# The Surface Energy Budget and the Mixing Height in Urban Areas: Status report of Working Group 2 of COST-Action 715

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## 1. Introduction

COST ("Co-operation in the fields of Science and Technology") is a framework for scientific and technical co-operation, allowing the co-ordination of national research on a European level and to encourage and facilitate mutual scientific exchange among participants. COST Actions consist of basic and pre-competitive research as well as activities of public utility. COST funds co-ordination and networking but not the research itself. The main scientific goals of a COST Action are fixed in a "Memorandum of Understanding", to be signed by at least five COST Member States. An action lasts in general five years. Started in November 1998, COST Action 715 *'Meteorology applied to urban pollution problems"* has been signed by 19 countries and will end in September 2003. Action 715 is chaired by Bernard Fisher, UK Environment Agency, and co-chaired by Michael Schatzmann, University of Hamburg, Germany.

The core objective of Action 715 is to increase knowledge of, and the accessibility to, the main meteorological parameters which determine urban pollution levels, by comparing and contrasting methods in use in European countries, leading to recommendations for using routine meteorological information in air pollution assessments. The Action will address the best ways of providing data to the community of model users. The holders of meteorological information will be able to consider improved ways of processing meteorological information in order that it may be used effectively in air quality assessments of urban areas. Good methods for undertaking urban air quality assessments are required if the Directive on air quality assessment and management is to be implemented effectively. This Action 715 develops the scientific work achieved under the former Action COST-710 (*"Harmonization of the preprocessing of Meteorological data for atmospheric dispersion models "*; Fisher et al., 1998) from rural to urban conditions, and of Action COST CITAIR 615 (*"Data base, monitoring and modelling urban air pollution"*) for links between meteorology and urban air quality.

COST Action 715 is organised in four Working Groups, dealing with (1) urban wind fields, (2) surface energy budget and mixing height, (3) air pollution episodes in cities, and (4) meteorological input data for urban site studies. The members of working group 2 (WG2) are the authors of this contribution.

## 2. Lines of Activities of Working Group 2

Urban pollution meteorology is characterised by a number of fundamental parameters and their evolution in time, which all have specific problems as to their monitoring, representativeness, parameterisation and modelling. Within COST-715, WG2 addresses the specific problems in describing the surface energy balance and the mixing height. The surface energy balance and the surface temperature and heat fluxes determine the hydrostatic stability conditions in the lower atmosphere and regulate its strength for mixing pollutants, the mixing height parameter determines the available volume for pollutants mixing.

From the outset, WG2 members decided to arrange their activities along the following lines:

a) To review theoretical concepts of the structure of the urban boundary layer.

b) To review and assess pre-processors, schemes and models for determining the mixing height, the surface energy budget and the stability that are available to the participants. Cases of strong stability and/or windless conditions are of special interest.
c) To review theoretical models together with available field measurements and LES for calculation of the minimum friction velocity and the heat transfer coefficient. Conditions of shear free convection over high roughness are of main importance
d) TTo identify and review suitable data sets within and outside the group that could be used to test and validate the pre-processors and models.
e) To carry out intercomparisons and to summarise comparisons of different schemes against each other and against data under specific conditions.
f) To assess the influence of the model outputs of certain specific effects such as complex topography, strong heterogeneity, slope effects and canopy trapping on radiative fluxes.
g) To assess the suitability of remote sensing tools to estimate canopy characteristics and surface fluxes.
h) To provide recommendations for the improvement of existing pre-processors and models and for the development of new schemes.
i) To provide recommendations for planning and conducting field campaigns in order to fill the important existing gaps for empirical data of key parameters for urban air pollution.
j) To promote co-ordination of related activities in Europe of presently scattered works, objectives, and responsibilities.

## 3. Status of activities

After 4 meetings the following progress against the background of the above-mentioned lines of activities was achieved by Working Group 2.

a) Some core widely-used pre-processors for the determination of the surface energy budget were identified and will be tested against three sets of data during this year. Some of the individual partners will test their own pre-processor against new data.
b) A preliminary list of data sets was established. It will be updated and, especially, WG2 will attempt to characterise these data sets for wider use.
c) Intercomparisons of different schemes are under planning.
d) New schemes are under development to take into account the specific features of urban surfaces and canopy.

## 4. WG2 specific COST studies

The performance of widely used boundary layer parameterisation schemes such as those of Holtslag and Van Ulden (1983) or Berkowicz and Prahm (1982) has not been tested in urban environments. Grimmond and Oke (2000) recently developed an urban pre-processor scheme LUMPS (Local-Scale Urban Meteorological Pre-Processing Scheme) which, similarly to the schemes mentioned above, requires standard meteorological observations, but additionally basic knowledge of the surface character of the target urban area. LUMPS was developed and tested for North-American cities, but not in Europe. A Study Contract proposal on the validation of net radiation and sensible heat flux parameterisations against measured data in three European cities was accepted by COST 715 and submitted to the COST Secretariat for approval. Using data from Birmingham (UK), Basle (CH) and Graz (A), a statistical comparison of modelled and measured net radiation and sensible heat flux time series will be undertaken. Based on the results, the performance as well as the applicability (with respect to data availability including land use and other surface descriptors) of the different schemes will be judged.

Another specific tool of COST, short-term scientific missions, were and will be conducted within Action 715 to exchange experience on certain pre-processors and data.

## 5. The Antwerp Expert Meeting

An expert meeting was arranged by WG2 to bring together experts to report on current understanding of the surface energy balance in urban areas and discuss future research needs. Eight presentations were given at Antwerp on 12 April 2000, consisting of both experimental and numerical contributions.

**Mathias Rotach** discussed proper siting of urban meteorological instrumentation and summarised the requirements for meteorological instruments in urban studies with respect to the horizontal dimensions and the vertical structure of the urban boundary layer. Noting, from ground upwards, the canopy (between elements) as a part of the roughness sub-layer (up to 2 - 5 times the building height), the inertial sub-layer (flow is representative of a larger area of elements), with the urban mixed layer above, a common and overall accepted nomenclature is not available yet.

**Sue Grimmond** and Tim Oke reported on their measurement campaigns in several North American cities conducted over a ten-year period using tall towers with careful attention to fetch. They discussed in particular net all-wave radiation, latent and sensible heat flux, atmospheric stability, and storage heat flux. Sites are characterised by GIS using maps/photos/aerial photos/surveys of the area. The analysis of e.g. the latent heat fluxes shows big variations between the cities mainly as a function of the fraction of vegetation cover and the fraction of irrigated area.

**Koen de Ridder** assessed some pros and cons of remote sensing of the urban energy balance by satellite. He presented two methods to derive a map of the surface energy balance from satellite images, the first based on the difference between the surface radiation temperature measured by the satellite and the local air temperature, the second consisting in estimating surface parameters from satellite remote sensing and land-use maps and computing the surface energy balance via a SVAT (Soil Vegetation Atmosphere Transfer) module.

**Valéry Masson** carried out a numerical study using the meso-scale atmospheric model MESO-NH in combination with the Town Energy Budget (TEB) scheme to compute urban surface fluxes to investigate the influence of Paris on the atmospheric boundary layer for an anticyclonic summer day.

**Tim Oke** and Sue Grimmond compared conventional views of urban/rural differences for the surface energy balance on the basis of measurements undertaken in Sacramento, Tucson, and Vancouver. In Tucson and Sacramento which are semi-arid, the sensible heat flux at the rural site is bigger than at the urban site with a reversal of the traditional heat island effect.

**Doug Middleton** in collaboration with Nicola Ellis reported on field measurements of the surface fluxes at an industrial site in Birmingham, UK, and showed a box model with an urban heat storage adjustment to delay the onset of stable conditions on summer evenings.

**Emmanuel Guilloteau** used the French SUBMESO model which has a force-restore model of rural soil introducing new parameterisations for the urban soil-atmosphere interactions. The water parameters were tested in considerable detail. Many different soil types are represented. The test of the new urban soil model on five typical European quarters with imposed atmospheric data derived from the Hapex-Mobilhy experiment demonstrate the need to model the influence of the canopy vertical surfaces through radiative trapping and sensible heat storage.

**Alberto Martilli** parameterised heat and momentum fluxes in urban areas by taking into account roofs, walls, and the canyon floor, to be used by mesoscale models, tested for 2D idealised cases of an urban boundary layer.

An overview of the Antwerp presentations appeared in the EURASAP Newsletter 38 (Middleton et al., 2000). Extended abstracts of the presentations will be published as a COST-report (Piringer, ed., 2000).

The main conclusions and recommendations from the meeting were:

1. A number of European groups run mesoscale models with sub-models of fluxes for urban areas.
2. The influence of the urban canopy, building energy flows and thermal properties along with effective albedo reduction by radiative trapping between canyon walls may be important and should be modelled.

3. Water flux is a very important determinant of city heat island effects; the surrounding countryside must also be considered as it differs significantly from the remote 'rural' areas.
4. The behaviour of turbulent flux profiles in the thick roughness sub-layer due to high roughness elements requires more study, both in the field and with models.
5. Urban meteorological masts should go above the roughness sub-layer into the inertial sub-layer and above. The heights of these layers vary with conditions and fetch (2 to 5 times the building height).
6. Horizontal inhomogeneity of the canopy means diffusivities differ, $K_E \neq K_H$, since water transfers are surface processes while heat transfers are mediated by the canopy's own thermodynamics.
7. Sites should be characterised with the help of aerial photos, local surveys, maps, building dimensions, GIS, and urban data bases.
8. Satellites can measure some aspects of the urban environment, but are incomplete on their own and require skilled interpretation.

## 6. Forthcoming work

An experiment on the urban boundary layer (UBL) is being planned during the large French photochemistry experimental campaign ESCOMPTE (June-July 2001). The UBL-Escompte experiment is concerned with urban meteorology and remote sensing by satellite, encouraged by the Antwerp expert meeting discussions and recommendations. The WG2 members are keen to help in planning this experiment and to use its data for testing/validating the existing schemes and models. Another opportunity to stimulate forthcoming work of WG2 will be BUBBLE, the Basle Urban Boundary Layer Experiment, already accepted by the Swiss COST financial authorities, a joint action of six Swiss institutes, lead by Mathias Rotach. The urban boundary layer at Basle will be investigated by a one-year monitoring of near-surface turbulence characteristics as well as the UBL's vertical structure. A mesoscale numerical model will be used to validate and improve urban surface parameterisations.

A recent COST 715 Management Committee Meeting in Greenwich, UK, decided to support exchange amongst the working groups by planning and conducting joint workshops. In May 2001, in close co-operation with BUBBLE, WG1 and WG2 will conduct a workshop on boundary layer parameterisations at Zurich, followed by a common WG2 and WG3 workshop on mixing heights in urban areas, with special emphasis on peak pollution episodes, scheduled for autumn 2001 in Toulouse.

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