Street canyon ventilation: Combined effect of cross-section geometry and wall heating

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Introduction

The vertical velocity of mass transfer of pollutants ($u_d$) is a function of:

- EXTERNAL FLOW
- ASPECT RATIO ($H/W$)
- WALL ROUGHNESS
- WALL HEATING ($\Delta T$)
- OBSTACLES (trees)

**Wind-tunnel experiments** to investigate the physical mechanisms that govern the vertical transfer of pollutants ($u_d$) from a canyon to the overlying atmosphere.
The experimental set-up

Measurement techniques
- **Thermal fluxes** at walls → heat flux sensors
- **Temperature** at walls → t-type thermocouples
- **Velocity** → PIV (4 Hz)
- **Concentration** → FID (300 Hz)

Configurations
- Different **geometries** (H/W)
- Different **roughness** conditions at walls
- Different **wall heating** (DW, UW)
- Different **thermal fluxes** (different $\Delta T$)

\[
Fr_i = \frac{U}{\sqrt{gH\Delta T/T_0}} = \frac{\text{inertia}}{\text{buoyancy}}
\]

<table>
<thead>
<tr>
<th>$\Delta T$</th>
<th>0 K</th>
<th>70 K</th>
<th>170 K</th>
<th>240 K</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Fr_i$</td>
<td>$\infty$</td>
<td>0.62</td>
<td>0.40</td>
<td>0.34</td>
</tr>
</tbody>
</table>
Effect of canyon geometry

Mean velocity field → Transition from 1 to 2 cells

Turbulent Kinetic Energy field → Penetration of TKE at street level is inhibited

Mean concentration → Higher concentration at street level
Effect of wall roughness

ROUGHNESS on downwind wall (DW) facilitates formation of 2\textsuperscript{nd} cell

slow down of canyon ventilation
Effect of wall heating – upwind wall

Unaltered mean velocity field with $\Delta T$

Unaltered Turbulent Kinetic Energy field with $\Delta T$
Effect of wall heating – downwind wall of a square cavity

Unaltered mean velocity with $\Delta T$

Increase in TKE with $\Delta T$

Acceleration of canyon ventilation
Effect of wall heating – downwind wall of a narrow cavity

Formation of second cell
Penetration of TKE at street level is inhibited
Slow down of canyon ventilation
Turbulent kinetic energy and canyon ventilation

The vertical transport is governed by the Turbulent Kinetic Energy (TKE) field
Vorticity balance interpretation

\[ \frac{D\omega}{Dt} = \omega \cdot \nabla u + \nu \nabla^2 \omega - S_T \times g, \]

**Geometry**

**Roughness**

**Heating**

\[ S_T = \frac{1}{T} \nabla T. \]
Conclusions

The removal of pollutants depends on the topology of the mean velocity field and on the TKE inside the cavity.

As H/W increases:
- Surplus of anticlockwise vorticity near the walls
- Formation of a 2nd second counter-rotating cell
- Slow down of removal of pollutant from the cavity

Adding roughness to the downwind wall facilitates the transition to two recirculating cells

Thermal fluxes at the upwind wall have negligible effects on both the mean and TKE fields

The heating of the downwind wall has opposite effects depending on the street aspect ratio
Bibliography


Check out our new paper in Quarterly Journal of the Royal Meteorological Society!

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