VALIDATION EXERCISE UTILIZING ADREA AND STAR-CD CODES IN URBAN SCALE. THE MUST EXPERIMENT

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INTRODUCTION

Addressing the problem of the local scale flow and dispersion modelling quality assurance and uncertainty, a validation and intercomparison exercise is taken place within COST Action 732. The whole effort is based on the "Mock Urban Setting Test - MUST", an extensive field test carried out on a test site of the US Army in the Great Basin Desert in 2001 (*Biltoft, C.A.*, 2001; *Yee, E.*, 2004). A total of 120 standard size shipping containers were set up in a nearly regular array of 10 by 12 obstacles, covering an area of around 200 by 200 m. The terrain of the field site is characterized as 'flat open terrain', an ideal horizontally homogenous roughness. Wind tunnel tests were carried out, in the large boundary layer wind tunnel facility at the Environmental Wind Tunnel Laboratory at Hamburg University (*Bezpalcova, K.*, 2005).

Accurate numerical models, such as CFD, are needed to predict the wind flow and pollutant dispersion in relatively complex areas like urban environments. However, the quality of such models must be determined and improved using extensive model evaluation. In this simulation the experimental data from wind tunnel have been used as a reference for the validation of the numerical codes. The computational simulations have been performed using: a) the laboratory code ADREA and b) the commercial code STAR-CD.

METHODOLOGY

ADREA and STAR-CD solve the Reynolds averaged equations of mass and momentum for an incompressible, fully turbulent and isothermal flow. Turbulence closure is obtained through the eddy viscosity concept, which is calculated by the most popular two-equation model, standard k-ε. The differential equations governing the conservation of mass and momentum within the fluid, are discretised by the finite volume method.

The computational site includes 120 buildings, which were positioned in such a way that they created the basic geometrical unit of the urban areas, street canyons. The buildings were positioned normal to the wind tunnel's axis (Figure 1).

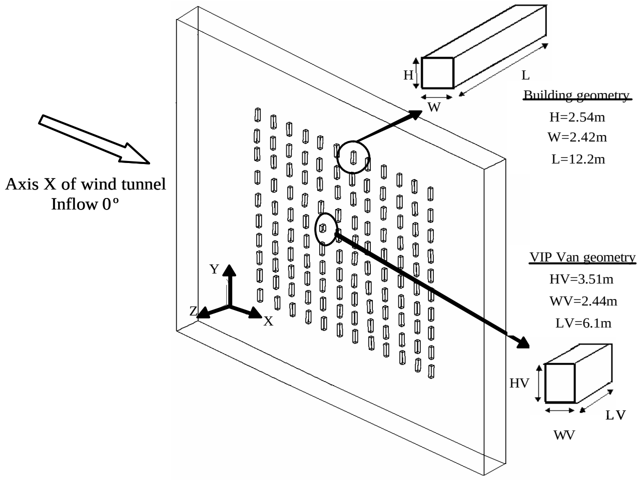

Fig. 1; Schematic diagram of the simulated case. The picture shows the dimensions of buildings and the VIP van as well as the orientation of the buildings in terms of the wind flow direction.

The dimensions X,Y,Z of the computational domain that includes all buildings in the area are different for the two models and are presented in Table 1.

Table 1. The total size of computational domain for ADREA and STAR-CD

Model	Length X(m)	Width Y(m)	Heigth Z(m)
ADREA	345.7952	345.1668	19.4301
STAR-CD	300	314	21.06

For the ADREA simulation the grid resolution was 176(x-axis) x 98(y-axis) x 32(z-axis) cells. The computational grid was uniform and dense in the area of buildings in order to capture the details of flow variables and had a logarithmic profile in the lateral areas (Figure 2).

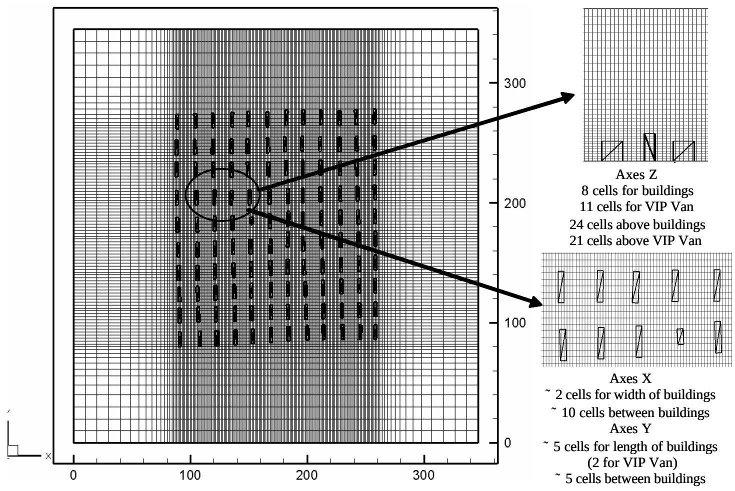

Fig. 2; The computational domain for ADREA simulation.

For STAR-CD simulation two different grid resolutions have been used. The second grid has been refined by a factor of two in the y direction only. The total number of cells for the coarse grid is 549760 and for the fine grid 1099520. The grid resolution is presented in Table 1.

Table 1. Grid resolution for STAR-CD

Direction	Area of buildings			Outside the area of buildings		
	Between buildings	Junction	Above buildings	Upstream of buildings	Downstream of buildings	Lateral
X	110	134	134	8	10	134
Y	50	45	95	115	115	20
Z	8	8	24	32	32	32

The computational domain was chosen in order to ensure that the mesh density is high only where needed, i.e. in regions of steep gradients of the flow variables and low elsewhere (Figure 3).

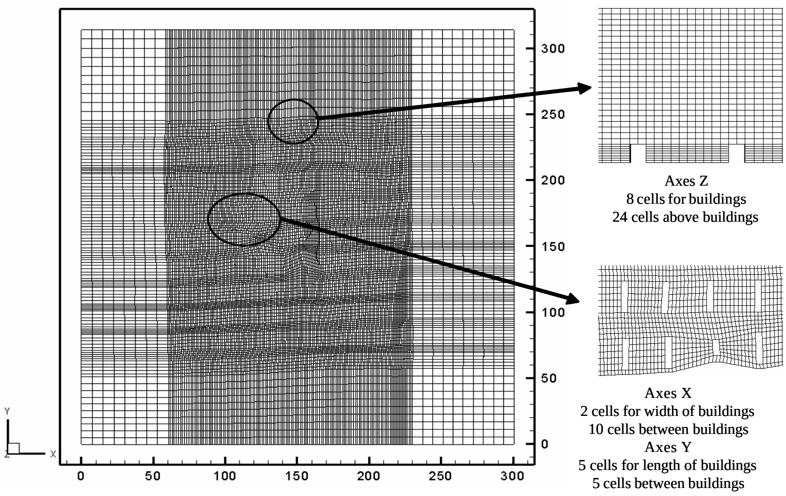

Fig. 3; The computational domain for STAR-CD simulation.

For ADREA code, the main inflow boundary for horizontal velocity is described from the following power law:

$$u(z) = u_{ref} \left(z / z_{ref} \right)^{1/n} \quad (2)$$

In this formula u_{ref} is the reference velocity (8m/s), 1/n the power law exponent (0.16), z the height above the ground and z_{ref} the reference height (8.0664, from mean velocity data of experiment). Turbulent kinetic energy at the inlet was calculated from wind tunnel data, while energy dissipation had the form:

$$e = \frac{1}{z} \quad (3)$$

where z is the height above ground. The outlet plane and the lateral planes are characterised as inlet-outlet boundaries, while for the top plane symmetry boundary condition had been used. The roughness of the ground surface is 0.032m (rough wall) while for the buildings 0.0004 (smooth wall).

For STAR-CD simulation, velocities for all wind components and the turbulent kinetic energy fitted to the reference wind tunnel experiment were used at the inflow boundary. The energy dissipation at the inflow boundary was calculated from the expression:

$$e = C_m^{3/4} \frac{k^{3/2}}{z_{ref}} \quad (1)$$

where z_{ref} is the reference height (7.29m given in the wind tunnel data), C_μ a numerical constant (0.09) and k the turbulent kinetic energy. At the outlet of the domain an outflow condition was assumed. For the lateral planes as well as the top plane symmetry boundary condition had been chosen. Standard wall functions were used for near-wall treatment. The ground surface was treated as rough wall (z_0=0.0165m), while for buildings smooth wall.

RESULTS AND DISCUSSION

Comparisons have been carried out of the CFD models and a comprehensive experimental wind tunnel data. Figure 4 presents the wind speed vector with STAR-CD for B/H˜5.5. Two clock-wise vortices are generated one behind the upwind building and one in front of downwind building. The air travels a sufficient distance down-wind of the first building before encountering the next obstacle and thus the isolated roughness flow is the characteristic regime (*Vardoulakis et al.*, 2003). The wind speed distribution in this canyon is similar to the ones in the upstream and downstream canyons as well as to the neighbourhood canyons.

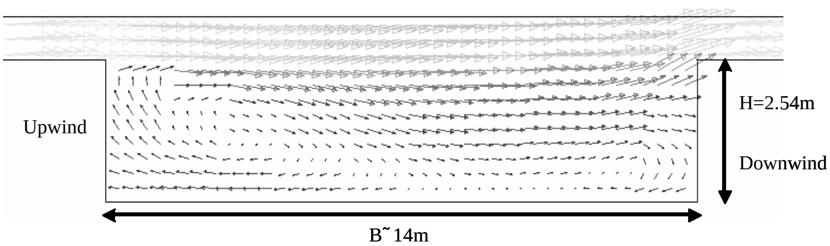

Fig. 4; Vector plot of simulated wind field inside a canyon (y plane normal)

To compare the model's flow measurements with experimental measurements, non-dimensional values of the calculated velocities and Reynolds stresses were determined. Figure 5 presents a comparison between non-dimensional velocity U values of the models results and experimental measurements at 1804 sensor positions, which correspond to different location and altitudes (along the road, between buildings, street crossing). It can be seen clearly from this graphs that the agreement between calculated velocity U and wind tunnel measurements is very good for both models. However, ADREA underestimate the results than STAR-CD.

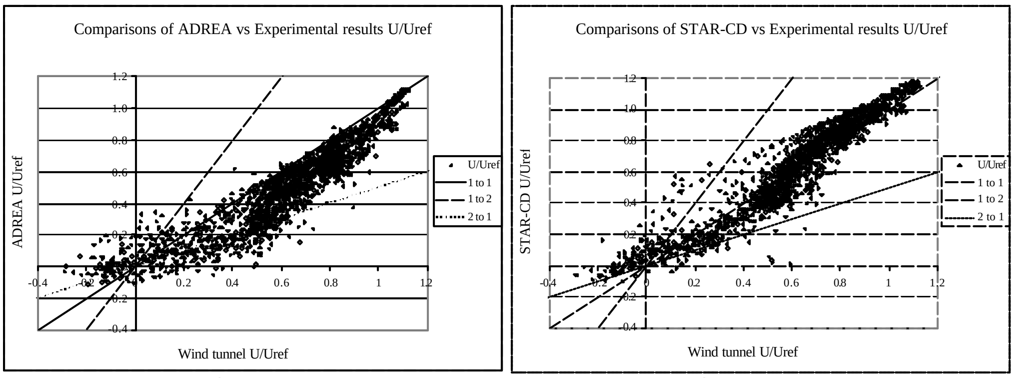

Fig. 5; Comparison of non-dimensional velocity U values of models against experimental results at 1804 sensor positions (ADREA: U_{ref}=6.7459m/s, STAR-CD: U_{ref}=8m/s).

As another validation of the model ADREA the predicted Reynolds stress u'w' are compared with the experimental results at two sensor locations, which were positioned the first behind the VIP van and the second in a junction between four buildings. ADREA model appears to be very reliable in this case (Figure 6).

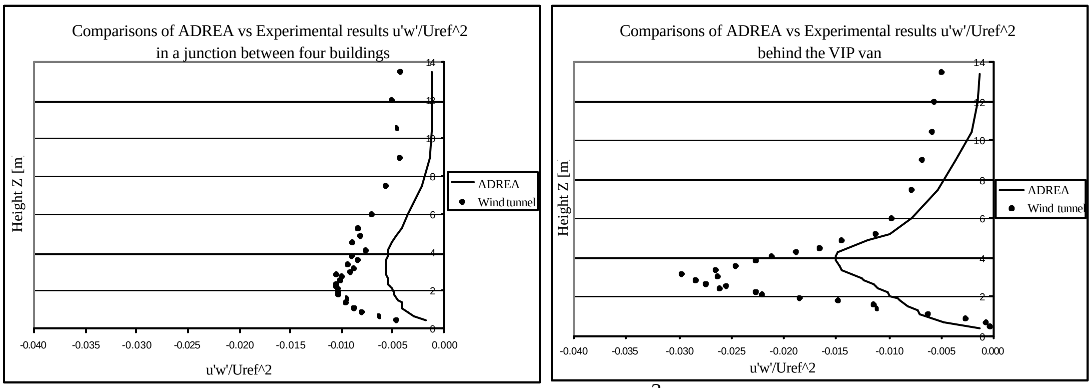

Fig. 6; Vertical profiles of Reynolds stresses $u'w'/U_{ref}^2$ at two sensor positions, the first in a junction between four buildings and the second behind the VIP van.

Finally, a statistical evaluation has been performed using the BOOT software (www.harmo.org/kit) in order to demonstrate the fidelity of the CFD models in simulating the flow field inside the urban canopy. Table 2 presents the performance metrics for velocity U/Uref in three different heights. The correlation coefficient, which reflects the linear relationship between the observed and predicted variables is better for STAR-CD in the first and last case. The R^2 for ADREA in the last case is very low, evidence that the variables are very diffusive. STAR-CD has about 76%, 97% and 100% of predictions within a factor of 2 of observations, while ADREA has about 64%, 85% and 100% of predictions within a factor of 2 of observations.

Table 2. Summary of performance measures, including FB, R and FAC2

Metrics	U/Uref z=1.275m		U/Uref z=2.55m		U/Uref z=5.1m	
	ADREA	STAR-CD	ADREA	STAR-CD	ADREA	STAR-CD
FB	0.289	0.015	0.325	0.024	0.166	-0.043
R^2	0.861	0.938	0.837	0.77	0.663	0.72
FAC2	0.641	0.761	0.849	0.97	1	1

CONCLUSIONS

The ability to predict the flow variables of the 'MUST Experiment', which is an urban configuration consisting of 120 buildings, has been investigated for two CFD models, ADREA and STAR-CD codes using the standard k-e turbulence model. Both models provide consistent results for the case of 0 degrees wind approach. The results of the statistical evaluation using the BOOT software suggest that both models have good performance and can be used for micrometeorology studies including urban areas with irregular streets and buildings of varying heights.

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