Tampere University

Fuel Droplet Size Control: A Key Refinement from Engine Performance to Canyon Street Air Quality

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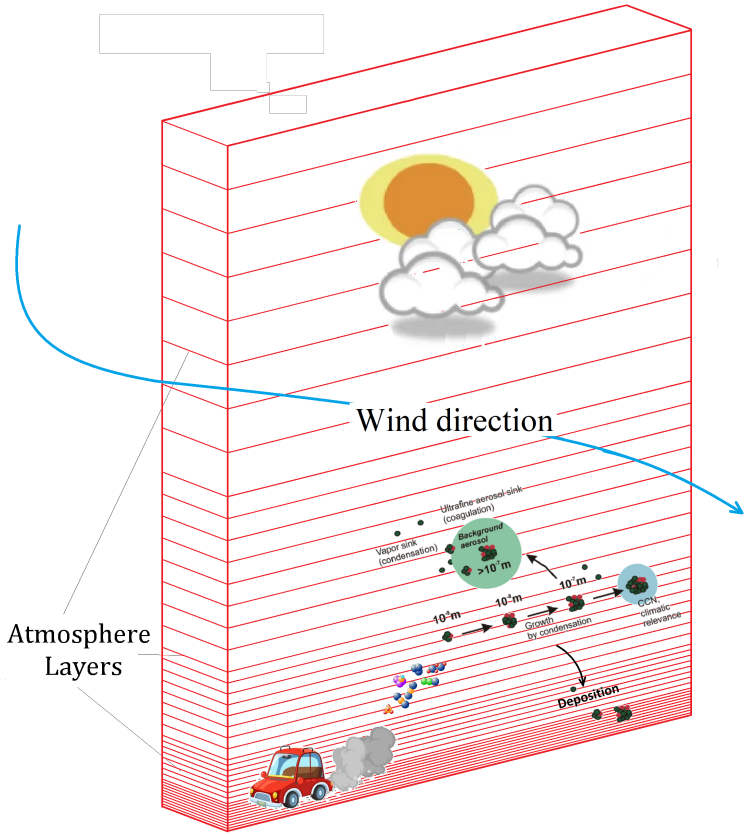
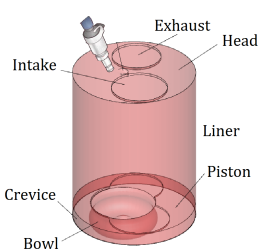
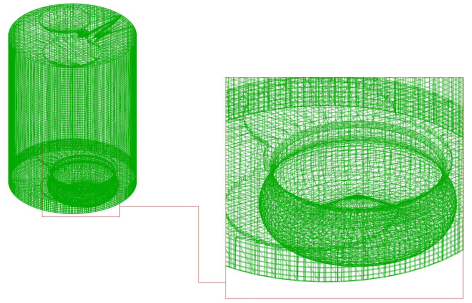
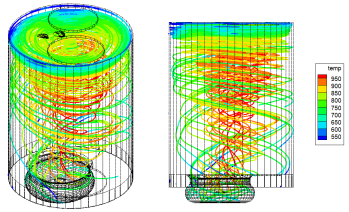
Research Overview

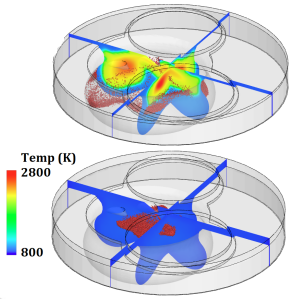
- **Combustion Engine:**
  - Injection
  - Droplet
  - Breakup
  - Evaporation
  - Combustion
  - Emission
- **Environmnet:**
  - Street Canyon Transport
  - Chemistry
  - SOA Formation
- **Linkage:** Engine design affects urban air quality

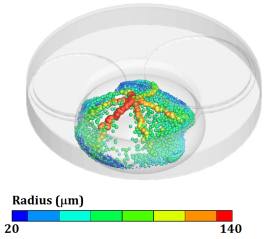






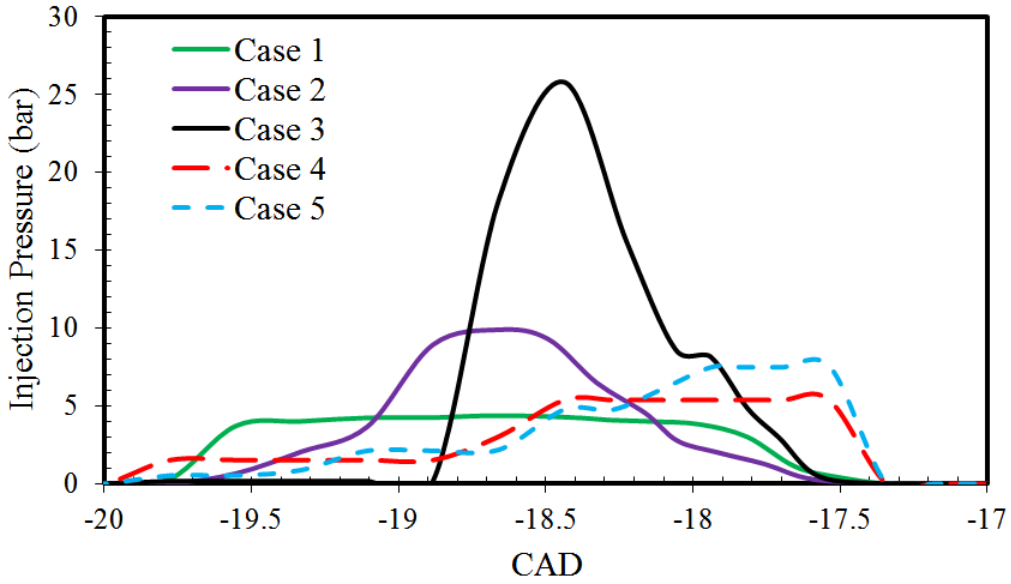


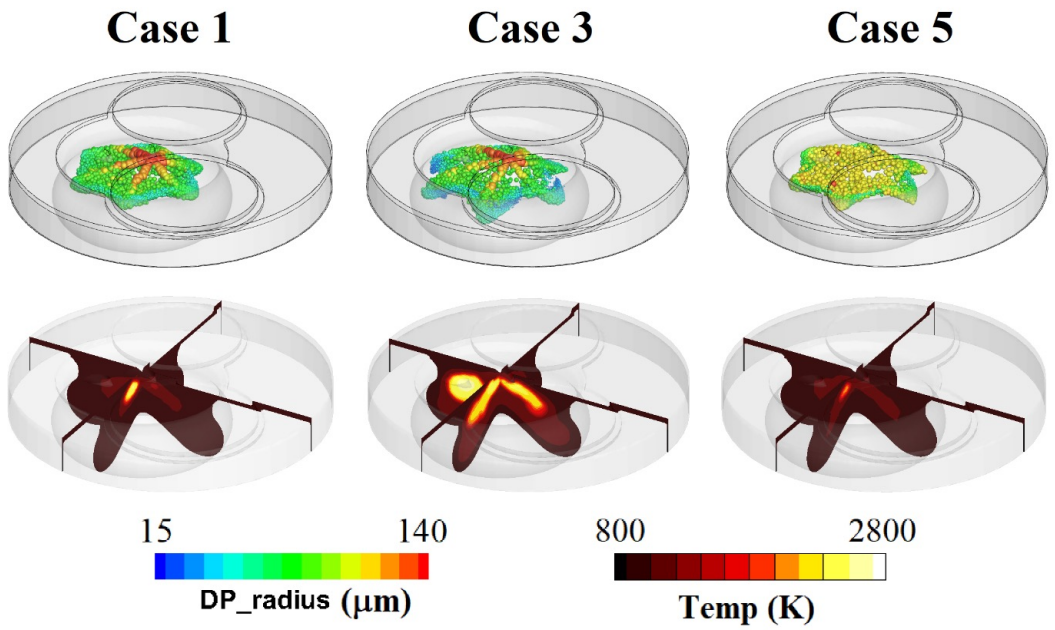




Droplet Size Distribution

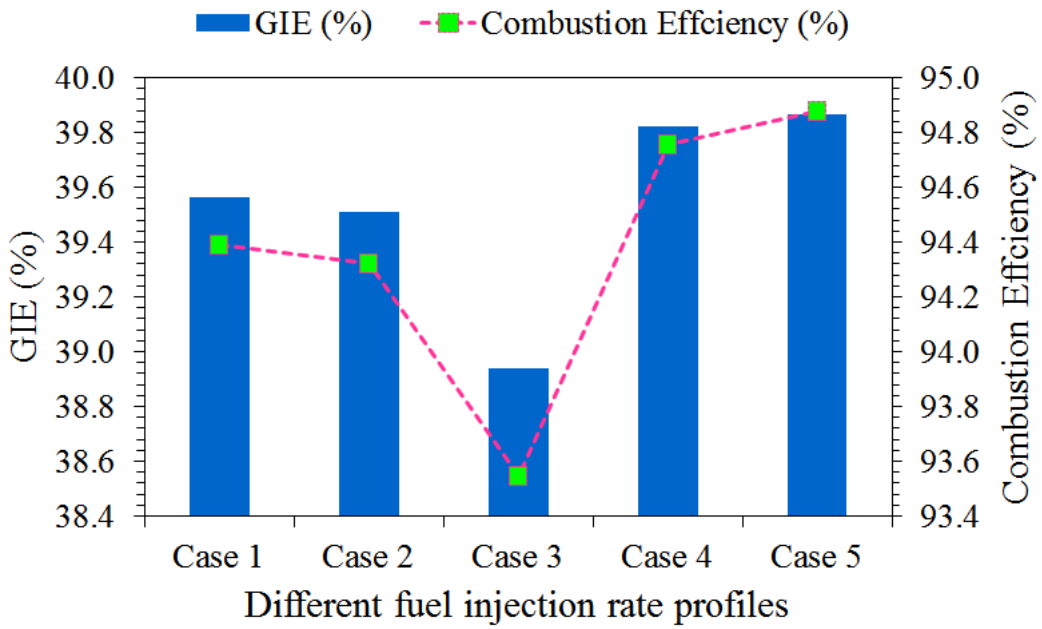
- Droplet size distribution affects combustion quality
- Too small droplets: wall adhesion, early ignition, premature burn
- Too large droplets: poor evaporation, incomplete burn

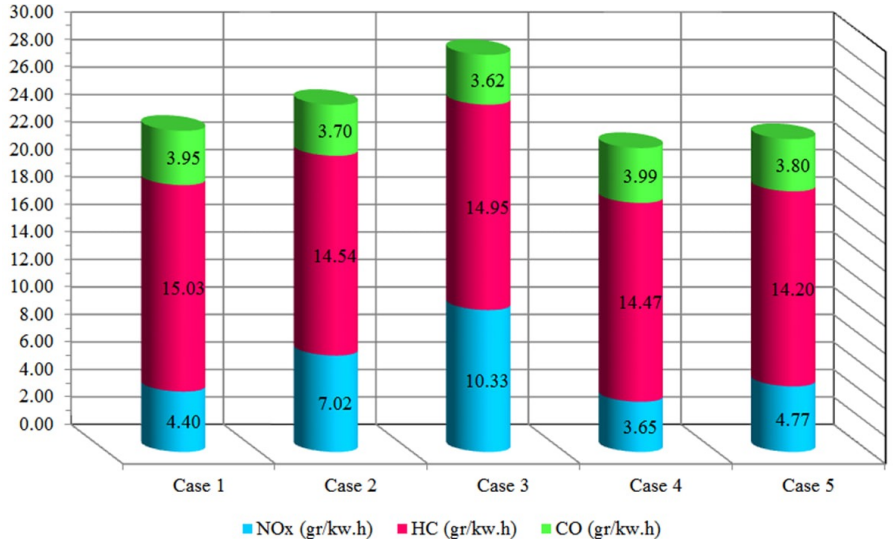




Efficiency & Emission

- Higher combustion efficiency with more uniform droplet size distribution
- Lower HC CO emissions with uniform droplet size distribution
- Most uniform distribution yields best performance
- Goal: Uniform droplet size distribution for optimal combustion



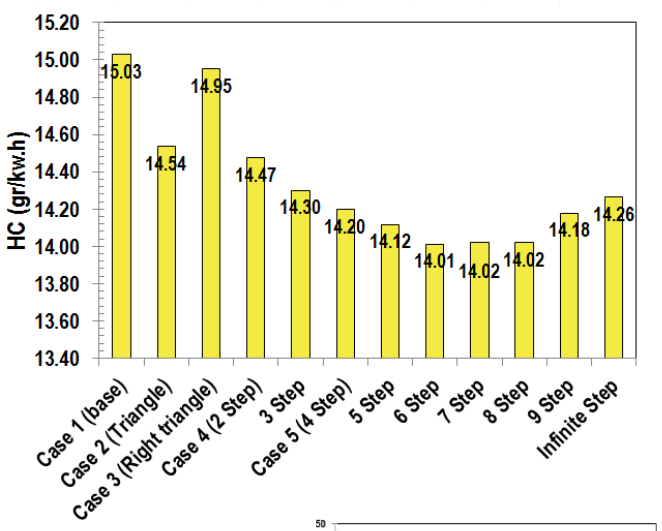


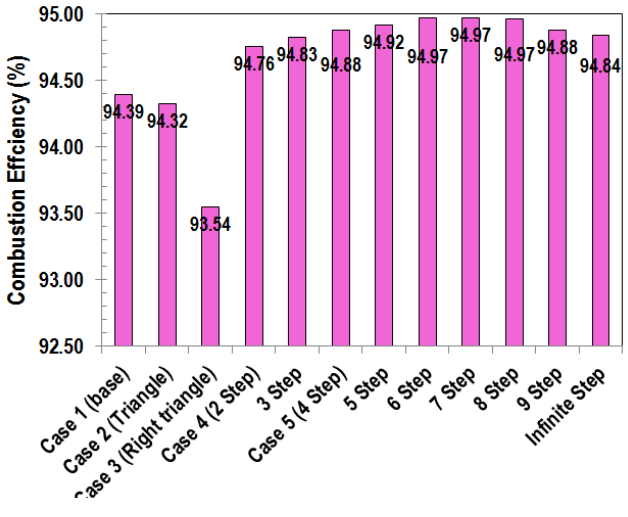
Uniformity in droplet sizes

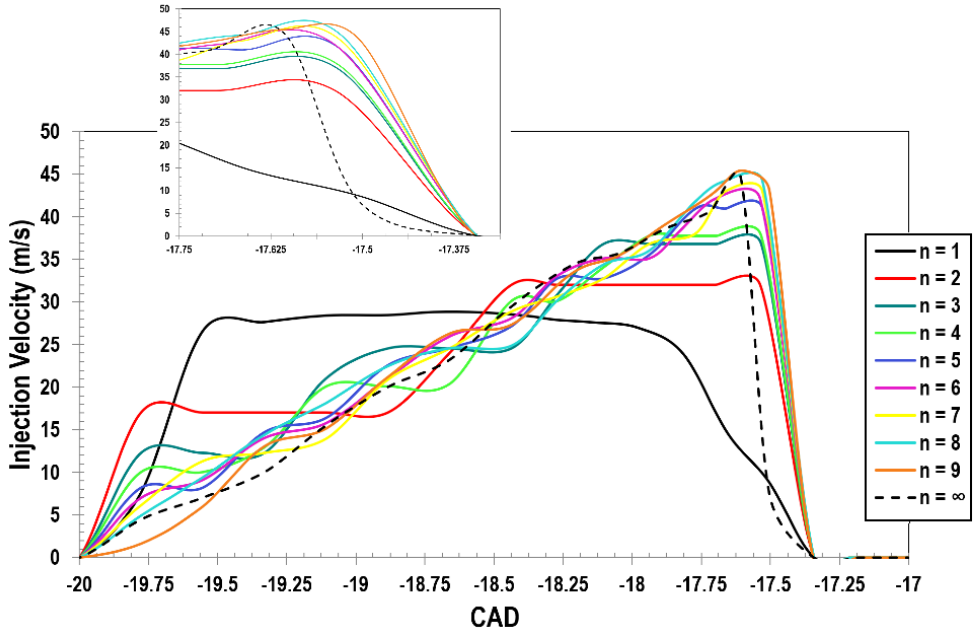
- **Continuous increase combined with optimal number of vibrations as two pivotal characteristics for injection pressure function:**

$$P(t) = \alpha t + \beta.\sin(2\pi n t/T)$$

- **Injection with six vibrations yields best performance**
- **Greater irreversibility → better waste heat recovery**
- **Improved economic performance**

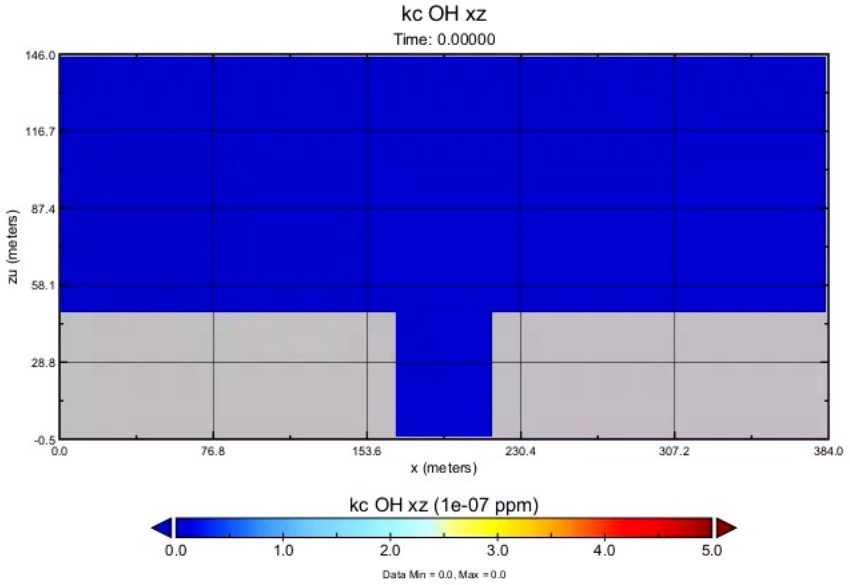


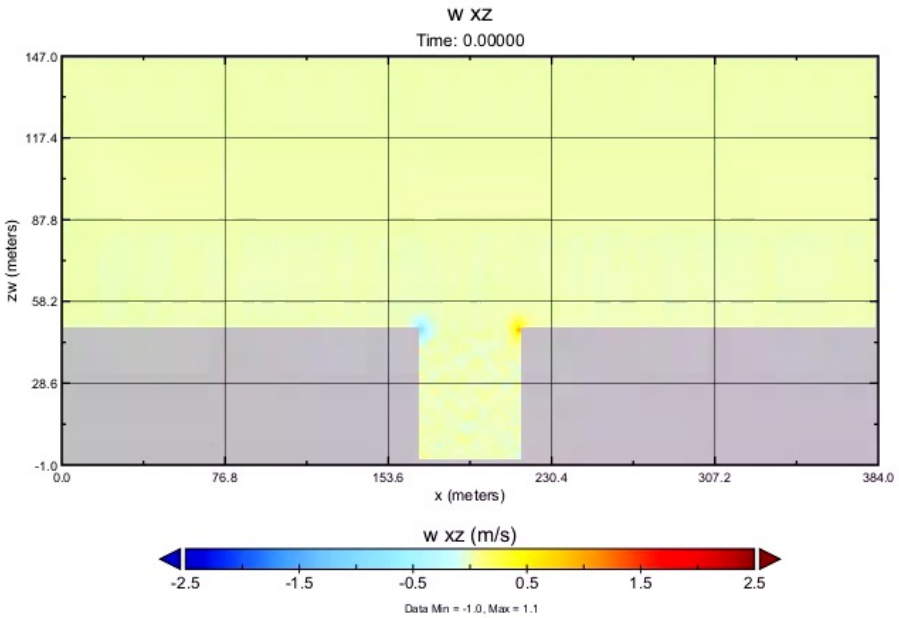


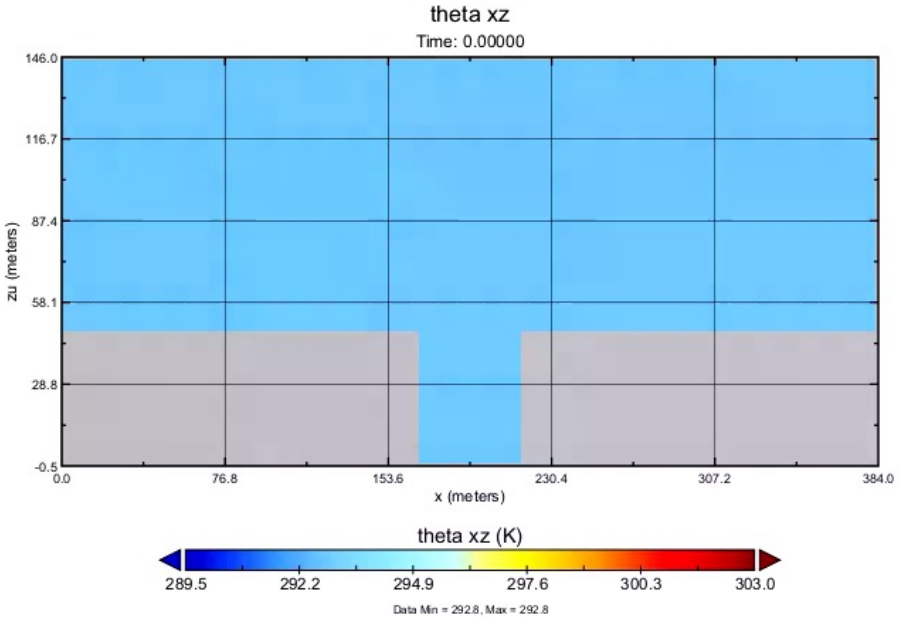


Flow and Thermal Structure in the Street Canyon

- **Flow and Thermal Structure in the Street Canyon**
- **Daytime:** Downward airflow from leeward facade, surface heating → clockwise vortex
- **Peak vortex:** 12:00–13:00
- **Night:** Cooling, loss of vortex, multiple weak thermally stable vortices

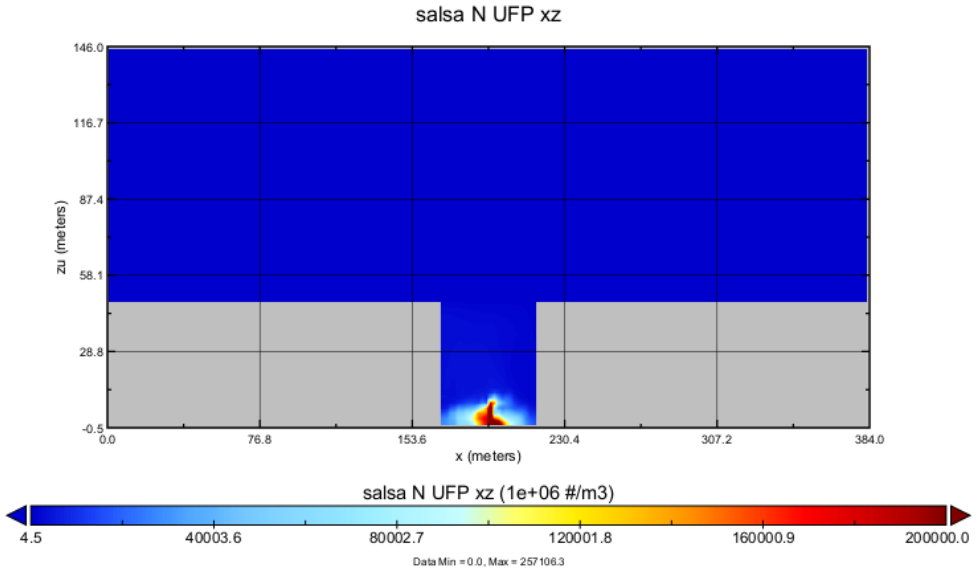






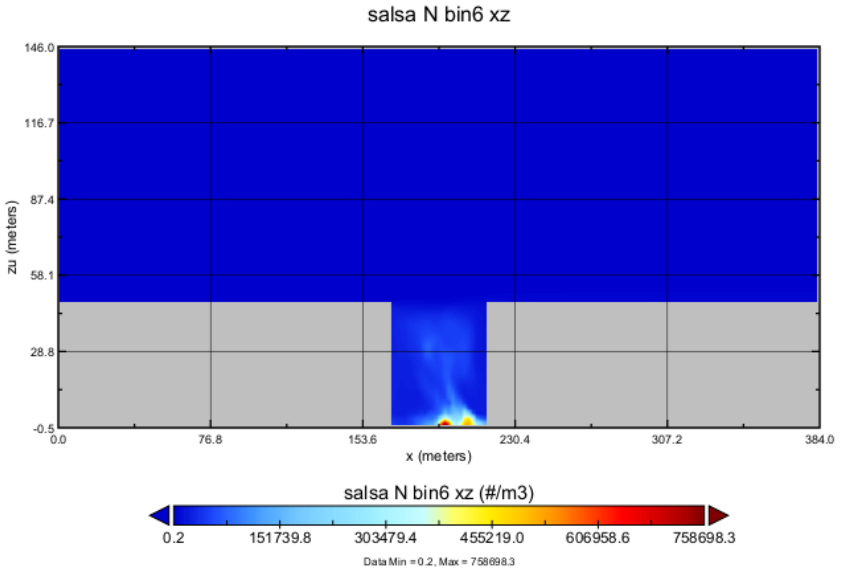
Ultrafine Particle Formation (Nucleation Mode)

- Dual sources: photochemical (solar-driven) & anthropogenic (engines)
- Noon: Nucleation peak → particles in vortex core
- Night: Continued emission but accumulation bear the surface due to poor mixing



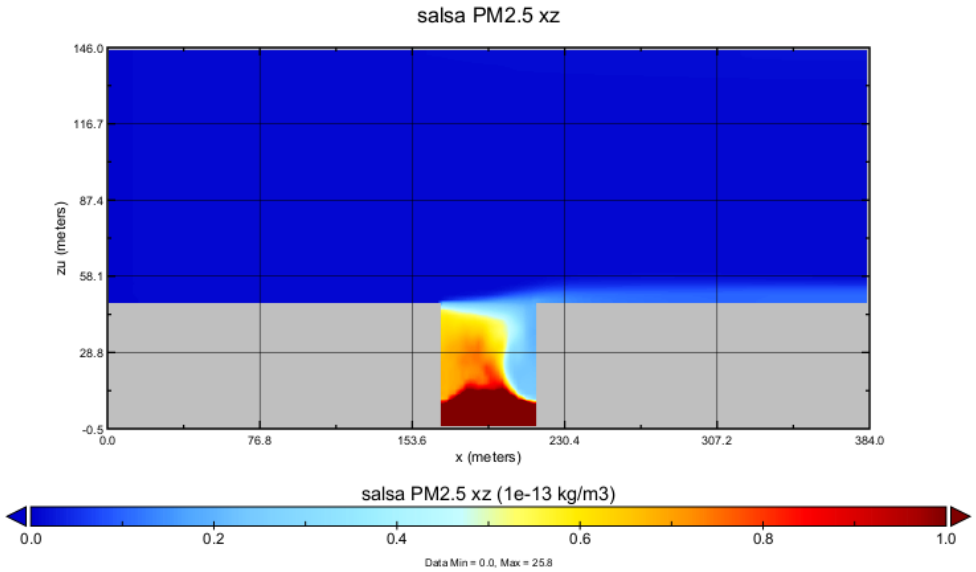
Growth & Dynamics of Larger Particles

- Coagulation & condensation dominate near walls and corners
- Vortex core: initial location, but aging near periphery
- Night: Higher residence time → particle growth near ground



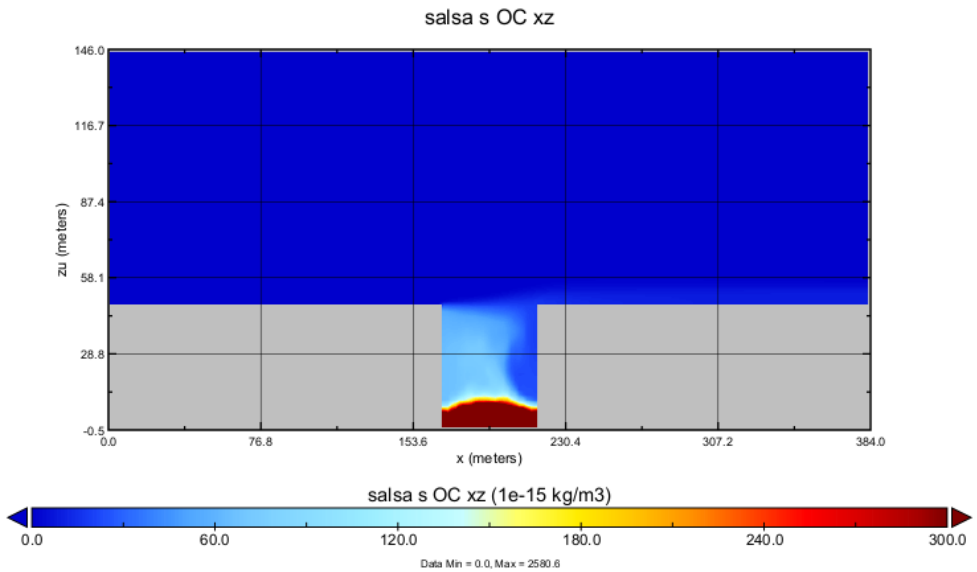
PM2.5 Mass Concentration

- Temporal and Spatial Distribution of PM2.5
- Day: Peak in vortex core due to nucleation
- Night: Accumulation near sources due to stagnation
- Asymmetric distribution during day → cleaner right



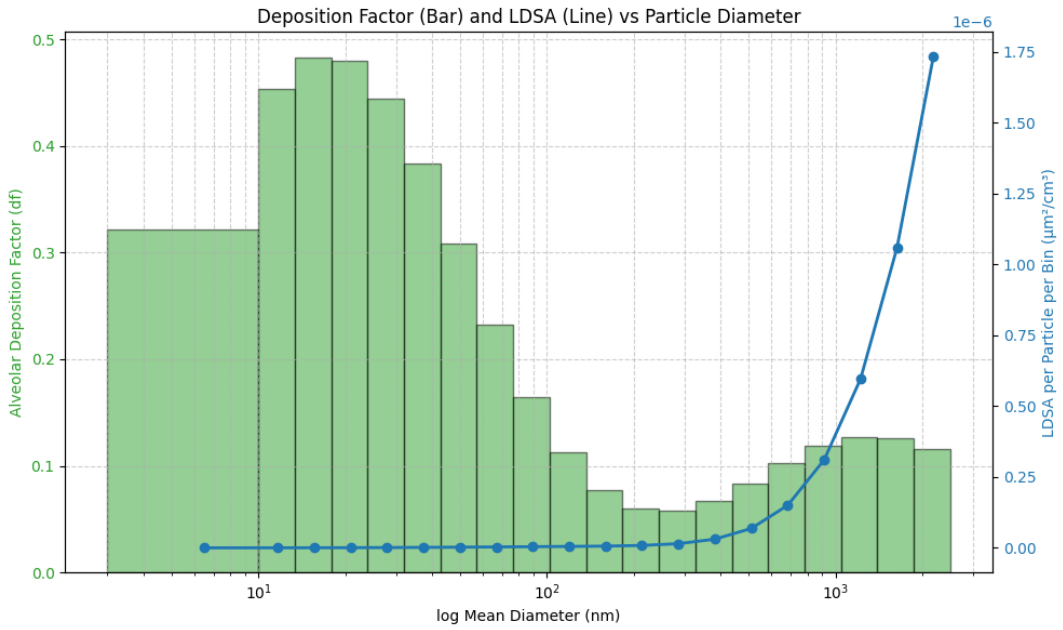
Organic Mass in Particles

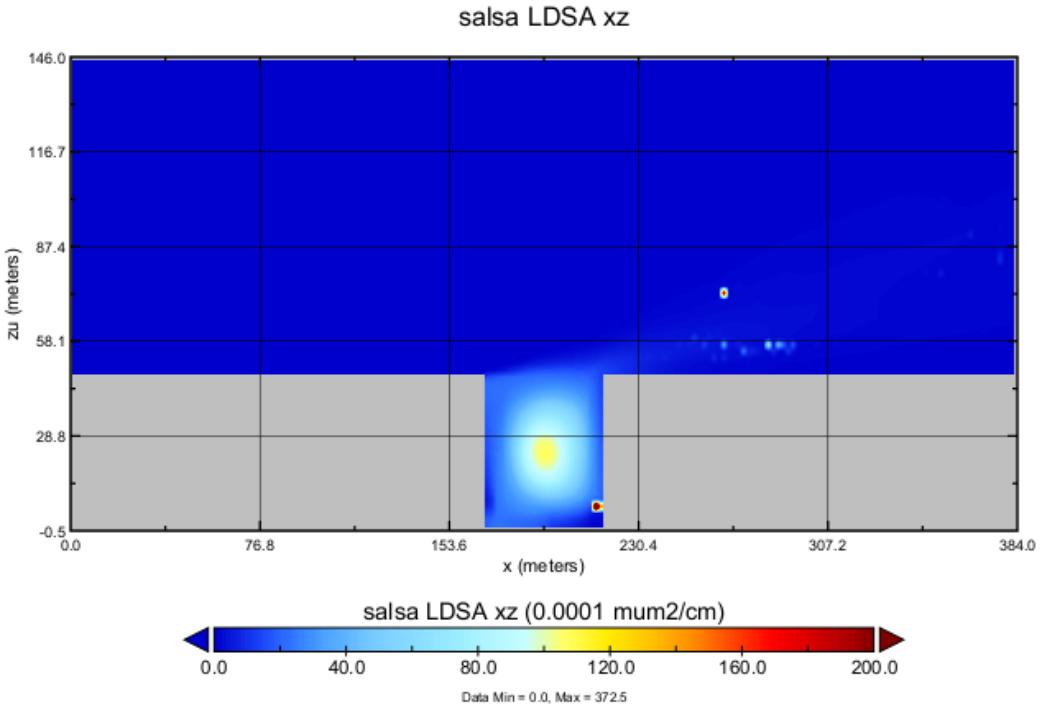
- Organic Aerosols and Secondary Formation
- Day: High photochemical activity → SVOC/LVOC condensation
- Night: Aging and accumulation near sources due to low dispersion



Lung Deposited Surface Area (LDSA)

- **Health-Relevant Metric for Exposure**
- **Highest number concentration ≠ highest LDSA**
- **Hotspot: leeward facade, 7.5–9 m height**
- **Stagnation and particle growth increase LDSA potential**

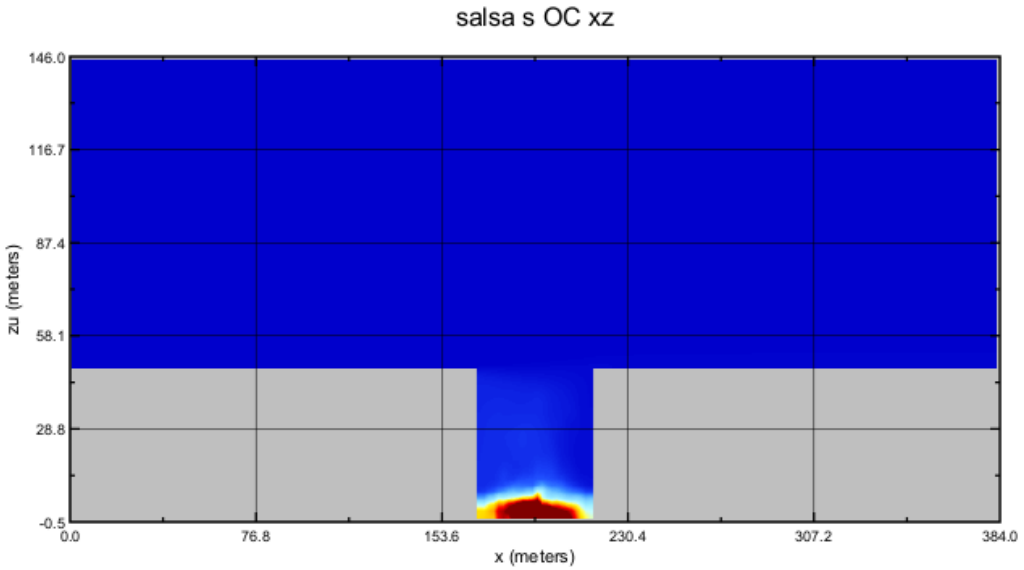




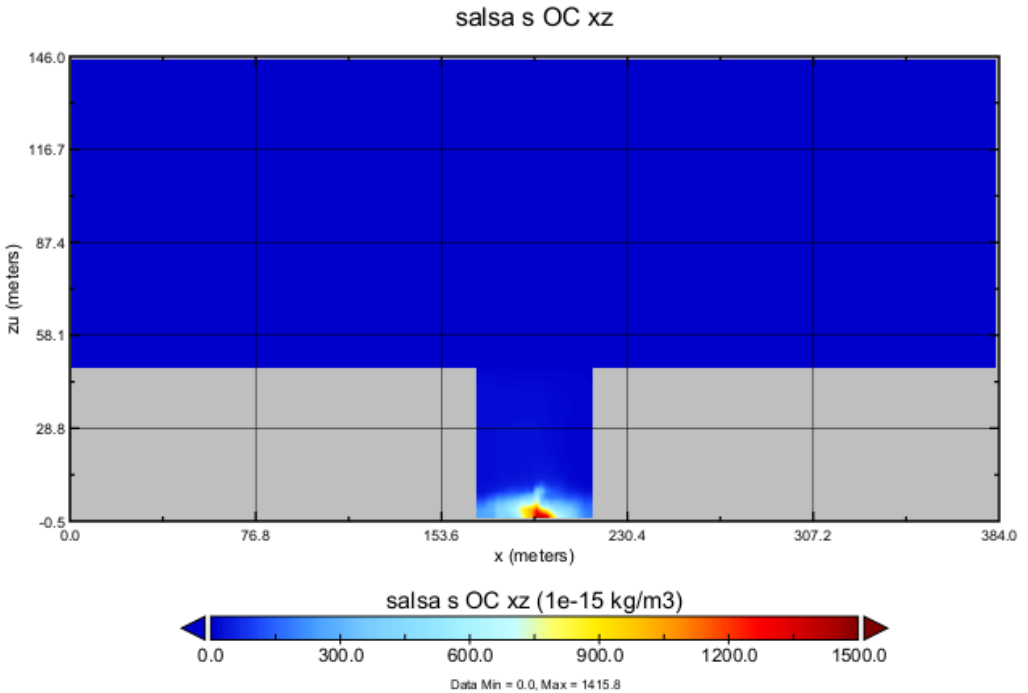
Organic Mass in Particles
Base VS Controlled

TIME 09 : 30

Base



Controlled



Less organic mass found in the formed particles when controlled fuel droplets were used in the engine compared to baseline.

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Summary & Recommendations & Future Focus

- **Uniform fuel droplet size distribution enhances combustion and reduces emissions, and it causes less SOA in Street canyons**
- **Injection optimization has measurable benefits across Energy, Exergy, Economic, and Environmental aspects**
- **Street canyon pollutant behavior is highly dynamic: diurnal airflow, nucleation, and aging processes**
- **Detailed chemistry pathways can lead to better understanding of SOA and more precise results**

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Any Question