ABSTRACT

Urban air pollution remains a critical environmental concern, driven by rapid urbanization and increasing traffic emissions. Street canyons formed by tall buildings flanking narrow roads significantly restrict natural ventilation, leading to the accumulation of traffic pollutants at pedestrian level, thereby increasing human exposure and potentially impacting indoor air quality. While field measurements and monitoring campaigns provide valuable insights, they often lack the spatial resolution and adaptability required to analyze diverse canyon configurations. In this context, Computational Fluid Dynamics (CFD) emerges as a powerful tool for resolving airflow and pollutant dispersion at fine scales.

This study employs CFD to investigate the influence of canyon geometry and wind direction on airflow patterns, pollutant dispersion, and ventilation performance. The research is conducted in two phases. The first phase focuses on idealized street canyon configurations to isolate fundamental flow structures and transport mechanisms. Results indicate that symmetric canyons exhibit maximum CO accumulation under parallel wind conditions, whereas step-up and step-down canyons show peak concentrations under oblique and perpendicular winds, respectively. Ventilation efficiency is highest in symmetric and step-down canyons under oblique winds, and in step-up canyons under perpendicular winds.

The second phase extends the analysis to a real street canyon in Kolkata, India, incorporating complex urban geometry and field measurements. Validation is performed for air temperature, CO concentration, wind speed, and direction. While temperature predictions show good agreement, moderate discrepancies in pollutant concentrations arise due to unsteady traffic emissions not fully captured in the model. Wind field predictions exhibit lower correlation, attributed to simplifications in urban morphology and uncertainties in inlet boundary conditions. Despite these limitations, multi-location validation provides a detailed assessment of model performance. The study further incorporates NO_x–O_3 photochemistry, revealing strong diurnal variability. Enhanced morning photolysis increases NO_2 reactivity, while midday conditions promote more uniform chemical activity. Ozone formation intensifies near the canyon top due to reduced NO titration. Transport budget analysis indicates that advection and turbulent diffusion dominate pollutant dynamics, with chemical reactions playing a secondary role.

Overall, this work establishes a validated CFD framework linking geometry, flow dynamics, and photochemical processes, offering practical insights for urban design strategies aimed at reducing pollutant exposure and improving urban air quality.