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Experimental assessment of the effects of obstacles on pollutant dispersion in urban canyons

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SUMMARY: (10 pt)
Air pollution in cities due to vehicular traffic emissions and reduced ventilation is a serious hazard to human health. Obstacles in the form of parked cars, trees, hedges, etc, are being explored as strategies to reduce pedestrians and nearby residents' exposure to pollutant concentration in street canyons. This study investigates the effect of parked cars and trees on the exposure of pollutant concentrations for pedestrians along the sidewalk, using wind tunnel experiments. The results show that, for wind flowing perpendicular to a street canyon where a passive scalar is released, the effects of tightly parked cars can have a positive effect on pedestrians on the sidewalk, while trees appear to cause an accumulation of pollutants and an increase in pollutant concentration levels. More studies investigating the effects of obstacles in different configurations and street geometries can lead to more conclusive evidence about the effect obstacles have within a street canyon.

Keywords: Air pollution, urban canyon, urban obstacles

1. INTRODUCTION

Local wind flow within urban canyons plays a decisive role in dispersing traffic-related pollutants and mitigating related risks to human health. To this end, many recent studies (Li et al., 2021; Buccolieri et al., 2022) point towards the potential of passive local strategies, such as barriers/obstacles (e.g., trees, hedges, parked cars, low boundary walls, roadside barriers, etc.), in altering source-receptor pathways, i.e., the pollutant path from street emissions to the pedestrians on sidewalks (Li et al., 2021).

Pollutant dispersion in urban canyons is most often studied through Computational Fluid Dynamics (CFD) models. Very few experimental validation studies (Nosek et al., 2017) have been carried out about the effect of obstacles such as cars, trees, or boundary walls on the concentration of pollutants in street canyons and, in particular, in the areas mostly frequented by pedestrians/residents, such as the walkway areas or residential open spaces.
In this context, this study aims to investigate the effect of different obstacles on traffic-related pollutant concentrations, with a specific focus on pedestrian walkways. Therefore, scaled-down

experiments are conducted in the wind tunnel to analyse the following scenarios:
Case A. Reference case urban street canyon.
Case B. With trees along the pedestrian walkway area.
Case C. With tightly packed parked cars along the pedestrian walkway area.

2. EXPERIMENTAL SETUP AND MEASUREMENT TECHNIQUES

The experiments were performed in the atmospheric wind tunnel at the Laboratoire de Mécanique des Fluides et d'Acoustique (LMFA) at the Ecole Centrale de Lyon. The aerodynamic circuit is composed of an axial fan, inducing a free stream velocity of 5 m/s (U_∞). To simulate an idealized urban district and the turbulent flow within and above it, the floor of the entire test section was overlaid with an array of square blocks. The blocks (made of wood and polystyrene) were 50 cm wide and 10 cm high, spaced 10 cm spanwise and 20 cm lengthwise. The reference street canyon matched a typical tree-lined boulevard 40 m wide with 20 m high buildings in a 1:200 scale (typical European city centres). Its length (*L*), width (*W*), and height (*H*) measured 0.5 m, 0.2 m, and 0.1 m, respectively (Figure 1a), thus providing the following aspect ratios: H/W = 0.5, L/H = 5, and L/W = 2.5.

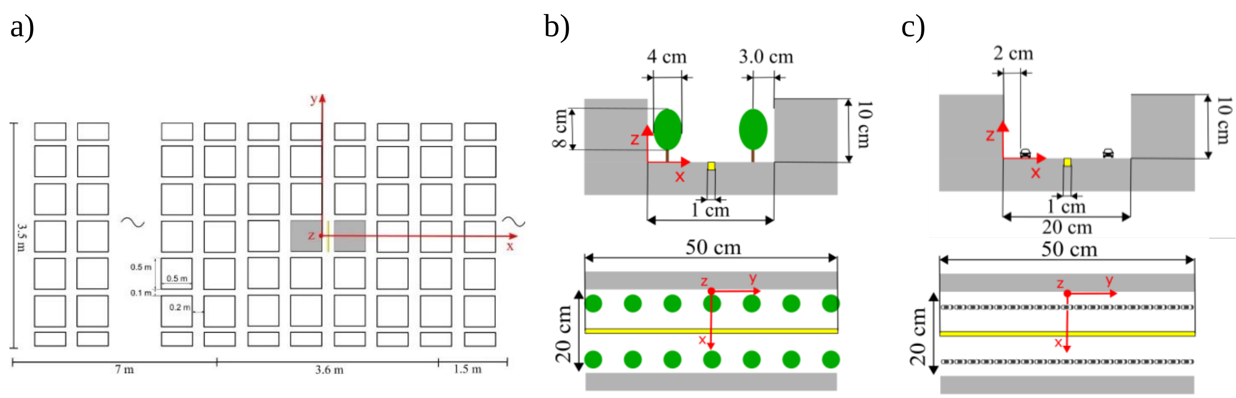

Figure 1. Sketch of the (a) urban canopy in the test section of the tunnel, (b) top and side view of urban canyon with trees – Case B, (c) top and side view of urban canyon with cars - Case C

Urban vegetation within this street canyon was modelled by means of two rows of plastic trees, 8 cm high, 4 cm wide and positioned 3 cm from the building walls (Figure 1b). The aerodynamic behaviour of the model trees was characterized by estimating their drag coefficient (C_d) and aerodynamic porosity (α_p) (Fellini *et al.*, 2022).

To simulate the effect of parked cars, two rows of miniature cars (1:200 scale) were placed 2 cm from the building walls (Figure 1c).To simulate vehicular emissions, ethane was emitted by a linear source at the centre of the reference street canyon (Marro *et al.*, 2020; Fellini *et al.*, 2022).

The velocity field above the obstacles was characterised by means of a Hot-Wire Anemometer (HWA), while the concentration field within the reference street canyon was measured using a Flame Ionisation Detector (HFR400 Fast FID) (Marro *et al.* (2020)). For each point, a sampling time of 2 minutes was fixed to provide a reliable estimate of the mean concentration.

3. RESULTS

For the three investigated configurations, Figure 2 shows the concentration field in a horizontal plane at pedestrian level (1 cm above ground, i.e., about 2 m in real scale) and in a front section at the leeward wall (1 cm from the wall, i.e., about 2 m in real scale).

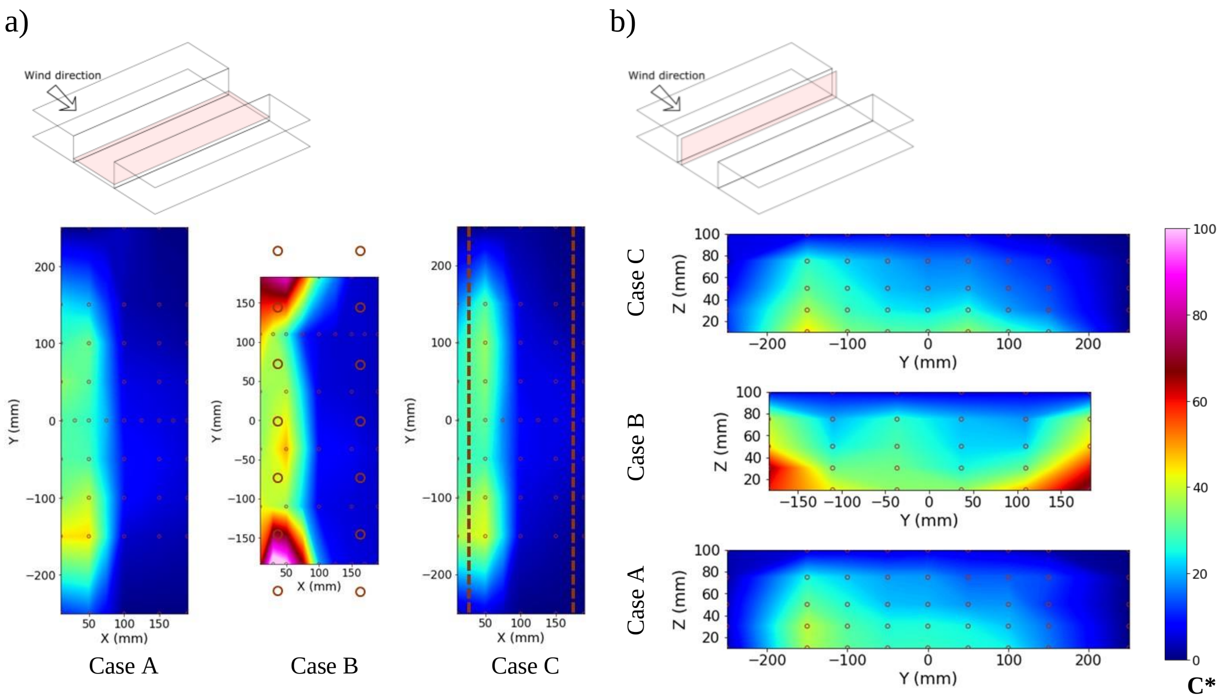

Figure 2. (a)Top and (b) front view of the normalized concentration C^* within the street canyon.

In all cases, the pollutant concentration is accumulated towards the leeward wall near the ground. Case B (with trees) suggest a higher accumulation of pollutants, especially at the lateral edges, while a minimal difference is observed between Case A (reference case) and Case C (with cars).

Concentration profiles along the length of the canyon for the pedestrian breathing are shown in Figure 4.

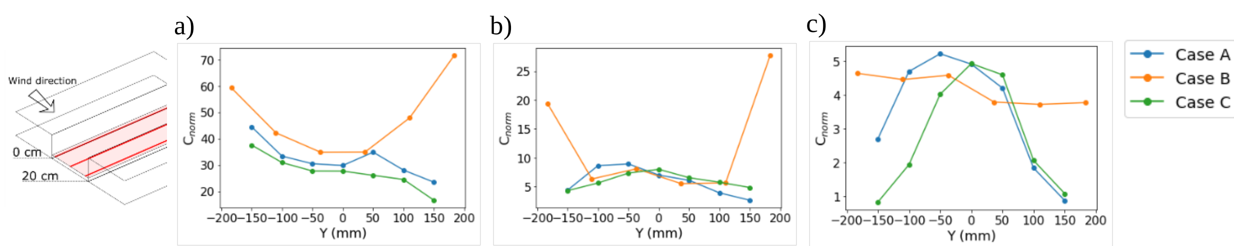

Figure 3. Concentration profiles C^* plotted for each case, along the entire length of the canyon near the pedestrian breathing zone, for (a) X=10 mm closest to the leeward wall, (b) X=100 mm centre of the canyon, (c) X=190 mm closest to the windward wall.

For each longitudinal profile, the average concentration is computed and the percentage differences with respect to the reference case are reported in the following table.

Figure 3 shows that Case B (with trees) is characterized by higher pollution concentration than Case A (reference case) for the pedestrian walkway area near the leeward wall, spatially averaged to be approximately 51% higher. For the same region, Case C (with cars) shows a 15% reduction in pollution.

4. CONCLUSIONS

From these experimental results, a few inferences can be summarized. First, the flow field within the canyon appears to observe a skimming flow pattern (Oke (1988)) characterized by a primary vortex that pushes the pollutants towards the leeward wall.

For the tree case scenario (Case B), there appears to be some sort of a trapping effect, wherein there is an increase in the concentration of pollutants and an accumulation near the pedestrian area. However, other studies have suggested that trees can have either a positive or a negative effect, depending on the configuration of the trees and the deposition effects (Buccolieri *et al.*, 2022). Hence, more studies should be done to ascertain whether the presence of trees would increase or decrease pollutant concentration for a specific street canyon.

For the cars case scenario (Case C), the lower concentration levels for the pedestrian walkway area are corroborated against previous studies, which also claim that parked cars – especially when parked parallel to the street – could reduce pollutant exposure in this area.

Overall, these studies confirm that the presence of obstacles within a street canyon affects local flow patterns, and further investigations – both experimental and numerical – should be conducted for diverse scenarios to assess their applicability.

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