Aerodynamic properties of a cubic building with windward trees

Krunoslav Drašković [1,2], Marta Vukoja [1,2], Christof Gromke [2], Hrvoje Kozmar [1]

[1]Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Ivana Lučića 5, 10000 Zagreb, Croatia, krunoslav.draskovic@fsb.unizg.hr, vukojamarta@gmail.com, hrvoje.kozmar@fsb.unizg.hr

[2]Laboratory of Building and Environmental Aerodynamics, Institute for Water and Environment, Karlsruhe Institute of Technology, Kaiserstraße 12, 76131 Karlsruhe, Germany, gromke@kit.edu

SUMMARY

The effects of windward vegetation on aerodynamic characteristics of buildings were experimentally studied in a boundary layer wind tunnel. A tree row was placed windward of a model building. Surface pressure and velocity measurements were acquired on the building model. Surface pressure measurements were performed using pressure transducers, while flow velocity measurements were conducted using Laser Doppler Velocimetry. The model building is a cube made of acrylic glass. A tree crown was manufactured using a porous material previously validated as a suitable aerodynamic substitute for real tree canopies. The results indicate that the tree row provides shielding by decreasing surface pressure at the windward and lateral walls as well as at the roof. For the studied configuration, the tree row even caused a suction pressure zone in the upper half of the windward wall.

Keywords: cubic building, trees, surface pressure, velocity field, wind-tunnel experiments

1. INTRODUCTION

Buildings are structures exposed to dynamic environmental forces. They are particularly vulnerable to wind-induced loads. One promising, yet unexplored, strategy for mitigating wind loads on buildings is the use of vegetation, especially in the form of strategically placed trees or hedgerows. Beyond their aerodynamic function, vegetation contributes to reducing residential energy consumption, making it a dual-purpose passive strategy in urban environments. Strategic placement of trees and windbreaks may yield decreased wind velocities in the vicinity of buildings, which lowers air infiltration through gaps and cracks in the building envelope, Mattingly and Peters (1977).

Some studies addressed this issue in the past, e.g., Ibrahim et al. (2025), but a more systematic approach is still lacking. The aerodynamic interaction between trees and buildings is, however, inherently complex. Trees can influence the approaching flow by acting as permeable obstacles that reduce mean wind velocities, while simultaneously increasing turbulence intensity in their wake, thereby altering the spatial distribution of pressure across building surfaces. Wind-tunnel experiments demonstrated that the number of trees and their upstream distance may cause significant variations in surface wind pressures, with certain arrangements even amplifying suction on the windward roof slope rather than reducing it, Kandamby et al. (2023).

This dual character of the vegetation-building interaction, where trees can be both protective and locally adverse, depending on their geometric parameters, underscores the need to systematically study the effect of key variables such as tree height, spacing, and distance to the building. Accordingly, the focus of the present study is to analyze the effect of trees on building aerodynamics based on surface pressure and velocity measurements on the building.

2. METHODS

Wind-tunnel experiments were carried out in an atmospheric boundary layer (ABL) wind tunnel at the Laboratory of Building and Environmental Aerodynamics at the Karlsruhe Institute of Technology (KIT), Germany. The ABL simulation was created to model rural areas and open land with trees or few buildings. The simulated ABL is comparable to the EN1991-1-4:2005, 2005 terrain category II wind conditions.

The cube building model edge length is 200 mm. Its surface was manufactured from acrylic glass (PMMA), a material that enabled distinct smooth surfaces and well-defined sharp edges essential for accurate wind-tunnel experiments. The building model incorporated a comprehensive pressure measurement system consisting of 78 flush-mounted pressure taps placed on wall and roof. The building model was placed on a rotating table to acquire detailed pressure distribution on all surfaces of the building model. The crown of a model tree was modeled using porous material that consists of interlacing polyester foam characterized by an isotropic open-pore structure. A tree crown was placed on a wooden stick, and the height of the canopy was properly adjusted. Pressure and velocity measurements were performed for a tree configuration with parameters shown in Figure 1.

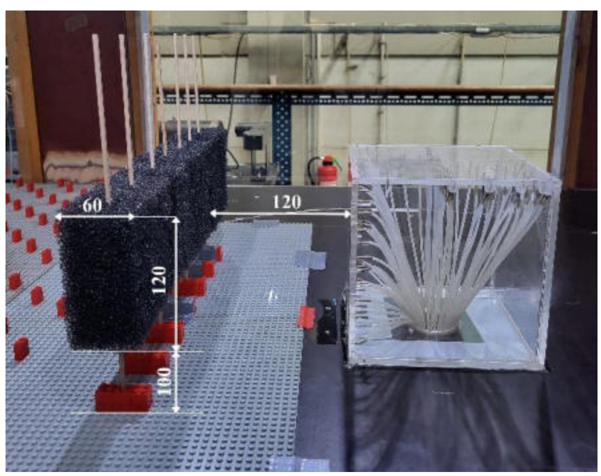

Figure 1. Tree configuration in the ABL wind tunnel

The pressure measurement acquisition time was 120 s at the sampling rate of 500 Hz, thus providing a comprehensive dataset for the statistical analysis of mean and fluctuating pressure components. Detailed flow field measurements were performed using Laser Doppler Velocimetry (LDV). The velocity measurement acquisition time was 60 s at the sampling rate of 100 Hz.

3. RESULTS

The mean pressure is normalized by the dynamic pressure at the building model height to obtain pressure coefficients according to:

$$\overline{C_p} = \frac{\bar{p}-\overline{p_\infty}}{\frac{1}{2}\rho\overline{u_{ref}}^2}, \tag{1}$$

where $\bar{p}$ is the local mean static pressure at the surface, $\overline{p_\infty}$ is the free stream mean static pressure, ρ is the air density and $\overline{u_{\mathrm{ref}}}$ is the mean undisturbed streamwise velocity at the building height.

The $\overline{C_p}$ distribution for a) the reference case and b) the tree configuration is shown in Figure 2. The maximum pressure coefficient for the reference case is 0.95 and located on the windward wall, while the minimum pressure coefficient, located near the roof leading edge, is -1.15. The windward tree placement may yield decreased pressure and emerging suction zones on the windward wall. In addition, a 62% decrease in suction is observed near the roof leading edge and near the sidewall leading edge. The $\overline{C_p}$ on the leeward wall is evenly spread and equal to -0.25 for the reference case and the tree configuration.

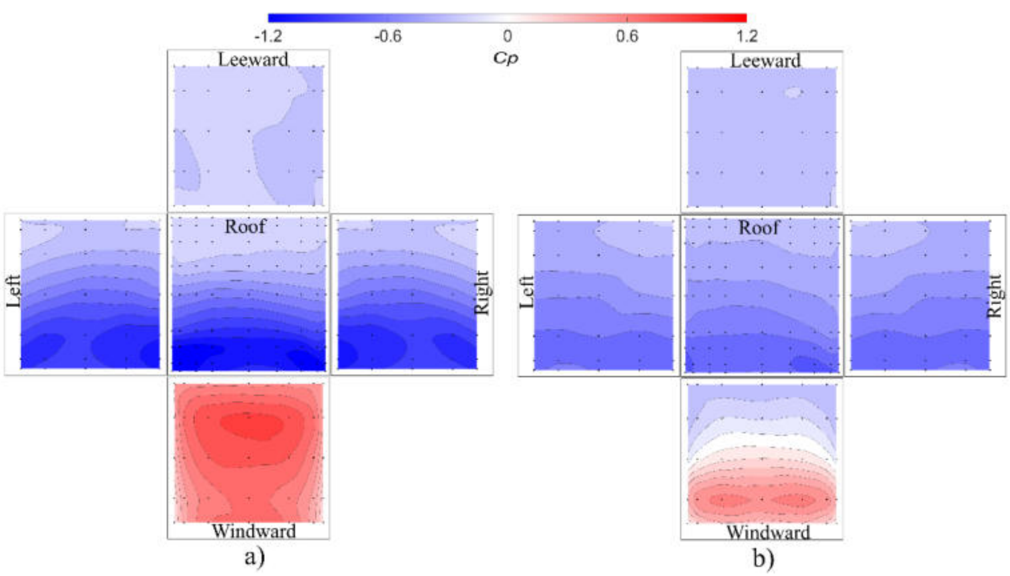

Figure 2. Mean pressure coefficient distribution on building surfaces for a) the reference case and b) the tree configuration

Flow measurements were performed along the vertical line above the turntable. The measurements were conducted at 188 measuring points for each configuration. The windward roof edge had more densely arranged measuring points for a detailed acquisition of the flow separation phenomenon. The flow fields of the reference case and the tree configuration are shown in Figure 3. The reference case exhibits properties typical for the flow around the cube. Flow separation is observed at the leading edge with the recirculation above the roof. Configurations with trees placed windward of the building alter the flow field, especially at the windward façade, where both the velocity magnitude and the flow direction are affected. The flow field measurements for the tree configuration exhibit a decrease in the air velocity near the windward edge relative to the reference case. Leeward of the tree crown, vortices are driven by the flow parallel to the windward wall.

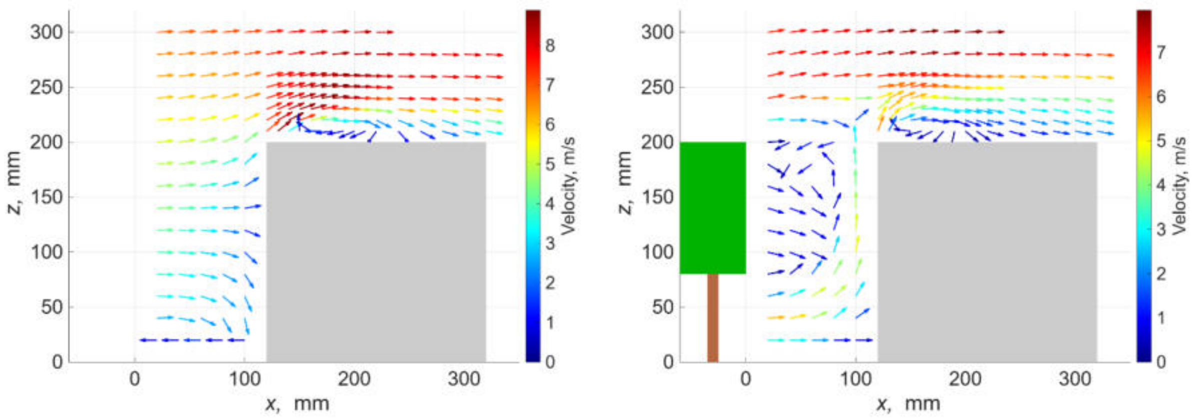

Figure 3. Flow field for the reference case (left) and the tree configuration (right)

4. CONCLUDING REMARKS

The effects of vegetation on building aerodynamics were experimentally studied in an atmospheric boundary layer wind tunnel. A model ABL was created to simulate suburban wind conditions according to the EN1991-1-4:2005, 2005 category II. Shielding provided by tree row yields a decrease of the pressure on the windward and lateral walls. However, suction on the leeward wall is not significantly affected by a tree shielding. The flow field measurements for the tree configuration exhibit a decrease of the conical vortex size at the roof leading edge relative to the reference case. Thus, reattachment line is closer to the leading edge yielding decreased zones of peak suction.

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