NUMERICAL MODEL INTER-COMPARISON FOR A SINGLE BLOCK BUILDING WITHIN ATREUS

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INTRODUCTION
An inter-comparison study of different microscale numerical models has been carried out within the European research network ATREUS (Advanced Tools for Rational Energy Use towards Sustainability with emphasis on microclimatic issues in urban applications). This work was conducted as part of an experimental/numerical validation study for these models so they could be further implemented to provide boundary condition data for building simulation codes. Put into context, the overall objective of ATREUS was to study the urban energy budget taking into account local meteorological and microclimatic conditions through the synthesis of climate models on all scales, i.e. from mesoscale to microscale to the building environment (Papadopoulos and Moussiopoulos, 2005).

METHODOLOGY
Experimental datasets
Two quality assured and fully documented experimental datasets produced in the wind tunnels of the Meteorological Institute of Hamburg University were used in this study. These datasets included wind and turbulence fields around two wall-mounted cubes of different dimensions and wall roughness: (a) The **CEDVAL** cube (0.125m x 0.125m x 0.125m) which was studied in the BLASIUS wind tunnel; and (b) the **ATREUS** cube (0.190m x 0.190m x 0.190m) which was built for the purpose of this study and placed in a multi-layer stratified wind tunnel. The blockage ratio of the wind tunnel models, i.e. the ratio of the cube frontal area to the test section area, was 1.6% in both cases.

Numerical models
Four Reynolds Averaged Navier-Stokes CFD (i.e. Computational Fluid Dynamics) codes using the standard k-ε turbulence model were applied to the two wall-mounted cube test cases. Three of these models, CHENSI, MIMO and VADIS, are research codes which have been used to simulate wind flow and traffic pollutant dispersion at local scales (Sahm et al., 2002). FLUENT is a general-purpose CFD model that has been used in a wide range of air pollution dispersion studies and other engineering applications.

Computational domains and boundary conditions
The models used the same computational domain and grid size. Non-equidistant grid spacing was used in all models apart from VADIS. Vertical profiles of the horizontal wind component and the turbulent kinetic energy fitted to the experimental data were used at the inflow boundary. The energy dissipation at the inflow boundary was calculated from the expression:

$$\varepsilon = C_{\mu}^{3/4} \cdot k^{3/2} / \kappa \cdot z \qquad (1)$$

where z is the height, κ the von Karman's constant (0.40), C_μ a numerical constant (0.09), and k the turbulent kinetic energy. A summary of model boundary and inflow conditions is presented in Table 1.

Table 1: Aerodynamic wall roughness (Z_o), friction velocity (u_*), reference velocity (U_{ref}) at height Z_{ref} (4H upstream) for the two wall-mounted cubes.

	Zo (m)	u_* (m/s)	Uref (m/s)	Zref (m)
CEDVAL	0.0004	0.3500	5	0.685
ATREUS	0.0365	0.0755	1	0.740

Standard wall functions were used by all models for near-wall treatment. Furthermore, Dirichlet conditions were imposed at the top boundary of the domain for all modelled quantities, except for pressure (Newman condition). Symmetry and Newman conditions were imposed at the lateral outflow boundaries. Detailed comparisons between observed and predicted vertical profiles of the longitudinal component of wind velocity (*u*), the vertical component of wind velocity (*w*), and the turbulent kinetic energy (*k*) in the centre plane of flow at positions x/H=-1.5, x/H=-0.625, x/H=0, x/H=0.625, x/H=1.5, x/H=2.5 are presented in this paper.

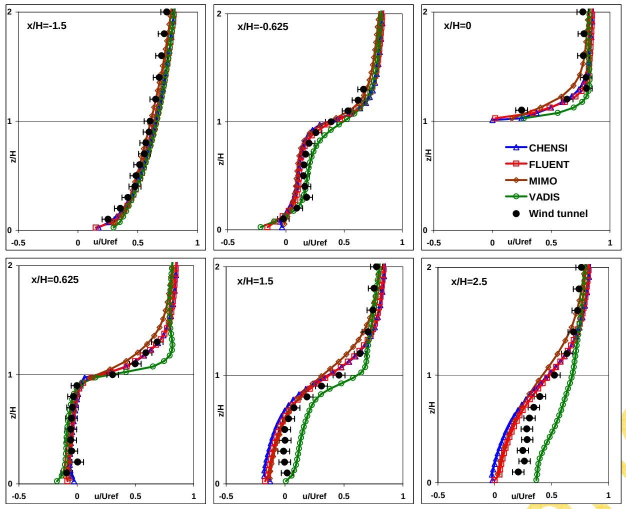
RESULTS AND DISCUSSION

(a) **CEDVAL cube**: The agreement between observed and modelled u-velocity data upstream of the obstacle was very satisfactory, although VADIS slightly overestimated the u-velocity near the cube walls (x/H=-0.625) (Fig. 1a). In agreement with the observations, all codes predicted very accurately the u-velocity for the leeward vortex in the cavity zone behind the obstacle (x/H=0.625). Close to the re-attachment point (x/H=1.5), all models (except VADIS) compute a negative u-velocity near the floor, indicating that this position is predicted to be still far inside the cavity zone. Thus, they overestimated the reattachment length, while VADIS slightly underestimated it (Table 2). In terms of the vertical velocity profiles, all the models except VADIS overestimated the w-velocity component close to the windward cube face (x/H=-0.625), mainly from z/H=0.75 and upwards (Fig. 2a). Downstream from the obstacle, MIMO, CHENSI and FLUENT simulated the w-velocity with reasonable agreement to the experimental data. VADIS significantly over-predicted the upward w-velocity behind the cube, which was probably a consequence of a smaller re-circulation region compared to both experimental results and other CFD simulations. Finally, all of the models had difficulties simulating the turbulent kinetic energy (*k*) near the upwind face of the cube (x/H=-0.625). In this case, VADIS came closest to predicting the observed data. However, it is clear that all four models greatly overestimated *k* in the impingement region near the upwind cube wall, which is a common problem with models using the isotropic eddy viscosity concept (Lakehal and Rodi, 1997). Further downstream the agreement was good, except that VADIS over-predicted k just behind the cube (x=0.625H), while the other three models produced satisfactory results (Fig. 3a).

Table 2: Characteristic lengths of the flow field
(a) CEDVAL cube (stagnation at x/H = -0.625, separation and reattachment at z/H=0.1)
(b) ATREUS cube (stagnation at x/H = -0.50, separation and reattachment at z/H=0.25)

Model	Stagnation (Z_S/H)		Separation (X_F/H)		Reattachment (X_R/H)	
	CEDVAL	ATREUS	CEDVAL	ATREUS	CEDVAL	ATREUS
Wind tunnel	0.64	0.70	-0.88	-0.75	1.50	1.34
CHENSI	0.62	0.80	-0.74	-0.77	2.18	1.89
VADIS	0.72	0.80	-0.83	-0.53	1.33	1.23
MIMO	0.68	0.79	-0.73	-0.50	2.27	2.19
FLUENT	0.65	0.88	-0.72	-0.55	2.24	1.60

(a)



(b)

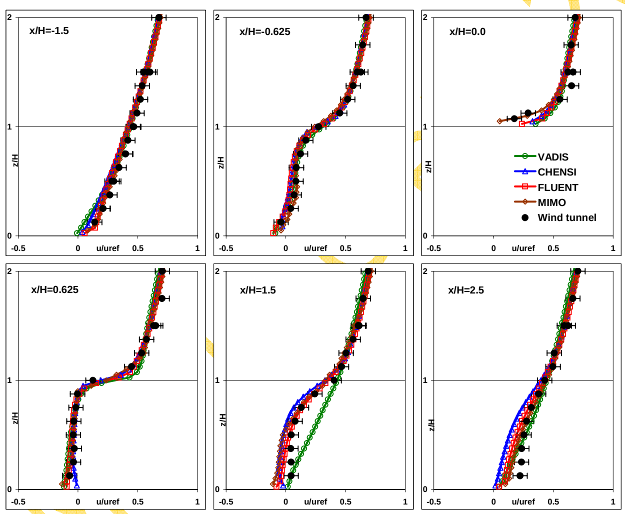


Figure 1: Comparison of experimental and modelled longitudinal velocity (u) profiles normalised with the free stream velocity (a) CEDVAL cube (top); (b) ATREUS cube (bottom)

(b) **ATREUS cube**: CHENSI, MIMO and FLUENT produced very similar results for the profiles of the wind flow components at the cube centre plane. In terms of the longitudinal velocity u shown in the vertical profiles, the agreement between models and experiment was very satisfactory, except downstream of the cube (x/H=1.5 and 2.5) (Fig. 1b). Again VADIS slightly under-predicted the re-attachment length, while the other three models over-predicted it (Table 2). At x/H=1.5 close to the floor (below z/H=0.5), MIMO, CHENSI and FLUENT produced negative u-velocity values, while VADIS calculated positive values, which indicates the different positions of the predicted re-circulation vortices. However, close to the cube at both the windward and leeward face, all models agreed excellently with each other and the measurements. Interestingly, all four models under-predicted the vertical velocity component near the upwind face of the ATREUS cube (x/H=-0.625), mainly above z/H=0.75 (Fig. 2b), which is the opposite of what was observed in the case of the CEDVAL cube (Fig. 2a). This may be due to the weaker local flow in the impingement region of ATREUS cube, which generated less turbulent kinetic energy and thus a larger upwind vortex (Fig. 3a-3b).

(a)

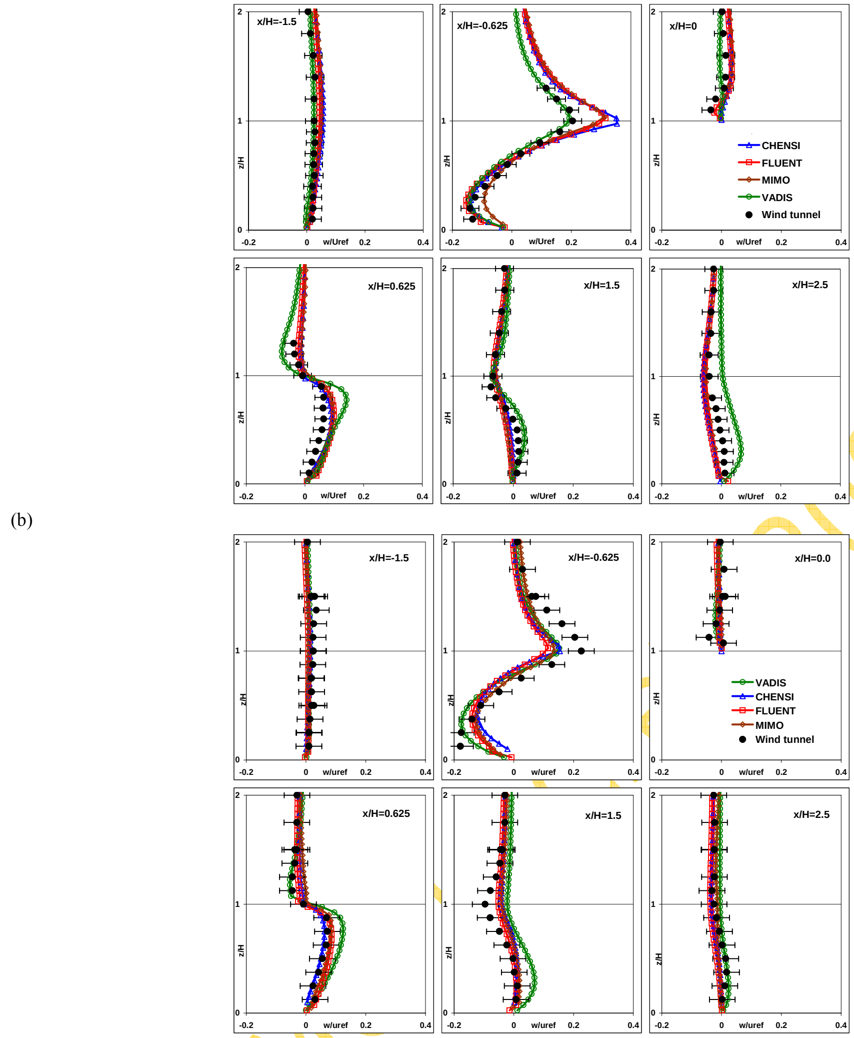


Figure 2: Comparison of experimental and modelled vertical velocity (w) profiles normalised with the free stream velocity (a) CEDVAL cube (top); (b) ATREUS cube (bottom)

CONCLUSIONS

A model inter-comparison study was carried out within ATREUS network in order to evaluate the ability of four CFD models (CHENSI, MIMO, VADIS and FLUENT) to simulate wind flow around simplified single block buildings. Although the models reproduced reasonably well the general flow patterns around two wall-mounted cubes of different characteristics, certain discrepancies between computed and experimental data were identified. In particular, all four models overestimated the turbulent kinetic energy generated in the upwind impingement region. Furthermore, CHENSI, MIMO and FLUENT over-predicted the length of the recirculation zone on the leeward side of the cubes, while VADIS slightly under-predicted this length. These results generally indicate a consistent behaviour of the models (except VADIS), despite certain deviations from the experimental data that are mainly due to the limitations of the standard k-ε turbulence model. Certain discrepancies observed between VADIS and the other CFD codes may be due to the different implementation of wall functions for near-surface treatment.

(a)

(b)

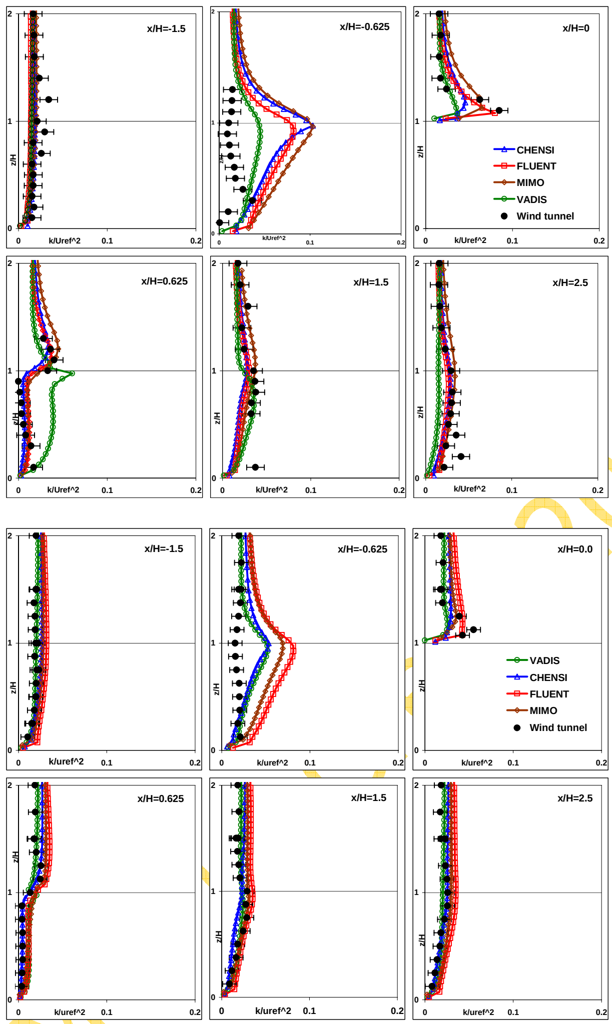


Figure 3: Comparison of experimental and modelled turbulent kinetic energy (k) profiles normalised with the free stream velocity (a) CEDVAL cube (top); (b) ATREUS cube (bottom)

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