Modelling the Recirculation Zone in Street Canyons with Different Aspect Ratios, using CFD Simulations

Arsenios Chatzimichailidis[1], Marc Assael[1], Matthias Ketzel[2], Konstantinos Kakosimos[3]

[1]Department of Chemical Engineering, Aristotle University of Thessaloniki, Thessaloniki, Greece

[2]Department of Environmental Science, Aarhus University, Roskilde, Denmark

[3]Chemical Engineering Department & Mary Cay ‘O Connor Process Safety Center, Texas A&M University at Qatar, Doha, Qatar

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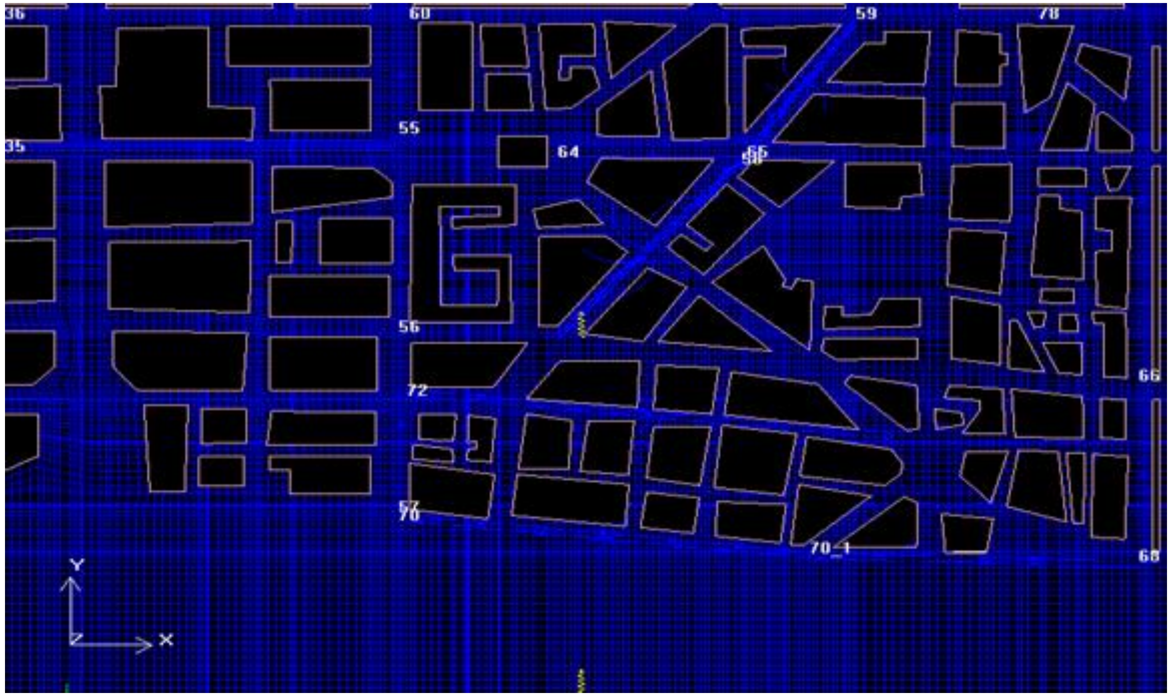
Outline

1. Motivation
2. Hypothesis
3. Methodology
4. Preliminary results
5. Further work

1. Motivation

- Dispersion depends on the wind flow and the city structure



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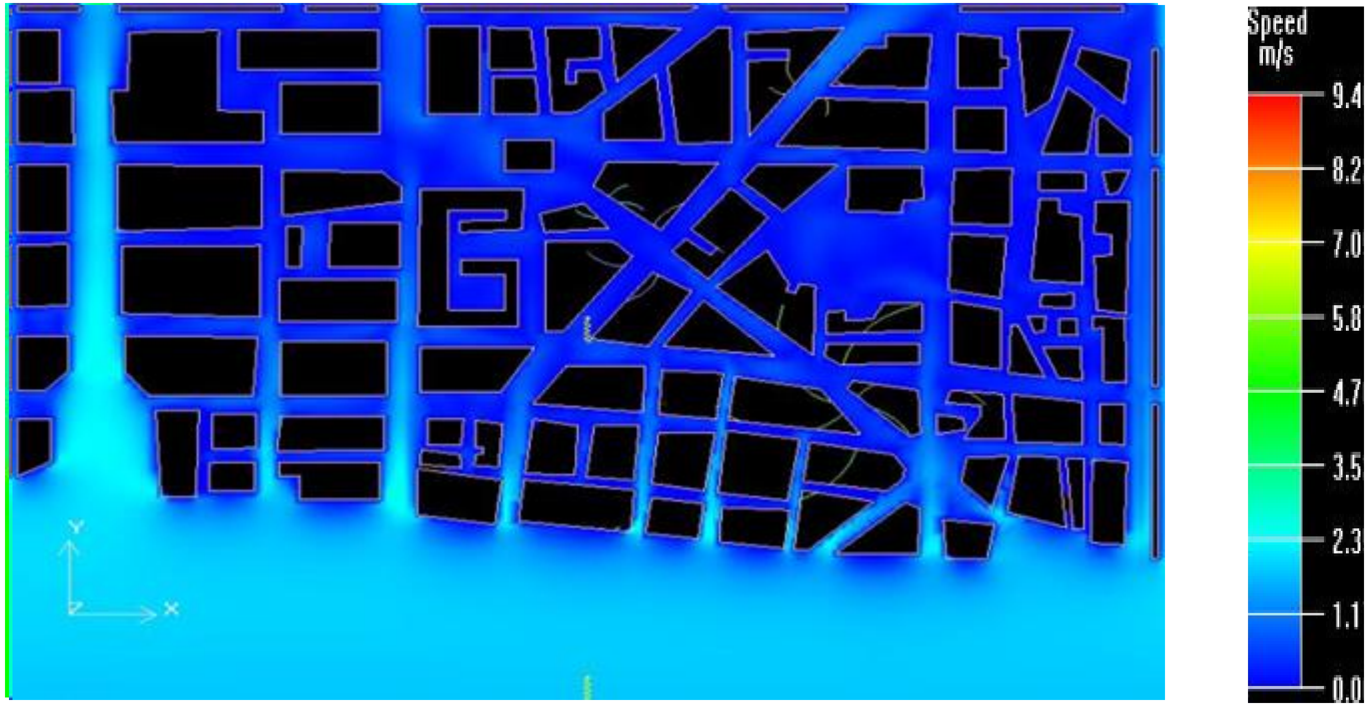

U_{ref} = 2 m/s

1. Motivation

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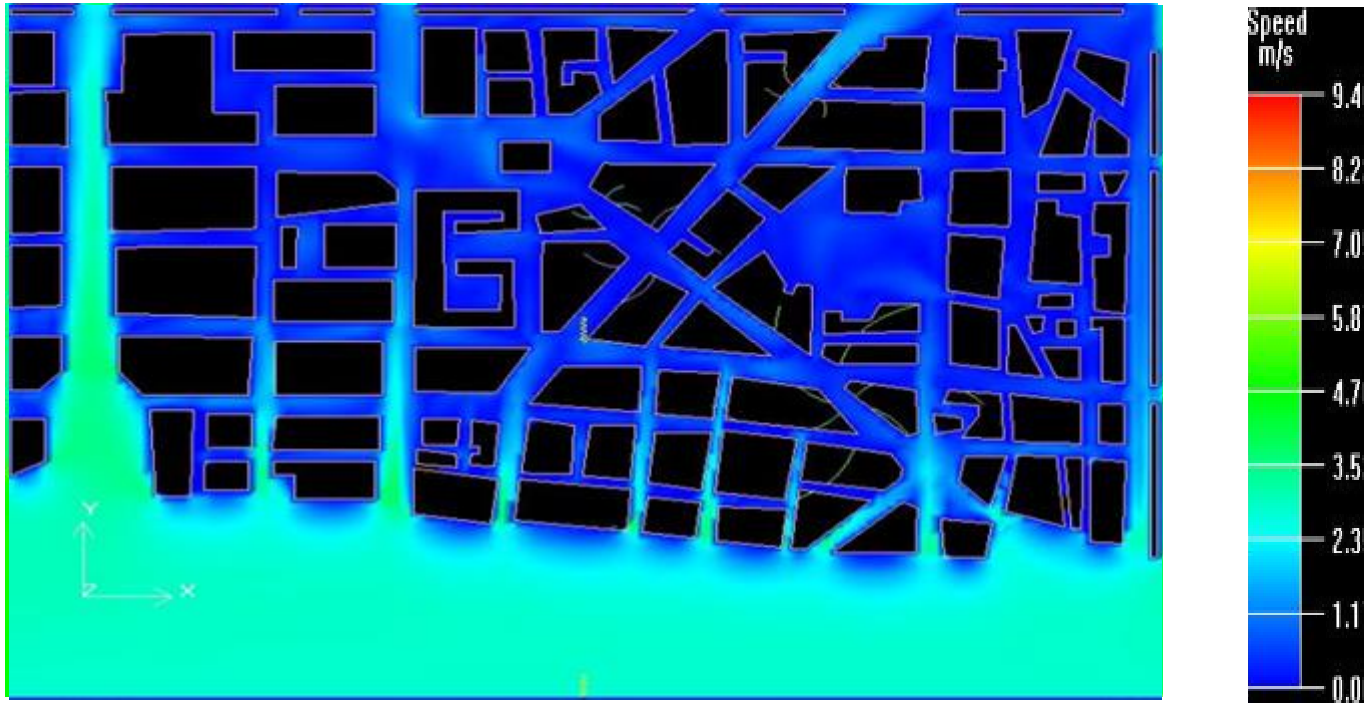

U_{ref} = 3 m/s

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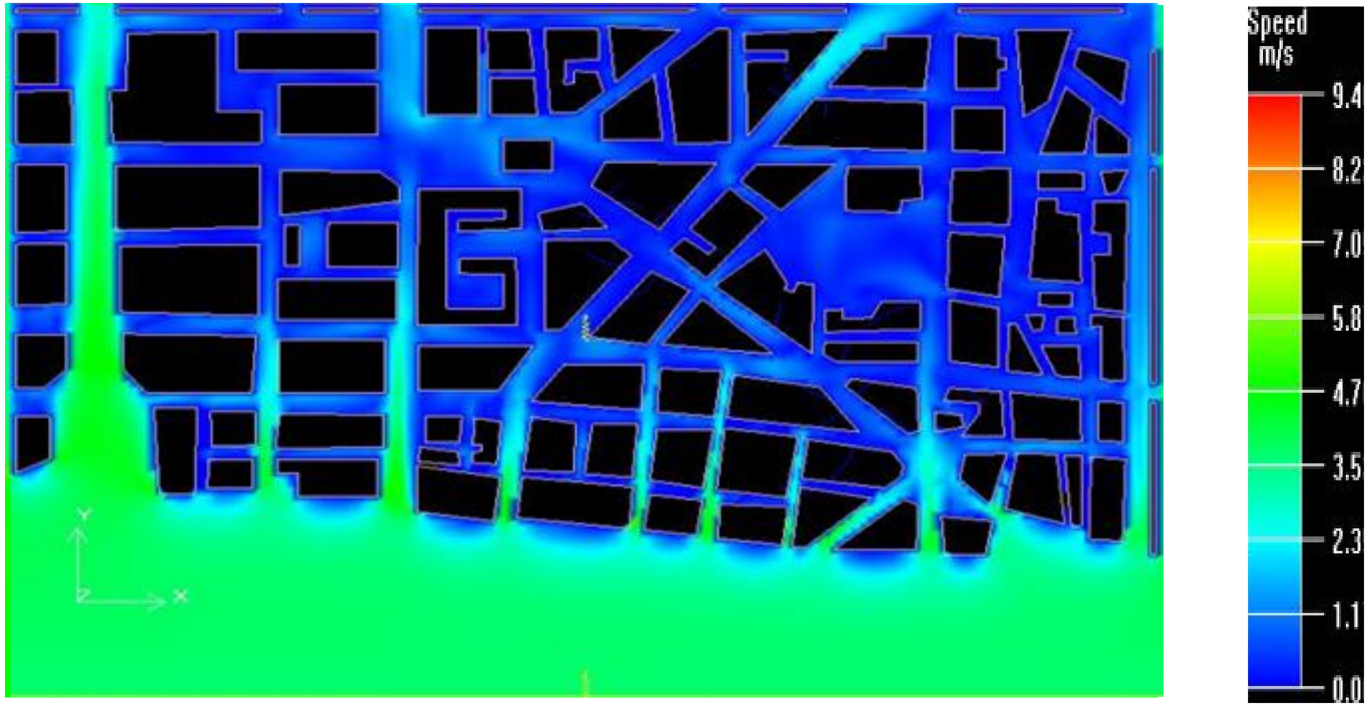

$U_{ref} =$ 4 m/s

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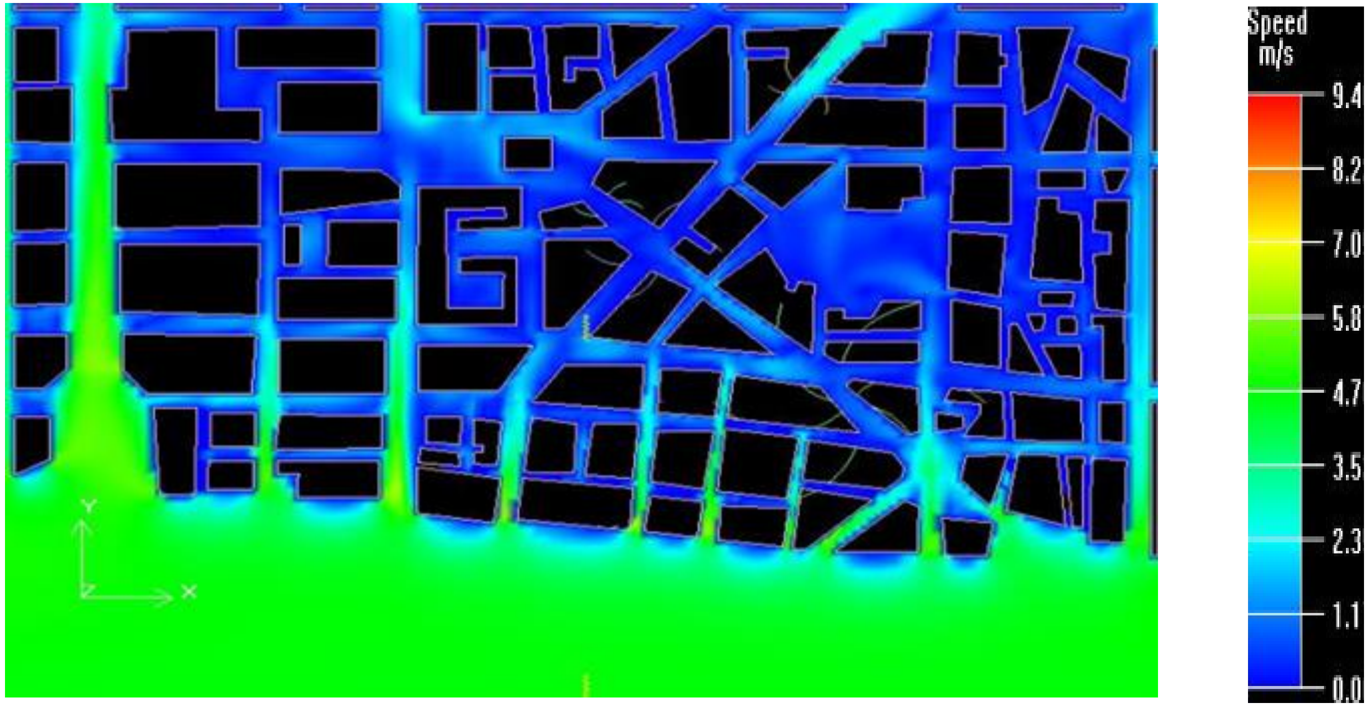

U_{ref} = 5 m/s

1. Motivation

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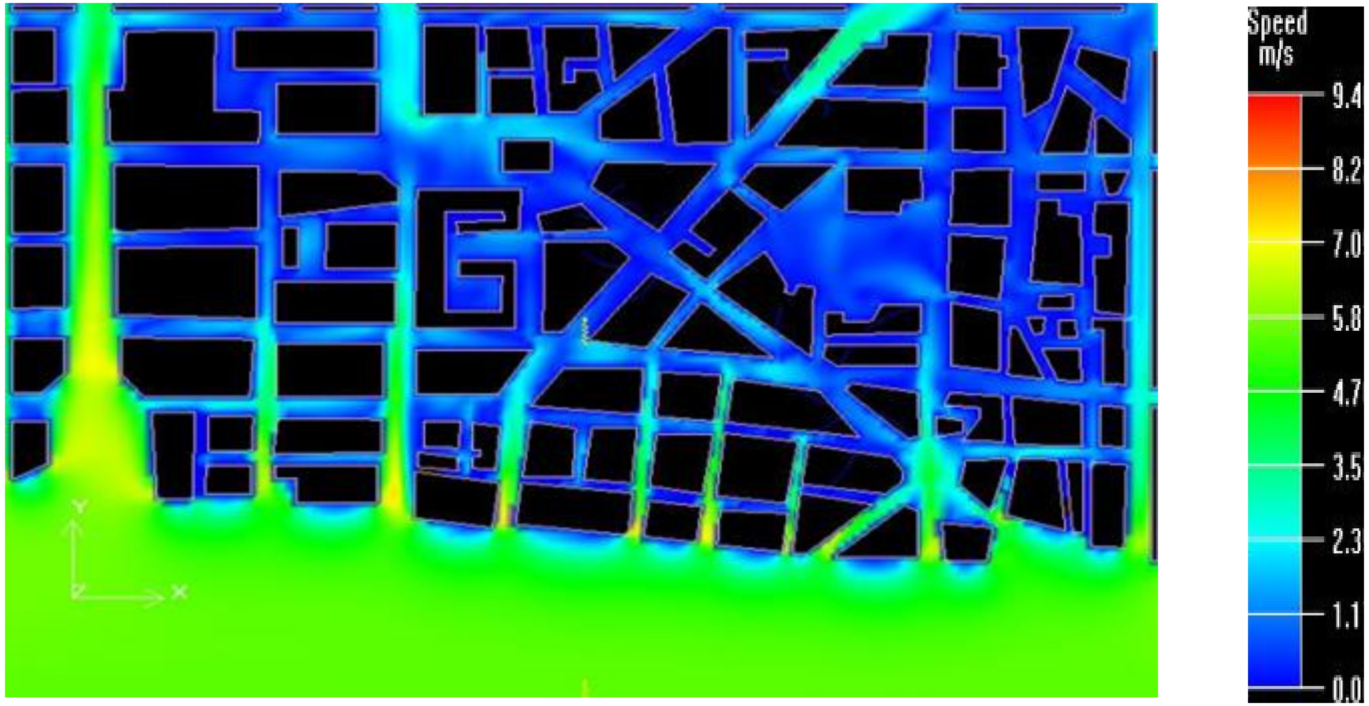

U_{ref} = 6 m/s

1. Motivation

- Instantaneous and average velocity flow fields

- Flow in street canyons is complex
- The hour average velocity field is considered in most models

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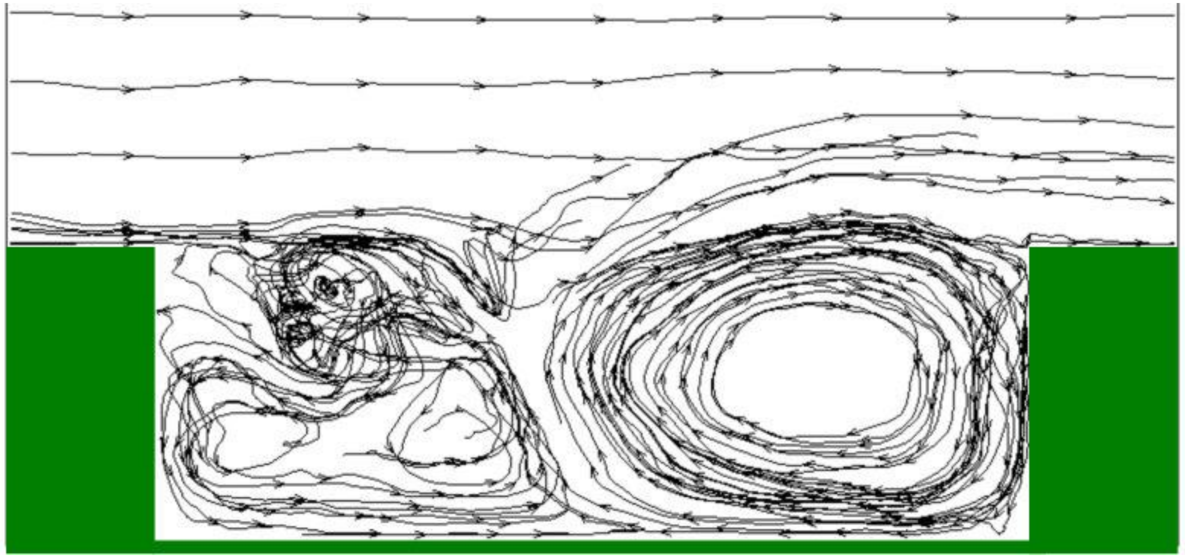
- Instantaneous and average velocity flow fields



- Flow in street canyons is complex
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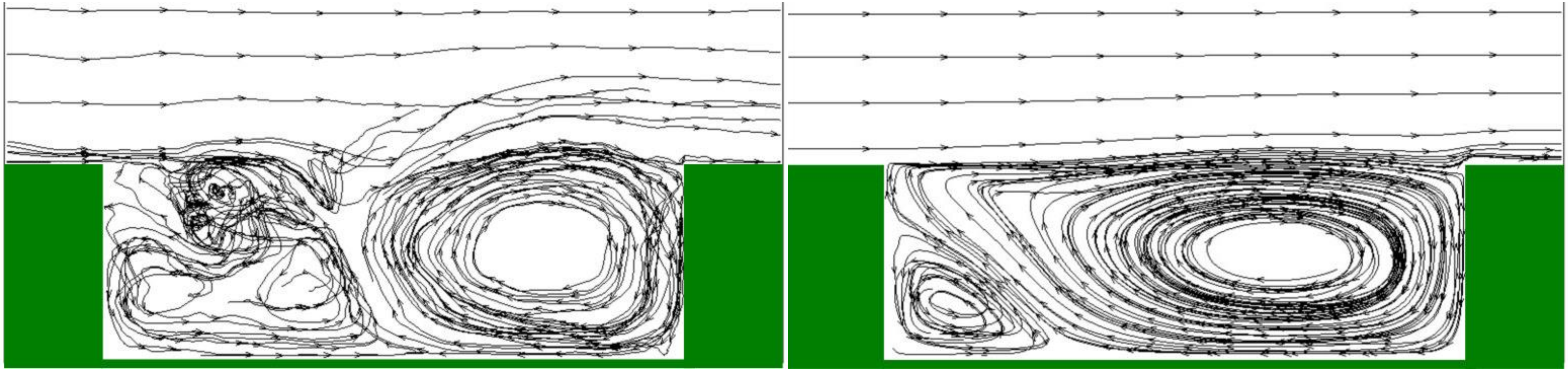
1. Motivation

- Instantaneous and average velocity flow fields



- Flow in street canyons is complex
- The hour average velocity field is considered in most models

1. Motivation

- Popular description - 3 flow regimes identified by (Oke, 1988)

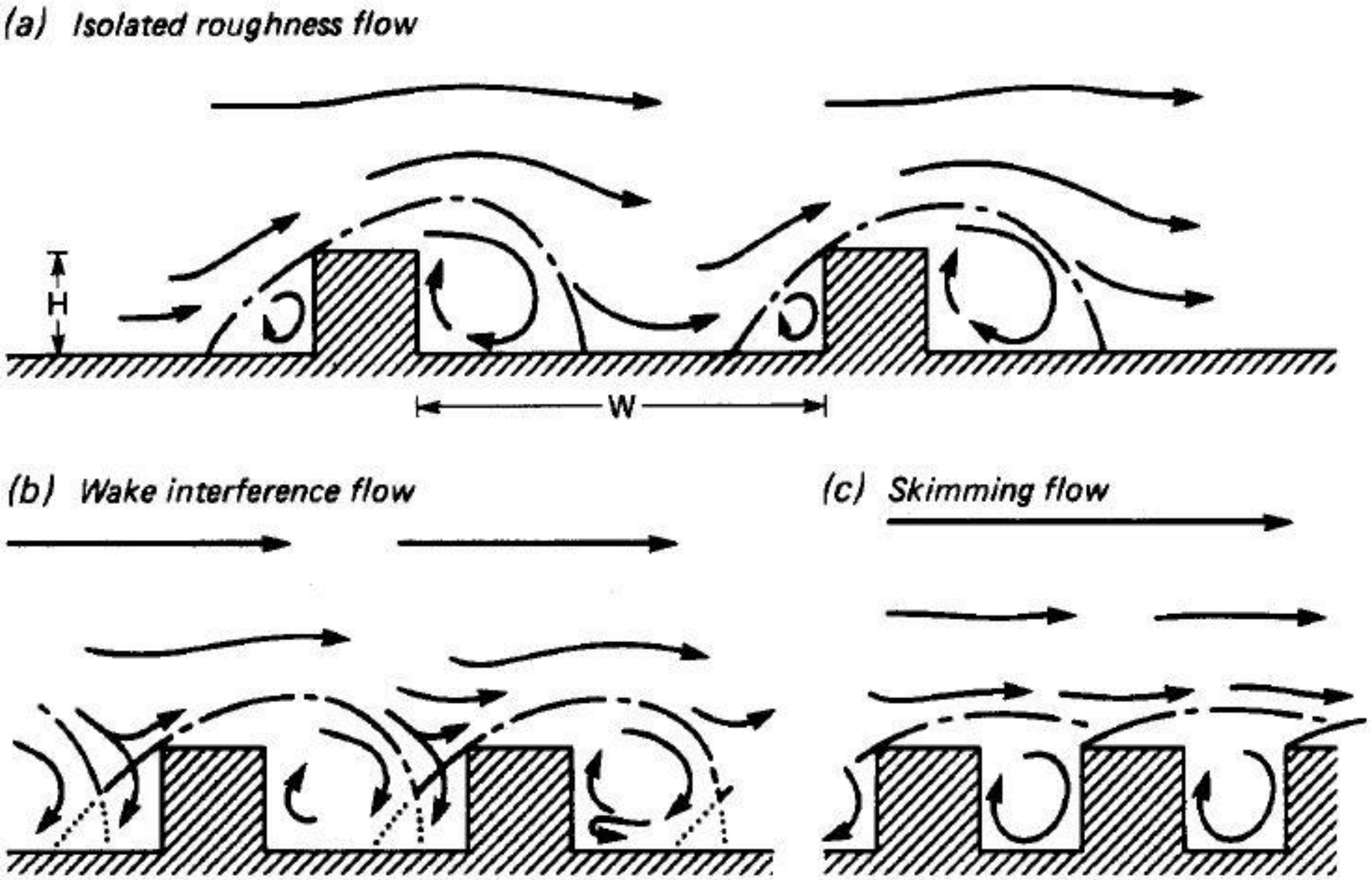
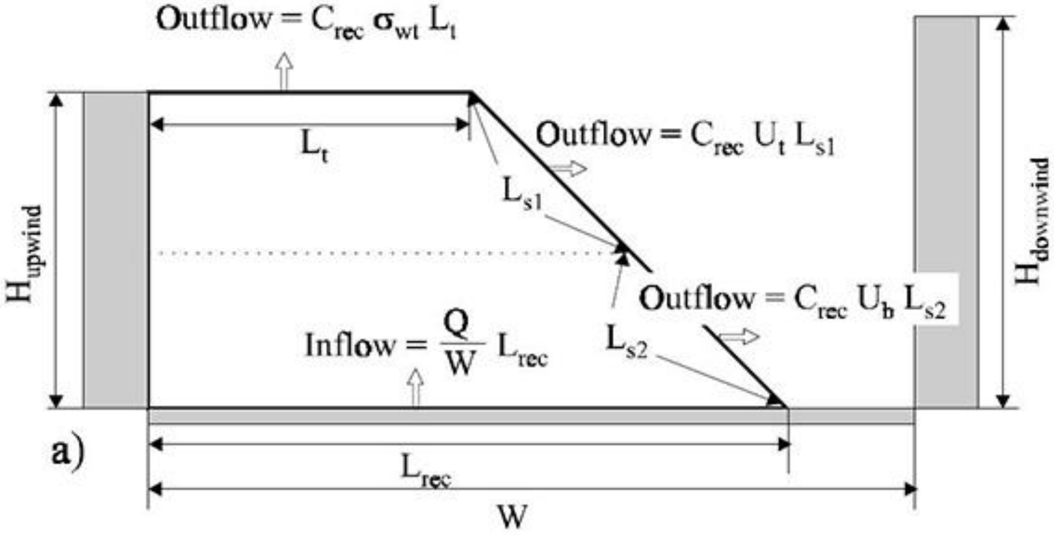


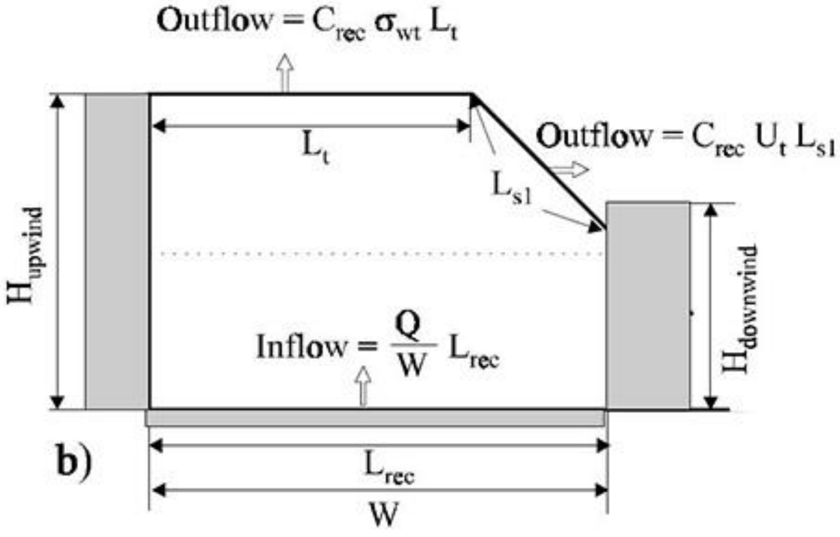
Fig. 1. The flow regimes associated with air flow over building arrays of increasing H/W.

1. Motivation

- This concept was used in models like OSPM (Berkowicz *et al.*, 1997)
- The recirculation zone is represented by a trapezium



wide canyon



narrow canyon

- The base is two times the upwind building height, $L_{rec} = 2 \cdot H_{upwind}$
- Recirculation zone is the 3rd most sensitive factor (Ottosen *et al.*, 2014)

2. Hypothesis

- Is there any quasi-universal expression for the “recirculation zone”, that could expand the applicability of the typical street canyon models?

- The goals are to study the recirculation zone formation
  - ➢in irregular street canyons
  - ➢in arbitrary wind direction
  - ➢variable meteorology
  - ➢scale of street canyons

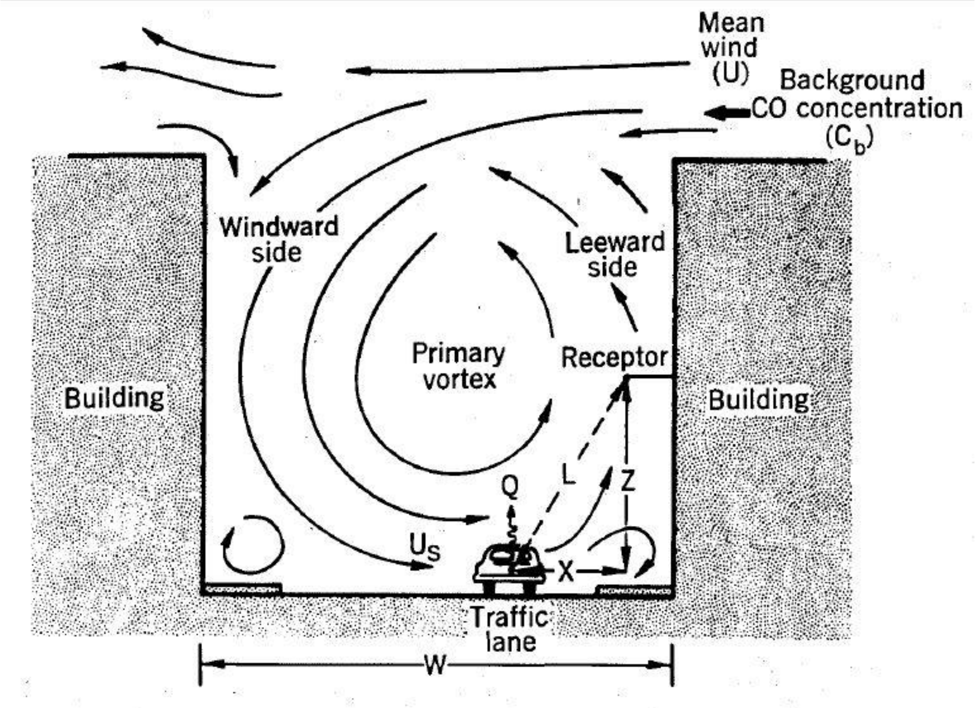
- Not intended to repeat the flow pattern study in street canyons, but improve the approach in empirical models.

3. Methodology

1. Review of the recirculation zone
2. General setup of CFD simulations
3. Validation of the CFD simulation setup
4. Use of vortex identification methods, to determine the vortex structure

3. Methodology: Review

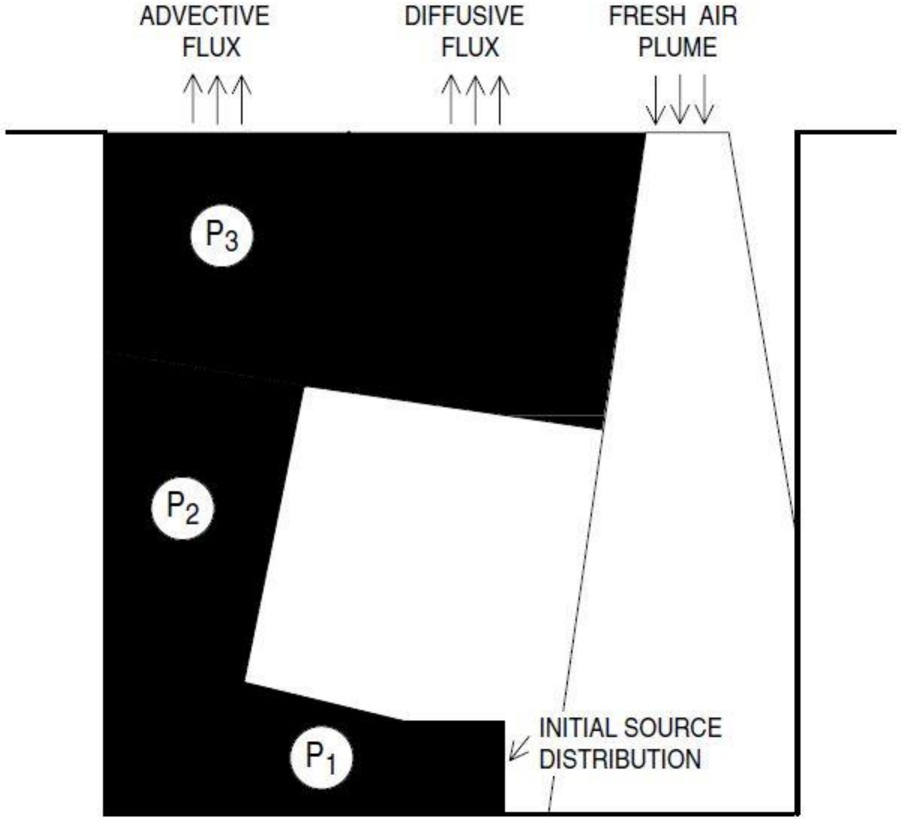
- Small scale street canyon dispersion models
- STREET-SR or ARPAC-1A (Johnson *et al.*, 1973)



- ➢ The first notion of recirculation
- ➢ Two different concentrations for upwind and downwind receptors
- ➢ Calibration using field data
- ➢ Implicit modelling of the recirculation, through the empirical parameters

3. Methodology: Review

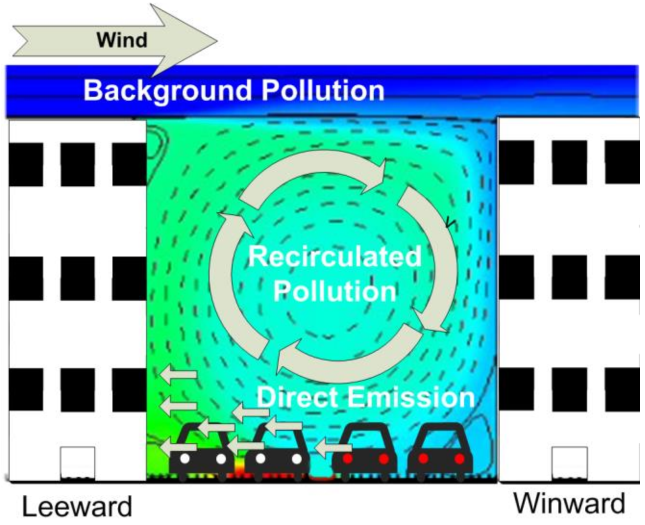
- Canyon Plume Box Model (Yamartino and Wiegand, 1986)

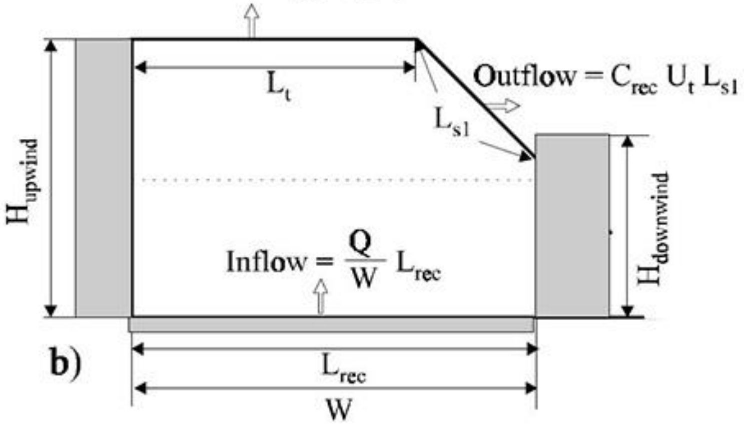


- ➢ Explicit use of a box model for the recirculation
- ➢ It covers the whole street
- ➢ The downwind receptor accounts for the “clean air injection”
- ➢ Calibration of parameters using field and wind tunnel data

3. Methodology: Review

- OSPM (Berkowicz *et al.*, 1997)





➢ Introduced the trapeze shape

➢ Numerical condition, not physical

Other models using similar formulation

➢ AEOLIUS (Buckland, 1998)

➢ ADMS – Urban (Sabatino *et al.*, 2007)

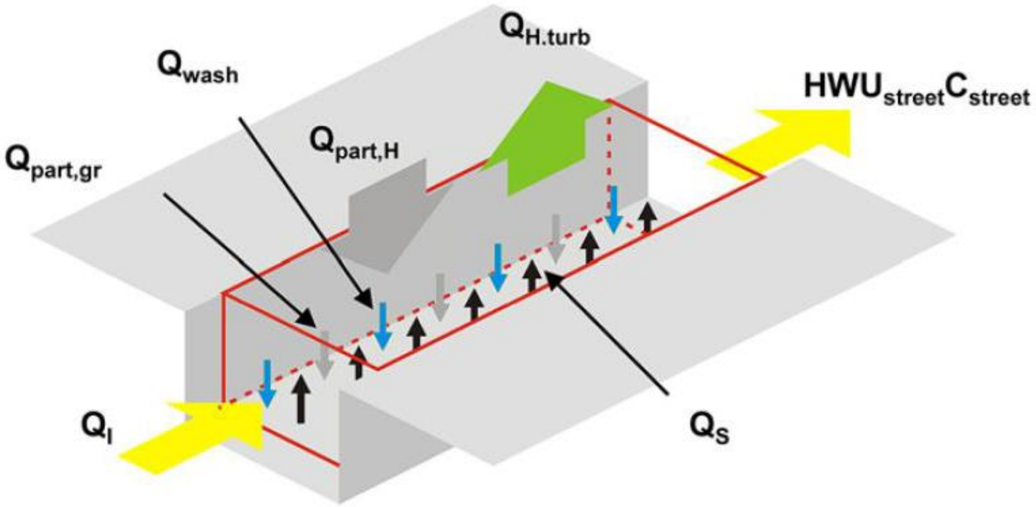
➢ $L_{rec} = 3 \cdot H_{upwind}$ (Harman *et al.*, 2004)

➢ $L_{rec} = 2 \cdot H_{upwind}$ (Yang and Shao, 2006)

➢ $L_{rec} = 3 \cdot H_{upwind}$ (Cherin *et al.*, 2015)

3. Methodology: Review

- SIRANE (Soulhac *et al.*, 2011)



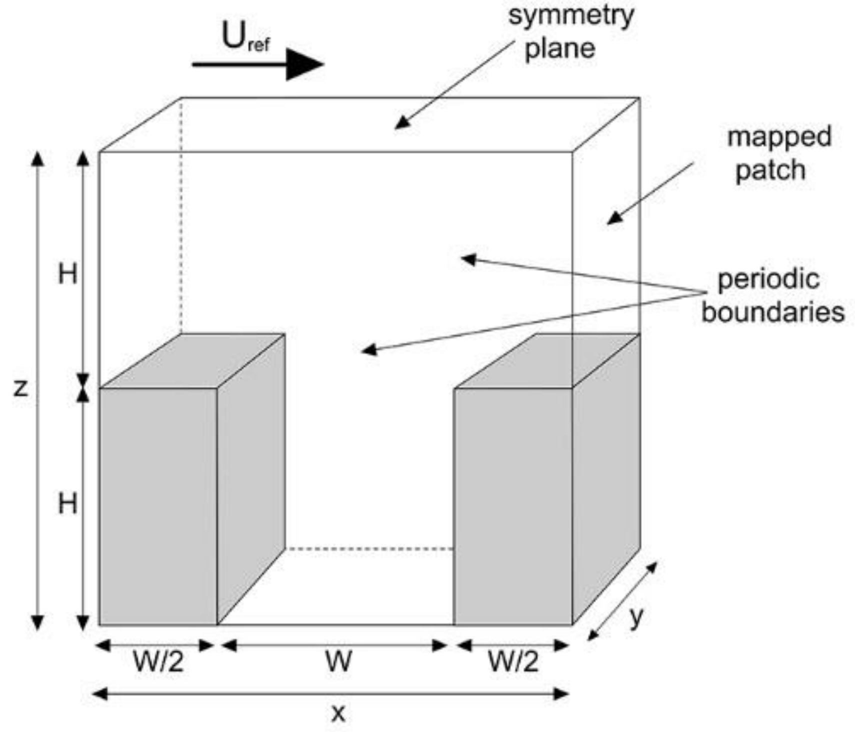
- ➢ Uniform concentrations in each street segment
- ➢ Mass balance with the street intersections and the atmosphere
- ➢ For H/W ≥ 1/3: street canyon
- ➢ For H/W < 1/3: open terrain

3. Methodology: Review

Available data from wind tunnel experiments and CFD simulations

- Irregular streets, wind tunnel (Addepalli and Pardyjak, 2013, 2014)
- Thermal effects, wind tunnel (Allegrini *et al.*, 2013)
- Thermal effects, CFD (Allegrini *et al.*, 2014)
- Thermal effects, field experiments (Dallman *et al.*, 2014)
- Thermal effects, field experiments (Idczak *et al.*, 2007)
- Roof shapes, CFD (Huang *et al.*, 2014)
- Roof shapes, CFD (Takano and Moonen, 2013)
- Roof shapes, wind tunnel (Kellnerová *et al.*, 2012)

3. Methodology: Simulation setup



OpenFOAM

The Open Source CFD Toolbox

- Large Eddy Simulation: large eddies are solved, small are modelled
- Transient solution of NS equations
- Fine mesh: 100 cells per 10 m
- Standard Smagorinsky model for the subgrid scales

3. Methodology: Validation

- CFD results against experiments from (Li, 2008)

- Aspect ratio H/W = 1

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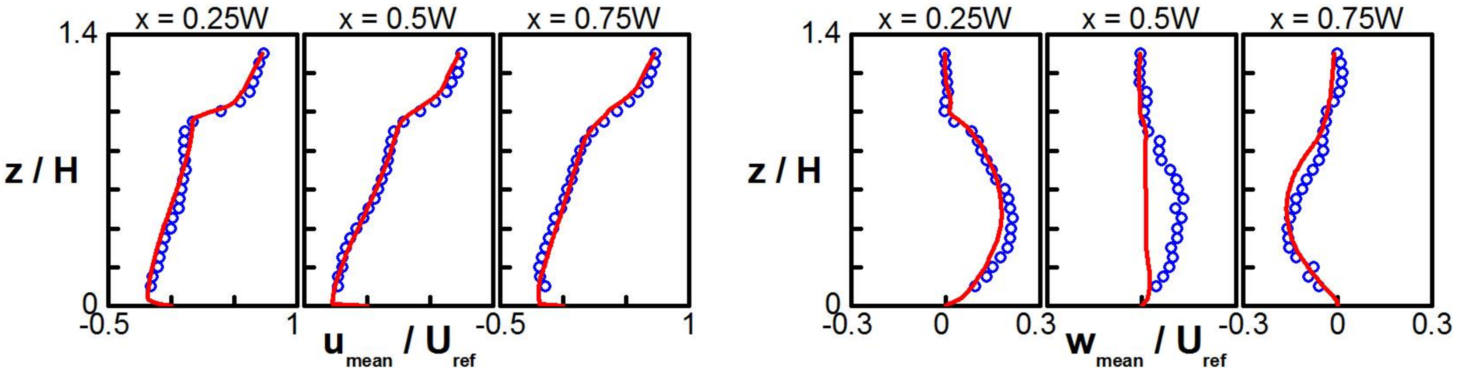

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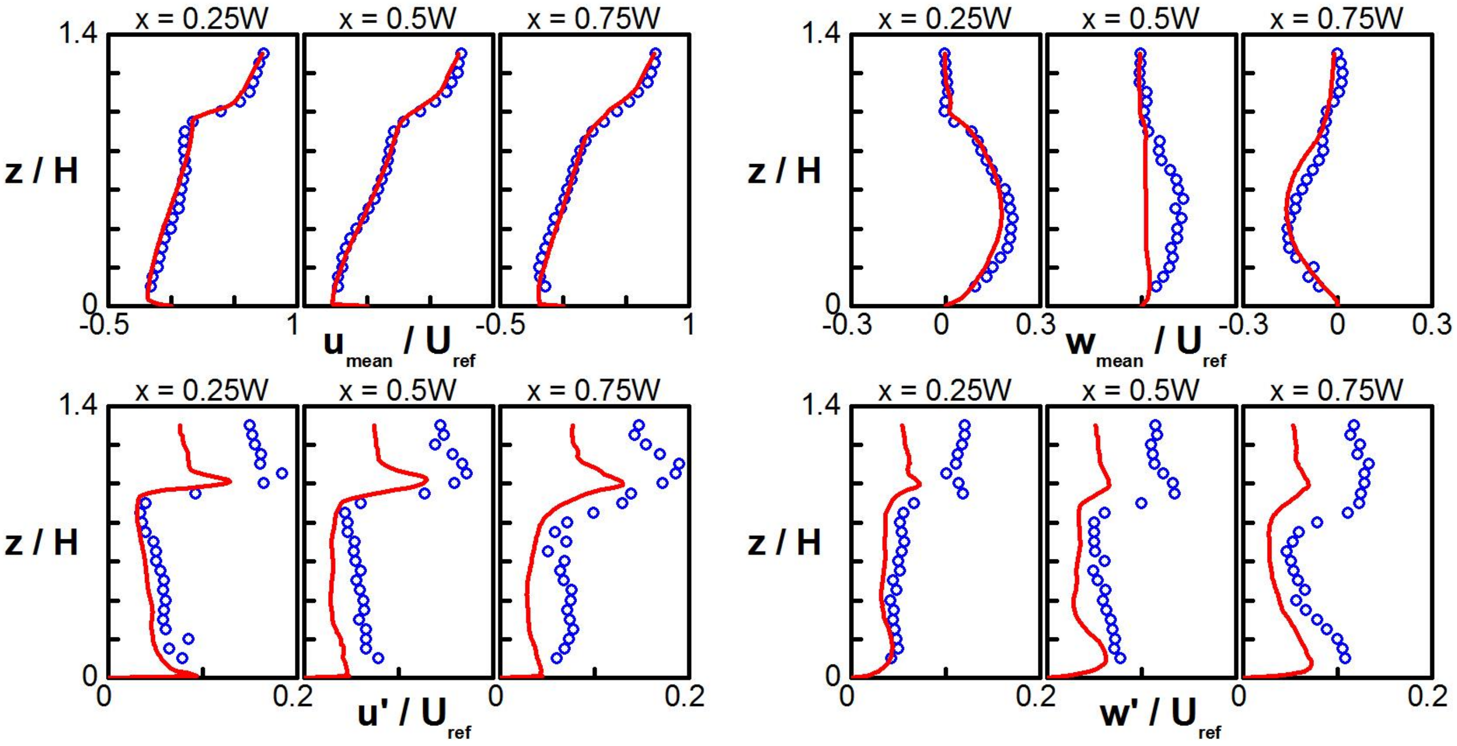


- Aspect ratio H/W = 1, excellent agreement

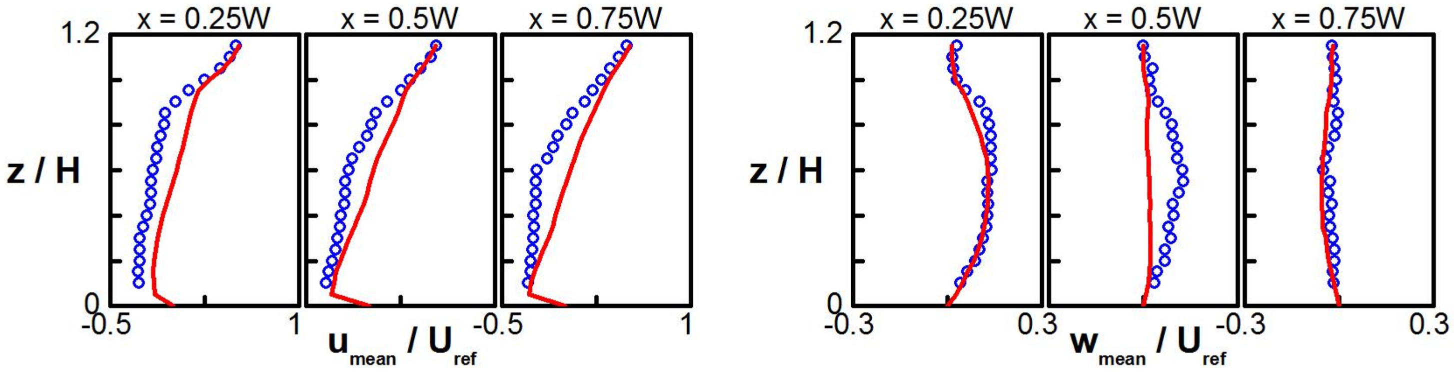
3. Methodology: Validation

- CFD results against experiments from (Li, 2008)

- Aspect ratio H/W = 0.5

3. Methodology: Validation

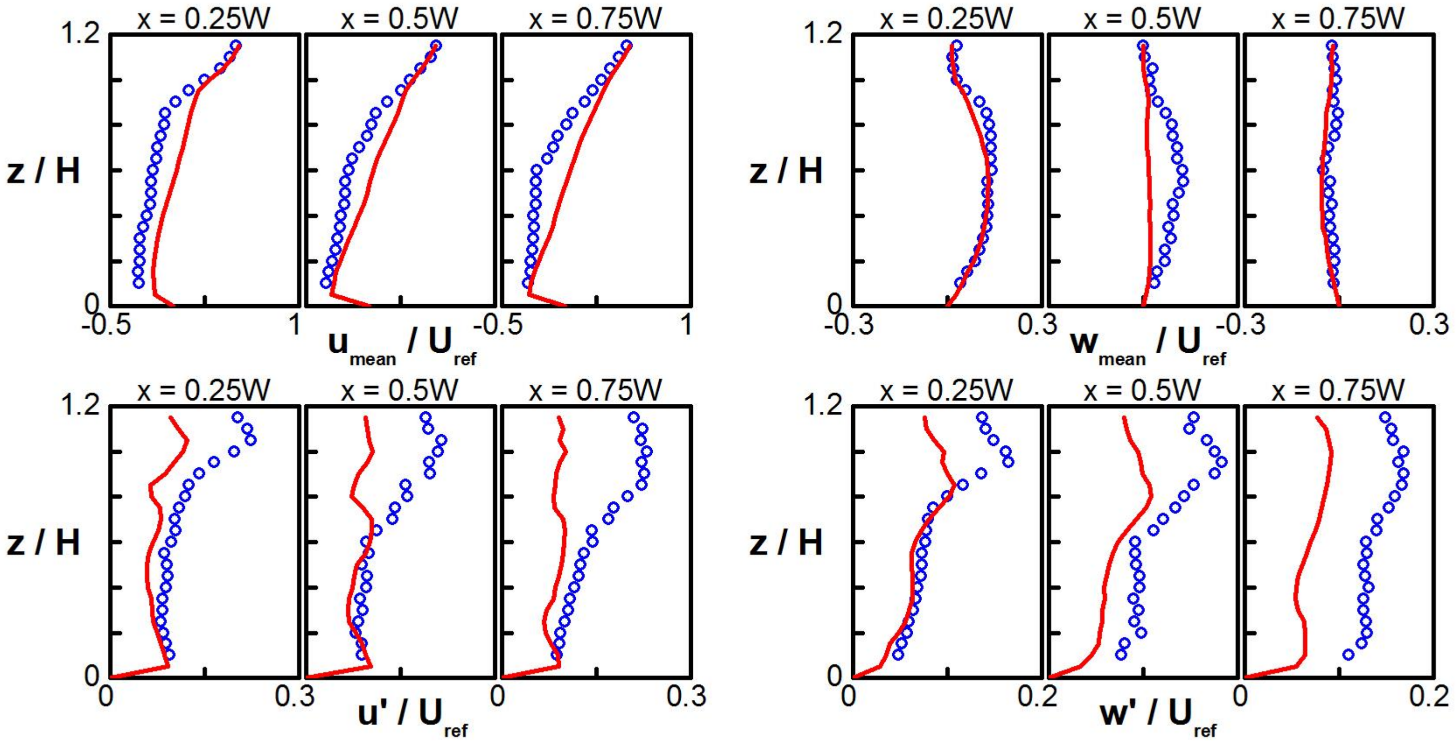
- CFD results against experiments from (Li, 2008)



- Aspect ratio H/W = 0.5

3. Methodology: Validation

- CFD results against experiments from (Li, 2008)

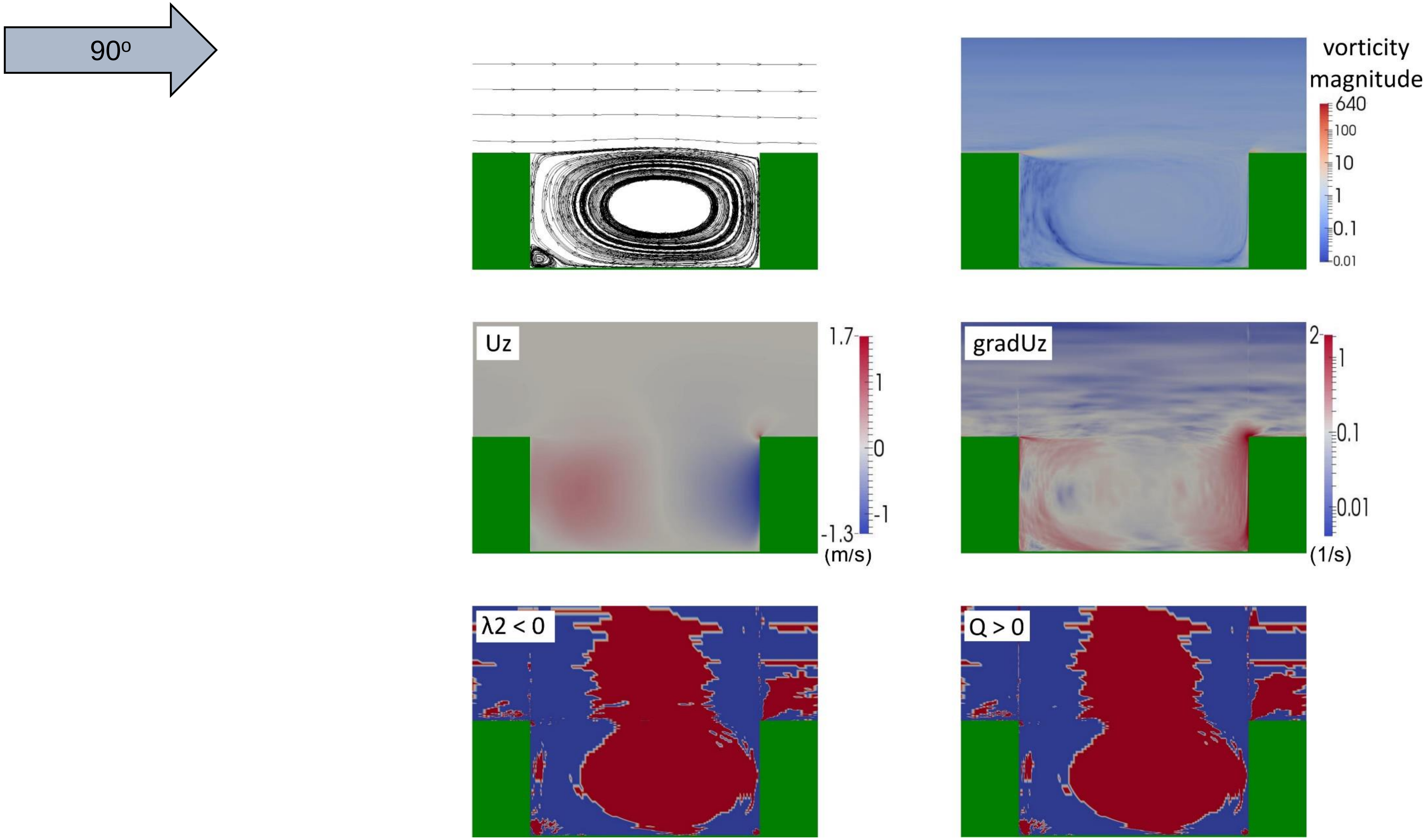


- Aspect ratio H/W = 0.5, fair agreement

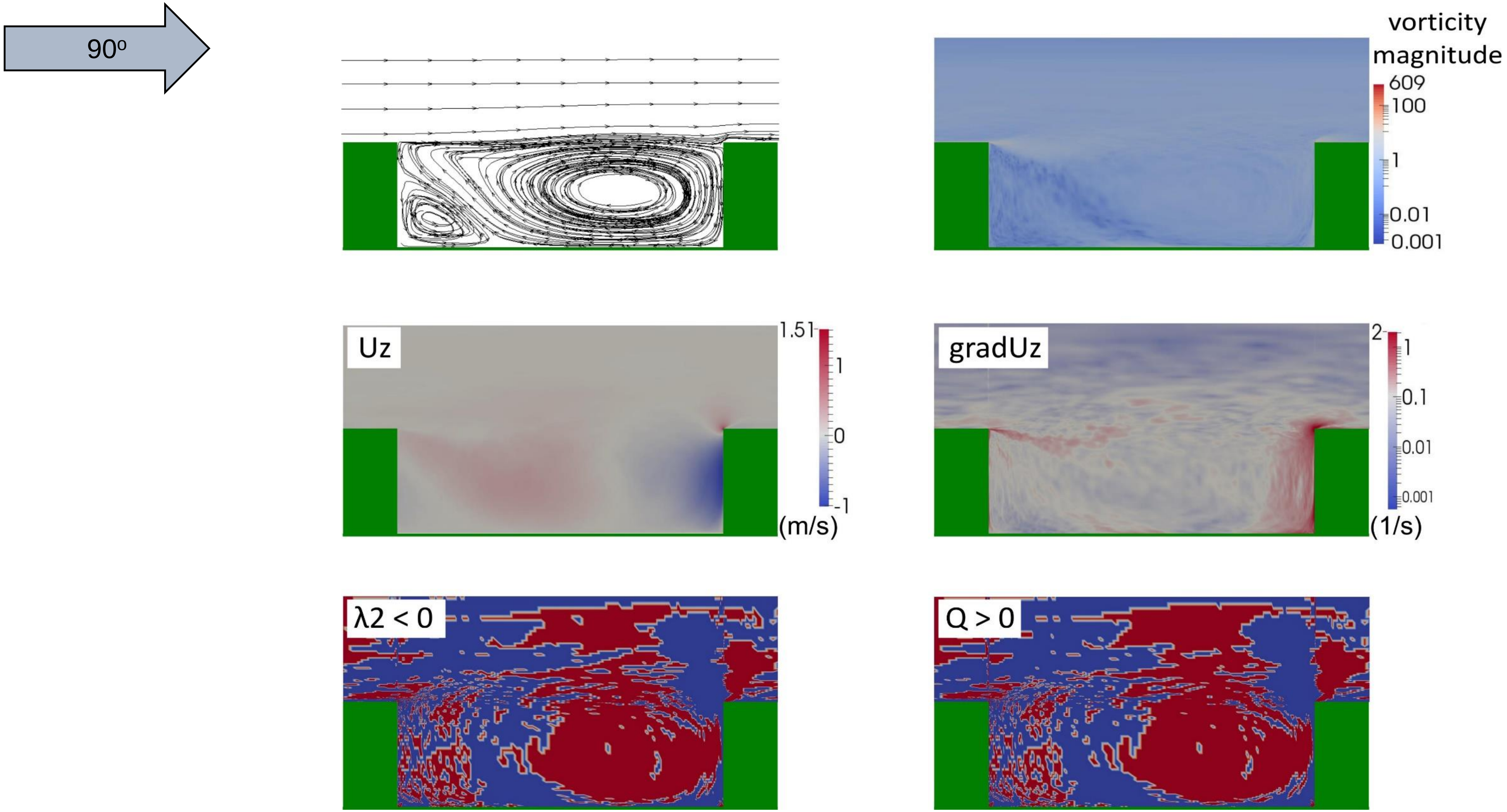
3. Methodology: Vortex identification

- Use of **vortex identification** methods
- **Intuition**: where there is a vortex, there is a recirculation zone
- **Universal**: analyze the whole velocity field
  - streamlines, tangent to the velocity vector curve at all points
- **Local**: analyze the $\nabla\mathbf{u}$ at a finite number of points
  - $\lambda_2 < 0$ (Jeong and Hussain, 1995)
    - $\nabla\mathbf{u}$ is decomposed in symmetric **S** and antisymmetric **Ω**
    - second largest eigenvalue of $\mathbf{S}^2 + \mathbf{\Omega}^2$
  - $Q > 0$ (Hunt et al., 1988),
    - second invariant of $\frac{1}{2}[\|\mathbf{\Omega}\|^2 - \|\mathbf{S}\|^2]$, $\|\mathbf{S}\|=[tr(\mathbf{S}\mathbf{S}^T)]^{1/2}$, $\|\mathbf{\Omega}\|=[tr(\mathbf{\Omega}\mathbf{\Omega}^T)]^{1/2}$
  - vorticity, $\vec{\omega} \equiv \nabla \times \vec{u}$

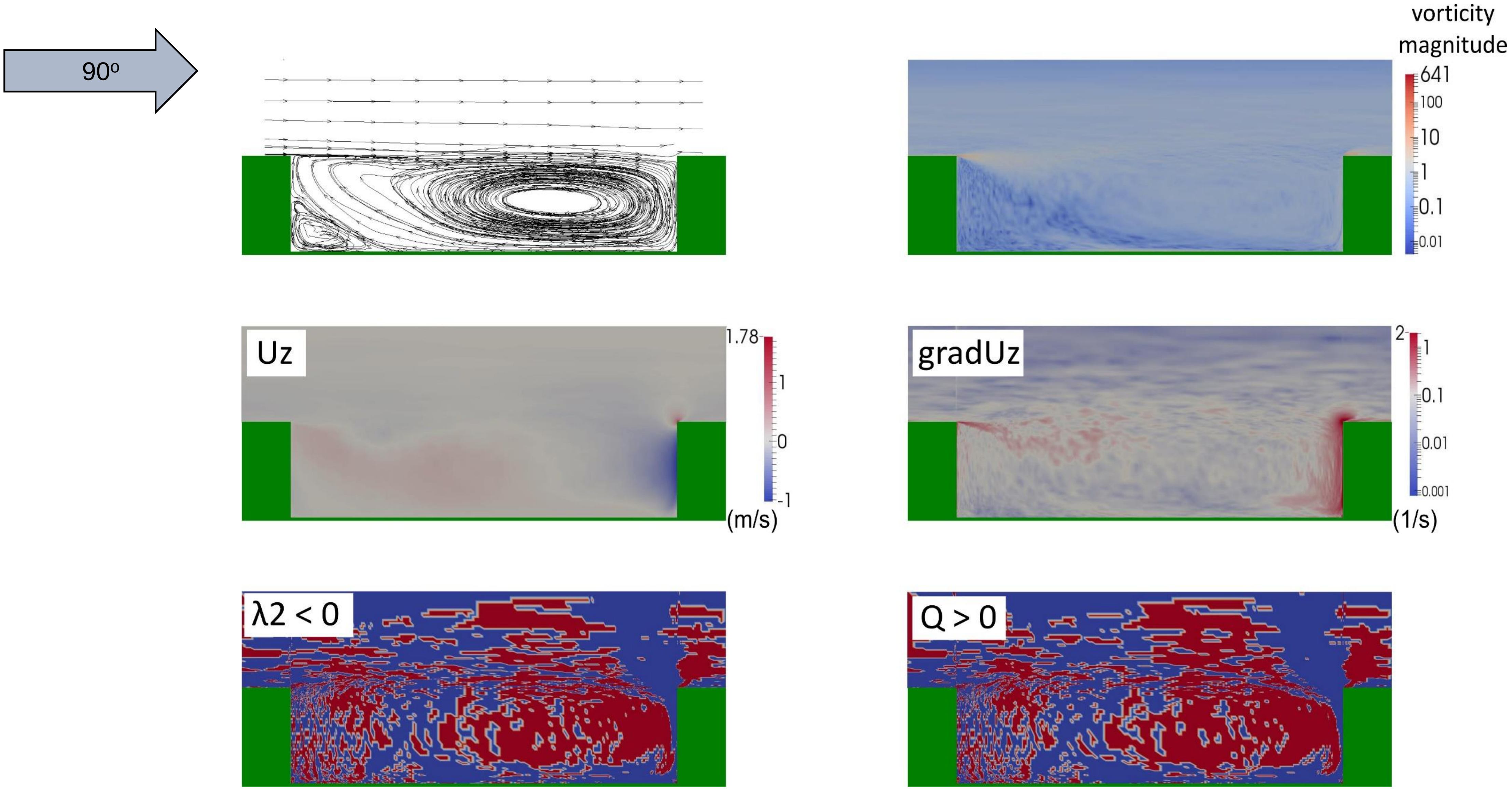
4. Preliminary results: aspect ratio = 1 / 2



4. Preliminary results: aspect ratio = 1 / 3



4. Preliminary results: aspect ratio = 1 / 4



5. Further work

Until now

- Application of the detection methods highlighted the big vortices
- No new insight to the size of the recirculation zone

Further steps of the study

- Pollutant dispersion as an indicator for the recirculation zone
- Irregular street canyons
- Arbitrary wind direction
- Effect of the wind speed, Reynolds number
- Effect of heated street facets
- Effect of the scale (eg. AR=1, when H=10m or 20m)

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