Microscale Modeling of Effects of Realistic Surface Heat Fluxes on Pollutant Distribution within a Simplified Urban Configuration

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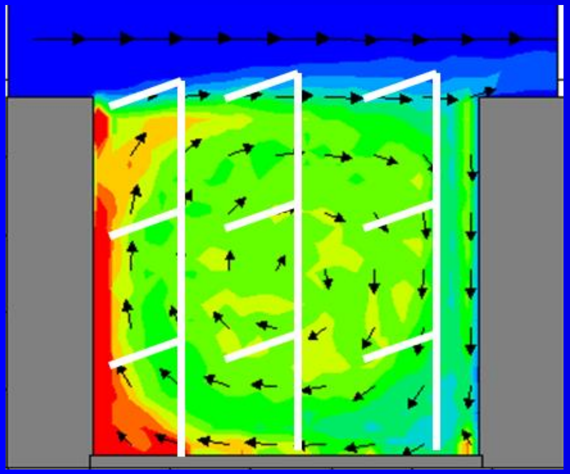
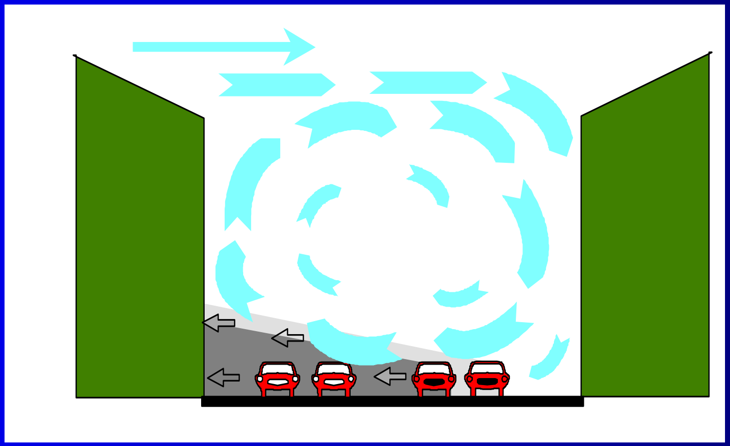
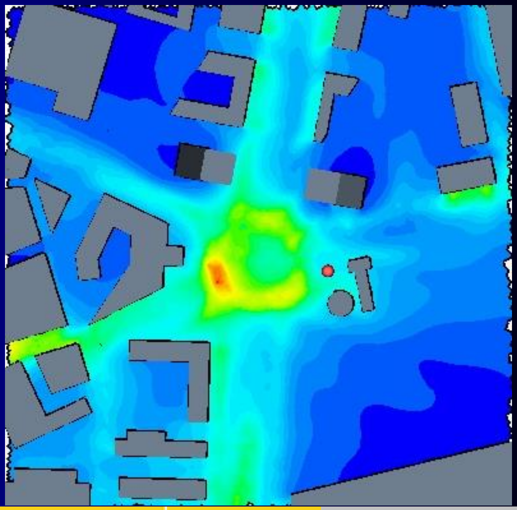
Introduction

- Micrometeorology and pollutant dispersion within cities are important for urban climate, air quality and pedestrian comfort.

- Interaction between the atmosphere and urban surfaces:
  - Complex flow patterns within the urban canopy
  - Heterogeneous distributions of temperature and pollutant concentration.

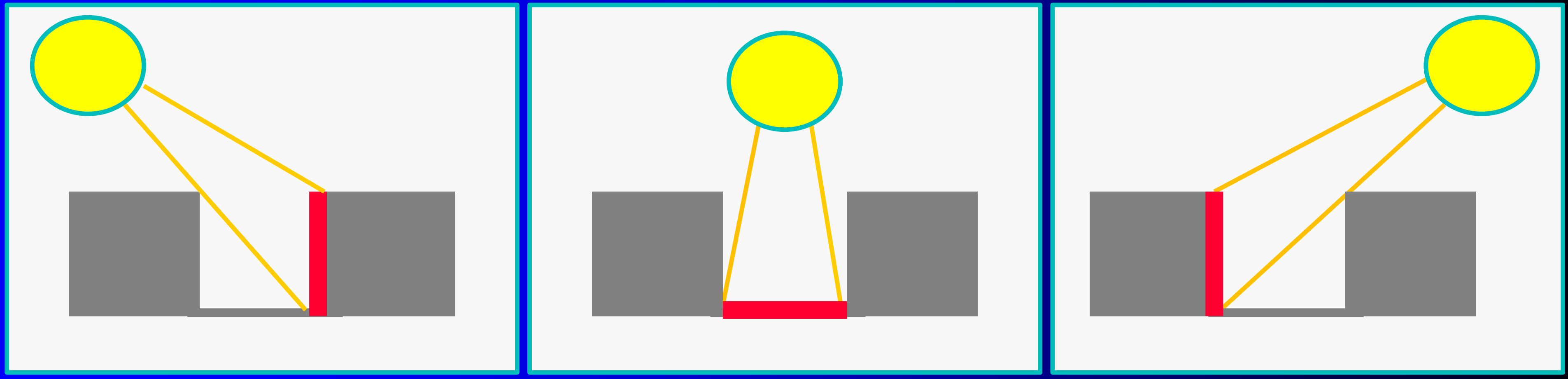






Introduction

- One important physical process: Interaction between heat fluxes from building surfaces and streets and the airflow.
- Thermal effects on flow within the canyon are not taken into account by the majority of microscale studies.
- Most scenarios studied (including thermal effects) to date have only heated one wall of the canyon, or the ground.



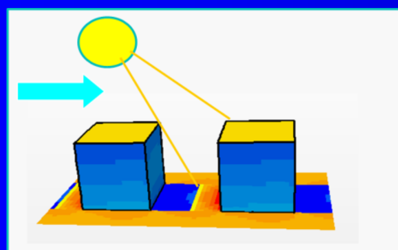
Objective

- The main objective is to determine the impact of ‘realistic’ distribution of urban surface heat fluxes corresponding to different solar positions on airflow properties and pollutant concentration for a range of ratios of buoyancy to dynamical forces.

Configuration and Set-up

Solar Positions

Realistic Distributions
Heat Fluxes
(TUF model)



Boundary Conditions
at walls

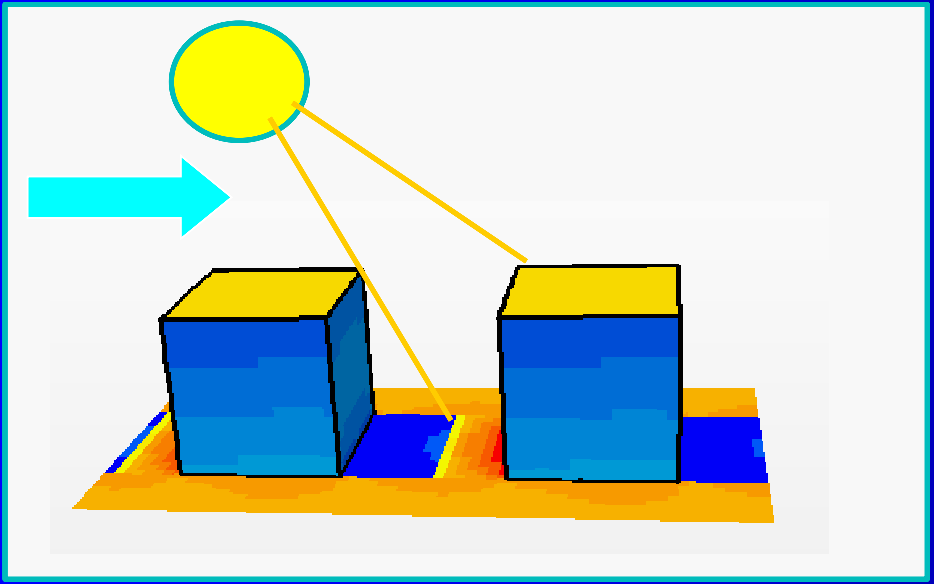
CFD simulation

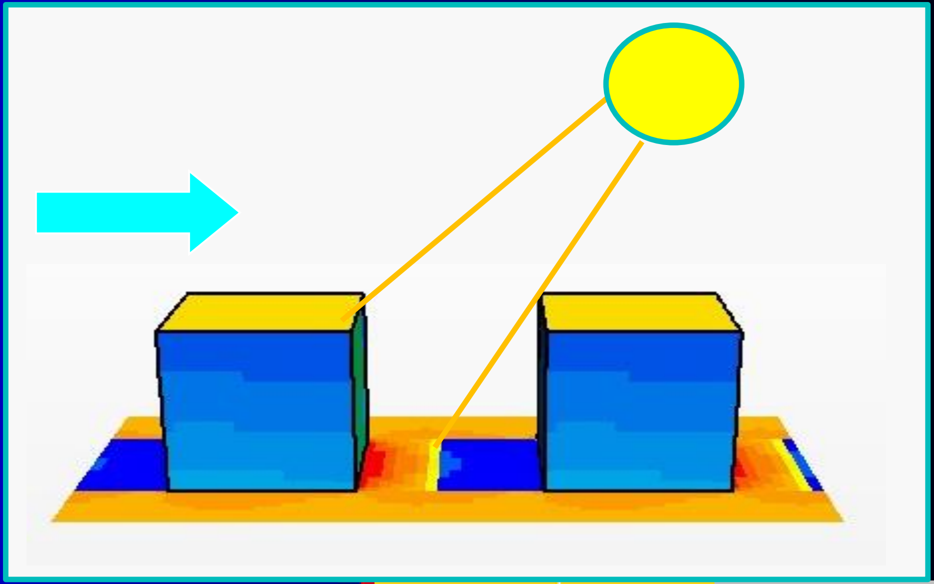
Microscale results
(flow, concentration)

Average results
(flow, concentration)

Configuration and Set-up

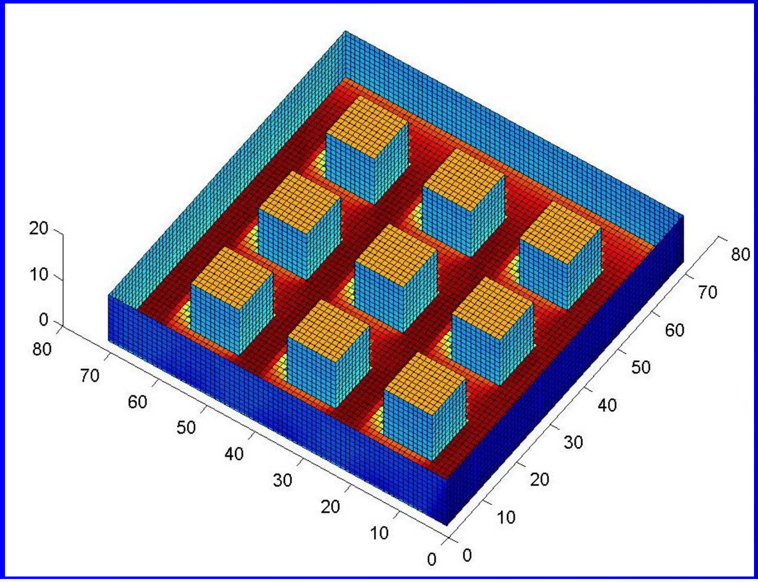
- Array of cubes: lambda= 0.25
- 7 solar positions. For each solar position different intensities of heat fluxes are studied.
- Realistic distribution of sensible heat fluxes for each scenario is introduced with high resolution in CFD simulations.

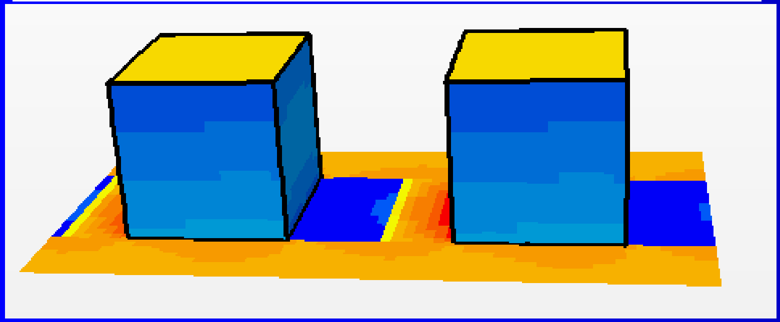




Configuration and Set-up

Boundary conditions for ground and building walls: Microscale 3-D urban energy balance model





- Temperatures of Urban Facets in 3-D (TUF3D) calculates radiative exchange and surface temperature at the patch/sub-facet scale in 3-D.
- The model assumes radiation is the primary driver of the surface temperature distribution.
- TUF3D compares well with surface temperature measurements from Vancouver and Basel.
- Heat Fluxes obtained with TUF3D are used by CFD model

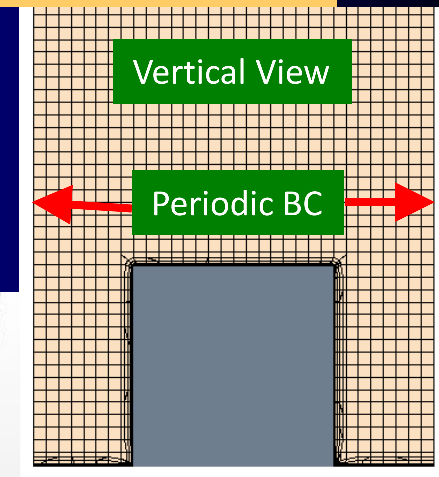
Krayenhoff E.S. and Voogt J.A. (2007) A microscale three-dimensional urban energy balance model for studying surface temperatures. *Boundary-Layer Meteorol.* 123, 433-461.

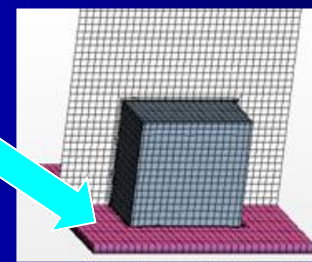
Configuration and Set-up

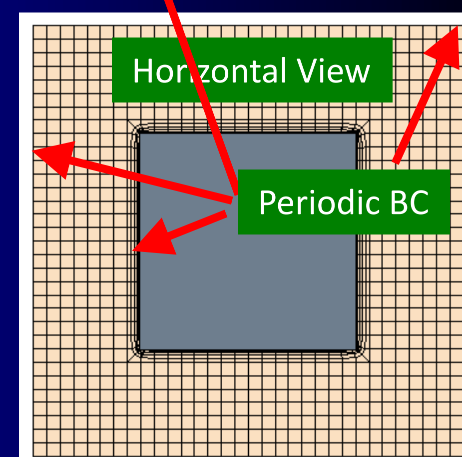
- Microscale (CFD) simulation: RANS model with *k*-ε turbulent closure. Transport equation for passive tracer.
- Mesh: Resolution: *h*/16 with prism layer close to building walls and ground.
- Emissions: bottom part of canopy (traffic)
- Top Boundary Conditions:
  - a downward flux of momentum ρu_{τ}^{2} in the X-momentum equation is imposed to maintain the flow.
  - Concerning temperature boundary conditions at the top, a *Tref* is fixed allowing a flux equals to

$$k_{eff}\left(T_{ref} - T\right)/\Delta z$$

where *keff* is the effective thermal conductivity.
  - Constant concentration

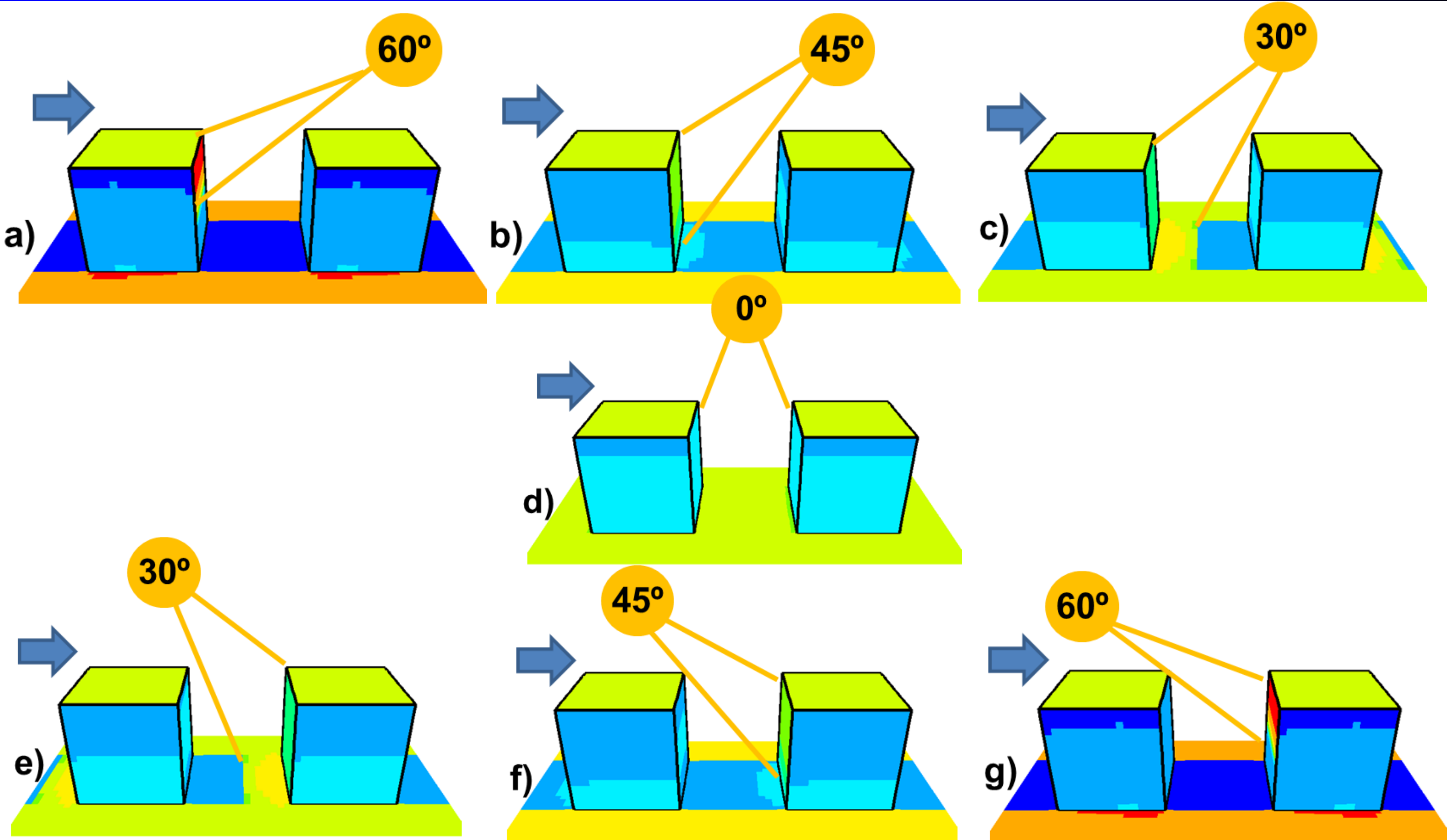






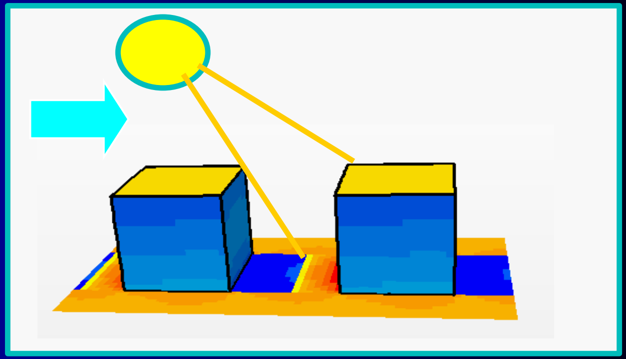
Cases studied

- 7 solar positions. For each solar position different intensities of heat fluxes are studied.

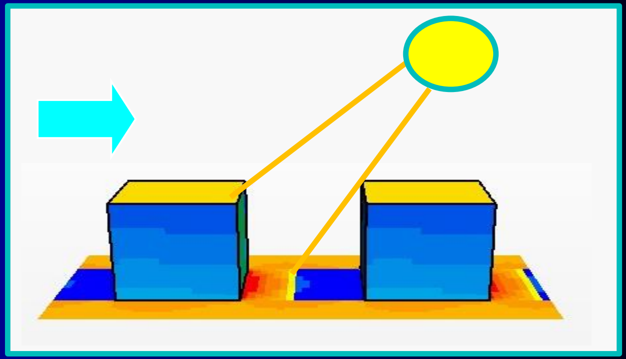


Cases studied

- For each solar position different heat flux intensity. (h/L_{urb}). Analogy with Monin-Obukhov length.

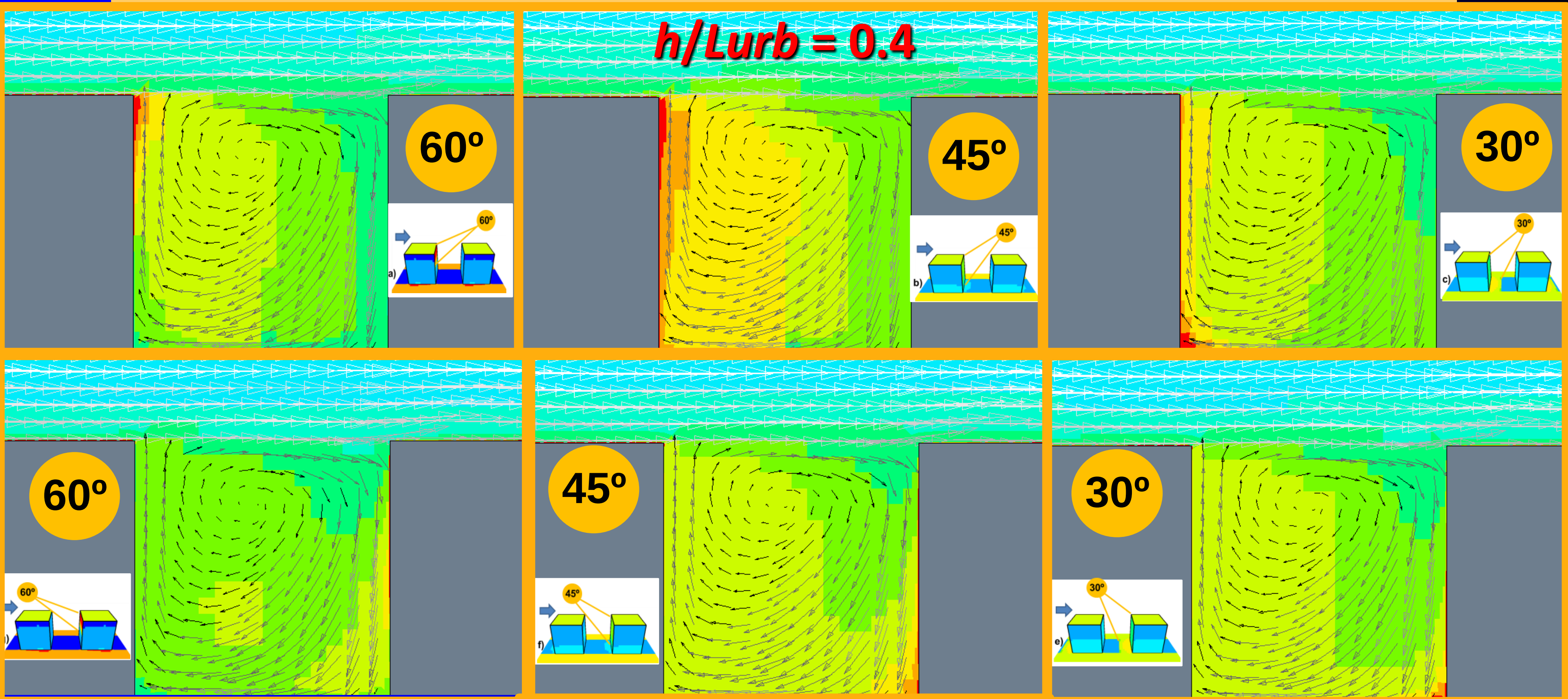


$$L_{urb} = \frac{{u_\tau}^3}{\left(\frac{g}{T_{ref}} \frac{Q_h}{\rho C_p} \right)}$$

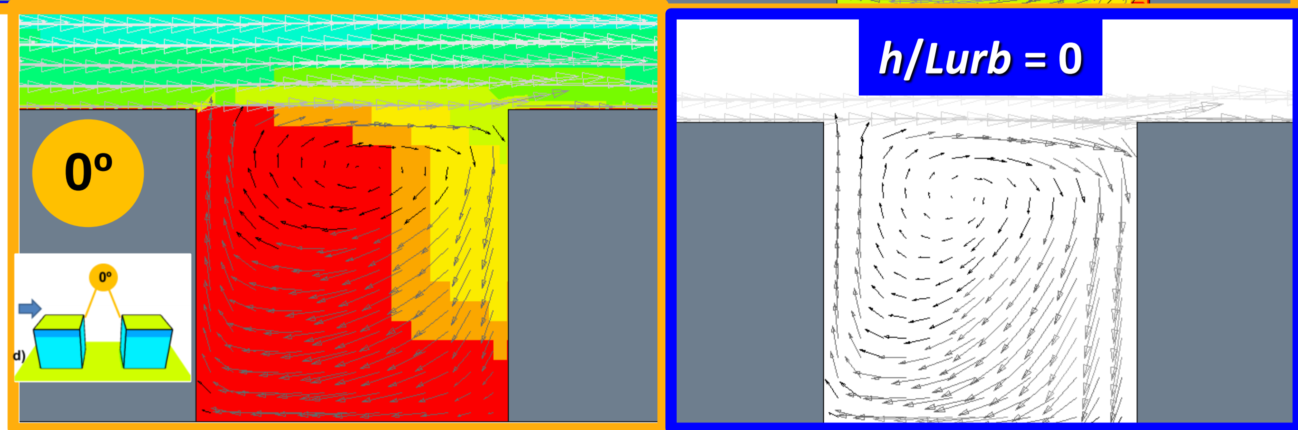


- h/L_{urb} = 0, 0.4, 0.75, 1.13, 1.5, 2.25, 3
- Two simulations with the same h/L_{urb} and the same solar position provides equivalent results (***checked***)

Microscale properties (Normalized Temperature)

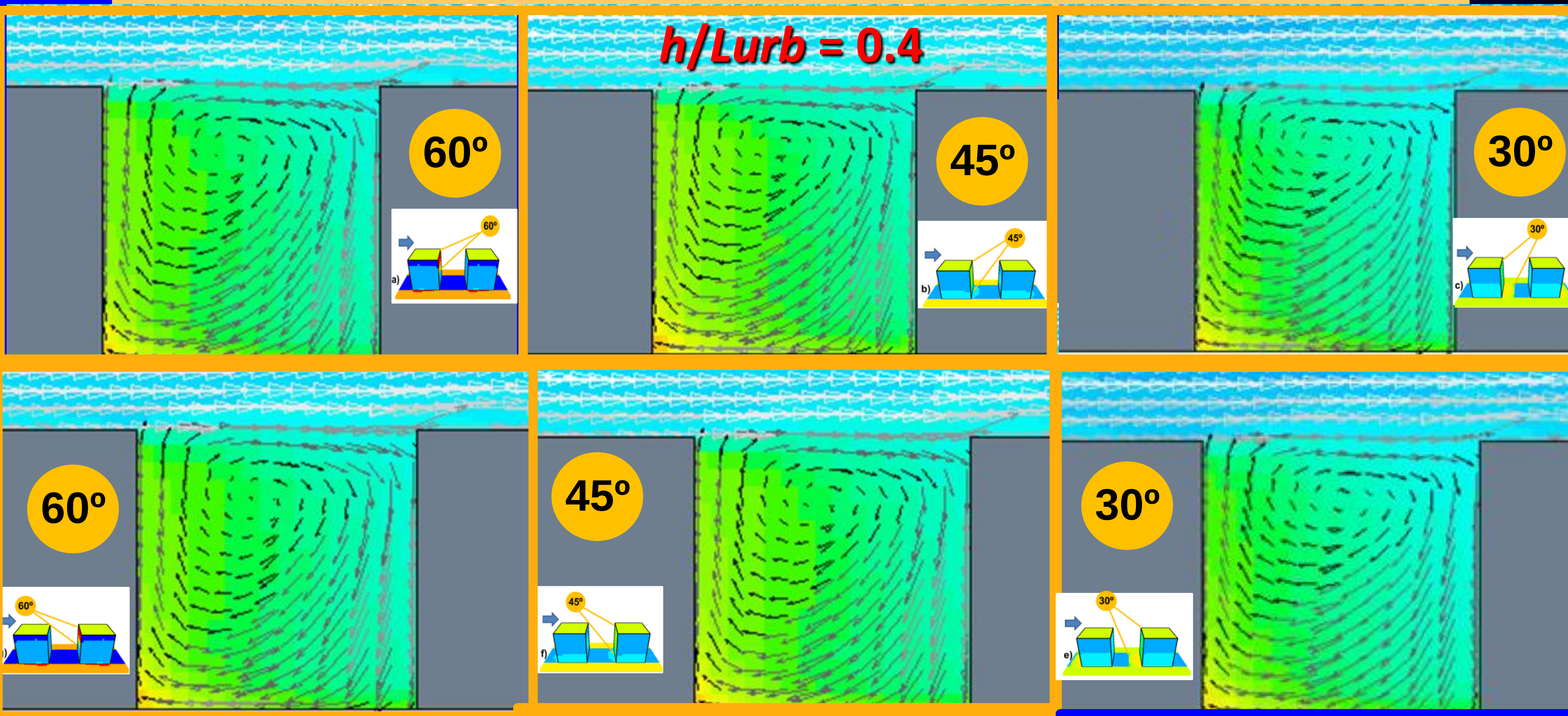


$$L_{urb} = \frac{u_\tau^{\ 3}}{\left(\frac{g}{T_{ref}} \frac{Q_h}{\rho C_p}\right)} \quad \Delta T_{norm} = \frac{\Delta T}{\frac{Q_h / \rho C_p}{u_\tau}}$$

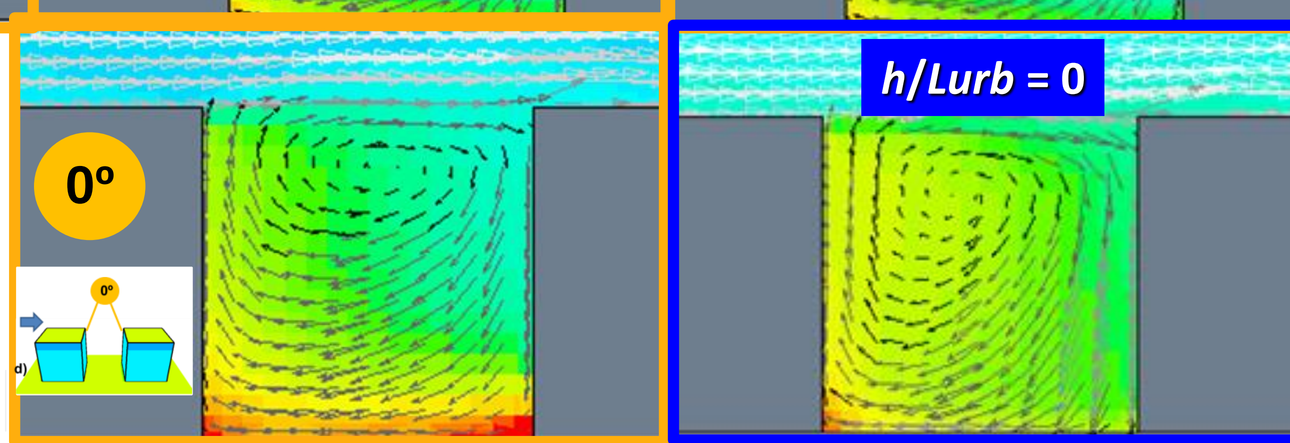


ΔT_{norm}

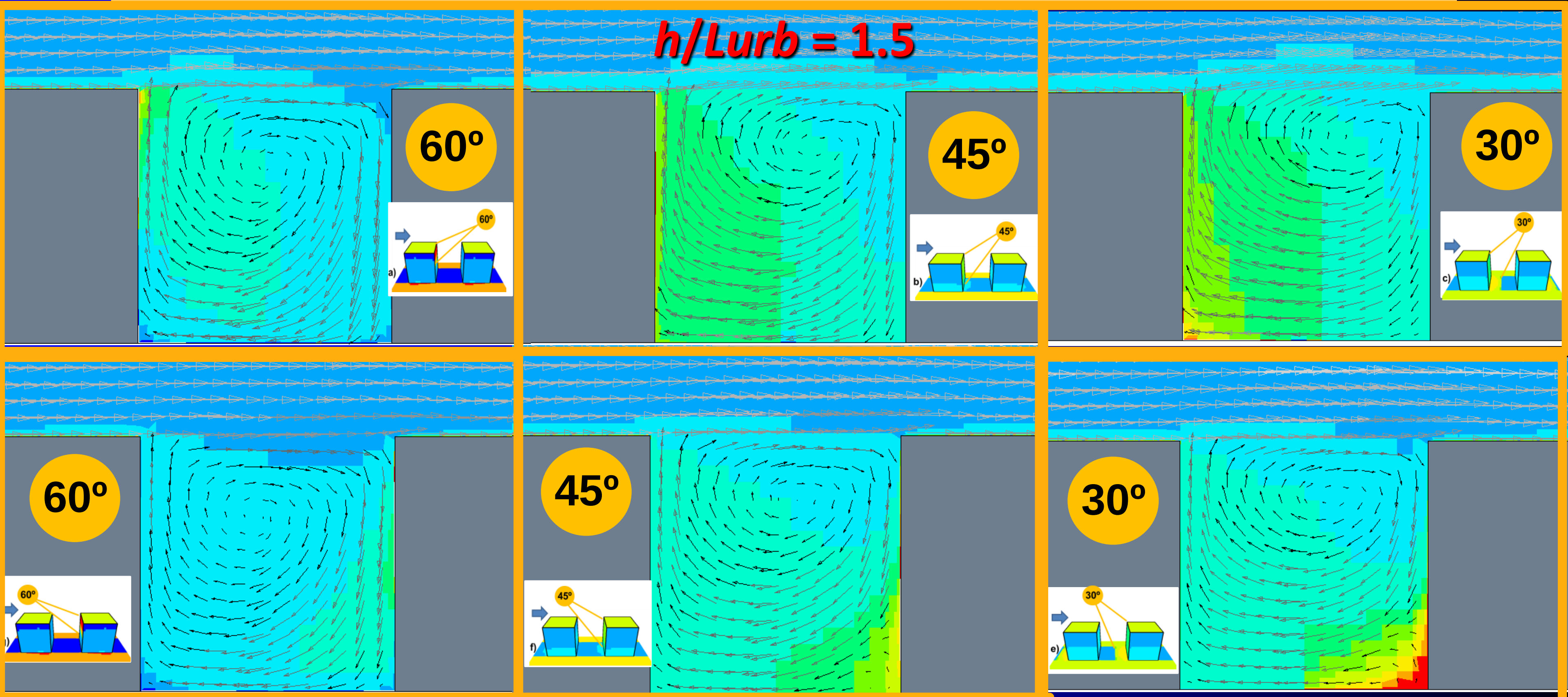
Microscale properties (Normalized Concentration)



$$L_{urb} = \frac{u_\tau^{\ 3}}{\left(\frac{g}{T_{ref}}\frac{Q_h}{\rho C_p}\right)} \quad C_{norm} = \frac{C \cdot u_\tau \cdot h^2}{Q_c}$$



Microscale properties (Temperature normalized)



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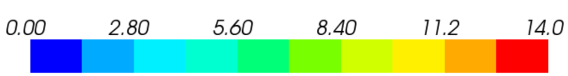
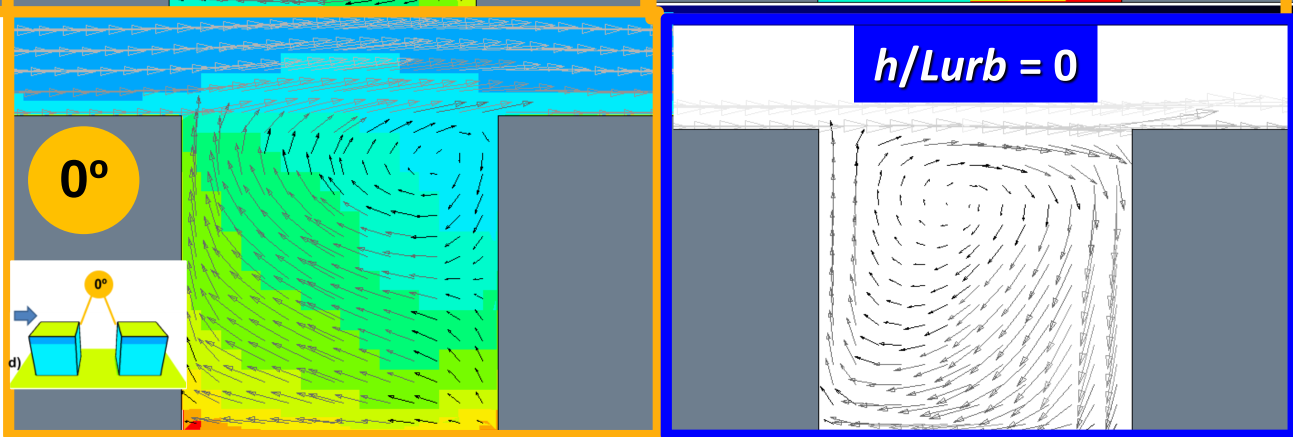
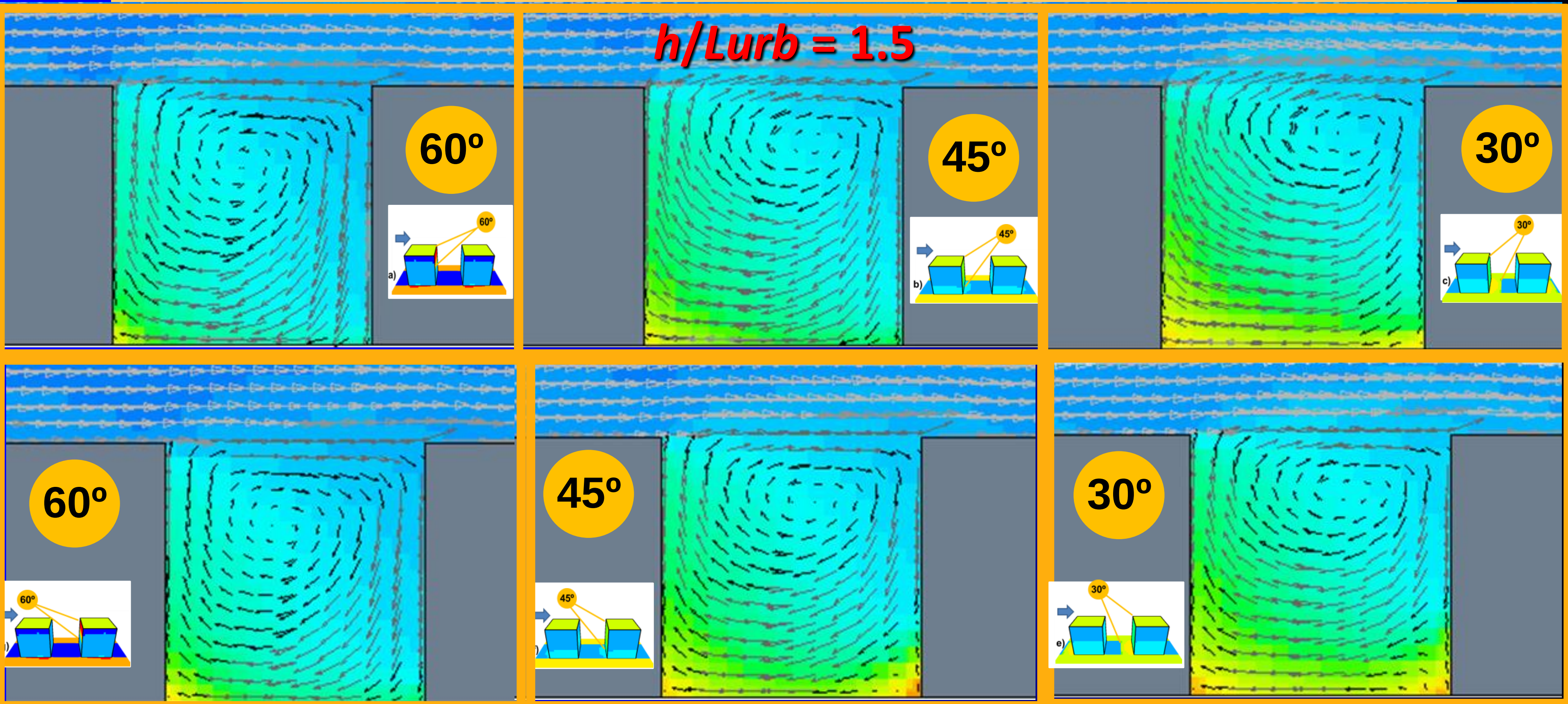
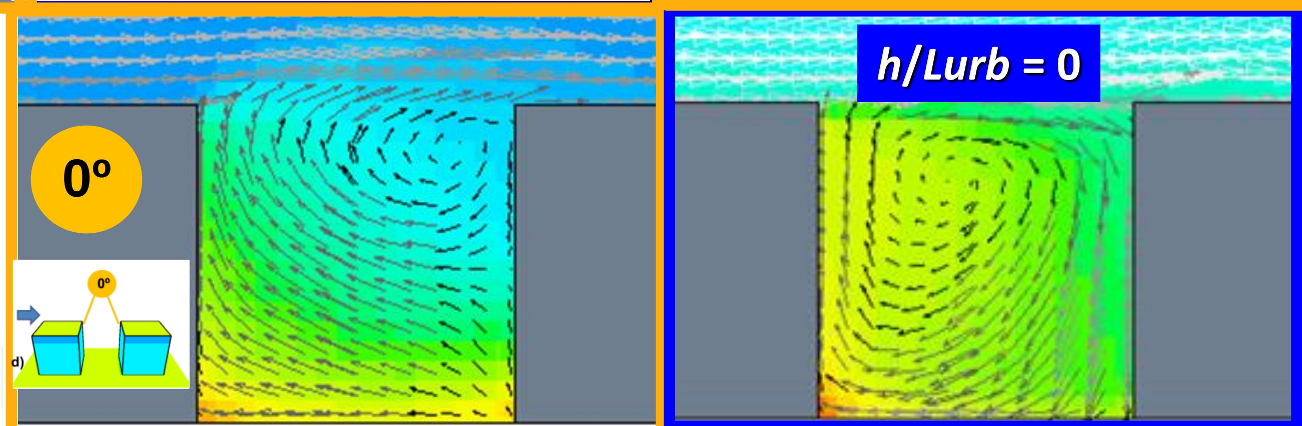




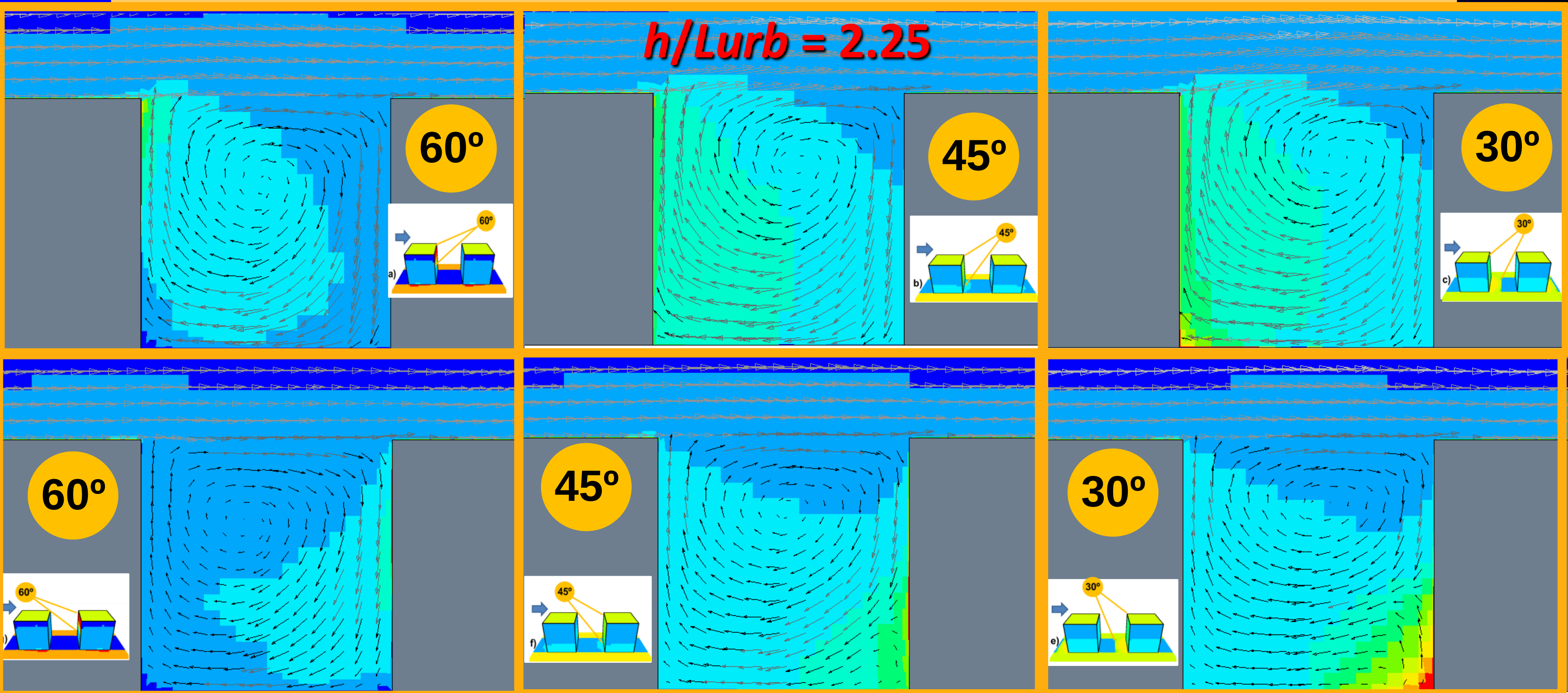
Microscale properties (Normalized Concentration)



$$L_{urb} = \frac{u_\tau^{\ 3}}{\left(\frac{g}{T_{ref}} \frac{Q_h}{\rho C_p}\right)} \quad C_{norm} = \frac{C \cdot u_\tau \cdot h^2}{Q_c}$$



Microscale properties (Temperature normalized)



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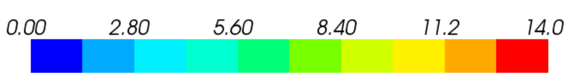
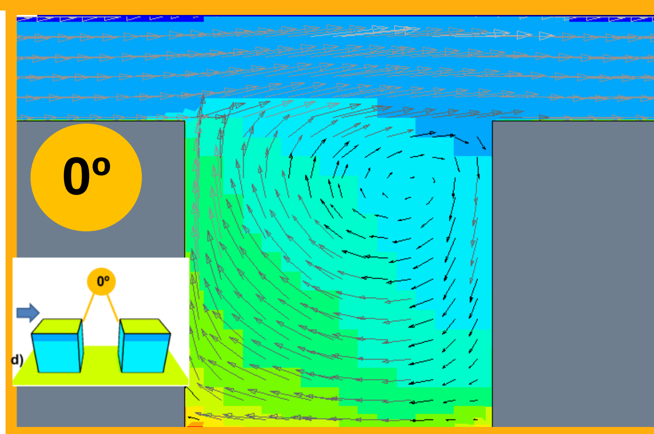
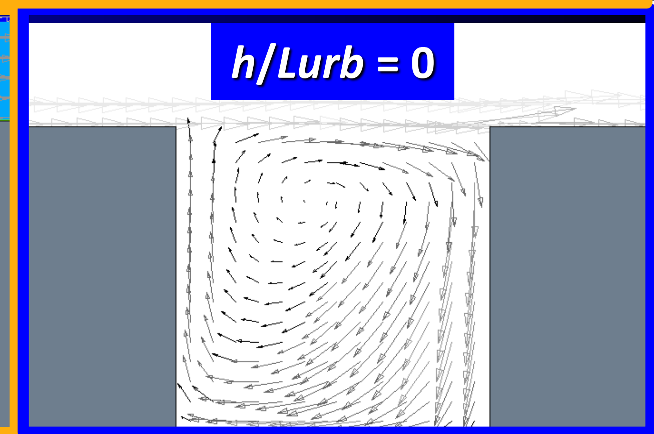
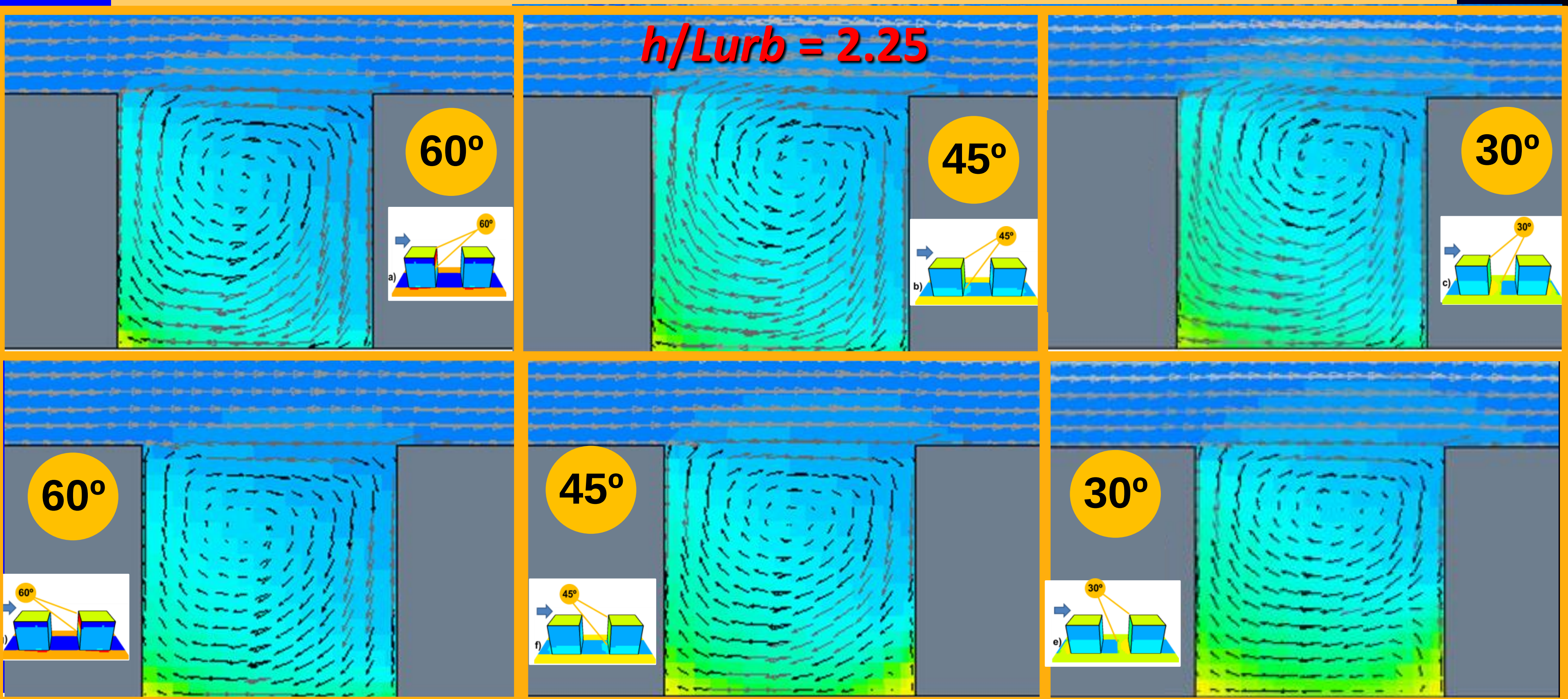






Microscale properties (Normalized Concentration)



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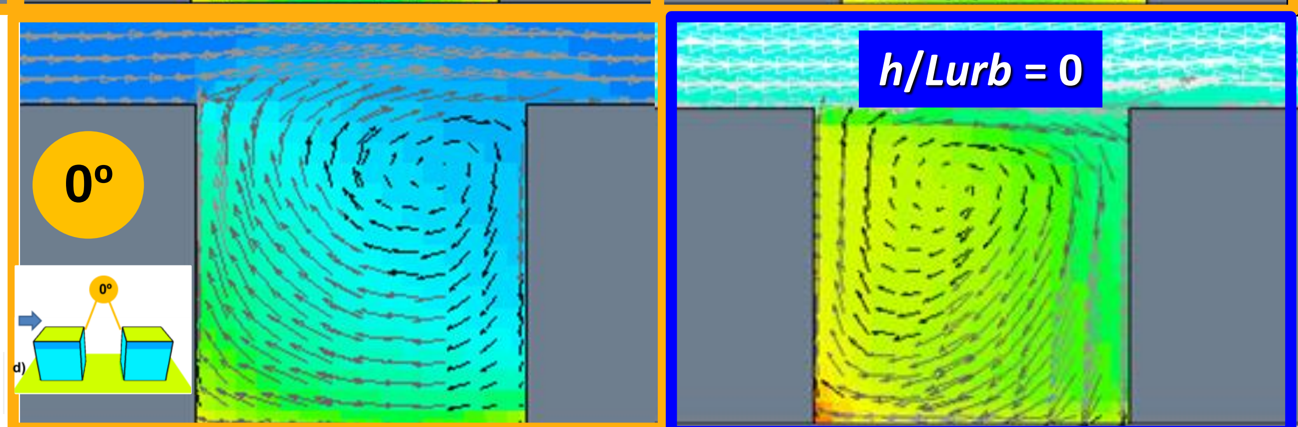
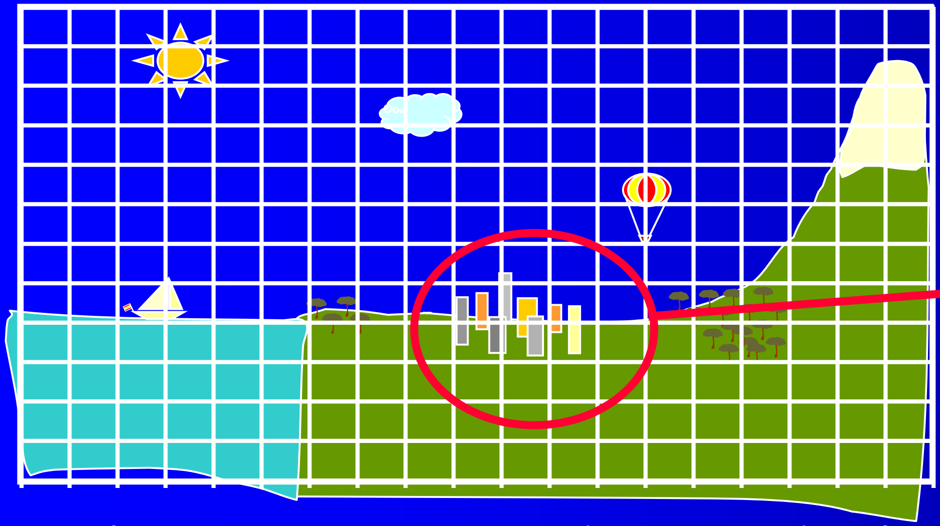
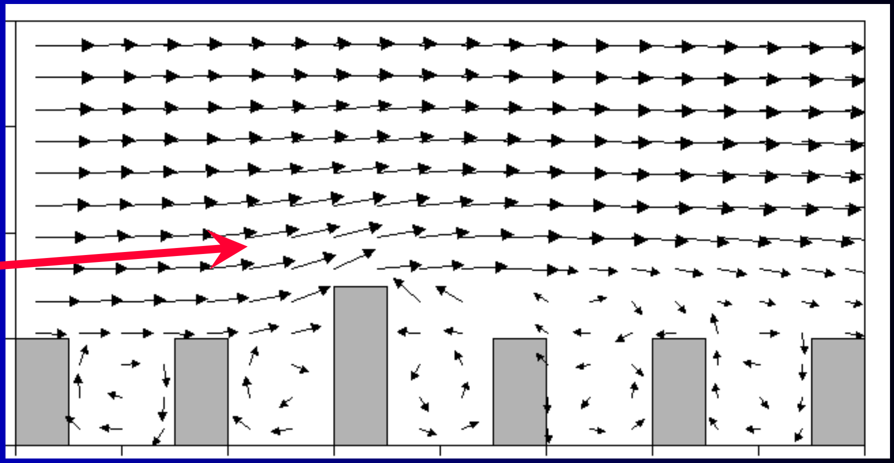


Spatially average flow properties

- CFD → High resolution information → Numerical domain cannot cover the whole city

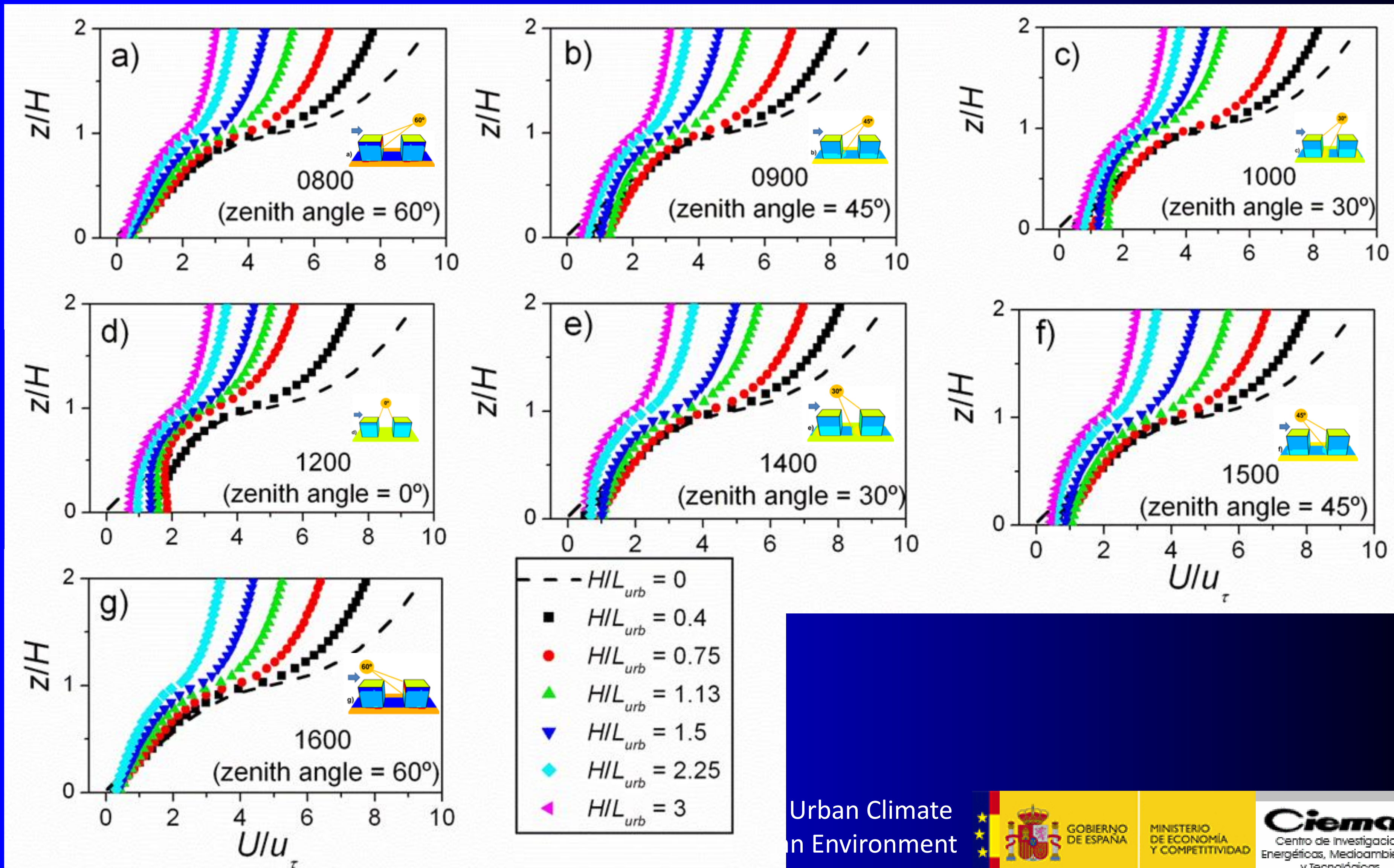
- Mesoscale models → Urban Canopy Models (compromise between simplicity and accuracy) to parameterize processes at smaller scale than mesoscale resolution (i.e. parametrization of drag forces induced by buildings).





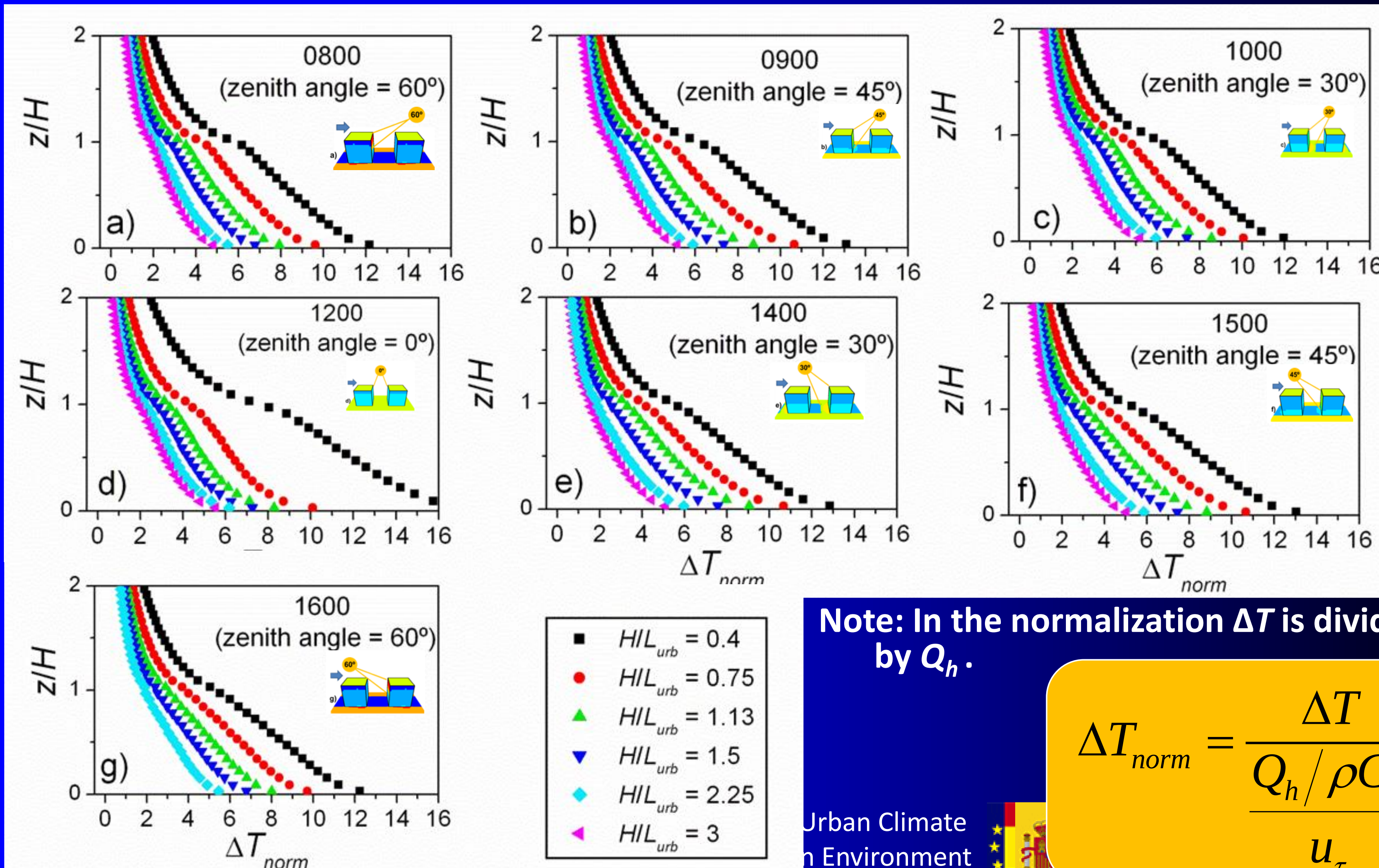
Spatially average flow properties

- Flow



Spatially average flow properties

- Normalized Temperature

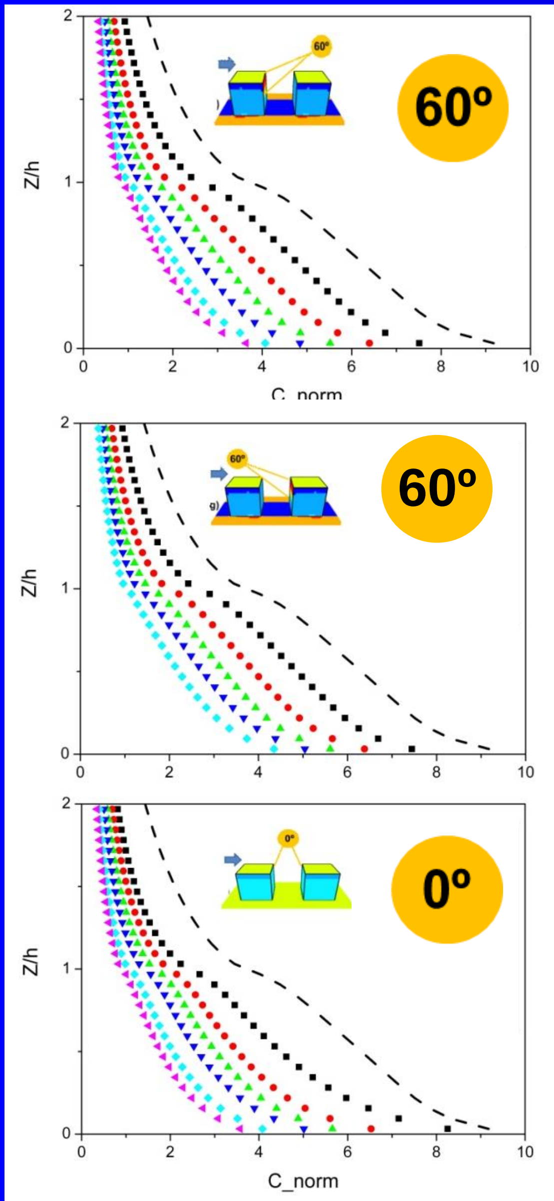


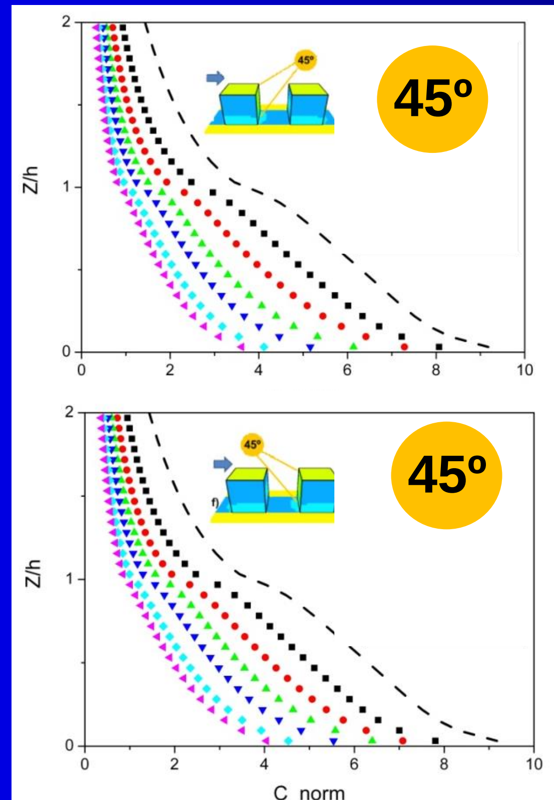
Note: In the normalization Δ*T* is divided by Q_h .

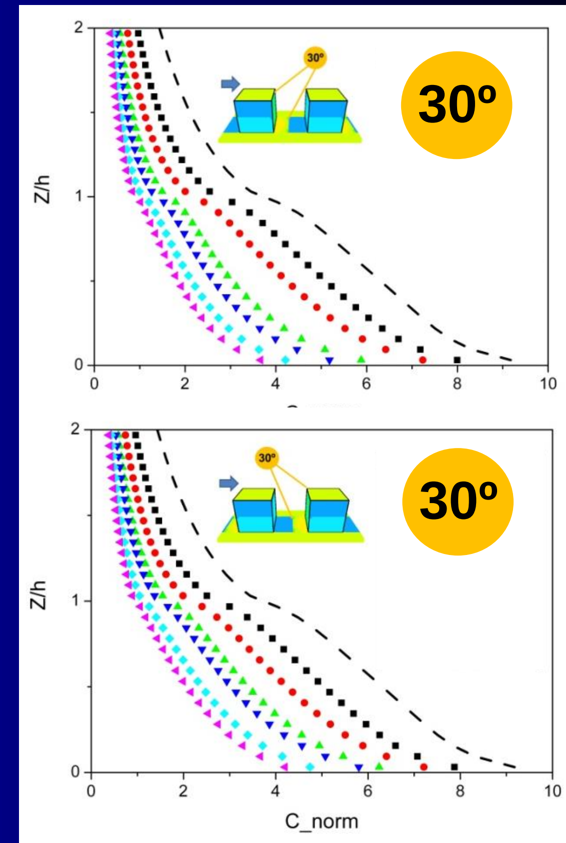
$$\Delta T_{norm} = \frac{\Delta T}{\dfrac{Q_h/\rho C_p}{u_\tau}}$$

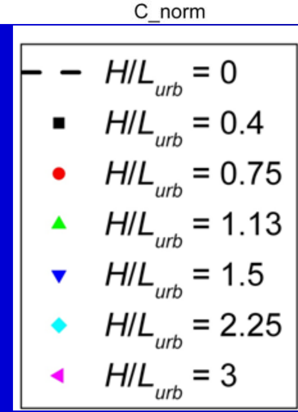
Spatially average flow properties

- Normalized Concentration









$$C_{norm} = \frac{C \cdot u_\tau \cdot h^2}{Q_c}$$

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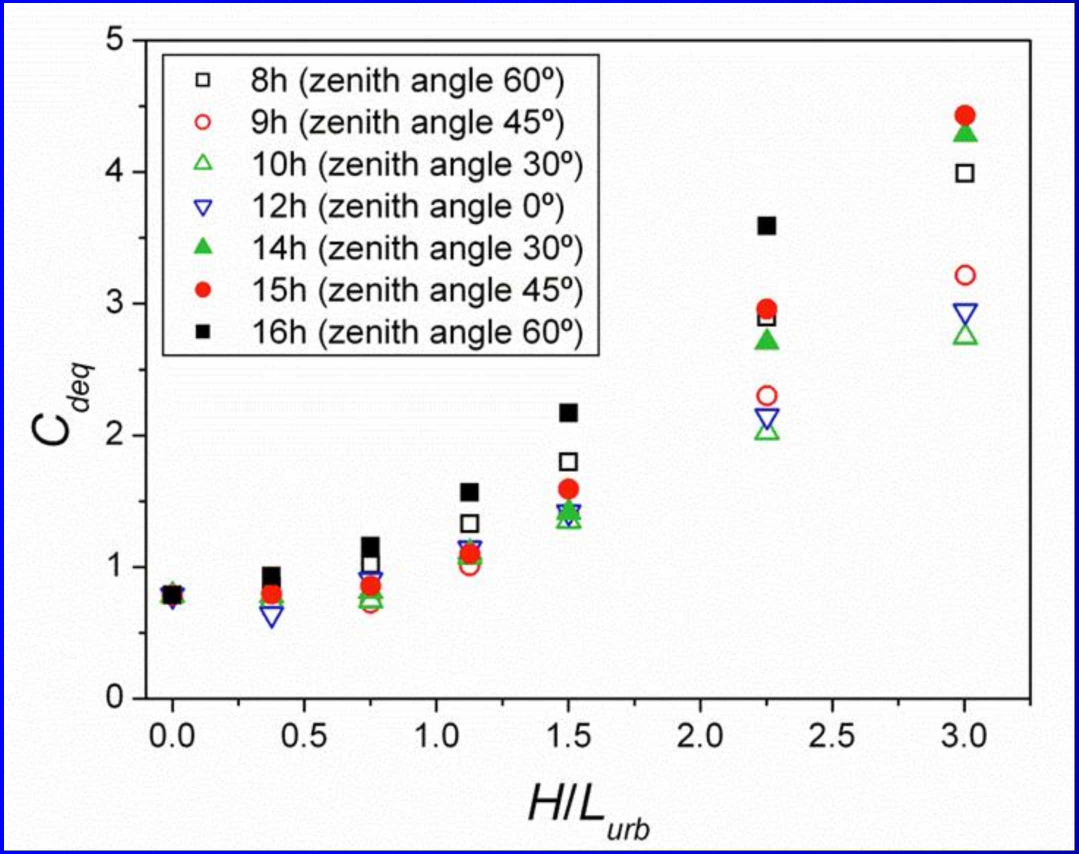
Spatially average flow properties

- Drag Coefficient (Urban canopy model)



$$\overrightarrow{Drag}(z) = -\rho S(z) C_d \left|U\right| \vec{U}$$

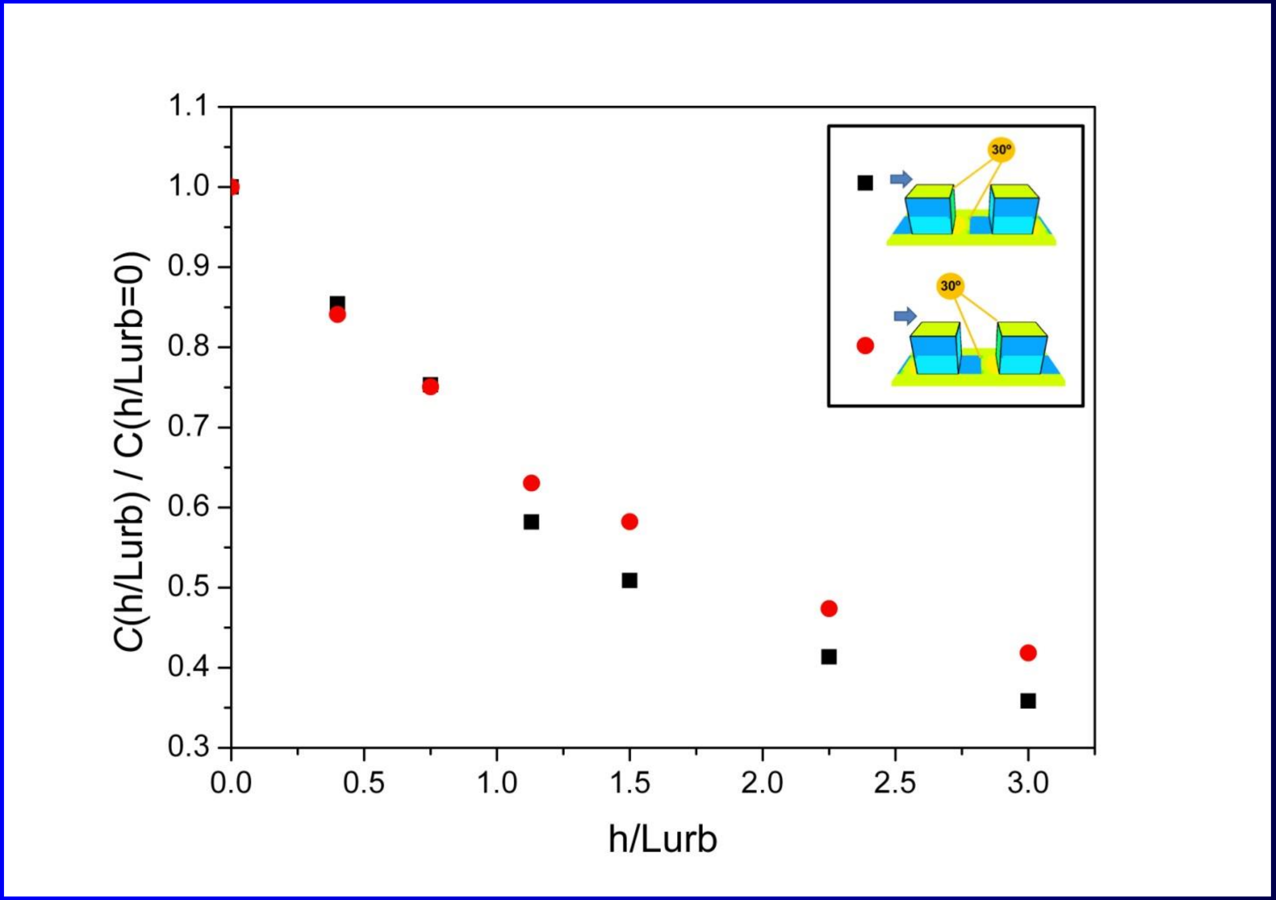
- $S(z)$ is the vertical surface building density (facing the wind), C_d is drag coefficient.

$$C_{deq} = \frac{\int_0^H \Delta P dz}{\rho \int_0^H U^2 dz}$$

- Drag force integrated in the whole canopy is equal to that computed by RANS simulations.

Spatially average flow properties

- Average concentration at 2.5 m



Summary and Conclusions

- Scenarios with **realistic distributions of heat fluxes** imposed at urban surfaces are simulated by a CFD model analyzing microscale and spatial average properties of the flow and concentration .

- Different solar positions and different intensities of ratios between buoyancy and dynamical forces (variation of ***h/Lurb***) for each position are simulated.

$$L_{urb} = \frac{u_\tau^{\ 3}}{\left(\frac{g}{T_{ref}} \frac{Q_h}{\rho C_p} \right)}$$

- For higher *h/Lurb*, cases with leeward shaded have higher average concentration close to ground than cases with the other wall heated. This is observed for *h/Lurb* > 1.0

- Cdeq increases substantially (high buoyancy force: *h/Lurb* > 1.0) → this effect should be important to include in parameterization of drag in UCP

Thank you for your attention