

CFD inter-comparison on a full-scale street-canyon

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1 Introduction

Air pollution dispersion in urban areas is dominated by modifications of the atmospheric flow caused by building-street geometry and architecture (aerodynamic effects) as well as by solar radiation and traffic effects. The aerodynamic effects of simple two- and three-dimensional configurations have been studied extensively by several wind-tunnel experiments, numerical studies and a few full-scale experiments (e.g. Oke, 1987; Hunter et al., 1992; Louka et al., 2000), while comprehensive real site three-dimensional studies are more rare.

Microscale computational fluid dynamics (CFD) models represent a state of the art tool that takes into account the urban structure explicitly and provide a useful method for the investigation of the airflow in complex configurations as well as for the assessment and prediction of air pollution dispersion in cities. For this reason, the proper validation of such models is crucial.

A working group on computational fluid dynamics modelling has been established within the framework of the European research network TRAPOS (URL1). Several numerical models employing the widely used 'standard k- ϵ -model' were applied to well defined test cases and their results are compared. The test cases chosen comprised a variety of two and three dimensional configurations for which measurements from wind tunnel and full-scale studies were available. The main goals of the inter-comparison are to illustrate the level of agreement that can be expected from CFD models in urban environments, to assess their differences when applied to the same well defined cases, and ultimately to improve their performance when dealing with different street architectures and give recommendations for practical applications.

This paper presents the inter-comparison of the predicted flow fields and pollution dispersion within a real street canyon (Göttinger Strasse in Hanover) investigated by five models (CHENSI (Sini et al., 1996), CHENSI-2 (Guilloteau, 1999), MIMO (Ehrhard et al., 2000), MISKAM (Eichhorn, 1989), and TASCflow (Raw et al., 1989)) for different wind directions. The inter-comparison of the models in the cases of a single cavity and a surface mounted cube are discussed elsewhere (Sahm et al., 2001).

2 Computational set-up

The dimensions of the domain are 370m \times 440m \times 240m resolved by 59 \times 72 \times 24 grid boxes. Figures 1 and 2 illustrate the modelling domain in three-dimensions and in its horizontal projection, respectively. Göttinger Strasse is a four-lane street canyon with a traffic load of ca. 30,000 vehicles/day. Its width is $W=25$ m with buildings on both sides that have mean height $H=20$ m giving a width of street over height of buildings aspect ratio, $W/H = 1.25$.

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Identical grids, inflow profiles, roughness of buildings and ground as well as boundary conditions were used by all codes (URL1). A detailed description of the CFD codes including numerical scheme, boundary conditions and values of parameters and constants can be found elsewhere (URL1). Comprehensive measurements of both wind speed and direction on the roof of the highest building and pollution concentration measurements of vehicular exhausts within the street and at the roof of the building (Figures 1 and 2) provided the necessary data sets for comparison with the model predictions (Ketzel et al. 2000). In addition to the full-scale experiment, wind tunnel measurements both for the concentration at the receptor point and for the flow field inside the street canyon were performed at the University of Hamburg and used for further comparison with the model results (Liedke et al., 1998; Chauvet et al., 2000).

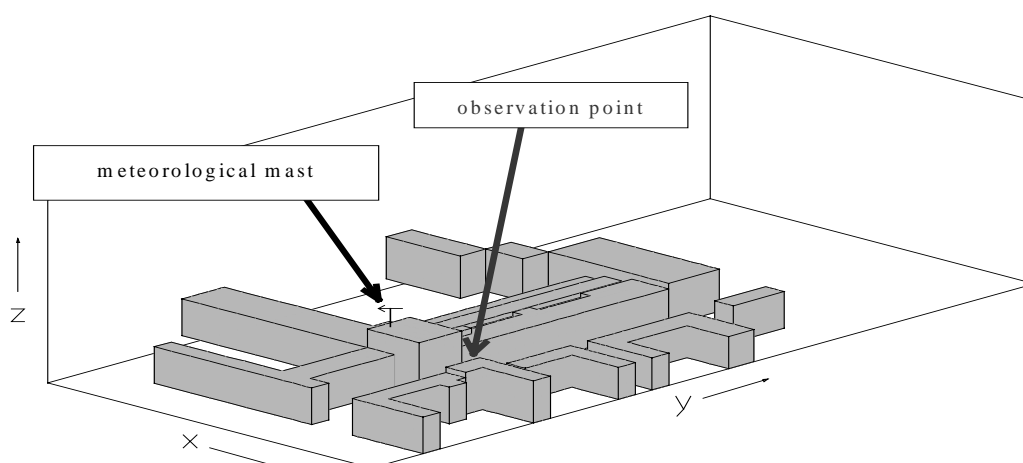


Figure 1 Schematic representation of the buildings in the simulated domain. The position of the meteorological mast and the location of the concentration measurements are shown.

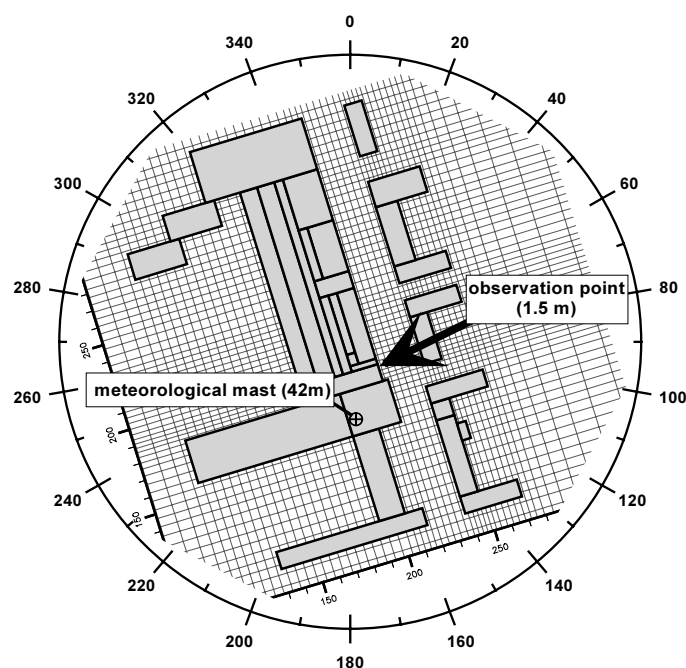


Figure 2 Horizontal plane of the modelled area. The grey areas indicate buildings. The spatial resolution of the grid in the horizontal plane is shown. The circular axis gives the direction with respect to North.

3 Main results

Figure 3 shows the airflow in the horizontal plane at $z=10\text{m}$ as predicted by the five models within Göttinger Strasse for wind direction 260° from the North, which corresponds to approaching wind perpendicular to the street. Although the aspect ratio of the street, $W/H=1.25$, would imply that a mean re-circulation should develop within the street for perpendicular wind (Oke, 1987), neither any of the models nor the wind tunnel results showed such a simple flow pattern. Both predicted and measured flows show complicated features mainly characterised by vortices developed at the corners of the buildings as well as air entrainment from the side streets, while the main flow pattern shows a strong flow parallel to the street in its northern part. These features are predicted by all models and generally agree with the wind tunnel observations.

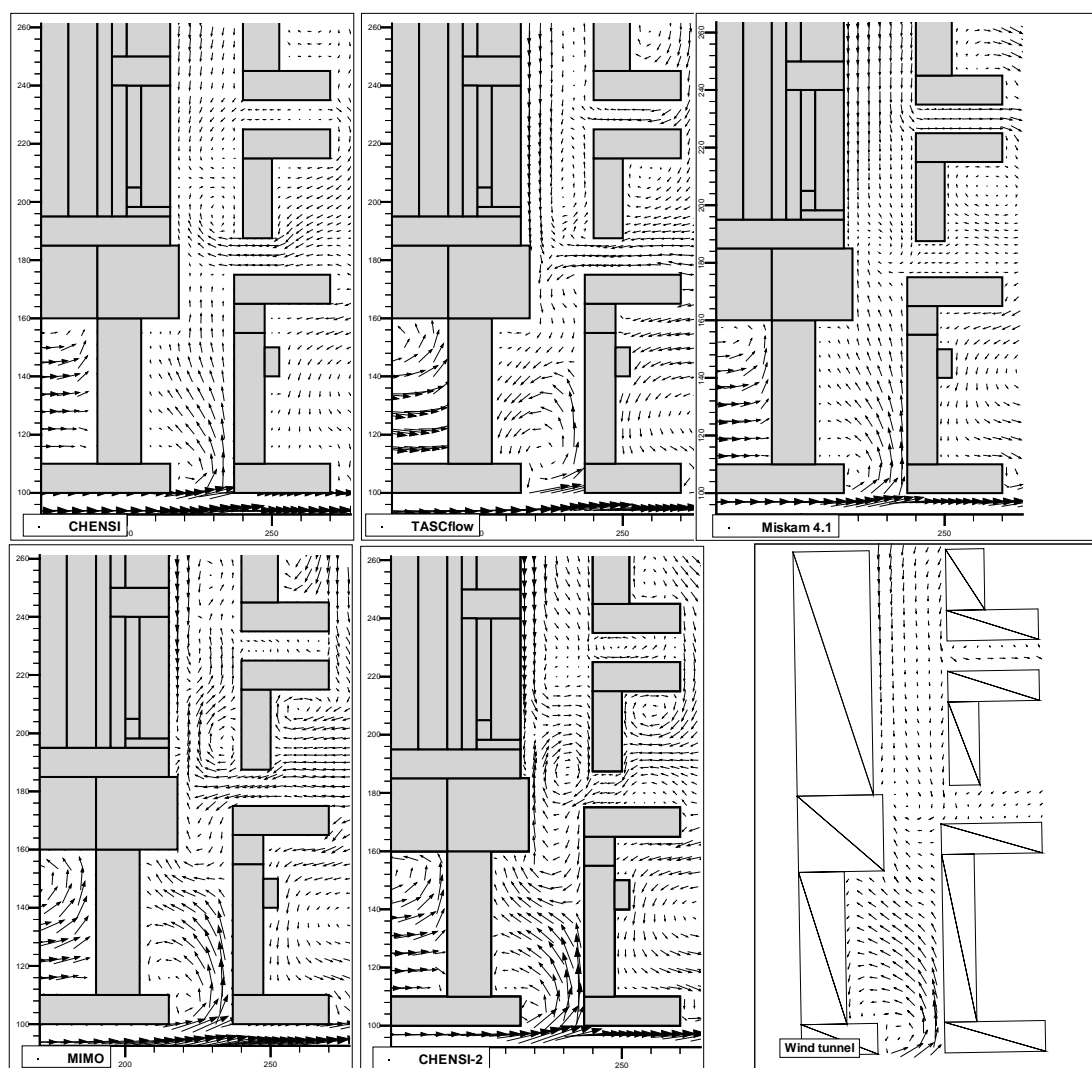


Figure 3 Flow field in horizontal plane calculated by 5 CFD models and measured in the wind tunnel (wind direction 260° from the North).

Taking a closer look at the flow pattern in the vicinity of the location of the concentration measurements, the models show some differences mainly in the location of the centre of the vortex produced in this area as well as in the intensity of the flow. These, generally small, differences have a large impact on the calculated concentrations. Figure 4 shows the normalised concentration $C^* = (CV_{ref}H_{ref})/(Q/L)$, where V_{ref} is the velocity at H_{ref} , Q is the source strength and L its length,

versus the wind direction. Agreement is found for the general shape of the graph for all codes. However, for specific wind directions the calculated concentration may vary by a factor 2 to 7. For wind direction 280°, the predicted C^* is in a range of values between 18 and 110, i.e. there is a difference of a factor of 6, even though that the general characteristics of the simulated flow were similar. This example illustrates the large difficulty in predicting the pollution concentration at a location that lies in a region with complex flow patterns and strong gradients. Thus any small difference in the predicted direction of the flow impinging at the measuring location may lead to a large discrepancy among the values predicted by similar codes.

The study of much simpler configurations (Sahm et al., 2001) suggested that a main reason for the discrepancies among the simulated flow fields found close to solid walls is the different implementation of the wall-function by the models and this may also be a reason in the present case. However, the question that is necessary to ask and discuss in this complex case is:

- Is the domain chosen suitable for all codes with respect to the grid resolution, size and complexity?

Regarding practical recommendations, an additional question would be: do we want to predict pollution concentration for recommendations on how to improve street-scale air quality? In that case several measuring locations are required for a more comprehensive picture of the flow field and concentration in the street and thus avoiding locations of geometrical irregularities that lead to only local effects.

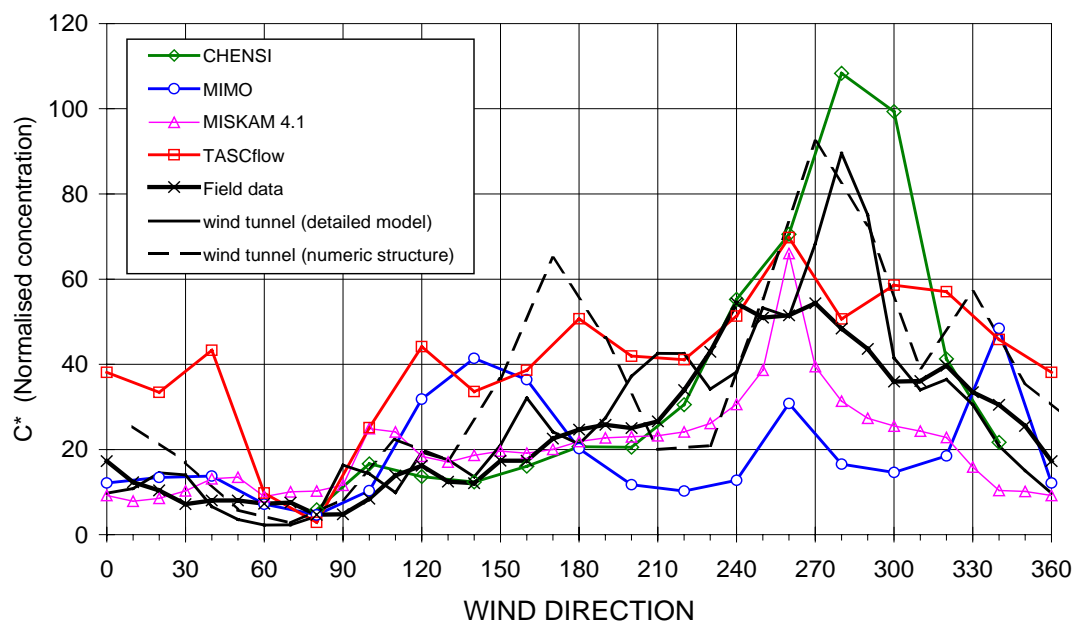


Figure 4 Normalised concentrations versus the wind direction calculated by 4 CFD codes and measured in the full-scale experimental site and in the wind tunnel.

4 Conclusions

Results of a model inter-comparison in a well-defined, geometrically complex case were presented. The simulated flow field was found to be generally similar for all codes and also similar to the field observed in the wind tunnel. However, predictions of the location of the centre of the small vortex structures and the intensity of the flow differ among the codes. These small differences lead to large differences in the calculated concentration at a location close to building irregularities. These differences may reach a factor of 7. It is suggested that the accuracy of the CFD modelling result for only one location affected by local gradients should be treated with special care. For practical purposes, an estimation of averages in time (over different inflow situations) or averages in space (to avoid large local gradients) would be more appropriate. Experimental campaigns in street canyons should avoid measuring meteorological parameters and air pollutant concentrations at just

one location or close to geometrical irregularities (intersections, gateways, towers, corners etc.) that are characterised by local effects only. A variety of measuring positions should be considered for a better representation of the street dispersion conditions and for the appropriate evaluation of street-scale pollution dispersion conditions.

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