

## **Twin Test #1:**

### **Effects of Vegetation on Flows in the Urban Environment**



**National  
Technical  
University  
of Athens**



Karlsruher Institut für Technologie




**POLITECNICO**  
MILANO 1863



Delft  
University of  
Technology



This project has received funding from the European Union's Horizon research and innovation programme under Grant Agreement Number: 101079125, Call Topic: HORIZON-WIDERA-2021-ACCESS-03-01



The following is an excerpt of the Book of Reference, published on the project web site<sup>1</sup>. The “twin test” involved measurements of the flow past a surface mounted cube, exposed to an atmospheric boundary layer. Measurements were performed for all experimental configurations both at Karlsruhe Institute of Technology<sup>2</sup> (KIT) and the National Technical University of Athens<sup>3</sup> (NTUA), in wind tunnels, at common locations around the building, in order to permit cross comparison of the results. However, the measurements were performed with different experimental measurement techniques: Laser Doppler Anemometry (LDA) at KIT and Particle Image Velocimetry (PIV) at NTUA.

The cube is intended to represent a building at a scale of 1:300, in agreement with the ABL scales. The height of the building model was  $H = 110$  mm, and the vertical openings on its side were: (height),  $h_e = 90$  mm and (width),  $w_e = 6$  mm. Inside the building, in the center, there was a vertical column of square cross section ( $22 \times 22$  mm<sup>2</sup>).

Besides the basic flow past the building model with smooth outer walls, tests were performed with modelled vegetation covering the windward façade and the roof of the building. Vegetation was modelled with open-cell reticulated foam materials and results are presented here for foams with a pore density of 60 PPI of 10 mm thickness, corresponding to a full scale (1:300) permeability value of  $\lambda_{fs} = 7.82$  m<sup>-1</sup>, which corresponds to dense hedges. Details on the permeability measurements and the scaling procedures for the foams can be found in previously published work<sup>4</sup>. The test configurations are shown in Figure 1 and are common for the tests in the KIT and the NTUA wind tunnels.

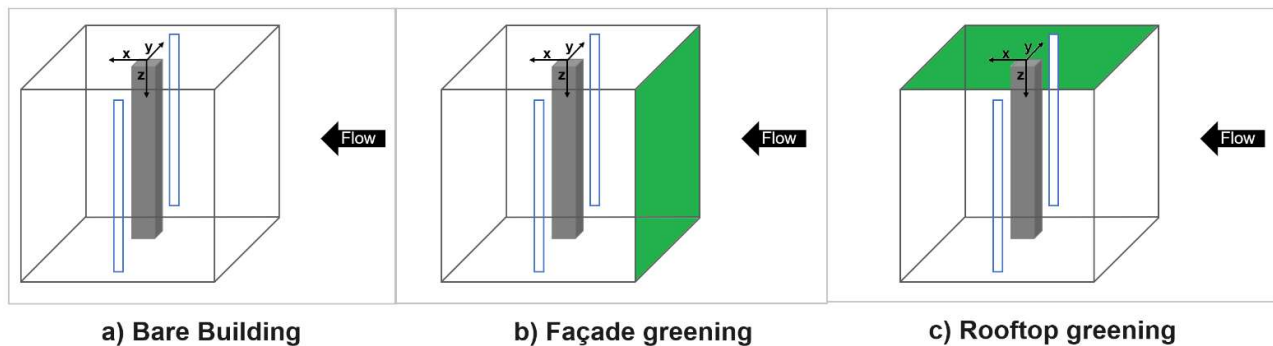


Figure 1 Tested configurations in both wind tunnels (KIT, NTUA): a) Bare building (without vegetation), b) Façade greening and c) Rooftop greening.

<sup>1</sup> [www.tweet-ie.eu](http://www.tweet-ie.eu)

<sup>2</sup> [www.ifh.kit.edu](http://www.ifh.kit.edu)

<sup>3</sup> [www.wt.fluid.mech.ntua.gr](http://www.wt.fluid.mech.ntua.gr)

<sup>4</sup> Pappa V., Bouris D., Theurer W., Gromke C. 2023. “A wind tunnel study of aerodynamic effects of façade and roof greening on air exchange from a cubic building” Building and Environment, 2023, 110023, ISSN 0360-1323, doi.org/10.1016/j.buildenv.2023.110023.

## KIT – LDA measurements

Velocity measurements at KIT were performed with Lased Doppler Velocimetry. Measurements were performed along three horizontal profiles on the side wall of the building, upstream and downstream of the opening, along three vertical profiles on the roof and three vertical profiles in the wake.

For the side wall, the measurement positions are schematically shown in Figure 2. Since LDV is capable of high sampling rates, for the points at close proximity to the side wall, where unsteady flow phenomena and high turbulent velocity fluctuations are expected, lateral velocities were sampled at a higher frequency. Details of the parameters used in the measurements are provided in the Table of Figure 2

Similarly, to the side wall, for the roof, the measurement positions are schematically shown in Figure 3. Again, for the points at close proximity to the roof, vertical velocities were sampled at a higher frequency. Details of the parameters used in the measurements are provided in the Table in the Figure Measurement positions in the wake and the relevant measurement parameters are shown in Figure 4 and its Table.

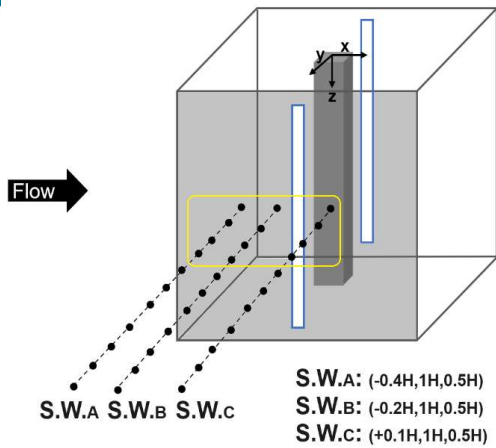


Figure 2 Measurement points' positions on the side wall of the bare building configuration. Black dots correspond to points sampled at a frequency of  $f_{samp} = 100$  Hz and the yellow box frame corresponds to the area where measurements were sampled with  $f_{samp} = 500$  Hz.

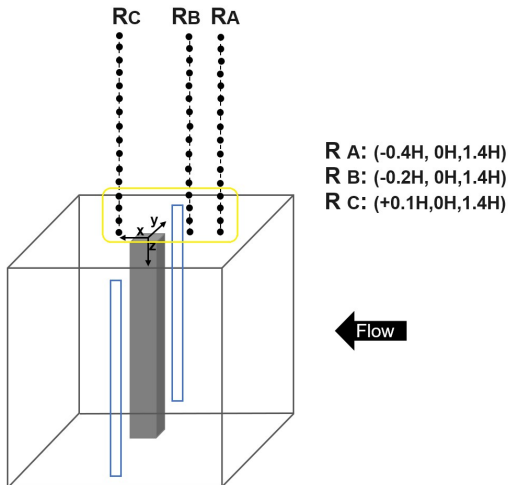


Figure 3 Measurement points' positions on the roof of the bare building configuration. Black dots correspond to points sampled at a frequency of  $f_{samp} = 100$  Hz and the yellow box frame corresponds to the area where measurements were sampled with  $f_{samp} = 500$  Hz.

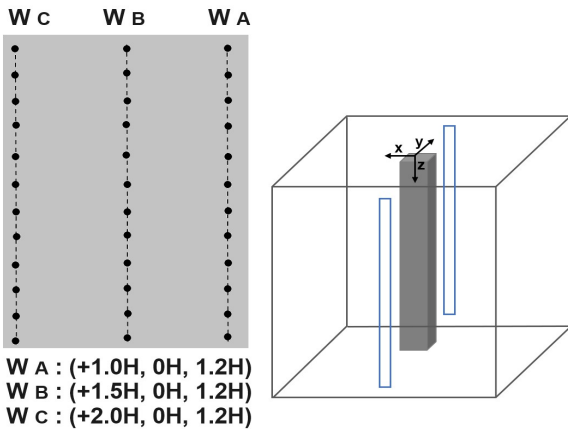


Figure 4. Measurement points' positions in the wake of the bare building configuration.

Laser Doppler Velocimetry (full range)	
2D velocity measurements	streamwise $u$ & lateral $v$
Sampling frequency, $f_{samp}$	100 Hz
Acquisition time, $t_{ac}$	120 sec
Number of points / configuration	32
Laser Doppler Velocimetry (wall proximity range)	
1D velocity measurements	lateral $v$
Sampling frequency, $f_{samp}$	500 Hz
Acquisition time, $t_{ac}$	120 sec
Number of points / configuration	12

Laser Doppler Velocimetry (full range)	
2D velocity measurements	streamwise $u$ & vertical $w$
Sampling frequency, $f_{samp}$	100 Hz
Acquisition time, $t_{ac}$	120 sec
Number of points / configuration	48
Laser Doppler Velocimetry (wall proximity range)	
1D velocity measurements	vertical $w$
Sampling frequency, $f_{samp}$	500 Hz
Acquisition time, $t_{ac}$	120 sec
Number of points / configuration	12

Laser Doppler Velocimetry (Wake I)	
2D velocity measurements	streamwise $u$ & vertical $w$
Sampling frequency, $f_{samp}$	100 Hz
Acquisition time, $t_{ac}$	120 sec
Number of points / configuration	36

## NTUA – PIV measurements

At NTUA, the velocity measurements were performed with Particle Image Velocimetry (PIV) in both 2D-2C and 2D-3C modes. The PIV method measures on a plane and these were chosen to include the LDV measurement position at KIT. Measurements were performed on three different planes, a horizontal one next to the side wall, a vertical one on the roof and a vertical plane in the wake, behind the building.

For the side wall, the camera was mounted over the building and the laser sheet was directed horizontally towards the side wall at half the building height ( $z/H=0.5$ ) (Figure 5). A 2D-2C PIV setup was chosen for this plane since a) suspension and alignment of two cameras was difficult to achieve reliably with the available infrastructure and b) the vertical velocity (in the  $z$  direction) was not expected to be significant. Parameters relevant to the setup are presented in

Table 1.

For the measurements in the wake and on the roof, a 2D-3C setup was chosen as the cameras could be placed on the floor of the wind tunnel, significantly alleviating difficulties appearing in the overhead suspension of the horizontal setup.

For measurement of the vertical plane above the roof, the cameras were slightly elevated in order to achieve optical access above the building and a horizontally oriented angle plane between the two cameras (Figure 6). The laser sheet was redirected to the vertical direction with a mirror suspended above the model. For the vertical plane in the wake, the cameras were positioned downstream and on either side of the building model (Figure 7), in order to ensure optical access to the area directly behind the building. Redirection of the laser sheet was achieved in the same manner as for the roof plane (Table 2). Details of the measurement parameters for both vertical planes are given in Table 2.

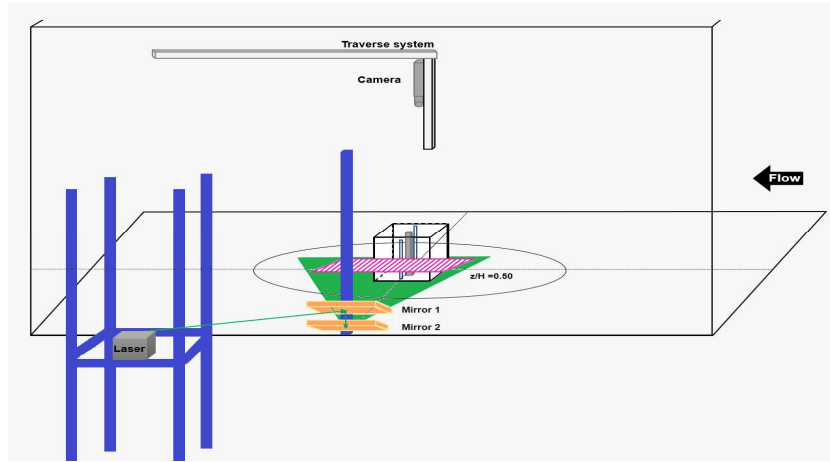


Figure 5 Mono PIV experimental set up of the Side Wall measurement plane (Horizontal Plane).

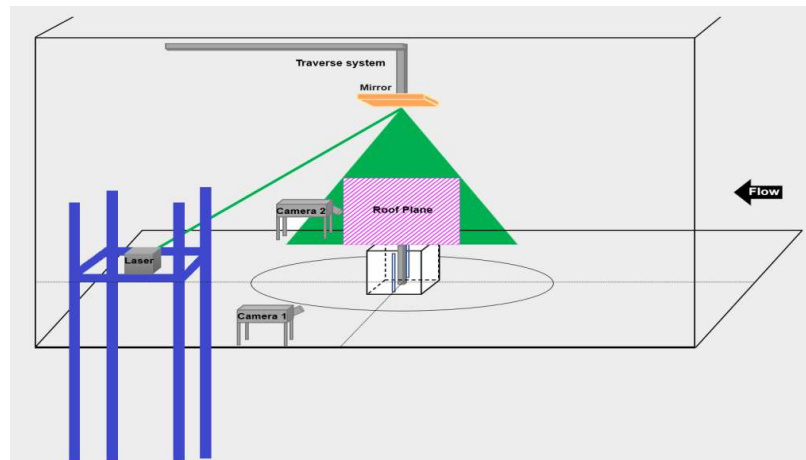


Figure 6. Stereo PIV experimental set up of the Roof measurement plane.

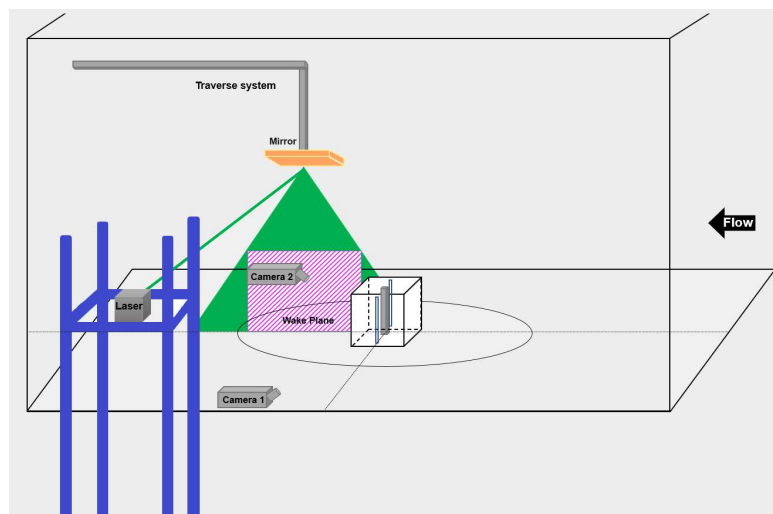


Figure 7 Stereo PIV experimental set up of the Wake measurement plane.

Table 1 Measurement parameters for the 2D-2C PIV measurements on the horizontal side wall plane

<b>Mono (2D – 2 component) Particle Image Velocimetry (2D-2C PIV)</b>	
<b>2D velocity measurements</b>	streamwise $u$ & lateral $v$
<b>Angle of attack (AoA)</b>	$0^\circ$
<b>Parameter</b>	Horizontal Plane
<b>Plane orientation with respect to free stream</b>	Normal
<b>Plane Size</b>	$1.82H \times 1.82H$
<b>Sampling frequency, <math>f_{smp}</math></b>	7.28 Hz
<b>Lenses</b>	90 mm
<b>Distance from measured plane</b>	12.36 H
<b>Interrogation area size</b>	32 px
<b>Interrogation area size</b>	1.61 mm
<b>Minimum resolvable velocity</b>	0.095 m/s
<b>Minimum resolvable velocity (normalized with respect to the free stream)</b>	1.9%
<b>Number of snapshots per plane</b>	1000

Table 2 Measurement parameters for the 2D-3C PIV measurements on the vertical planes above the roof and in the wake

<b>Stereo (2D – 3 component) Particle Image Velocimetry (2D-3C, Stereo PIV)</b>		
<b>3D velocity measurements</b>	streamwise $u$ & lateral $v$ & vertical $w$	
<b>Angle of attack (AoA)</b>	$0^\circ$	
<b>Parameter</b>	Roof Plane	Wake Plane
<b>Plane orientation with respect to free stream</b>	Parallel	Parallel
<b>Plane Size</b>	$1.82H \times 1.82H$	
<b>Sampling frequency, <math>f_{smp}</math></b>	7.28 Hz	
<b>Lenses</b>	150 mm	150 mm
<b>Camera contained angle</b>	$90^\circ$	$90^\circ$
<b>Distance from measured plane</b>	15.45 H	15.45 H
<b>Interrogation area size</b>	32 px	32 px
<b>Interrogation area size</b>	1.72 mm	1.66 mm
<b>Minimum resolvable velocity</b>	0.10 m/s	0.10 m/s
<b>Minimum resolvable velocity (normalized with respect to the free stream)</b>	2%	2%
<b>Number of snapshots per plane</b>	1000	1000