5.08 METHODS FOR INCORPORATING THE INFLUENCE OF URBAN METEOROLOGY IN AIR POLLUTION ASSESSMENTS

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The COST 715 programme is a European activity which supports scientific exchange and networks, on meteorology applied to urban air pollution problems. For urban pollution assessments one needs the input of heat, energy, or pollution near the ground, averaged over an area. The properties of the urban surface vary enormously over very short distances making this difficult regardless of computing power. This paper is concerned with ways of averaging dispersion to account for urban processes.

COST 715 has considered most of the available methods. All methods require measurements for testing, but as these need to be made above roof level, where data is not routinely available, except during detailed measurement campaigns. There is an ongoing debate as to where to site meteorological instruments in urban areas. COST 715 has concluded that regulators in many European countries are applying methods to urban dispersion problems which may be suspect, because of the way urban meteorological data is handled. An inventory of European urban meteorological sites has been prepared and COST 715 has made recommendations on the sitting of urban meteorological instruments so that pollution calculations are more reliable.

Table 1 illustrates some of the methods proposed in practical urban dispersion calculations. No single solution to the averaging problem has emerged. Although more complex computer models are seen as the way of tackling this complex issue, it is worth cautioning that they often make assumptions that may not be realistic. These are, for example, assuming a low blending height in the atmosphere, above which horizontally averaged variables satisfy similarity theory, and that the flow is in equilibrium, in layers below the blending height.

Table 1 Some Methods for Urbanising the Meteorological Input

Meteorological pre-processor	Transport model	Where tested
Minimum L, increased z_0	ADMS, UDM-FMI	Urban calculations
Roughness sub-layer scaling	Lagrangian stochastic particle model, OML	Indianapolis, Lillestrøm Wind tunnel BUBBLE experiment, Zürich
LUMPS	Any dispersion model	Multi-city urban hydromet database N American cities
Oke parameters Urban heat storage	BOXURB	Birmingham
Downscaling and wind filed modelling		See COST 715 reports
AERMET based on Oke, z_0 and Bowen ratio modifications	AERMOD	See model specification
Roof to street wind adjustment	OSPM	Street canyons in various European cities
Wind tunnel modelling		Gottinger St, Hannover

Sensitivity to meteorological parameterisation

The practical outcome of urban dispersion estimates are predictions to compare with air quality objectives. The performance of some air quality models in which the effect of urban modifications have been taken into account are listed in Table 2. The overall performance of models is influenced by factors besides the urban meteorology, and agreement within a factor of 2 is regarded as acceptable. From the basic integral equation for the concentration of a tracer

$$\int_{x_1}^{x_2} q(y)G(x, y)dx = C_{meas}(x_2) \qquad (1)$$

where q(y) is the emission density, G(x,y) describes the dispersion, and C_{meas} is the measured concentration at a monitoring site, one sees that the urban meteorology influences the dilution, but large uncertainties arise from variations in source strength q(y), which is probably poorly known in magnitude, or position in a grid square. There is a danger that the problem is ill-posed and this is avoided by considering truncated solutions in which near-field effects are neglected. The same argument is applied when treating urban heat, humidity or roughness, for which G describes the urban footprint. The blending height at a level some way above the surface is used.

Typically G(x,0) has the form

$$G(x,0) = \frac{1}{ku_*x(1+n)} \qquad (2)$$

where k is von Karman's constant, u* the friction velocity, x distance downwind and n a power law constant defining the wind profile. Hence concentrations depend strongly on distance and to a lesser extent on the urban influence on the friction velocity.

The models in Table 2 assume the same pattern of dispersion throughout the urban area. They can still be computational demanding because of emissions. A model, which describes the spatial variability over the emissions grid, is preferred, and can provide forecasts of air pollution episodes (Baklanov et al, 2002). Increasing computer power allows meso-scale meteorological models to be run at high spatial resolution. More grid points will be truly 'urban' grid points, requiring a surface exchange parameterization that takes into account urban surface characteristics and exchange processes e.g. Martelli et al (2002). Urban exchange schemes are starting to be tested (Roulet, 2003) using measured urban profiles from field experiments, such as BUBBLE. Piringer et al (2002) have reviewed some of the surface exchange schemes proposed in meso-scale models. These still require assumptions to treat the spatial averaging within grid squares and the blending height assumption is usually adopted.

Measurements have been made in Basel, in the BUBBLE experiment, of wind profiles (Christen et al, 2003), sensible heat flux, turbulence and tracers (Rotach et al 2003a,b). Wind tunnels provide an efficient way of extending measurements spatially (Feddersen et al, 2003). Results indicate that the sensible heat flux is upward during the night during the whole year produced by the daytime storage of heat. An example of the application of these ideas is in the estimation of urban concentrations, and in deciding on how to select appropriate meteorological data.

Sensitivity to urban meteorology

For London urban meteorological data from the London Weather Centre and rural data at Manston have been compared. The urban adjustment included changes in roughness length,

surface albedo, surface heat storage, Bowen ratio. In the figure below the friction velocity is compared based on routine meteorological data. The stability over the urban area is generally close to neutral. The BUBBLE experiment suggests that the heat flux is nearly always upward. The friction velocity in the urban area should be interpreted as the value at the top of the surface roughness layer. It is not the value applied in dispersion equation (2).

Friction velocity
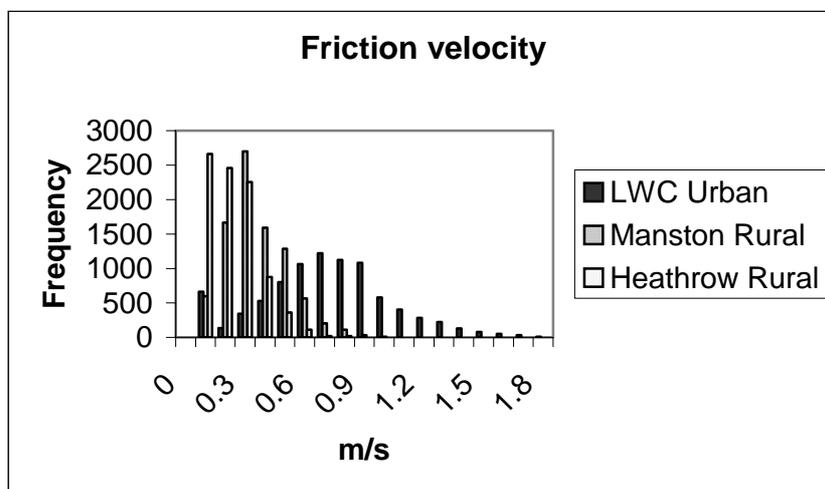
A daytime storage term has been included with a typical urban Bowen ratio (sensible to latent heart ratio) and an urban roughness, to compare urban and rural parameterisations of H, L and u_*, using routine hourly data from meteorological sites around London. The u_* for central London derived from the urban pre-processor tends to be larger than that obtained from the rural sites but refers at the top of the roughness sub-layer above roof level. Hence it is not necessarily the correct scaling for urban dispersion and the turbulence level needs to be adjusted before applying a dispersion formula. Thus urban dispersion is a balance between competing urban factors!

In other cities the Inventory of Urban Meteorological Sites may be consulted as the starting point to urban meteorological pre-processing. More complex urban relationships are provided in COST 715 publications, but simple guidance from COST 715 is not yet available. Other authors have made practical suggestions (Hanna, Britter and Franzese, 2003).

Other factors which are relevant to the urban boundary layer, such as mixing height, are discussed in COST 715 publications listed below:
(1) Surface energy balance in urban areas. Extended abstracts of an expert meeting, Antwerp 12 April 2000, COST report EUR 19447
(2) Preparation of meteorological input data for urban site studies. Proceedings of the workshop 12 June 2000 Prague COST report EUR 19446
(3) Meteorology during peak pollution episodes. Working Group 3 status report. COST report EUR 19448.
(4) Workshop on urban boundary layer parameterisations. Extended abstracts. Zurich 24-25 May 2001 COST Report EUR 20355
(5) Mixing height and inversions in urban areas. Proceedings of the workshop 3-4 October 2001, Toulouse COST report EUR 20451

Web addresses:
COST715   http://www.dmu.dk/atmosphericenvironment/cost715.htm
Working Group 1   http://www.geo.umnw.ethz.ch/research/cost715/cost715_2.html
Working Group 2   http://cost.fmi.fi/wg2/
Working Group 3   http://cost.fmi.fi
Working Group 4   http://www.mi.uni-hamburg.de/cost715/form.html
Urban Meteorological Station Survey:
                        http://www.mi.uni-hamburg.de/cost715/inventory.html

REFERENCES

Baklanov A, Rasmussen A, Fay B, Berge E and Finardi S, 2002: Potential and shortcomings of numerical weather prediction models in providing meteorological data for urban air pollution forecasting, Water, Air and Soil Pollution: Focus 2, 43-60

Christen A, Vogt R, Rotach M W, 2003: Profile measurements of selected turbulence parameters over different urban surfaces. 4th International Conference on Urban Air Quality, Prague March 25-27 2003, 408-411

Christen A, Bernhofer C, Parlow E, Rotach M W, Vogt R, 2003: Partitioning of turbulent fluxes over different urban surfaces. Fifth International Conference on Urban Climate, September 1-5, 2003, Lodz, Poland 4p.

Feddersen B, Leitl B, Rotach M W, Schatzmann M, 2003: Wind tunnel investigation of the spatial variability of turbulence characteristics in the urban area of Basel City, Switzerland, Workshop Proceedings PHYSMOD2003, September 3-5, 2003, Prato, Italy, 23-25, Firenze University Press.

Gryning S-E, Batchvarova E, Rotach M W, Christen A, Vogt R, 2003: Roof level urban tracer experiment: measurements and modelling. 26th ITM NATO/CCMS international technical meeting on air pollution modelling and its application, May 26-30, 2003 Istanbul, 8p.

Hanna S, Britter R and Franzese P, 2003: A baseline urban dispersion model evaluated with Salt Lake City and Los Angeles tracer data, Atmospheric Environment, 37, 5069-82

Martilli A, Clappier A and Rotach M W, 2002: An urban surface exchange parameterisation for mesoscale models, BLM, 104, 261-304

Piringer M., Grimmond C S B, Joffre S M, Mestayer P, Middleton D R, Rotach M W, Baklanov A, De Ridder K, Ferreira J, Guilloteau E, Karppinen A, Martilli A, Masson V, Oke T R, Tombrou M, 2002: Investigating the surface energy balance in urban areas – recent advances and future needs, Water, Air and Soil Poll. Focus, 2, 1-16.

Rotach M, 2001: Simulations of urban scale dispersion using a Lagrangian stochastic model, Boundary layer meteorology, 99, 379-401

Rotach M W, Batchvarova E., Christen A, Gryning S-E, Vogt R, 2003: The BUBBLE near-surface tracer release experiment. 4th International Conference on Urban Air Quality, Prague, March 25-27 2003, 30-33

Rotach M W, Christen A, Vogt R, 2003: Profiles of turbulence statistics in the urban roughness sublayer with special emphasis to dispersion modelling. Fifth International Conference on Urban Climate, September 1-5 2003, Lodz, Poland 4p

Roulet Y-A, 2003: Modelling of urban effects over the city of Basel (Switzerland) as a part of the BUBBLE project. Fifth International Conference on Urban Climate, September 1-5 2003, Lodz, Poland 4p

Table 2 Accuracy of urban air quality models - Some examples of urban meteorological modification

Study	Model	Pollutants	Uncertainty
Modification of an operational dispersion model for urban applications, de Haan et al (2001)	OML with urban corrections (z_0, urban sub-layer, L_{min}) for Zürich	Annual average SO_2 and NOx (P predicted) and (O observed) Urban effect ~ 30% increase	Correlation coefficient r = 0.845(NOx) and 0.770(SO_2) Normalised mean square error NMSE = 0.132(NOx) and 0.053(SO_2) Fractional bias FB = 0.178(NOx) and 0.53(SO2) Factor of two (Fa2) (= $0.5 \leq (P/O) \leq 2$) = 0.93(NOx) and 1.0(SO_2) Improved performance with urban modification
Simulation of urban-scale dispersion using a Lagrangian stochastic dispersion model, Rotach (2001)	Particle model, crosswind integrated concentrations	Urban tracer data, Copenhagen (C), and Indianapolis (I), elevated releases	r = 0.89 (C) and 0.55 (I), NMSE = 0.10 (C) and 0.49 (I), FB = 0.19 (C) and 0.26 (I), Fa2 = 1.0 (C) and 0.58 (I) Some improved performance with urban modification
Comparison of modelling predictions with the data of an urban measurement network in, Helsinki, Finland, Karppinen *et al* (2000)	UDM-FMI, CAR-FMI with urban z_0, roughness sub-layer, L_{min}	NOx, NO_2	r^2 = 0.5 to 0.6, NMSE = 0.26 to 0.45, FB = -0.09 to +0.12 Index of agreement IA = 0.69 to 0.79 No non-urban comparison
Statistical and diagnostic evaluation of Helsinki model, Finland, Kousa *et al* (2001)	UDM-FMI, CAR-FMI	NOx, NO_2	r^2 = 0.39 to 0.68, NMSE = 0.21 to 1.19, FB = -0.29 to +0.26
Semi-empirical model of urban PM_{10} in Helsinki, Finland, Kukkonen *et al* (2001)	Study specific	Annual mean for each hour of the day, PM_{10}, at 4 monitoring stations, 1 year of data	r^2 = 0.36 to 0.9, FB = –0.04 to 0.09
Evaluation of CAR-FMI Model near a major road, Finland, Kukkonen *et al* (2001)	CAR-FMI	Hourly NO_x, NO_2	r^2 = 0.79 (NO_x) and 0.80 (NO_2), NMSE = 0.22 (NO_x) and 0.21 (NO_2) FB = 0.06 (NO_x) and -0.19 (NO_2), Fa2 = 0.94 (NO_x) and 0.67 (NO_2)
Evaluation of Street Canyon Model, Helsinki, Finland, Kukkonen *et al* (2001)	OSPM	Hourly NO_x, NO_2	r^2 = 0.77 (NO_x) and 0.83 (NO_2), FB = 0.045 (NO_x) and 0.22 (NO_2)

De Haan P, Rotach M W, and Werfeli M, 2001: Modification of an operational dispersion model for urban applications (2001) J App Met, 40, 864-879

Karppinen A, Kukkonen J, Elolähde T, Konttinen M and Koskentalo T, 2000: A modelling system for predicting urban air pollution: comparison of model predictions with the data of an urban measurement network in Helsinki, Atmospheric Environment, 34, 3735-43

Kukkonen J, Harkonen J, Karppinen A, Pohloa M, Pietarila H and Koskentalo T, 2001: A semi-empirical model for urban PM_{10} concentrations, and its evaluation against data from an urban measurement network, Atmospheric Environment, 35, 4433-4442

Kukkonen J, Harkonen J, Walden J, Karppinen A and Lusa K, 2001: Evaluation of the CAR-FMI Model against measurements near a major road, Atmospheric Environment, 35, 949-960

Kukkonen J, Valkonen E, Walden J, Koskentalo T, Aarnio P, Karppinen A, Berkowicz R and Kartastenpaa R, 2001: A measurement campaign in a street canyon in Helsinki and comparison of results with predictions of the OSPM Model, Atmospheric Environment, 35, 231-243

Kousa A, Kukkonen J, Karppinen A, Aarnio P and Koskentalo T, 2001: Statistical and diagnostic evaluation of a new-generation urban dispersion modelling system against an extensive dataset in the Helsinki area, Atmospheric Environment, 35, 4617-28