5.35 MODELLING THE AIR FLOW IN SYMMETRIC AND ASYMMETRIC STREET CANYONS

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INTRODUCTION

In recent years a large amount of research has been conducted on urban scale and street canyon. Control of air quality inside cities is important for human health. To achieve this objective, street canyon modelling plays a significant role. Pollutant dispersion inside canyons are determined by wind flow around this complex geometry. Experimental investigations have been made by means of field measurements such as Vachon, G. et al. (2000) or wind tunnel experiences as Meroney, R.N. et al. (1996) or Kastner-Klein, P. and E.J. Plate (1999) . In many of these researches, they have used CFD models in several configurations, for instance Assimakopoulos, V.D. et al. (2003) or Sini, J.-F. et al. (1996). These models are based on a numerical resolution of Navier-Stokes equations with a turbulence closure.

In this study, the aim is contribute to the understanding of air circulation inside street canyons. In order to achieve this purpose, several configurations of canyons are investigated. Two-dimensional sequences of real-scale street canyons (order to obstacles height is meters) with different features (symmetric canyons and asymmetric canyons forming step-up and step-down notch configurations) are simulated. These general configurations are modified to investigate some parameters such as aspect ratio, W/H, where W is the width of street and H is the height of buildings. Flows with high Reynolds numbers are modelling. FLUENT CFD software is used.

MODEL DESCRIPTION

FLUENT CFD software is used to calculate air flow characteristics in different configuration of street canyons. In this case, it is based on Reynolds-Averaged Navier-Stokes equations (RANS). RNG k-ε turbulence model is turbulent closure used.

RNG- k-ε turbulence model is similar to k-ε standard turbulence model, both solve two equations, one of them for turbulent kinetic energy (k) and other for dissipation (ε). Three differences exist among both models. RNG k-ε turbulence model solve ε equation with an additional term. Moreover, Prandtl numbers and effective viscosity are computed by analytical expressions (Chan, T.L. et al., 2002).

The resolution of governing equations is made by means of a collocated grid system using the finite volume method. The segregated method is employed to solve discretised equations and the algorithm used to solve pressure-velocity coupling is SIMPLE (Semi-Implicit Method for Pressure-Linked Equations). The advection-differencing scheme applied was the second-order upwind scheme.

SIMULATION FEATURES

Air flow in a sequence of five street canyons is simulated in each case. The grid used inside canyons are 0.125m x 0.125m. Outside, an irregular mesh is used.

Flow inlet boundary conditions are the same in all cases studied. These conditions are described in the following expressions:

$$u\ (z) = \frac{u_*}{\kappa}\ln\left(\frac{z}{z_0}\right) \tag{1}$$

$$v = 0 \tag{2}$$

$$k = \frac{u_*^2}{\sqrt{C_\mu}} \tag{3}$$

$$\varepsilon = \frac{u_*^3}{\kappa z} \tag{4}$$

where, u and v are horizontal and vertical velocity respectively. k and ε are turbulent kinetic energy and its dissipation. In addition, u_* represents friction velocity (was set at 0.3 m s^{-1}, u=5.5 m s^{-1} approximately in the top of the domain) and z_0 is roughness length (was set at 0.1 m). C_μ is a model constant and κ is von Karman's constant ($\kappa = 0.4$).Under these conditions the Reynolds number employed is very high (~10^7).

The geometry consists of a sequence of five street canyons in all situations.

Symmetric cases

In these cases, buildings have the same height (20 m). Only street width is changed to obtain, in each case, a different aspect ratio (W/H). W represents the canyon width and H the building height. Situations with W/H = 2, 1, 0.5 and 0.25 are simulated.

Asymmetric cases

In these simulations, one building of the central canyon is taller (30 m) than others. Two situations are studied. In one of them, the windward buildings of central canyons are 30m-high buildings forming step-up notch configurations in these canyons. In the other one the leeward buildings of central cavities are 30m-high buildings forming step-down notch configurations in these canyons. Several configuration with different aspect ratios (W/H = 1, 0.5, 0.25) are analysed.

RESULTS

Simulations are made in sequences of street canyons with different characteristics, but analyse of results are focused on respective central canyons.

Symmetric cases

Wind flow features obtained is according to Sini, J.-F. et al. (1996). Several flow regimes (skimming flow, including multi-vortex regimes) have been found in these simulations with different aspect ratio (W/H). In addition, highest values of turbulent kinetic energy are detected in upper corner of windward buildings (see Figure 1).

Asymmetric cases and its comparison with symmetric cases

Wind flow characteristics obtained in central canyons of asymmetric cases are very different depending on central canyons forming a step-up or a step-down notch configuration. These results are shown and compared to those of symmetric cases in two different subsections.

Step-up notch configuration in central canyon

Wind flow patterns of different aspect ratio configurations are shown in Figure 2. In W/H=1 case, one vortex distorted (its centre slightly shifted upwards and towards the downwind wall) is detected in central cavity. In W/H=0.5 configuration, two counter-rotating vortices appear. The lower vortex is much weaker than other, and the upper one is distorted and displaced to upward due to high building. Finally, when canyon aspect ratio is 0.25, four counter-rotating vortices are found. Comparing these flow pattern to symmetric cases with same aspect ratios (W/H=1, 0.5, 0.25), it can be concluded that they are radically different.

Turbulent features of wind flow are also changed comparing to symmetric configurations. In step-up situations, a large value of turbulent kinetic energy (*k*) have been found in windward wall. It seems to be produced by the tallest obstacles. For instance, in W/H=1 configuration, the maximum value of k in this zone is twice as much as in the symmetric canyon.

Step-down notch configuration in central canyon

Wind flow patterns of different aspect ratio configurations are shown in Figure 3.An important result in these configurations is the wake created by 30m-high buildings, affecting to air circulation in central canyons. In W/H=1 situation, a counter clockwise-rotating vortex in central cavity is detected. It rotates in opposite direction than symmetric case with W/H=1. Similar situations appear in W/H=0.5 and W/H=0.25 configurations. In the first case two counter-rotating vortices are observed, but their rotation direction is opposite than symmetric canyon case with W/H=0.5. Inside the central street canyon of the last configuration, three vortices and an additional weak vortex collocated in the bottom corner of the leeward wall are detected. Their rotation direction is also opposite than the corresponding symmetric case. These results are due to the wakes created by the tallest buildings which is situated above central cavities.

Maximum values of turbulent kinetic energy (*k*) in central canyons with step-down configuration are found in upper zone of upwind wall. This fact seems to be due to re-circulating zone, produced by 30m-high obstacles, collocated above them. This situation is radically different comparing with symmetric cases where the maximum values of *k* in central cavities are in upper corner of windward wall.

CONCLUSIONS

Only a taller building affects the air flow feature inside canyons. It seems to be this influence very important. Flow patterns and turbulent properties are radically different in symmetric and asymmetric situations. In addition, the 30m-high obstacle affects upwind zone (step-up notch configuration in central canyons) and downwind zone (step-down notch configuration in central canyons).

Pollutant distribution inside street canyons are determined by wind flow characteristics inside them. Thus, it is important the existence of one building taller than the others because it affects very much flow pattern, and then pollutant distribution inside canyons could be radically different with or without it.

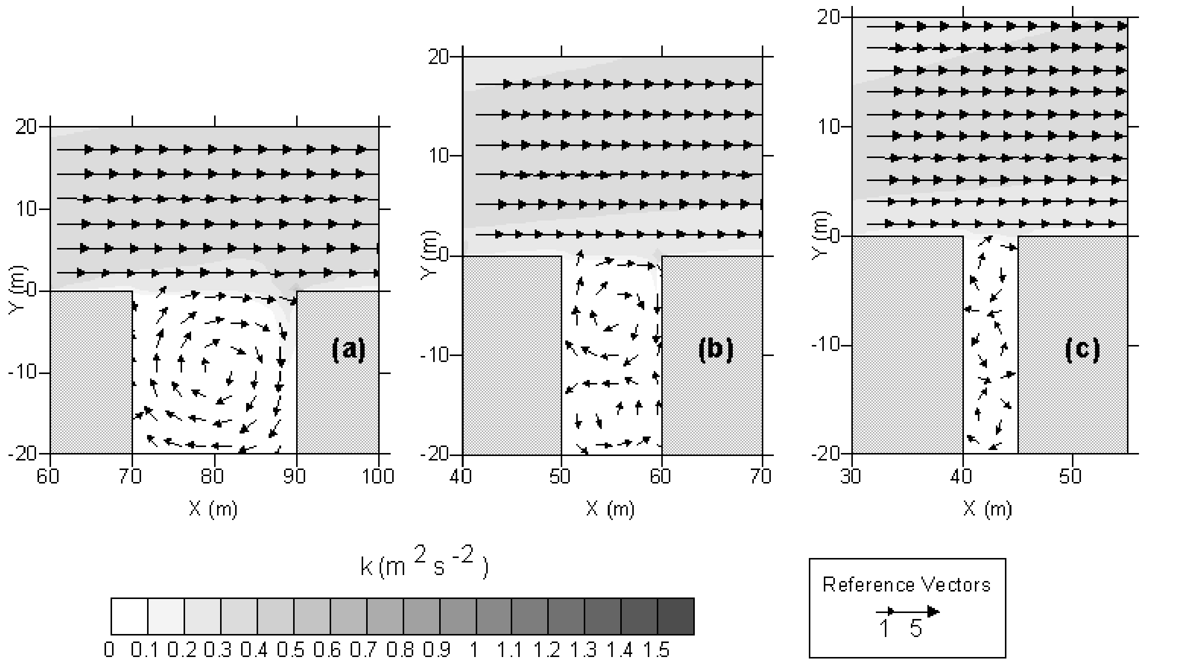

Figure 1. Wind flow and turbulent kinetic energy contours in central canyons of symmetric configurations.

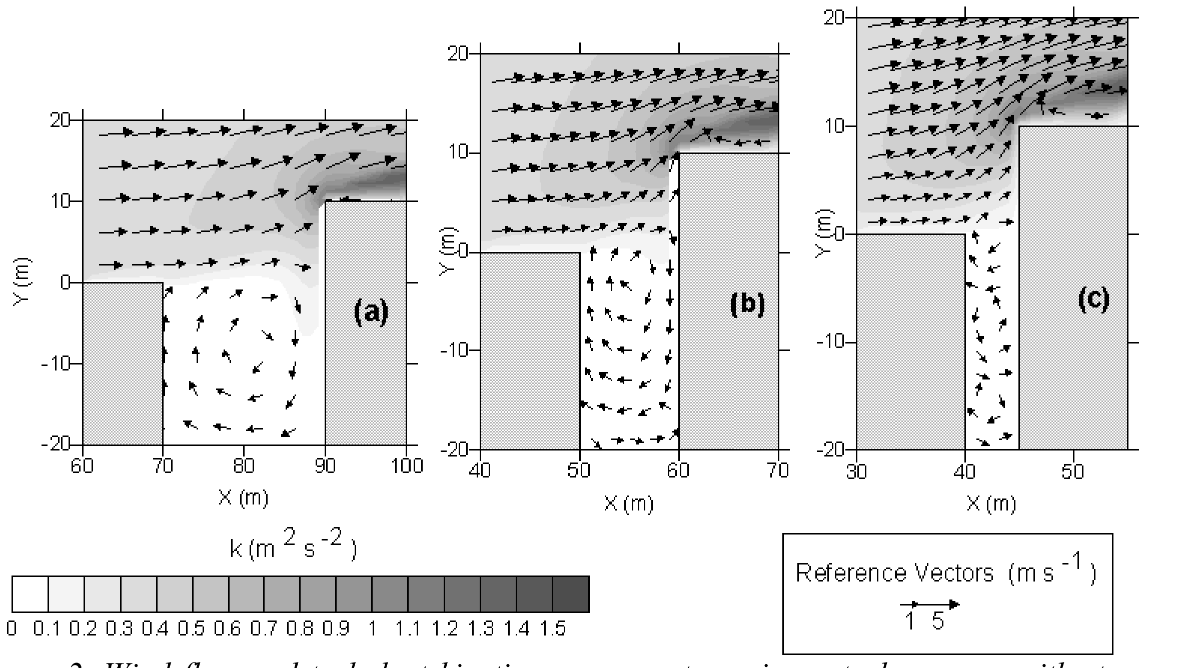

Figure 2. Wind flow and turbulent kinetic energy contours in central canyons with step-up notch configurations.

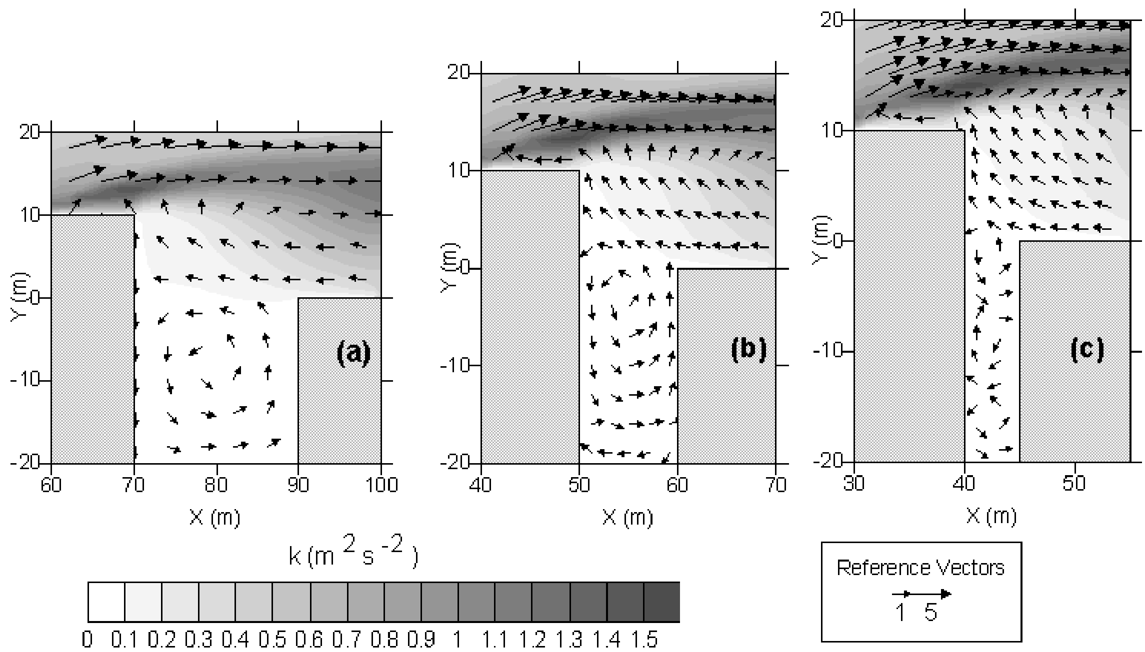

Figure 3. Wind flow and turbulent kinetic energy contours in central canyons with step-down notch configurations.

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