Boltzmann-type equations for multi-agent systems with label switching

PHYSMOD Lyon 2024

PHYSMOD 2024 – International Workshop on Physical Modelling of Flow and Dispersion Phenomena
Ecole Centrale de Lyon, Ecully, France – August 28-30, 2024

Turbulent flow field within an urban canyon with vegetation for any wind directions

A.V. Del Ponte[1, 2], S. Fellini[1], M. Marro[2], L. Soulhac[2], L. Ridolfi[1], P. Salizzoni[2]

[1]Politecnico di Torino, DIATI, Corso Duca Degli Abruzzi 24, 10129, Torino, Italy.
[2]Univ Lyon, Ecole Centrale de Lyon, CNRS, Univ Claude Bernard Lyon 1, INSA, LMFA, UMR5509, 69130 Ecully, France.

Introduction

The greening of cities is known as a promising strategy to mitigate the impacts of climate change. However, the aerodynamic effect of vegetation on urban canyon ventilation is not well understood and its benefits on the air quality are debated. For example, recent studies report that the presence of trees within a canyon, perpendicular to the external wind flow, causes an around 30% increase of pollutant concentration at the pedestrian level (*Fellini et al. 2022*) and a significant decrease of turbulent kinetic energy (*Del Ponte et al. 2024*). However, the effect of the wind direction or canyon geometry on the flow filed within canyons with trees is poorly investigated. *Gromke and Ruck 2012* is the only work investigating the influence of wind direction and canyon height-to-width ratio on the mean concentration field within a vegetated canyon. In this framework, we present the results of an experimental campaign aimed at investigating the turbulent flow field within a canyon with trees, considering different wind directions.

Experimental setup

The experiments were performed in the closed-circuit wind tunnel of the École Centrale de Lyon (figure 1a). In the test section, we reproduced a regular street network covering the floor with blocks of constant height and spacing. A neutrally-stratified boundary layer, of thickness 0.9 m and with a free-stream velocity (U_∞) of 5 m/s, develops above the obstacles. Within the street network we selected a squared street 3.5 m long, 0.1 m high (H) and 0.1 m wide, as reference canyon. The street intersections were hindered, allowing for a two-dimensional flow field within the canyon. The aerodynamic effect of vegetation was modelled using plastic miniatures of trees, with a trunk 2 cm high and a crown 6.5 cm high and 4.5 cm wide. We considered two vegetation configurations, an empty canyon and a canyon with two parallel rows of trees, along the side walls. Both canyons were oriented with angles of 0°, 30° (see figure 1b), and 60°, with respect to the external wind flow. The turbulent flow field was measured on a two-dimensional transversal section of the canyon, using a Laser Doppler Anemometer.

Results and discussion

The flow field within the canyon parallel to the external wind is dominated by an advective motion along the street axis, while, when the canyon is oriented with an angle, the flow shows a complex helicoidal structure. As a consequence, in the empty canyon the mean longitudinal velocity progressively decreases with the increase of the inclination angle, while the transversal mean velocity deviates from zero, following a recirculating structure (see figure 1d, for the 30° wind direction). When the canyon is oriented parallel to the external wind flow, the presence of trees causes an around 80% decrease in the mean longitudinal velocity in between the trees and a 30% decrease of it above the tree crowns. For the 30° and 60° wind directions, trees weaken the transversal recirculation, mostly in the lower part of the canyon (figure 1e, for the 30° wind direction), as well as they hinder the axis parallel flow. This hindering effect is less marked in the downwind upper corner of the 30° rotated canyon (figure 1f), while it affects the entire transversal section of the 60° rotated canyon. The interaction between the external flow and the tree crowns leads to an increase in the flow velocity fluctuations, with respect to the empty canyon, in the upper part of the parallel canyon and along the downwind wall of the rotated canyons. Conversely, around the trees the flow velocity fluctuations are dampened: they decrease of around 10% for the 0° and 30° wind directions and around 40% for the 60° inclination. The experimental data provide useful information to model the urban microclimate and to validate analytical models that simulate pollutant dispersion in urban-like geometries, like *SIRANE* (*Soulhac et al. 2008, 2011*).

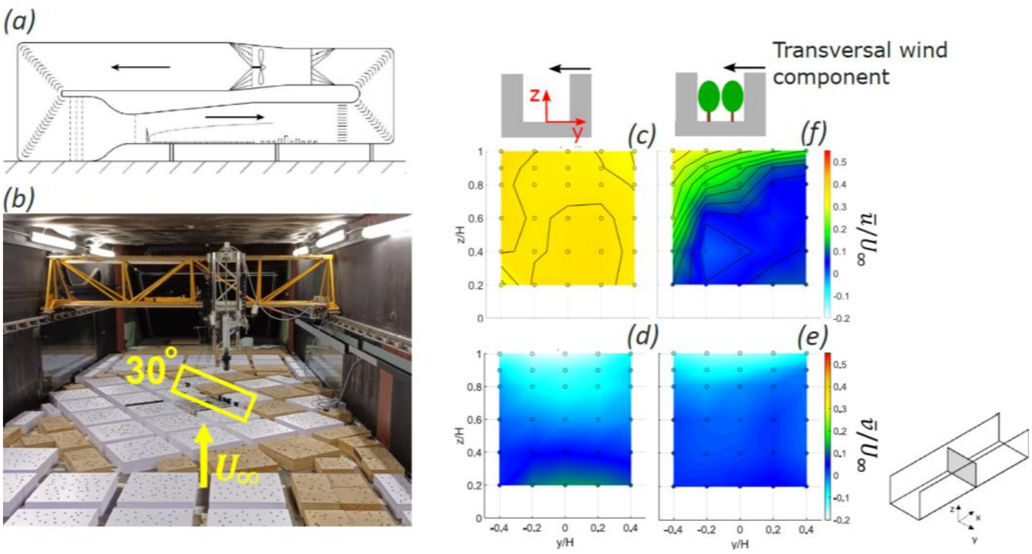

Figure 1: (a) Wind tunnel. (b) Urban network with the street canyon rotated 30° with respect to the wind direction. Mean longitudinal and transversal velocity in the empty (c,d) and vegetated (f,e) canyons, rotated of 30° with respect to the wind direction (see the yellow arrow in panel b).

References

Soulhac, L., Perkins, R. & Salizzoni, P. (2008) Flow in a Street Canyon for any Wind Direction. *Boundary-Layer Meteorology*, 126:365-388.

Soulhac, L., Salizzoni, P., Cierco, F.X. & Perkins, R. (2011) The model SIRANE for atmospheric urban pollutant dispersion; part I, presentation of the model. *Atmospheric Environment*, 45, 7379-7395.

Gromke, C. & Ruck, B. (2012) Pollutant concentrations in street canyons of different aspect ratio with avenues of trees for various wind directions. *Boundary-Layer Meteorology,* 144:41-64.

Fellini, S., Marro, M., Del Ponte, A.V., Barulli, M., Soulhac, L., Ridolfi, L. & Salizzoni, P. (2022) High resolution wind-tunnel investigation about the effect of street trees on pollutant concentration and street canyon ventilation. *Building and Environment*, 226(109):763.

Del Ponte, A.V., Fellini, S., Marro, M., van Reeuwijk, M., Ridolfi, L. & Salizzoni, P. (2024) Influence of Street Trees on Turbulent Fluctuations and Transport Processes in an Urban Canyon: A Wind Tunnel Study. *Boundary-Layer Metheorology*, 190:6.