17th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes

9-12 May 2016, Budapest, Hungary

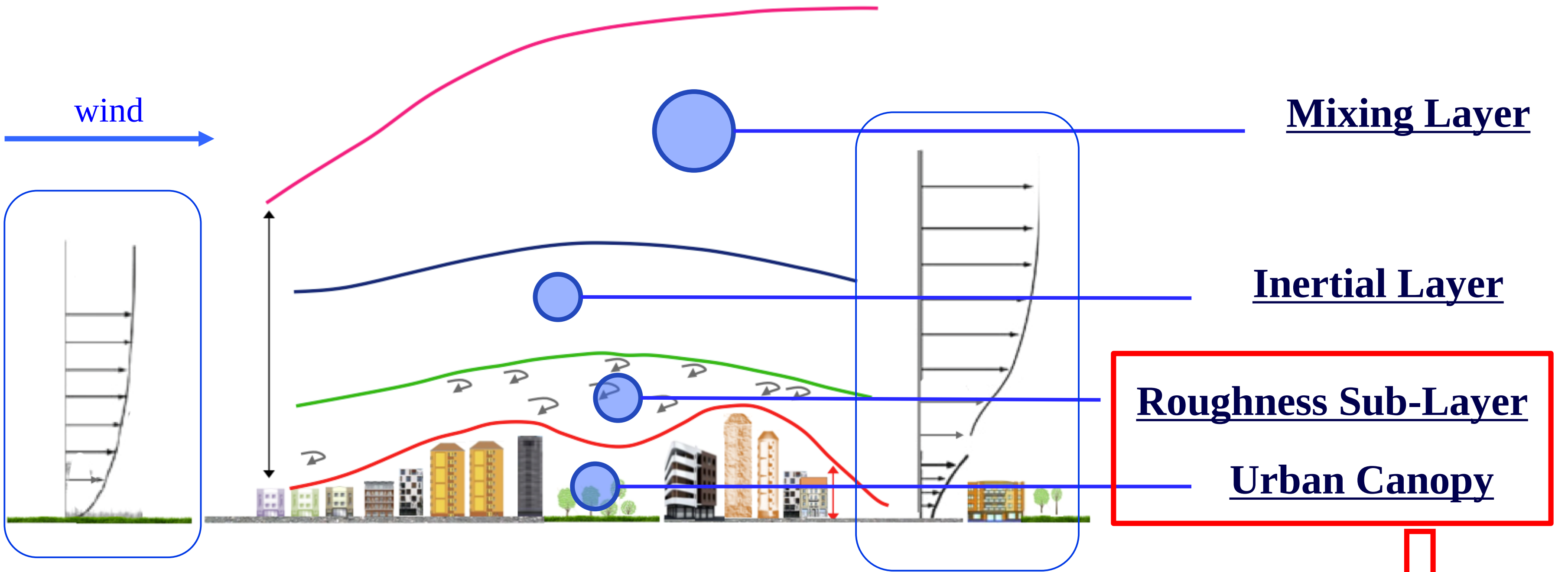
Session 15 - Topic: “Modelling air dispersion and exposure to accidental releases”

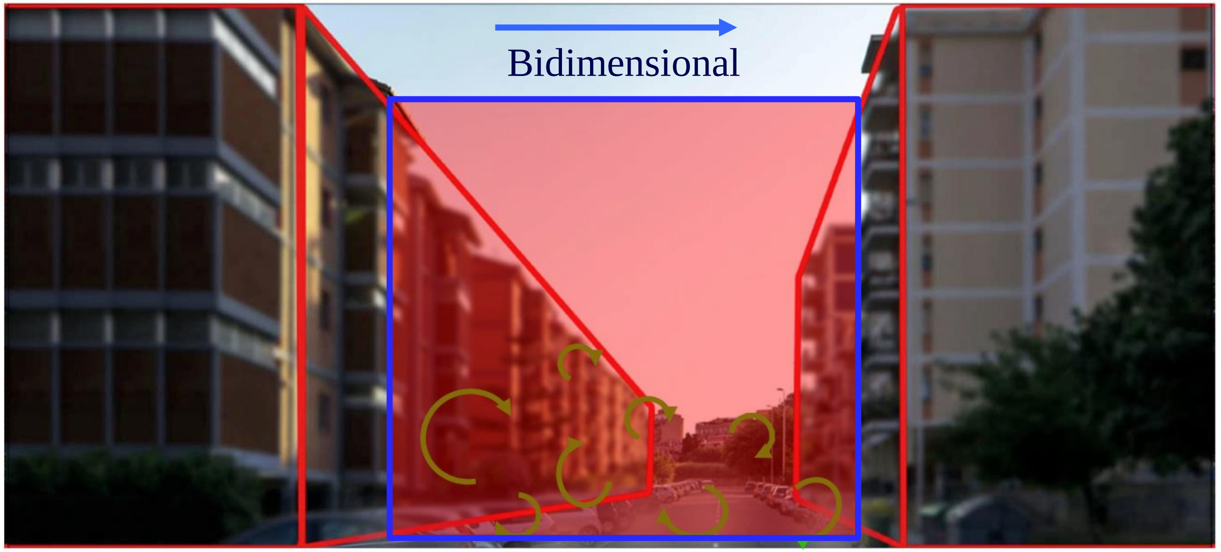
THE AIR QUALITY IN TWO-DIMENSIONAL URBAN CANYONS WITH GABLE ROOF BUILDINGS: A NUMERICAL AND LABORATORY INVESTIGATION

Simone Ferrari[1], Maria Grazia Badas[1], Michela Garau[1], Alessandro Seoni[1] and Giorgio Querzoli[1]
(1) DICAAR - Department of Civil Engineering, Environmental and Architecture
Section of Hydraulic Engineering, Università di Cagliari, Cagliari, Italy

Budapest, Hungary, May 11th 2016

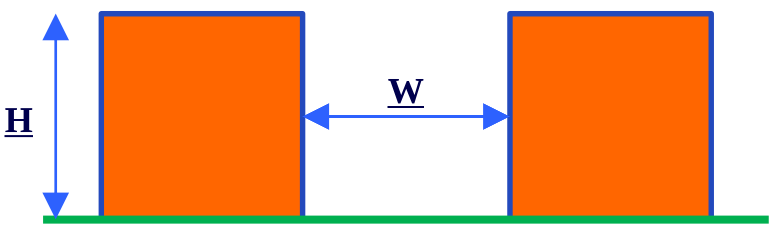
INTRODUCTION TO PHYSICAL PHENOMENON (URBAN CANYON)



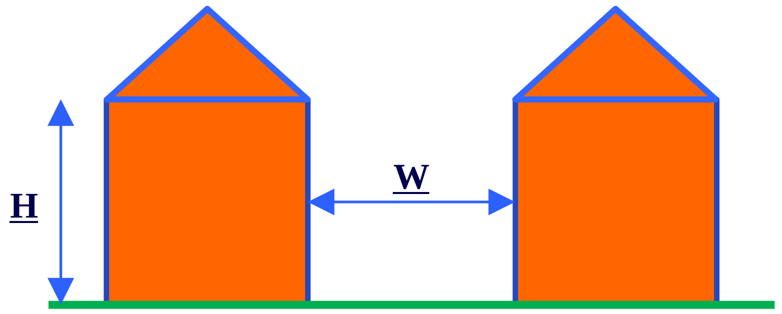


INTRODUCTION TO PHYSICAL PHENOMENON (URBAN CANYON)

Aspect ratio: AR = W/H

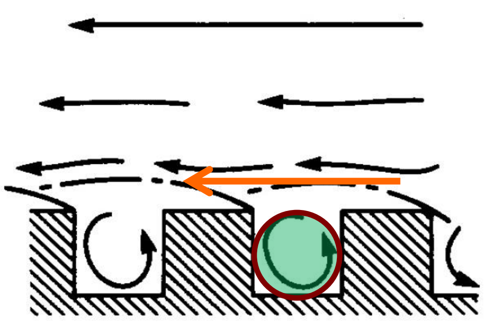


FLAT ROOFS

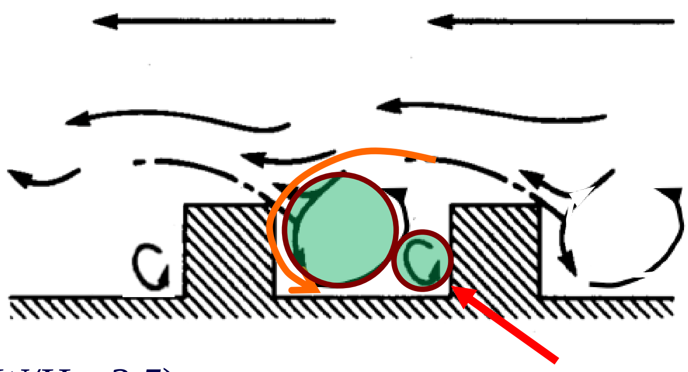


DUAL-PITCHED ROOFS

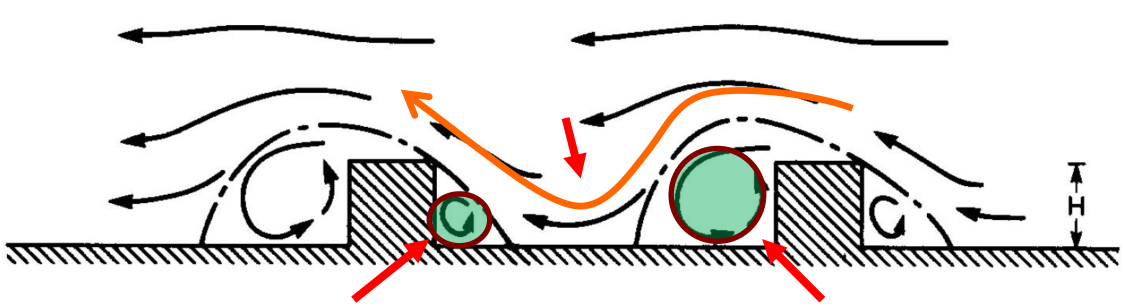
Skimming flow (*W/H* <*1.5*)



Wake interference (1.5<*W/H* <*3.5*)



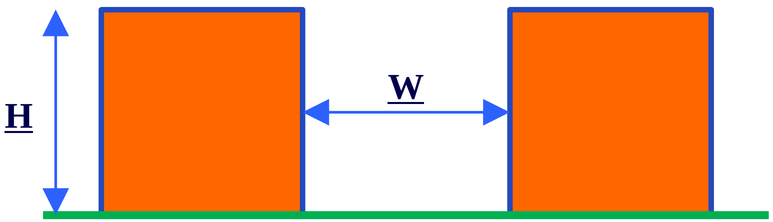
Isolated Roughness (*W/H* >*3.5*)



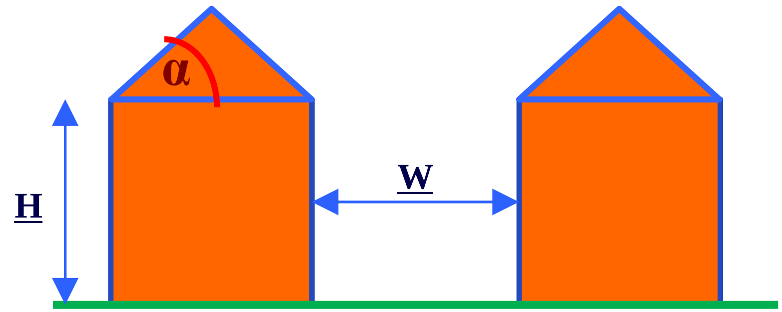
(Oke 1988)

URBAN CANYON: EXPERIENCES AND OBJECTIVES

Aspect ratio: AR = W/H



FLAT ROOFS



DUAL-PITCHED ROOFS

FOCUS

a) Are simple Numerical simulations able to reproduce Laboratory experiments?

b) How the Dual-pitched roofs could influence the *air exchanges* in street canyons?

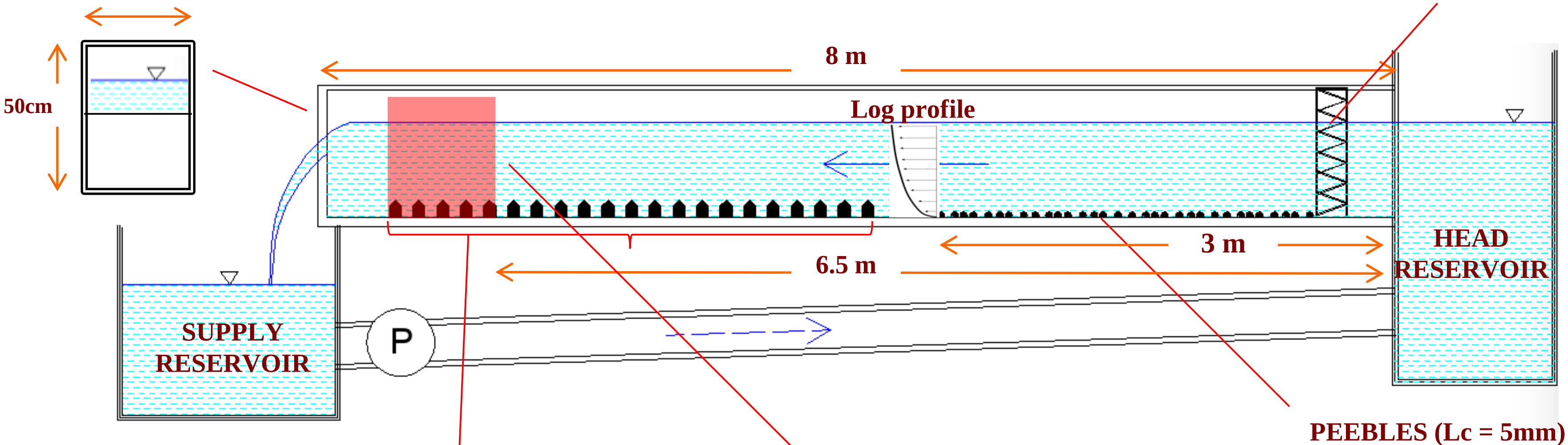
[$\alpha = 0°$, $45°$]

c) How different Aspect Ratios could modify the flow regimes between inner and outer flows?

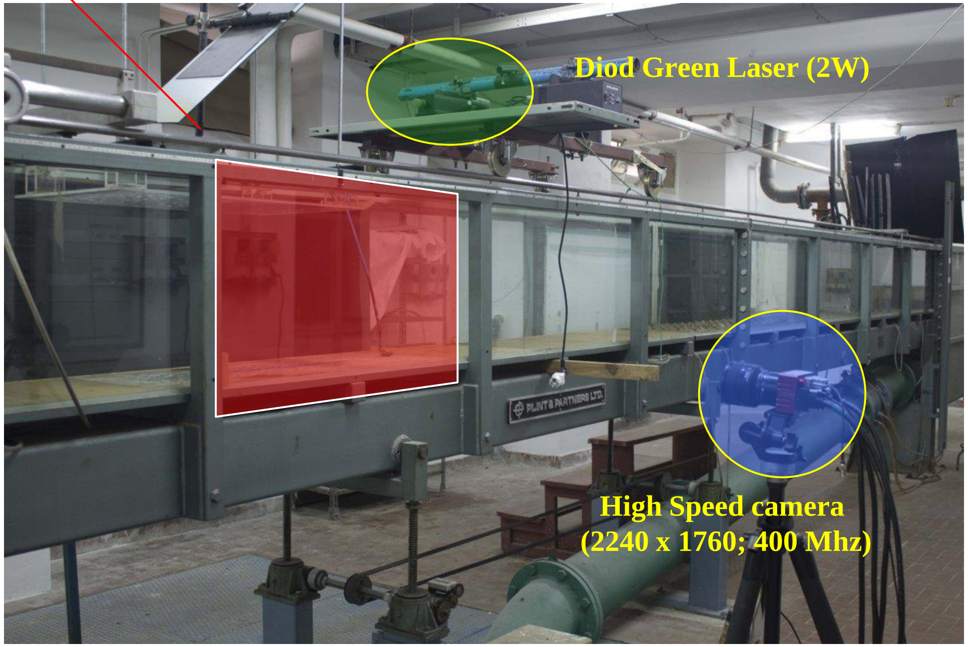
[AR = 1, 2, 3, 4, 6]

EXPERIMENTAL SET-UP AND MEASUREMENT TECHNIQUE

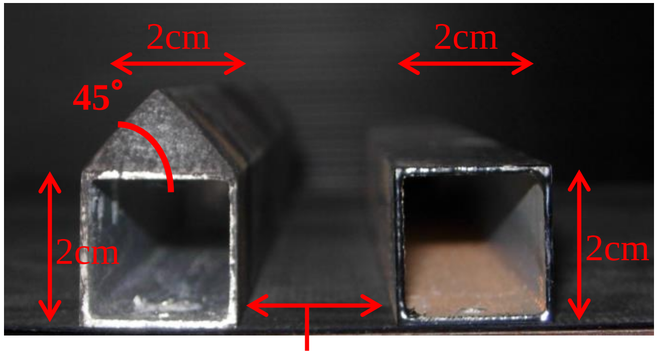
CLOSED-LOOP WATER CHANNEL

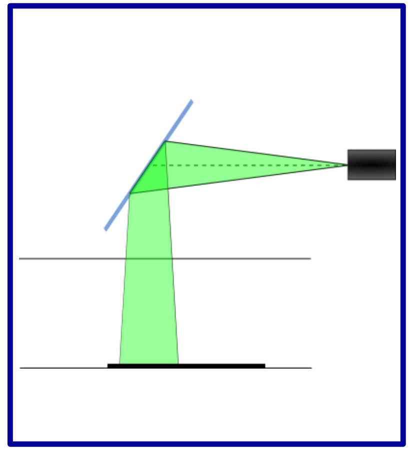


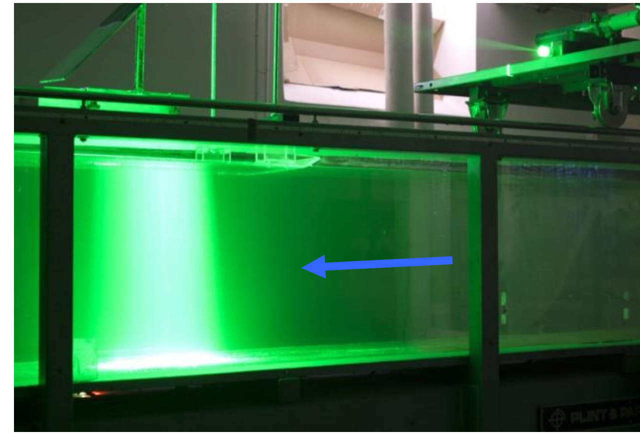
ARRAY OF 20 BUILDINGS

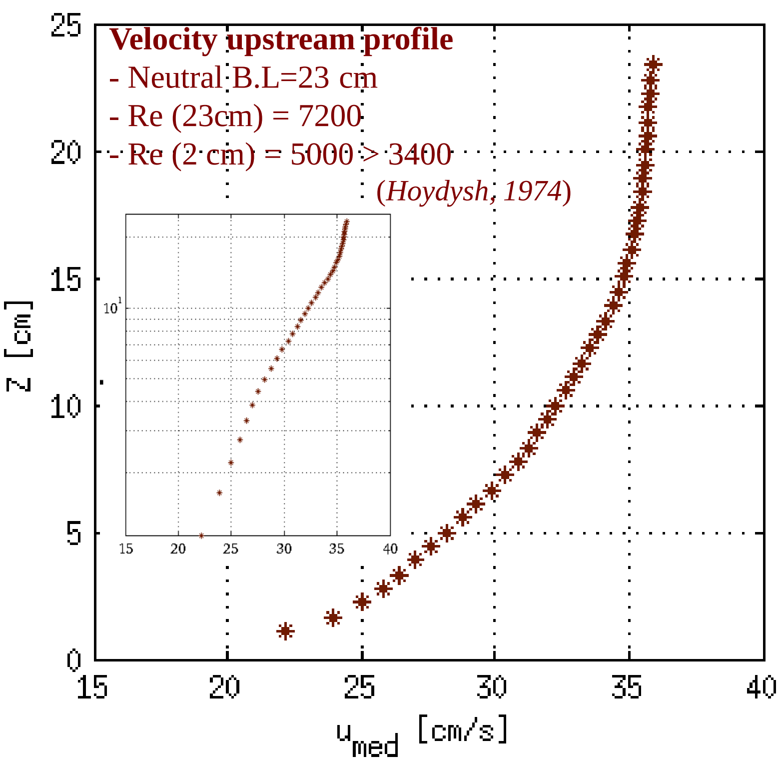


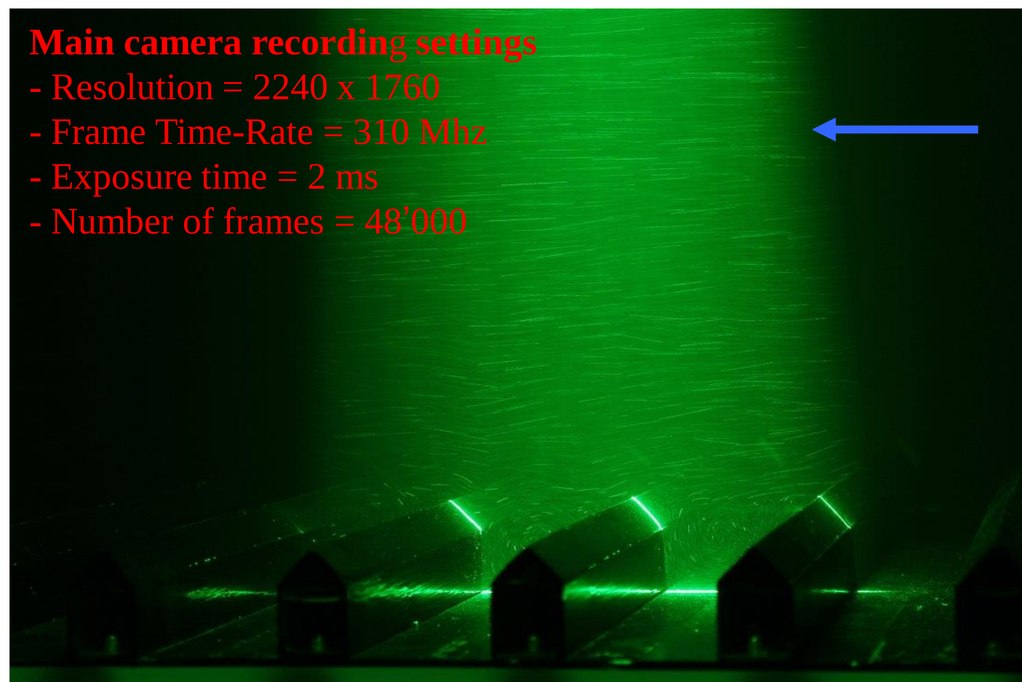
EXPERIMENTAL SET-UP AND MEASUREMENT TECHNIQUE





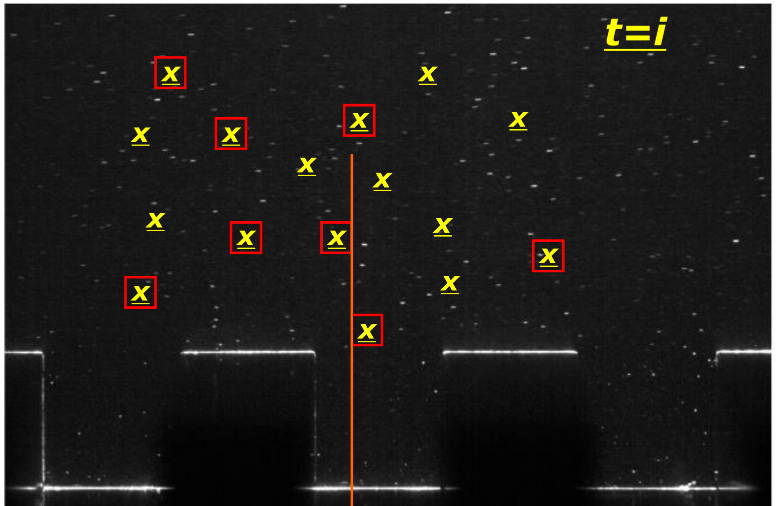


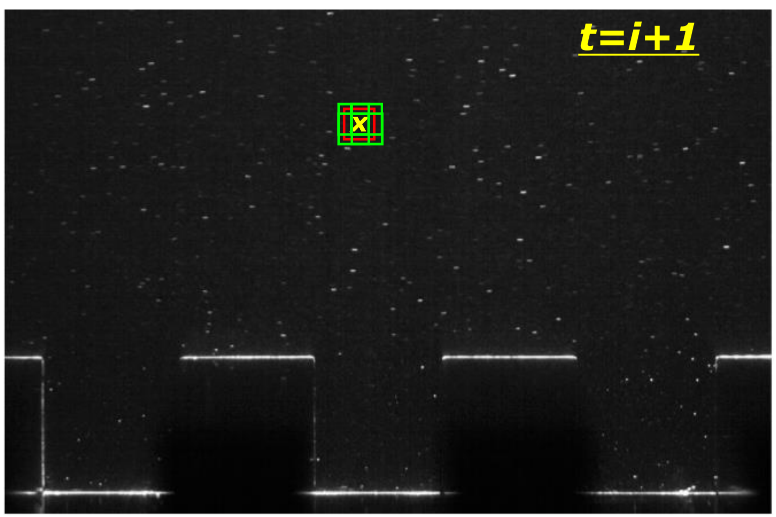




FEATURE TRACKING VELOCIMETRY (FTV)

FTV (Feature Tracking Velocimetry) compares windows only where the motion detection may be successful: tracking of regions with high luminosity gradients (i.e. features).





Feature identification (Harris corner detection)

↓

Selection of the best features (cornerness)

↓

Comparison of a window centered on a feature in image i with windows around its position in the image i+1 within a range of displacements (dx, dy), with a measure of the dissimilarity computed using the robust (insensitive to outliers) Lorentzian estimator (Black & Anandan, 1991)

↓

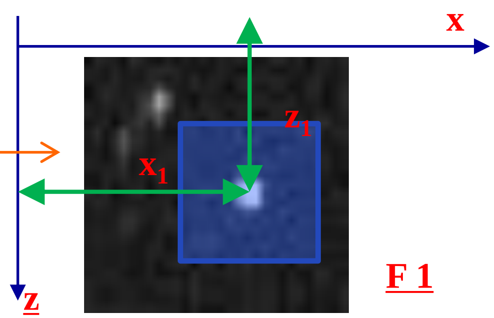
Displacement minimizing the dissimilarity

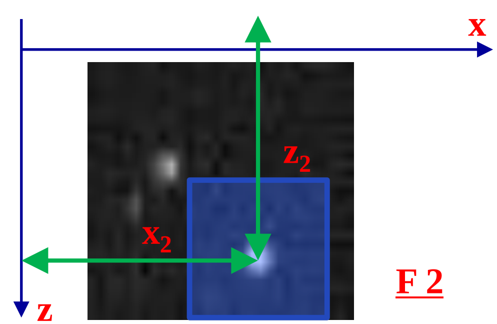
↓

Calculating velocity

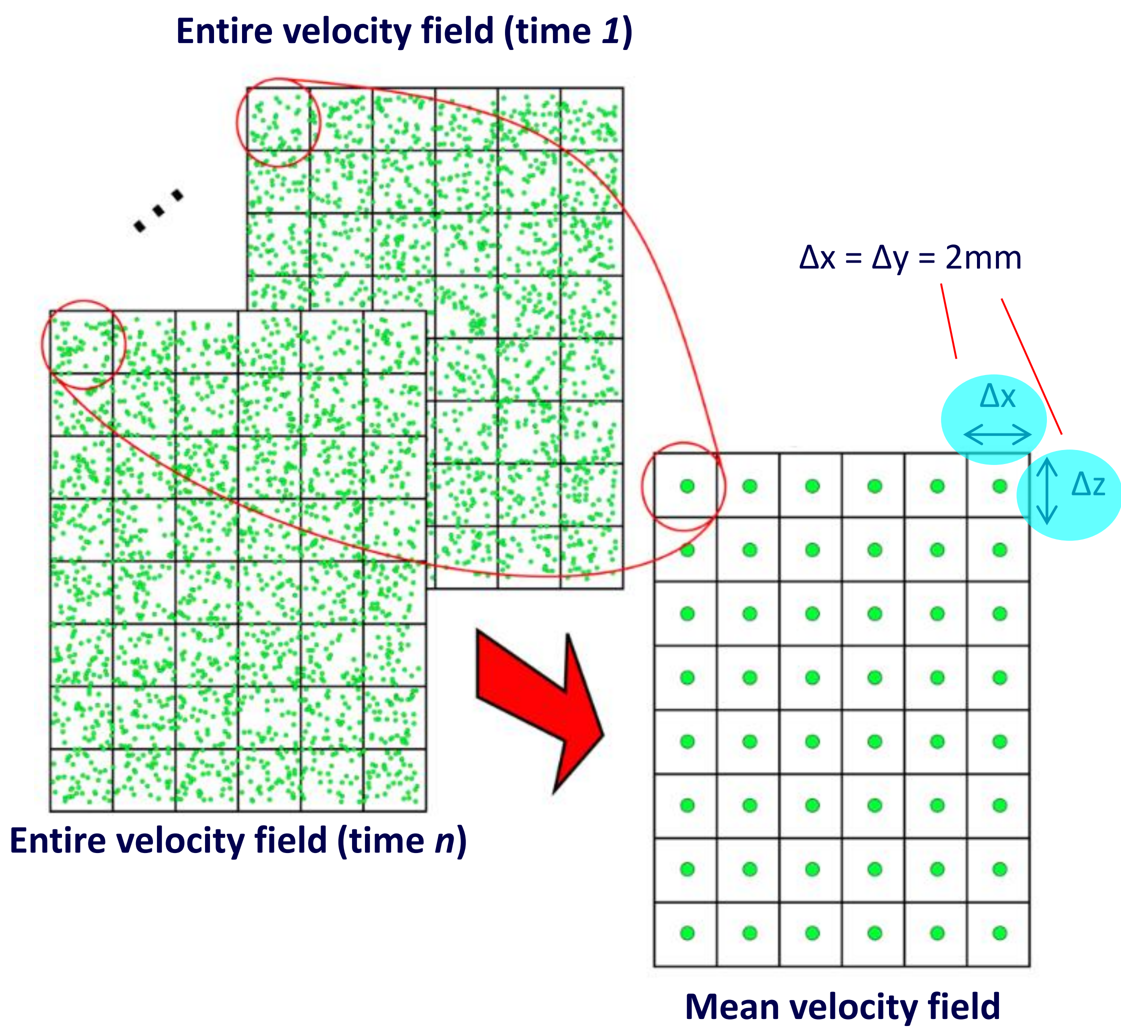
↓

Validation with an algorithm based on Gaussian filtering of first neighbors (defined by the Delaunay triangulations).





MEAN FIELD CALCULATION



Calculation of elementar components in each cell (*i,j*), e.g x-axis

Mean velocity

$$\langle u_{ij} \rangle = \frac{1}{N_{val}} \sum_k u_k$$

Velocity variance

$$\langle u'^2 \rangle = \langle u^2 \rangle - \langle u \rangle^2$$

Reynolds stresses

$$\langle u'w' \rangle = \langle u \rangle \langle w \rangle - \langle uw \rangle$$

RANS

Reynolds Averaged Navier-Stokes equations

$$\bar{u}_{i,t} + \bar{u}_j \, \bar{u}_{i,j} = -g z_{,i} - \frac{1}{\rho}\bar{P}_{,i} + \nu \nabla^2 \bar{u}_{i,jj} - \left(\overline{u'_i u'_j}\right)_{,j}$$

K-ε model

$$\tau_{Rij} = 2\nu_t \tau_{ij} - \frac{2}{3} k \delta_{ij}$$

OPEN FOAM

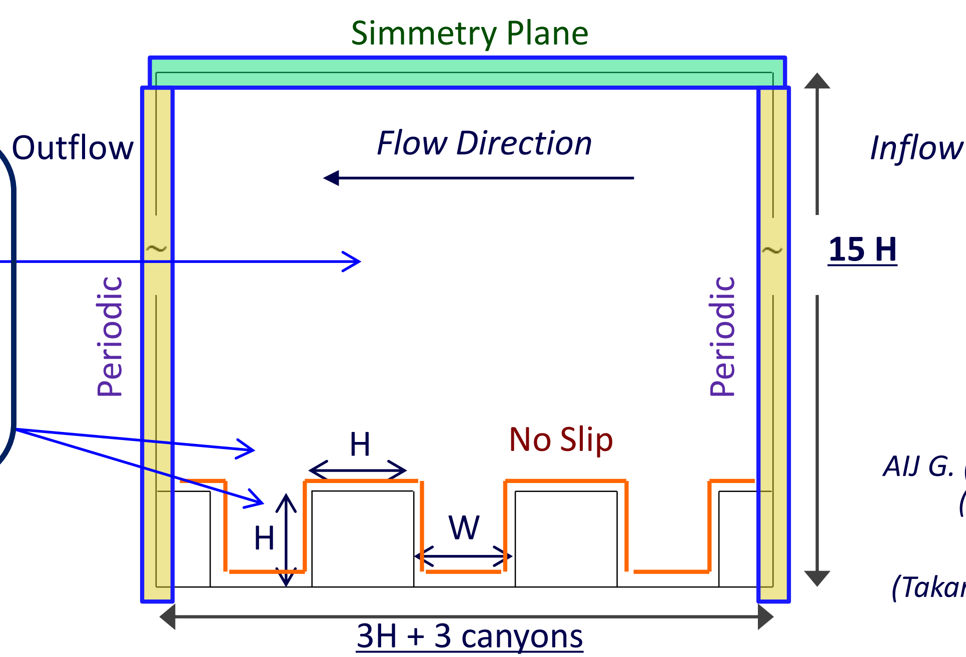
Open Source Field Operation and Manipolation (OpenFOAM) C++Library

(*H. G. Weller, G. Tabor, H. Jasak, C. Fureby, 1998*)

COMPUTATIONAL DOMAIN (bidimensional)

COMPUTATIONAL GRID

- *Starting cell size H/6*
- *Stretching factor = 1.3*
- *On roof and inside canyons H/48*

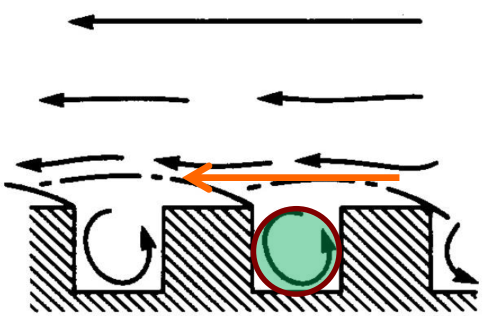


AIJ G. (Tominaga et al.. 2008)
(Blocken, 2015)

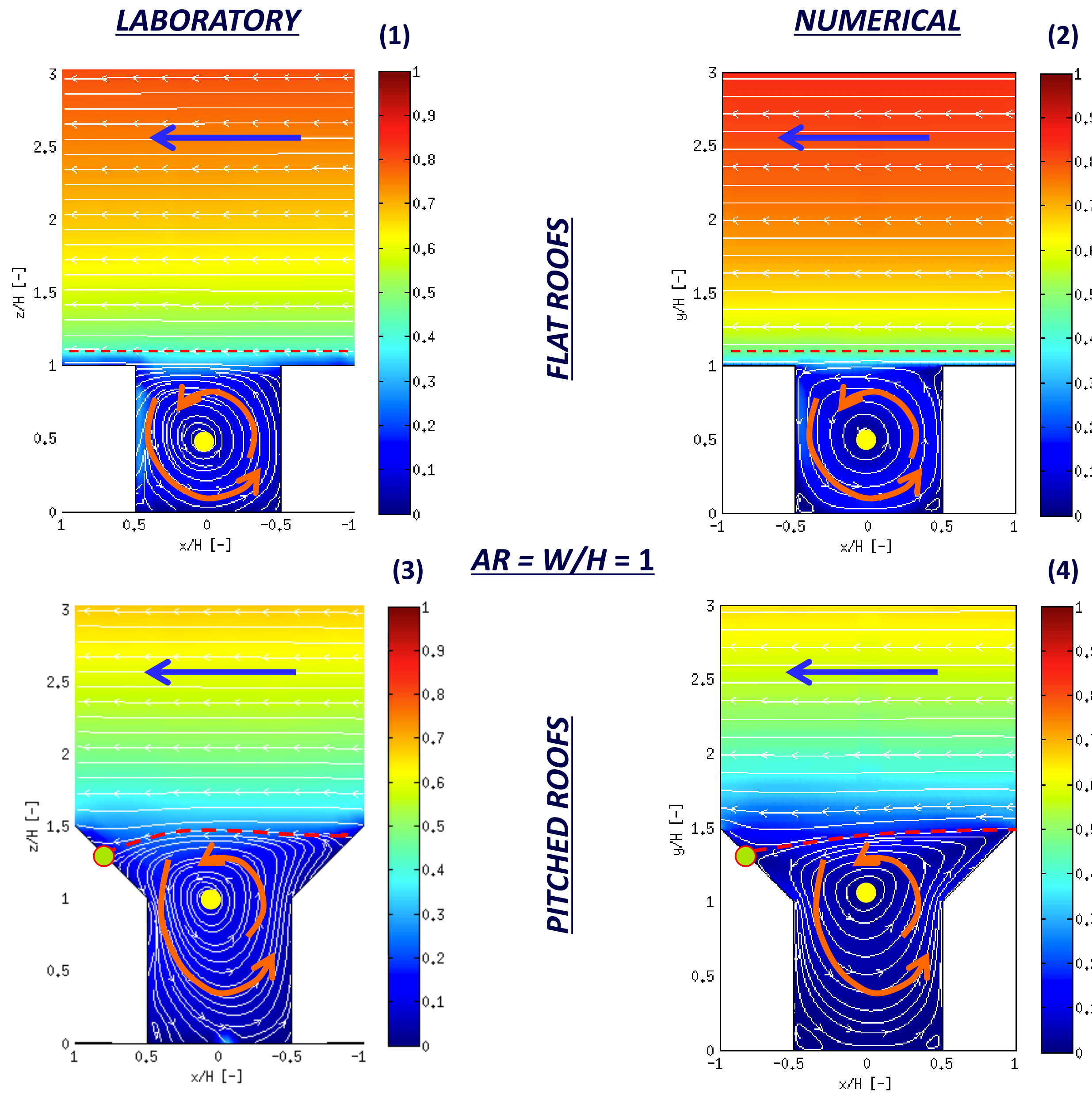
(Takano and Moonen, 2013)

$Re = U_H \, H / \nu = 43200 > 15000$
(Snyder, 1981)

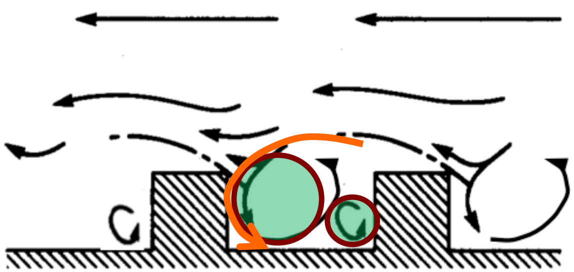
RESULTS: NON-DIMENSIONAL MEAN VELOCITY FIELDS (*u/U*)



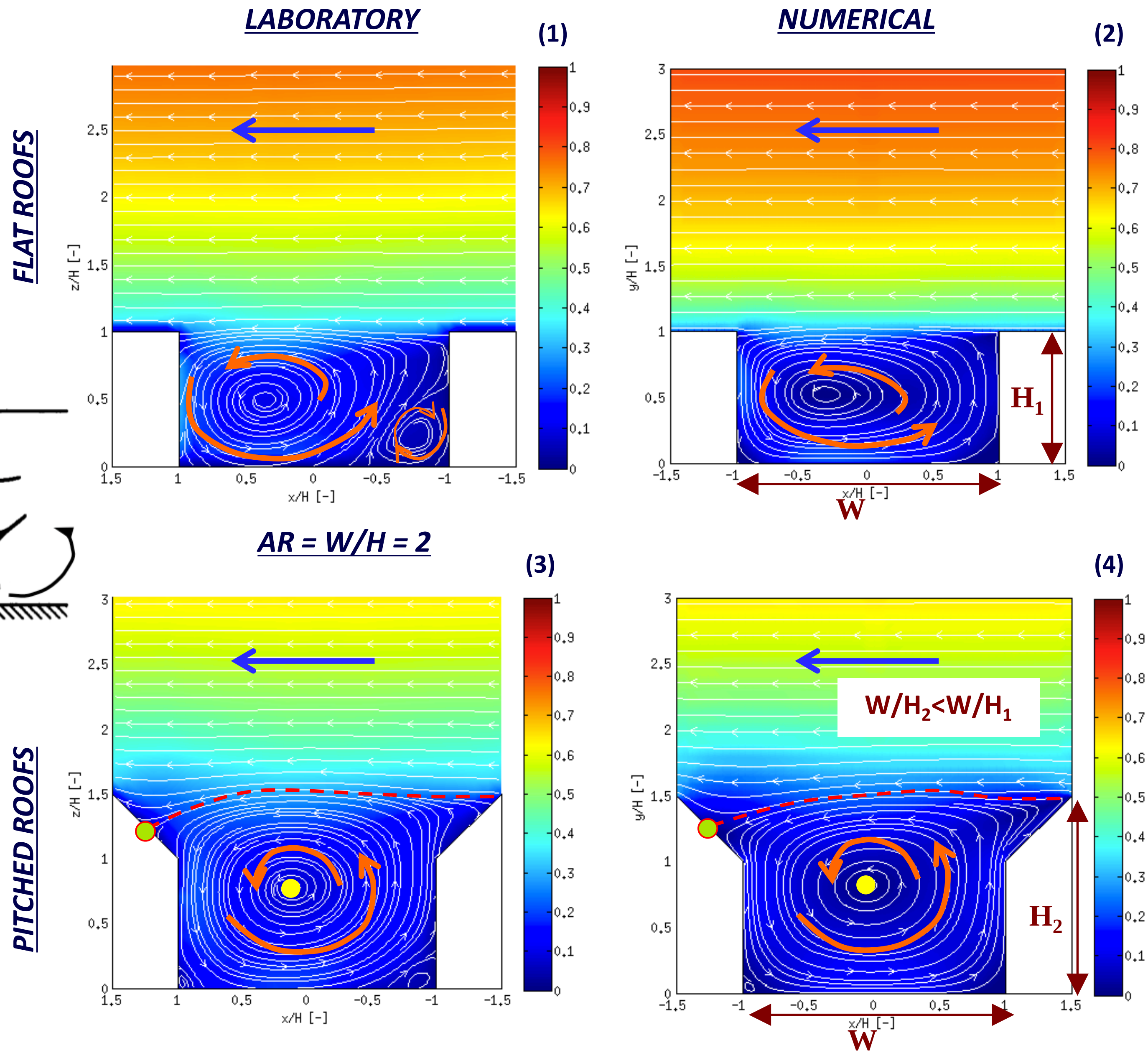
Skimming flow



RESULTS: NON-DIMENSIONAL MEAN VELOCITY FIELDS (*u/U*)



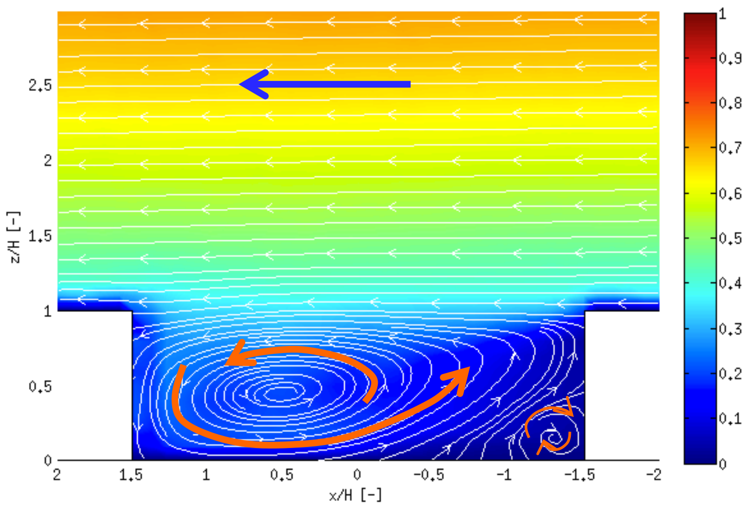
Wake interference



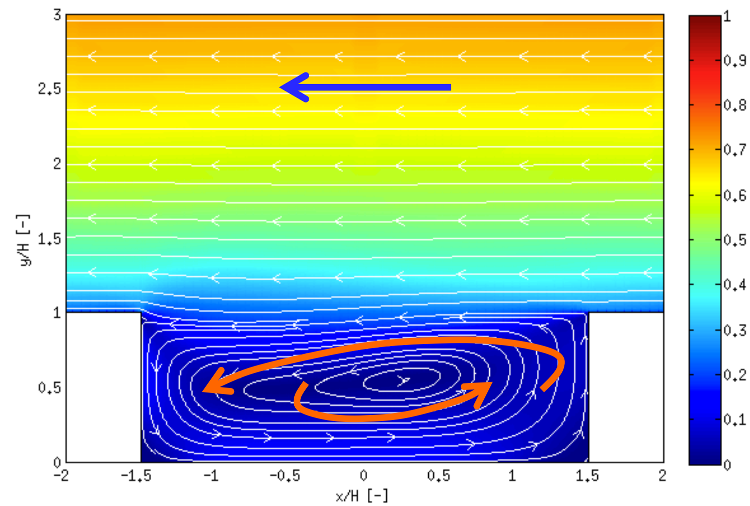
RESULTS: NON-DIMENSIONAL MEAN VELOCITY FIELDS (*u/U*)

FLAT ROOFS

LABORATORY **(1)**



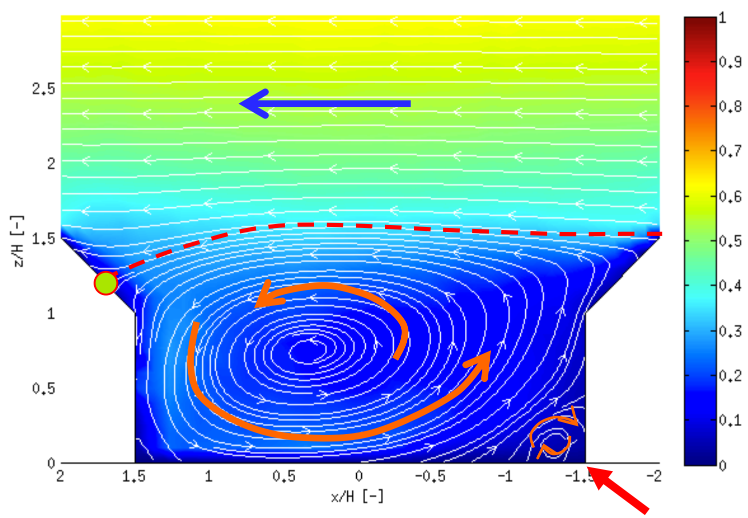
NUMERICAL **(2)**



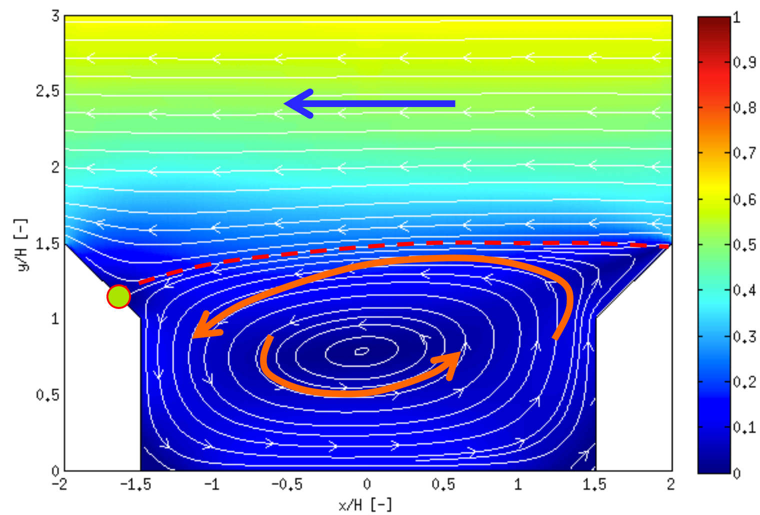
AR = W/H = 3

PITCHED ROOFS

(3)

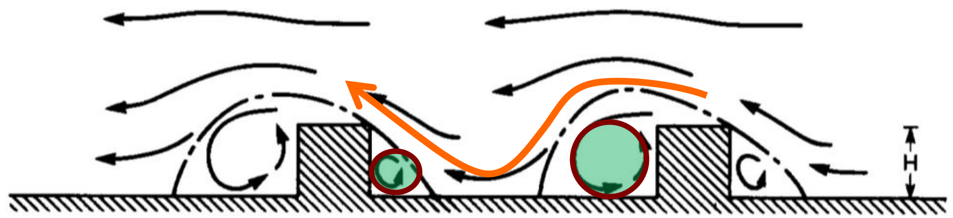


(4)



RESULTS: NON-DIMENSIONAL MEAN VELOCITY FIELDS (*u/U*)

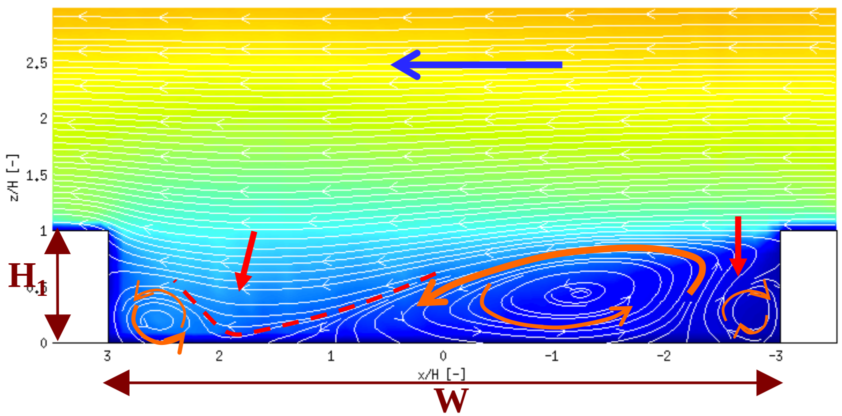
Isolated Roughness



LABORATORY

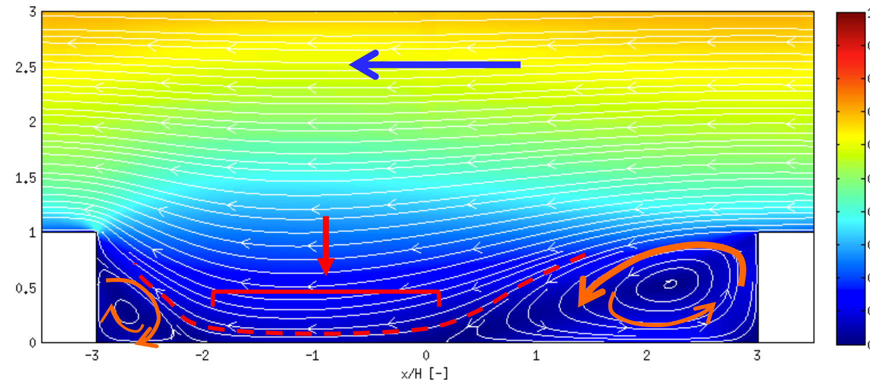
NUMERICAL

(1)



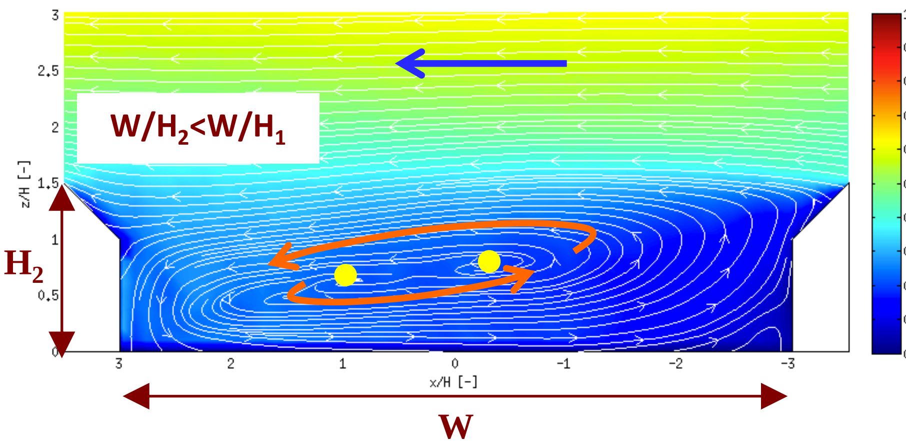
FLAT ROOFS

(2)



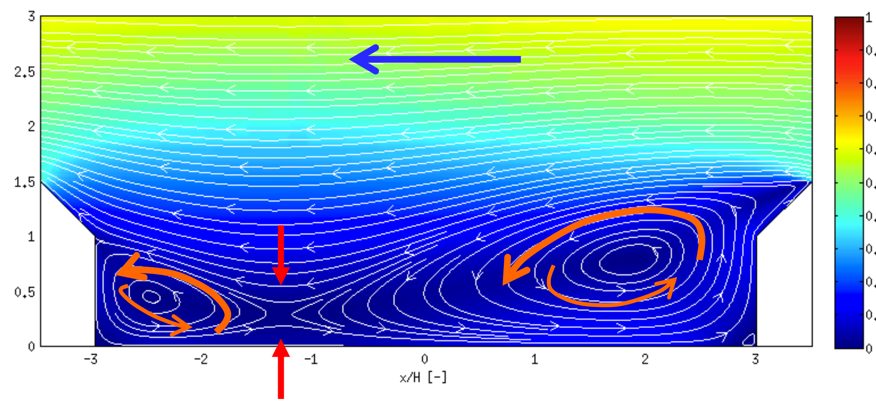
AR = W/H = 6

(3)



PITCHED ROOFS

(4)



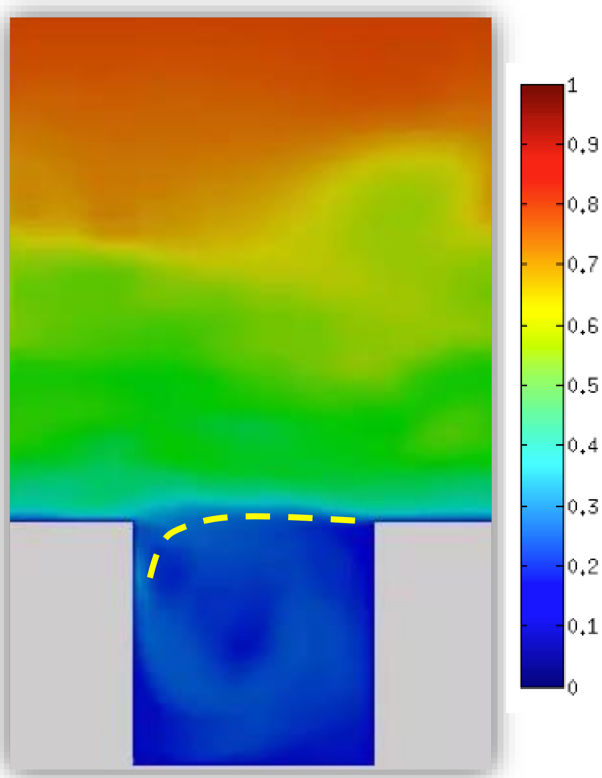
NON-DIMENSIONAL TOTAL KINETIC ENERGY FIELDS (*TKE/U²*)

WE HAVE SEEN MEAN VELOCITY FIELDS.

BUT (UN)FORTUNATELY THE FLOW REGIME IS NOT STEADY

$$TKE = \frac{1}{2}\left(\langle u'^2 \rangle + \langle v'^2 \rangle + \langle w'^2 \rangle \right)$$

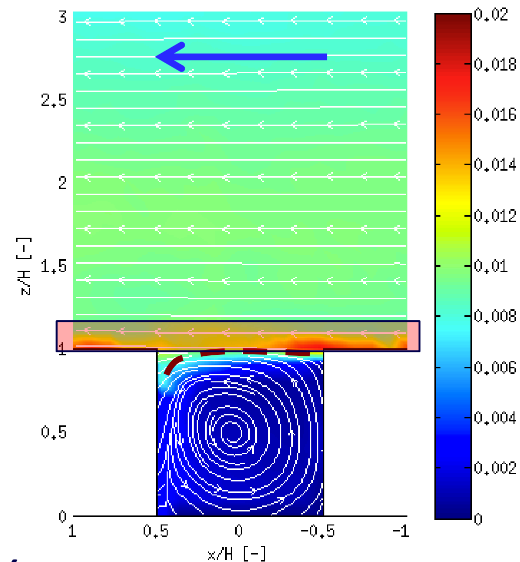
ISTANTANEOUS VELOCITY



LABORATORY

FLAT ROOFS

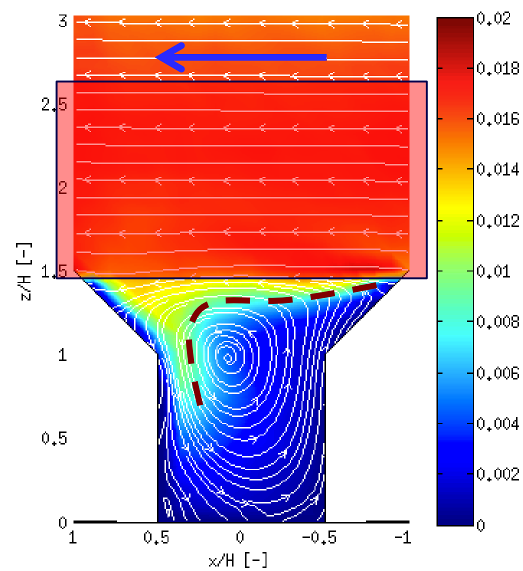
(1)



AR = W/H = 1

PITCHED ROOFS

(2)

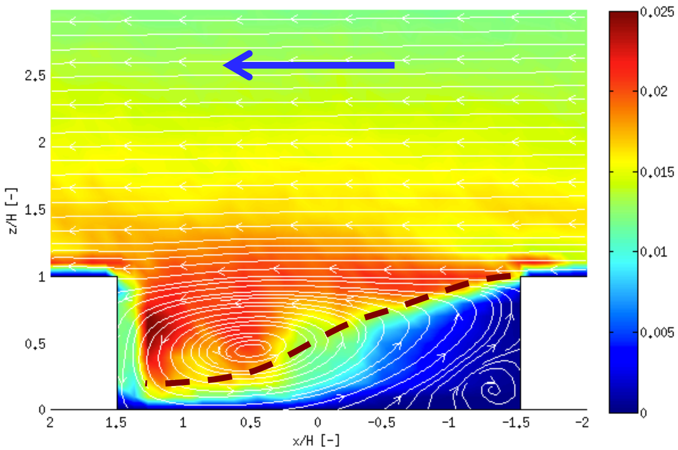


NON-DIMENSIONAL TOTAL KINETIC ENERGY FIELDS (*TKE/U²*)

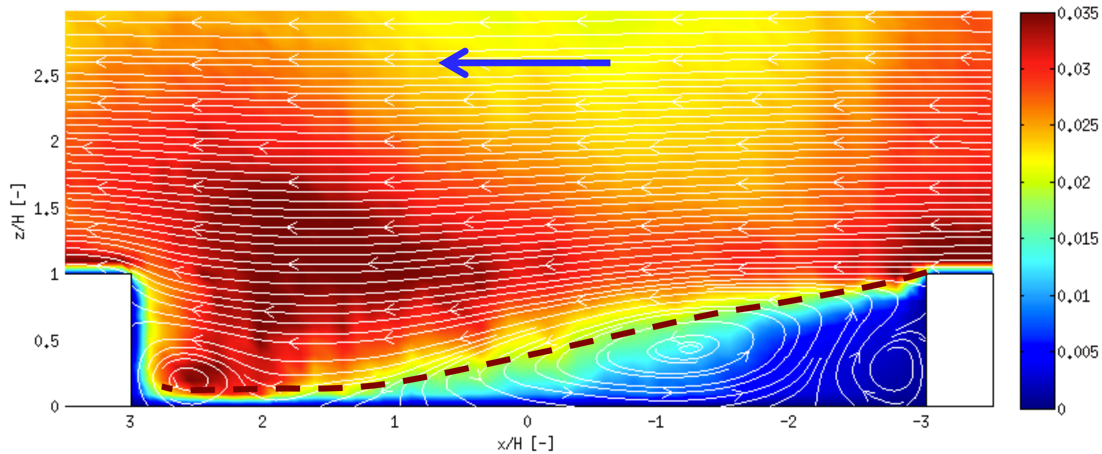
LABORATORY

FLAT ROOFS

(1)



(2)

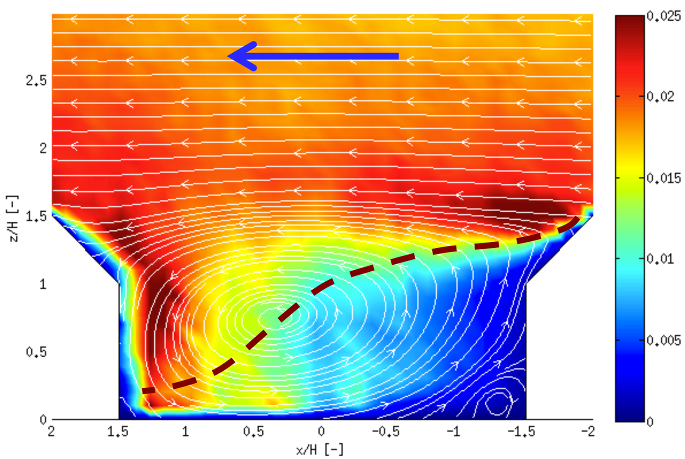


AR = W/H = 3

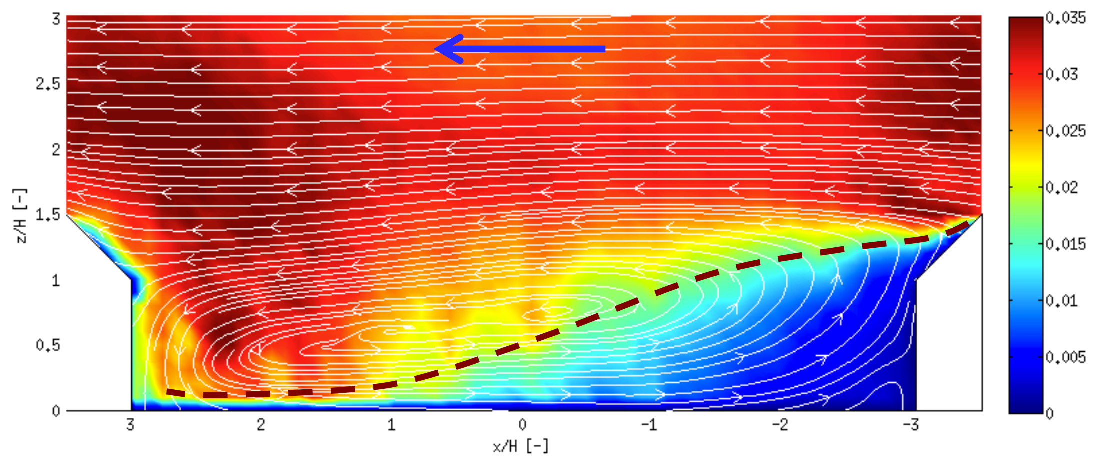
AR = W/H = 6

PITCHED ROOFS

(3)



(4)

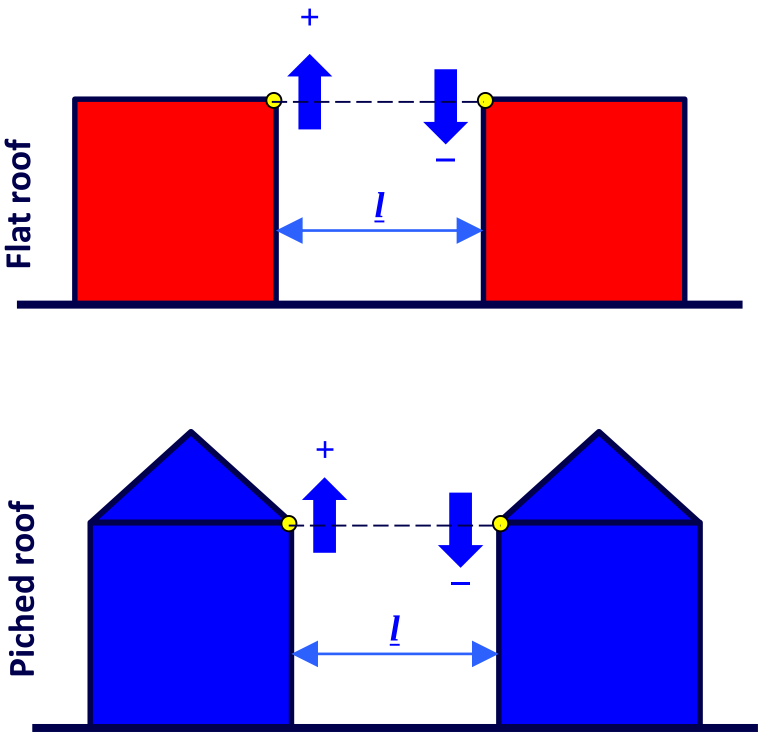


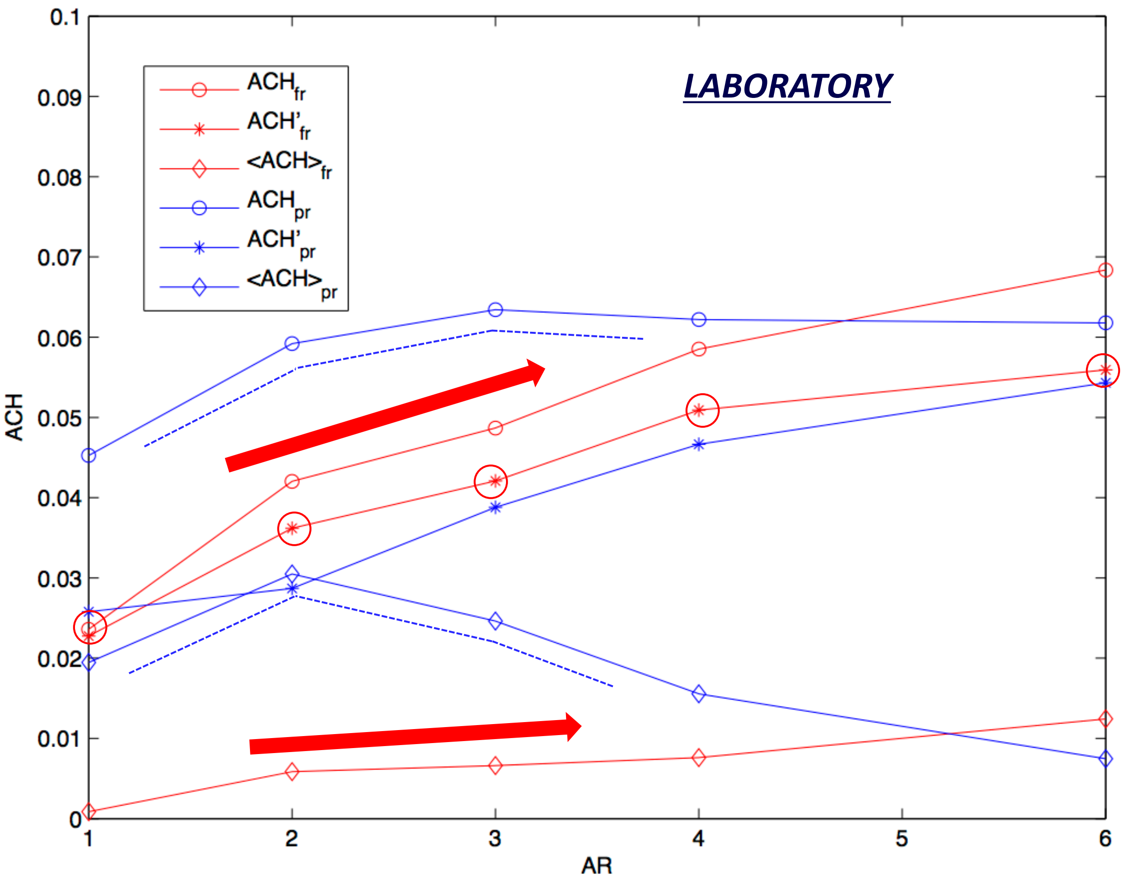
CANYON VENTILATION: A QUANTITATIVE ANALYSIS
AIR-EXCHANGE RATE, *ACH*

TOTAL = MEAN + TURBULENT

$$ACH = \overline{ACH} + ACH' = \int_l \overline{w}_+ \, dx + \int_l w'_+ \, dx,$$

Liu et al (2005)
Ho et al (2015)





CONCLUSIONS

- RANS numerical simulations are able to properly reproduce laboratory investigations only in some cases. Difficulties arise where topology of flow regimes becomes complex.

- Comparisons with more accurate computational techniques (*e.g. L.E.S.*) are desiderable, and are currently in progress.

- The experiences have highlighted the meaningful role of dual-pitched roofs on natural ventilation inside urban canyons: both through the topology of the mean velocity fields and through an apparent turbulence enhancement.

- The canyon ventilation has been also quantified using an integral parameter, *i.e. ACH*. Results confirm a clear improvement in the air exchange rate using dual-pitched roofs, mostly for the lower aspect ratios.