5.14 COMPUTATIONAL MODELLING OF AIRFLOW IN URBAN STREET CANYON AND COMPARISON WITH MEASUREMENTS

J. Pospisil[1],M. Jicha[1], A. Niachou[2] and M. Santamouris[2]
[1] Brno University of Technology, Faculty of Mechanical Engineering, Brno, Czech Republic
[2] National and Kapodestrian University of Athens, Athens, Greece

INTRODUCTION

Residential buildings in cities are ventilated using different systems of ventilation. Except systems that consist in opening windows there are more sophisticated systems that are controlled by different manners. Among them, hybrid systems are recently gaining more attention as they promise to be energy effective with a good control of indoor air quality. Operation of such ventilation systems can be significantly influenced by airflow in street canyons. Thus, correct prediction of airflow is a prerequisite for a good function of such systems. Authors of this paper choose Agiou Fanouriou street canyon in Athens as a test canyon for comparison of modelling and field measurements.

Computational model of the street canyon was formed with several blocks of buildings on each side of the canyon according to the actual situation. Three different directions of wind were assumed, namely perpendicular, oblique under the angle of 45 ° and parallel with speeds of 3m/s and 6m/s at the height of 25m above the ground level. Computational modelling was done for three different turbulence models, namely K-ε Hi-Re, K-ε RNG and K-ε Lo-Re. Two different types of boundary conditions were tested: a) velocity profile for neutral stratification assigned at all inlet boundaries and b) velocity of wind assigned at the height where the wind velocity was measured.

GEOMETRY OF THE STUDIED STREET CANYON

The Agiou Fanouriou Street canyon is located in residential part of city of Athens. Regular net of perpendicularly intersecting street canyons forms this urban area, see fig.1. Information about geometry of the urban canyon was obtained from *Niachou,* (2002). The studied canyon has a SSE orientation and its main axis is 150 degrees from the North direction. The canyon's length is 76 m, width is 8 m and the average height of buildings is 21 m. Balconies and shades in the form of awnings disturb facades forming street canyon. Cross section of the canyon is shown in fig.2. Buildings have two floors above the ground with plane façade. Terraces form other tree floors of the building. Roof of buildings is flat. Buildings of same geometry form the studied street canyon. The canyon is modelled without trees and without standing cars. A numerical model of a calculated area involves the studied street canyon and surrounding buildings as shows fig.1.

Balconies and awnings were taken into account in the model because they significantly influence airflow in a façade boundary layer. Undisturbed wind velocity and wind directions were obtained from anemometer located on rooftop at height 25m above ground level. Measured wind conditions were used as input parameter for numerical prediction. A 3D anemometer located on 2nd floor (Fig.2) served for comparison of predicted and measured values.

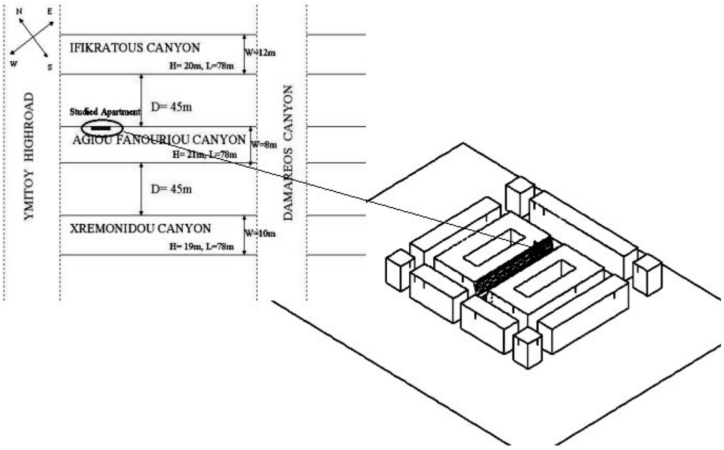


Figure 1. *Ground plan of solution domain and corresponding numerical model*

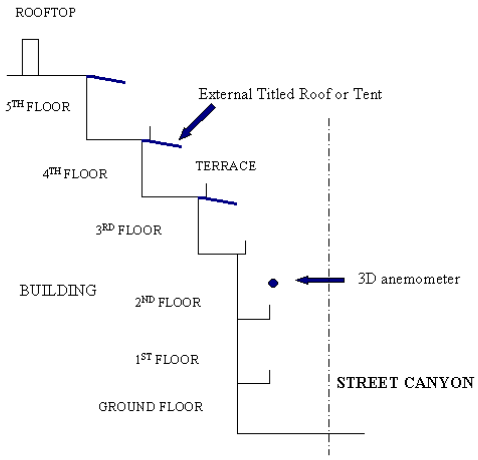


Figure 2. Sketch of the building's façade

GAS PHASE EQUATIONS AND SOLUTION PROCEDURE

The governing equations for the continuous phase were solved using the commercial CFD code Star-CD based on the finite volume procedure. The set of equations for the conservation of mass and momentum is solved for steady incompressible turbulent flow. The equation for a general variable ϕ has the form:

$$\frac{\partial(\rho\phi)}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_i\phi)=\frac{\partial}{\partial x_i}\left(\Gamma\frac{\partial\phi}{\partial x_i}\right)+S_\phi \tag{1}$$

Variable ϕ stands for velocity components and S_ϕ represents source term.

Boundary conditions

The numerical model represents only a part of the actual urban area. Size of the numerical model is limited by the hardware capacity. Numerical model consists of 1 million control volumes. Limited size of the numerical model emphasises importance of appropriate boundary conditions, which must correctly substitute influence of surrounded area and wind conditions. Top face of the numerical model is assigned "slip wall" boundary condition. Side boundaries enable setting actual wind velocity profile created in canopy layer as a result of surrounding urban area. Parametrical roughness is specified on ground surface in the area between boundaries and models of buildings. Parametrical roughness enables to simplify obstacles with complex geometry located on ground surface. Buildings and other obstacles located close to the studied street canyon were modelled with actual geometry, since directly influence wind flow field in the canyon. Boundary condition "no slip wall" is set on ground surface between buildings, building facades, roofs and other obstacles.

Wind conditions

Wind velocity and wind direction were assigned in two different ways. The first one includes wind velocity profile prescribed at incoming-air faces of the numerical model. This way enables to involve influence of surrounded area at position of boundary faces using the following formula for wind velocity profile:

$$\frac{u}{u_{ref}}=\left(\frac{z-d_0}{z_{ref}-d_0}\right)^{0.23} \tag{2}$$

The wind velocity profile is developing above the ground surface as a result of parametrical roughness of the area. Longer distance between boundaries with the above-assigned velocity profile and buildings results in stronger deformation of the boundary wind velocity profile.

Second method of boundary condition assignment uses measured value of wind velocity in the layer above the studied street canyon. In the numerical model, the measured wind velocity was assigned in the air layer at the height corresponding to the position of the anemometer located on rooftop at height 25m above ground level where the wind velocity was measured. Pressure boundary conditions are assigned on side faces of the numerical model. This approach keeps the wind velocity above the studied canyon in accordance with measurements. Wind velocity profile at the canopy layer then results from the actual geometry of buildings and ground roughness. Parametrical roughness is set on ground surface in the area between boundaries and modelled buildings in the same way as mentioned above.

Turbulence models

In total, three different turbulence models were used. As a first one, K-ε Hi-Re model was used as most common model used in CFD. As a second, K-ε RNG model of turbulence was taken in to account. From different studies follow that this model provides good results of air flow in urban areas. Third, the K-ε Lo-Re model of turbulence (*Lien, F.S., Chen, W.L., and Leschziner, M.A*., 1996) was used. Three different wind directions, two different wind velocities and two different types of boundary conditions were tested with all models of turbulence.

RESULTS AND DISCUSSION

Geometry of the calculated area is the most important parameter forming the air velocity field. Terminal airflow patterns are strongly influenced by interaction of undisturbed wind velocity profile with the first modelled buildings in the solution domain. If a street canyon is oriented parallel with the wind then the major quantity of air passes through this canyon and perpendicular canyons are without intensive longitudinal air motion. Airflow field is much less predictable in cases when wind direction is oblique to the axis of the street canyon.

Series of calculations were done fore three different wind directions, namely longitudinal, perpendicular and oblique (45°) wind direction. The wind direction orientation is related to the orientation of the longitudinal axis of the studied street canyon. Velocity fields were solved for wind velocities 3 m/s and 6 m/s as obtained from the measurements at height 25 m above ground level. Predicted velocity fields show that K-ε Hi-Re model of turbulence differs from two others. K-ε Lo-Re and K-ε RNG models of turbulence give very similar air velocity fields.

The most intensive movement of air appeared with oblique wind direction to the canyon axis. This wind direction forms a more complex air velocity field showing two vortexes with opposite rotation in the cross section. Velocity field obtained for longitudinal wind direction show lower air velocity movement at the studied canyon in comparison with oblique wind direction. This results from buildings configuration in the area in front of the studied canyon in the direction of a longitudinal axis of the canyon. Front side (entrance) of the canyon forms border of a perpendicularly oriented highway. Continuous block of buildings was modelled on the opposite side of the highway. This block of buildings lifts the air above the studied canyon in situations of parallel wind direction. Perpendicular wind direction creates one vortex in the upper part of the canyon. This wind direction causes very different velocity fields around the ends of the canyon compared with central part of the canyon.

Wind velocity values obtained from 3D anemometer were used fore comparison of results obtained by CFD modelling. Box plots in figures 3, 4 and 5 compare experimental values (Niachou, 2003) with CFD prediction.

CONCLUSIONS

- When comparing two methods of boundary conditions assignment, it is seen that parallel wind direction flow with wind velocity profile gives higher wind velocities in comparison with wind velocity layer. This trend is not so clear for other wind directions. For oblique wind direction this trend is valid only for the vertical component of the wind velocity. Longitudinal and transverse wind components are nearly similar for both kinds of boundary conditions.
- From comparison of measured values with CFD predictions it is obvious that in case of oblique wind direction, an average experimental value is often located between predicted values obtained by two mentioned kinds of wind conditions.
- Results obtained for wind velocity layer boundary conditions correspond with the average experimental values in case of parallel wind flow.
- On the other hand the wind velocity profile boundary condition overestimates wind velocity at the same position.
- Predictions obtained by both kinds of wind conditions underestimate wind velocity in case of perpendicular wind direction.

Experience obtained from this study shows that comparison of predicted and experimental results is difficult due to very unsteady wind conditions during field measurements. CFD modelling provides very detailed (much more than any measurements can do) 3D velocity field over a part of urban area. This complex velocity field can serve as input data for calculation of air infiltration into buildings. Experimental measurement is necessary completion as a validation tool for predictions but it has a very serious limitation due to unstable meteorological conditions that mostly prevail in a real situation.

ACKNOWLEDGEMENT

Financial support from the Brno University of Technology Research Plan MSM262100001 is gratefully acknowledged.

REFERENCES

A. Niachou, K.Papakonstantinou, M. Santamouris, 2002: RESHYVENT ClusterProject - WP10-Urban Impact in the EU, Report No. RESHYVENT-WP10-TR-2-June 2002

A. Niachou, M. Santamouris, 2003, RESHYVENT ClusterProject - WP10 - Urban Impact in the EU, Report No. RESHYVENT-WP10-TR-10-March 2003

Lien, F.S., Chen, W.L., and Leschziner, M.A. 1996, 'Low-Reynolds-Number Eddy-Viscosity Modelling Based on Non-Linear Stress-Strain/Vorticity Relations', Proc. 3rd Symp. on engineering Turbulence Modelling and Measurements, Crete, Greece.

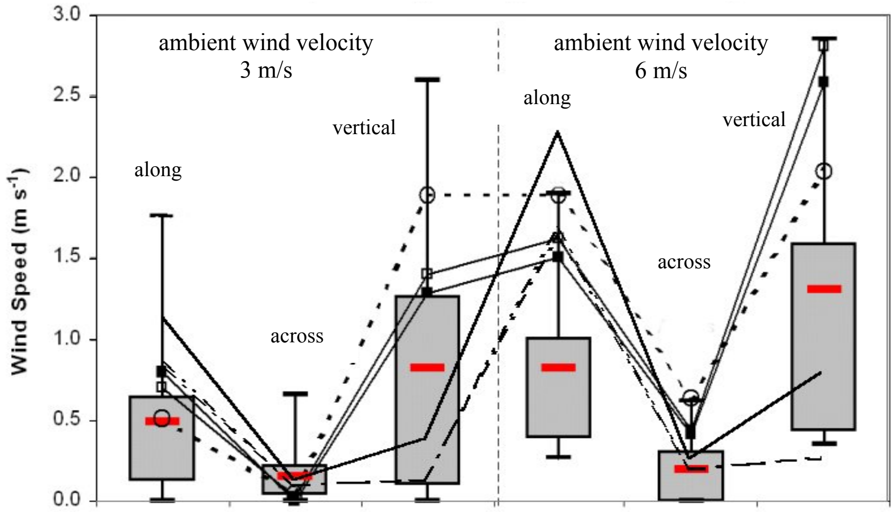
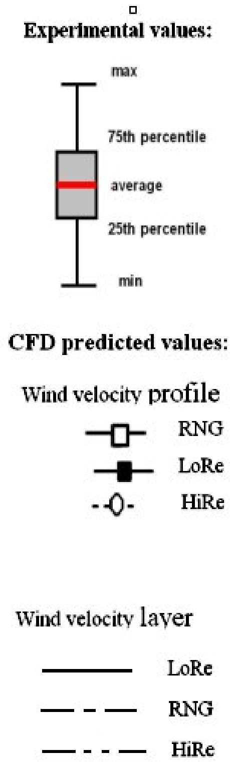


Figure 3. Comparison of velocity components results obtained for oblique flow



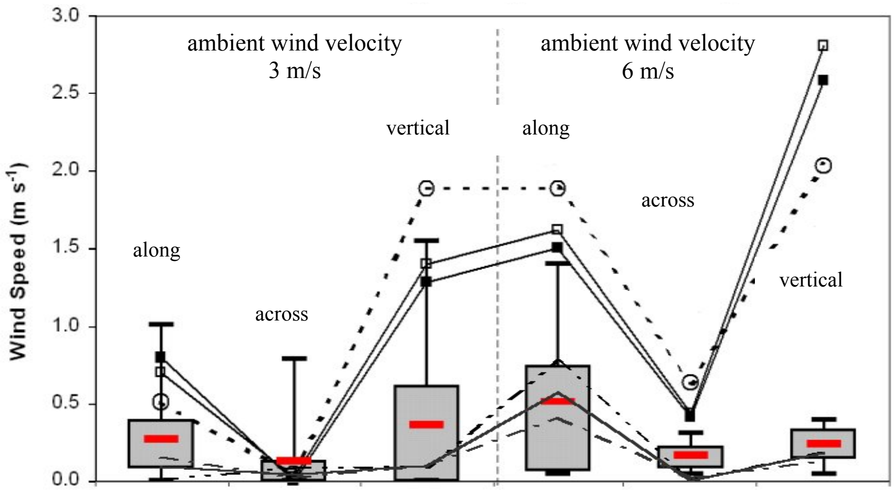


Figure 4. Comparison of velocity components results obtained for parallel flow

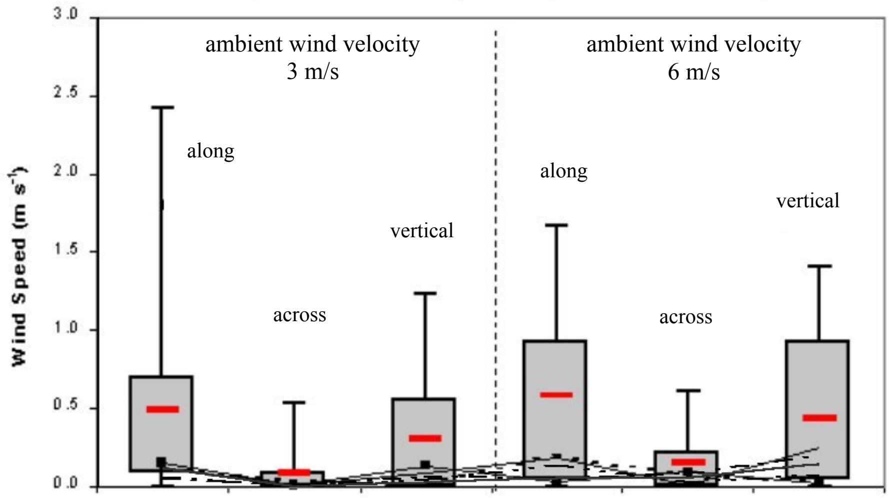


Figure 5. Comparison of velocity components results obtained for perpendicular flow