On the relationship between inhomogeneous temperature distribution and pollutant concentration for real street canyons with and without trees using computational fluid dynamics modelling

Beatrice Pulvirenti[1], Federico Prandini[1], Silvana Di Sabatino[2]

1 Department of Industrial Engineering, University of Bologna, Italy
2 Department of Physics, University of Bologna, Italy

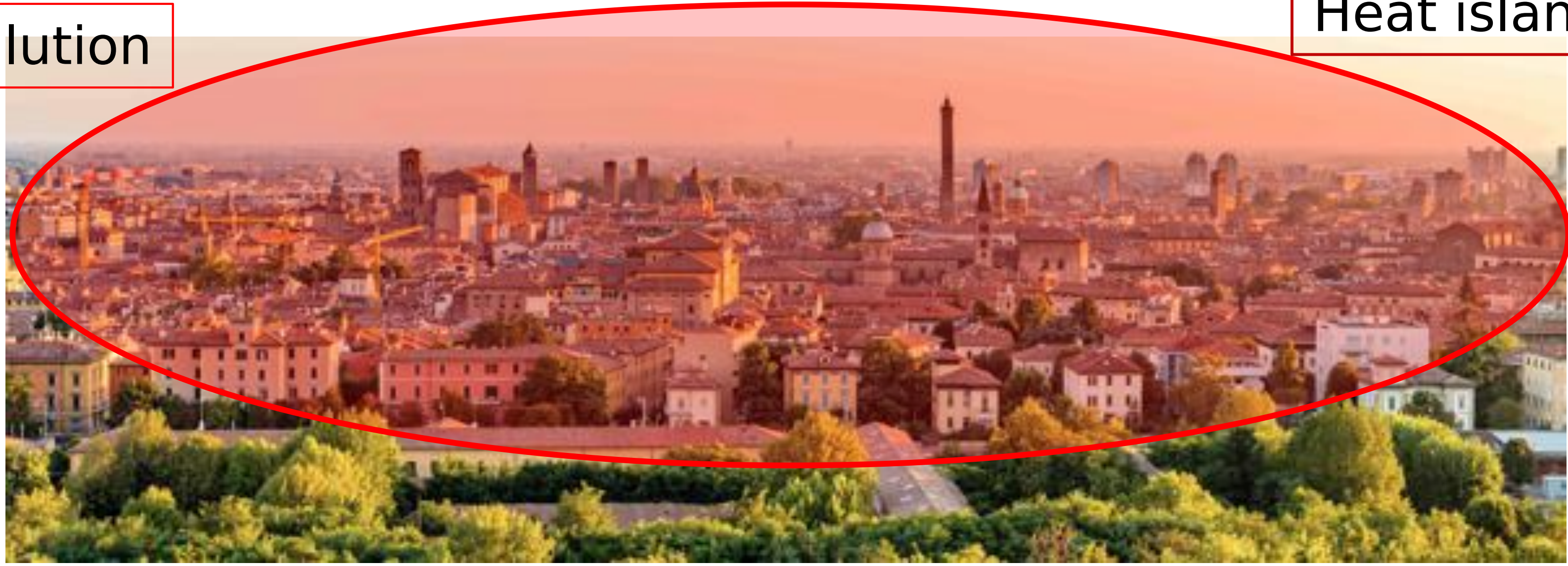
This study has been supported by iSCAPE Project (Improving Smart Control of Air Pollution in Europe) which is fouded by the European Community's H2020 H2020-SC5-04-2015 under the Grant Agreement No. 689954

Motivation

The progressive climate-changes influence the comfort levels within the cities. We want to study the influence of solar radiation and trees to the temperature and pollutant distribution at street-level.

Pollution

Heat island

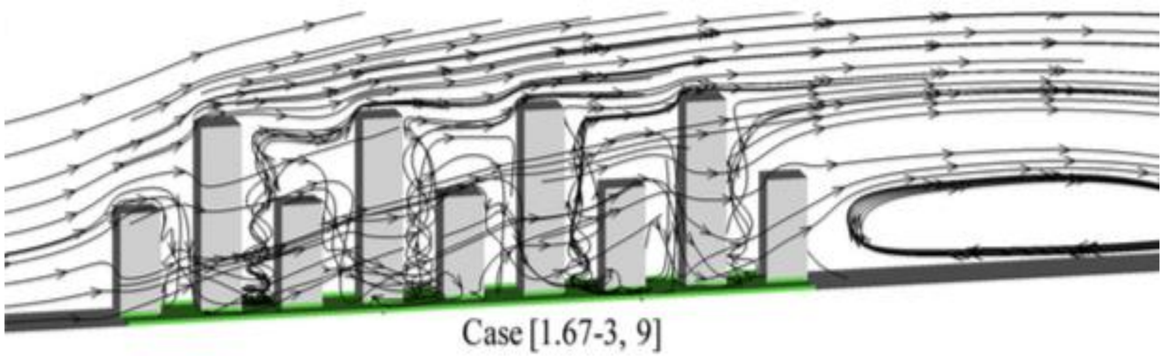


Street canyons

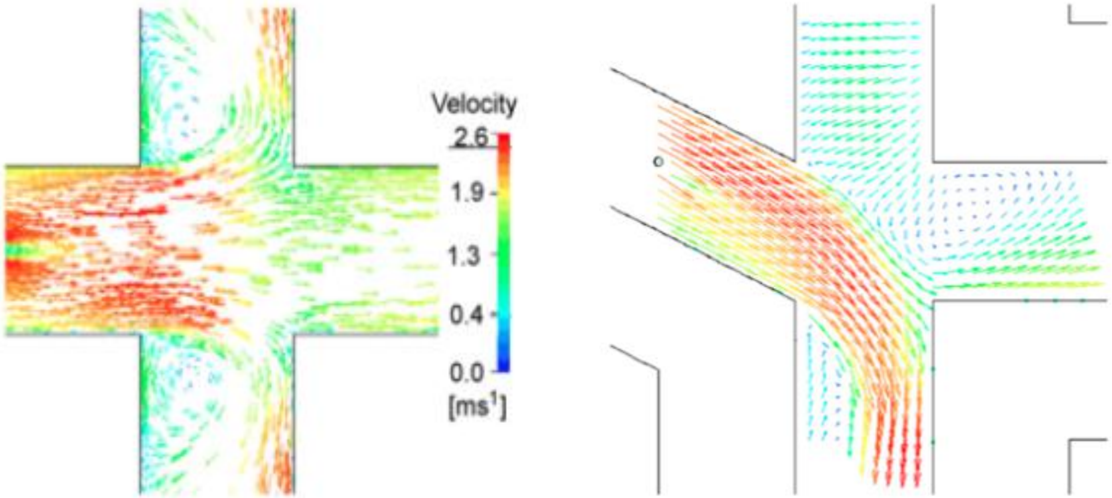
Climate-changes

Mitigation by vegetation

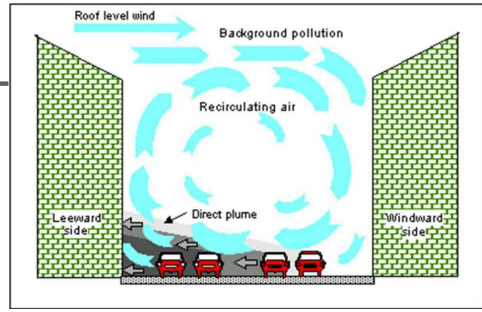
Influence of city morphology and trees

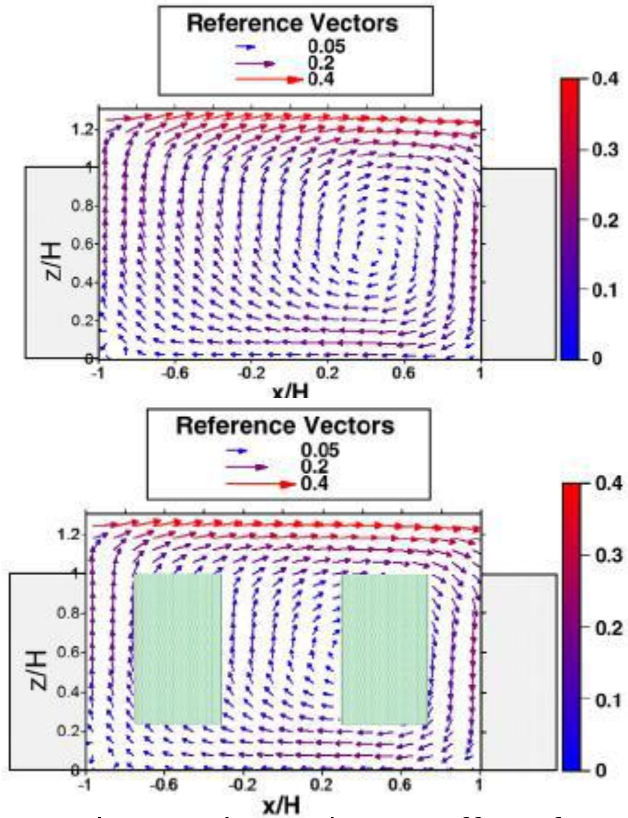


Jian Hang et al., The influence of building height variability on pollutant dispersion and pedestrian ventilation in idealized high-rise urban areas. *Building and Environment,* 2012



Wang X et al., Effects of street orientation on dispersion at or near urban street intersections. *Journal of Wind Engineering and Industrial Aerodynamics,* 2007





Buccolieri R.et al., Aerodynamic effect of trees on pollutant concentrations in street canyons *Science of the Total Environment,* 2009

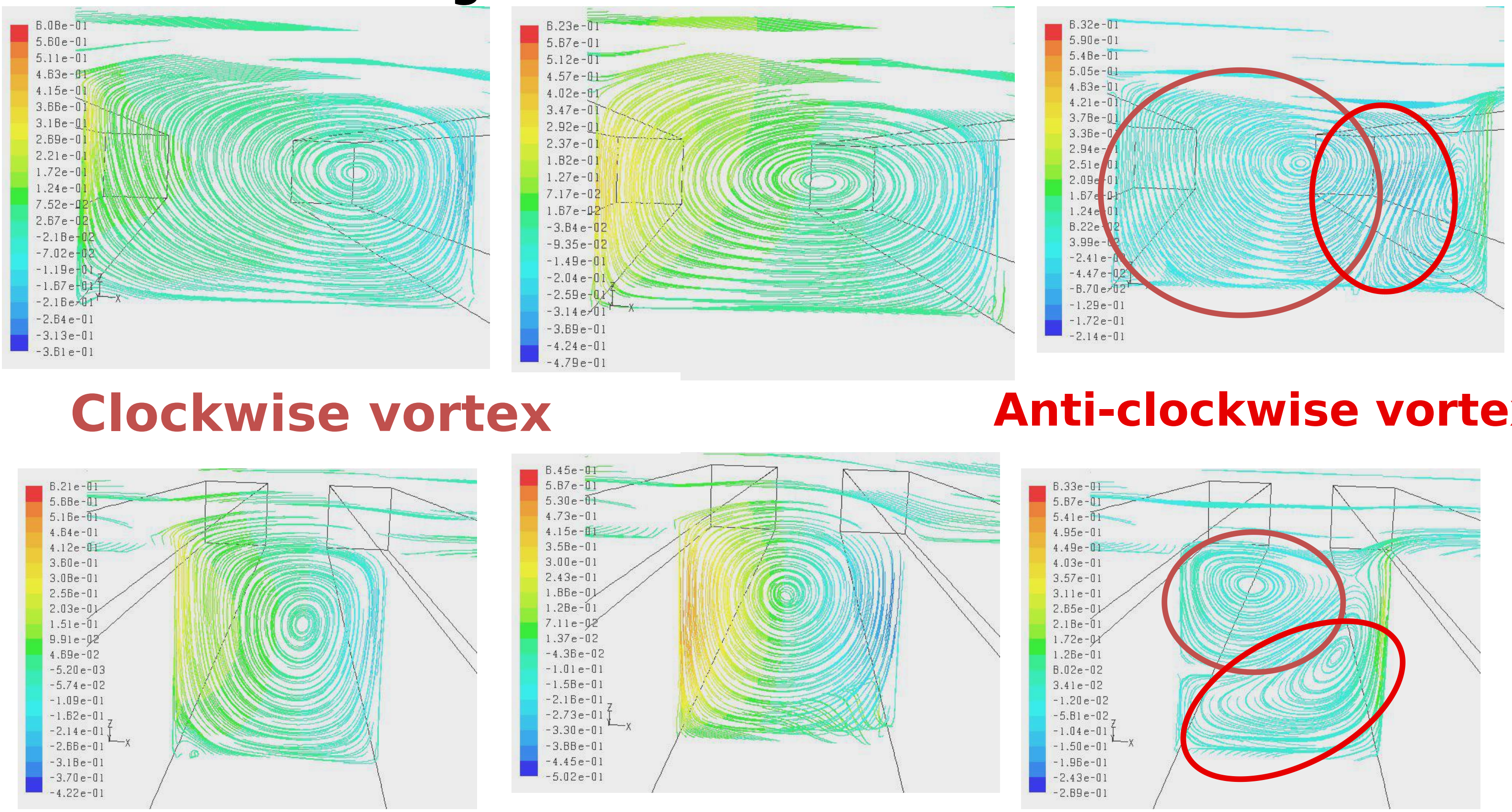
Thermal circulation within street-canyon

leeward heating | **ground heating** | **windward heating**

W/H=2

Clockwise vortex | **Anti-clockwise vortex**

W/H=1

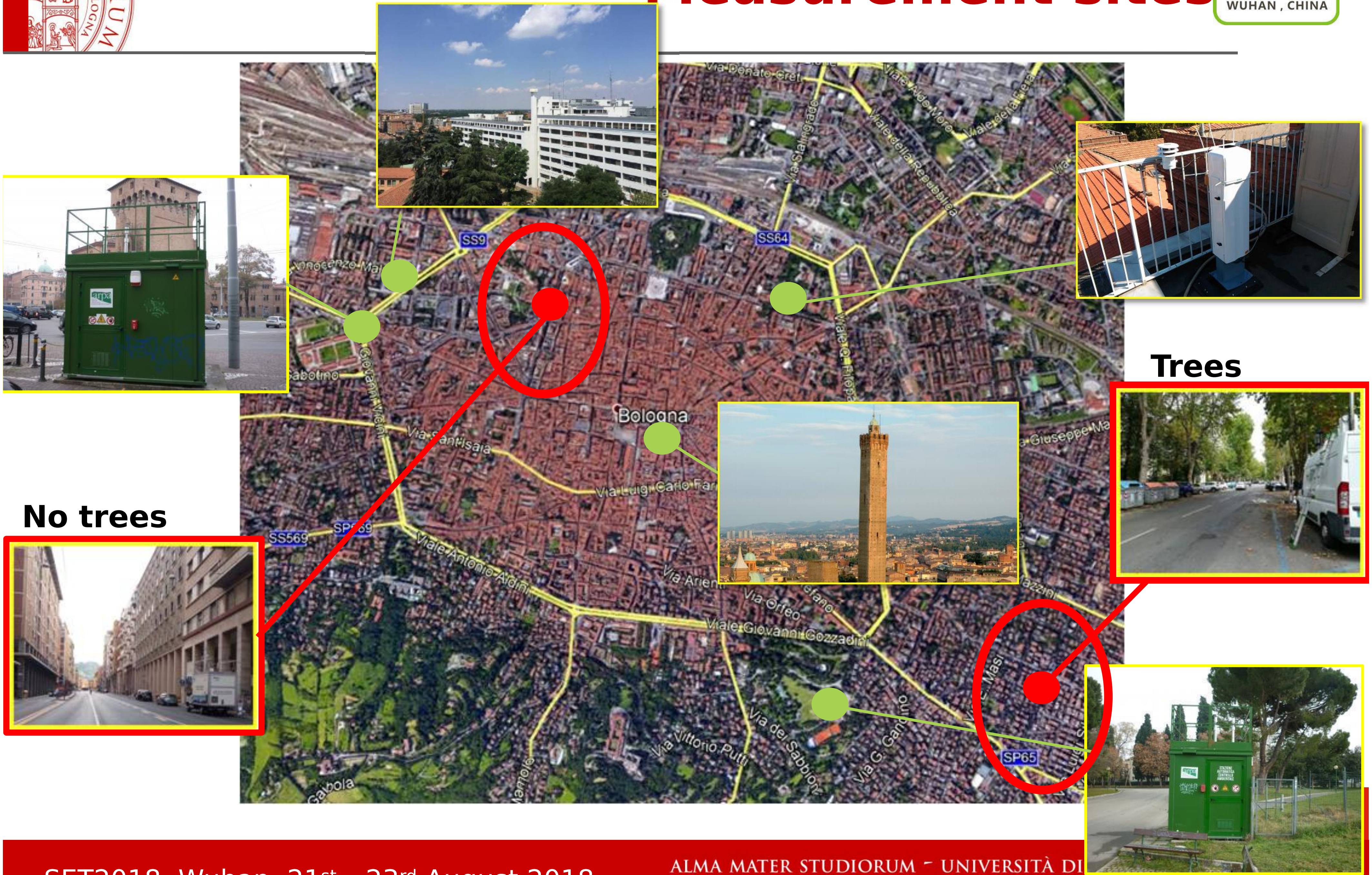


weak dependence on the aspect ratio (the vortex is enhanced by the buoyancy)

vortex weaker as the aspect ratio increases (larger vertical velocity could break the vortex at smaller aspect ratios)

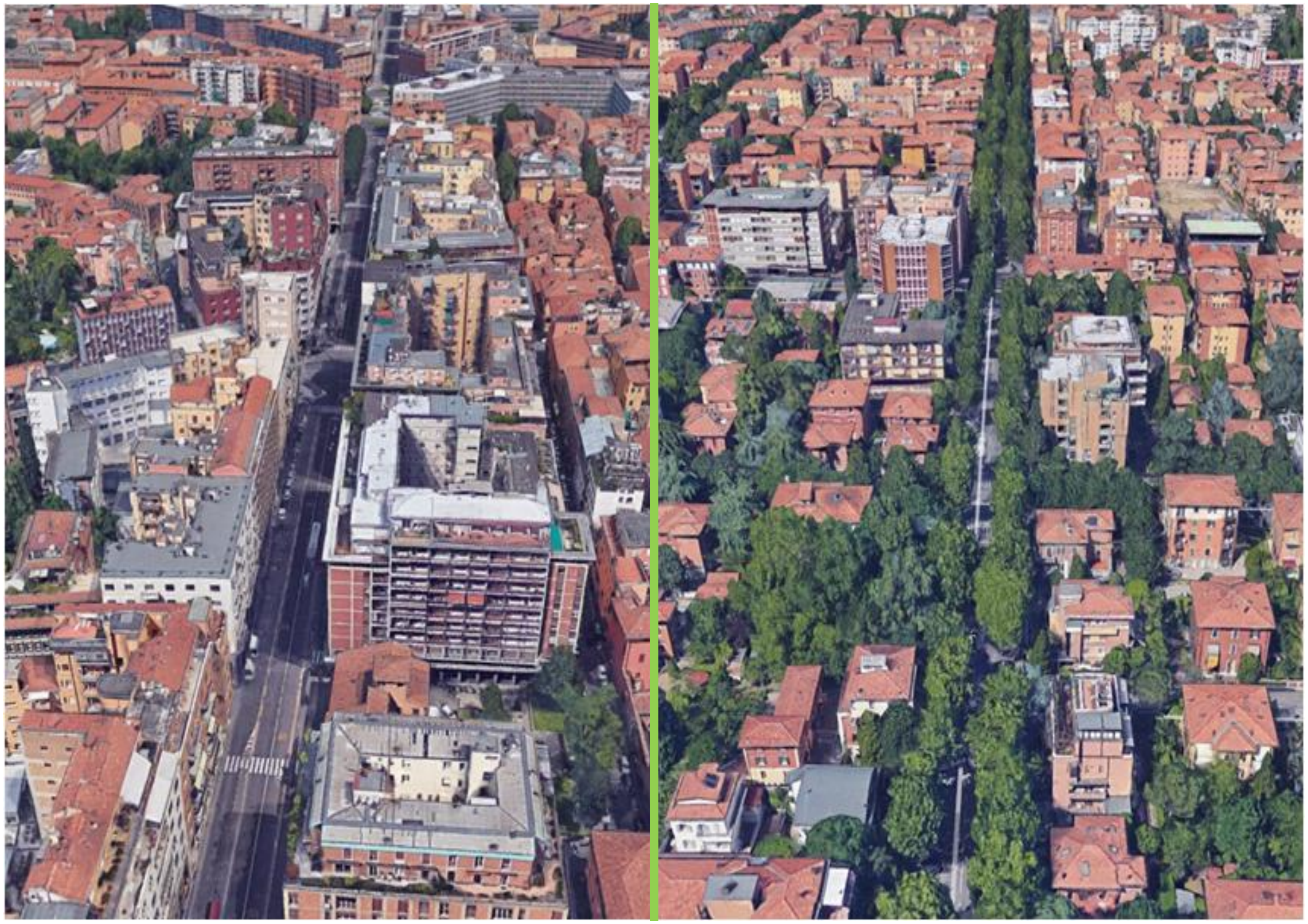
clockwise vortex suppressed by the anti-clockwise vortex as W/H decreases

Two street canyons and Measurement sites

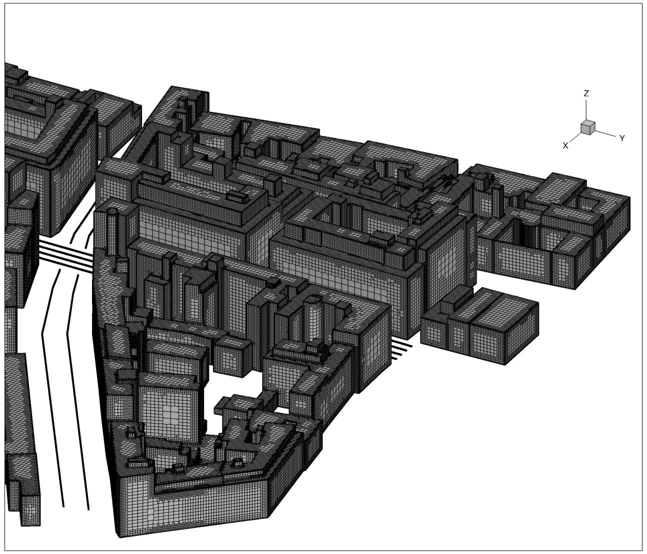


Comparison between the two street canyons

Via Marconi | No trees | Via Laura Bassi | Trees

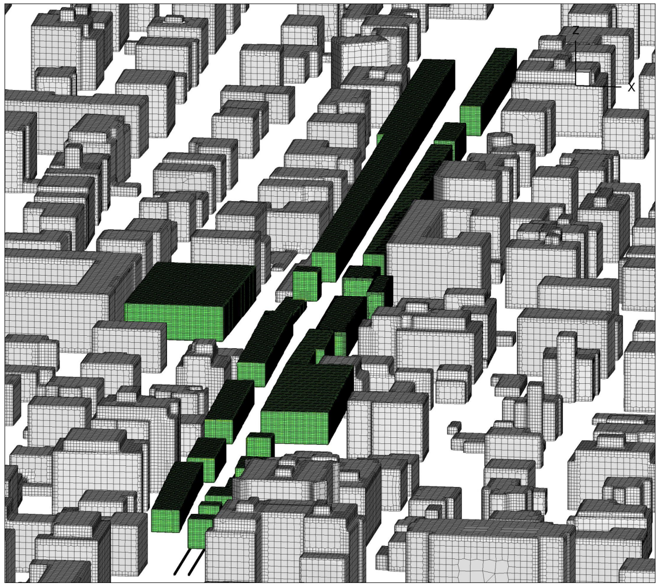
Via Marconi		Via Laura Bassi
$\Theta = 20°$		$\Theta = 25°$
H = 29 m W = 20 m H/W = 1.65		H = 17m W = 25m H/W = 0.7
City center		Residential
No trees		Trees
4 lanes		2 lanes
Buses		Cars

Domain chosen for CFD



No trees

mesh: 19 million of unstructured parallelepiped elements with a high refinement within the canyon



Trees

trees modelled as porous materials with LAD (Leaf Area Density Index) = 1.6 $m^2\,m^{-3}$

Velocity boundary conditions

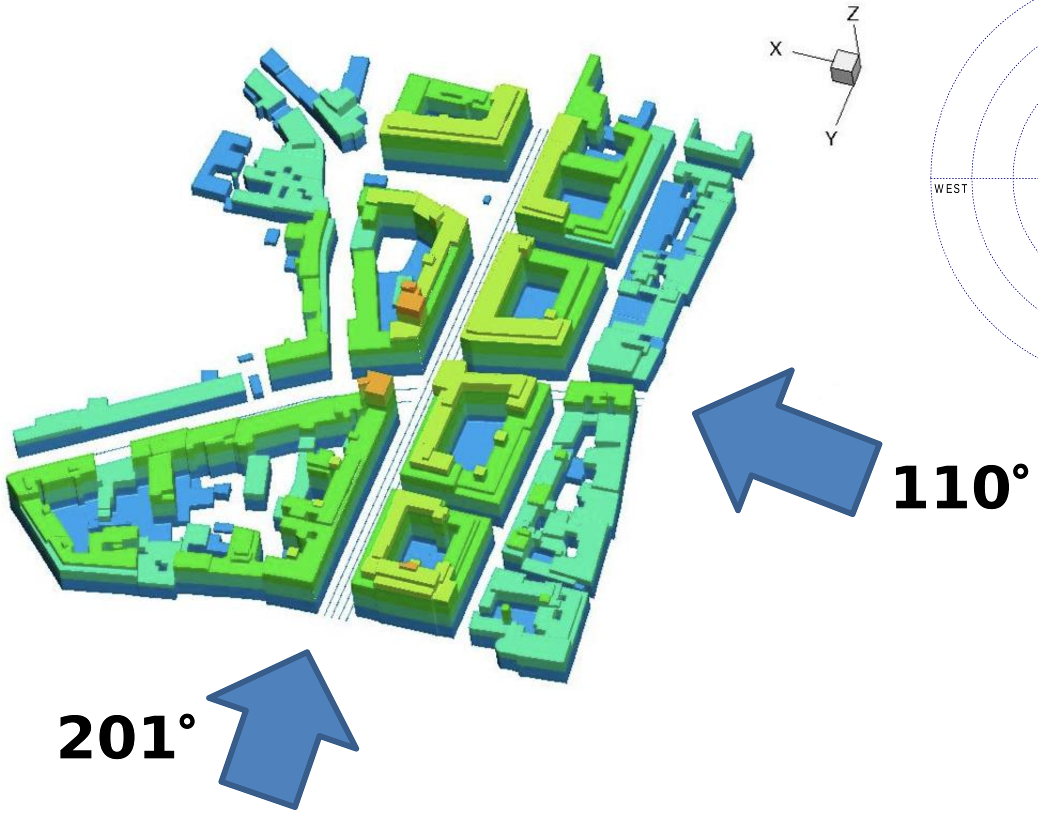
Measurements from
AUGUST 22nd, 12.00 (2017) to
AUGUST 23rd 12.00

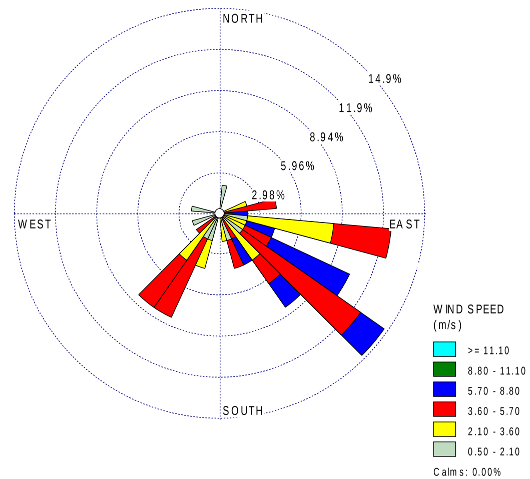
$$u(z) = \frac{u^*}{\kappa} \ln \frac{z + z_0}{z_0}$$

$$\varepsilon(z) = \frac{u_*^3}{\kappa z}\left(1 - \frac{z}{\delta}\right)$$

$$k(z) = \frac{u_*^2}{\sqrt{C_\mu}}\left(1 - \frac{z}{\delta}\right)$$

Atmospheric Boundary Layer (ABL)





time	direction (°)	velocity (m/s at 150 m)	no trees canyon CO (g/h)	trees canyon CO (g/h)
14:00	110	3,5	56069	23627
01:00	201	2,9	16677	8793

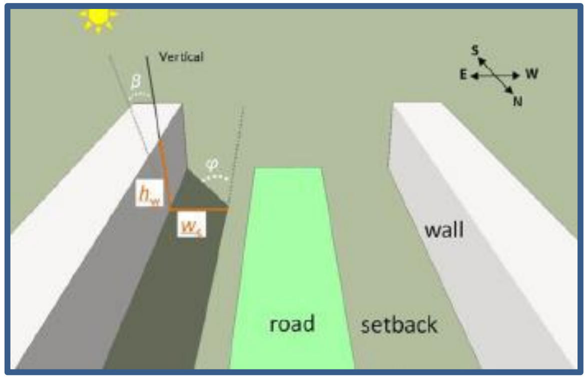
Temperature boundary conditions: measurements by IR cameras

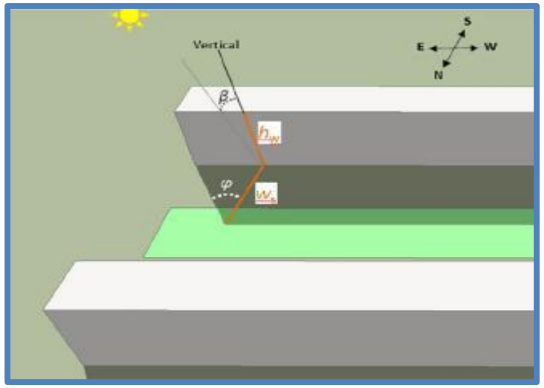
No trees

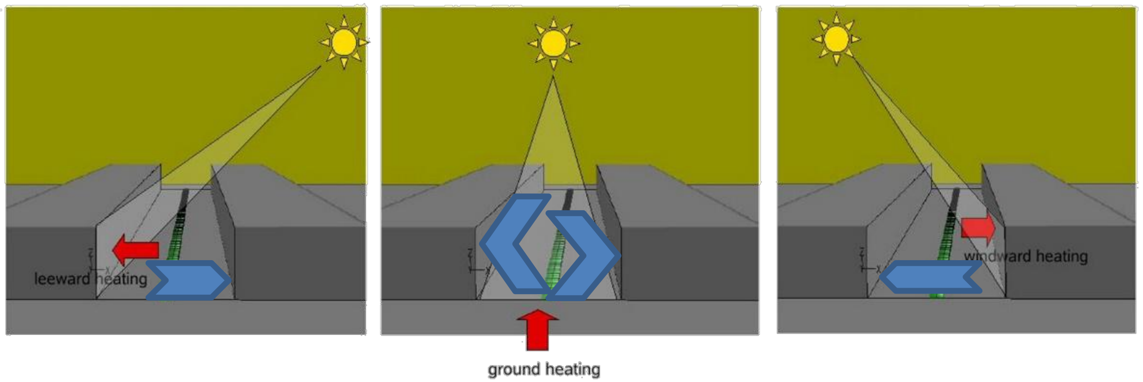
Trees

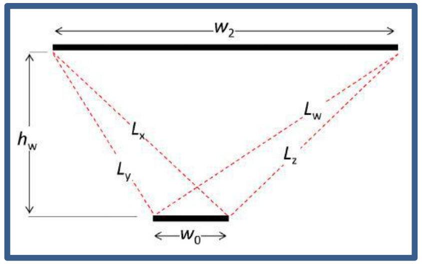
S. Di Sabatino, F. Barbano, C. Barbieri, E. Brattich, A.F. Brunetti, A. Drebs, P. Kumar, K. Jylhä, E. Minguzzi, M. Nardino, F. Pilla, B. Pulvirenti, L. Torreggiani, A. Valmassoi, Urban Heat Island, Air Pollution and Climate Change: the Bologna (IT) iSCAPE case study. **AMS Annual Meeting, Austin, Texas, 2018**

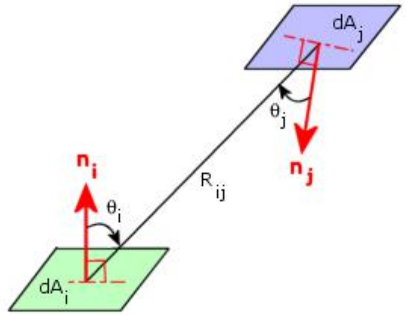
New approach:
radiation view factors evaluation

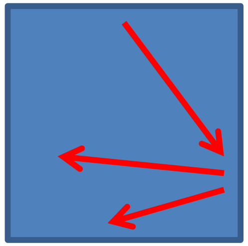






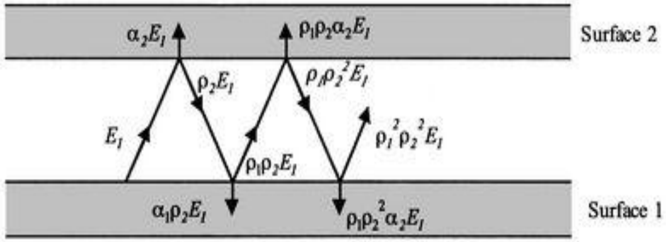






Heat flux to the walls

Surfaces partially overlooked



CEYLING TO WALL

$$F_{X \to Y} = \frac{1}{2}\left(1 + \frac{h}{w} - \sqrt{1 + \left(\frac{h}{w}\right)^2}\right)$$

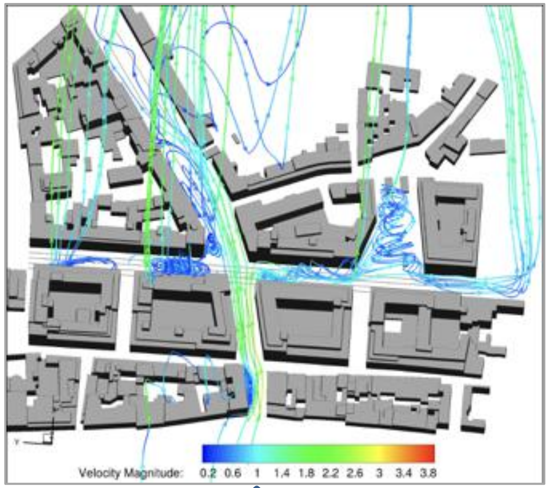
FLOOR TO CEYLING

$$F_{0 \to 2} = \frac{L_x + L_W - L_y - L_z}{2w_0}$$

$$F_{1 \to 2} = \frac{1}{A_1}\int_{A_1}\int_{A_2} \frac{\cos\theta_1 \cos\theta_2}{\pi s^2}\, dA_2\, dA_1$$

CFD results

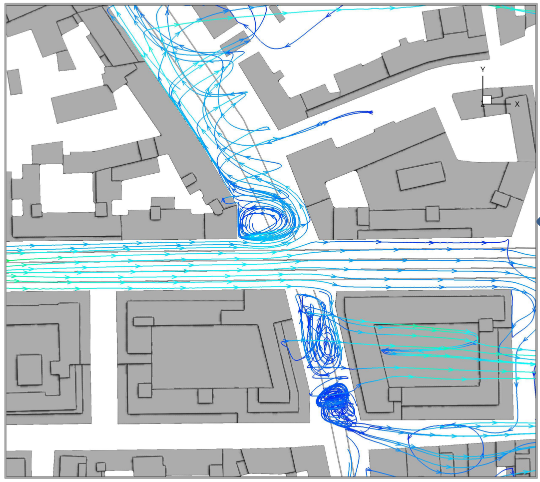
Effect of city morphology
Effect of building facades heating



Perpendicular wind

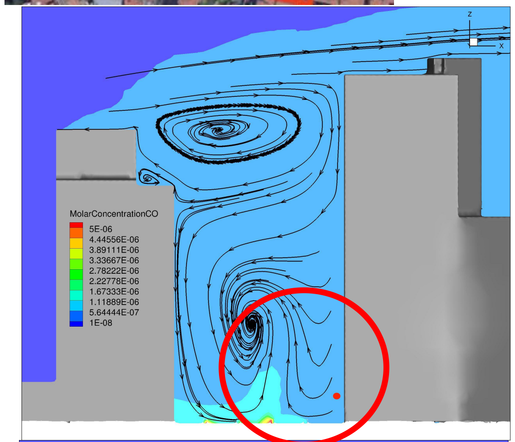
wind direction

CO concentration

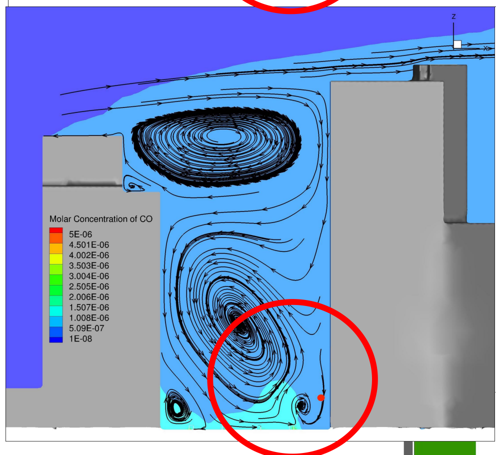


wind direction

Parallel wind

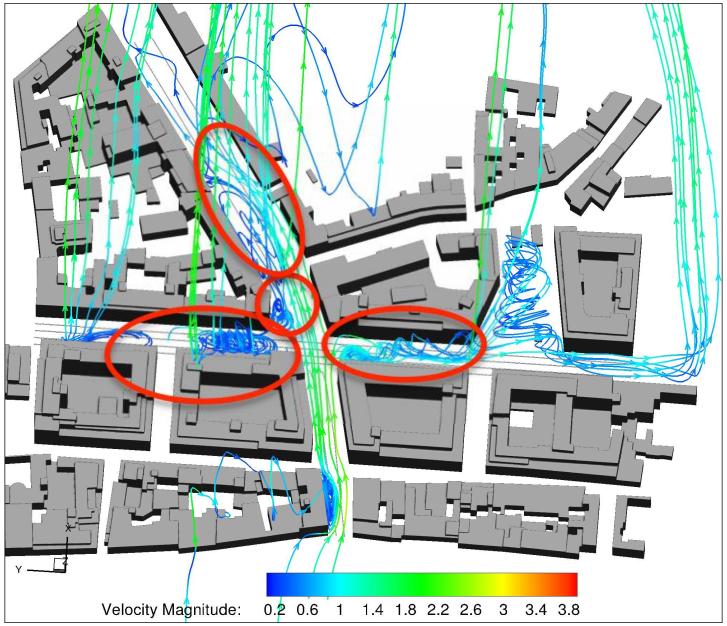


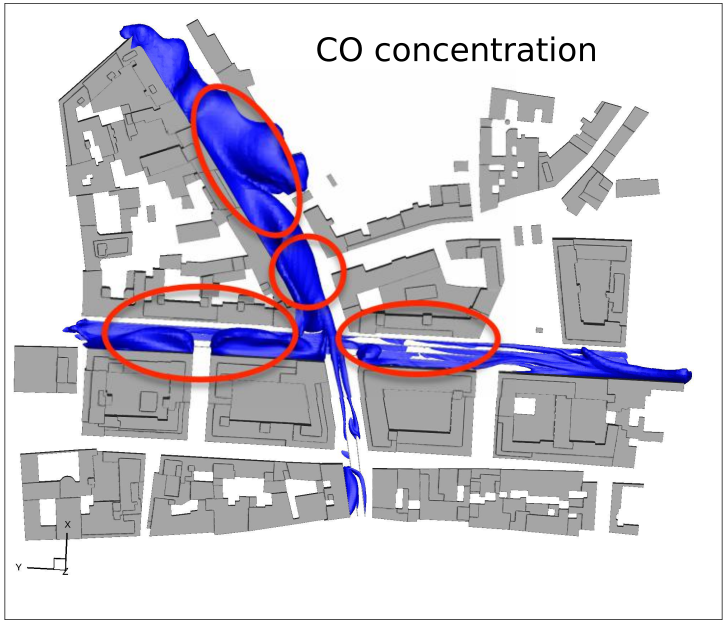
No heating



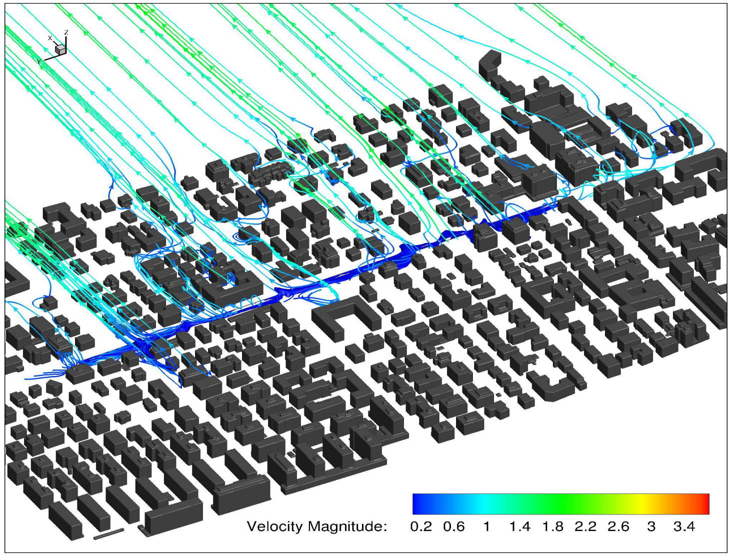
Heating

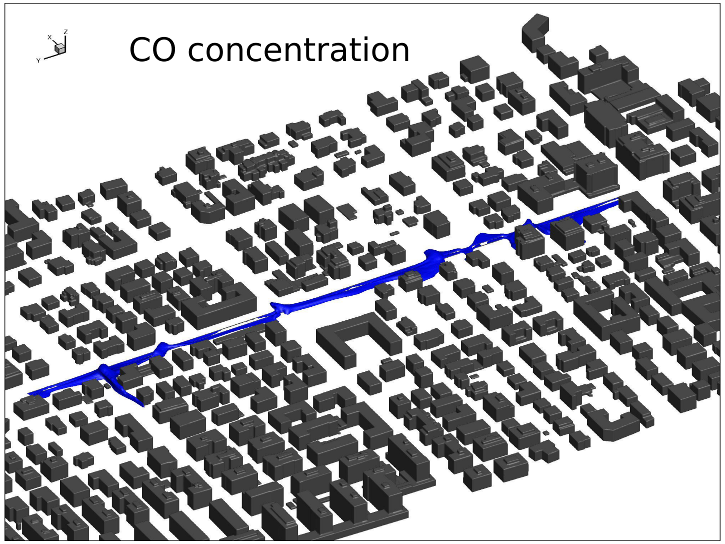
CFD results - comparison between the two canyons





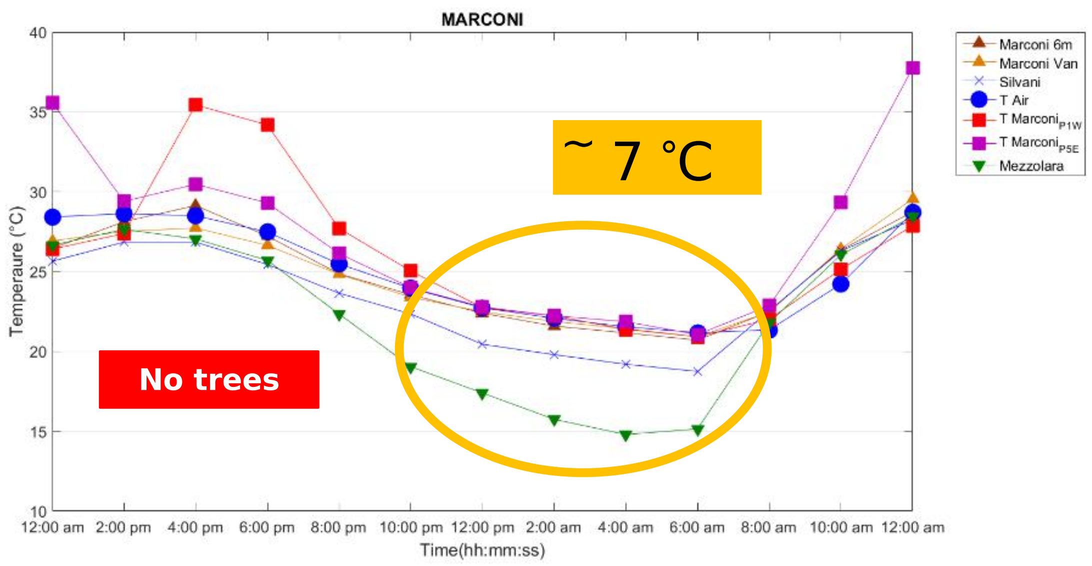
No trees

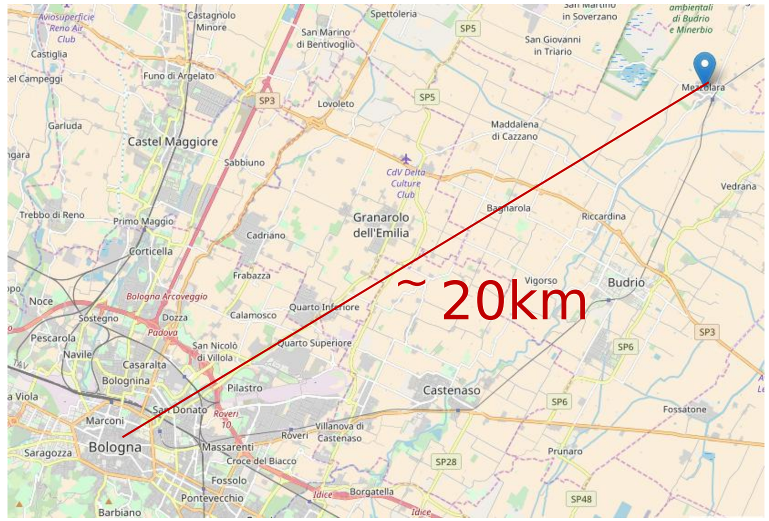


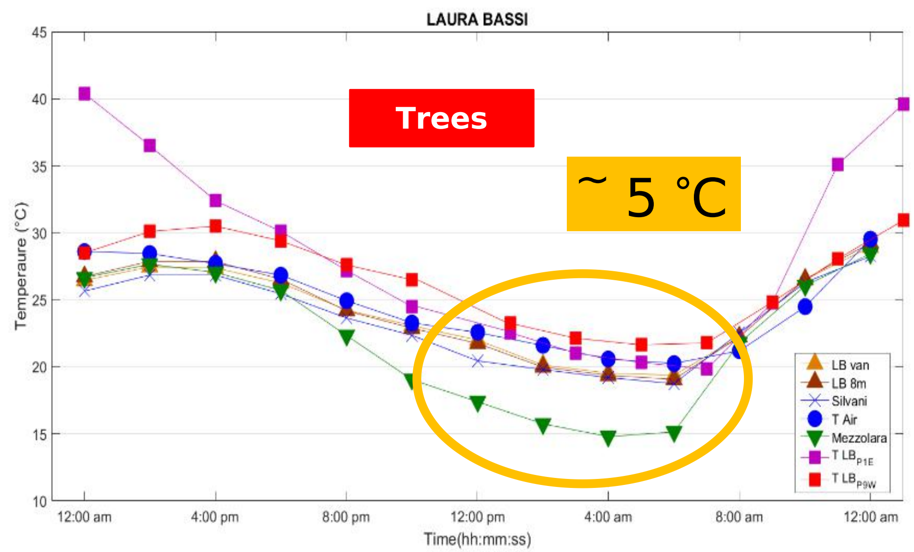


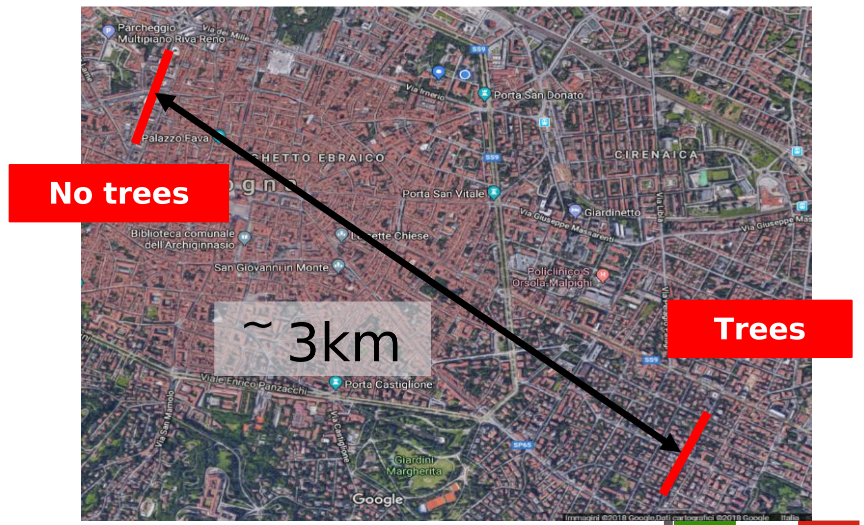
Trees

Heat island effects









Conclusions

- The pollutant concentration is affected by the urban canyon morphology. The morphology represents then a **structural constraint** that affects the atmospheric circulation and consequently the **pollutant hotspots**.

- In particular, near **street intersections** many hotspots are observed, for all the directions of the wind. Street intersections are then structural elements that should be designed *ad hoc* if possible.

- The **heat island** effect is strong, showing a difference of **2-3 degrees** within short distances.

- **Thermal circulation** within the urban street canyon produces higer pollutant concentration at a street level. **The presence of trees could mitigate this effect, especially during the night.**

Thank you!

This study has been supported by iSCAPE Project (Improving Smart Control of Air Pollution in Europe) which is fouded by the European Community's H2020 H2020-SC5-04-2015 under the Grant Agreement No. 689954

Aknowledgements:

The Authors are grateful to **Francesco Barbano and Erika Brattich** for their precious help in the interpretation of experimental results

The Authors are grateful to **ARPAE group (Luca Torreggiani and Carla Barbieri)** for their measurements stations