and 14). Figure 1d clearly demonstrates the quality of the computation at the 14 sampling points. The computed pollutant concentrations from the present numerical models fit quite well with experimental data. A linear relationship between the computed data and the experimental data is obvious.

## 3 Numerical simulations for wind flow in street canyons

### 3.1 Wind field around two identical buildings with different inflow velocities

Wind fields with different inflow velocities ($U_0 = 0.1, 0.5, 1.5, 6.0\mathrm{m/s}$) in the target street canyon are studied. The street canyon is composed of two identical buildings of $2D$ in height, where $D$ is the building width. The gap distance between the two buildings is $3D$. The computed wind fields are shown in Figure 2. The approaching flow at rooftop of the target street canyon is not parallel to the ground. A counter-clockwise rotating vortex is maintained unchanged in the street canyon in all simulations while inflow velocities varies from low ($U_0 = 0.1\mathrm{m/s}$) to high ($U_0 = 6.0\mathrm{m/s}$). Wind profiles in the target street canyon shows that the maximum wind velocity $U_{max}/U_0$ almost maintains at a constant value, though the inflow velocity $U_0$ increases from 0.1 m/s to 6.0 m/s. It implies that the absolute maximum flow velocity increases proportionally with the inflow velocity. The flow regime in the street canyon doesn't change with the inflow velocity under the testing Reyonlds numbers. This flow regime in the street canyon is different from previous studies, in which the flow at rooftop is usually assumed parallel to the ground, resulting a clockwise rotating vortex in the street canyon in a two-building case. This assumption came out of wind tunnel experiments, in which perfect arrangement of identical buildings were usually used. Under this special building configuration, the approaching flow at roof top becomes parallel to the ground when it reaches the target street canyon. However, it can be clearly seen that the incident flow is separated at the front corner of the upstream building and generates a clockwise rotating vortex in the wake area above the target street canyon, which drives a counter-clockwise rotating vortex in the street canyon. The counter-clockwise rotating vortex will eventually cause low pollutant concentration at the leeward side of the upstream building and high pollutant concentration at the windward side of the downstream building. Therefore, the assumption that a clockwise rotating vortex in the street canyon cannot be made even in a two-building case.

### 3.2 Pollutant dispersion in street canyons with multiple non-identical buildings

Both upstream and downstream urban roughness buildings are placed adjacent to the target street canyon. The building configuration in the second simulation is the simplest combination for the representation of complex urban street canyons. The target street canyon is composed of two identical low buildings surrounded by tall buildings with identical height. The width of the target canyon is 0.06 m.

Very complex dispersion mode can be seen while the low target street canyon is surrounded by tall buildings B02 and B05 (Figure 3). A counter-clockwise vortex appears in the target street canyon C03. The high particle density appears at the windward side of downstream building B04. Besides, strong velocity fluctuation is found in the canyon C03, which facilatates pollutant particles escaping out of the canyon, due to the surrounding tall buildings. This reveals that the target street canyon cannot be isolated from the surrounding building settings when a dispersion mode in urban street canyons is concerned. The released pollutant in a canyon with different surrounding building configurations may have completely different behaviours. Though a lot wind tunnel experiments have been conducted concerning the effect of the height and width of street canyons on flow pattern, the building configurations are too ideal and may not match the situation in real world. Further study will be conducted concerning the effect of complex building configurations on the flow pattern in street canopies.

### 3.3 Pollutant dispersion around multiple building blocks

Geographic Information System (GIS), e.g. ARC/INFO, provides sophisticated funtions for the management of spatial database. On the other hand, pollutant dispersion in street canyons are largely spatial related. Therefore, GIS can be useful in air quality management while integrated with atmospheric dispersion models. In this case study, pollutant dispersion around buildings at Mongkok, a severe vehicular pollution area in Hong Kong, is simulated. The computation domain is first constructed by importing the real world building boundary information in ARC/INFO.

Traffic emissions from two major intersected roads, Nathan Road (in South-North direction) and Argyle Street (in East-West direction), are studied. Vehicular emissions are simulated using four line sources for each road. Each line source is represented by 21 point sources that are evenly distributed along the simulated roads. The strengths of point source are assumed to be identical and constant throughout the temporal domain.

Figure 4a shows the computed wind field around the group buildings. Very complex wind structure are found around them. The wind velocity reduces and forms a stagnation area when approaching the group buildings. Flow seperates at the two corners of the front building face, generating two wake areas at the northern and southern sides of the group building, respectively. The side wake areas are broken into several small vortices due to the discontinuous building blocks. An oscillation wake area, which consists of two large counter-rotating vortices accompanied with several small vortices, is generated downstream the group buildings.

When the approach wind is oblique to the axis of Nathan Road, the distribution of pollutant concentration at roadside, e.g. the intersection of Nathan Road and Argyle Street, is not symmetric. The pollutant concentration at the north-west corner (labelled as $NW$) is lower than that of the south-east corner (labelled as $SE$), as can be seen from the pollutant trajectories at T=60. It is expected that the distribution of pollutant concentration at roadside will be changed while the direction of the approach wind is changed. A problem associated with this result is that where is the suitable place for roadside pollution monitoring that can truly reflect the air pollution level at roadside? It is not easy to give an answer. A suitable place for roadside pollution monitoring requires that pollutant will not accumulated and can reflect the average pollutant concentration level. Apparently, further numerical simulations with different directions of approach wind are needed for a given study area.

## 4 Conclusions

Wind field model and dispersion model for air pollutant dispersion in street canyons are developed using the computational fluid dynamics (CFD) techniques. Numerical results from the developed models are compared with published wind tunnel data. A linear relationship between the two data sets is found. Simulation results show that a counter-clockwise rotating vortex could appear in street canyons. This implies that wind flow at rooftop cannot be assumed parallel to the ground even in a two-building case when the street canyon flow is modelled. Increasing in building height under certain situations may facilitate pollutant dispersion and improve natural ventilation in street canyons. GIS, which possess powerful capabilities in spatial data management, are useful in air quality management while incorporated with environmental models.

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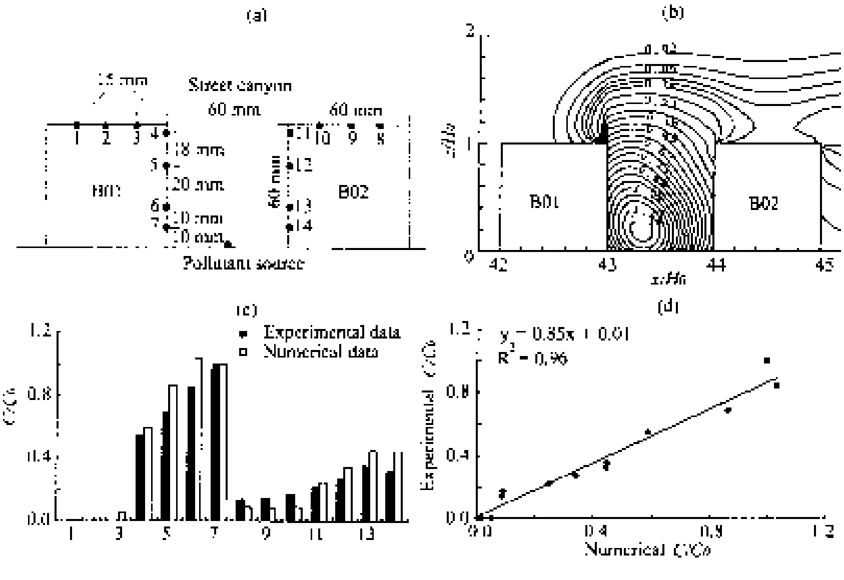

Figure 1: Comparison between the numerical results and the wind tunnel data of Meroney et al.(1996). (a) building geometry and sampling points (b) normalised pollutant concentration $C/C_0$ in the street canyon (c) pollutant concentration comparisons at the 14 sampling points (d) least square data fit between the numerical data and the experimental data.

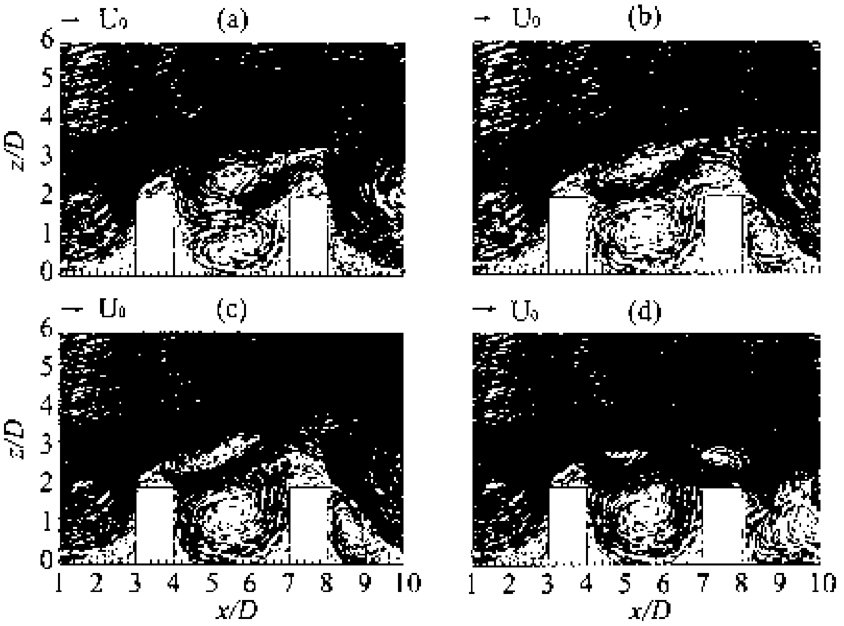

Figure 2: Wind field around two identical buildings at different inflow velocities. (a) $U_0$ = 0.1 m/s (b) $U_0$ = 0.5 m/s (c) $U_0$ = 1.5 m/s (d) $U_0$ = 6.0 m/s

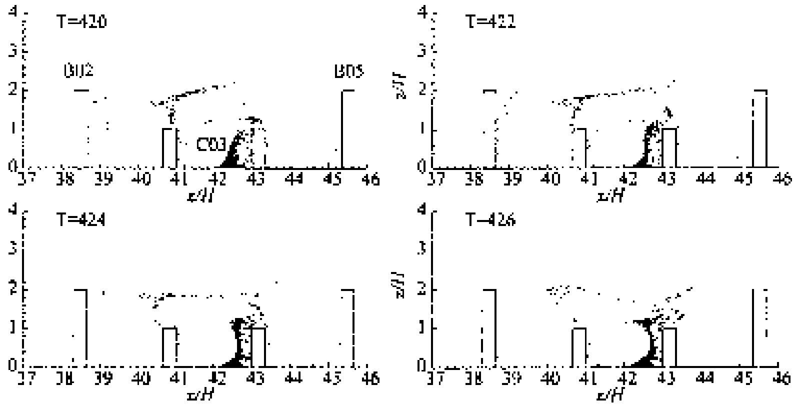

Figure 3: Pollutant dispersion among two low buildings surrounded by high buildings

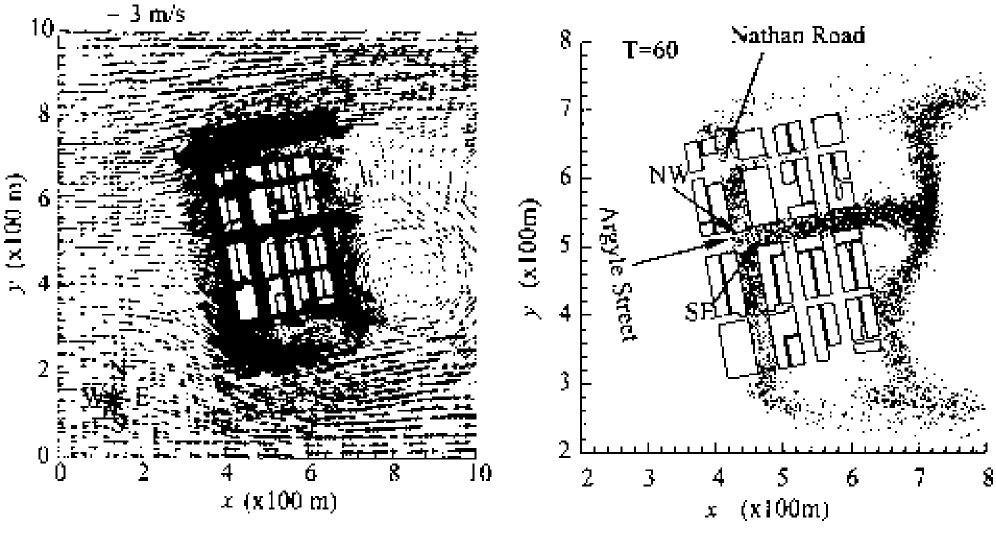

Figure 4: Wind field around buildings with an approaching wind velocity of 3.0 m/s