Flow and dispersion in a tree-lined perpendicular street canyon

PHYSMOD 2024 – International Workshop on Physical Modelling of Flow and Dispersion Phenomena
Ecole Centrale de Lyon, Ecully, France – August 28-30, 2024

Flow and dispersion in a tree-lined perpendicular street canyon

S. Fellini [1], A.V. Del Ponte [1,2], M. Marro[2], L. Soulhac[2], L. Ridolfi[1], P. Salizzoni[1,2]

[1] Politecnico di Torino, DIATI, Corso Duca Degli Abruzzi 24, 10129, Torino, Italy.
[2] Univ Lyon, Ecole Centrale de Lyon, CNRS, Univ Claude Bernard Lyon 1, INSA, LMFA, UMR5509, 69130 Ecully, France.

Abstract

Despite advancements in environmental legislation, air pollution in cities remains a significant health risk. Understanding pollutant transport between urban canyons and the atmosphere is crucial for effective urban planning, necessitating both numerical and experimental research (Zhao et al., 2023). Trees play a critical role in urban canyon ventilation. While greener cities improve the urban microclimate and mitigate climate change, the effect of trees on pollutant dispersion is debated. Trees can inhibit air circulation, reducing ventilation and potentially increasing pollutant concentrations at pedestrian level (Gromke et al., 2009; Carlo et al., 2024). This study employs wind tunnel experiments to investigate the effect of trees on the turbulent flow field and pollutant concentration within a street canyon oriented perpendicularly with respect to the prevailing wind (Fellini et al., 2022, Del Ponte et al. 2024).

The experiments were conducted in the wind tunnel at Ecole Centrale de Lyon, featuring a test section 12 m long, 2 m high, and 3.5 m wide. An idealized urban geometry at a 1:200 scale was created with a canyon oriented perpendicularly to the wind, with an H/W ratio of 0.5. Two rows of plastic tree model, were placed along the street sides. The tree models' drag coefficients and aerodynamic porosity were measured to ensure aerodynamic similarity. Vehicle emissions were simulated using a linear ethane gas source at street level. The incident flow was controlled and measured to represent an urban atmospheric boundary layer. Concentration fields within the canyon were measured using a Flame Ionization Detector (FID), while velocity fields were obtained using a Laser Doppler Anemometry (LDA). The latter was coupled with the FID for synchronous concentration and velocity measurements. The experiments were characterized by a Reynolds number based on the obstacle height ($Re_H = U_H H/\nu$) of 12500.

The presence of trees significantly alters the concentration pattern within the canyon, transitioning from a nearly two-dimensional to a three-dimensional distribution, depending on tree density. Peaks in concentration alternate with low-pollutant regions, particularly in the canyon's lower portion, suggesting significant spatial variation in pedestrian exposure. Despite this alteration, the average pollution levels and overall ventilation efficiency do not exhibit a specific trend with tree density.

The vertical exchange at the canyon roof, governed by both mean flow and turbulent fluctuations, does not change with tree density. However, vegetation-induced reduction in turbulent mass fluxes within the canyon may account for the observed heterogeneity in pollutant concentration. Spectral

analysis of vertical velocity and turbulent mass fluxes indicates a decrease in energy content of large-scale structures with increasing tree density.

These findings underscore the importance of considering the aerodynamic properties of vegetation in street canyons and contributes valuable experimental data for understanding the intricate interactions between vegetation, airflow, and pollutant dispersion in urban environments, providing a basis for more effective urban design and validation of numerical studies.

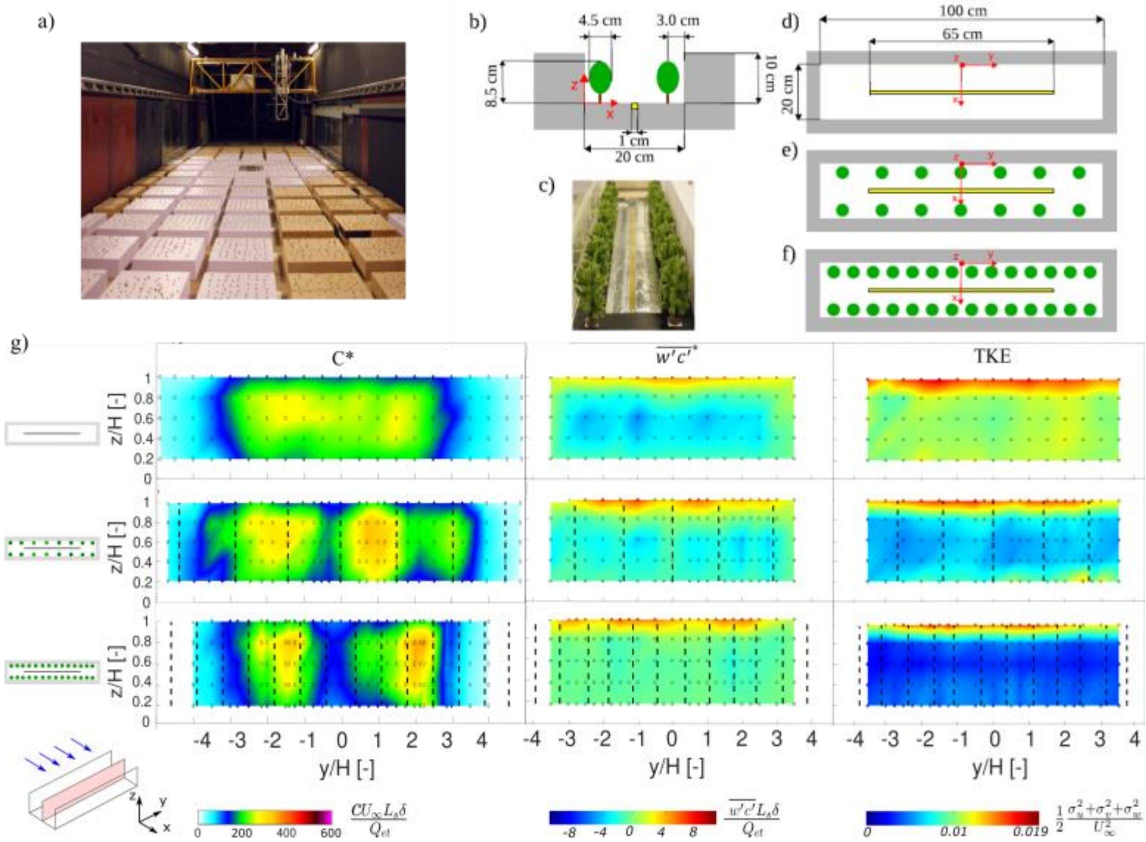

Figure 1: a) The modeled urban canopy in the wind tunnel. Sketch (b) and photo (c) of the front view of the street. Top view of the street canyon model for different tree density configurations (d-f). g) Average concentration fields, vertical turbulent mass fluxes, and turbulent kinetic energy fields in the central section of the canyon for an increasing number of trees in the side rows.

References

Zhao, Y., Chew, L. W., Fan, Y., Gromke, C., Hang, J., Yu, Y., ... & Carmeliet (2023). J. Fluid tunnel research for challenges of urban climate. *Urban Climate*, 51, 101659.

Fellini, S., Marro, M., Del Ponte, A.V., Barulli, M., Soulhac, L., Ridolfi, L. & Salizzoni, P. (2022). High resolution wind-tunnel investigation about the effect of street trees on pollutant concentration and street canyon ventilation, *Building and Environment*, 226(109):763.

Del Ponte, A.V., Fellini, S., Marro, M., van Reeuwijk, M., Ridolfi, L. & Salizzoni, P. (2024). Influence of Street Trees on Turbulent Fluctuations and Transport Processes in an Urban Canyon: A Wind Tunnel Study, *Boundary-Layer Metheorology*, 190:6.

Gromke, C. & Ruck, B. (2009). On the Impact of Trees on Dispersion Processes of Traffic Emissions in Street Canyons, *Boundary-Layer Metheorology*, 131(1):19–34.

Carlo, O. S., Fellini, S., Palusci, O., Marro, M., Salizzoni, P., & Buccolieri, R. (2024). Influence of obstacles on urban canyon ventilation and air pollutant concentration: An experimental assessment, *Building and Environment*, 250, 111143.