5.27 A STUDY OF HEAT TRANSFER EFFECTS ON AIR POLLUTION DISPERSION IN STREET CANYONS BY NUMERICAL SIMULATIONS

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INTRODUCTION

Depending on the street canyon aspect ratio, urban flow is characterised by the formation of a centrally located single vortex (Berkowicz, 1998) or a system of counter rotating vortices (San Jin Jeong et al., 2001). However, apart from the building/street canyon geometry, thermal exchange between buildings and air is known to largely influence transport phenomena within the street canyon (Nakamura and Oke, 1988, Sini et al. 1996, Louka et al. 2000). In fact, heat transfer between heated walls of a street canyon and the street canyon air may substantially affect the flow field and hence also the pollution dispersion pattern.

NUMERICAL MODELLING

In the present paper the numerical model MIMO is used for the simulation of the in-street flow and pollutant dispersion in typical street canyon situations taking into account heat transfer between the walls and air in the street canyon. MIMO is a three-dimensional, prognostic microscale model which allows describing the air motion near complex building structures at street level. It solves the conservation equations for mass, momentum and scalar quantities as potential temperature, turbulent kinetic energy and specific humidity (Ehrhard et al., 2000). The model was extended by a heating module which can calculate heat transfer through conduction, convection and radiation. Concerning the heat transfer from the street canyon walls to the air, the heat transfer coefficient is calculated by:

$$\alpha = \frac{|Q_f|}{(T_0 - T_\infty)} = \frac{\rho c_p |u_* \theta_*|}{(T_0 - T_\infty)} \tag{1}$$

where u_* is the friction velocity and θ_* is the surface layer temperature scale (Kunz, 2001). The remainder of the paper deals with a numerical study of the effects of heated street canyon walls on the dispersion of pollutants within various street canyon configurations. MIMO predictions are compared with corresponding results of the commercial code CFX – TASCflow (URL1).

Simulations were performed in 2D for street canyons with different aspect ratios (0.33, 1.0 and 2.0). In all cases the temperature difference between the heated wall (leeward or windward) and ambient air was assumed to vary from 5K to 15K in steps of 5K. The computational domain used for all simulations is shown in figure 1. The total mesh of the grid comprised of 142×115, 167×115 and 207×115 cells for the aspect ratios of 0.33, 1.0 and 2.0 respectively. An inlet logarithmic wind profile with a reference speed U_δ=5 m/s was assumed at the surface layer height δ=100 m, with the wind direction perpendicular to the street canyon. In all cases the following assumptions were made: roughness length z_o=0.05m, inflow turbulence intensity 0.03 and mass flow of passive pollutants at the mid-section of the street canyon Q_s=1.5mg/s. The standard *k-e* turbulence model was used and standard wall functions were assumed.

RESULTS AND DISCUSSION

From all simulations performed the following discussion concentrates on the isothermal case and the cases of (leeward or windward) heating by 15K. Results are presented for the flow and temperature fields in the street canyon and for the calculated concentration across the street canyon at heights of Y/H=0.15, 0.5 and 1.0.

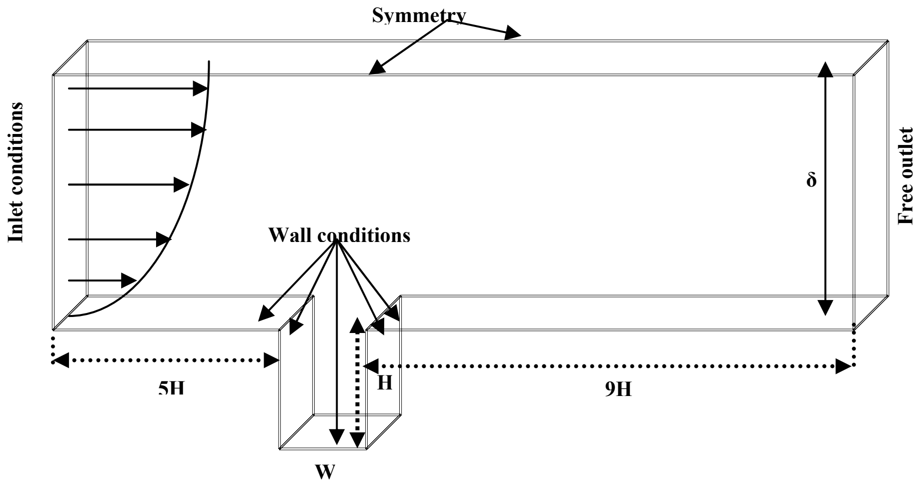


Figure 1. Sketch of the computational domain

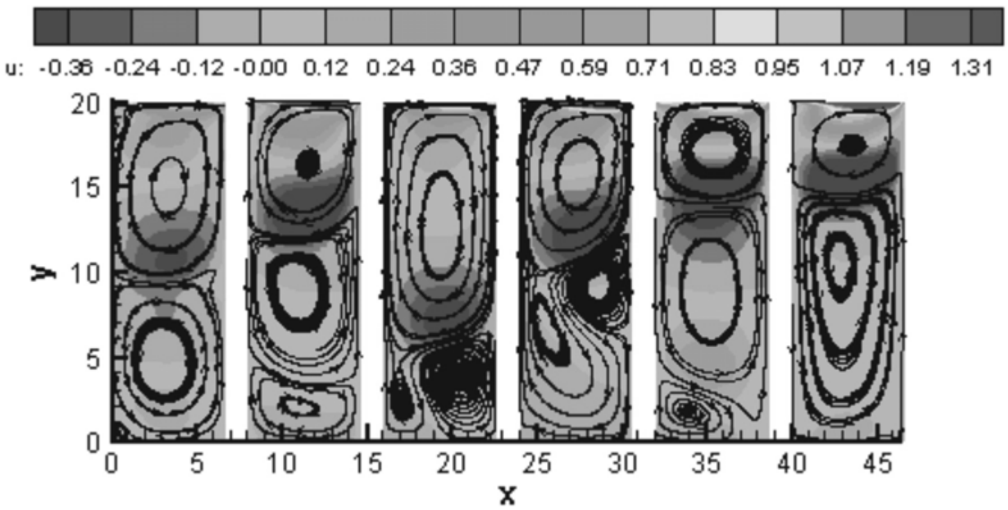
Non-dimensional values of the calculated concentrations were determined using the following equation:

$$C^* = CU_{\delta}H/(Q_s/L) \qquad (2)$$

where C^* is the non-dimensional concentration, C the calculated inert pollutant concentration, U_{δ} the reference wind velocity, H the height of the street canyon, Q_s the mass flow of the passive pollutants and L the characteristic length of the source.

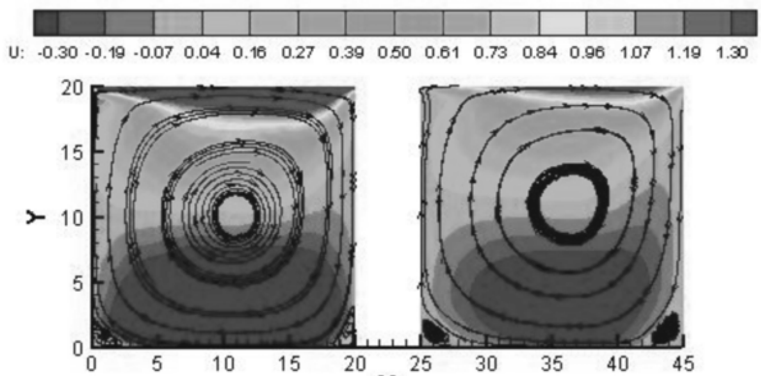
The obtained results reveal a partial disagreement between the flow fields computed with MIMO and TASCflow for the case of aspect ratio 0.33: Under isothermal conditions MIMO predicts a system of two counter rotating vortices, while TASCflow a system of three vortices with adjacent ones rotating in opposite directions (figures 2a, 2b). The consequence is that MIMO predicts in the isothermal case maximum concentrations near the windward side, while TASCflow near the leeward wall side (figure 5a). In cases where the leeward wall is heated, the simulations indicate a strong effect of heat transfer phenomena on the flow field and the corresponding dispersion pattern. Both codes predict a system of three vortices. In particular, MIMO predicts a large primary vortex and two smaller ones at the lower part of the street canyon with the smaller of the two lying near the leeward wall side (figure 2c). On the other hand TASCflow predicts a larger vortex near the leeward wall side (figure 2d). As a result of this disagreement in the size of the vortices which lie near the leeward wall side MIMO predicts relatively equal concentrations near the two wall sides while TASCflow predicts maximum concentration near the windward wall side (figure 5a). When the windward wall is heated, TASCflow predicts a system of two counter rotating vortices, with the secondary vortex covering 75% of the total street canyon area. On the other hand MIMO, predicts a system of three vortices with the third one extended over a small region at the street canyon ground level near the leeward wall side (figures 2e, 2f). As a result, in this case, MIMO predicts maximum concentrations near the leeward side, while TASCflow near the windward wall side.

For the cases of aspect ratios 1.0 and 2.0 the flow fields predicted by both MIMO and TASCflow seem to be in good agreement (figure 3). Both codes predict a flow field consisting of a centrally located vortex with two small ones at the street canyon ground level, near each of the building walls. It should be noted that for aspect ratio 2.0 TASCflow predicts a larger secondary vortex aspect ratios heat transfer phenomena do not seem to affect markedly the flow field regardless of which wall is heated.



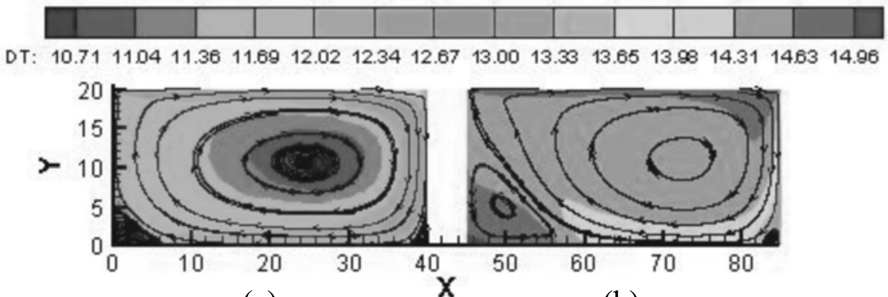
(a) (b) (c) (d) (e) (f)

Figure 2. Flow field comparison for aspect ratio 0.33 as computed by MIMO and CFX – TASCflow for ΔT=15K (a) (b)isothermal case (c) (d) leeward wall heated and (e) (f) windward wall heated respectively



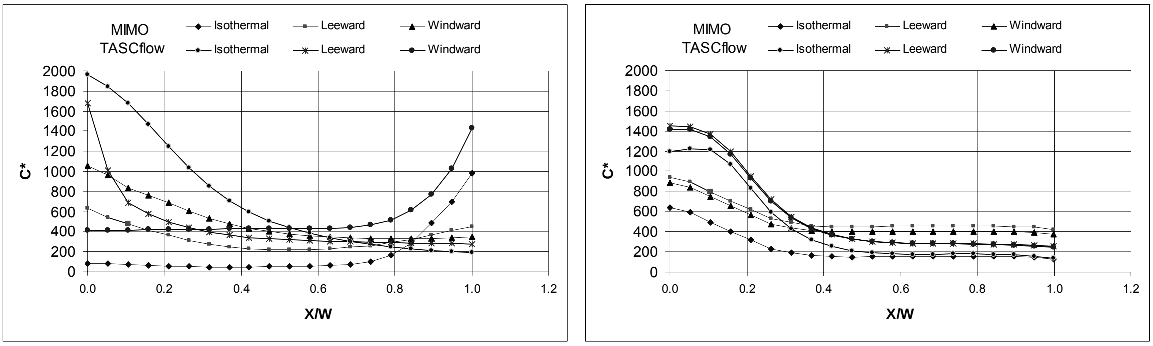
(a) (b)

Figure 3. Flow field comparison for aspect ratio 1 as computed by (a) MIMO and (b) CFX – TASCflow for the isothermal case



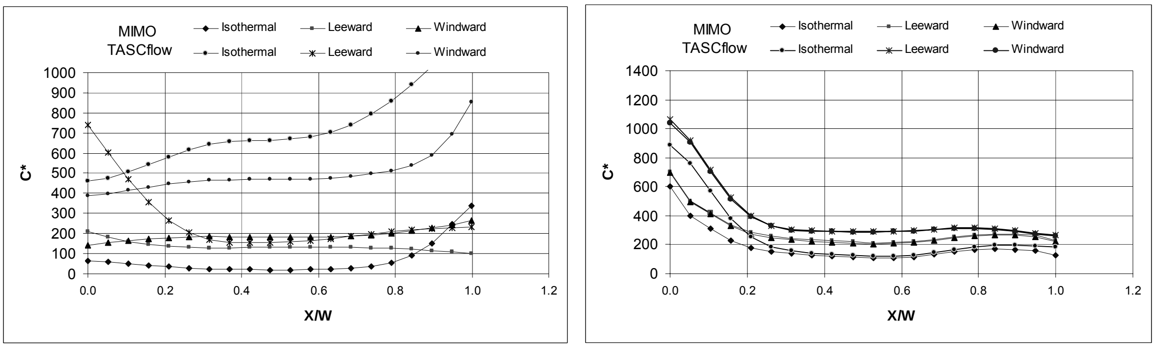
(a) (b)

Figure 4. Temperature difference field for aspect ratio 2 as computed by (a) MIMO and (b) CFX –TASCflow (windward wall heated) for ΔT=15K



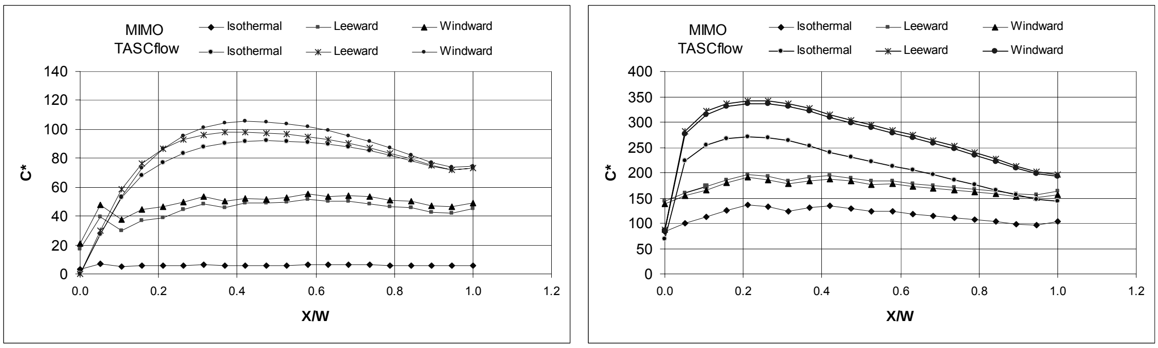
(a) (b)

Figure 5. Comparison of dimensionless concentration across the street canyon for aspect ratios (a) 0.33 and (b) 1.0, at Y/H=0.15



(a) (b)

Figure 6. Comparison of dimensionless concentration across the street canyon for aspect ratios (a) 0.33 and (b) 1.0, at Y/H=0.5



(a) (b)

Figure 7. Comparison of dimensionless concentration across the street canyon for aspect ratios (a) 0.33 and (b) 1.0, at Y/H=1.0

Calculated concentrations increase when either the leeward or the windward wall is heated. In all cases considered for the aspect ratios 1.0 and 2.0 and for height Y/H ≤ 0.5, both codes predict maximum concentrations near the leeward wall side (figures 5b, 6b). However, for height Y/H = 1 both codes predicts maximum concentrations at X/W = 0.2 (figure 7b). It is worth to notice that for all cases and aspect ratios considered highest concentrations result at the lower levels of the street canyon (figures 5-7).

In all cases and for all aspect ratios considered, MIMO predicts higher velocity components than TASCflow. As a result, the calculated concentrations predicted by MIMO are significantly lower, even for the case of aspect ratio 1.0 where the flow fields predicted by the two codes are in good agreement (figure 3).

CONCLUSIONS

In this paper we presented results of numerical simulations with the CFD codes MIMO and TASCflow for the air flow and pollution dispersion in street canyons of different aspect ratios. Both the isothermal case and the cases of heated walls were considered. Results show that there is good agreement in the flow fields predicted by the two codes for the cases of aspect ratios 1.0 and 2.0, both with and without (leeward or windward) wall heating. However MIMO predicts higher velocity components and as a result there is a significant disagreement between the corresponding concentration fields.

For the case of aspect ratio 0.33 there is a disagreement in the flow field predicted by the two codes for all cases (isothermal, leeward and windward heated walls). As a result, the two codes predict maximum concentrations at different regions near the building walls.

The disagreement between the results of the numerical codes used in this study reveals that many factors can affect the results of numerical models applied to simulate the heat transfer effects on air pollution dispersion in street canyons. Much attention should therefore be paid to the selection of the turbulence model and the wall functions for an adequate description of the heat transfer influence on the in-street flow characteristics and dispersion patterns.

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