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Comparative analysis of wind tunnel experiments and uDALES simulations for pollutant dispersion in tree-lined street canyons

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While street trees enhance microclimatic conditions and mitigates climate change, their impact on air quality remains debated. Computational fluid dynamics (CFD) simulations are powerful tools for analyzing the interactions between airflow, street canyons, and vegetation. However, their validation through experimental data remains an ongoing challenge.

This study compares high-resolution wind tunnel experiments and Large-Eddy Simulations (LES) to examine the flow field and pollutant dispersion within a street canyon oriented perpendicular to the prevailing wind. The configuration includes two rows of trees placed along the street sides, vehicle emissions at street level, and an incident flow representative of an urban atmospheric boundary layer.

Experiments were conducted in the wind tunnel at École Centrale de Lyon, where pollutant concentrations and velocity fields were measured using a Flame Ionization Detector (FID) and Laser Doppler Anemometry (LDA), respectively. Additionally, the FID and LDA systems were synchronized to quantify turbulent mass fluxes. Simulations were performed using uDALES, a high-resolution, building-resolving LES code for urban microclimate and air quality modeling.

The results validate numerical simulations against experimental data, highlighting key factors for aligning CFD models with wind tunnel experiments. In particular, the study emphasizes the need to accurately reproduce the boundary layer above buildings and select proper dimensional scaling for consistency. Simulations provide a detailed view of flow and concentration fields, showing that trees significantly alter pollutant distribution. Instead of a uniform two-dimensional pattern, concentrations vary three-dimensionally with tree density, creating alternating high- and low-pollutant regions. However, average pollution levels and overall ventilation efficiency show no clear trend with tree density.

By demonstrating the synergy between numerical simulations and experimental measurements, this study provides valuable insights into vegetation-airflow-pollutant interactions, contributing to more effective urban design strategies aimed at improving air quality in street canyons.