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

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ÉCOLE CENTRALE LYON

POLITECNICO DI TORINO
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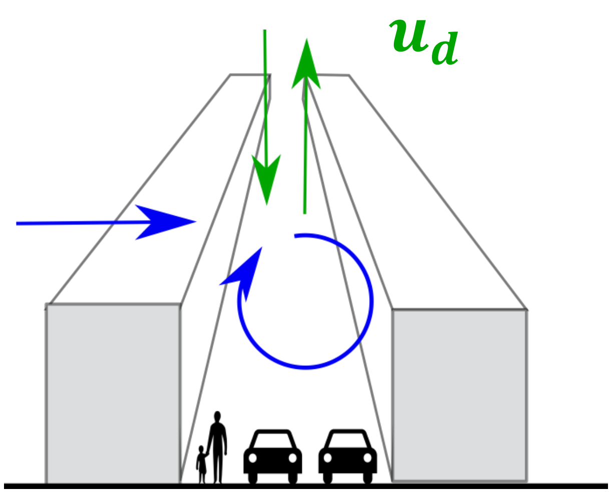
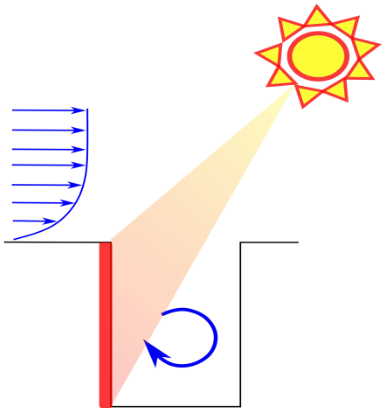
Introduction



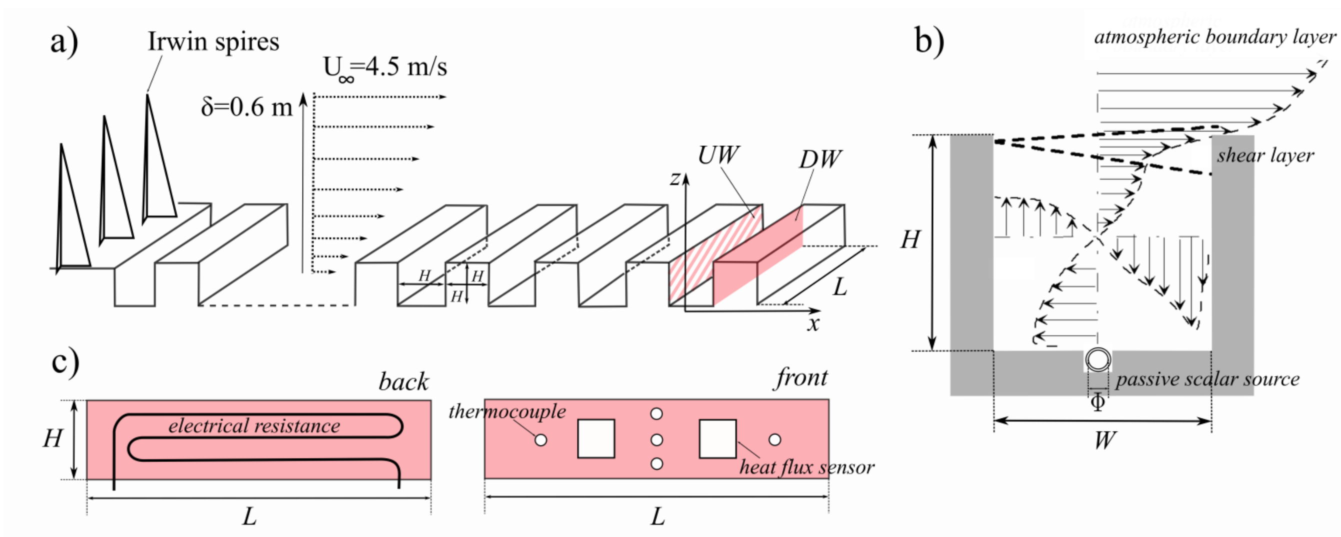
The vertical velocity of mass transfer of pollutants (u_d) is a function of:

- EXTERNAL FLOW
- **ASPECT RATIO (H/W)**
- **WALL ROUGHNESS**
- **WALL HEATING (ΔT)**
- 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

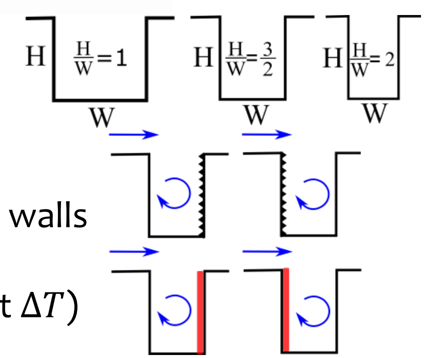
The experimental set-up



Measurement techniques

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

Configurations

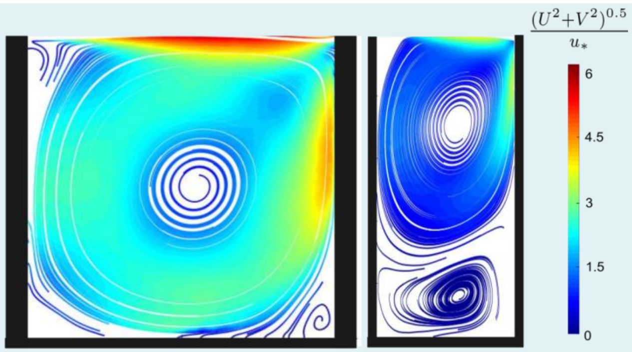


- Different **geometries** (H/W)
- Different **roughness** conditions at walls
- Different **wall heating** (DW, UW)
- Different **thermal fluxes** (different ΔT)

$$Fr_i = \frac{U}{\sqrt{gH\Delta T/T_0}} = \frac{inertia}{buoyancy}$$

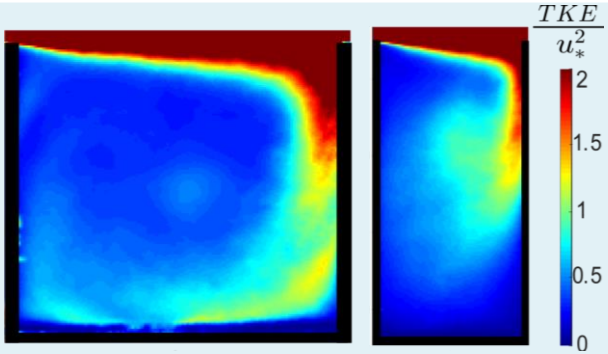
ΔT	$0\ K$	$70\ K$	$170\ K$	$240\ K$
Fr_i	∞	0.62	0.40	0.34

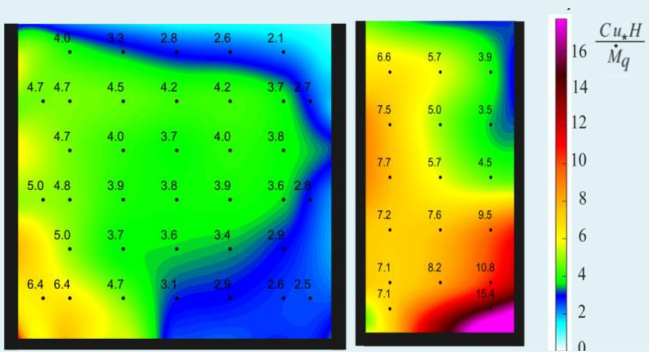
Effect of canyon geometry



Mean velocity field → Transition from 1 to 2 cells

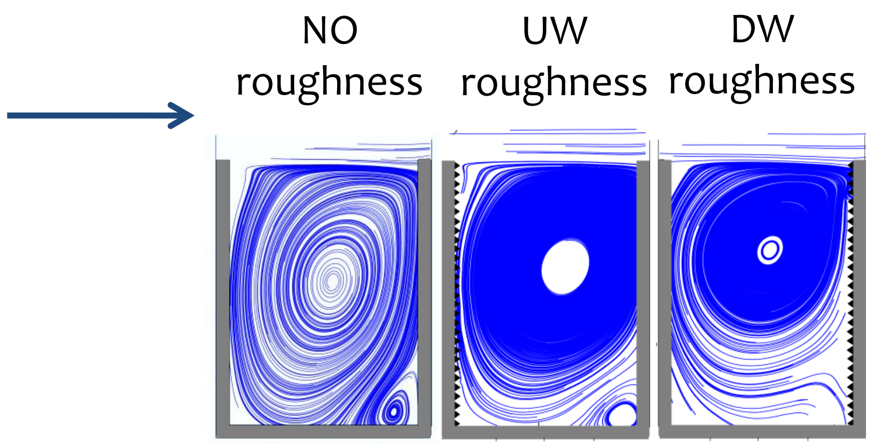
Turbulent Kinetic Energy field → Penetration of TKE at street level is inhibited

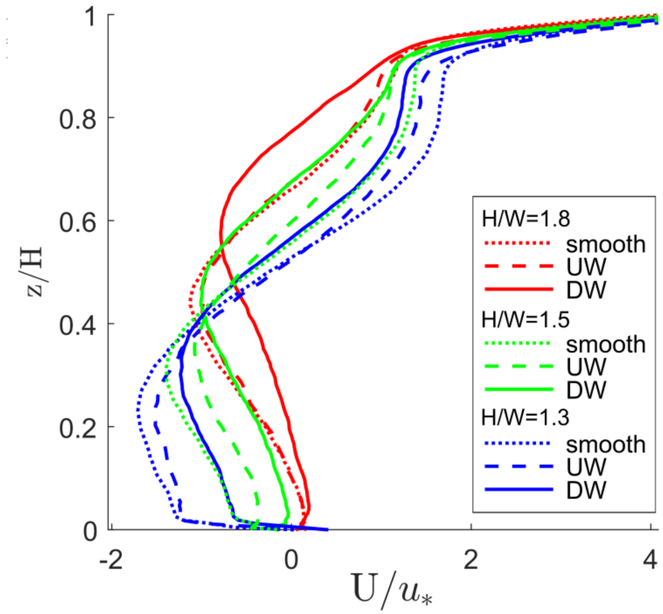




Mean concentration → Higher concentration at street level

Effect of wall roughness





ROUGHNESS on downwind wall (DW) facilitates formation of 2nd cell

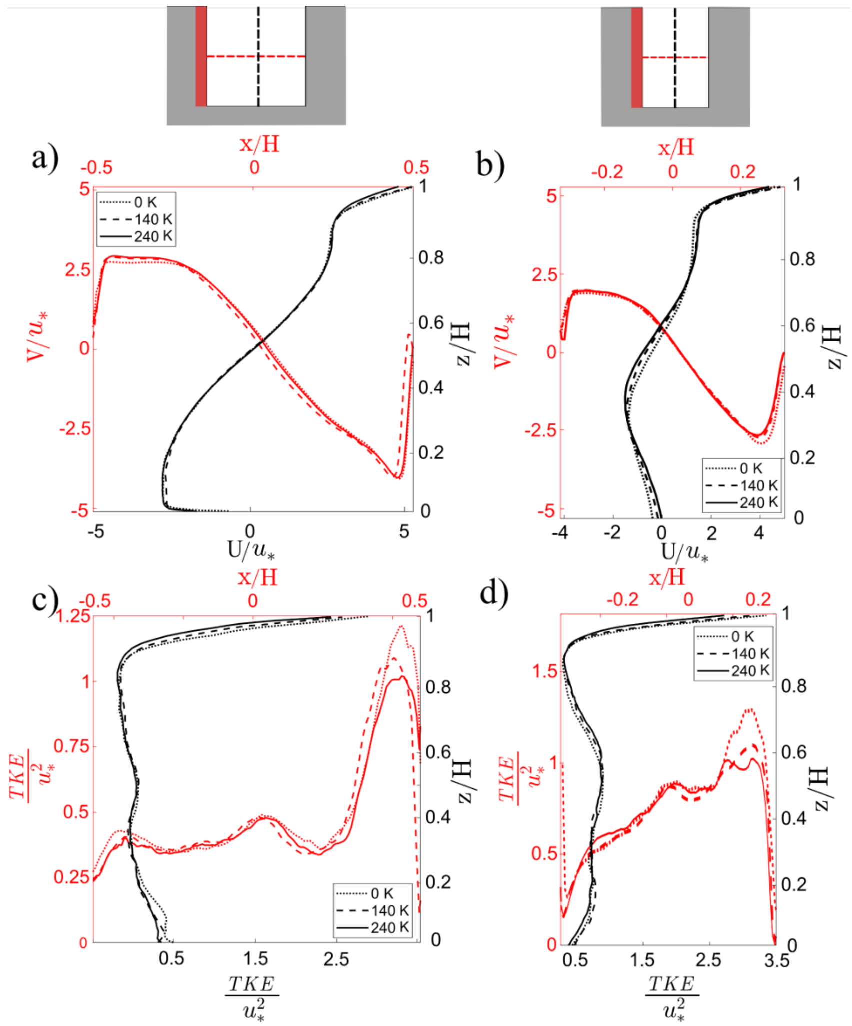
↓

slow down of canyon ventilation

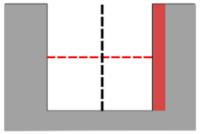
Effect of wall heating – upwind wall

Unaltered
mean velocity field
with ΔT

Unaltered
Turbulent Kinetic
Energy fIeld
with ΔT



Effect of wall heating – downwind wall of a square cavity



Unaltered mean velocity with ΔT

Increase in TKE with ΔT

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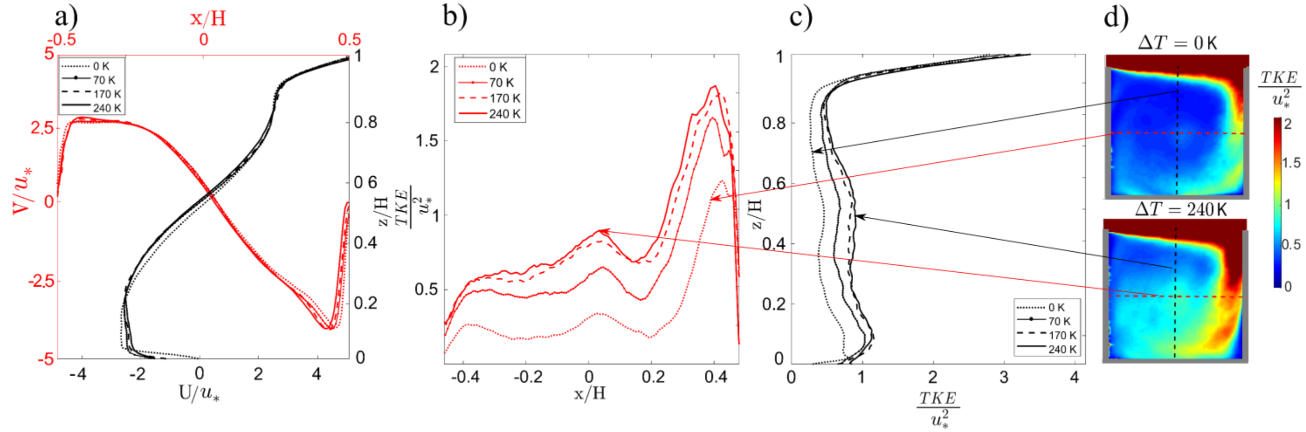
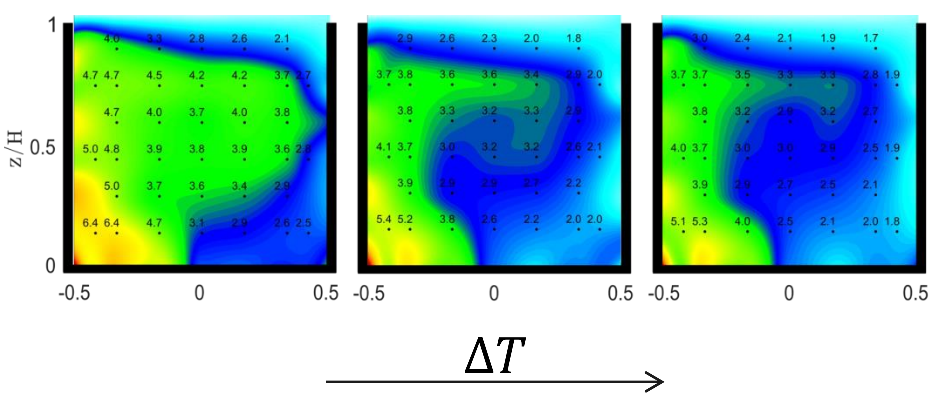
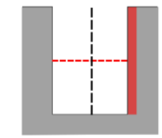
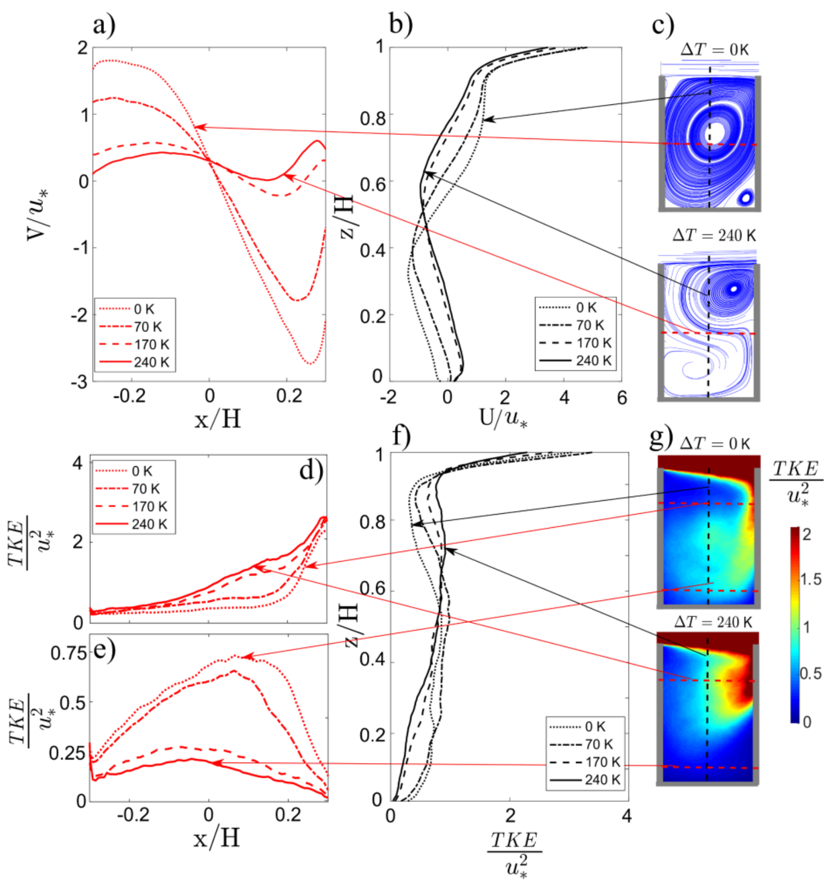
Acceleration of canyon ventilation





Effect of wall heating – downwind wall of a narrow cavity





Formation of second cell

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Penetration of TKE at street level is inhibited

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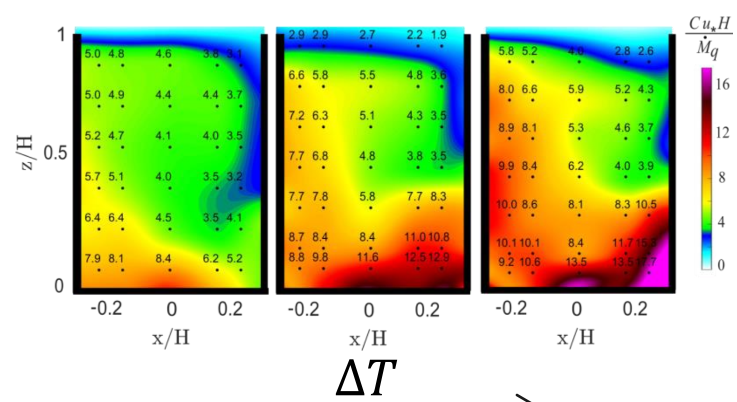
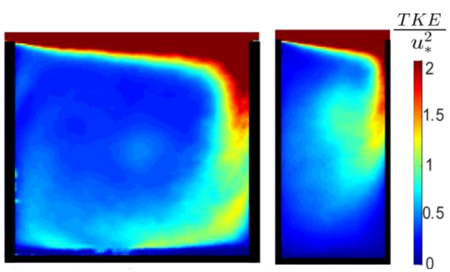
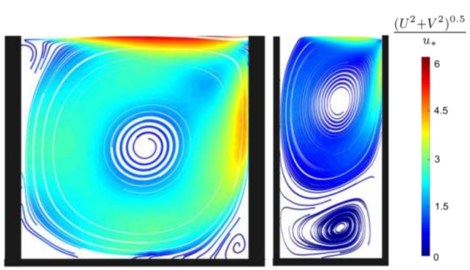
Slow down of canyon ventilation

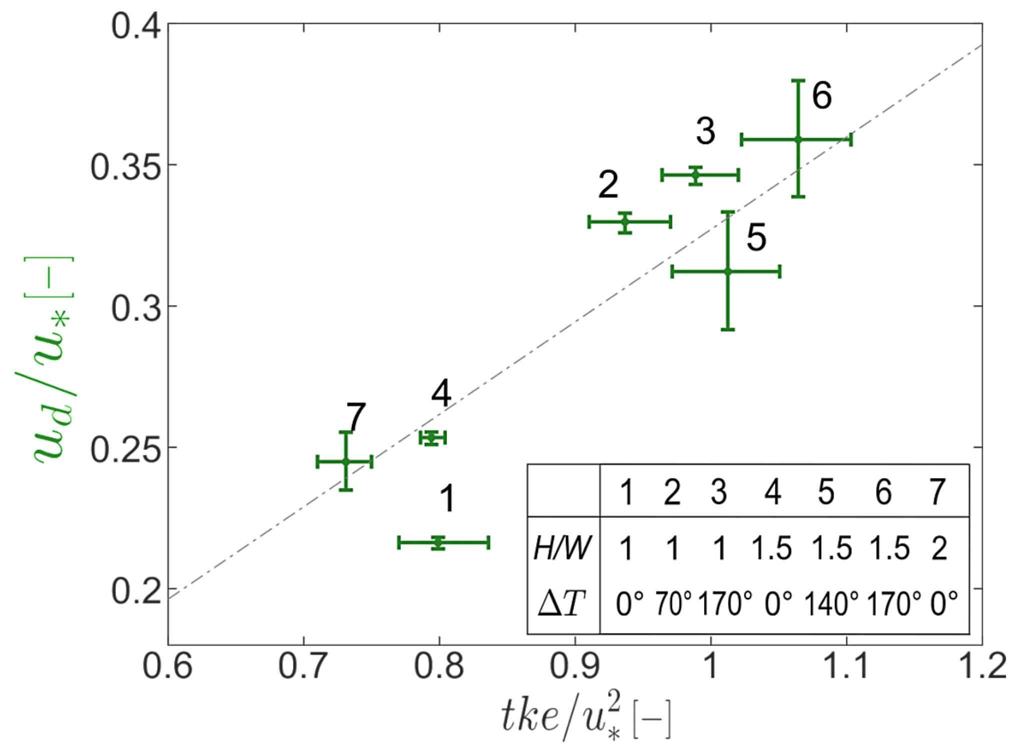


Turbulent kinetic energy and canyon ventilation

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



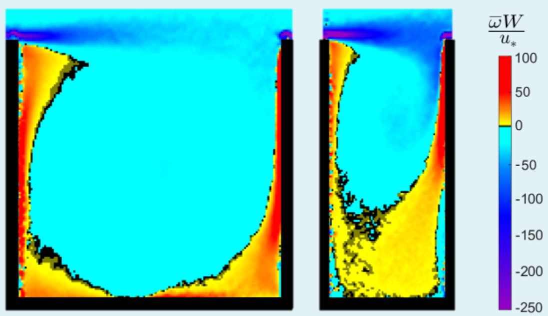


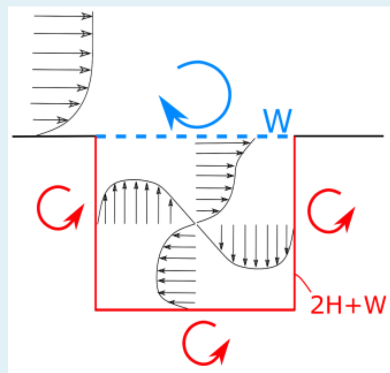


Vorticity balance interpretation

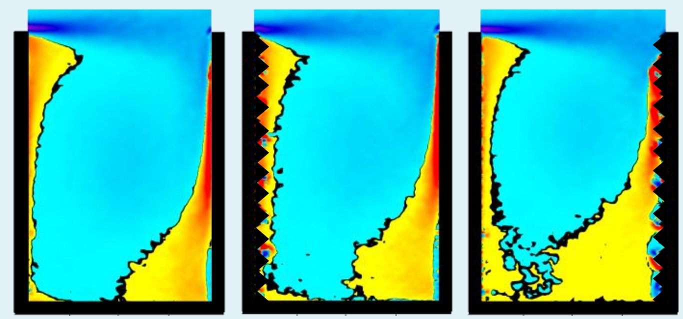
$$\frac{D\boldsymbol{\omega}}{Dt} = \boldsymbol{\omega} \cdot \nabla \mathbf{u} + \nu \nabla^2 \boldsymbol{\omega} - \mathbf{S_T} \times \mathbf{g},$$

Geometry



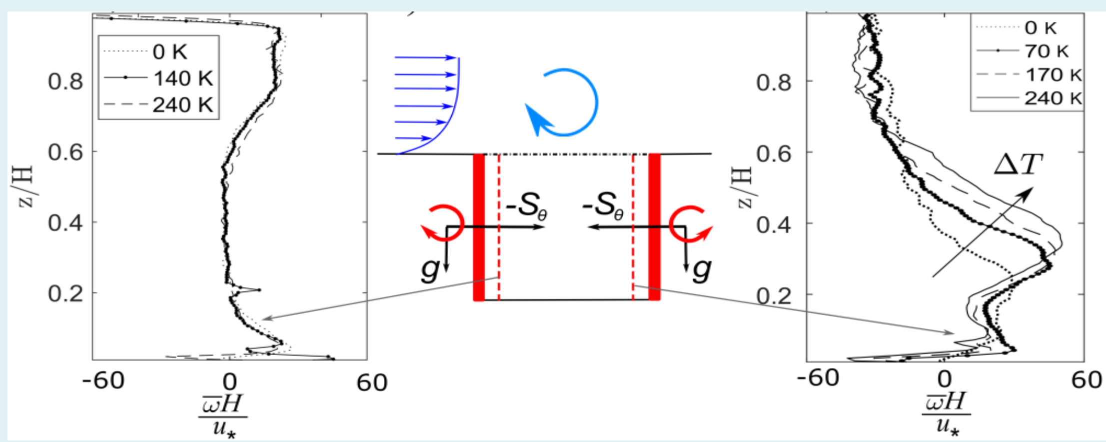


Roughness

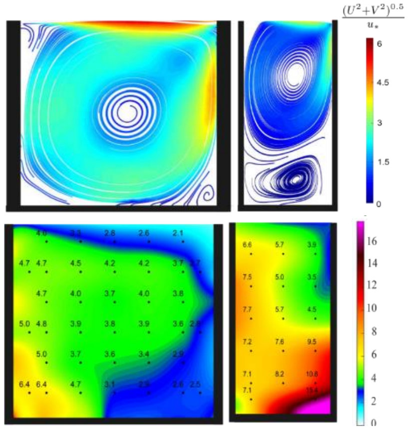


Heating

$$\mathbf{S_T} = \frac{1}{T} \nabla T.$$



Conclusions



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

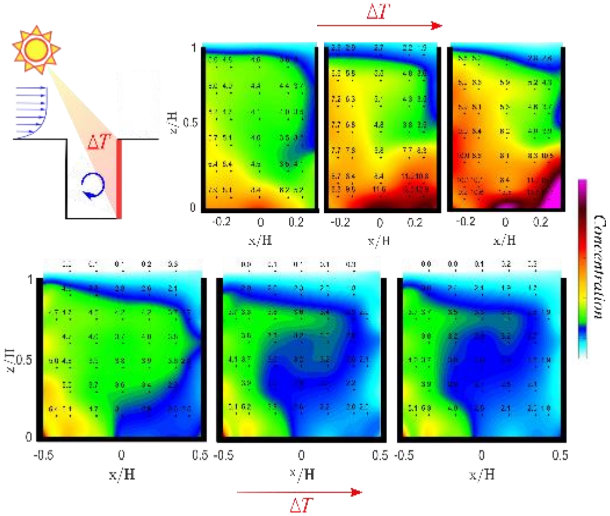
As H/W increases:

- 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



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