Evaluating thunderstorm outflow propagation in street canyons using CFD simulations and wind tunnel data

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Thunderstorm outflows can produce intense, rapidly spreading winds upon reaching the earth's surface, posing significant hazards to buildings and the environment. While the traditional wind engineering approach is to assess wind actions on buildings through wind tunnel testing, numerical simulations are becoming more accurate and computationally efficient. This study addresses a gap in understanding the interactions between thunderstorm outflows, background atmospheric boundary layer (ABL) winds, and urban canyons.

Computational Fluid Dynamics (CFD) simulations are validated against physical experiments from a wind tunnel study by Richter et al. (2017). Their experiment simulated a negatively buoyant gust using a jet impinging into a street canyon under the influence of a background ABL flow. Velocity fields within the canyon were measured using a two-dimensional Time-Resolved Particle Image Velocimetry system. For the CFD simulations, the Reynolds-Averaged Navier-Stokes approach is adopted, employing the Launder and Sharma low-Reynolds number k-ε turbulence model. This model is selected due to its effectiveness in capturing near-wall flow characteristics and resolving flow through the viscous sublayer using thin cell layers with y^+ values mostly below 5.

The CFD and wind tunnel results are compared for both open terrain (i.e., no street canyon) and street canyon scenarios using vertical profiles of normalized horizontal velocity at several streamwise positions downstream of the jet. The CFD model accurately replicates the physical experiments, with Root Mean Square Error values within the acceptable range. There is a trend of increasing error downstream from the downdraft, particularly in the canyon case. The CFD simulations become less accurate as the flow develops within the canyon after impingement, likely due to the turbulent eddies being modelled rather than resolved in the turbulence models. CFD offers valuable insights into critical flow regions near the surface and rooftop level, where experimental instruments could not capture wind data. It accurately resolves peak velocities absent in measurements, highlighting its importance in complementing wind tunnel experiments and guiding future experimental designs.

In the urban canyon, horizontal velocities remain higher at all heights compared to open terrain. Furthermore, peak velocities downstream of the jet decay way more slowly within the canyon than in open terrain, and they extend over greater distances due to flow confinement. This directly escalates wind loads and increases the vulnerability of urban infrastructure, thus underscoring the critical impact of canyon geometry on outflow dynamic.

Richter, A., Ruck, B., Mohr, S., & Kunz, M. (2018). Interaction of severe convective gusts with a street canyon. Urban Climate, 23, 71-90. https://doi.org/10.1016/j.uclim.2016.11.003

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