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Local and non-local effects of building arrangements on pollutant fluxes within the urban canopy

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ABSTRACT

This work investigates the vertical and horizontal mass (scalar) flux of a contaminant emitted from an area source located in an array of blocks representing an urban environment. Arrays consisting of buildings with random and uniform heights and staggered and aligned arrangements were tested. Results shows that the vertical scalar flux close to the source can affect downwind clean zones. It is also shown that taller buildings increase the vertical scalar flux and the fluctuations of the vertical velocity above the smaller buildings. The vertical advective scalar flux was found to have an effect on dispersion in the vicinity of the building (a local effect), while the vertical turbulent fluxes are associated with pollutant transportation downwind above the smaller buildings (a non-local effect).

1. Introduction

The wind flow over urban environments is affected by the geometrical features of buildings which in turn influence the vertical and horizontal fluxes of pollutants within the urban canopy and above. This influence can be seen locally in the vicinity of each building and also in the pollutants' transport from one region of the urban area to another further away.

Numerous experimental studies and numerical investigations have focused on understanding the wind flow and air pollutants dispersion affected by the presence of a buildings array which represents urban environments [1–11]. These can help urban planning for air quality improvement by supporting the choice of a more appropriate urban configuration in terms of the positioning of buildings and their three-dimensional characteristics [12], or give support for building emergency plans in case of accidental or intentional releases of contaminants [27,28].

The presence of buildings, especially tall buildings, disturbs the atmospheric flow considerably. [13] presented a review of near-field pollutant dispersion in built environments in which they explained the interaction between buildings and dispersion. Direct Numerical Simulation (DNS) of flow [2,3] and dispersion [7] of a passive pollutant emitted by a point source located within an array of cubic-like buildings revealed that the most significant processes controlling dispersion in urban areas are channelling flow along the streets, topological dispersion due to the presence of buildings [7,14,15], plume skewing due to the flow turning with height, detrainment by turbulent dispersion, entrainment to building wakes, and development of secondary sources.

Recently, [26] using the same set of DNS data as [7]; investigated pollutant dispersion within and above the urban canopy. The results showed that the vertical pollutant mass (scalar) flux within the urban canopy is dominated by the turbulent component. On the other hand, the horizontal scalar flux below the canopy is dominated by advection while above the canopy there is a counter-gradient part of the turbulent horizontal scalar flux. As pointed out by Ref. [26], the vertical flux has an important role on how pollutants spreads through the array. Initial detrainment reduces pollutant concentration within the array. However, re-entrainment could increase concentration further away from the source.

Large Eddy Simulation (LES) has been used in numerical investigations of turbulent flow over an array of buildings. Refs. [4,8,9] have shown that LES can yield excellent agreement with experimental and DNS data and therefore can be a reliable tool to investigate building-affected dispersion. Another recent example of LES reliability in modeling atmospheric turbulence in urban areas is the work of [16] who used it to investigate the effects of building height variability on turbulent flows in the lower part of the urban boundary layer in Kyoto, comparing results to field experimental data. They showed that the plan-area index λ_p (the ratio of the plan area occupied by buildings to

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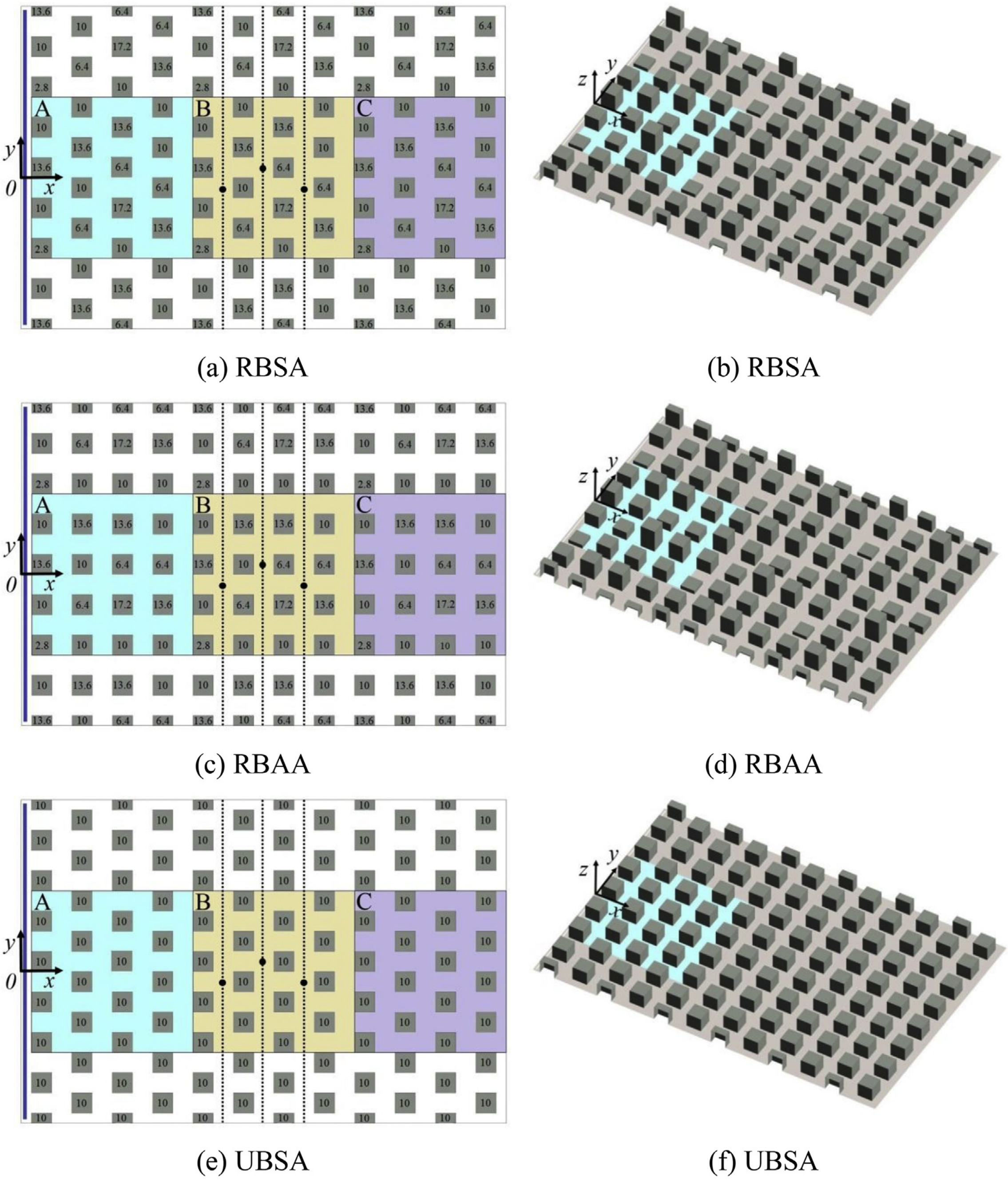

Fig. 1. (a), (c) & (e) are plan views of the urban configurations shown in (b), (d) & (f), respectively. The grey squares denote the building positions and the number inside each square denotes the building height in mm. The width in both streamwise and lateral directions of the buildings is 10 mm. The width of the streets is 10 mm. (a) staggered array with random buildings height (RBSA), (b) aligned array with random building height (RBAA) and (c) staggered array with uniform buildings height (UBSA). The regions marked with the capital letters A, B and C (in (a), (c), (e)) denote repeating units comprising sixteen blocks ($8H_m$ by $8H_m$), where the light blue zone (zone A) coincide with the area source. Black dots show the locations of the vertical concentration profiles. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

the total surface area) is an important parameter in distinguishing the effects of building height variability. A threshold for the influence of height randomness on turbulence variables become evident on flow and dispersion. It means that for sparsely populated (of buildings) sites, with $\lambda_p < 0.17$ according to [17]; the height variability effects are not important. Our three simulated cases have $\lambda_p = 0.25$, so it is important to study the heights randomness effects.

A series of studies investigate how the high-rise building affects the flow and dispersion in pedestrian level. Ref. [18] used wind tunnel and numerical simulation to investigate the effect of a tall building in flow and dispersion in a neighbourhood area. They found that the tall buildings affected the surrounding air flows and dispersion patterns, with the generation of “dead-zones” and high concentration “hotspots” in areas where these did not previously exist.

Refs. [19] and [20] investigated the flow and ventilation rates over array with high-rise building. They found that the ventilation rates decrease over arrays with tall buildings. While building height variation enhance vertical mean flows and therefore enhance the vertical ventilation in comparison to uniform buildings heights.

Ref. [21] studied pollutant dispersion over arrays with high-rise building. They found that, regarding pollutant removal, for canopies with the same average height (with different building height), the