FIELD EXPERIMENTS OF FLOW AND DISPERSION WITHIN STREET CANYONS USING OUTDOOR URBAN SCALE MODEL

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Background

In urban (built-up) areas;

- Many small sources of pollutants
  - Motor vehicles
  - Low chimneys
  - Distributed power generators
- Accidental / deliberate releases
  - Hazardous materials
  - Toxic substances

→ Flow and pollutant transport in near buildings (street canyons, obstacle arrays)

Harmo12, Cavtat, Croatia
Background

Flow and dispersion inside street canyons;

- Field measurements
- Laboratory scale physical modelling (wind tunnel, water channel, towing tank)
- Computational Fluid Dynamics (k-ε, LES)
  - Aspect ratio (building height/building width)
  - Step-up and step-down notch
  - Roof shape (flat vs. slanted)
  - Wind speed, direction
  - Wall (Floor) heating

Effects of atmospheric turbulence???

Harmo12, Cavtat, Croatia
COSMO

COSMO = Comprehensive Outdoor Scale MOdel experimental facility for urban climate

- Saitama Prefecture, JAPAN
- Size of the test site = 50m × 100m
- Block height & width = 1.5m
- Number of blocks = 512
- Street width = 1.5m
- Area density = 25%
- 1/5 the scale of typical residential buildings
Plane view of the COSMO Meteorological tower measurement point.

Wind vector in the X and Y directions.
Measuring instruments

- Concentration
  - digitalPID (Aurora Scientific Inc.)\(\times8\)
  - Tracer gas: Propylane (\(C_3H_6\))
  - Line source: \(L=1.5m\)
  - Flow volume: 1 ~ 4L/min.
  - Sampling time: 30min./RUN
  - Sampling frequency: 50Hz

- Velocity
  - Ultra sonic anemometer
    - (Kaijyo DA-600 & TR90-AH)\(\times6\)
  - Sampling frequency: 50Hz
Layout of instruments

Harmo12, Cavtat, Croatia
Flow characteristics measured at z=2H

- **Averaging time** = 3 min. ( = 10 cases x 11 RUN )
  - \( z' = z - d \)
  - d: zero-plane displacement
  - \( L \): Monin-Obukhov length
- **Wind directions** = ±10 deg. -> 57 cases

<table>
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<th>RUN</th>
<th>Date</th>
<th>U(m/s)</th>
<th>( \phi )(deg)</th>
<th>( \sigma_u )(m/s)</th>
<th>( \sigma_v )(m/s)</th>
<th>( \sigma_w )(m/s)</th>
<th>( u^* )(m/s)</th>
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Harmo12, Cavtat, Croatia
Vertical profiles of mean velocity and turbulence statistics

- COSMO
- wind tunnel

(Uehara et al., 2000, Atmos. Environ.)

Vertical profiles of mean velocity and turbulence statistics at Harmo12, Cavtat, Croatia.
Horizontal and vertical velocity within the canyon

Mean wind speed at z=1.2H (m/s)

Harmo12, Cavtat, Croatia
Visualization of canyon flow
Vertical profile of tracer gas concentration

Harmo12, Cavtat, Croatia
Time series of concentration measured within the canyon
Velocity statistics measured at $z=1.2H$ and average concentration

$U_{1.2H} = 2.7 \sim 3.3 \text{m/s (average} \pm 10\%)$
Velocity statistics measured at $z=2H$ and average concentration

\[ \ast U_{1.2H} = 2.7 \sim 3.3 \text{m/s} \]
Time series of fluctuating $u', w'$ at $z=2H$ and concentration near ground

Case 1 $U_{1.2H} = 2.9\text{m/s}$

Case 2 $U_{1.2H} = 2.8\text{m/s}$
Estimation of concentration

\[ \frac{C L}{Q} = \frac{\sqrt{\pi}}{U_0 W} \left( \sqrt{\frac{\sigma_w^{\text{ext}}}{U_0}} \frac{l^{\text{ext}}}{W} \right)^{-1} \]

C: Concentration

\(Q/L\): Line source input rate

\(U_0\): External velocity

\(W\): Canyon width

\(\sigma_w^{\text{ext}}/U_0\): Turbulence intensity

\(l^{\text{ext}}\): Turbulence length scale

Caton, F., Britter, R.E. and Dalziel, S.,
Atmospheric Environment (2003)

Harmo12, Cavtat, Croatia
Conclusions

- A stable vortex-type flow was observed in the street canyon of the outdoor urban scale model, and the strength of the vortex was proportional to the above canyon wind speed.
- The tracer gas from the line source near the ground was carried to the leeward side of the upstream building by the vortex circulation, and the concentrations near the leeward side of the upstream building was higher than that measured at the windward side of the downstream building.
- Diffusion to the leeward side of the canyon by an unsteady turbulent flow and re-entry of the gas at the top of the canyon were verified by measuring the concentrations at several points within the canyon simultaneously.
- Average concentrations inside the canyon decreased with the mean wind speed and the velocity variances. Concentrations could be estimated by considering the external turbulence in addition to the wind velocity.