A laboratory investigation of flow and turbulence over a two-dimensional urban canopy
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**Purposes**
- To determine mean and turbulent fields in correspondence of a two-dimensional array of parallel-kipped obstacles in the case of neutral boundary layers
- To examine differences between different geometrical configurations, as a function of the Aspect Ratio of the array, in order to investigate the main characteristics of the turbulence both in skimming flow and wake interference regime
- To analyze the mean velocity, the variance, the Reynolds stress, the skewness factor, the production term of the turbulent kinetic energy and its rate of dissipation for each geometrical configuration
- To study the concentration fields associated with stationary sources of passive tracers located within and above the canyon area
- To measure the mean, the variance and the skewness factor of the concentration
- To determine parametrical laws relating concentration fields and canyon geometry

**Introduction**
- Interaction between urban areas and atmosphere has obtained increasing attention in research in last decades, because of the rapid growth of population in large cities, that determined degradation of environmental quality and human comfort and increase of air pollution. One of the most important parameters used to describe the geometrical configuration, developed by Housian M. and Lee H. M. (1986), is the Aspect Ratio $AR=\frac{W}{H}$, i.e. the ratio of the spacing between buildings, $W$, to the height of the buildings.
- Both three-dimensional and two-dimensional building array are investigated through numerical simulations and experiments to study turbulence flow and concentration fields.
- For example Salzizzi P. et al. (2011) studied the turbulent transfer between a two-dimensional cavity and the overlying boundary layer, presenting the vertical profile of different parameters.
- Wilh. Brens W. et al. (2014) and Li X.-R. et al. (2014) used numerical simulation (LES) to simulate transport processes within and above a two-dimensional street canyon.

**Experimental set up**

**Measurement technique**
- High Speed CMOS-Camera
  - resolution: 1024 * 1024 pixels
  - maximum frame rate: 120000 frames per second
- LD PUMPED ALL-SOLID-STATE GREEN LASER
  - wavelength: 532 nm
  - output power: 5 W
- ROYOHMINE WT – WATER ($C_{0}=100\mu g/l$)
  - excitation wavelength: 440 nm
  - emission wavelength: 625 nm

**Feature Tracking** is a technique that allows reconstruction of velocity field identifying local regions of interest (features) in several consecutive images, based on light intensity gradients, i.e. using a laplacian approach.
In all the experiments presented the frame rate is set to 250 frames per second and the time duration of each experiment is 40 s.

**Results**

**MEAN VELOCITY FIELD**

Velocity components are expressed as $U$ and $W$. For $AR=1$, the vortex is slightly shifted downstream and towards the top of the canyon and, at the bottom-right corner of the canyon, a little counter-rotating vortex is present. For $AR=2$, instead, the main vortex is significantly shifted downstream and a well-defined counter-rotating vortex form near the leeward building.

**HORIZONTAL VELOCITY VARIANCE**

According to other works reported in the literature, the variance of the non-dimensional horizontal velocity components, $\frac{u'^2}{U^2}$ (here primes are fluctuations around the mean) assumes lower values inside the canyon (nearly one order of magnitude) irrespective of $AR$.

**VERTICAL VELOCITY VARIANCE**

The non-dimensional vertical velocity variance, $\frac{w'^2}{U^2}$, shows large values within a tongue-like feature, coming from the outer flow, near the windward wall when $AR=1$, while $AR=2$, (b), where in the right-hand of the canyon $\frac{w'^2}{U^2}$ is of the same order of that present in the outer flow.

**REYNOLDS STRESS**

The non-dimensional, vertical momentum flux $\frac{\langle u'w' \rangle}{U^2}$ is negative above the canyon for both the configurations, while, inside, it strongly depends on $AR$. In fact, for $AR=1$, it is positive almost everywhere while, for $AR=2$, it is positive only near the bottom right corner of the canyon.

**HORIZONTAL SKEWNESS FACTOR**

$S_h = \frac{\langle u'^3 \rangle}{\langle u'^2 \rangle^\frac{3}{2}}$ for $AR=1$ (a) and 2 (b) is negative almost everywhere inside the canyon for both ARs, except near the canyon top, where, for $AR=1$, a region of large, positive $S_h$ is present. For $AR=2$, large (positive) values are located also near the buildings top. The skewness factor of the vertical velocity component has been calculated too, but it is not presented here.

**SHEAR PRODUCTION TERM**

The production term $P$ is defined $P = -\frac{\partial<u'w'>}{\partial z}$ ($=1.2,1.2,1.3$) indicate the axis of the coordinate system. It is positive above the canyon top for both $AR=1$ (a), where the region of maxima corresponds with the mixing, characterized by strong vertical shear. For $AR=2$ (b) the region of maxima is still present, even though it is less evident.

**DISSOLUTION RATE**

The rate of dissolution of TKE, $\alpha$, is estimated as $\alpha = \frac{1}{3} \frac{\partial \langle u'^2 \rangle}{\partial z}$.

Lower values occur for both ARs within the canyon, particularly near the leeward building. Above the canyon, $\alpha$ reaches higher values, with peaks above the rooftops.

**Conclusions**
- Analysis of the mean flow and of the turbulence inside and above a 20 urban canopy layer through a water channel experiment.
- Focus on the representation of 20 maps of vertical and horizontal mean velocity, vertical and horizontal velocity variance, Reynolds stress, skewness of horizontal and vertical velocity, different terms of the shear production of the TKE budget and the dissipation rate.
- The study concerns two different kind of flow, skimming flow and wake interference regime, according to aspect ratio.
- Evaluation of concentration fields considering a stationary, point source, giving special attention to mean concentration, concentration variance and skewness factor.

**References**

DICEA - Dipartimento di Ingegneria Civile Edile ed Ambientale

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