AIR QUALITY ASSESSMENT IN A STREET-CANYON IN HELSINKI USING THE CFD MODEL ADREA-HF

P. Neofytou[1], M. Haakana[2], J. Kukkonen[2], A. Venetsanos[1], A. Kousa[3], J. Bartzis[1]
[1]Environmental Research Lab., INT-RP, NCSR Demokritos, 15310 Athens, Greece
[2]Finnish Meteorological Institute, Air Quality Research, Sahaajankatu 20 E, FIN-00880 Helsinki, Finland
[3]Helsinki Metropolitan Area Council, Opastinsilta 6 A, FIN-00520 Helsinki, Finland

INTRODUCTION

Air quality within a street canyon is influenced by traffic flow and emissions, building geometry, urban background concentrations and ambient meteorological parameters. Computational Fluid Dynamics (CFD) is proved to be a cost-efficient and accurate tool for evaluating the dispersion of traffic-originated pollution in populated areas assuming different wind speed and direction cases and specifying their effects. In addition, CFD offers the capability of accurately describing the geometry of the surrounding buildings so as to include their effects on the flow field.

CFD is applied widely in order to predict air-flow and pollution dispersion in urban areas. Pullen *et al.* (2005) used a CFD approach by employing the commercial code Star-CD for predicting plume concentrations for different release-scenarios in both Washington DC and Chicago. Pospisil *et al.* (2004) integrated a Lagrangian model and a traffic dynamics into Star-CD code so as to simulate the traffic-induced flow field and turbulence. They applied their model in an urban area in Hannover, Germany and they stressed out the importance of taking into account the actual geometry of the buildings around the area of interest for deriving accurate results. The importance of accurately describing the geometry of an urban area for pollution dispersion predictions was even more prominent in the work by Chu *et al.* (2005) who used a Geographic Information System (GIS) software in order to extract in detail the coordinates and heights of the buildings of the area of interest. The CFD software that they used was CFX5.5 and their predictions cover the wind field and pollution dispersion in an urban area in Hong Kong. Parametric studies with respect to different wind speed and wind direction scenarios have been carried out by Neofytou *et al.* (2005a) in order to study the pollution dispersion attributes in an urban area in Bremen, Germany by using the ADREA-HF CFD code.

In the current study, the ADREA-HF code is used for numerically predicting the flow field and concentration distribution in the vicinity of Runeberg Street, a street canyon in Helsinki, Finland. Previously, the OSPM street canyon dispersion model has been evaluated against the measurements that were carried out in this street canyon in 1997 (Kukkonen et al., 2001 and 2003). More recently, a measurement campaign was conducted in this canyon during the period from 19 February 2003 to 31 December 2004. Some preliminary results of the model computations with the ADREA-HF model, including comparison with measured data, were presented by Neofytou et al. (2005b).

In this study, the primary aim is to help local authorities responsible for the urban pollution control to understand the factors affecting on air quality in urban environments. In cooperation with the representatives of the Helsinki Metropolitan Area Council, the pollution levels of NO_x were decided to be computed assuming various ambient wind conditions at 16 locations within the canyon and behind the canyon-buildings.

METHODOLOGY

1.9. Measurements

In the analysis of the measured data, the focus is on the time period of 1.1.2004 - 30.4.2004 when, in addition to air quality monitoring at one street canyon station, wind speed and wind direction measurements took place at the roof level in Runeberg Street. NO_x concentrations, wind-direction and wind-speed data are available with the time resolution of one minute.

1.10.

1.11. Computational Data

For solving the Navier-Stokes equations in the computational domain, the ADREA-HF code is utilised following a method described by Neofytou *et al.* (2005). The computational domain that includes all buildings in the area surrounding Runeberg Street is constructed using actual building coordinates and heights provided by the Helsinki Metropolitan Area Council and is shown in Figure 1. It consists of a 900mx900mx180m area discretised as a 78x65x35 grid, which has a higher spatial resolution near the measurement location in order to more accurately capture the wind field and concentration distributions.

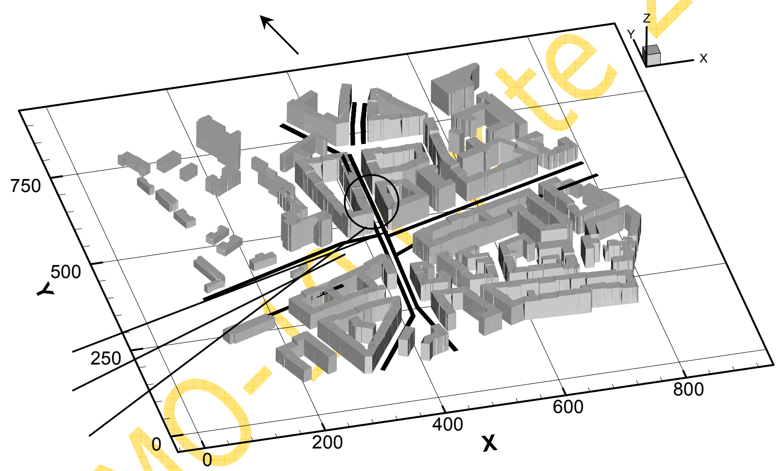

Fig. 5; Computational domain of the Runeberg Str. area.

1.12. Receptor Points

For studying the air-quality at the street canyon area, 16 receptor points are assumed and are divided in 4 groups of 4 receptors. The receptors in each group have the same *x* and *y* coordinates and are numbered as from 1 to 4 so as to indicate positioning heights of 4, 10, 15 and 20 meters respectively (Figure 2i). The first two groups are the REF and RWF and are located at the east and west side, respectively, within the Runeberg street-canyon; whereas the other two groups are REB and RWB and are located behind the buildings of the east and west side, respectively, of the canyon (Figure 2i). All receptor points are located in the same vertical cross-section, which is perpendicular to the Runeberg Street axis (Figure 2ii) and is at a distance of 52 and 40 meters from Hesperian and Döbel Streets, respectively. All points are at a distance of 1.2 meters from the adjacent building walls. The receptor point REF1 corresponds to the air quality monitoring site in the Runeberg Street canyon.

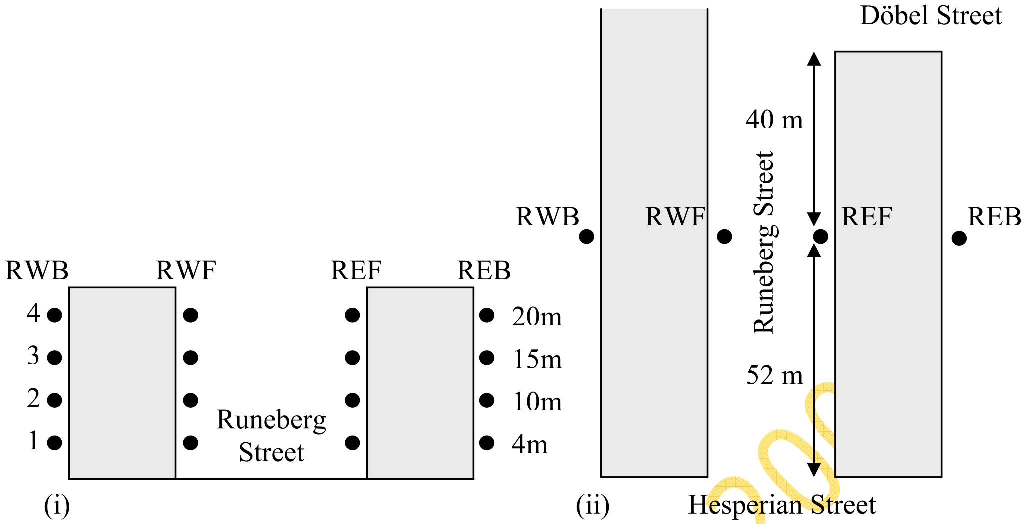

Fig. 2; Positioning of receptors in the Runeberg Street area: (i) the vertical (ii) and horizontal cross-section.

1.13. Selected traffic flow and meteorological conditions

The computations are carried out assuming different cases involving various wind directions and wind speeds. In total, there are 2 different case groups each consisting of 4 cases that correspond to the wind directions of 6, 186, 96, and 276 degrees. For the first group, the wind speed is 1 m/s, whereas for the second group the wind speed is 3 m/s (Table 1). The directions of 6° and 186° correspond approximately to the northerly and southerly wind directions, respectively, and are parallel to the Runeberg Street axis, whereas the directions of 96° and 276° correspond approximately to the easterly and westerly directions, respectively, and are perpendicular to the Runeberg Street axis.

As the computations were performed only for the NO_x concentrations, the ambient temperature and solar radiation do not influence the results. Based on traffic data of the area that correspond to typical, less congested weekday daytime traffic of 1200 vehicles/hour, the emission rate of NO_x from Runeberg Street was taken as 30.52 $\mu g/m^2/s$. The emissions were computed based on the national Finnish emission factors. The urban background concentrations were not taken into account in the computations, and the numerical results therefore correspond only to the contribution of emissions originated from the local traffic in the Runeberg Street. The average urban background concentration of NO_x was approximately 55 $\mu g/m^3$ in daytime (between 6 a.m. and 6 p.m.) in January- April 2004.

Data points corresponding to the selected wind speed and direction cases were also selected from the measurement data. In order to obtain adequate amount of data, NO_x concentrations were equalised with respect to the traffic volume of 1200 vehicles/hour:

$$c_{eqt} = \frac{TV_t}{TV} c_t \qquad (1)$$

where c_{eqt} is the equalized one minute NO_x concentration at the time t, TV_t is the hourly traffic volume representing the time t, TV is the traffic volume of 1200 vehicles/hour, and c_t is the one minute NO_x concentration at the time t.

RESULTS AND DISCUSSION

The numerical results are presented in Tables 1 and 2 and show a clear dependency on the wind direction. This dependence is more pronounced for higher wind speeds (u=3 m/s) rather than for lower wind speeds (u=1 m/s). When the measuring point is on the windward side, concentrations are substantially smaller, compared with the corresponding results for the leeward side. The leeward side is influenced directly by the traffic emissions in the street (in addition to the recirculated polluted air and urban background air), while the windward sector is only influenced by the urban background air and the recirculated contribution from street level emissions. The concentrations for parallel to the street canyon winds from the north and from the south are nearly the same, except for the highest receptor locations. For all receptor locations, the concentrations decrease with the height.

Table 1. Predicted NOx concentration (μg/m^3) at receptors within the canyon (contribution from the local traffic in the Runeberg Street only)

Case	WS (m/s)	WD (deg)	REF1	REF2	REF3	REF4	RWF1	RWF2	RWF3	RWF4
1	1	6	393.9	157.5	62.5	14.4	367.8	169.3	72.3	18.6
2	1	186	391.5	168.4	73.0	21.8	364.1	157.8	67.3	19.8
3	1	96	414.2	284.4	227.1	141.2	24.5	16.6	14.8	11.3
4	1	276	14.5	10.8	9.7	7.0	264.2	182.0	156.7	84.5
5	3	6	123.3	48.2	19.1	4.6	124.4	58.7	25.6	6.7
6	3	186	127.4	55.4	24.6	7.7	115.7	49.7	21.2	6.4
7	3	96	137.3	93.6	74.1	46.4	8.0	5.2	4.6	3.5
8	3	276	4.2	3.1	2.8	2.0	82.2	56.5	48.8	27.0

Table 2. Predicted NOx concentration (μg/m^3) at receptors behind canyon-buildings (contribution from the local traffic in the Runeberg Street only)

Case	WS (m/s)	WD (deg)	REB1	REB2	REB3	REB4	RWB1	RWB2	RWB3	RWB4
1	1	6	1.8	1.8	1.9	2.0	2.2	2.1	2.2	2.4
2	1	186	4.4	4.5	4.6	4.7	3.9	4.1	4.3	4.4
3	1	96	0.1	0.1	0.1	0.1	6.3	6.4	6.6	7.5
4	1	276	4.0	4.0	4.0	4.2	0.1	0.1	0.1	0.1
5	3	6	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.0
6	3	186	1.7	1.7	1.7	1.7	1.5	1.6	1.6	1.7
7	3	96	0.0	0.0	0.0	0.0	1.9	1.9	2.0	2.3
8	3	276	0.9	1.0	1.0	1.0	0.0	0.0	0.0	0.0

Figure 3 shows the comparison between measurements and predictions. The observed NO_x concentrations are median concentrations equalised to the hourly traffic volume of 1200 vehicles/hour. The numerical results, added with the average background concentration of 55 μg/m^3, agree relatively well with the measured data. However, in the cases 4 and 6, the NO_x concentrations were clearly underpredicted. The case 4 may be explained by the absence of traffic induced turbulence in the applied version of the ADREA-HF code. With very low wind speeds, such as 1 m/s, the traffic induced turbulence may change the dispersion pattern and thereby increase windward air pollutant concentrations.

As expected, the concentrations are substantially lower behind the buildings of the street canyon. On the basis of the numerical results, the influence of Runeberg Street on air quality in the yard side of the buildings with the studied wind conditions can be considered negligible compared to the urban background levels.

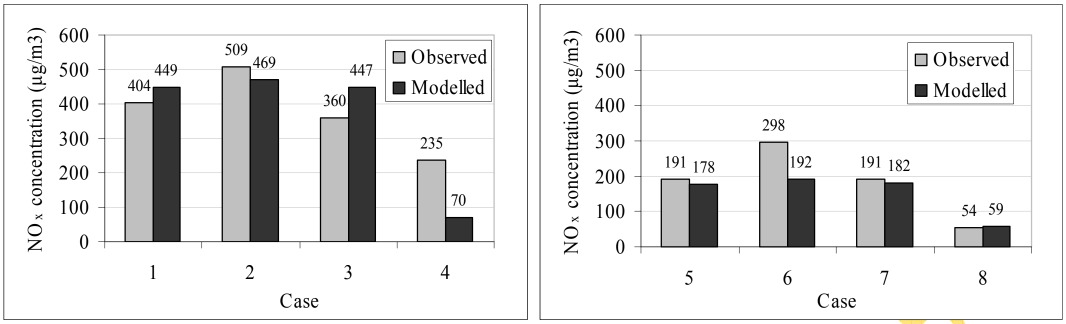

Fig. 3; Modelled and observed NO_x concentrations at the receptor point REF1 and with the wind speeds of 1 m/s (left) and 3 m/s (right).

CONCLUSIONS

Numerical results were computed for a street canyon in Helsinki, for selected environmental conditions at receptor locations within the canyon and in its immediate vicinity. Overall, predictions exhibit a good agreement with available experimental data. However, the clear underprediction in two cases with perpendicular wind directions needs to be further analysed.

ACKNOWLEDGEMENTS

The financial support from the European Union under the contract EVK4-CT-2002-00083 (the OSCAR project) is gratefully acknowledged.

REFERENCES

Chu A.K.M., Kwok R.C.W. and Yu K.N, 2005: Study of pollution dispersion in urban areas using Computational Fluid Dynamics (CFD) and Geographic Information System (GIS). *Environ. Modell. Softw.*, **20**, 273-277.

Kukkonen J., Valkonen E., Walden J., Koskentalo T., Aarnio P., Karppinen A., Bercowicz R., Kartastenpää R., 2001: A measurement campaign in a street canyon in Helsinki and comparison of results with predictions of the OSPM model. *Atmos. Environ.* **35**, 231-243.

Kukkonen J., Partanen L., Karppinen A., Walden J., Kartastenpää R., Aarnio P., Koskentalo T., Bercowicz R., 2003: Evaluation of the OSPM model combined with an urban background model against the data measured in 1997 in Runeberg street, Helsinki. *Atmos. Environ.* **37**, 1101-1112.

Neofytou P., Venetsanos A.G., Rafailidis S. and, Bartzis J.G., 2005a: Numerical Investigation of the Pollution Dispersion in an Urban Street-Canyon. *Env. Modell. Softw*, In press.

Neofytou P., Haakana M., Venetsanos A., Kousa A. , Bartzis J., and Kukkonen J., 2005b. Computational fluid dynamics modelling of the pollution dispersion and comparison with measurements in a street canyon in Helsinki. In: *Proc. of the 5th International Conference on Urban Air Quality*. Valencia, Spain, 29.-31. March, 2005.

Pospisil J., Katolicky J., Jicha M., 2004: A comparison of measurements and CFD model predictions for pollutant dispersion in cities. *Science of the Total Environment*, **334-335**, 185-195.

Pullen J., Boris J.P., Young T., Patnaik G. and Iselin J., 2005: A comparison of contaminant plume statistics from a Gaussian puff and urban CFD model for two large cities. *Atmos. Environ*, **39**, 1049-1068.