Influence of vegetation on urban canyon ventilation. Part II: velocity field and turbulent mass fluxes

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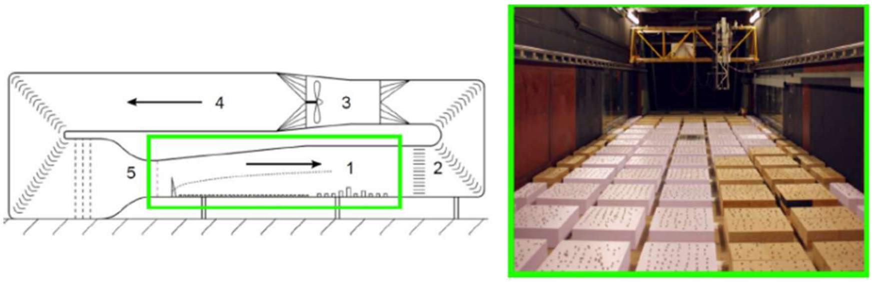
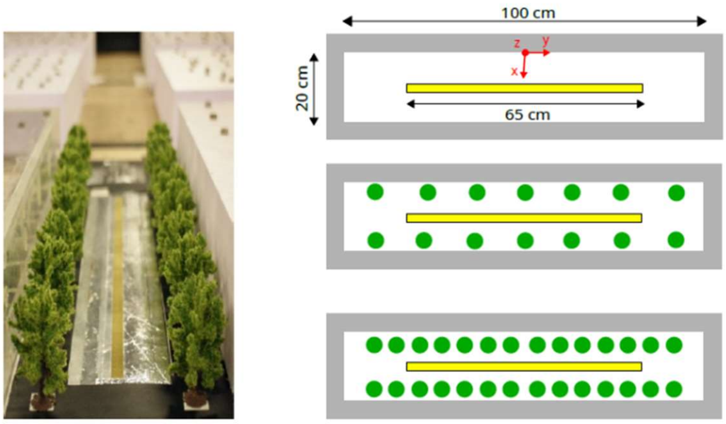
Abstract

The greening of cities is one of the most encouraged mitigation strategies to face the urban heat island phenomenon, as vegetation increases the evapotranspiration and the shading. Moreover, trees enhance the pollutant deposition rate thanks to their large surface area. However, few studies on the impact of tree planting on the natural ventilation and dispersion mechanisms inside urban street canyons are available.

In this framework, we present the results of an experimental campaign carried out in the wind tunnel of École Centrale de Lyon, in France (*figure 1a*). The study was aimed at understanding how the presence and the density of trees affect the flow field inside a street canyon, and if they hinder the air exchange with the external atmosphere. Concentration, velocity, and combined concentration and velocity measurements have been performed inside a street canyon, without street intersections, oriented perpendicular to the wind direction, inserted in an urban network reproduced inside the test section of the wind tunnel. The vehicular pollution has been simulated by a linear source of ethane, which behaves as a passive scalar. The aerodynamic behavior of trees has been reproduced by inserting plastic miniatures of trees along the two long sides of the canyon, using three different tree density configurations: absence of trees inside the canyon, two low density tree rows, and two high density tree rows (*figure 1b*).



(a)



(b)

Figure 1: (a) Scheme of the wind tunnel (left): 1 test section; 2 heat exchanger system; 3 fan; 4 diverging system; 5 converging system and generating turbulence grid. Street network simulated inside the test section (right). (b) Plastic miniatures of trees placed inside the model street canyon (left). Tree density configurations (right): Zero configuration, Half configuration, Full configuration.

The measurements of the mean concentration field reveal that the presence of trees determines the transition from a two-dimensional concertation field to a three-dimensional one. Indeed, the concentration is homogeneous along the longitudinal direction of the empty canyon while, when trees are inserted, the concentration field becomes heterogeneous, with areas of accumulation of pollutant and areas of low concentration. However, the bulk vertical exchange velocity is almost constant varying the tree density. To unveil the reasons for this, we have investigated the structure of the velocity field within the canyon by performing velocity measurements with the LDA (Laser Doppler Anemometer), and we have evaluated turbulent mass fluxes using the LDA coupled with the FID (Flame Ionization Detector).

From the velocity measurements, we find that the mass transfer inside the canyon is governed by recirculating cells transporting the pollutant from the downwind wall to the upwind wall, and they are not weakened by the presence of trees. Moreover, we find that the presence of trees homogenizes the mean vertical velocity, and it decreases the turbulent kinetic energy. Turbulent mass fluxes have been evaluated both inside the canyon and at the rooftop. It is found that inside the empty canyon the turbulent mass fluxes are strongly homogeneous and negative, while they are almost negligible in the case with trees. A quadrant analysis of the turbulent mass fluxes at the rooftop reveals that the ventilation of the canyon is dominated by the entrance of clean air, and its local contribution to the total turbulent mass flux is homogeneous along the canyon, with and without vegetation.

The statistical analysis of concentration time series measured in different spatial points inside the canyon reveals that the dispersion phenomenon can be entirely modeled with a Gamma distribution, even if the Lognormal and the Weibull 2p distributions perform a good fitting as well, and that the extreme concentration events are governed by an exponential law.

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