Comparison of the Jagtvej field data set with corresponding wind tunnel results

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1 Introduction

European legislation has forced the authorities to install monitoring stations in city areas with heavy traffic load (hot spots). Field data sets covering the immission situation over long periods of time (1 year or more) are now available. These long time series should be statistically significant enough in order to determine particular dispersion patterns which are characteristic for the street canyon under investigation. It is a worthwhile task to test whether the most important of these patterns can also be found when the same dispersion scenario is simulated within a physical or numerical model experiment.
Within the frame of the EU-funded TMR-project TRAPOS, an urban monitoring site located in Jagtvej, Copenhagen, Denmark, was chosen to be replicated in a wind tunnel experiment. The physical model study was carried out in a boundary layer wind tunnel of the University of Hamburg.
The objectives of this work were

- to show the degree of agreement between the results of small-scale physical model experiments and full-scale measurements within the urban canopy layer,
- to investigate the reasons for possible deviations between laboratory and field data, and
- to help interpret specific features both data sets exhibit.

2 Experimental Set-Up

The experiments were carried out in the multi-layer wind tunnel of Hamburg University. The length, width and height of the working section of this tunnel are 8.7 m x 2.3 m x 1.0 m. The tunnel was operated in a neutral stratification mode. Details of the tunnel characteristics are given in Schatzmann et al., 1995.
In order to obtain sufficient spatial resolution for the subsequent model experiments, a boundary layer in the scale of 1:200 was established. Only the lowest about 100 m of the field boundary layer were properly represented in the tunnel. The boundary layer characteristics of the approach flow were in fair agreement with those of a typical urban boundary layer. It had a mean vertical velocity profile exponent of n = 0.28, a roughness length of z_o . 1 m, a vertical turbulence intensity distribution acc. to ESDU (1974) and a shear velocity of $u_* = 0.055\ U_4$ (with U_4 being the free stream velocity).
Fig. 1 shows a view on the wind tunnel model of the Jagtvej site. The location of the monitoring station which is in the centre of the model area at the pedestrian walkway of a busy, 2-lane inner-city road. Based on automated traffic counts and information on the composition of the vehicle fleet, reasonably good estimates of pollutant emission rates were available. The above-roof wind and background concentrations were also measured, although this background measurement station was some distance apart from the site at the roof of the building of the Technical University.
In the wind tunnel, the traffic lanes were represented by line sources. Special care was taken to achieve uniform and nearly momentum free emissions, thereby using the experience accumulated in previous experiments (Meroney et al., 1996). In the final design of the source, hundreds of needles from syringes with an internal diameter of 0.2 mm and a length of 42 mm were mounted next to each other. The line sources had a length of about 200 m (full scale).

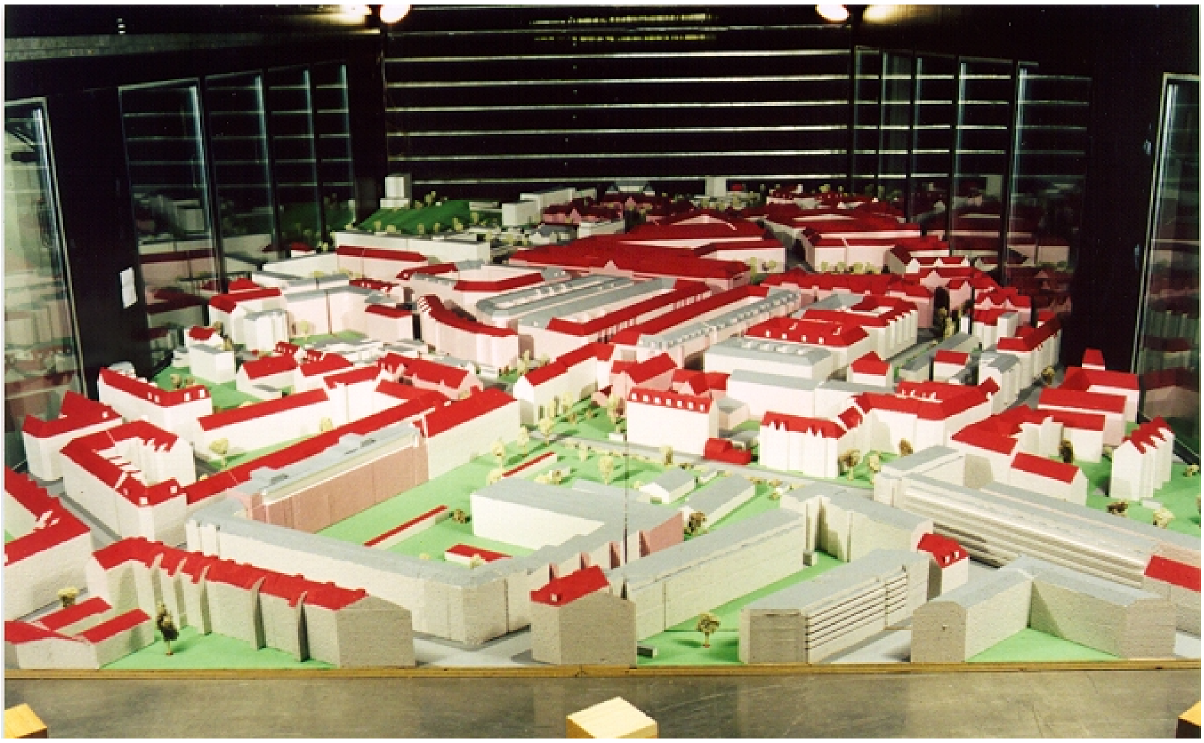

Figure 1 View on a section of the wind tunnel model of the Jagtvej site. The position of the monitoring station is in the centre of the figure.

Velocity measurements in the wind tunnel were made at the same (above-roof) position as in the field and in a reference height 100 m above ground. Common hot wire anemometers were used for that purpose.

In order to not disturb the flow within the street canyon, the concentration detectors (based on the flame ionisation principle) were built into the model buildings. Only the tiny suction pipe reached into the canyon and ended at the position of the air intake of the corresponding field monitoring station.

3 Results

In order to make the results from the field and from the wind tunnel comparable to each other, NO_x concentrations determined in the field over a period of one year (1997) were grouped according to the wind direction (10° steps) and brought into the non-dimensional form $c^* = C \cong u_{ref} \cong H/(Q/L)$, where C is the time mean value of the measured concentration (30 min average, in excess above background), u_{ref} is a reference velocity, taken at a height of 100 m, H is a characteristic length (the average height of the surrounding buildings) and (Q/L) is the source strength of the line source. According to theory, it is to be expected that c* is solely a function of wind direction as long as only passive pollutants are considered which are released by one or several line sources and which are solely dispersed by the ambient wind. The c*-concept assumes furthermore that other factors like traffic induced turbulence or atmospheric stratification are of secondary importance only. For a detailed analysis of the concept see Schatzmann et al. (2001).

In the wind tunnel experiments, these conditions can be easily fulfilled , in the field experiments they hold only approximately. In order to achieve nevertheless a curve c* = f (wind direction) from the field experiments, even more assumptions and simplifications have to be made:

- it has to be assumed that the emissions from several moving sources (vehicles) can be regarded as a line source. The source strength of the line source can be determined only indirectly from traffic counts and from emission factors in combination with information on the traffic fleet,

- the measured NO and NO_2 concentrations need to be combined to NO_x-concentrations since only NO_x can be treated as chemically passive over the time interval of interest here,
- the background NO_x-values transported to the Jagtvej street monitoring station from sources outside the canyon have to be subtracted from the measured values, and
- finally, hourly mean values of NO_x from a sufficiently long period (e.g. 1 year) need to be grouped according to the wind direction prevailing during the measurement interval and then averaged, thereby assuming that all meteorological and traffic parameters remain constant over the averaging period (1 hour in this case).

As can be expected, a c* = f (wind direction)-curve derived in the way described contains an inherent uncertainty which can not easily be determined. It exhibits a large scatter since many of the conditions are only poorly fulfilled. In order to reduce the scatter, Ketzel et al. (2000) selected solely concentration values from measurements taken at wind speeds above 3 m/s at reference height and during day time. The expectation was that at higher wind speeds traffic induced turbulence and stratification would indeed be of minor importance, and that during day time the traffic should be dense enough to justify the line source concept. Disadvantage of this strategy is that at high winds the relative importance of the background concentration increases. Since the determination of the background is full of uncertainties in any way, this strategy might not fully pay off.

The curve provided by Ketzel is plotted in Fig. 4, together with the maximum and minimum deviation from the mean values (broken line). Also integrated into Fig. 4 are the results from the wind tunnel experiments which were done with two different geometrical realisations of the site. Realisation 1 consisted of a model with all details as shown in Fig. 1. Since modern computers are still not powerful enough to accommodate more than about 100 x 100 x 50 grid cells, we built another model which resembled in its geometrical structure how a numerical model using a Cartesian grid would “see” the Jagtvej site (Fig. 2).

The agreement between the field and wind tunnel data is generally fair, with the exception of winds from about 120 degree (about perpendicular to the street canyon, see Fig. 3). The reason for this deviation is not fully understood. Although the peak is very narrow, it is fully reproducible in the wind tunnel experiments.

When we compare the results from the two wind tunnel realisations with each other, we notice still some differences, again dependent on the wind direction. From this it can be concluded that although the spatial resolution of the model acc. to Fig.2 is already impressive, the resolution is still not sufficient to ensure grid size independent results.

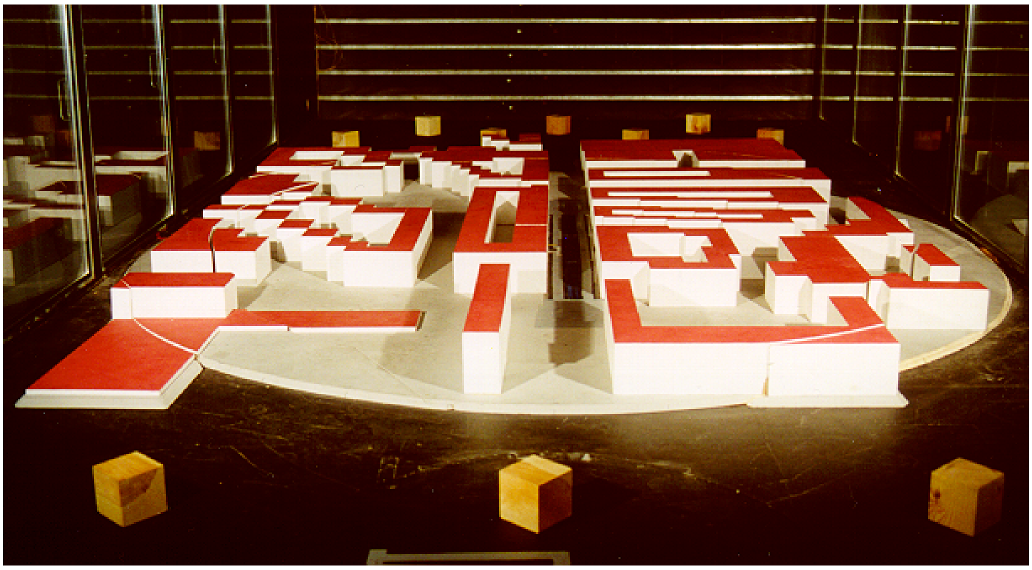

Figure 2 Physical representation of the Jagtvej building array as an advanced, obstacle-resolving Cartesian grid model would ’see’ the site.

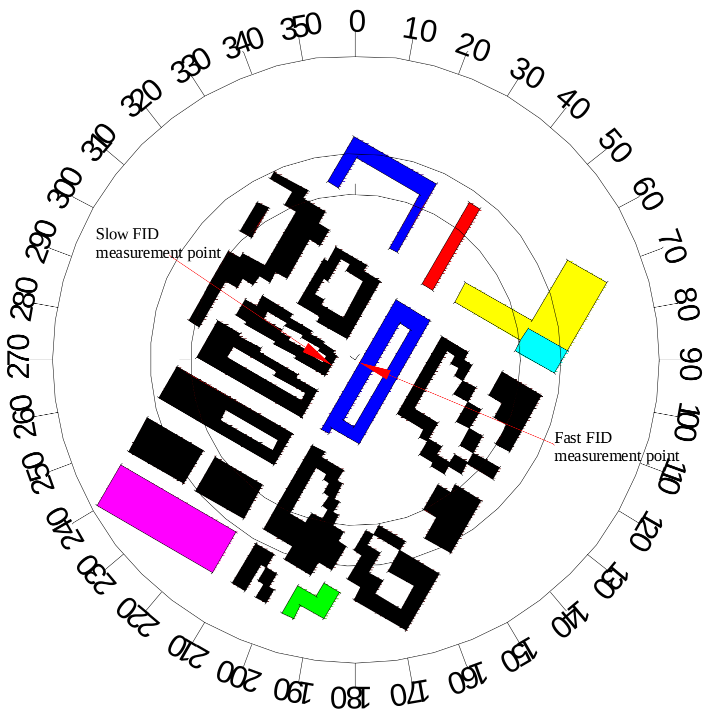

Figure 3 Top view on the building array shown in Fig. 2 and indication of wind directions.

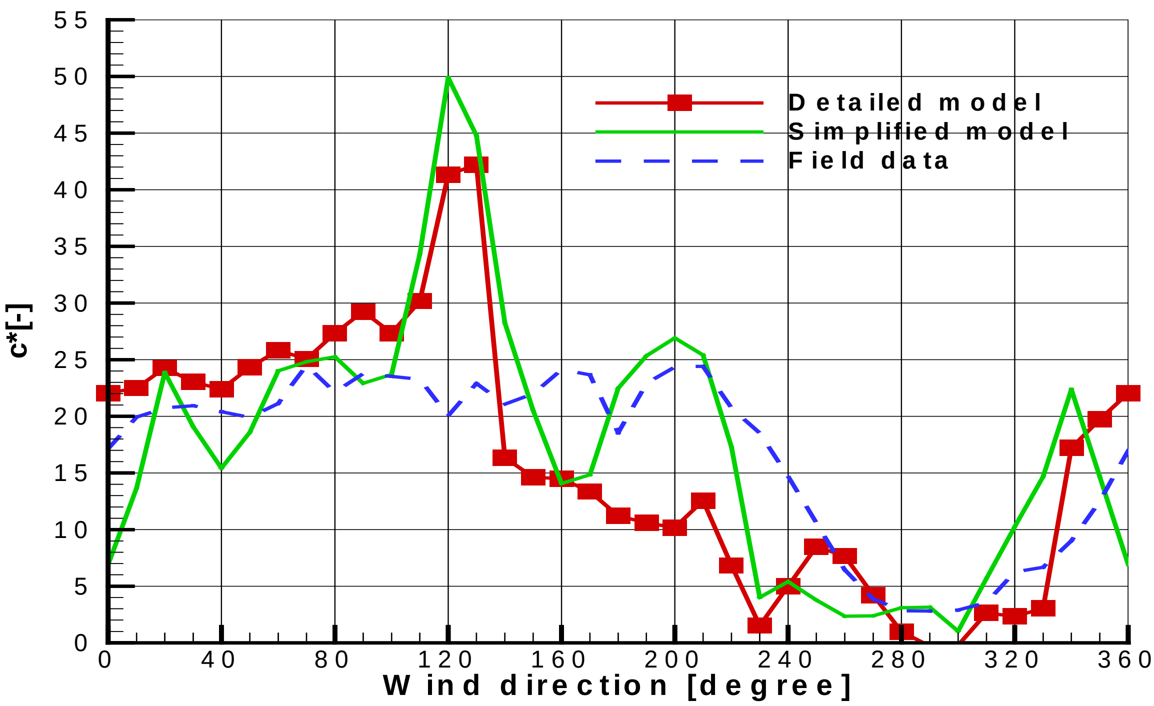

Figure 4 Comparison of results from field measurements with those from the wind tunnel experiments with the obstacle configurations shown in Fig. 1 and Fig. 2.

4 References

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