9th International Colloquium on Bluff Body Aerodynamics and Applications
University of Birmingham, Birmingham, UK
29th July – 2nd August 2024

Twin wind tunnel tests of flow past a building with openings and façade and rooftop greening

Vasiliki Pappa[a], Christof Gromke [b], Demetri Bouris [c]

[a]*School of Mechanical Engineering, National Technical University of Athens, Athens, Greece, vaspappa@mail.ntua.gr*
[b]*Institute for Water and Environment, Karlsruhe Institute of Technology, Karlsruhe, Germany, christof-bernhard.gromke@kit.edu*
[c]*School of Mechanical Engineering, National Technical University of Athens, Athens, Greece, dbouris@fluid.mech.ntua.gr*

SUMMARY:
In the context of studying vegetation effects on flow in the urban environment, twin studies of the flow past a cube shaped building are performed in the wind tunnels of the Karlsruhe Institute of Technology (KIT) and the National Technical University of Athens (NTUA). Identically shaped buildings with openings were used with comparable upstream atmospheric boundary layer profiles in terms of mean velocity, turbulence intensity and integral length scales. Simulated vegetation was placed on the building's upstream face and roof. Measurements were performed with Laser Doppler Velocimetry (LDV) at KIT and 2D-3C Particle Image Velocimetry (PIV) at NTUA. The two measurement sets indicate the same qualitative trends of flow structure and vegetation effects and quantitative results are in close agreement. Results are publicly available (Pappa et al. 2023b) and provide an opportunity to analyse the effects of differences in upstream conditions, wind tunnel configurations and measurement techniques.

Keywords: wind tunnel tests, urban flow, atmospheric boundary layer, vegetation, air exchange

1. INTRODUCTION

The presence of vegetation on outer building surfaces (building greening) has received increased attention lately as it affects the urban microclimate, pedestrian comfort and air quality, but also the air exchange within the buildings, and thus indoor air quality. Wind tunnel testing is a common research tool in this context (Li et al, 2022) but there are still challenges in its implementation, mainly related to modelling of the vegetation and the atmospheric boundary layer as well as to the measurement techniques. In this scope, the current effort addresses the effects of vegetation, embedded on the outer surfaces of a simplified model building, on the flow around the building and through its openings. Two tests of the same geometrical configuration are performed in two different wind tunnels, ensuring similar conditions between the two tests so that measurement space overlaps and comparison of the results is meaningful. This serves the purpose of identifying, characterizing and categorizing important sources of deviations such as external conditions, testing equipment etc. Measurement data are available in a public database (Pappa et al., 2023b) for validation purposes.

2. EXPERIMENTAL SETUPS

One of the main goals of the study was to achieve, as much as possible, identical experimental setups in the two wind tunnels. This involved the building model's geometry, the simulated vegetation, the upstream mean flow and turbulence characteristics and Reynolds number independence. The test sections upstream of the turntable in the wind tunnels at Karlsruhe Institute of Technology (KIT) and the National Technical University of Athens (NTUA) are shown in Figure 1. The tunnels' cross sections (width×height) are 2.0×1.0m at KIT and 3.5×2.5m at NTUA, both ensuring dp/dx=0 i.e. no streamwise pressure gradient.

Figure 1. Wind tunnel test sections and views of the building model at KIT (left) and NTUA (right)

The tests involved measurements of the flow past a surface mounted cube, intended to represent a building at a scale of 1:300, in agreement with the scale of the simulated atmospheric boundary layers. 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, at the center, there was a vertical column of square cross section (22x22 mm).

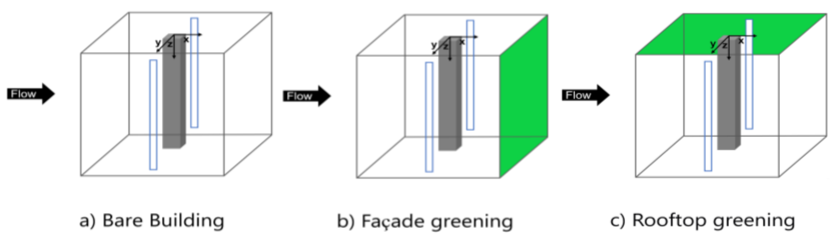

Figure 2. Tested configurations at KIT and NTUA: a) Bare building and b) Façade and c) Rooftop greening

Tests were performed at KIT and NTUA for the reference flow past the building model with bare outer walls and, when simulated vegetation (greening) covered the windward façade or the roof of the building (Figure 2). Photographs of the building models with greening configurations are visible in Figure 1. Greening was modelled with 10 mm thick open-cell reticulated foam material with a pore density of 60 PPI (pores per inch). The full scale value of pressure drop coefficient for this material (λ_{fs} =7.82 m^{-1}) corresponds to dense hedges or ivy (Gromke, 2018, Pappa et al., 2023a).

The upstream boundary layer profiles of streamwise mean velocity and turbulence intensity were measured with constant temperature hot wire anemometry (Figure 3). The free stream velocity was U_∞=5 m/s in both wind tunnels but the reference velocity, taken at building height, was U_{ref}=3.27 m/s at KIT and U_{ref}=2.36 m/s at NTUA, giving building height Reynolds numbers of Re_H=23500 and 16500, respectively, both above the commonly accepted Re independence limits of Re_{crit}=10000, (VDI, 2000). The scale factor was calculated to M=1:300 (Cook, 1978). From the KIT mean velocity profile, a power law exponent of α=0.28, a full scale aerodynamic roughness length of z_o=0.54 m and a friction velocity of u*=0.25 m/s were calculated, corresponding to the lower limits of an urban atmospheric boundary layer (0.24≤α≤0.40), (VDI, 2000). The corresponding values for the upstream profile at NTUA were α=0.22, z_o=0.39 m and u*=0.22 m/s i.e. a suburban atmospheric boundary layer (0.18≤α≤0.24) (VDI, 2000).

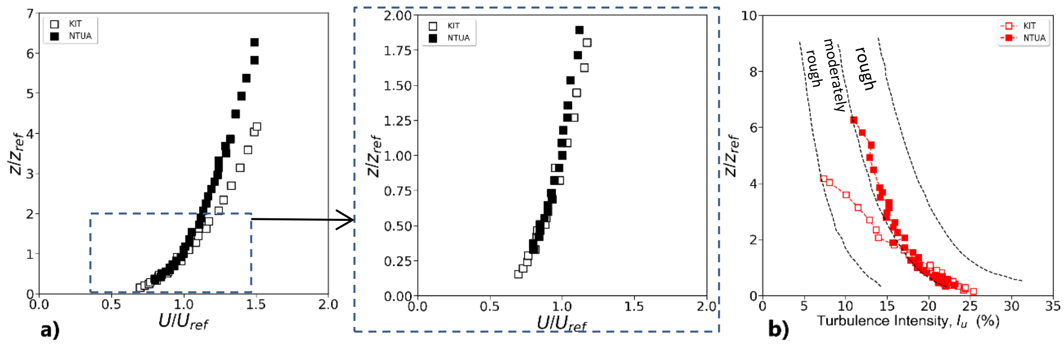

Figure 3. Measured upstream profiles of streamwise a) mean velocity component (detail shown for $Z/Z_{ref} \leq 2$) and b) turbulence intensity.

As observed in Figure 3, the non-dimensional mean velocity and turbulence intensity profiles are quite similar up to roughly two building heights (Z_{ref}=H but notation is retained for comparison with ABL standards). The turbulence integral length scales (not shown here) are also comparable up to one building height from the ground, with the NTUA values increasing above this height, most probably due to the greater height of the test section at the NTUA wind tunnel. Considering the Reynolds number independence of both the simulated ABL and the flow past the building, results may be considered favorable for comparing the measurements from the two wind tunnels.

Measurements were performed for all building configurations (Figure 2) at locations on the side, the roof and the wake of the building. Measurements at KIT were performed with 2 component Laser Doppler Anemometry (LDA) at a sampling frequency of 100-500Hz. At NTUA, planar 3 component Particle Image Velocimetry (2D-3C PIV) was employed, except for the horizontal plane, perpendicular to the building's side wall, where planar 2 component PIV was utilised (2D-2C PIV).

3. RESULTS

Indicatively, Figure 4a shows the mean streamwise velocity distribution and streamtraces on a horizontal plane at z/H=0.5 next to the sidewall of the building, without surface greening. Both LDV and PIV measurements from the two wind tunnels confirm that the recirculation zone is also present with façade greening (Figure 4b). Even though there are differences (~15%) between the measured mean values further away from the wall in Figure 4b, possibly due to the different test section blockage values, the fluctuating values agree quite well in Figure 4c (<10%). The effect of greening is discernable in the lateral velocity fluctuations closer to the vertical leading edge (0.1H) in Figure 4d-e, where measurements in both setups indicate damping when façade greening is present but minimal effect when it is on the roof. Further analysis of the large data sets is ongoing and is expected to provide more information on the effects of greening properties and position as well as on the sources of the differences in the two measurement sets. These will be presented in the full paper and at the conference.

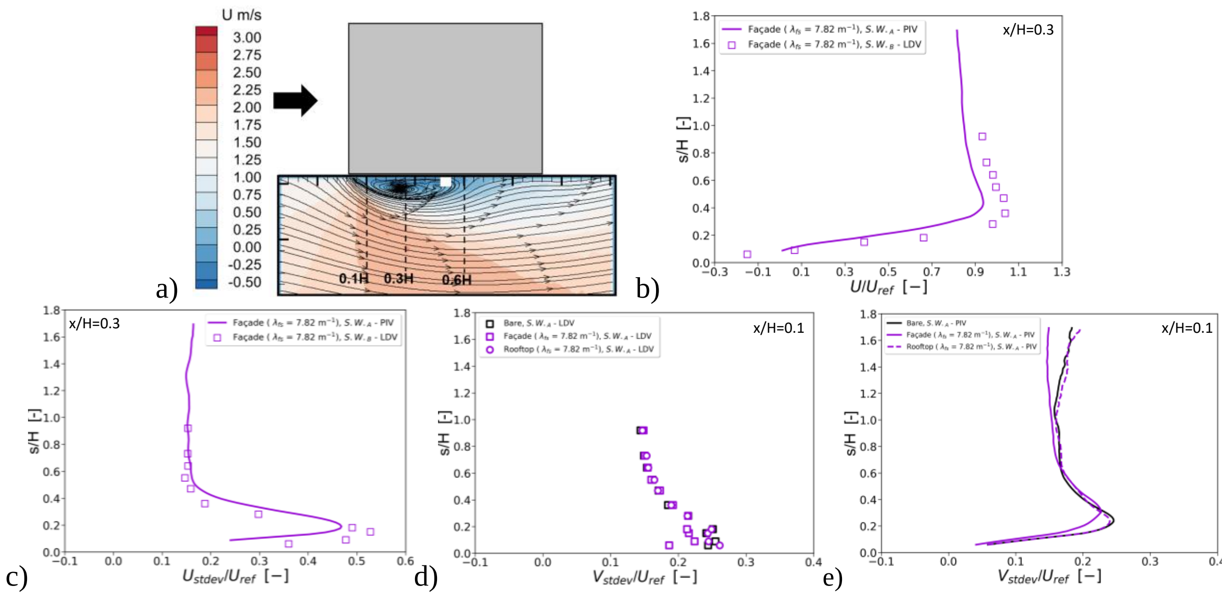

Figure 4. a) Contours and streamtraces on a horizontal plane (z/H=0.5) next to the side wall of the bare building (i.e. top view). LDV and PIV profile positions are indicated (0.1H, 0.3H, 0.6H from the vertical leading edge). b) Mean and c) Standard deviation profiles of the streamwise velocities at position 0.3H when façade greening is present. d) LDV and e) PIV profiles at position 0.1H for the bare building and for façade or rooftop greening.

5. CONCLUSIONS

A twin wind tunnel test has been performed for the flow past a building with or without greening on its windward façade or rooftop. Measurements were performed at two wind tunnels, ensuring matching upstream boundary layer profiles and building geometry. Measurement results provide insight into the effects of building outer surface greening on the flow and an opportunity to evaluate sources of discrepancy when measuring the same setup in different wind tunnels.

ACKNOWLEDGEMENTS

The authors would like to acknowledge funding by the European Union under the project TWEET-IE : Twin Wind tunnels for Energy and the EnvironmenT - Innovations and Excellence (PR# 101079125)

REFERENCES

Gromke, C., 2018.Wind tunnel model of the forest and its Reynolds number sensitivity. Journal of Wind Engineering and Industrial Aerodynamics 175, 53-64

Pappa, V., Bouris, D., Theurer, W., Gromke, C., 2023a. A wind tunnel study of aerodynamic effects of façade and roof greening on air exchange from a cubic building. Building and Environment 231, 110023.

Pappa, V., Gromke, C., & Bouris, D., 2023b. Twin test 1: Effect of vegetation on urban flows. PIV data from NTUA WT experiment and LDV from KIT WT experiment (1.0.0) [Data set]. Zenodo. DOI: 10.5281/zenodo.10019002

Cook N.J., 1978. Wind-tunnel simulation of the adiabatic atmospheric boundary layer by roughness, barrier, and mixing-device methods. Journal of Industrial Aerodynamics 3, 157–176.

VDI 3783 Part 12. 2000. Environmental Meteorology Physical Modelling of Flow and Dispersion Processes in the atmospheric boundary layer. Applications of wind tunnels. VDI. Berlin: Beuth Verlag.

Li H., Zhao Y., Shutzl B., Kubilay A., Carmeliet J., 2022. Impact of green walls on ventilation and heat removal from street canyons: Coupling of thermal and aerodynamic resistance. Building and Environment 214, 108945.