The effect of trees on street canyon ventilation

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ÉCOLE CENTRALE LYON

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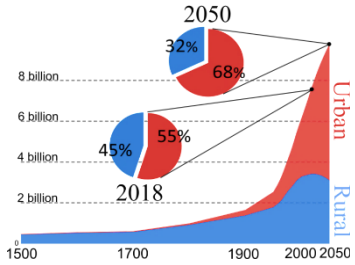
POLITECNICO MILANO 1863

Motivations

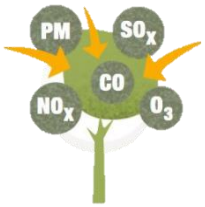
- In 2050, **70% world population** in urban areas
- Air pollution is a **major risk to health**



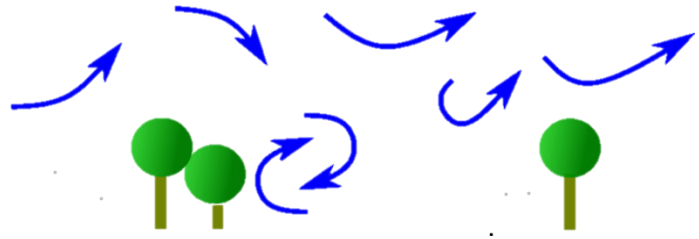
City administrations are looking for solutions for **sustainable and safe cities**

TREE PLANTING IN URBAN AREAS

Temperature regulation
Filters for urban pollutants
Regulate water flow
Physical and mental health
Urban biodiversity



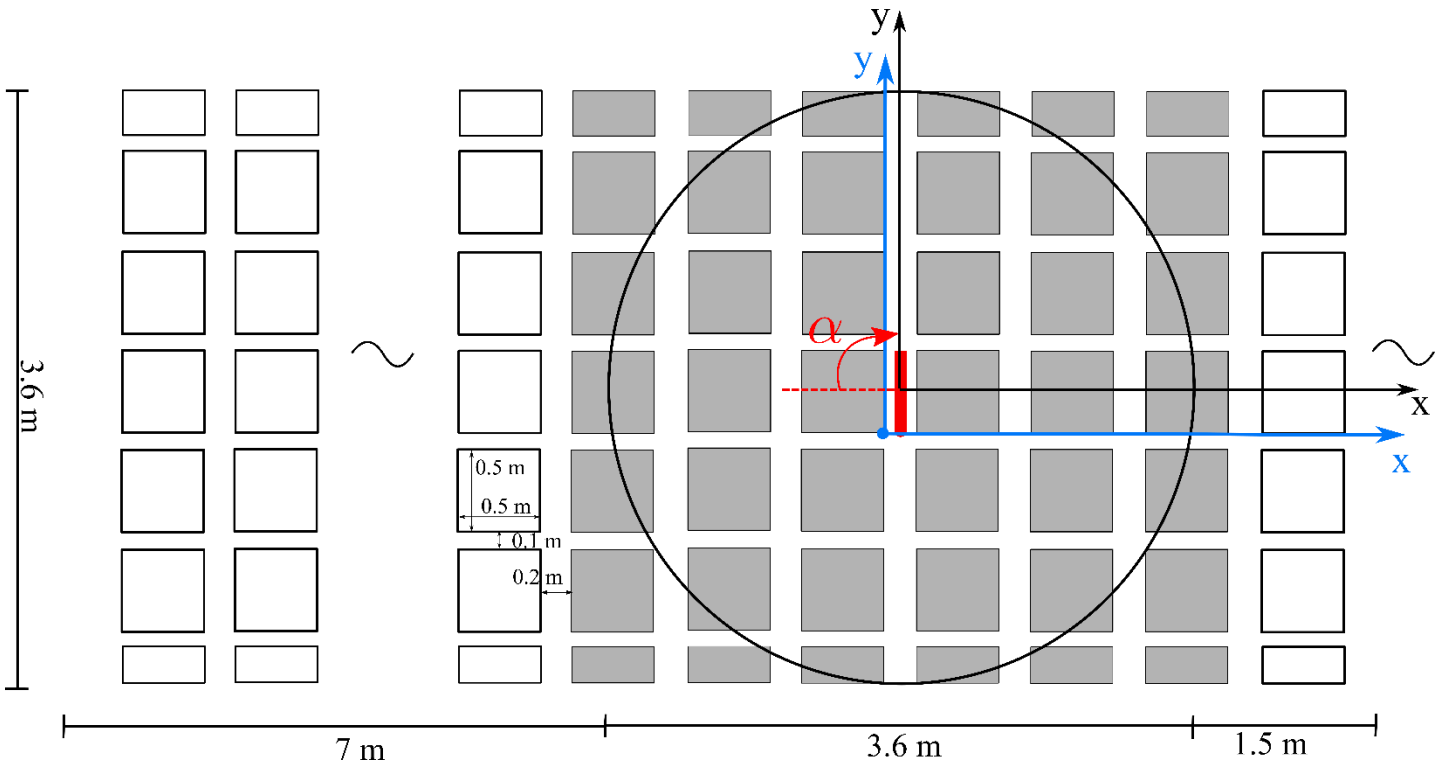
What about the aerodynamic effect?



The experimental setup – The urban canopy

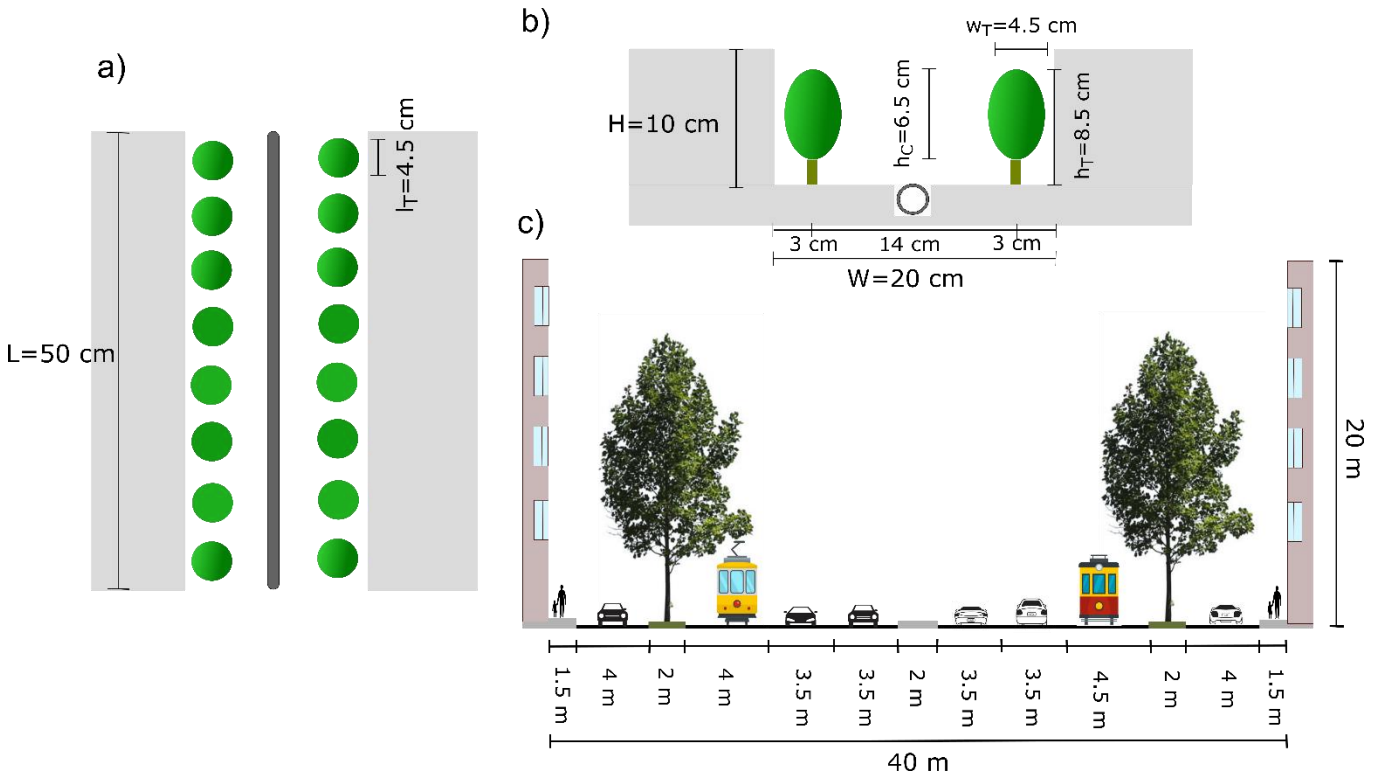
- Realistic interaction between turbulent flow and urban canopy
- Separation between the flow within and above the canopy
- Periodic geometry suitable for comparison with numerical simulations

The experimental setup – The urban canopy



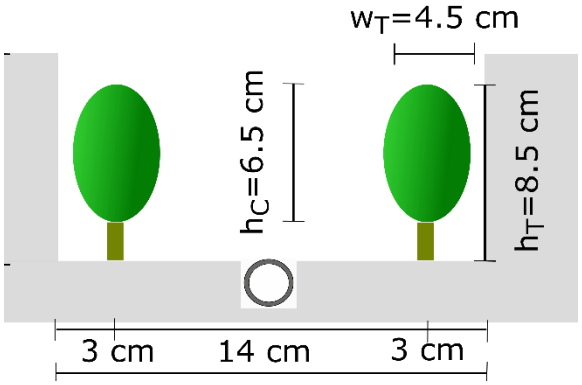
- 50 cm x 50 cm square blocks, 10 cm high
- Large perpendicular canyons (H/W=0.5) and square aligned canyons (H/W=1)
- 3.6 m x 3.6 m rotating plate (α) to simulate different wind directions

The experimental setup – The street canyon



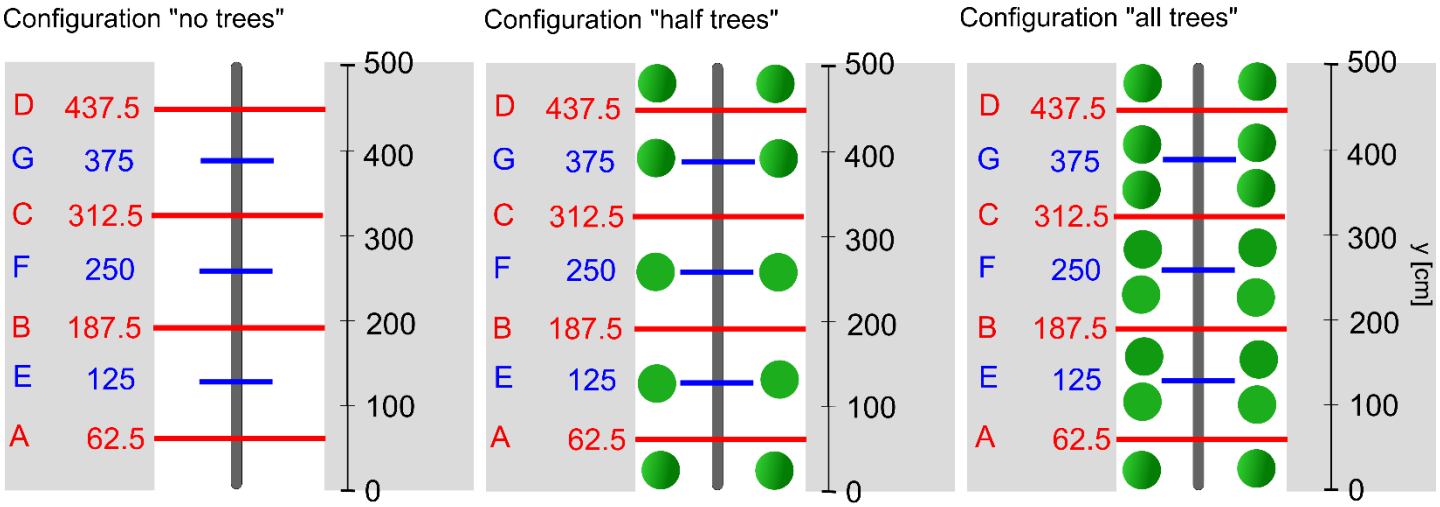
- Scale 1:200
- Large street canyon with height 10 cm, width 20 cm, length 50 cm
- Tree disposition: two lateral rows of trees, with space between 14 cm and space from the buildings 3 cm.

The experimental setup – The trees

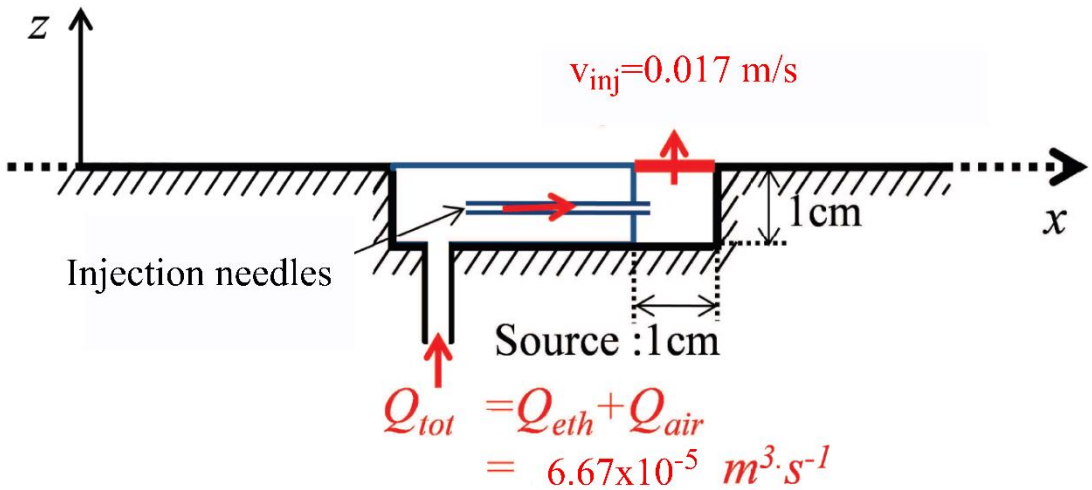


- Plastic trunk with crown in plastic porous material
- Size of trees: height 8.5 cm, width 4.5 cm, depth 4.5 cm. Height of crowns 6.5 cm.

3 configurations of tree density

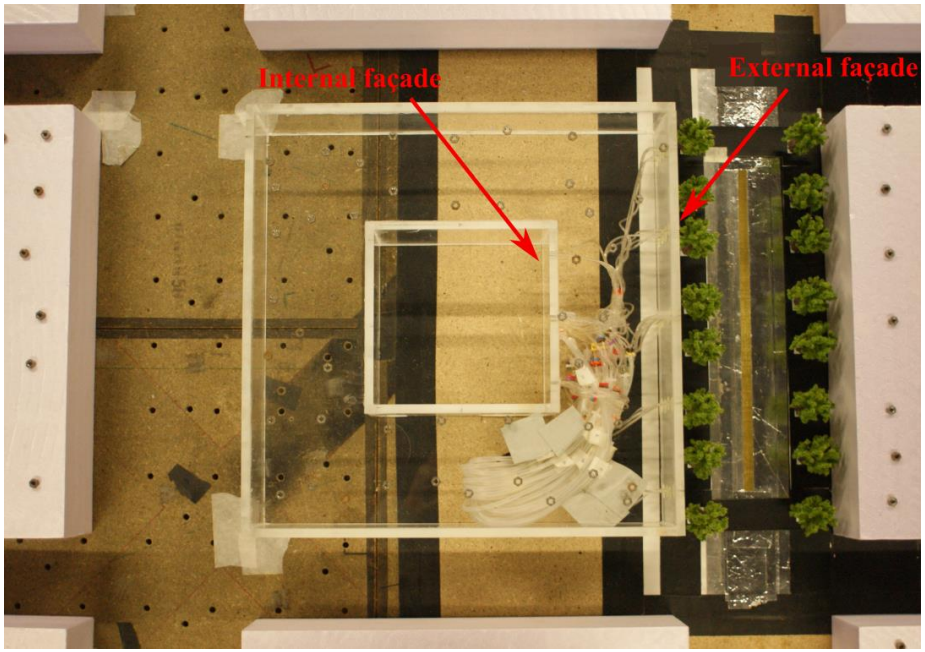


The experimental setup – The tracer source



- Ethane as passive scalar
- Linear source (40 cm x 1 cm) in the center of the canyon at street level
- Stainless tube with needles emitting in a 1 cm x 1 cm homogenization chamber
- Total flow: 4 l/min ⟶ Injection velocity = 0.017 m/s

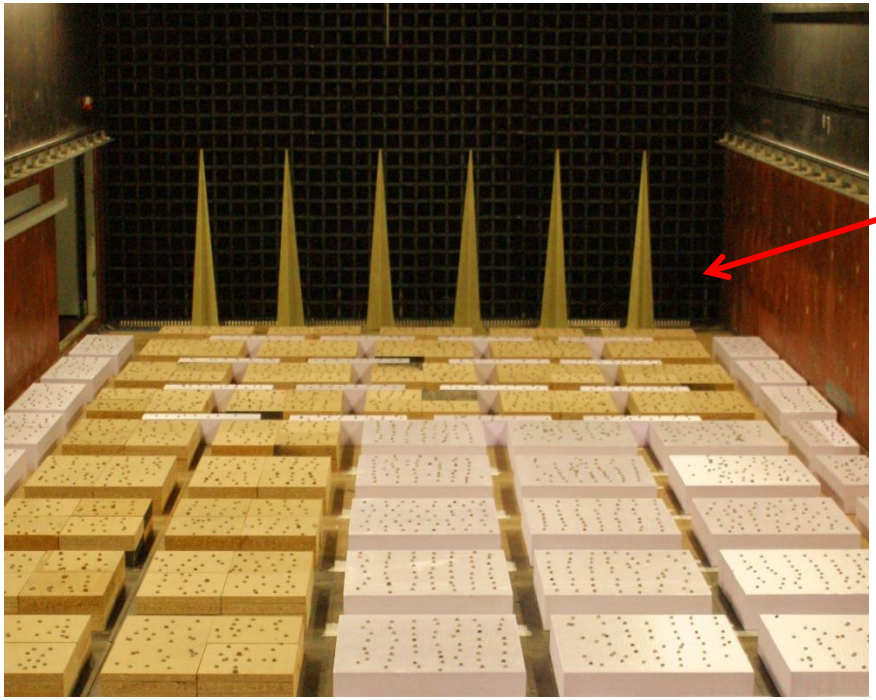
The experimental setup – The building

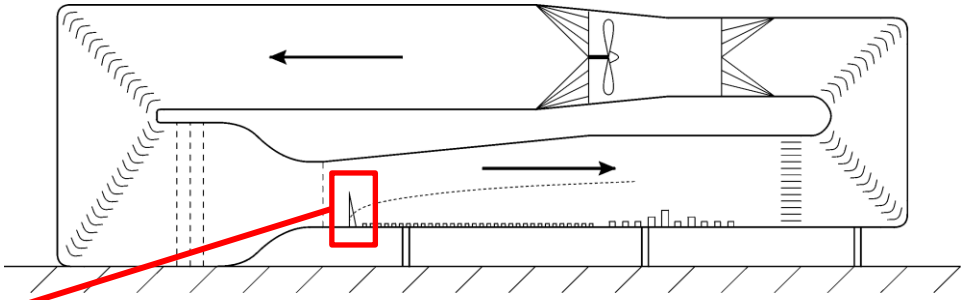


Pressure difference between the wall facing the street and the wall facing the courtyard of a model building, by means of 40 pressure taps (25 external wall, 15 internal wall), connected to a pressure scanner.

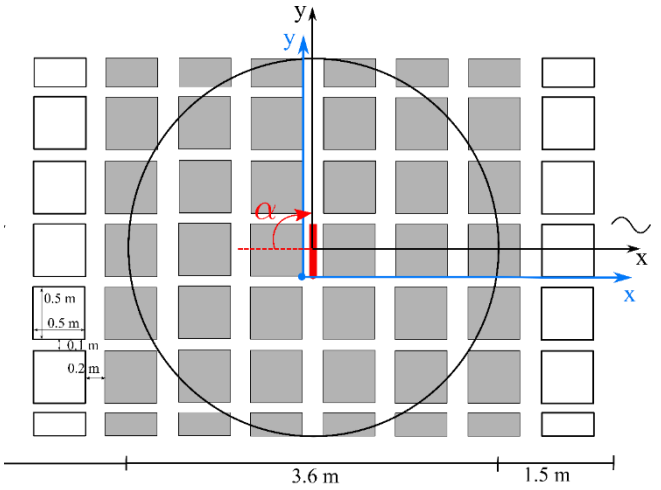
What is the effect of trees on pressure difference and thus on natural ventilation of buildings?

The experimental setup – The external wind



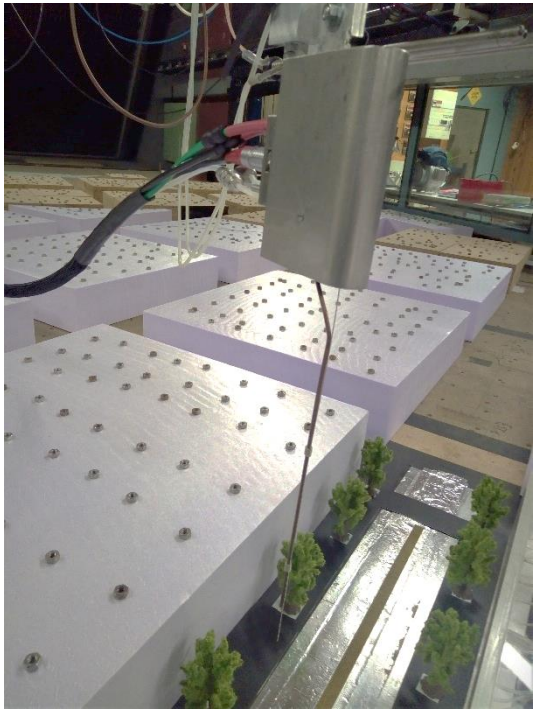


- Irwin spires 95 cm high
- $U_\infty = 5.5 \frac{m}{s}$
- 4 wind directions approaching the street canyon $\alpha = 0°, 30°, 60°, 90°$



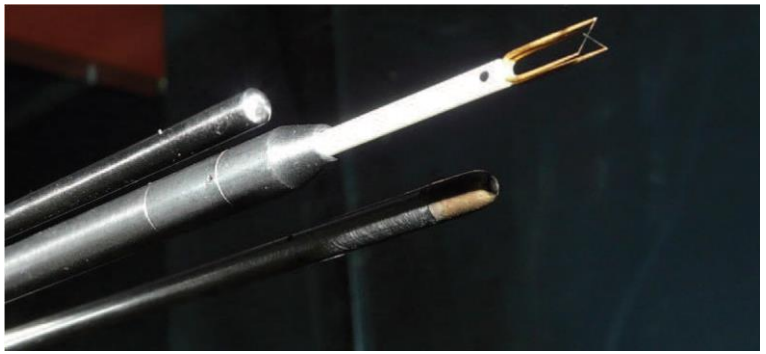
Measurement techniques

Flame Ionization Detector



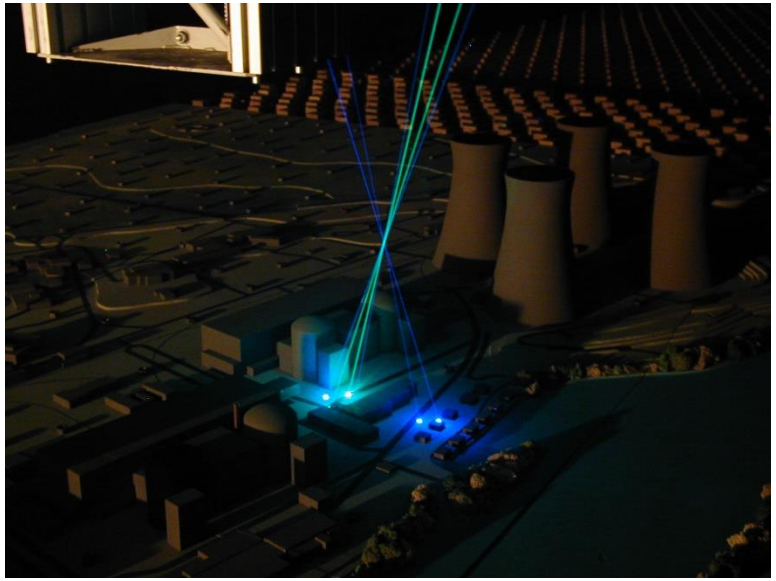
120 s, 1000 Hz

Hot Wire Anemometer



60 s, 5000 Hz

Laser Doppler Anemometer



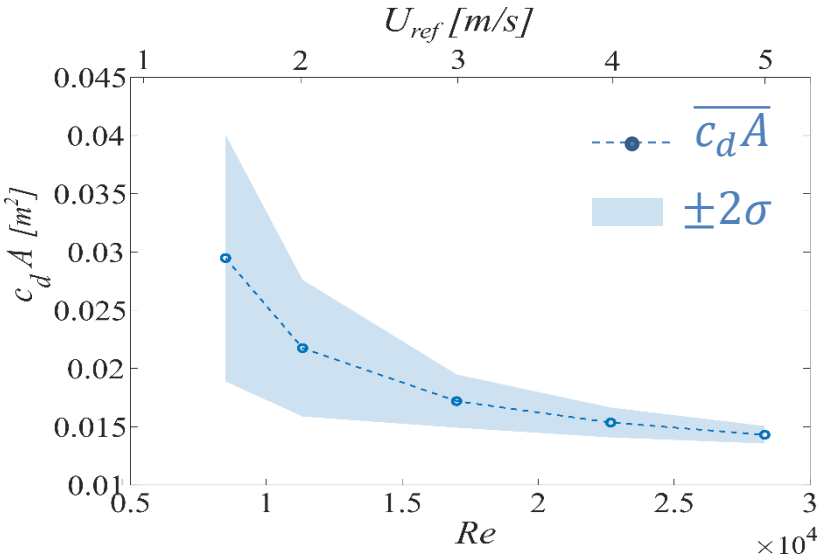
Preliminary measurements – Characterization of model trees

DRAG COEFFICIENT

$$c_d A = \frac{2F}{\rho U_{ref}^2}$$

In small wind tunnel, multiple measurements

- Load Cell ⟶ F
- Pitot Tube ⟶ U_{ref}



For U_{ref} > 2 m/s

⟶

$\simeq$ constant $c_d A$

Preliminary measurements – Characterization of model trees

CROWN POROSITY

Optical porosity β

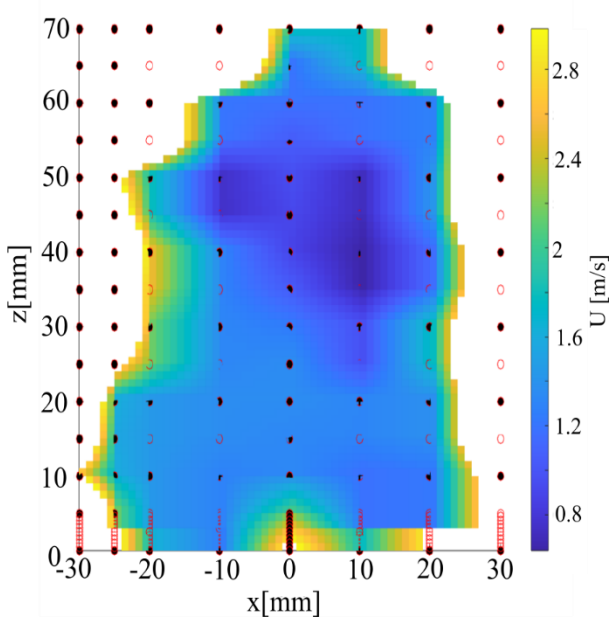
Elaboration of digital photos of a tree

$$\beta = \frac{n^\circ\ white\ pixel}{n^\circ\ total\ pixel} = 0.05$$

$$\alpha = \beta^{0.4} = 0.3$$

[Guan et al. 2003]

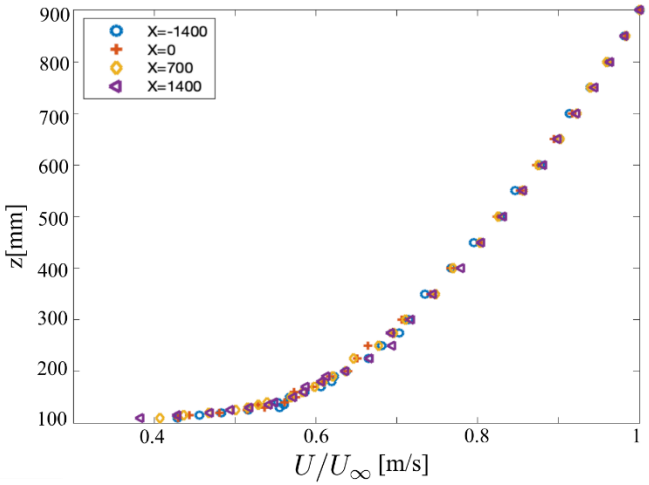
Aerodynamic porosity α



Velocity measurements with Pitot Tube

$$\alpha = \frac{\int_A U(x,y,z)dA}{\int_A U_0(x,y,z)dA} \simeq 0.3$$

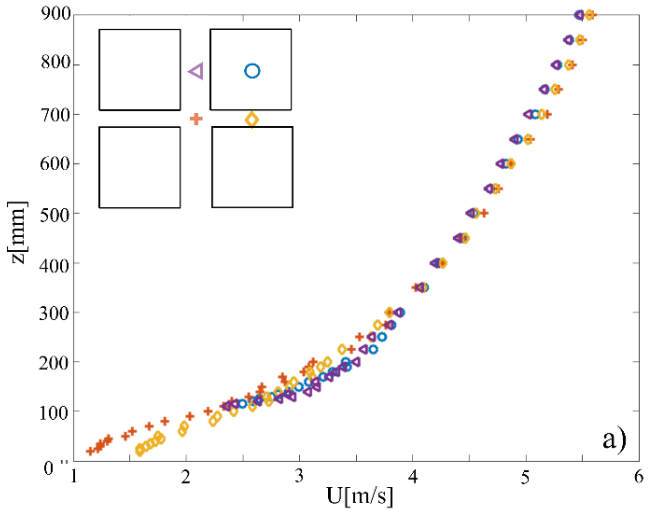
Preliminary measurements – Characterization of wind profile



Vertical profile at progressive distances from wind-tunnel entrance

↓

Full development of the boundary layer

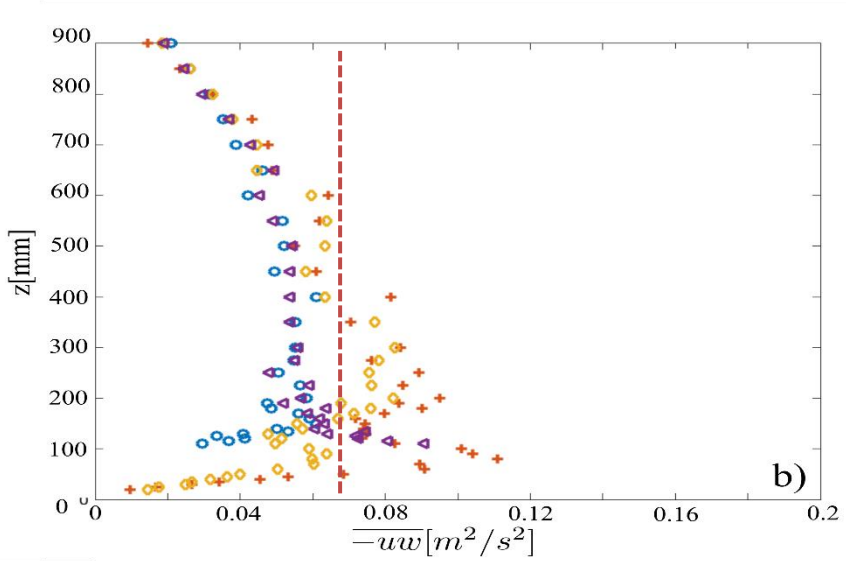


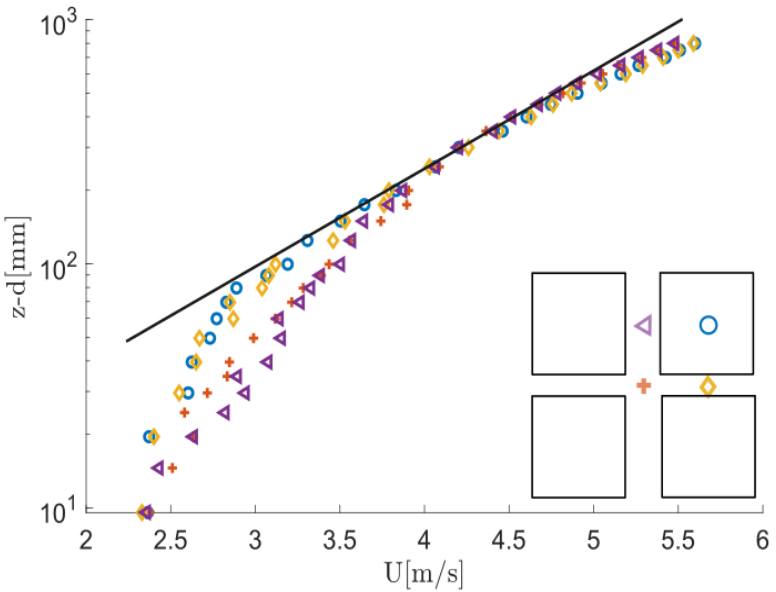
Vertical profiles at different position in periodic unit

↓

Extension of roughness sublayer up to 300 mm

Preliminary measurements – Characterization of wind profile





Determination of parameters of logarithmic law

$$\frac{U(z)}{u_*} = \frac{1}{k}\, ln\left(\frac{z-d}{z_0}\right)$$

u_* from Reynolds shear stress profile

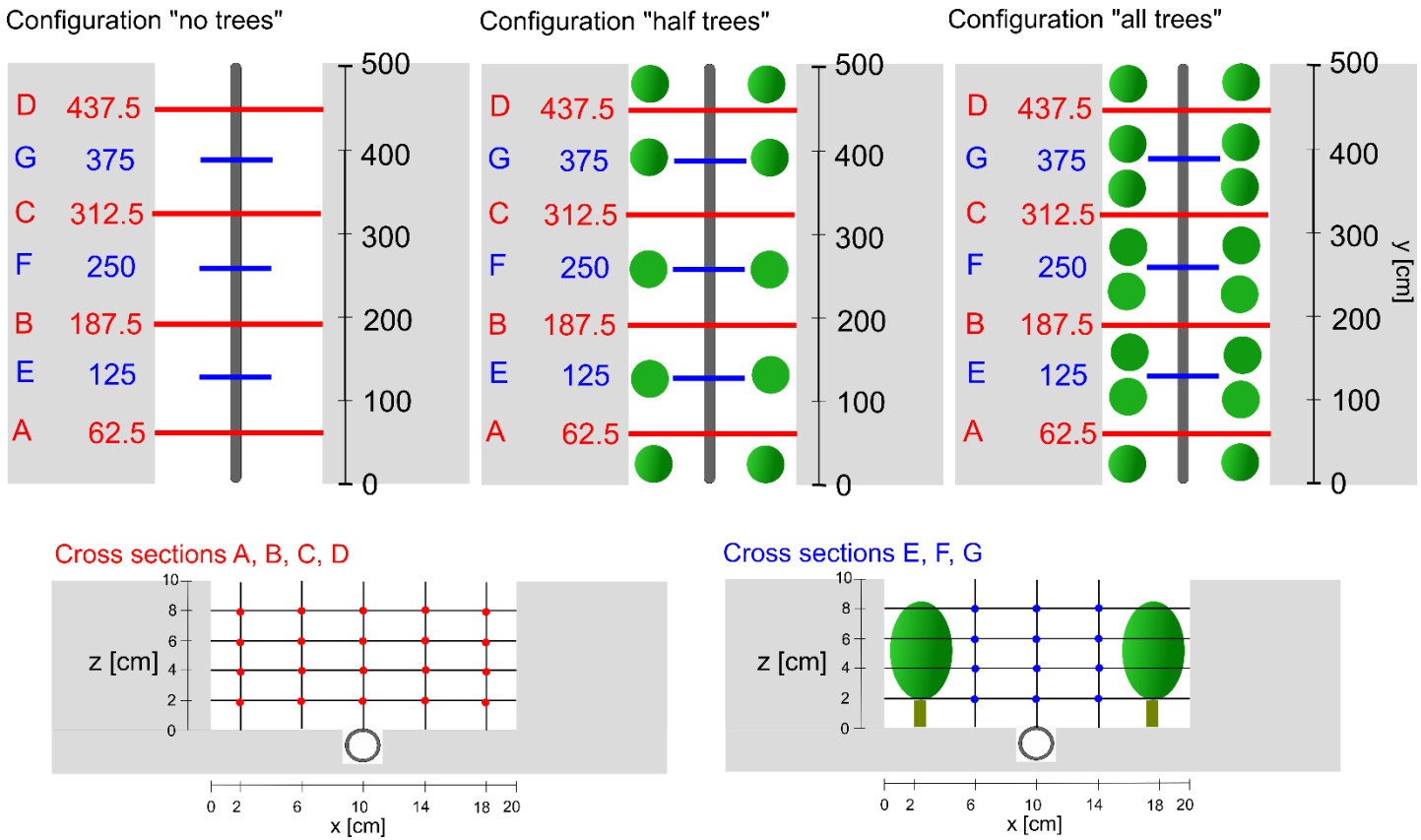
$$u_* = \sqrt{\overline{-uw}} = 0.3 \text{ m/s}$$

z_0 and d from linear regression in semi-log plot

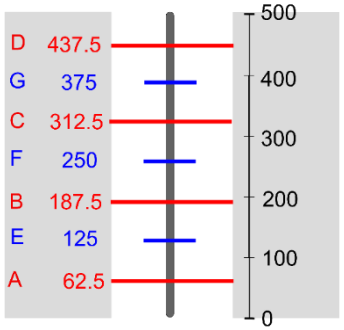
$$z_0 = 1.2\ mm, \qquad d = 93\ mm$$

Passive scalar concentration in the street canyon

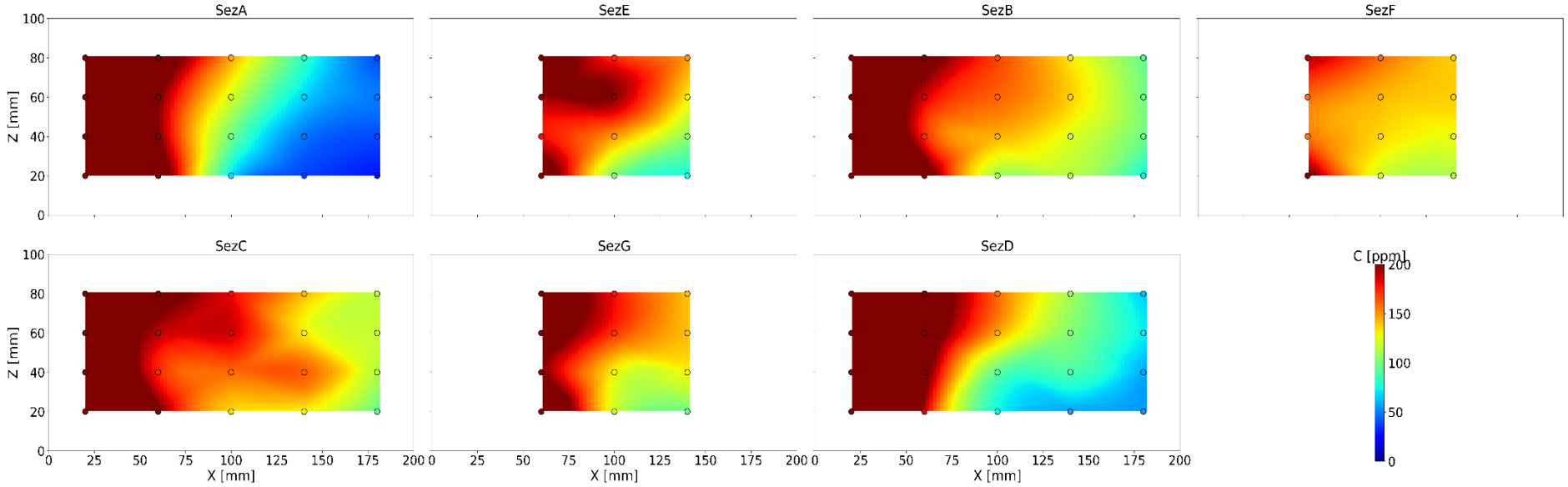
MEASUREMENT POINTS



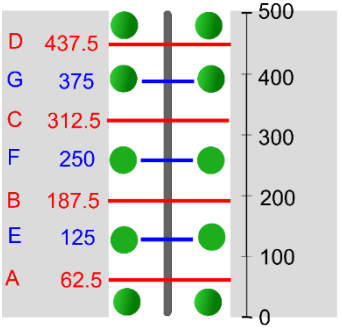
Passive scalar concentration in the street canyon



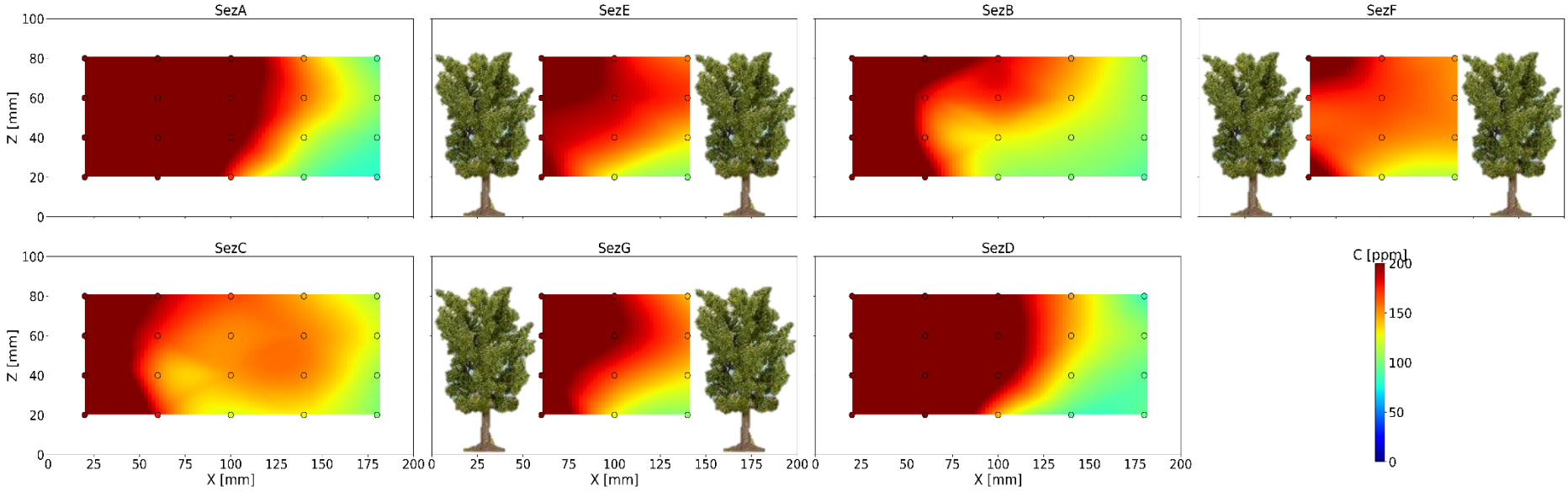
$\alpha = 90°$, no trees



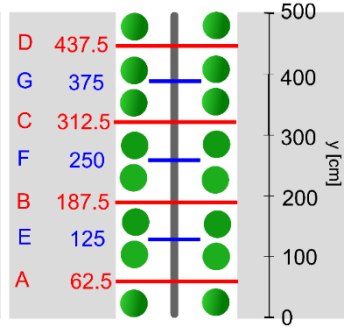
Passive scalar concentration in the street canyon



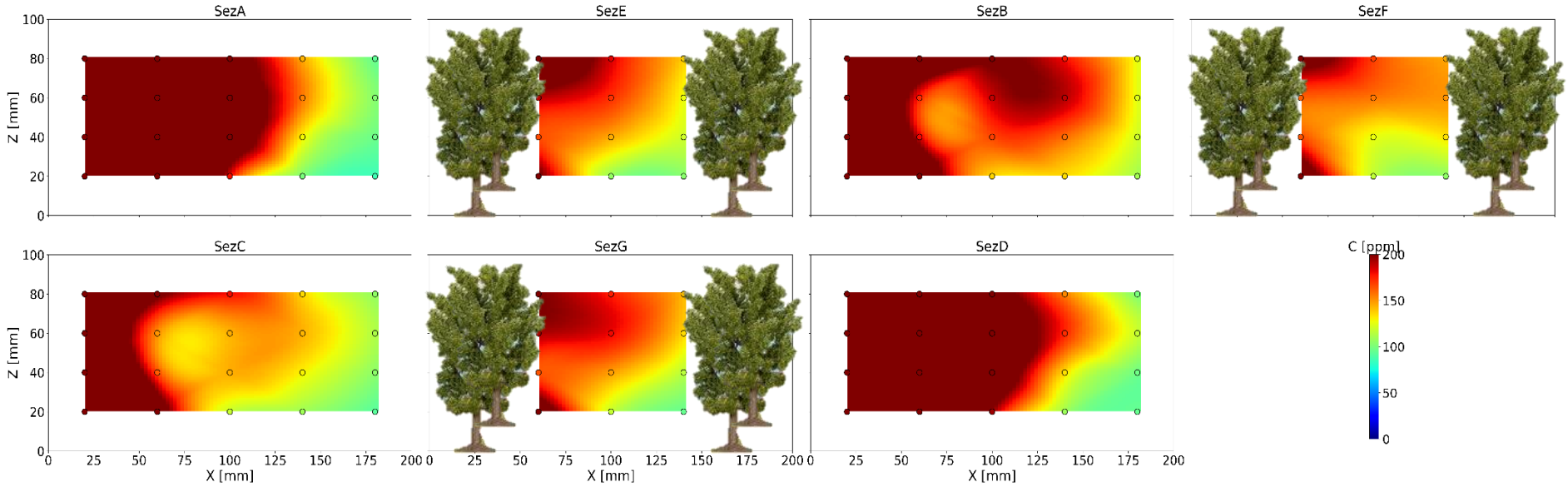
$\alpha = 90°$, low tree density



Passive scalar concentration in the street canyon

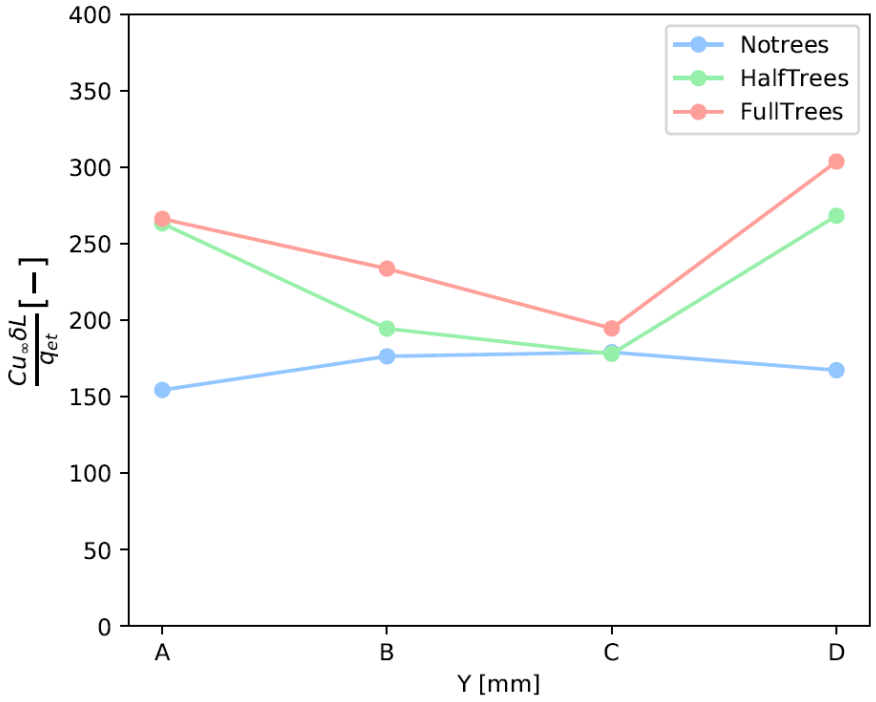


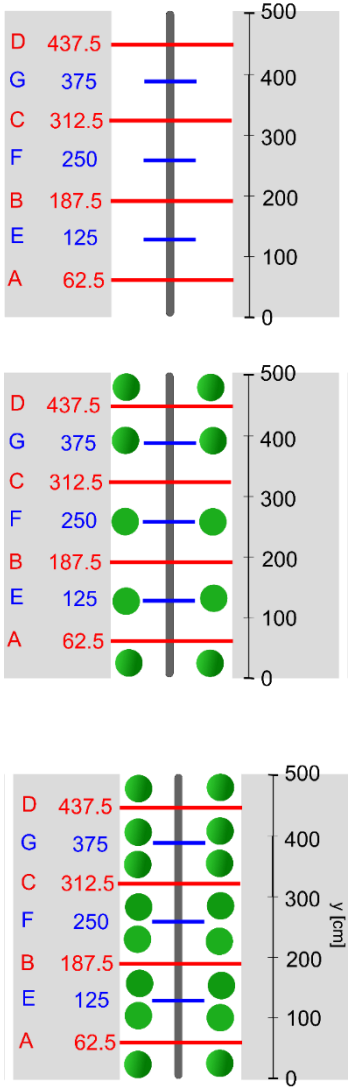
$\alpha = 90°$, high tree density



Passive scalar concentration in the street canyon

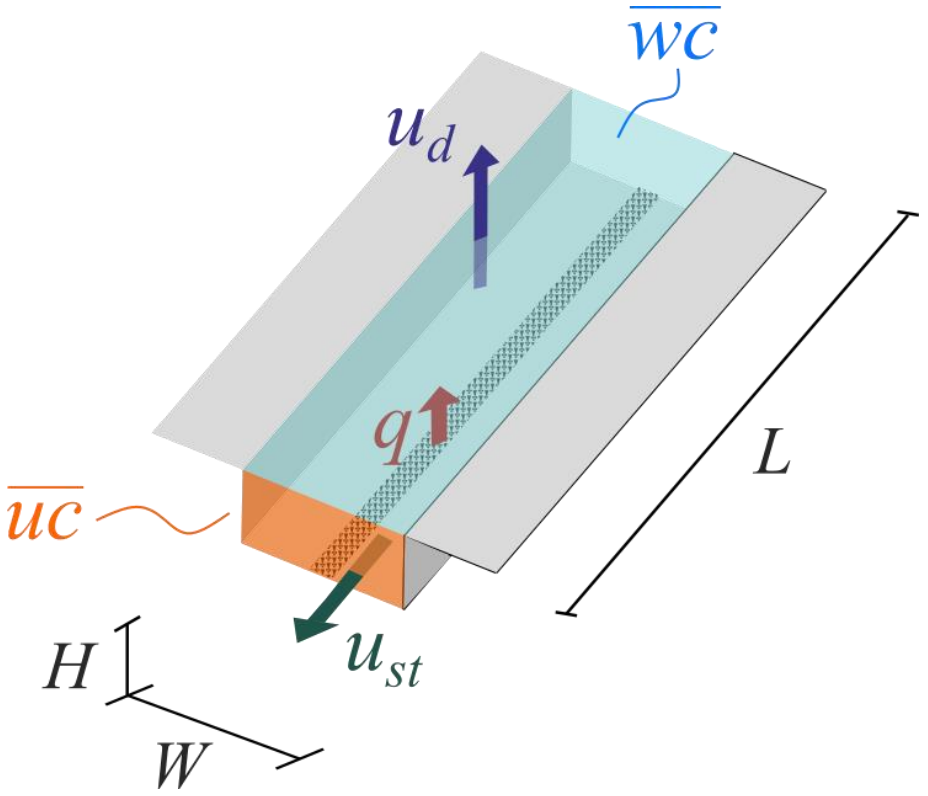
$\alpha = 90°$, mean concentration in each section





Bulk velocities of mass exchange

$$\begin{cases} q = u_d LW < c > + u_{st} < c > HW \\ < c > = \int_V c \, dV \\ u_d = \dfrac{1}{LW < c >} \iint_{L\,W} \overline{wc} \, dx \, dy \\ u_{st} = \dfrac{1}{HW < c >} \iint_{H\,W} \overline{uc} \, dx \, dz \end{cases}$$

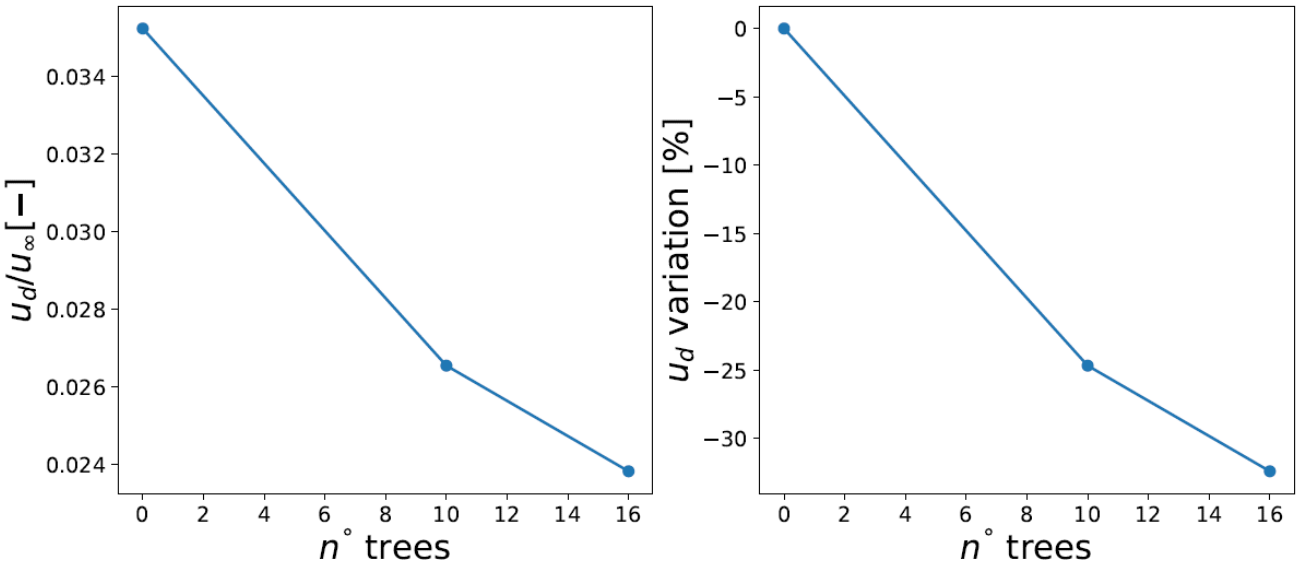


q with flow rate meter
c with FID
$\overline{wc}$ and $\overline{uc}$ with coupled LDA-FID measurements

Unknown quantities $< c >$, u_d, u_{st}

Bulk velocity of vertical mass exchange for α=90°

$$\begin{cases} q = u_d LW < c > \\ < c > = \int_V c \, dV \end{cases}$$



25% decrease in canyon ventilation for the “half trees” configuration

32% decrease in canyon ventilation for the “full trees” configuration

Conclusions

The assessment of tree effect on street canyon ventilation is crucial for the effective planning of tree planting in urban areas.

Given the complex interaction between the atmospheric flow and the vegetation in the streets, wind tunnel experiments are required.

A careful characterization of trees from the aerodynamic point of view is mandatory.

Preliminary results confirm that tree planting lead to an increase in pollutant concentrations within the street canyon, for a street perpendicular to the wind direction.

….and ongoing work

Combined effect of trees and wind direction on street canyon ventilation.

Effect of trees on the natural ventilation of buildings.

Accurate estimation of the bulk velocities of mass exchange.

Bibliography

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