SEVENTH FRAMEWORK PROGRAMME

THEME 6: Environment (including climate change)

Contract for: **Collaborative Project**

D.3.5

BRIDGE observation protocols

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1. Introduction

The term "*urban metabolism*" is used to indicate the exchange and transformation of energy and matter between a city and its environment. In the BRIDGE (sustainaBle uRban plannIng Decision support accountinG for urban mEtabolism) project, the WP3 is dedicated to collect data of urban fluxes measured in five European cities (Helsinki, Athens, London, Firenze and Gliwice) as representative of the different city typologies and influenced by different policy and resource availability. Urban fluxes are strongly affected by the urban surface characteristics and changes in land use (e.g. new buildings construction, increasing of green areas etc.) mainly determine changes at regional scale.

Exchanges of energy, heat, moisture, carbon and pollutant are then measured using different techniques, during the project, for each case study. Also, local and regional urban fluxes are simulated by models in selected cities. In addition, GIS data and remote sensing methodologies are used to investigate on the role of land use in affecting the surface exchanges between the urban canopy and the atmosphere.

1.1 Purpose of the document

This document is the D.3.5_BRIDGE observation protocols. Work package 3 has the role of systematically monitor the main fluxes using remote in situ measurements and sensing techniques and to address socioeconomic issues for each case study (Helsinki, Athens, London, Firenze and Gliwice). The final products of WP3 are datasets and maps of energy and water fluxes, pollution concentrations, land cover and vegetation per each case study.

The **aim of this document** is to provide a comprehensive report on the methodologies applied and lessons learned in the course of the measurements campaigns carried on in the measurement campaigns of the BRIDGE Project.

1.2 Definitions and Acronyms

Acronyms

CoP	Community of Practice
DSS	Decision Support System
GIS	Geographical Information System
RS	Remote Sensing
DEM	Digital Elevation Model
ASTER	Advanced Thermal Emission and Reflection Radiometer

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1.4 Project Overview

Urban metabolism considers a city as a system and distinguishes between energy and material flows. “Metabolic” studies are usually top-down approaches that assess the inputs and outputs of food, water, energy, etc. from a city, or that compare the metabolic process of several cities. In contrast, bottom-up approaches are based on quantitative estimates of urban metabolism components at local scale, considering the urban metabolism as the 3D exchange and transformation of energy and matter between a city and its environment. Recent advances in bio-physical sciences have led to new methods to estimate energy, water, carbon and pollutants fluxes. However, there is poor communication of new knowledge to end-users, such as planners, architects and engineers.

BRIDGE aims at illustrating the advantages of considering environmental issues in urban planning. BRIDGE will not perform a complete life cycle analysis or whole system urban metabolism, but rather focuses on specific metabolism components (energy, water, carbon, pollutants). BRIDGE’s main goal is to develop a Decision Support System (DSS) which has the potential to propose modifications on the metabolism of urban systems towards sustainability.

BRIDGE is a joint effort of 14 Organizations from 11 EU countries. Helsinki, Athens, London, Firenze and Gliwice have been selected as case study cities. The project uses a “Community of Practice” approach, which means that local stakeholders and scientists of the BRIDGE meet on a regular basis to learn from each other. The end-users are therefore involved in the project from the beginning. The energy and water fluxes are measured and modeled at local scale. The fluxes of carbon and pollutants are modeled and their spatio-temporal distributions are estimated. These fluxes are simulated in a 3D context and also dynamically by using state-of-the-art numerical models, which normally simulate the complexity of the urban dynamical process exploiting the power and capabilities of modern computer platforms. The output of the above models lead to indicators which define the state of the urban environment. The end-users decide on the objectives that correspond to their needs and determine objectives’ relative importance. Once the objectives have been determined, a set of associated criteria are developed to link the objectives with the indicators. BRIDGE integrate key environmental and socio-economic considerations into urban planning through Strategic Environmental Assessment. The BRIDGE DSS evaluates how planning alternatives can modify the physical flows of the above urban metabolism components. A Multi-criteria Decision Making approach has been adopted in BRIDGE DSS. To cope with the complexity of urban metabolism issues, the objectives measure the intensity of the interactions among the different elements in the system and its environment. The objectives are related to the fluxes of energy, water, carbon and pollutants in the case studies. The evaluation of the performance of each alternative is done in accordance with the developed scales for each criterion to measure the performance of individual alternatives.

Several studies have addressed urban metabolism issues, but few have integrated the development of numerical tools and methodologies for the analysis of fluxes between a city and its environment with its validation and application in terms of future development alternatives, based on environmental and socio-economic indicators for baseline and extreme situations. The innovation of BRIDGE lies in the development of a DSS integrating the bio-physical observations with socio-economic issues. It allows end-users to evaluate several urban planning alternatives based on their initial identification of planning objectives. In this way, sustainable planning strategies will be proposed based on quantitative assessments of energy, water, carbon and pollutants fluxes.

2. Summary

Urban communities consume material and energy and eliminate the wastes from the process. Energy and mass are exchanged by urban environments and fluxes are modulated by human activities, such as heating and air conditioning, vehicular traffic, changes in vegetative cover, waste production etc., in what has been termed "urban metabolism".

The work package three of BRIDGE project includes the Data Collection and Analysis activities in the various case studies, representing a unique attempt to collect and to analyse an integrated database suitable for the development and validation of models and methodologies for the analysis of fluxes between the city and its environment.

The work package is further subdivided into 3 tasks, aiming at investigating the urban environment and quantitatively assessing geographic, bio-physical and socio-economic variables by appropriate approaches. Task 3.1 applies established and newly developed methodologies aimed at collecting comprehensive data sets by means of in situ observations.

The overall BRIDGE measurement plan in the 5 case studies was not orthogonal – in the sense that not all relevant parameters are measured or common methodologies applied in in every city – due to the limitation in available resources for the project.

A common core of measurements had been performed in all case studies. These concerns chiefly meteo data and the turbulent exchange of mass and energy as measured on an hourly basis by city adapted eddy covariance apparatus. All case studies but Athens feature a tower were such data are recorded on a continuous basis. Some of these sites have by now collected time series as long as five years (Firenze) or slightly less (Helsinki), thanks to installations that already existed and were operational when BRIDGE was started.

In some case studies, the main observation tower was complemented with other micrometeorological apparatus providing hourly measurements of the net flux of species different form CO_2 and H_2O, such as dust particles in Firenze and Helsinki. In the first instance fluxes were segregated by particle diameter and the net flux for several aerosol size classes could be assessed, in the other one only the overall net exchange across a range of sizes was available.

This document details BRIDGE observation protocols and aims to provide a comprehensive report on the methodologies applied and lessons learned in the course of the measurements campaigns carried on in the different case studies of the project.

Sections on urban meteorology, air quality, turbulent fluxes provide most of the details, as they were part of the common core of observations, as discussed above. These were the fields were a specific experience could be established by the consortium and lessons learnt were compared across study sites.

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3 Urban meteorology & air quality

3.1 Urban meteorology

3.1.1 Standard meteorological measurements (tower based measurements)

In monitoring urban meteorological environment there is a need to fully appreciate the scales of urban climates (micro-, local- and meso-scale) as they impact phenomena and measurement methods. The good guidance for planning and instalment of instruments and observing methods to urban meteorological observations is given in (Oke, 2006). For mesoscale observation networks we refer to (Koskinen et al., 2011), which provides the description of the platform in Finland called the Helsinki Testbed. However, the strict guidelines to be rigidly followed cannot be set and the guidance must be taken as rules to be applied in flexible manner depending on individual resources and aims. Although urban environment differs from natural ecosystems, there are also lot of similarities and one can partly follow also guidelines created for measurements for tall forests. ICOS (Integrated Carbon Observation System; http://www.icos-infrastructure.eu/) is standardising the meteorological, flux and ecophysiological measurements for natural and semi-natural ecosystems.

Scales of meteorological processes

The presence of the Urban Canopy Layer defines a micro-scale dominated layer beneath roof-level and a layer above roof level and the Roughness Sub-layer, which responds to the local scale. The above roof layer represents a blended influence that brings within questions on the rate of internal boundary layer growth and the location of the source areas ('footprints') for meteorological sensors. The essential first step in selecting urban station sites is to evaluate the physical nature of the urban terrain. This will reveal areas of 'homogeneity' and conversely areas of transition and inhomogeneity. A new site classification system has been devised to describe any urban site. It is based on measures of the urban structure, land cover, building fabric and metabolism (anthropogenic heat, water and pollution), rather than land-use zones which only relate to function, which is not necessarily climatically significant. The suggested classes are called Urban Climate Zones.

On the other side, the clarity of the reason for establishing an urban station is essential to its success. Two of the most usual reasons are, the wish to represent the meteorological environment at a place for general climatological purposes; and the wish to provide data in support of the needs of a particular user. In both cases the spatial and temporal scales of interest must be defined and, as outlined below, the siting of the station and the exposure of the instruments in each case may have to be very different.

There is no more important input to the success of an urban station than an appreciation of the concept of scale. There are three scales of interest

a) Microscale – every surface and object has its own microclimate on it and in its immediate vicinity. Surface and air temperatures may vary by several degrees in very short distances, even millimetres, and airflow can be greatly perturbed by even small objects. Typical scales of urban microclimates relate to the dimensions of individual buildings, trees, roads, streets, courtyards, gardens, etc. Typical scales extend from less than one metre to hundreds of metres. The formulation of the guidelines aims to avoid microclimatic effects. The climate station recommendations should be designed to standardize all sites, as far as practical. Hence the use of a standard height of measurement, a single surface cover, minimum distances to obstacles and little horizon obstruction. The aim is to achieve climate observations that are free of extraneous microclimate signals and hence they characterize local climates. With even more stringent standards at first order stations they may be able to represent conditions at synoptic space and time scales. The data may be used to assess climate trends at even larger scales. Unless the objectives are very specialized, urban stations should also avoid microclimate influences, but this is hard to achieve.

b) Local scale (also called neighbourhood scale) – this is the scale that standard climate stations are designed to monitor. Note that in the community of natural ecosystem research this scale is called the ecosystem scale. It includes landscape features such as topography but excludes microscale effects. In urban areas this translates to mean the climate of neighbourhoods with similar types of urban development (surface cover, size and spacing of buildings, activity). The signal is the integration of a characteristic mix of microclimatic effects arising from the source area in the vicinity of the site. The source area is the portion of the surface upstream to the wind that contributes the main properties of the flux or meteorological concentration being measured. Typical scales are one to several kilometres. The scale of turbulent fluxes is typically one order of magnitude smaller, the order of 100 m - 1 km (Vesala et al, 2008).
c) Mesoscale – a city influences weather and climate at the scale of the whole city, typically tens of kilometres in extent. A single station is not able to represent this scale.
An essential difference between the climate of urban areas and that of rural or airport locations is that in cities the vertical exchanges of momentum, heat and moisture does not occur at a (nearly) plane surface, but in a layer of significant thickness called the urban canopy layer (UCL). The height of the UCL is approximately equivalent to that of the mean height of the main roughness elements (buildings and trees), z_H. The microclimatic effects of individual surfaces and obstacles persist for a short distance away from their source but are then mixed and muted by the action of turbulent eddies. The distance before the effect is obliterated depends on the magnitude of the effect, the wind speed and the stability (i.e. stable, neutral or unstable).

Location of sensors

The objective of an instrumented urban site is to monitor the local scale climate near the surface. there are two viable approaches:

a) locate the site in the UCL at a location surrounded by average or ‘typical’ conditions for the urban terrain, and place the sensors at heights similar to those used at nonurban sites. This assumes that the mixing induced by flow around obstacles is sufficient to blend properties to form a UCL average at the local scale; or
b) mount the sensors on a tall tower above the RSL and obtain blended values that can be extrapolated down into the UCL. In general approach (a) works best for air temperature and humidity, and approach (b) for wind speed and direction and precipitation. For radiation the only significant requirement is for an unobstructed horizon. Urban stations, therefore, often

consist of instruments deployed both below and above roof-level and this requires that site assessment and description include the scales relevant to both contexts.

A sensor placed above a surface 'sees' only a portion of its surroundings. This is called the 'source area' of the instrument which depends on its height and the characteristics of the process transporting the surface property to the sensor. For upwelling radiation signals (short- and longwave radiation and surface temperature viewed by an infrared thermometer) the field-of-view of the instrument and the geometry of the underlying surface set what is seen. By analogy sensors such as thermometers, hygrometers, gas analyzers, anemometers 'see' properties such as temperature, humidity, atmospheric gases, wind speed and direction that are carried from the surface to the sensor by turbulent transport.

The most obvious requirement that cannot be met at many urban sites is the distance from obstacles. The standard weather monitoring requires that the sensors must be located close to the ground and the length of the open fetch must be at least the same as the height of the surrounding roughness elements, such as buildings or trees. It is recommended that the urban station be centred in an open space where the surrounding aspect ratio is approximately representative of the locality. However, often the purpose is to get information on canopy and roughness sub-layer (RSL) and intertial sublayer (IS) properties and processes and thus some of the measurements are especially located within the canopy (rather than on the open space) and above it possibly at various heights. Tall buildings help to get a way to high but must one assess the interference effects of the building, which is not so big problem in the case of towers with lighter constructions. When installing instruments at urban sites it is especially important to use shielded cables because of the ubiquity of power lines and other sources of electrical noise at such locations.

WMO recommendations regarding the documentation of metadata, including station identifiers, geographical data, instrument exposure, type of instruments, instrument mounting and shelters, data recording and transmission, observing practices, metadata storage and access and data processing should be observed at urban stations.

BRIDGE examples: Firenze and Helsinki

During BRIDGE project we improved the instrumentation installing automatic weather station especially suited for urban environment, following the guidelines exposed above.

The meteo variables collected were:

- Air temperature; often the profile covering at least the canopy and RSL is desired
- Air humidity
- Wind speed anddirection; often the profile covering at least the canopy and RSL is desired; 2-D sonic anemometers have recently started to replace the cup anemometer and wind vane
- Global solar radiation
- Rainfall; precipitation observations must be conducted near ground at an unobstructed site, or above the canopy; at high latitudes the snow precipation may be important even on annual basis, the reliable collection of snow especially at windy conditions is challenging
- Atmospheric pressure
- Solar radiation (short and long wave, incoming and outcoming); from these the net radiation and albedo can be calculated; with the exception of incoming components, for which a roof

site is acceptable, the sensors must be located high on a tower to see the range of surface types; however, it must ensured that the plane of a sensor is horizontal and that a downward sensor does not see incoming radiation at large angles, and the radiative flux divergence must be considred

- A-class rain gauge 0.1mm resolution,
- High precision barometer
- Infra-red thermometer for roof/wall surface temperature

As an example, in the case of the Ximeniano tower in Firenze, all sensors were installed on top of a tower mast taller than the average surrounding buildings, free of obstacles 7 meters above the observatory roof level.

In Helsinki, two extensive measurement sites have been operating utilizing a tower and buildings as platforms (Vesala et al., 2008; Järvi et al., 2009). These publications provide information on the older site away from the city centre and on the newer site located in the city centre no publications are yet available.

The surroundings of the Kumpula site away from the city centre consists of some green areas, rather low buildings and roads with large traffic rates. The site utilizes one of the buildings belonging to the University Campus and on the roof (51 m) the temperature, humidity, pressure, global radiation and incoming longwave radiation are measured. Wind speed and direction are measured by means of the short tower 6 m above the roof. The surroundings of the measurement location on the roof is open. Beside the standard BRIDGE variables also photosynthetically active radiation (PAR) and cloud base (Ceilometer) are monitored on the roof.

For variables, which cannot be measured without the interference of the roof, a 31-m high tower was erected. It includes wind speed and direction and temperature profiles (4, 8, 16 and 31 m), global radiation, PAR and incoming and outcoming longwave radiation (all at 31 m). Beside these,

the turbulent flux of momentum, sensible heat, carbon dioxide, water vapour and number of aerosol particles are measured at 31 m by the eddy covariance technique.

The site in the Helsinki city centre is built-up utilizing the tallest tower-like building (a hotel) and some radiation sensors are located in a commercial telephone tower. The measurements include the basic set-up of variables and a special attention was paid to longwave radiation measurements of canopy surfaces to get information on temperature distributions. Accordingly, four infrared radiation analyzers were mounted at the building to measure temperature of four different surfaces. The analyzers are located between 36 and 38 meters from the ground level. One of the analyzers is measuring black sheet metal roof located at the south-east side of the tower. The distance to the surface is 0.7 m. The second analyzer is directed towards a concrete wall also at the south-east side of the tower and its distance to the wall is 20 cm. The other two analyzers are measuring concrete floor and concrete wall at the south-west side of the tower. Their distances from the surfaces are 72 and 56 cm, respectively. All four analyzers have a narrow field of view (Half angle 18°) and 15 meter long data cables lead to a data logger situated inside a measurement container located at the level of 36 meters.

3.1.2 Heat island measurements

Introduction

Surface and atmospheric modifications due to urbanization generally lead to a modified thermal climate that is warmer than the surrounding non-urbanized areas. This phenomenon is the urban heat island (UHI).

Heat islands can be defined for different layers of the urban atmosphere, and for various surfaces and even the subsurface (Oke, 1995; Voogt & Oke, 1997). It is important to distinguish between these different heat islands as their underlying mechanisms are different (Oke, 1982; Roth et al., 1989).

Heat islands may be defined for:

a) the urban canopy layer (UCL), that layer of the urban atmosphere extending upwards from the surface to approximately mean building height, and

b) the urban boundary layer (UBL), that layer above the UCL that is influenced by the underlying urban surface. This region typically extends no more than 1.5 km from the surface

c) The urban surface

The first two, consist the atmospheric urban heat islands and the third is the surface urban heat island (SUHI)

Canopy layer UHI are typically detected by in situ sensors at standard (screen-level) meteorological height or from traverses of vehicle-mounted sensors, UBL heat island observations are made from more specialized sensor platforms such as tall towers, radiosonde or tethered balloon flights, or from aircraft-mounted instruments. These direct, in situ measurements require radiation shielding and aspiration to give representative measurements and their setting relative to surrounding features is important. A variety of sources can be used to take these measurements, including National Weather Service stations; military weather stations; urban or regional weather station networks, field campaigns and transect studies, which involve using hand-held measurement devices or mounting measurement equipment on cars or aircraft.

On the other hand, thermal remote sensors observe the surface urban heat island (SUHI), or, more specifically they 'see' the spatial patterns of upwelling thermal radiance received by the remote sensor (most often directional radiometric temperatures or directional brightness temperatures corrected only for atmospheric transmission) (Voogt and Oke 2003). In contrast to the direct in situ measurements made of atmospheric heat islands, the remotely sensed SUHI is an indirect measurement requiring consideration of the intervening atmosphere and the surface radiative properties that influence the emission and reflection of radiation within the spectral wavelengths detected by the sensor.

The following table summarises the basic characteristics of the atmospheric and surface urban heat islands

Table 1: Basic characteristics of surface and atmospheric urban heat islands (EPA 2009)

Feature	Surface UHI	Atmospheric UHI
Temporal Development	• Present at all times of the day and night • Most intense during the day and in the summer	• May be small or non-existent during the day • Most intense at night or predawn and in the winter
Peak Intensity (Most intense UHI conditions)	• More spatial and temporal variation: ▪ Day: 18 to 27°F (10 to 15°C) ▪ Night: 9 to 18°F (5 to 10°C)	• Less variation: ▪ Day: -1.8 to 5.4°F (-1 to 3°C) ▪ Night: 12.6 to 21.6°F (7 to 12°C)
Typical Identification Method	• Indirect measurement: ▪ Remote sensing	• Direct measurement: ▪ Fixed weather stations ▪ Mobile traverses
Typical Depiction	• Thermal image	• Isotherm map • Temperature graph

CLUHI measurement methodology

The scope of this section is to provide guidelines for assessing the spatiotemporal heat island characteristics at the urban canopy level (CLUHI).

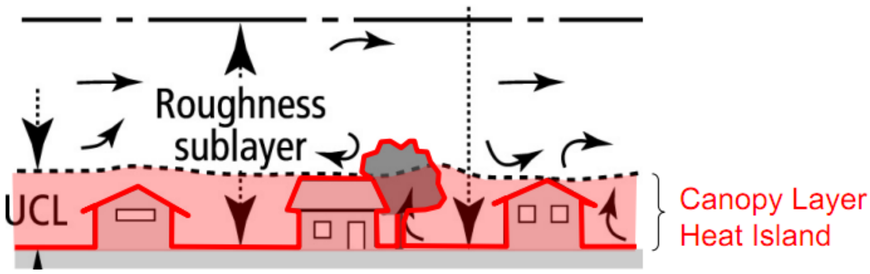

Fig. 1 Canopy layer heat island (Voogt 2007)

Canopy layer urban heat islands are assessed by typically measuring air temperatures through a dense network of sampling points from fixed stations or mobile traverses.

The scope of the sensors network is to characterize spatial features of the urban climate so the typical spatial form of urban climate distributions should be considered. Location and site of each sensor should be chosen carefully in order to fulfil the needs of the experiment. Sensor location is critical in urban environments and before choosing the proper location questions like "What are the measurements trying to represent?", "Are there multiple rural –non-urban types surrounding the city" etc. should be answered. In general the approach is to locate the site in the UCL at a location surrounded by average or 'typical' conditions for the urban terrain, and place the sensors at heights similar to those used at nonurban sites. This assumes that the mixing induced by flow around obstacles is sufficient to blend properties to form a UCL average at the local scale. Since the aim is to monitor local climate attributable to an urban area it is necessary to avoid extraneous microclimatic influences or other local or mesoscale climatic phenomena that will complicate the urban record (Oke 2006).

The network of stations should include sensors located in suburban and rural locations around the city in order to calculate the heat island.

Air temperatures should usually be measured at about 1.5 meters above the ground, where standard weather observations are taken. Sensors must be adequately shaded and ventilated in order to provide reasonable measurements as in the UCL a sensor assembly may be relatively close to warm surfaces such as a sunlit wall, road, etc. Therefore shields should be of a type to block radiation effectively. Similarly, an assembly placed in the lower UCL may be too well sheltered, so forced ventilation of the sensor is recommended. If a network includes a mixture of sensor assemblies with/without shields and ventilation this may contribute to inter-site differences, so practices should be uniform (Oke 2006).

Details on traverse measurements are described in section 3.1.3

Figure 2 illustrates an isotherm map that depicts an atmospheric urban heat island.

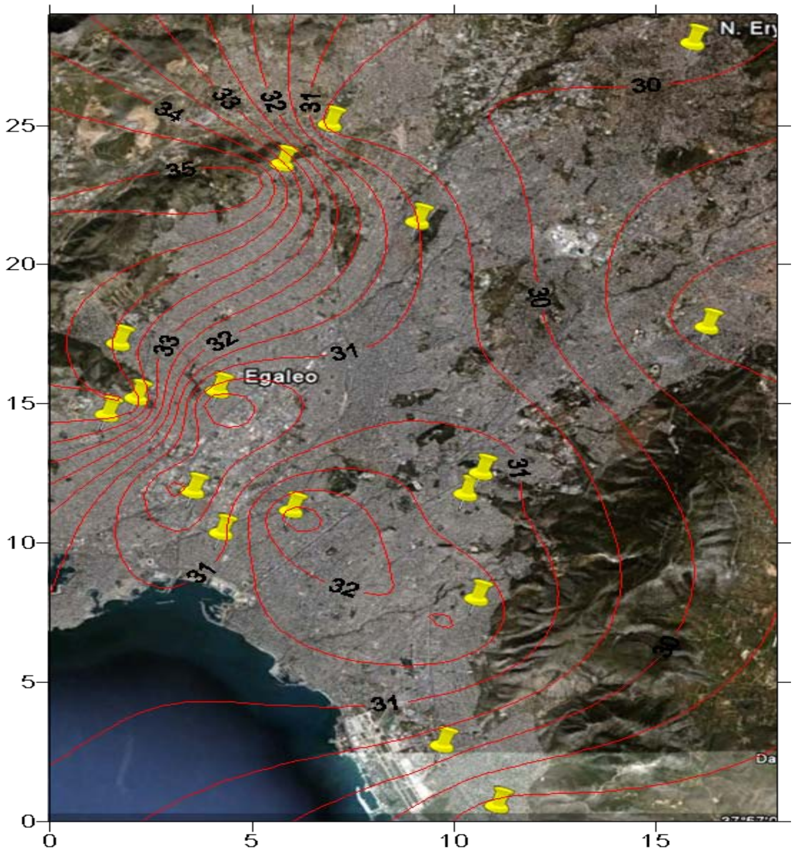

Figure 2: Isotherm map of the Athens atmospheric urban heat island as calculated from a network of 17 sensors.

A simple graph of temperature differences, as shown in Figure 3, is another way to show the results.

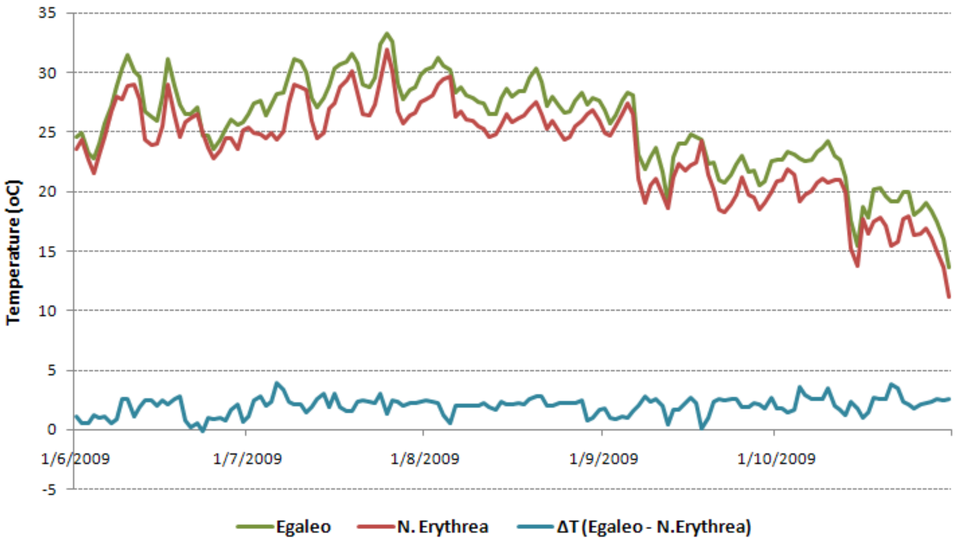

Figure 3: Temperature differences between an urban (Egaleo) and a rural station (N. Erythrea)

In order to provide proper analysis of the collected data, detailed information on sensor location (local scale surroundings like dominant land-use, topography, roughness Class, % of land cover

veg/built/water/open etc.) and site (microscale surroundings like sensor heights, surface cover, building types and materials etc) should also be collected

Factors that affect urban heat islands that should be taken into account when collecting and analyzing heat island data include:

-Time (day, season)

- Geographic Location (climatic conditions, topography, rural surrounds etc.)

- Weather (wind, cloud cover etc.)

- city characteristics (materials, geometry, greenspaces, pollution etc.)

3.1.3 Transect measurements (mobile station measurements)

For the purposes of monitoring an urban heat island (UHI) effect and/ or outdoor environmental quality (e.g. thermal comfort, pollutants etc.) at local level, a transect study could be conducted that measures temperature, humidity and wind speed changes across a sample area (transect), often using measuring equipment mounted on a vehicle and/or handheld, portable devices. () A transect study offers a more localised data pool, which can provide a higher spatial and temporal resolution for a specific area than other modes of data acquisition (e.g. large-scale remote sensing) (EPA website). A mobile meteorological station can also be used for measurements in urban canyons and in general in the canopy layer. (Georgakis & Santamouris 2006)

Fig. 1: Measurements with the mobile meteorological station and the telescopic mast.

Measurement and Data Collection Guidelines

A complete UHI transect study should include sample areas of various land uses and land cover so as to adequately represent the urban topography. Timing and weather conditions are also important, both for meaningful comparison and the fact that the e.g. UHI is usually most intense in the early evening (EPA website).

Instruments such as thermometers, wind speed and wind direction sensors can be mounted on a telescopic mast so as to provide data for several altitudes (typically 1.5, 3.5, 7.5, 11.5 and 15.5 m). Thermal sensors should be shielded against direct sunlight and adverse weather, while still allowing air to flow around them (Oke T. R., 2004).

Points to consider in optimising the quality of the acquired data would be the following (Voogt, J., 2007):

- Corrections for temperature changes during the time of the traverse. At least the start and end-points should be common.
- Consider the frequency of sampling in conjunction with distance covered. Changes in vehicle speed could lead to under- or over-representation of certain locations.
- Make sure the thermal sensors are not affected by the vehicle exhaust.
- In case of radiant heat sensors, consider whether the source area of the sensor is representative of the larger area under study.
- A GPS should be used to define the exact location and time of measurements

3.2 Air quality

3.2.1 Gaseous pollutants

The improvement of air quality was identified as a key planning objective and three air quality indicators were identified as follows:

- Greenhouse gases and CO_2 emissions per capita.
- Concentrations of pollutants (ozone and particulate matter).

- Emissions from transport, split per type: private and public

Measuring surface fluxes of energy, mass and momentum from urban environments can provide important information on the urban energy balance, and emission dynamics to be used in a number of different tools, ranging from atmospheric models to emission models, DSS systems and in conventional planning systems.

Concentrations of gaseous pollutant and dust (particulate matter of aerodynamic diameter less than 10µm) and CO2 fluxes were required to run both the offline and on line models linked to the BRIDGE Decision Support System. Air quality data and emission data were recorded at each of the case study cities as described below.

Methods

Measurement of turbulent fluxes of carbon dioxide (CO2), water vapour (H2O) and aerosol particulate number with eddy covariance techniques.

Turbulent fluxes of carbon dioxide (CO2), water vapour (H2O) and aerosol particulate number were measured with eddy covariance technique at four of the case study sites. In Helsinki these measurements were made at the top of a 31 meter tower. The measurement set-up consists of a Metek ultrasonic anemometer (USA-1, Metek GmbH, Germany) to measure all three wind components and sonic temperature, open and closed – path infrared gas analysers (LI-7500 and LI-7000) respectively, LI-COR, Lincoln, Nebraska USA) to measure CO2 and H2O densities and mixing ratios, and a water-based condensation particle counter (WCPC, TSI-3781, TSI, Incorporated USA) to measure aerosol particle number concentration starting from a size of 6nm (Järvi et al 2009b) .The aerosol particle and gas concentration instrumentation was situated in an air conditioned container next to the measurement tower. Sample air for the instrumentation was drawn through inlets located at four meters from the ground. The measurements of aerosol particle size range from 3 to 950nm were made with a twin differential mobile particle sizer (DMPS). In this set-up, the first DMPS measures particles in the size range 3-50nm, the second 10-950nm. The measured aerosol particle size range was divided into 3-30nm, 30-100nm and 100-950nm size particles.

Turbulent fluxes were measured on tall towers at the Kings College, London observation site. Sensible, latent heat, and CO2 and H2O fluxes were measured using Eddy Covariance (EC) systems consisting of a CSAT3 sonic anemometer (Campbell Scientific) and a Li7500 open path infrared gas analyser (LiCOR Biosciences). ECpack (van Dijk et al. 2004) is used for EC processing with several pre- and post processing steps performed using scripts written in R (R Development Core Team 2005). Commonly used corrections are applied to the data in order to optimize reliability of the resulting fluxes. Firstly, the pre-processing addresses the possible time lag between the time series of IRGA and sonic readings. Not accounting for this can result in flux errors of the order of 10 % (Mauder et al. 2007). Time series are shifted to meet maximal cross correlation between H2O concentration and sonic temperature. Subsequently, quality control identifies any raw data that are questionable. Gas concentration readings are excluded from all processing if the Li7500 gas analyzer reports path obstruction of at least 75%, indicated by the diagnostics value. Similarly observations from all variables are classified as erroneous if the CSAT3 diagnostic parameter indicates problems. The range of observed values is further restricted to physically reasonable values, which are defined by the measurement range of the instruments. In addition to these general restrictions, single values and short term periods which differ distinctly from the pattern observed during the respective 30 min period are detected. Those 'spikes' are commonly found in EC raw data (e.g. due to irregularities in power supply) but need to be removed because of their high impact on (co-) variance calculations. The despiking procedure used in this study is developed following the one described by Schmid et al. (2003). It is adapted to site specific requirements .

An eddy covariance (EC) flux station was installed in Firenze (438479N, 118159E) in at the Osservatorio Ximeniano, in the centre of the city, and was operated continuously for the project duration. A mast of 3m was mounted on a typical tile roof of an ancient building of the observatory at 33 m above the street level. Turbulent fluxes of CO2, momentum, and sensible heat were collected using a sonic anemometer and an open-path CO2/H2O infrared gas analyzer (Li7500). Ancillary measurements are provided by a Class A weather station. Flux data are computed at a 30 minutes time resolution, and quality checked with state of the art procedures (Foken et al 2006) . For the analysis presented in this study, data have been averaged across various time scales, in order to resolve daily courses, weekly, monthly and seasonal courses of energy balance and surface emissions. Seasonal analysis has been accomplished by grouping together periods with similar overall emissions: Nov-Dec-Jan-Feb ('winter' period), March-April-May-Sept-Oct ('spring-autumn' period), June-July-August ('summer' period). Averaging process has been accomplished only on quality-checked dataset.

At Gliwice a 9m high mast was installed on the balcony of a 25m high building at the Silesian University of Technology (50o17'38.01"N, 18o40'53.21"E) for the measurement of carbon dioxide (CO2) water vapour (H2O) an aerosol particle number were measured using eddy covariance techniques. The raw covariances (half hourly means) were rotated into a streamline coordinate system according to McMillen (1988) . Sensible heat flux was calculated using the sonic temperature corrected for buoyancy effects of humidity fluctuation on the speed of sound (Schotanus et al., 1983) . Latent heat flux and CO2 flux were adjusted after Webb et al. (1980) to compensate for the fluctuations of temperature and water vapor that affect the measured fluctuations in the density of CO2 and H2O. Measurements of sonic anemometers (i.e. the Young 81000V) and open path gas analyzers (Li-7500) are subject to errors during rainfall. Rainy periods were therefore excluded from the analysis. Further on there were some longer periods of power failure. Monthly totals were calculated from monthly daily means to account for missing data. Maintenance of the station was performed every 2 weeks. Windows of the Li-7500 were cleaned with ethanol and the domes of the CNR1 were cleaned with distilled water. Storage card was exchanged and data was backed up. Raw data (the 10 Hz time series) are kept for further analysis.

Concentrations of pollutants (CO, NO, NO2, O3, SO2, PM10 – PM2.5, and heavy metals - As, Cr, Cu, Fe, Ni, Pb, V and Zn).

All the necessary information regarding air quality assessment is included in the Directive 2008/50/EC "on ambient air quality and cleaner air for Europe".

According to the Directive Assessment of ambient air quality should be performed in relation to sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter, lead, benzene and carbon monoxide. In order to ensure that the information collected on air pollution is sufficiently representative and comparable across the Community, it is important that standardized measurement techniques and common criteria for the number and location of measuring stations are used for the assessment of ambient air quality. Techniques other than measurements can be used to assess ambient air quality and it is therefore necessary to define criteria for the use and required accuracy of such techniques.

In the directive advice for classification of the territory of each Member State into zones or

agglomerations reflecting the population density is given. Air quality assessment and air quality management shall be carried out in all zones and agglomerations

The upper and lower assessment thresholds SO_2, NO_2 and NO_X, PM_{10} and $PM_{2,5}$, Pb, benzene and CO, mentioned in art. 5 are specified in Section A of Annex II. Each zone and agglomeration shall be classified in relation to those assessment thresholds. The classification shall be reviewed at least every five years in accordance with the procedure laid down in Section B of Annex II, or more frequently in the event of significant changes in activities relevant to the ambient concentrations of these pollutants.

Assessment criteria of ambient air quality in zones and agglomerations are described in art. 6, where the level of those pollutants:

- exceeds the upper assessment threshold, fixed measurements shall be used to assess the ambient air quality, which may be supplemented by modelling techniques and/or indicative measurements to provide adequate information on the spatial distribution of the ambient air quality;
- is below the upper assessment threshold, a combination of fixed measurements and modelling techniques and/or indicative measurements may be used to assess the ambient air quality;
- is below the lower assessment threshold, modelling techniques or objective-estimation techniques or both shall be sufficient for the assessment of the ambient air quality.

The location and the number of sampling points for the measurement of SO_2, NO_2 and NO_X, PM_{10} and $PM_{2,5}$, Pb, benzene and CO in ambient air is established by art.7 and shall be determined using the criteria listed in Annex III. For zones and agglomerations within which information from fixed measurement sampling points is supplemented by information from modelling and/or indicative measurement, the total number of sampling points specified in Section A of Annex V may be reduced by up to 50 %.

The respective, ambient air quality assessment criteria in relation to ozone are defined in art. 9 and specified in Section A and B of Annex VII, and the siting and the number of sampling points in art. 10. Annex VIII defines in details the criteria for classifying and locating sampling points for assessments of ozone concentrations, and Section A of Annex IX determines the criteria for the minimum number of sampling points for fixed measurement of concentrations of ozone.

The reference methods for assessment of pollutant concentrations are mentioned in art. 8 and are precised in Section A and Section C of Annex VI (sampling, measurement, standardisation) and in Section B of Annex VI (demonstration of equivalence). Reference measurements methods are as follows:

1. EN 14212:2005 “Ambient air quality — Standard method for the measurement of the concentration of sulphur dioxide by ultraviolet fluorescence”.

2. EN 14211:2005 “Ambient air quality — Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence”.

3. EN 14902:2005 “Standard method for measurement of Pb/Cd/As/Ni in the PM10 fraction of suspended particulate matter”.

4. EN 12341:1999 “Air Quality — Determination of the PM10 fraction of suspended particulate matter — Reference method and field test procedure to demonstrate reference equivalence of measurement methods.

5. EN 14907:2005 “Standard gravimetric measurement method for the determination of the PM2,5 mass fraction of suspended particulate matter”.

6. EN 14662:2005, parts 1, 2 and 3 “Ambient air quality — Standard method for measurement of benzene concentrations”.

7. EN 14626:2005 “Ambient air quality — Standard method for the measurement of the concentration of carbon monoxide by non-dispersive infrared spectroscopy”.

8. EN 14625:2005 “Ambient air quality — Standard method for the measurement of the concentration of ozone by ultraviolet photometry”.

The data quality objectives for SO_2, NO_2, and NO_X, CO, benzene, $PM_{10}/PM_{2,5}$ and lead, O_3 and related NO and NO_2, are specified in Section A of Annex I, divided into three groups: fixed measurements, indicative measurements, modeling uncertainty and objective estimation.

Chapter III regulates ambient air quality management issues inter alia:

1. requirements where levels are below the respective limit values (art. 12);
2. limit values and alert thresholds for the protection of human health (art. 13, Annex XI, Section A of Annex XII);
3. critical levels (art. 14, Annex XIII assessed in accordance with Section A of Annex III);
4. national PM2,5 exposure reduction target (art. 15) and PM2,5 target value and limit value for the protection of human health (art. 16, Section D and F of Annex XIV);
5. requirements in zones and agglomerations where ozone concentrations exceed the target values and long-term objectives (art. 17) or meet the long-term objectives (art. 18);
6. measures required in the event of information or alert thresholds being exceeded (art. 19);
7. contributions from natural sources (art. 20).

Member States establish air quality plans (according to art. 23 and the information listed in Section A of Annex XV) for zones and agglomerations in order to achieve the related limit value or target value specified in Annexes XI and XIV. The air quality plans shall set out appropriate measures, so that the exceedance period can be kept as short as possible. The air quality plans may additionally include specific measures aiming at the protection of sensitive population groups, including children.

Member States shall draw up short term action plans (art. 24) indicating the measures to be taken in the in order to reduce the risk or duration of exceedance one or more of the alert thresholds specified in Annex XII.

Member States in the accordance with art. 26 shall ensure public available information, free of charge, adequate and in good time by any easily accessible media, including the Internet or any other appropriate means of telecommunication, take into account the provisions laid down in Directive 2007/2/EC. The information shall be available appropriate organisations such as:

- environmental organisations,
- consumer organisations,
- organisations representing the interests of sensitive populations,
- other relevant health-care bodies and
- the relevant industrial federations.

Member States shall make available to the public annual reports for all pollutants covered by this Directive (summarising the levels exceeding limit values, target values, long-term objectives, information thresholds and alert thresholds, for the relevant averaging periods, assessment of the effects of those exceedances, information and assessments on forest protection as well as information on other pollutants for which monitoring provisions are specified, such as, selected non-regulated ozone precursor substances as listed in Section B of Annex X (nitrogen oxides (NO and NO_2, and appropriate volatile organic compounds (VOC)).

In order to replace the national exposure reduction target and to review the exposure concentration obligation laid down in art. 15, in 2013 the Commission shall review the provisions related to $PM_{2,5}$ and, as appropriate, other pollutants, and shall present a proposal to the European Parliament and the Council (art. 32), taking into account, *inter alia*, the following elements:

- latest scientific information from WHO and other relevant organizations;
- air quality situations and reduction potentials in the Member States;
- the revision of Directive 2001/81/EC;
- progress made in implementing Community reduction measures for air pollutants;
- more ambitious limit value for $PM_{2,5}$, reviewed as the indicative limit value of the second stage for $PM_{2,5}$ and consider confirming or altering that value;
- the experience and on the necessity of monitoring of PM_{10} and $PM_{2,5}$, technical progress in automatic measuring techniques, new reference methods for the measurement of PM_{10} and $PM_{2,5}$.

CAFE directive addresses the possibilities of human health protection, including:

- upper and lower assessment thresholds SO_2, NO_2 and NO_X, PM_{10} and $PM_{2,5}$, Pb, benzene and CO (Section A of Annex II), and target values for ozone (Section B of Annex VII);
- sampling points of SO_2, NO_2 and NO_X, PM_{10} and $PM_{2,5}$, Pb, benzene and CO concentration sited in the areas where population is directly or indirectly exposed to the significantly highest concentrations, levels in other areas which are representative of the exposure of the general population, representativeness of air sampling for air quality in urban areas (traffic-orientated and industrial sites) for several square kilometers, installation sampling point downwind of the source in the nearest residential area for assessing contributions from industrial sources or within the main wind direction, where the background concentration is not known, positioning inlet sampling point in the breathing zone (Section B of Annex III);

- minimum number of sampling points for fixed measurement to assess compliance with limit values for the protection of human health and alert thresholds in zones and agglomerations where fixed measurement is the sole source of information for diffuse and point sources SO_2, NO_2, and NO_X, Pb, benzene and CO as well as, excepted sum of PM_{10} and $PM_{2,5}$ (Annex V);
- sampling points of O_3 concentrations applied to fixed measurements in urban, suburban, rural and rural background to assess the exposure of population (Annex VIII) and minimum number of sampling points for fixed measurement of concentrations of ozone (Annex IX);
- limit values for protection of human health (Annex XI for SO_2, NO_2, benzene, CO, Pb, and PM_{10}, Annex XIV for $PM_{2,5}$ and target values and long-term objectives for ozone Section B and C of Annex VII), see Table 1;

Table 1. Limit values for protection of human health

Averaging period	Limit value	Margin of tolerance
Sulphur dioxide		
One hour	350 µg/m^3, not to be exceeded more than 24 times a calendar year	150 µg/m^3 (43 %)
One day	125 µg/m^3, not to be exceeded more than 3 times a calendar year	None
Nitrogen dioxide		
One hour	200 µg/m^3, not to be exceeded more than 18 times a calendar year	50 % on 19 July 1999, decreasing on 1 January 2001 and every 12 months thereafter by equal annual percentages to reach 0 % by 1 January 2010
Calendar year	40 µg/m^3	50 % on 19 July 1999, decreasing on 1 January 2001 and every 12 months thereafter by equal annual percentages to reach 0 % by 1 January 2010
Benzene		
Calendar year	5 µg/m^3	5 µg/m^3 (100 %) on 13 December 2000, decreasing on 1 January 2006 and every 12 months thereafter by 1 µg/m^3 to reach 0 % by 1 January 2010
Carbon monoxide		
maximum daily eight hour mean	10 mg/m^3	60 %

Lead		
Calendar year	0,5 µg/m^3	100 %
PM_{10}		
One day	50 µg/m^3, not to be exceeded more than 35 times a calendar year	50 %
Calendar year	40 µg/m^3	20 %
$PM_{2,5}$		
Calendar year	20 µg/m^3	20 % on 11 June 2008, decreasing on the next 1 January and every 12 months thereafter by equal annual percentages to reach 0 % by 1 January 2015
Ozone		
maximum daily eight hour mean	120 µg/m^{3}not to be exceeded on more than 25 days per calendar year averaged over three years	

- maintaining ozone levels below the long-term objectives and preserving through proportionate measures the best ambient air quality compatible with sustainable development and a high level of environmental and human health protection;
- information on the type of population concerned, possible health effects and recommended behaviour:
  - information on population groups at risk,
  - description of likely symptoms,
  - recommended precautions to be taken by the population concerned,
  - where to find further information;

Below a short description of the main aspects of the most important pollutants are reported:

Sulfur dioxide

In much of western Europe and North America, concentrations of sulfur dioxide in urban areas have declined in recent years. Annual mean concentrations range from 20 to 60 µg/m3, with daily means seldom more than 125 µg/m3, excluding large cities where coal is still widely used for domestic heating or cooking, or poorly controlled industrial sources (5–10 times values).

Exposure duration is not critical because responses occur very rapidly, continuing the exposure further does not increase effects.

The observed health effects of short-term exposure include reductions in FEV1 or other indices of ventilatory capacity, increases in specific airway resistance, symptoms such as wheezing or shortness of breath, mortality (total, cardiovascular and respiratory) and hospital emergency admissions for total respiratory causes and chronic obstructive pulmonary disease at lower levels of exposure (mean annual levels below 50 μg/m3; daily levels usually not exceeding 125 μg/m3). Such effects are enhanced by exercise, which increases the volume of air inspired thereby allowing sulfur dioxide to penetrate further into the respiratory tract.

Adverse effects with significant public health importance have been observed at much lower levels of exposure, with uncertainty of adverse effects for ultrafine particles or some other correlated substance. Guidelines for sulfur dioxide are not linked with particles recommend the values as follows:

24 hours: 125 μg/m3

annual: 50 μg/m3

The 24 hour level is the same like established by CAFE directive, but value for short term exposure e.g. less than 1 hour e.g. 10 minutes was not define in WHO guidelines.

Nitrogen dioxide

Levels of nitrogen dioxide vary widely, and natural background of annual mean concentrations are in the range 0.4–9.4 μg/m3. Outdoor urban levels have an annual mean range of 20–90 μg/m3 and hourly maxima in the range 75–1015 μg/m3.

Asthmatics are likely to be the most sensitive subjects. Exposed mild asthmatics for 30–110 minutes to 560 μg/m3 during intermittent exercise. One of these studies indicated that nitrogen dioxide can increase airway reactivity to cold air in asthmatics. At lower concentrations, the pulmonary function of asthmatics was not changed significantly.

Annual average concentrations of 50–75 μg/m3 or higher are associated with increased respiratory symptoms and lung function decreases in children. In these epidemiological studies, nitrogen dioxide has appeared to be a good indicator of the pollutant mixture.

Asthmatics and patients with chronic obstructive pulmonary disease are clearly more susceptible to acute changes in lung function, airway responsiveness and respiratory symptoms. A clear lowest-observed-effect level is 375–565 μg/m3 induced the small changes in lung function (< 5% drop in FEV1 between air and nitrogen dioxide exposure) and changes in airway responsiveness. At double Recommended guideline at level 400 μg/m3 means, that evidences suggest possible small effects in the pulmonary function of asthmatics. Base on these human clinical data, a 1-hour guideline of 200 μg/m3 is proposed.

It is proposed that a long-term guideline for nitrogen dioxide be established. Review conducted for the Environmental Health Criteria document on nitrogen oxides recommended an annual value of 40 μg/m3, and in the absence of support for an alternative value, this figure is recognized as an air quality guideline.

Both one-hour and annual limit values recommended by WHO and established in CAFE directive are the same.

Benzene

Sources of benzene in ambient air include cigarette smoke, combustion and evaporation of benzene-containing petrol (up to 5% benzene), petrochemical industries, and combustion processes. Mean ambient air concentrations of benzene in rural and urban areas are about 1 μg/m3 and 5–20 μg/m3, respectively.

Inhalation is the dominant pathway for benzene exposure in humans. The most significant adverse effects from prolonged exposure to benzene are haematotoxicity, genotoxicity and carcinogenicity. Benzene demonstrated induction of both numerical and structural chromosomal aberrations, sister chromatid exchanges and micronuclei in experimental animals and humans after *in vivo* benzene exposure. The *in vivo* data indicate that benzene is mutagenic.

Benzene is carcinogenic to humans and no safe level of exposure can be recommended. The geometric mean of the range of estimates of the excess lifetime risk of leukaemia at an air concentration of 1 μg/m3 is 6 × 10–6.

Carbon monoxide

Global background concentrations of carbon monoxide range between 0.06 mg/m3 and 0.14 mg/m3. In urban traffic environments of large European cities, the 8-hour average carbon monoxide concentrations are generally lower than 20 mg/m3 with short-lasting peaks below 60 mg/m3.

The air quality data from fixed-site monitoring stations seem to reflect rather poorly short-term exposures of various urban population groups, but appear to reflect better longer averaging times, such as 8 hours.

Carbon monoxide diffuses rapidly across alveolar, capillary and placental membranes. Approximately 80–90% of the absorbed carbon monoxide binds with haemoglobin to form carboxyhaemoglobin (COHb), which is a specific biomarker of exposure in blood. The affinity of haemoglobin for carbon monoxide is 200–250 times that for oxygen. The binding of carbon monoxide with haemoglobin to form COHb reduces the oxygen-carrying capacity of the blood and impairs the release of oxygen from haemoglobin to extravascular tissues. These are the main causes of tissue hypoxia produced by carbon monoxide at low exposure levels. At higher concentrations the rest of the absorbed carbon monoxide binds with other haem proteins such as myoglobin, and with cytochrome oxidase and cytochrome P-450. The toxic effects of carbon monoxide become evident in organs and tissues with high oxygen consumption such as the brain, the heart, exercising skeletal muscle and the developing fetus. The neurobehavioural effects include impaired coordination, tracking, driving ability, vigilance and cognitive performance at COHb levels as low as 5.1–8.2%.

The WHO guideline values have been determined in such a way that the COHb level of 2.5% is not exceeded, even when a normal subject engages in light or moderate exercise and for 8 hours amounts 10 mg/m3, and is also the same as the CAFE directive limit value.

Lead

Average air lead levels are usually below 0.15 μg/m3 at nonurban sites. Urban air lead levels are typically between 0.15 and 0.5 μg/m3 in most European cities.

Inhalation of airborne lead is a significant route of exposure for adults (including pregnant women) but is of less significance for young children, for whom other pathways of exposure such as ingested lead are generally more important. Additional routes of exposure must not be neglected, such as lead in dust, a cause of special concern for children.

The level of lead in blood is the best available indicator of current and recent past environmental exposure, and may also be a reasonably good indicator of lead body burden with stable exposures. Biological effects of lead will, therefore, be related to blood lead as an indicator of internal exposure.

Health outcomes observed in environmentally exposed children and adults are following: reduced haemoglobin levels, delta-aminolaevulinic acid dehydrase (ALAD) inhibition, elevation of free erythrocyte protoporphyrin, vitamin D3 reduction, cognitive and hearing impairment.

Since both direct and indirect exposure of young children to lead in air occurs, the air guidelines for lead should be accompanied by other preventive measures. These should specifically take the form of monitoring the lead content of dust and soils arising from lead fallout. The normal handto-mouth behaviour of children with regard to dust and soil defines these media as potentially serious sources of exposure.

Guidelines for lead in air based on the concentration of lead in blood. Critical adverse effects were considered in the adult organism include elevation of free erythrocyte protoporphyrin, whereas for children cognitive deficit, hearing impairment and disturbed vitamin D metabolism. A critical level of lead in blood of 100 μg/l is proposed.

WHO recommends that annual average lead level in air should not exceed 0.5 μg/m3. It was took into consideration, that the at least 98% of an exposed population, including preschool children, have blood lead levels that do not exceed 100 μg/l (with the median blood lead level not exceed 54 μg/l).

Annual limit value for lead in CAFE directive has the same level.

Particulate matter

Data on exposure levels to airborne inhalable particles are still limited for Europe. Data have mostly been obtained from studies not directly aimed at providing long-term distributions of exposure data for large segments of the population. In northern Europe, PM10 levels are low, with winter averages even in urban areas not exceeding 20–30 μg/m3. In western Europe, levels seem to be higher at 40–50 μg/m3, with only small differences between urban and non-urban areas.

As a result of the normal day-to-day variation in PM10 concentrations, 24-hour averages of 100 μg/m3 are regularly exceeded in many areas in Europe, especially during winter inversions.

A variety of methods exist to measure particulate matter in air, was expressed as the thoracic fraction(~ PM10), and/or fine particles (PM2.5), sulfates and strong aerosol acidity.

Recent studies suggest that short-term variations in particulate matter exposure are associated with health effects even at low levels of exposure (below 100 μg/m3). The current database does not allow the derivation of a threshold below which no effects occur. This does not imply that no threshold exists; epidemiological studies are unable to define such a threshold, if it exists, precisely.

effects on mortality

Traditionally, particulate matter air pollution has been thought of as a primarily urban phenomenon. It is now clear that in many areas of Europe, urban–rural differences in PM10 are small or even absent, indicating that particulate matter exposure is widespread. Primary, combustion-related particulate matter may not be higher in urban areas.

Most of the information that is currently available comes from studies in which particles in air have been measured as PM10, although the latest studies are showing that PM2.5 is generally a better predictor of health effects than PM10. Evidence is also emerging that constituents of PM2.5 such as sulfates are sometimes even better predictors of health effects than PM2.5 *per se*.

The available information does not allow a judgement to be made of concentrations below which no effects would be expected. Effects on mortality, respiratory and cardiovascular hospital admissions and other health variables have been observed at levels well below 100 μg/m3 (estimate of the effect of a 3-day episode on a population of 1 million people), expressed as a daily average PM10 concentration. For this reason, no guideline value for short-term average concentrations is recommended either.

Some studies have suggested that long-term exposure to particulate matter is associated with reduced survival, and a reduction of life expectancy in the order of 1–2 years. Other recent studies have shown that the prevalence of bronchitis symptoms in children, and of reduced lung function in children and adults, are associated with particulate matter exposure. These effects have been observed at annual average concentration levels below 20 μg/m3 (as PM2.5) or 30 μg/m3 (as PM10). For this reason, no guideline value for long-term average concentrations is recommended.

The respective values in CAFE directive are as follows:

50 $\mu g/m^3$ PM_{10} for one day,

40 $\mu g/m^3$ PM_{10} for calendar year,

20 $\mu g/m^3$ $PM_{2,5}$ for calendar year (and will be reviewed).

Ozone and other photochemical oxidants

Ozone and other photochemical oxidants are formed by the action of short-wavelength radiation from the sun on nitrogen dioxide. In the presence of volatile organic compounds, the equilibrium favours the formation of higher levels of ozone. Background levels of ozone, mainly of anthropogenic origin, are in the range 40–70 μg/m3 but can be as high as 120–140 μg/m3 for 1 hour. In Europe, maximum hourly ozone concentrations may exceed 300 μg/m3 in rural areas and 350 μg/m3 in urbanized regions.

The selection of guidelines for ambient ozone concentrations is complicated by the fact that detectable responses occur at or close to the upper limits of background concentrations.

Ozone toxicity occurs in a continuum in which higher concentrations, longer exposure duration and greater activity levels during exposure cause greater effects. Short-term acute effects include respiratory symptoms, pulmonary function changes, increased airway responsiveness and airway inflammation, exacerbations of respiratory symptoms and symptomatic and functional exacerbations of asthma in exercising susceptible people. Ozone exposure has also been reported to be associated with increased hospital admissions for respiratory causes and exacerbation of asthma.

That these effects are observed both with exposures to ambient ozone (and copollutants) and with controlled exposures to ozone alone demonstrates that the functional and symptomatic responses can be attributed primarily to ozone.

Although chronic exposure to ozone can cause effects, quantitative information from humans is inadequate to estimate the degree of protection from chronic effects offered by this guideline.

In any case, the ozone concentration at which any adverse health outcome is expected will vary with the duration of the exposure and the volume of air that is inhaled during the exposure.

Thus, the amount of time spent outdoors and the typical level of activity are factors that should be considered in risk evaluation.

Epidemiological data show relationships between changes in various health outcomes and changes in the peak daily ambient ozone concentration. These observations may be used to quantify expected improvements in health outcomes that may be associated with lowering the ambient ozone concentration.

A guideline value for ambient air of 120 μg/m3 for a maximum period of 8 hours per day is established as a level at which acute effects on public health are likely to be small. 8-hour WHO guideline would protect against acute 1-hour exposures in this range and thus it is concluded that a 1-hour guideline is not necessary.

CAFE directive established maximum daily eight hour mean as limit value at the same level.

In the context of Bridge the following methodologies have been applied for measuring the concentrations of gaseous pollutants:

Air quality data were used from the London Air Quality Network (http://www.londonair.org.uk/London/asp/default.asp/). This network consists of 37 automated measuring systems located across identified urban climate zones within the 17 London Boroughs. Full details of the LAQN instrumentation are available on the network's website. The website also provides the data and links to various reports of data analysis.

For Athens air quality data were retrieved from the Directorate of Air Pollution & Noise of the Greek Ministry of Energy, Environment and Climate Change. This Directorate is responsible for the operation of a network of 15 stations installed in the greater Athens area that measure air pollution. At these sites carbon monoxide (CO) is measured by infrared absorption (NDIR) nitrogen oxides (NO, NO2) by chemiluminescence, ozone (O3) by UV absorption, sulphur dioxide (SO2) by fluorometry, particulate matter (PM10 – PM2.5) by Beta radiation absorption and benzene (C6H6) by gas chromatography (GC). The measurements are conducted on a constant basis throughout the day. The response time of the automatic analysers is one minute, meaning that approximately one value is given every minute by each analyser. A microprocessor is located in every automatic station and is connected to the automatic analysers. Through this microprocessor the hourly average values for pollution are calculated every hour. These values are transferred to the central computer of the Authority via phone line. In this way, the constant monitoring of the atmosphere pollution levels of the area is achieved.

Calibration includes the checking of good instrument operation and regulation. It is based on the transfer of a gas with a pollutant of known concentration, through the instrument. The preparation of this standard gas, involves the use of a dynamic dilution apparatus that is connected to a 'clean' air source and the use of a bottle containing a mixture of nitrogen gas at a known standard concentration. This 'clean' air is free of main pollutants and is produced by sending air through special filters that remove pollutants. By changing the provision of 'clean' air and bottled gas, it is possible to achieve gas mixtures that contain the corresponding pollutant at known concentrations. This process of calibration is performed in regular intervals and after maintenance of repair of an analyser.

Air quality data were from continuous measurements carried out at the Voivodeship Inspectorate of Environmental Pollution at Gliwice and both the methodology and data are available on the website (http://stacje.katowice.pios.gov.pl/monitoring/).

Tuscany Regional Agency for Environmental Protection (ARPAT) under BRIDGE project provided the whole database of a Network of 5 air quality monitoring stations installed in order to measure concentration of pollutants (PM10, CO2, NO2, SO2, CO). Data are available for the period 01/01/2003 – 31/12/2010.

Emissions from transport, split per type: private and public

In addition the spatial models run for the five case study cities require emission inventory data and these were taken from the Airbase databases of the European Environment Agency (European Topic Centre on Air Pollution and Climate Change Mitigation – ETC/ACM Eionet). Details of the methodology and the data themselves are available on the Airbase website: http://acm.eionet.europa.eu/ .

3.2.2 Dust turbulent fluxes

Turbulent fluxes of particulate matter could be measured by means of the EOLO system, firstly developed and deployed for measuring particulate fluxes during intense desert wind erosion events (dust storms formation) as well as dust emissions due to wind action on bare agricultural soils. The system is fully described in Fratini et al. (2007), while Fratini et al. (2009) deployed EOLO to evaluate and parameterize a wind erosion model. In the following, guidelines for the use of EOLO in an integrated urban monitoring station are provided.

EOLO Data Processing

EOLO is based on the Eddy Covariance micrometeorological technique. High frequency (5 Hz) particle number concentration and 3D wind components and sonic temperatures are measured by means of an Optical Particle Counter (OPC) and a sonic anemometer. The underlying assumption is that particles behave in the atmosphere as a passive tracer (such as CO2 concentration, or air temperature). Fratini et al. (2007) demonstrated that this assumption is largely verified for particles up to at least 20 μm. Therefore EOLO features a typical Eddy Covariance processing software, including of a well established sequence of operations: despiking (Vickers and Mahrt, 1997), double rotations for tilt correction (Wilczak et al., 2001), time lag compensation (Fan et al., 1990), linear detrending (Moncrieff et al., 2004). A spectral correction schemes is supported to compensate for high-frequency attenuations, relying on sonic temperature time series as a proxy for a nearly perfectly sampled passive scalar; a method very similar to that described in Fratini et al. (2010), but applied in EOLO without consideration of relative humidity effects. Also, low frequency flux attenuation introduced by the 30-minutes block averaging and linear detrending are compensated adopting an analytic correction approach (Rannik and Vesala, 1999).

Estimating mass from number concentrations and fluxes

The OPC used in EOLO (OPC CI-3100 by Climet Instruments Co.) measures particles with diameters in the optical range 0.26 to 7.00 μm (divided in 12 dimensional sub-ranges), the corresponding aerodynamic range depending on the refraction index of sampled particles and on their shape factor. Fratini et al (2007) showed that for Asian desert dust the corresponding aerodynamic range is ca. 0.-35-9.5 μm. In terms of mass concentration, this provided a close approximation to PM10. However, in the present application particle optical and geometrical properties were not known, thus it was not possible to determine the corresponding aerodynamic range. For this reason, a calibration procedure was developed to turn native number concentrations (and fluxes) into mass. In this procedure, a preliminary mass estimation is performed by assuming constant density and spherical particles, with aerodynamic diameters equal to optical ones. Then, by comparing average (e.g. daily) concentration measurements from EOLO with accurate PM concentrations retrieved at the site, an *a posteriori* scaling factor can be determined. If a multiplicative scaling factor proves effective throughout the dataset, it can also be safely applied to fluxes.

This procedure can be applied as a backup solution, if particles optical properties cannot be determined. However, it is worth to point out that mass fluxes rescaled with such empirical procedure should be considered with due care; for example, they should not be used for quantitative exercises, such as closing mass budgets. However, mass data calculated this way can safely be used for evaluating trends and determining drivers and seasonal patterns.

Quality control

EOLO supports 4 quality control tests on calculated fluxes, designed to select only sound and reliable data for further analysis. The first two quality tests, applied as a routine step of the flux computation procedure, attempt at determining if conditions hold for applying the Eddy Covariance technique. Thoroughly described in literature (Foken et al., 2004; Foken and Wichura, 1996; Gockede et al., 2008) and well established in the scientific community, they test for stationary and well developed turbulence and provide flags that can be used to filter out bad data. Two further tests are specific to the EOLO system. The first is a flux-level despiking filter (not to be confused with the raw-level despiking applied in the data processing), eliminating individual flux values that show too large differences with the respect to the preceding and the following values in the time series. The threshold difference is to be determined empirically, by visual inspection. It is worth to note that, somewhat different from typical occurrences in the natural environments, flux spikes in an urban landscape might be physically explainable and actually spies of interesting phenomena. However, for the purpose of an ensemble analysis, spikes have to be removed to avoid biasing average values.

The last quality criterion is based on particle counting uncertainty, estimated in EOLO as in Buzorius et al. (2003). Individual flux values are eliminated if relative uncertainty is larger than a certain threshold. Despiking and uncertainty filter can be tuned by the user at processing time by adjusting the corresponding thresholds.

In order to obtain more robust mass estimates we strongly suggest collecting samples of airborne particulate matter during the monitoring campaign with EOLO and performing geometrical and optical analysis, in order to measure refractive indices and evaluate shape factors of particles in the range of interest, thereby allowing a proper derivation of mass quantities from raw number quantities.

Furthermore, a thorough analysis of measured fluxes would strongly benefit from the application of a 2D footprint model (on a 30-minutes basis) coupled with inventory data of particulate matter sources in the fetch area, along with standard meteorological data.

3.2.3 Dust effects on vegetation

The aims of this work were to develop an approach to model estimates of PM_{10} deposition to urban green space that is applicable in different cities and which will allow evaluation of different planning scenarios. In order for the model to be applicable to any city it needs to run with only those inputs which are commonly available from routine meteorological and pollution monitoring and it should function for different vegetation covers and climate types.

Methods

To meet the aims set out above the pollutant deposition component of the UFORE (Urban FORest Effects) model (Nowak et al., 1994) was adapted as described in Tallis et al. (2011).These adaptations included assessing the model with reduced input requirements and assessing different parameter values for deposition to various green space surfaces, within two case study sites; one in central London and one in Firenze (as reported in D3.4). For the London case study site, modelled estimates of PM_{10} deposition to tree canopies compared well with measured data from trees within the study zone (Beckett et al. 2000) as reported in BRIDGE deliverable 3.4. For the proposed development at Parco San Donato different approaches to parameterise deposition to grassland were also assessed. Daily mean concentrations of PM_{10} exposure were provided for the initial modelling work for Firenze while hourly mean values were provided for the Greater London Authority area. The ability of the model as adapted in this study to use different input data illustrated its potential use for a significant number of cities more widely.

Applicability to cities other than BRIDGE case studies.

To assess the whole city application of this work, modelled estimates of PM_{10} deposition to the whole of the Greater London Authority (GLA) (not just street trees of the Central Activity Zone - CAZ) were evaluated against those for Chicago (Nowak et al., 1994), as reported in Tallis et al. (2011). The results of this evaluation were used to develop an empirical relationship between local PM_{10} concentration ([PM_{10}]) and deposition to green space. This general relationship was then tested for its applicability to different cities.

Relationships between the annual mean percentage PM_{10} removal from the mixing layer above the broad leaved canopy and local annual mean [PM_{10}] were derived from modelled data for London, as given in Tallis et al. (2011) (3.25% for UFORE– 5.36% for adapted-UFORE). This general relationship was tested for its predictive ability in another city which experiences a different climate and PM_{10} exposure to London. Predictions were made for deposition to the broadleaved canopy proposed within the case study site of Firenze using measured annual mean [PM_{10}] and modelled annual mean mixing layer height for this site. The predicted deposition to the broad leaved canopy proposed for the Parco San Donato site were then compared with the modelled outputs of PM_{10} deposition for this site, using the UFORE and adapted-UFORE models. Comparisons of predicted deposition and modelled deposition are given in Table 1. This exercise is a simple validation of estimating deposition based on the empirical relationship which has been developed compared to estimates based on running the model with site specific data. This indicates that linking these empirical relationships with pollution dispersal models such as URBAIR will give a good estimate of PM_{10} removal by a planned area of trees or green space, although more *insitu* measured data is needed to validate and confirm this. URBAIR is an online model linked to the BRIDGE DSS and currently this approach is being developed to estimate the decreases of [PM_{10}] of the well mixed boundary layer resulting from a planned increase of green space..

Table 1: Estimating the deposition to the broad leaf canopy area proposed in the Parco San Donato development. Estimates were made using the general empirical relationship between PM_{10} deposition and [PM_{10}] (Predicted) and data modelled explicitly for this site (Modelled).

	Estimated PM_{10} removal by broadleaved trees planned for Parco San Donato	
	UFORE parameterised	Adapted UFORE
Predicted annual PM_{10} deposition (kg yr^{-1})	40	63
Modelled annual PM_{10} deposition (kg yr^{-1})	54	77

Lessons learnt

More measured data is required to assess the model performance; this will be undertaken in 2011 as part of a M. Sc. project from the University of Southampton. The estimate of removal from the boundary layer may be improved using measurements of boundary layer height and the model should be developed to include a process-based approach to estimate boundary layer height.

3.2.4 Biomonitoring

Introduction

In the last century, pollution has become one of the most important risks for environment. In particular, heavy metal presence in air, water and soil induces toxic effects on ecosystems and human health.

Monitoring airborne trace element over large areas is a task not easy to reach since the concentrations of pollutants are variable in space and time. Data from automatic devices are site-specific and very limited in number to describe spatial-temporal trends of pollutants. In addition, especially in Italy, trace elements concentrations are not often recorded by most of the automated monitoring stations (Bargagli, 2002). In the last decades, development of alternative and complementary methods as biomonitoring techniques allowed to map deposition patterns not only near single pollution sources, but also over relatively large areas at municipal or even regional scale

(Nimis et al., 2000; Giordano et al., 2005). Biomonitoring includes a wide array of methodologies finalised to study relationships between pollution and living organisms (Little and Martin, 1974; Goodman and Smith, 1975; Ratcliffe, 1975; Duggan and Burton, 1983; Thomas, 1983; Pilegaard, 1993Woltelbeek, 2002). The two main tools for biomonitoring are: bioaccumulators and bioindicators. The first ones are organisms that accumulate pollutant; the second ones are organisms that react in a characteristic way to a specific pollutant.

Mosses and lichens have been widely used as bioaccumulators for assessing the atmospheric deposition of heavy metals in natural ecosystems and urban areas. The bioaccumulation efficiency of mosses derives from the simple anatomy and absence of a cuticle, from their substantial cation exchange capacity, which is due to cell wall negative-charged constituents that may establish ionic bonds with cationic elements in soluble form, and from the fact that elements can also be retained in particles trapped in intercellular spaces (Figueira et al., 2002).

The moss-bag technique has been set up and developed in order to provide an inexpensive way of monitoring the intensity and distribution of heavy metal pollution (Hynninen, 1986). This technique was introduced by Goodman and Roberts (1971) and modified by Little and Martin (1974). The moss-bag method is also suitable for monitoring high pollutant level sites in urban areas. During '70–'90 period, moss bags as bioaccumulators were used in several country (Roberts, 1972; Makinen, 1977; Goodman et al., 1975, 1979; Cameron and Nickless, 1977; Godbeer et al., 1981; Udoessien and Bell, 1982; Makholm and Mladenoff, 2005). Recently, the moss-bag method has been relatively widely used also in Italy (Bargagli et al., 2002; Adamo et al., 2003, 2007, 2008; Giordana et al., 2005; Schintu et al., 2005; Cesa et al., 2006; Tretiach et al., 2007; Basile et al., 2008; Cesa et al., 2008). Research studies indicate that the moss-bag method is a simple, inexpensive and useful technique, which provides information on atmospheric element deposition in terms of time and space.

Moss-bags technique

Moss bags consist of a nylon net containing water-washed mosses. Several moss species have successfully employed for the estimation of atmospheric traces metal deposition in urban area (*Bryum radiculosum, Hylocomium splendens, Hypnum cupressiforme, Haplocladium microphyllum, Pleurozium schreberi, Scleropodium touretii, Sphagnum capillifolium*). For BRIDGE Project *Hypnum cupressiforme* was used (Figure 1).

The moss material should be collected from trees and rocks in areas characterised by absence of air pollution, and at least 300 m far from main roads and houses. In order to avoid contamination, samples of moss material should be handled wearing plastic gloves.

In laboratory, the moss carpets are cleaned from particles of soil, dead material, attached litter and other extraneous materials. After cleaning, moss is washed seven consecutive times with distillate water. The washed material is finally air dried and carefully mixed.

For BRIDGE Project moss bags are prepared by weighing out 2 g air-dried weight, and packing it loosely in nylon net of 25 cm in diameter with mesh of 4 mm^2 (Figure 2).

Figure 1 - Moss carpet of *Hypnum cupressiforme.*

Figure 2 - Moss-bag

Moss-bags should be positioned, in each exposure site, about 3 m above ground surface. At least two or three bags should be placed in each site to reduce site variability. The exposure period can be variable; generally, length of each exposure period should be at least of 6-9 weeks. In order to calculate the heavy metal concentration in moss bags before exposure period, some moss-bags are not exposed and are used as control. At the end of the exposure period, the samples exposed are collected and kept for chemical analysis.

Following exposure, moss samples both exposed and not exposed are removed from the nylon net and brought in laboratory to be analyzed for heavy metal.

Prior to their chemical analysis, the moss samples are dried to constant weight in a thermostat oven at 45°C for 48 h. Then they are ground into powder in agate or zirconium mill. Subsequently, 500 mg of moss powder are weighed for digestion with a solution of HNO_3 in a microwave oven. At the end of the mineralization, the solution is diluted in distilled water for chemical analysis. At least two parallel samples should be made for each moss sample.

The concentrations of metals for the moss samples can be determined using different techniques such as Inductively Coupled Plasma Atomic Emission Spectrometry (ICP/OES), Inductively Coupled Plasma - mass spectrometry (ICP-MS) or Atomic Absorption Spectrophotometry (AAS).

The precision of the method should be assessed by the analysis of three samples of Certified Reference Material (CRM; NBS National Bureau of Standard).

Conclusions

The relative ease of sampling and the lack of complicated and expensive technical equipment make this methodology promising for biomonitoring application. The moss-bags method has the advantage of collecting information integrated over the whole exposure time, without being influenced by momentary changes in pollutants and it is found to provide a high density of sampling points, which is essential to draw reliable maps of pollutant depositions (Berg and Steinnes, 1997; Bargagli et al., 2002).

However, this methodology is still open to several criticisms and some problems are still unresolved. There is currently a lack of standardisation regarding the selection of suitable moss species and sample pre-treatment, the amount of plant material, and the exposure time. Further information is also needed on uptake and accumulation processes of airborne pollutants, on their persistence in moss bags, and possible synergistic and/or antagonistic effects of climatic and environmental factors. Finally, relationship between concentrations in atmospheric deposition in PM10 collected in the same site and those in moss bags should be investigated. In conclusion, the above mentioned aspects need to be clarified in order to achieve a better knowledge on the use of moss-bags as operational method for trace-elements biomonitoring.

3.2.5 Indoor physical environment measurements

Introduction

Environmental measurements inside a building refer to those parameters that are essential for a comfortable and healthy environment. These are divided into three categories: Thermal comfort, lighting and indoor air quality.

Thermal comfort is defined as the state of mind which expresses satisfaction with the thermal environment. This condition arises when a person feels thermally neutral and does not know whether he/she would prefer a higher or lower ambient temperature. Achieving thermal comfort is an effort concerned with establishing an environment which is best suited to the needs of the people occupying it. The consideration of thermal comfort levels must therefore take into account the environment, clothing, individual sensitivity and climatic needs according to activities performed (ASHRAE 2003). In practical terms, this can be reduced to an energy balance relating personal factors such as thermal insulation of clothing and level of activity (metabolic rate), and environmental parameters such as air temperature, mean radiant temperature, air velocity and relative humidity. Due to the large physiological and psychological variations between persons, it is difficult to satisfy everyone at any given time. However, based on field studies and data collection, statistical analysis has defined conditions that a specified percentage of occupants will find thermally comfortable (ASHRAE 2003, EN ISO 7730)

Adequate lighting levels are essential for people to be able to perform their tasks efficiently and without strain. Such levels can be achieved by daylight, artificial light or a combination of the two.

For reasons of health, comfort and energy conservation, the use of daylight is preferred over artificial light, unless the latter is provided in minimal amounts as an auxiliary to daylight. Of course this is subject to change, depending on factors such as standard occupancy hours, location (amount of time that daylight is available) etc (EN15251).

Indoor air quality (IAQ) can be affected by internal factors, such as building/furniture materials, operational factors (heating, cooking) and human respiration and external factors such as the presence of contaminated air in the vicinity near the building. An acceptable standard of IAQ can usually be achieved through a sufficiently high ventilation rate, except in the cases of naturally ventilated buildings in areas with poor external air quality. Poor IAQ can lead to unpleasant odours and sick building symptoms such as irritation of the eyes and respiratory tract (EN15251).

Measurement and Data Collection Guidelines

Before any measurements are evaluated, data should be collected on the characteristics of the building. Such data can be, but not restricted to, floor and building plans, ventilation system specifications, heating/cooling system specifications, U values of walls and windows (estimations can be made if actual data is unavailable) etc.

Thermal comfort

Measurements should be made in occupied zones, in locations where the occupants are known to or are expected to spend most of their time and during representative weather conditions, both for the heating and the cooling period. If occupancy distribution cannot be estimated, then the measuring locations should be the following (ASHRAE 2003):

- In the centre of the room or zone.
- 1.0 m inward from the centre of each of the room’s walls.
- In the case of exterior windowed walls, 1.0 m inward from the centre of the largest window.

Sensors should be located away from surrounding blocking objects to allow proper circulation around them. Air temperature thermometers should not be placed in direct sunlight or near artificial sources of heating and cooling. Regarding the placement height of sensors, air temperature and speed should be measured at the 0.1, 0.6 and 1.1 m levels for seated occupants and at the 0.1, 1.1 and 1.7 m levels for standing occupants. The temperatures for the calculation of the PMV-PPD indices should be those at 0.6 and 1.1 m for seated and standing occupants respectively (ASHRAE 2003).

Radiant asymmetry should be measured at 0.6 m for seated and 1.1 m for standing occupants. If strong radiant sources and sinks are blocked by furniture, then the measurements should take place above desktop level. Floor surface temperatures should be measured with all floor coverings installed (ASHRAE 2003).

Humidity need only be determined at one location within the occupied zone of a room or HVAC controlled zone, provided there is no reason to expect large variations in the humidity of the space under consideration (ASHRAE 2003).

The measurement period for all parameters should be sufficient to provide a dependable profile of the situation, e.g. at least 10 days (EN15251)

In addition to the objective evaluation of the data, it is important to determine the satisfaction level of the occupants, as indicated by PMV and PPD values, to ensure that the conditions are comfortable for an acceptable percentage. Ideally, the survey should be performed for every operating mode and in every design condition. The survey sheets should require at least the following data from the occupants (ASHRAE 2003):

- Name, date and time.
- Approximate outside temperature.
- Clear/overcast sky (if applicable).
- Seasonal conditions (i.e. time of year).
- Occupant's clothing and activity level.
- Applicable equipment (e.g. computer).
- General thermal comfort level.
- Occupant's location.

The survey should also be numbered and signed by the surveyor.

Lighting

Light measurements are based on illuminance, which can easily be measured by lux meters. Illuminance levels should be evaluated at task area height, which for a typical office is the height of a desk surface, around 0.6 m. The lighting standards must be met at all operational times. If the building operates during night time, measurements must be made in absence of daylight (EN15251)

Indoor air quality

Generally, IAQ and ventilation can be evaluated by taking representative samples and measurements in different air handling units and zones of a building. In the case of ventilation rates, evaluation can be made through measurements of the air flow in ducts or by using tracer gas methods. In the case of IAQ in buildings where people are the main source of pollution, the principal method is measuring the average CO_2 concentration of the building during maximum occupation hours, either by taking representative samples of room air or by measuring the CO_2 concentration of the exhaust air. The latter is only applicable to mechanically ventilated buildings. For basic natural and hybrid systems it is necessary to assume that, on average, monitored pollutants will be fairly uniformly mixed in the space. Certain places however will have a higher risk of producing false readings and need to be avoided. Such places are those in the vicinity of open windows or vents where air is likely to be entering the monitored room (EN15251). A suitable solution for this could be a sensor suspended in the centre of the room, or a wall mounted sensor either in the furthest wall from the vent openings (single sided ventilation), or midway between vent openings (cross flow ventilation).

In most cases, IAQ measurements are tackled indirectly through the measurement of ventilation rates. However, if there are specific complaints about air quality, while measured ventilation rates indicate an adequate supply of fresh air, supplemental measurements of specific pollutants (e.g.

Volatile Organic Compounds, fine particles (PM10, PM2.5, PM1)) are advised. The exception to this rule is CO_2 concentration in densely populated buildings. In this case, measurements should be made in the areas where occupants spend most of their time, preferably at head level and during the "worst case" hours. However, care should be taken so that CO_2 sensors are not placed in a direct breathing zone, as contact with exhaled air may give excessively high readings. If possible, CO_2 measurements should be taken during the winter period, when the supply of fresh air is at its lowest (minimal use of operable windows). In the case of mechanically ventilated buildings the amount of fresh air supply is often a more accurate indication of IAQ than CO_2 concentration (EN15251).

4 Plant & soil measurements

4.1. Introduction

In the context of urban metabolism it is important to know how vegetation and their growing media contribute to material and energy fluxes. This information is important as the extension of green areas is an important planning instrument when designing sustained urban texture. Vegetation influences most the fluxes of carbon and water and their interactions (Nemani et al. 2003). In urban context the growing sites of vegetation are mostly artificial, differing in both the soil composition, properties of surfaces and also often due to paved surfaces that efficiently hinder many material fluxes between soil and green canopies. Therefore it is important to know how those features influence the water and carbon fluxes at vegetated sites. In the context of Bridge – project the methods of long term monitoring of vegetation and soil fluxes within urban context have been tested at the Helsinki study site. Measurements were mostly conducted at two experimental streets in Viikki area, 4 km east from the SMEAR III flux site in Kumpula but some soil CO_2 studies were done within the footprint of the flux site. The tree gas exchange has concentrated on the continuous monitoring of tree – atmosphere water fluxes and simultaneous linking of water with carbon fluxes through campaign-wise measurements of leaf gas exchange. Tree growth has been used as an independent measure of carbon sequestration and fluxes. Parallel to tree measurements, soil gas-concentration profiles have been studied, in particular carbon dioxide, and also its fluxes from soil to atmosphere. The measurements have included monitoring of the soil water content and temperature profiles as those impose an important condition for the gas fluxes. In the following we give a short account for the used methodology which comprises both continuous and campaign-wise measurement.

When setting up research in public space, protection of equipment against external disturbances and public safety concerns need attention. Our soil monitoring equipment was hidden from view under cast-iron lids. Sensors on tree trunk were installed behind rugged metal trunk guard covered with metal mesh. All wiring was installed under pavement and loggers were placed in sturdy, locked metal boxes installed permanently at the site.

4.2. Tree water fluxes

Tree-atmosphere gas exchange can be observed at local scale with micrometeorological methods described in section 3.1. or at micro-scale using chamber methods (Hari et al. 1999). Alternatively water fluxes can be interpreted from the sap flux rates in tree stems for which several heating based methods have been developed (Steppe et al. 2010). As the sapflux is driven by pressure variations it can also be estimated from the dimensional changes that the pressure variation is causing at tree stems (Irving and Grace 1997, Sevanto et al. 2005). In the sense of technical feasibility, the stem based methods are generally more simple to arrange for continuous monitoring than the chamber based monitoring.

At our site we studied tree crown level transpiration by measuring the flow rate of xylem sap flowing through tree stems and simultaneously measuring the driving pressure gradient that can be estimated from the short term variation that it imposes on wood dimensions. For the sapflow we used Granier type thermal dissipation method (Granier 1987) and for the trunk diameter variation we used modification of setup described by Irvine and Grace (1997) where Solartron™

displacement transducers were mounted on rigid steel frame that was attached to stem at one side and letting the transducer measuring heads at opposite site follow the movement of stem surface, on one hand, and wood through screw surface that was forced through bark to xylem, on the other hand (see Sevanto et al. 2003 for more detailed description of the method).

Both described methods are well suited for urban measurements as the sensors can be well protected from vandalism. Also the measuring setup is simple and affordable. Determination of instantaneous and absolute transpiration rates with Granier type method is problematic (Sevanto et al. 2009, Steppe et al. 2010) but it is well suited to study changes in daily transpiration rates. For example the decline in transpiration due to depletion of soil moisture was well observed during the drought periods (Duursma et al. 2008). In multiyear observations, the sensors need to be repositioned annually, in particular when measuring fast growing softwoods.

The displacement method is very robust and the sensors rarely malfunction. Maintenance is mainly needed for adjusting the sensor frame for trunk and callus growth around frame attachment points. As the typically observed diurnal dimensional variation is 10-100 µm the frame temperature needs to be measured to account for thermal expansion. The measurement produces estimation of the diurnal variation of driving pressure and estimation of sap flow rate requires further assumptions of stability of wood permeability and occurrence of embolism (Perämäki et al. 2005, Sevanto et al. 2005)

4.3. Tree carbon fluxes

Tree carbon sequestration was estimated with two indirect methods. First attempted to estimate carbon fluxes from sap-flux measurements and second relied on measured carbon accumulation in tree structures.

As mentioned, continuous following of carbon dioxide exchange between tree canopies and atmosphere involves very heavy instrumentation. For that reasons we chose an approach where we measured campaign-wise the leaf gas-exchange parameters and used existing photosynthetic models to link the carbon flows to continuously measured tree water fluxes.

The light and CO_2 response of leaf gas exchange was measured both early and late summer with Ciras-2 portable photosynthesis system (PP-systems) at different heights at tree crowns. These measurements were started already before the start of the Bridge project and quite stable leaf response was observed between years. Measurements were used to parameterize Farquhar- type leaf photosynthesis model within the canopy photosynthesis model SPP (Mäkelä et al. 2005) and the modelled fluxes were compared with sap-flux and eddy-covariance results.

Described approach includes several error possibilities, including the dynamic variation of responses of photosynthesis to environment that is difficult to account for with campaign wise measurements. Repeatability of photosynthesis measurement require well established measuring setup and good access to the tree crown. Stability of the response curves between years, however, indicate that good repeatability can be achieved.

Tree growth was quantified from annual shoot extension growth and from annual measurement of crown allometry i.e. dimensional relationships between tree organs at different height in the tree crown. When these relationships are known from year to year also the biomass accumulation can be estimated (e.g. Nikinmaa 1992). For carbon sequestration of urban trees quite general allometric equations are currently used (Pillsbury et al. 1998). Locally measured allometric parameters can help to avoid over- and underestimations in tree carbon sequestration.

Tree shoot annual extension and branch basal area – branch leaf area relationship were measured manually every year after the growth had stopped. Each year, good correlations have been observed between the measured values but quantitatively there was some variation between the years in the relationships. Tree shoot annual extension measurement requires sample size within tree ≥ 30 and careful randomization. The measurement requires the use of a sky-lift in large trees. Branch basal area – branch leaf area relationship measurements are labour-intensive.

4.4. Soil measurements

Urban soils for vegetation are in most cases artificially established and the high population density of cities imposes different wear on the soils than that in natural areas. Two different types of urban soils and their behaviour were studied at the Helsinki study site. We studied the temperature, soil moisture and gas concentration dynamics of soils below paved surfaces along streets in Viikki area and we compared the CO_2 production in these soils and non-paved urban soils around the SMEAR III flux- station.

Soil gas concentrations were estimated with 2 methods. Gas collection tubes were buried into the soil at different depths and air samples were collected at regular intervals from which the gas composition was analysed with gas chromatograph. In the other method, CO_2 sensors were buried in soil and the variation in CO_2 concentration was monitored continuously.

Soil gas samples collected and analyzed with gas chromatograph were useful for spatial and temporal coverage. They give very accurate yet relatively low-cost measurement if care is taken to analyse the air samples soon after collection. Sampler protection from water intrusion requires attention. Continuous measurements of CO_2 concentrations which we did with Vaisala ™ CO_2 probe give data on short-term variation. This is easily automated measurement but sensors require maintenance from time to time. Therefore attention should be paid for their easy access. Similarly as for gas collectors also these sensors require careful protection from water intrusion.

Soil water content and temperature profiles affect dynamics of the soil gas concentrations. These were measured continuously at Viikki sites. For soil moisture and temperature Theta-probes (Delta-T Devices Ltd) and moisture protected thermistors were installed at different depths in the soil and they were continuously logged every 5 to 20 minute intervals. Both sensor types have shown to be very reliable and robust over period of 8 years.

CO_2 flux from soil was measured at both Viikki and Kumpula sites to estimate the contribution of soil in carbon balance with a portable closed chamber CO_2 exchange measuring system. The success of the measurements relies on successful spatial sampling of the measured area as there is very high spatial variation in soil CO_2 flux. Flux varies also temporally both seasonally and diurnally and measurement timing has to account for this. At any new site, careful planning of plot placement and measuring schedule need to be set up. Pre-study of local spatial variability in soil CO_2 flux is recommended.

5 Stormwater quality and urban hydrology

Urban hydrology is an essential part of urban metabolism. As the majority of urban land surfaces is sealed with impermeable substrates, rain water entering urbanized settings will not percolate into the soil but is conveyed through underground pipeline systems as stormwater to adjacent surface waters. Following the quality and quantity of stormwater provides an ideal mean of getting insights of typical features of urban hydrology.

Three sites (= sub-catchment areas) with differing land use intensity were established in the city of Helsinki, Finland. The size of the catchments is ca. 10 ha. In each catchment an automatic stormwater station was established in the fall 2010 with the following device:

1) The flow of the stormwater was measured using an ultrasonic flowmeter (Nivus OCM Pro CF) which was programmed to measure water flow once per minute. This method allows achieving and accurate profile of the flow event.

2) Automatic sampler (Aquacell S50) that was programmed to take water samples according to the rate of flow of the water. Basically, each rain event was sampled at the onset of the rain, in the middle and at the end of the rain event.) Turbidity of the run-off water was measured using AquaSensor's Turbidity Datastick, basing on the absorption of light (IR) and its dispersion. The measurement interval was once per minute.

4) Conductivity in the run-off water was analysed using AquaSensor's Conductivity Datastick. The method is based on measuring changes in electric resistance in the liquid between two electrodes.

5) All the data is collected into a data-logger at the measurement stations. This data are transferred via gsm into a server at the office.

Recommendations: Due to the short time of analyzing the urban run-off waters little experience and recommendations have accumulated. A few recommendations have emerged.

Under cold climate, electricity and heating should be provided to prevent freezing of the device and the samples. Adequate cooling of the station during warm summer periods is also necessary – particularly if nutrients in the run-off water will be analyzed. Due to often short duration of the rain events, frequent measurement of the flow – at 1 minute interval – is recommended. The measurements are best to conduct in storm water sewer pipes rather than in open ditches to prevent water other than that derived from surface flow from being analysed. This would also hinder most of damage the measurement device might encounter.

6 Turbulent fluxes

6.1 Introduction

The eddy covariance (EC) method is a well-established approach to quantify the turbulent exchange of momentum, energy, water vapour and greenhouse gases between terrestrial ecosystems and the atmosphere. Originally, EC measurements have been mainly performed over flat and homogeneous surfaces in order to meet the requirements for its application (i.e. stationarity in time, homogeneity in space). However, today, most flux towers are in areas of complex terrain and various additional data-processing procedures were developed in the past two decades to derive accurate fluxes also from non-ideal sites. In this sense, many of the restrictions on EC measurements over very rough surfaces, like forests, also apply to urban surfaces, although there are some differences mainly originating from the presence of a deep urban roughness sub-layer, where the flow is significantly modified by buildings. The aggregation of buildings, trees and other objects in a city can therefore be regarded as the ‘urban canopy’ (Oke, 1975) or as the ‘urban ecosystem’. The turbulent fluxes of energy and matter are strongly modified by the specific properties of the urban surface, i.e. 3D geometry, high roughness, impervious surfaces, complex source/sink distribution and injections of heat, water and carbon into the urban atmosphere by human activities (traffic, heating, waste management, etc.). The influence of these urban-specific modifications has to be carefully evaluated for the interpretation of EC measurements in urban areas.

6.1.1 Urban scales and the urban atmosphere

Some basic concepts have to be kept in mind when measuring fluxes by the means of the EC method in urban environments. Modifications of the surface-atmosphere exchange by urban areas span over space and time scales of several orders of magnitude. Figure 1 provides a compact overview of urban boundary layers and urban scales.

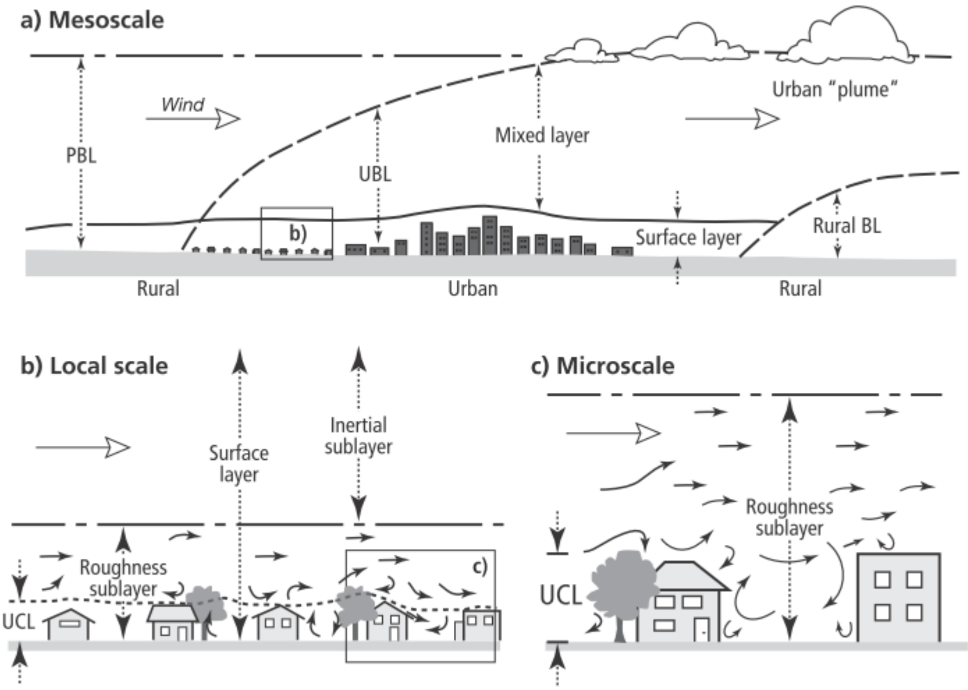

Fig. 1: Vertical (PBL planetary boundary layer, UBL urban boundary layer, UCL urban canopy layer) and horizontal scales (mesoscale, local scale, microscale) in urban boundary layers. Adapted from Oke (2006)

Figure 1b essentially shows the segmentation of the urban surface layer into two sub-layers: the urban roughness sub-layer (RSL) closer to the urban canopy responding to individual microscale elements, and the overlying inertial sub-layer (ISL) due to the mixing of all sub-neighborhood scales in the RSL. The lowest part of the urban RSL from the ground up to the height of buildings z_h in fig. 1c is called 'urban canopy layer' (UCL). The restricted convective and radiative coupling between the air-space located in the canopy (e.g. street canyons) and the roughness sub-layer above roofs allows the UCL to maintain its own climate. Microclimatic effects only persist for a short distance away from their source until they are blended, horizontally and vertically, by turbulence. In the horizontal, these effects may persist for a few hundred meters, whilst in the vertical, they are evident in the urban RSL. It arises from fig. 1 that the measurement instruments of urban flux towers are often located in the roughness sub-layer, which extends from ground level to about 1.5 z_h over densely built-up areas up to 5 z_h in low density areas (Grimmond and Oke, 1999). Exchange in the RSL is not only driven by turbulent exchange, but also by dispersive fluxes and small-scale advection, that – in contrast to permeable and irregular natural canopies - contribute significantly to the exchange in the UCL through stationary vortices arising from the flow around buildings and other large surface elements. In the ideal case, EC measurements above the RSL, i.e. in the ISL, are supposed to measure a blended, spatially-averaged signal that is representative of the local scale.

6.1.2 Source area and footprint

The footprint, also referred to as the source area, is defined as the region of ground that affects the turbulent flux measurement above the surface. Alternatively, an analogous footprint can be defined for scalar concentrations or for radiative fluxes (AMS, 2000). Note that the footprint of turbulent fluxes and the footprint of e.g. radiation or scalars are generally not identical (see fig. 2).

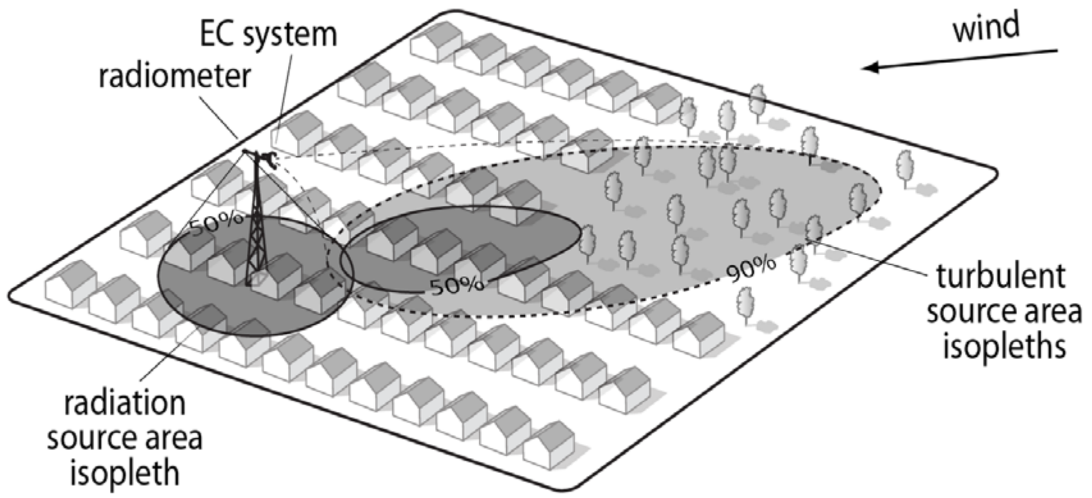

Fig. 2: Illustration of the different source areas for turbulent fluxes and radiative fluxes (courtesy of A. Christen, UBC Vancouver, adapted from Christen et al., 2010).

A correct interpretation of EC measurements in urban environments requires an accurate characterization of the source area. If the sensor is placed in the ISL, where Monin-Obukhov similarity theory (MOST) applies, footprint models may provide reliable estimates of the source area of turbulent fluxes and gaseous and/or particulate substances (e.g. Vesala et al., 2008), although footprint modelling in complex terrain, and especially in cities, still suffers from considerable uncertainties. In the RSL, however, the turbulent fluxes of momentum, energy and matter are height dependent due to the complex 3D geometry of buildings and blockage and channelling of the flow (Rotach, 2001).

The properties and the growth rate of internal boundary layers that form in the surface layer (fig. 1b) are crucial to the location of the source areas and have an important impact on the height/fetch ratio of the sensor location. Internal boundary layer properties (flow structures and thermodynamic properties) reflect the characteristics of the surface type in the source area and the growth rate depends on roughness and stratification. Due to the enhanced mechanical and thermal turbulence originating from high roughness and the heat island effect, cities tend to neutral conditions. Considering all the effects mentioned above, we propose a typical height/fetch ratio of 1:25…1:50. This means that surface properties inside the fetch should be similar, if the measurements should be representative for the local urban ecosystem. Fetch requirements can therefore be a significant restriction when choosing a site location.

6.2 EC measurements in urban areas

Experimental attempts using the EC technique in cities have been originally performed to better quantify the fluxes that contribute to the urban energy balance (UEB), i.e. the sensible and latent heat flux and, indirectly, the storage heat flux. Such campaigns were often connected to studies of the urban heat island (UHI) phenomenon (e.g. Oke, 1975). More recently, increasing interest has been paid to the measurement of CO_2 fluxes in cities. In this context, the International Association for Urban Climate (IAUC) organizes and documents urban flux sites (in analogy to the FLUXNET network, fluxnet.org) into the "urban flux network", which is accessible by the IAUC website (www. urban-climate.org). Numerous papers dealing with EC measurements of momentum flux, sensible and latent heat flux, and CO_2 flux over urban areas have been published to date. We refer to the BRIDGE report D.2.1. (Grimmond et al., 2010) for comprehensive bibliography of studies related to energy, water and CO_2 fluxes in cities. Most recently, new fast response instruments for VOC (volatile organic compounds), N_2O and particle measurement became available, which attracted researchers to combine the new sensors and the EC technique in the context of better understanding the urban atmospheric chemistry (e.g. Velasco et al., 2009; Famulari et al., 2009; Dorsey et al., 2002; Fratini et al., 2007).

6.2.1 Siting of urban flux towers

Despite the many problems with the EC technique in complex terrain listed in the previous sections, representative fluxes can be measured if some urban-specific principles and concepts are considered when choosing the location of the urban flux tower. First and foremost, the "ideal" location for EC measurements in a city does not exist. Observations in urban areas are mostly limited to certain aspects of the turbulent exchange in a restricted urban area, just because normally there is only one single flux tower available. Logistical and safety restrictions and the need of public and regulatory acceptance further limit the choice. Existing towers from broadcast and/or mobile phone companies are an alternative, however, such towers may be restricted in height or have an non-adequate fetch. Flexibility is always a good companion when choosing a possible location, because "non-standard" exposures in terms of height, surfaces, buildings and anthropogenic sources of the parameters to measure are rather the norm than the exception. A practical "guidance to obtain representative meteorological observations at urban sites" is given in Oke (2006).

In the framework of BRIDGE, the motivation of the EC measurements is to measure integrative fluxes for a given urban district that is defined by the extension of the respective case study. In this case, EC systems should be mounted on sufficiently tall towers near the top or above the RSL. Logistical limitations however often require a trade-off between an acceptable level of RSL-influence and non-ideal footprints. Simple footprint models may give a first idea which sector(s) are to exclude from further analysis. Note also that for energy balance studies the footprints of turbulent fluxes and radiative fluxes are unlikely to match. In this case special care must therefore be taken to gather energy balance measurements (available energy and fluxes) that represent the same surface properties. EC measurements in the RSL can provide useful information, but the interpretation of such measurements is severely limited because many underlying assumptions of the EC theory are not fulfilled. Especially zones that are characterized by streamlines perturbed by flows around isolated high-rise buildings, roof geometry and street canyons should be avoided (if not explicitly desired).

Despite all these issues urban sites have also some advantages compared to flux towers in non-urbanized ecosystems. Cities are usually excellently documented, e.g. by city authorities, and the researchers should make extensive use of the available information (aerial photographs, emission inventories, high resolution maps, 3D surface/building models, census data, traffic statistics, etc.) for the characterization of the source areas. This should allow for a comprehensive and sophisticated interpretation of the measurements.

6.2.2 Conceptual framework – the volume balance approach

Due to the 3D nature of urban ecosystem balances including the turbulent fluxes of sensible and latent heat and CO_2 are preferably treated in the context of a volume balance approach, i.e. all measured and derived terms in the balance equation represent fluxes into or out of, or the storage change inside a control volume, as illustrated in fig. 3.

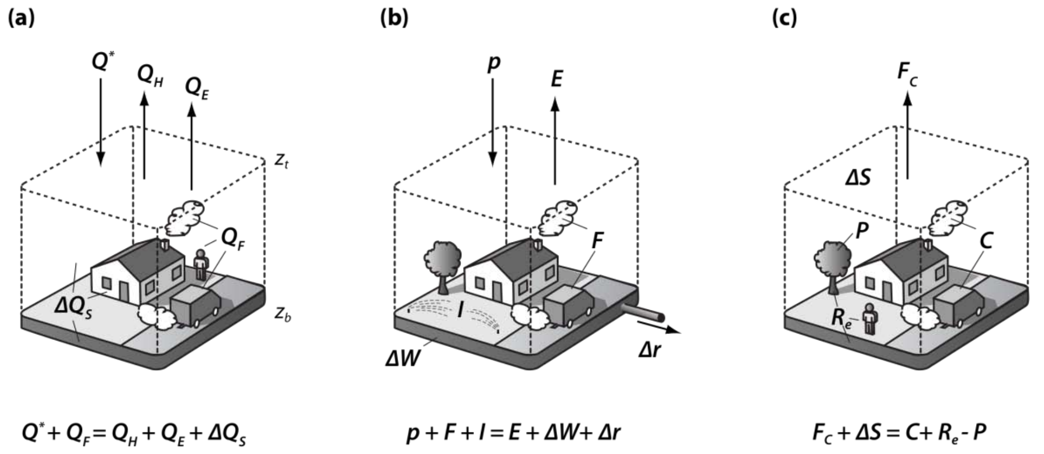

Fig. 3: Conceptual diagrams illustrating the volume balance approach for (a) the urban energy balance, (b) the urban water balance, and (c) the urban carbon balance. All arrows indicate the definition of positive flux densities. Note that advective fluxes are not considered here. For a description of symbols see the text. (Illustration courtesy of A. Christen, UBC Vancouver).

The energy balance in an urban system (fig. 3a) is defined as

$$Q^* + Q_F = Q_H + Q_E + \Delta Q_S \quad , \qquad (1)$$

with Q_* as net all-wave radiation, Q_F the anthropogenic heat flux, Q_H the sensible heat flux, Q_E the latent heat flux and ΔQ_S the net storage heat flux. Q_H and Q_E can be directly measured by an EC system.

The water balance in an urban system (fig. 3b) is defined as

$$p + I + F = E + \Delta W + \Delta r, \qquad (2)$$

with precipitation p, water input by irrigation I and combustion processes F. E denotes evapotranspiration, ΔW the storage of water in the subsurface material and Δr the run-off. Evapotranspiration E can be derived from the latent heat flux measured by the EC system.

The carbon balance in an urban system (fig. 3c) is defined as

$$F_C + \Delta S = C + R_e - P, \qquad (3)$$

with F_C as the turbulent CO_2 flux and ΔS as the storage change over time in the control volume. C refers to CO_2 emissions by combustion processes, R_e to ecosystem respiration and P to photosynthesis. F_C is directly measured by the EC system.

For a comprehensive and detailed overview on the state of the art in urban energy, water and carbon balances refer to BRIDGE report D.2.1 (Grimmond et al., 2010).

6.3 Data processing

6.3.1 Standard methods

In general, processing of urban EC data follows straightforward the same procedures as for data measured over non-urban ecosystems. This means that typical EC processing software (commercial or open source) may be used to derive fluxes from raw data (e.g. EddySoft , EddyRe, ECO2S, ECPack, eth-flux, see reference section). The main steps of processing are: despiking of the raw time series, coordinate rotation and tilt correction, linear detrending, averaging, compensation of sonic temperature for humidity fluctuations (applies to sensible heat flux, Schotanus et al., 1983), compensation on measured fluctuations in H_2O and CO_2 for the effects of fluctuations of temperature (thermal expansion) and water vapour (dilution), i.e. the WPL-correction (applies to open path sensors, Leuning, 2007), time lag compensation (applies mainly to closed path systems) and spectral correction for high frequency and low frequency attenuations (e.g. Moore, 1986), and instrument surface heating correction (for open path sensors, Burba et al., 2008). Note that, although the methodology is in principle well-established, several modifications of the single procedures exist. For a detailed and comprehensive description of the standard methodology refer to Aubinet et al. (2000) and/or the Handbook of Micrometeorology (Lee et al., 2004).

6.3.2 Urban specific perturbations and how to handle them

6.3.2.1 Advection and storage

While fluxes from grassland, crops, and forests are supposed to be representative of a specific ecosystem, urban fluxes rather represent a specific urban surface type, if at all. Advection occurs at three scales in cities. Firstly, at the microscale, horizontal advection occurs e.g. for sensible heat between shadowed and sunlit patches, for latent heat between wet and dry patches, and for air pollutants between high-emission patches (e.g. streets) and passive patches (e.g. courtyards). However, because turbulence blends these effects and the EC system on top of the RSL responds to the integral effects of a microscale patchwork, microscale advection is not a major issue. Secondly, at the local scale, advective fluxes may occur due to the close proximity of urban parks, water bodies, and between built-up areas of different density. If the study is not specifically interested in such fluxes, source areas should be avoided. Thirdly, mesoscale advection occurs between the city as a whole and the surrounding rural environment (“urban breeze”), or, for coastal cities, due to the presence of sea breezes (Pigeon et al., 2007). Further, the surrounding topography may also induce anabatic and katabatic flows similar to those found in connection with other ecosystems (e.g. mountain-valley and/or slope wind systems, drainage flows). In practice, advection is rarely measured in urban field experiments and similar difficulties to those reported from non-urbanized ecosystems (Aubinet et al., 2010) may arise in interpreting the impact of advective fluxes in urban environments.

Another urban-specific challenge arises from the fact that storage terms in Eqs. 1-3 include the horizontally averaged concentration change at various heights. While air within forest canopies can be expected to be reasonably well mixed (horizontally), we often encounter horizontally disconnected air spaces in the lower UCL, e.g. inner courtyards can be separated from street canyons, and show different concentrations and changes over time. Under such situations a single profile is inadequate to quantify the storage change, and ideally, several, horizontally separated measurements are preferable.

6.3.2.2 Flow distortion

Average streamlines that are not parallel to the ground are a problem for flux measurements (Finnigan et al., 2003). Appropriate rotation and calibration procedures are usually applied to overcome this issue. However, flow distortion in urban environments can also arise from flow separation and deflection around and over local and distant buildings in an urban canopy. In contrast to plant canopies that are mostly permeable and porous, buildings are bluff bodies that are impermeable and inflexible. Therefore, buildings create strong dynamical pressure differences across their facets that in turn lead to significant vertical wind components, decreased mean wind, and enhanced turbulent kinetic energy. For isolated buildings, a displacement of the mean streamlines can be detected several building heights above the roof and significant wake effects can be still found 10 to 15 times the building's height downwind (e.g. Oke, 1987). As a consequence, EC measurements near dynamical pressure gradients, i.e. exposed walls or isolated high-rise buildings, are to be avoided (Oke, 2006). In summary, not only is the height of the EC measurements a determinant of the location of urban flux measurements, but also flow distortion can be a severe limitation in the choice of appropriate platforms and measurement locations.

6.3.2.3 Night flux problem, gap filling and QC/QA

The typical premises that lead to the night flux problem (e.g. Moncrieff et al., 1996), - i.e. low u_*, and a stably stratified and decoupled canopy layer - are rarely found in urban atmospheres. The significant roughness of all urban surface forms produces mechanical turbulence which together with the release of stored and anthropogenic heat promotes thermal turbulence, leading to a well-mixed ISL day and night. Hence, an underestimation of fluxes during nighttime is not an issue as it is in a forest ecosystem, because unstable situations dominate the nighttime atmosphere at the urban sites due to significant storage and anthropogenic heat releases (Christen and Vogt, 2004).

It follows from this discussion that gap filling of urban EC data is mainly restricted to statistical methods, since the models for respiration and light response have to be adapted to the specific urban conditions and/or are of lesser importance for certain urban surface types. Quality-control tests as proposed by Foken et al. (2004) may result in a large number of rejected data, since these tests are heavily based on MOST, which is subject to fail in the urban RSL and instationarity is likely to be increased, in particular during daytime, due to enhanced thermal convection. However, because there is currently no urban specific QC/QA framework available, we recommend using the QC/QA procedures in Foken et al. (2004) as a first step. Some restrictions may be eased in a further step. Additional criteria based on threshold values for the individual fluxes may be considered to increase the quality of urban EC fluxes. Such additional rejection criteria however are highly site-specific and general recommendations cannot be given.

6.4 Service and maintenance of instruments

In addition to the particular problems arising from the very nature of a city, as described in previous sections, contamination of instruments (transducers, IRGA windows) due to aerosols is the most crucial issue. This implies increased attention to service and maintain the site and the instruments in particular. Advantages and disadvantages of open and closed path systems also apply for urban flux towers and instrumentation (Järvi et al., 2009). However, for both systems, additional care should be taken. For closed path systems we recommend an interval of a maximum of one week for the replacement of the inlet filters, and this may need to be reduced to a few days in heavy polluted environments. The same rule applies to the cleaning interval of open path sensors. Internal sampling cells of closed path system IRGAs, though protected by air filters, also need increased attention when exposed to urban polluted air. Sonic anemometers however do not seem to be seriously affected by increased air pollution.

6.5 Summary and conclusions

Using the EC methodology for urban areas is still no a plug and play application. With some efforts however, adequate results from EC measurements in urban areas can be obtained if attention is paid to certain urban specific peculiarities. Siting of an urban flux tower is much more crucial as it is for sites in non-urbanized ecosystems. It is of highest importance that the researcher is aware of the site-specific influences on the flux measurements, because the “ideal” urban flux site does not exist. Extensive knowledge of the source area characteristics and careful analysis of the flow distortion by the close surroundings of the site are inevitable for a proper interpretation of the measurements. Keeping this in mind and applying the usual data processing chain, flux measurements by the EC technique can be a valuable tool for the characterization of part of the urban metabolism, i.e. energy and mass fluxes. Originally restricted to fluxes of energy, water and carbon, new instruments made the EC technique also attractive to measure fluxes of particle matter, VOC and N_2O, which in term is helpful for the characterization of the chemistry of the urban atmosphere in the context of air pollution studies.

The instrumentation of an urban and a “non-urban” flux tower is essentially identical and the same advantages and disadvantages for open and closed path sensors apply. Some attention should be paid to the increased contamination of instruments and air filters due to the higher air pollution, apart from that, urban flux towers are serviced in the same manner as flux towers in non-urbanized ecosystems.

EC processing software:

EddySoft: http://edoc.mpg.de/348920

EdiRE: http://www.geos.ed.ac.uk/abs/research/micromet/EdiRe/

ECO2S: http://gaia.agraria.unitus.it/newtcdc2/eco2s_sw.aspx

ECPack: http://www.met.wau.nl/projects/jep/report/ecromp/

eth-flux: http://homepage.agrl.ethz.ch/~eugsterw/eth-flux/index.html

7 Remote sensing and GIS

7.1 Local scale DEM extraction from ASTER stereo imagery

In BRIDGE geo-referenced cartographic/geo-spatial data are used, therefore accurate knowledge and visualization of the topography of the surface is required at different scales. Digital Elevation Models (DEMs), as digital representations of the Earth's topographic relief provide the basis for many geographic applications like topographic analysis, hydrological modeling, or landscape visualization. Topographic attributes, such as slope, aspect or curvature, can be computed over the grid structure of a DEM in a straightforward manner (Chrysoulakis et al. 2004) and can be subsequently used for geometric, radiometric and atmospheric corrections of satellite data (Chrysoulakis et al. 2010). The production of geocoded, ortho-rectified raster images, a necessity for incorporating image data in a Geographic Information Systems (GIS) database, also requires elevation data in the form of DEMs (Toutin 2008). However, the general ability of the DEM to represent the topography depends on both the roughness of the true surface and the resolution of the DEM. Namely, since terrain contains variations on many scales, and different uses of terrain models require different accuracy, the scale imposed by the DEM resolution affects the topographic parameters. Relying on the observation that relief conserves the same statistical characteristics over a wide range of scales, several DEM characterization techniques have been developed that perform a multi-scale analysis of the elevation data.

DEM generation has become an important part of international research in the last 15 years as a result of both the existence of many satellite sensors that can provide stereo imagery and the development of new DEM extraction algorithms (Toutin 2008). For the production of DEMs from optical satellite data, the respective satellite sensors must have stereo coverage capabilities. Two methods have been proposed to obtain stereoscopy with images from satellite scanners (Toutin 2001): the along-track stereoscopy with images from the same orbit using fore and aft images and the across-track stereoscopy from two different orbits. The former method is used in ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) imagery. The ASTER Visible - Near Infrared (VNIR) subsystem consists of two telescopes – one nadir looking with a three band detector (Channels 1, 2 and 3N) and the other backward looking (27.7° off-nadir) with a single band detector (Fujisada 1994; Abrams 2000). The data products provided by the ASTER have been summarized by Yamaguchi et al. (1998). The ASTER method (along track stereo acquisition using a nadir and a backward looking telescope) gives a strong advantage in terms of radiometric variations (because of its near simultaneous nadir and backward acquisitions) versus the multi-date stereo-data acquisition with across-track stereo, which can then compensate for its weaker stereo geometry (base to height ratio of 0.6). The viability of stereo correlation for parallax difference from digital stereoscopic data has been described and evaluated in previous studies (Lang and Welch 1999, Toutin 2001, 2004). The basic characteristics of stereoscopy and its application to the ASTER system for DEM generation have been recently reviewed by Toutin (2008). He addressed the methods, algorithms and commercial software to extract absolute or relative elevation. Furthermore, Toutin (2008) assessed their performance using results from various organizations and discussed the use of the DEMs derived from ASTER stereo pairs in different applications.

Many efforts to assemble global elevation datasets have been undertaken in the past few decades. The SRTM mission (Werner 2001, Rosen et al. 2001, Farr et al., 2007) was the first mission using space-borne single-pass interferometric Synthetic Aperture Radar (SAR). The SRTM DEM products are being distributed mainly under two forms; these are the SRTM 1 and SRTM 3, with spatial resolution of 1 arc-second (around 30 m) and 3 arc-seconds (around 90 m), respectively. The first is available only for the USA, while the latter is available for the rest of the globe. The most recent global DEM source is the ASTER Global Digital Elevation Model (GDEM) which was released by Japan's Ministry of Economy, Trade and Industry (METI) and United States National Aeronautics and Space Administration (NASA) on June 29, 2009. GDEM is a global DEM generated using ASTER data, with 30 m posting. At the November 2007 GEO Ministerial Summit, NASA and METI were invited by GEO to contribute this global DEM to GEOSS (Global Earth Observation System of Systems). Both countries accepted the invitation. The ASTER GDEM was created by stereo-correlating the entire ASTER archive; stacking and averaging the individual DEMs; cloud screening; filling voids or holes using SRTM 3 arc-second data; and validating the GDEM against higher resolution DEMs worldwide (Abrams et al. 2010). GDEM was found to contain significant anomalies, which will affect its usefulness for certain user applications. Given that the water bodies can be effectively masked in ASTER imagery, there are two primary sources of these anomalies. One is residual clouds in the ASTER scenes used to generate the GDEM, and the other is the algorithm used to generate the final GDEM from individual ASTER DEMs available to contribute to the final elevation value for any given pixel (GDEM Validation Team 2009).

Global elevation datasets are inevitably subject to errors, mainly due to the methodology followed to extract elevation information and the various processing steps the models have undergone (e.g interpolation). Extensive and systematic evaluation of such datasets is difficult due to lack of substantial ground truthing. Error in elevation data is widely recognized to comprise mainly two components: the horizontal, often referred as positional accuracy, and the vertical component. However, horizontal and vertical accuracy generally cannot be separated; the error may be due to an incorrect elevation value at the correct location, or a correct elevation for an incorrect location or some combination of these. The theoretical accuracy of ASTER DEMs is governed by the accuracy of the control data, the Base to Height ratio (B/H) and the image matching. Since an error of ± 0.5 - 1 pixel or better for the parallax measurements in the automated matching process has been achieved with different datasets from other sensors, the potential relative accuracy for the elevation with the ASTER stereo data (B/H = 0.6, pixel spacing of 15 m) could be of the order of 12 - 25m or better (Welch et al., 1998), depending on the type of terrain. In addition, the accuracy of the DEM will also be dependent on the geometric parameter calibration, as well as the accuracy of the ephemeris and attitude data for computing the direct georeferencing (Toutin, 2008).

A detailed study compared conterminous United States (CONUS) GDEM data (934 GDEM tiles) to the United States Geological Survey (USGS) National Elevation Dataset (NED) and calculated an overall vertical Root Mean Square Error (RMSE) of 10.87 m (GDEM Validation Team 2009). When compared with more than 13,000 GCPs from CONUS, the RMSE dropped to 9.37 meters (Abrams et al. 2010). In the framework of BRIDGE the GDEM was validated for the whole area of Greece (where in situ elevation information was available for validation) by Chrysoulakis et al (2011). They found a vertical accuracy of around 20 m (RMSE = 11.08 m) when GDEM derived elevations were compared with GPS derived elevations.

ASTER raw data were processed to derive a DEM for the Case Study of Athens, whereas for the rest BRIDGE Case Studies the GDEM was used.

7.2 Surface albedo estimation based on satellite observations

The basic reasons for land surface reflectance anisotropy are: a) Specular scattering such as sunglint, also observed where forward-scattering leaves or soil elements are present. b) Radiative transfer-type volumetric scattering by finite scatters (leaves of plant canopies) that are uniformly distributed, potentially non-uniformly inclined, which themselves have anisotropic reflectance. c) Geometric-optical surface scattering, which is given by shadow-casting and mutual obscuration of three-dimensional (3-D) surface elements (for example, of trees in a sparse forest or brushland or of clods on a plowed field or of rock-strewn deserts).

The spectral albedo of a plane surface is defined as the ratio between the hemispherical integrals of the up-welling (reflected) spectral radiance $L^{\uparrow}(\lambda,\theta_{out},\phi_{out})$ and the down-welling spectral radiance $L^{\downarrow}(\lambda,\theta_{in},\phi_{in})$ weighted by the cosine of the angle between the respective reference direction and the surface normal:

$$a(\lambda) := \frac{\int_{2\pi} L^{\uparrow}(\lambda,\theta_{out},\phi_{out})\cos\theta_{out}\,d\Omega_{out}}{\int_{2\pi} L^{\downarrow}(\lambda,\theta_{in},\phi_{in})\cos\theta_{in}\,d\Omega_{in}} \quad (1)$$

where $d\Omega_{out} = \sin\theta_{out}\,d\theta_{out}\,d\phi_{out}$ and $d\Omega_{in} = \sin\theta_{in}\,d\theta_{in}\,d\phi_{in}$ .The expression in the denominator defines the spectral irradiance $E^{\downarrow}(\lambda)$. By introducing the bi-directional reflectance factor *R*, the up-welling radiance distribution can be expressed in terms of the down-welling radiation as:

$$L^{\uparrow}(\lambda,\theta_{out},\phi_{out}) = \frac{1}{\pi}\int_{2\pi} R(\lambda,\theta_{out},\phi_{out},\theta_{in},\phi_{in})L^{\downarrow}(\lambda,\theta_{in},\phi_{in})\cos\theta_{in}\,d\Omega_{in} \quad (2)$$

And equation (1) becomes:

$$a(\lambda) = \frac{\frac{1}{\pi}\int_{2\pi}\int_{2\pi} R(\lambda,\theta_{out},\phi_{out},\theta_{in},\phi_{in})L^{\downarrow}(\lambda,\theta_{in},\phi_{in})\cos\theta_{in}\cos\theta_{out}\,d\Omega_{in}\,d\Omega_{out}}{E^{\downarrow}(\lambda)} \quad (3)$$

In general the spectral albedo of non-Lambertian surfaces depends on the angular distribution of the incident radiation - which in turn depends on the concentration and properties of scattering agents (e.g. aerosols) in the atmosphere and in particular on the presence of clouds. Therefore the spectral albedo is not a true surface property but rather a characteristic of the coupled surface-atmosphere system.

In the idealised case of purely direct illumination at incidence angles (θ_{dh},ϕ_{dh}) the downwelling radiance is given by:

$$L^{\downarrow}(\lambda,\theta_{in},\phi_{in}) = \sin^{-1}\theta_{dh}\,\delta(\theta_{in}-\theta_{dh},\phi_{in}-\phi_{dh})E_0(\lambda) \quad (4)$$

which results in

$$E^{\downarrow}(\lambda) = E_0(\lambda)\cos\theta_{dh} \quad (5)$$

and

$$L^{\uparrow}(\lambda,\theta_{out},\phi_{out};\theta_{dh},\phi_{dh}) = \frac{1}{\pi}R(\lambda,\theta_{out},\phi_{out},\theta_{dh},\phi_{dh})E_0(\lambda)\cos\theta_{dh} \quad (6)$$

By inserting these expressions into Equations (1) or (3) we obtain the spectral directionalhemispherical (or "black-sky") albedo $a^{dh}(\lambda;\theta_{dh},\phi_{dh})$:

$$a^{dh}(\lambda;\theta_{dh},\phi_{dh}) = \frac{1}{\pi}\int_{2\pi} R(\lambda,\theta_{out},\phi_{out},\theta_{dh},\phi_{dh})\cos\theta_{out}d\Omega_{out} \quad (7)$$

On the other hand, for completely diffuse illumination the down-welling radiance $L^{\downarrow}(\lambda,\theta_{in},\phi_{in}) = L_0(\lambda)$ is constant and the irradiance becomes $E^{\downarrow}(\lambda) = \pi L_0(\lambda)$. By inserting these terms into Equation (3) and after making use of Equation (7) the spectral bihemispherical (or "white-sky") albedo $a^{bh}(\lambda)$ can be written as:

$$a^{bh}(\lambda) = \frac{1}{\pi}\int_{2\pi} a^{dh}(\lambda;\theta_{in},\phi_{in})\cos\theta_{in}d\Omega_{in} \quad (8)$$

These two quantities are true surface properties and correspond to the limiting cases of point source $\left[a^{dh}(\lambda;\theta_{dh},\phi_{dh})\right]$ and completely diffuse illumination $a^{bh}(\lambda)$.

For conversion of the satellite signals into the surface albedo, the following steps must be made:

- Computing the incoming narrowband radiative fluxes at the top of the atmosphere.
- Converting the satellite signals into narrowband radiances by means of the calibration coefficients for the satellite sensors.
- Applying an atmospheric correction.
- Correcting the incoming fluxes for the orientation of the surface.
- Applying a correction for anisotropic reflection by the surface.
- Converting the narrowband surface albedos into the ‘broadband surface albedo, which includes all of the solar radiation (short-wave). Broadband depends on the atmospheric conditions through downward fluxes that are the weighting function of the conversion from narrowband to broadband albedos.

The role of atmospheric correction is to decompose the signal received by the satellite sensor and to extract the component that originates from the target, in order to estimate the target reflectance. As discusses by Chrysoulakis et al. (2009), past studies have shown that these radiative transfer codes can accurately convert satellite measurements to surface reflectance. However, these corrections require accurate measurements of atmospheric optical properties at the time of image acquisition. These measurements are frequently unavailable or of questionable quality, which makes accurate atmospheric correction of images difficult with radiative transfer codes. In addition, an accurate correction requires a correction for the atmospheric point spread function and coupling of the surface Bidirectional Reflectance Distribution Function (BRDF) and atmosphere effects.

A directional sampling of surface reflectances from sensors such as MODIS can only be obtained by the accumulation of sequential observations over a specified time period. Cloud obscuration routinely reduces the number of clear looks. A 16-day period (or more) should be chosen as a trade-off between the sufficiency of angular samples and the stability of surface reflectivity. These directional observations can be coupled with semi-empirical models to describe the BRDF and integrals necessary to provide spectral albedos. As discussed by Lucht et al. (2000), the BRDF can be expanded into a linear sum of terms (the so-called kernels), characterizing different scattering modes. The superposition assumes that these modes are either spatially distinct within the scene viewed with little cross-coupling, physically distinct within a uniform canopy with negligible interaction, or empirically justified. The MODIS BRDF/Albedo algorithm makes use of a kernel-driven, linear BRDF model which relies on the weighted sum of an isotropic parameter and two functions (or kernels) of viewing and illumination geometry to determine reflectance R (Schaaf et al., 2002):

$$R(\theta,\upsilon,\varphi,\lambda)= f_{iso}(\lambda)+ f_{vol}(\lambda)\,K_{vol}(\theta,\upsilon,\varphi)+ f_{geo}(\lambda)\,K_{geo}(\theta,\upsilon,\varphi)$$

where θ, υ and φ are the solar zenith, view zenith and relative azimuth angles; $K_k(\theta, \upsilon, \varphi)$ are the model kernels; and $f_k(\lambda)$ are the spectrally dependent BRDF kernel weights or parameters. In MODIS BRDF/Albedo algorithm, the first of these kernels, $K_{vol}(\theta, \upsilon, \varphi, \lambda)$, is the RossThick kernel and represents volumetric scattering from a dense leaf canopy based on a single scattering approximation of radiative transfer theory (Ross, 1981; Roujean et al., 1992) and the second $K_{geo}(\theta, \upsilon, \varphi, \lambda)$, is the LiSparse kernel which is derived from the geometric-optical mutual shadowing model and assumes a sparse ensemble of surface objects (Li and Strahler, 1992). Because two kernels in the Ross-Li model diminish to zero when $\theta_v = \theta_s = 0$, parameter $f_{iso}(\lambda) = R\ (0, 0, \varphi, \lambda)$, which is the bi-directional reflectance at nadir view and overhead sun. The kernel weights $f_k(\lambda)$ will be selected from those that will best fit the available observational data. Their derivation, i.e., the process of model inversion, will be achieved through a fitting procedure that tunes the model to observed data points by minimizing mean square residuals. For a successful inversion, the observations must cover a range of sun-target-viewer geometries (and ideally, the entire range). In practice, however, this requirement is rarely achieved. For a fixed location on the Earth's surface, some satellite systems, such as the MISR, can obtain multiple angular views virtually instantaneously, while others, such as MODIS, build up sequential angular views over a period of time. This approach, referred to as a pixel-based fitting (PBF) method, is currently implemented in the MODIS operational albedo retrieval algorithm. It provides, as it has been already mentioned, surface albedo for each 1-km pixel at 16-day intervals.

The black-sky albedo $a^{dh}(\lambda;\theta_s,\phi_s)$, as well as the white-sky $a^{bh}(\lambda)$ albedo were computed using polynomial expressions of the kernel weights as described by Schaaf et al. (2002. To obtain an approximation of the albedo for ambient illumination conditions (blue-sky albedo), it is suggested (Lewis and Barnsley, 1994; Schaepman-Strub et al., 2006) to linearly combine the BHR for isotropic diffuse illumination conditions (white-sky albedo) and the DHR (black-sky albedo) corresponding to the actual ratio of diffuse to direct illumination. The diffuse component then can be expressed as a function of wavelength, optical depth, aerosol type, and terrain contribution. Therefore, for partially diffuse illumination the actually occurring spectral albedo value may be approximated as a linear combination of the limiting cases:

$$a(\lambda)=\left[1- f_{diffuse}(\lambda)\right]a^{dh}(\lambda;\theta_s,\phi_s)+ f_{diffuse}(\lambda)a^{bh}(\lambda) \quad (9)$$

where $f_{diffuse}$ denotes the fraction of diffuse radiation and (θ_s,ϕ_s) the solar direction.

For many applications the quantity of interest is not the spectral but rather the broad-band albedo which is defined as the ratio of up-welling to down-welling radiation fluxes in a given wavelength interval $[\lambda_1, \lambda_2]$:

$$a_{[\lambda_1,\lambda_2]} := \frac{F^{\uparrow}_{[\lambda_1,\lambda_2]}}{F^{\downarrow}_{[\lambda_1,\lambda_2]}} = \frac{\int_{\lambda_1}^{\lambda_2}\int_{2\pi} L^{\uparrow}(\lambda,\theta_{out},\phi_{out})\cos\theta_{out} d\Omega_{out} d\lambda}{\int_{\lambda_1}^{\lambda_2}\int_{2\pi} L^{\downarrow}(\lambda,\theta_{in},\phi_{in})\cos\theta_{in} d\Omega_{in} d\lambda} \quad (10)$$

In BRIDGE, MODIS level 2 albedo product was used to provide surface albedo for all Case Studies. Time series of MODIS black-sky and white sky albedo products were downloaded for the broader area of all BRIDGE Case Studies for 2008. The fraction of the diffuse radiation was calculated form lok-up tables as a function of solar zenith angle and aerosol optical thicjness. Using the back sky albedo, the white sky albedo and the fraction of diffuce radiation, the surface albedo was calculated for all 16-dyas intervals of 2008 and 2009, for all BRIDGE Case Studies. The spatial resolution of this product is the spatial resolution of the MODIS derived black and white sky albedo products (1 x1 km).

7.3 Surface emissivity estimation based on satellite observations

Emissivity is a measure of the inherent efficiency of the surface to convert heat energy into radiant energy outside the surface. It depends largely on the composition, roughness and other physical parameters of the surface, such as its moisture. Furthermore, depending on the nature and composition of the surfaces, it varies with wavelength, therefore for land surface, the effects of emissivity may be very large. In order to measure the radiometric temperature from space, besides the radiometric calibration and the cloud screening procedures, it is necessary first to separate surface emissivity and surface temperature effects from the measured radiance and then to perform both atmospheric and emissivity corrections. By definition, the channel emissivity ε_i is given by (Becker and Li 1990):

$$\varepsilon_i = \frac{\int f_i(\lambda)\varepsilon_\lambda \mathrm{B}_\lambda(LST)\,d\lambda}{\int f_i(\lambda)\mathrm{B}_\lambda(LST)\,d\lambda}$$

where B_λ(LST) is the Planck's function for blackbody emission, $f_i(\lambda)$ is the spectral response of the radiometer in channel I, ε_λ, is the spectral emissivity and LST is the Land Surface Temperature. Although ε_i depends theoretically on LST from the above equation, as it has been checked numerically by Becker and Li (1990), this variation of ε_i with LST is negligible ($\Delta\varepsilon_i$= 10^{-4}). Therefore, the channel emissivity can be given as:

$$\varepsilon_i = \frac{\int f_i(\lambda)\varepsilon_\lambda\,d\lambda}{\int f_i(\lambda)\,d\lambda}$$

As explained by Wan and Dosier (1996), the band emissivity provided by the latter formula is more accurate, because it does not vary with the sub-pixel temperatures. The emissivity of the surface affects the radiance measured at satellite in at least three important ways (Prata 1993): a) the reduction of emissivity from unity causes a reduction in the magnitude of the upwelling surface radiance; b) the nonblack behavior of the surface gives rise to a contribution from the reflected radiance from the surface; c) the anisotropy of the reflectivity and emissivity of the surface can either increase the total radiance received at the satellite. Other factors associated with the surface emissivity effects are mixed pixel effects and zenith angle effects induced by the topography.

Several method have been developed to retrieve surface emissivity (Becker and Li 1990, Watson 1992, Kealy and Gabell 1990, Valor and Caselles 1996, Snyder et al. 1998, Sobrino and Raissouni 2000). Dash et al. (2002) have summarized the different emissivity estimation techniques and have analyzed their main constrains. Constrains like the assumption of graybody behavior, the requirement of acquisitions twice a day along with the assumption that day/night emissivity differences are negligible or the need of a priori knowledge of emissivity for land cover classes are most of the constrained of these methods. Within a particular surface type the variation of emissivity is not well known, but measurements suggest it is small, around ± 0.01, except when structural changes occur as in senescent vegetation. The scheme for accounting for emissivity variations between surface types relies on a surrogate measure of the surface structure (fractional vegetation cover and vegetation type).

The classification-based emissivity method proposed by Snyder et al. (1998) to estimate emissivity from conventional static land cover classes and dynamic information and used it to develop an emissivity knowledge-base. The method was developed using linear Bidirectional Reflectance Distribution Function (BRDF) models, which have spectral coefficients derived from laboratory measurements (Salisbury and D'Aria 1992, 1994, Salisbury et al. 1994, Snyder et al. 1997), of material samples and structural parameters derived from approximate descriptions of the cover type (Snyder and Wan 1998). In Snyder et al. (1998) emissivity retrieval scheme, each pixel was classified into one of 14 emissivity classes; biospherically distinct cover types, which model estimates showed to have nearly the same emissivity, e.g. evergreen needle forest and green deciduous forest, are merged into one class. Kernel models were applied to determine the BRDF that is then integrated to obtain hemispherical reflectance $\rho(\theta)$. Assuming that there is no azimuthal dependence, emissivity was then computed as $1- \rho(\theta)$. In this way the directional variation of emissivity was also taken into account. Generally, this variation was found to be strongest with view angles greater than 50° or so. It was determined that some arid soils and water were the only materials where the angular effects may make a significant difference in the spectral area 10 - 12 µm. For all of the other emissivity classes used by Snyder et al. (1998), it was indicated that the angular effects were small or that the variations caused by other factors are larger than the change with angle. The emissivity uncertainty may be high when estimated from land-cover mapping methods, because land-cover maps are typically not updated often and their number of land-cover types is very limited.

The MODIS Level 2 emissivity product (spectral emissivities for MODIS channels 31 and 32) is available as daily global maps at 1 km spatial resolution. It has been produced using the classification based emissivity (Snyder et al., 1998). In BRIDGE, MODIS level 2 emissivity product was used to provide surface emissivity for all Case Studies. Time series of MODIS channel 31 and channel 32 daily emissivty products were downloaded for the broader area of all BRIDGE Case Studies for 2008. The time series of these MODIS derived emissivity products were descaled, geometrically corrected and reprojected to Geographic WGS84. The surface emissivity was produced for each day, for each BRIDGE Case Study, as a spatial average of MODIS derived spectral emissivities.

7.4 Processing of satellite imagery for Athens case study

In order to describe the surface characteristics of the metropolitan area of Athens, Greece, four parameters of the physical environment were used: land surface albedo (LSA), land surface emissivity (LSE), land surface temperature (LST) and vegetation. These parameters were extracted from high-spatial resolution image data of Athens collected from the Landsat 5 satellite. Landsat 5 satellite was launched on March 1, 1984 with the primary goal of providing a global archive of images. It is designed for a 705 km, sun-synchronous, earth mapping orbit with a 16-day repeat cycle. Landsat 5 image data are distributed from the USGS's Center for Earth Resources Observation and Science (USGS EROS) and can be ordered from two USGS websites: the USGS Global Visualization Viewer (GloVis) (http://glovis.usgs.gov) and the USGS Earth Explorer (http://edcsns17.cr.usgs.gov/NewEarthExplorer).

Landsat 5 carries the Thematic Mapper (TM) sensor which observes the Earth's surface in seven spectral bands, with a spatial resolution of 30 meters for Bands 1 (blue-green) to 5 and 7 (mid-infrared), and a spatial resolution of 120 meters for Band 6 (thermal infrared). The approximate image size that TM provides is 170 km north-south by 183 km east-west.

Processing of the satellite imagery was performed by using the ERDAS IMAGINE software. ERDAS IMAGINE is aimed primarily at geospatial raster data processing and allows the user to prepare, display and enhance digital images for use in other software such as Arc GIS. It is a toolbox allowing the user to perform numerous operations on an image and generate an answer to specific geographical questions. The guidelines for the methodologies applied to TM image data leading to the measurement of the four physical parameters (LSA, LSE, LST and vegetation) are given below.

Land Surface albedo (LSA): This parameter was extracted from a TM image acquired over Athens during the warm season under clear atmospheric conditions. Using the band image data of TM recorded in the visible (TM1, TM2, TM3), near-infrared (TM4) and mid-infrared (MIR) part of the electromagnetic spectrum (TM1-5, TM7), the total shortwave albedo (0.25-5.1μm), the visible albedo (0.4-0.7 μm) and the near-infrared albedo (0.7-5.0 μm) for the metropolitan Athens area were calculated at the spatial resolution of 30 meters. The processing technique applied, included: a) atmospheric correction of the image data (TM 1-5, TM7) using the COST method developed by Chavez (1996), b) conversion of the digital number (DN) values of each image (TM1-5, TM7) to at-sensor spectral radiance and then to surface reflectance (Chander and Markham, 2003) and c) narrowband to broadband surface albedo conversion applying the algorithms developed by Liang (2001).

Vegetation: For mapping the vegetation coverage of metropolitan Athens, the Normalized Difference Vegetation Index (NDVI) was measured from a TM image. The index was computed by using the surface reflectance values derived from the DN image data of bands TM3 and TM4 (Chander and Markham, 2003) and applying the formula: NDVI = (TM4-TM3)/(TM4+TM3). Calculations of NDVI for a given pixel always result in a number that ranges from -1 to +1; surfaces fully covered by vegetation are designated with an NDVI value of +1, whereas surfaces with no vegetation exhibit NDVI values close to 0. Water surfaces correspond to negative NDVI values.

Land surface emissivity (LSE): This physical parameter was extracted at a spatial resolution of 30 meters after processing three TM images collected over Athens during the warm season of 2005 (8/4/2005, 27/6/2005, 14/8/2005). For each TM image, effective LSE in the 10-12μm waveband was derived applying the algorithm proposed by Caselles et al. (1991). The algorithm requires a priori knowledge of the mean thermal emissivity value for the city and for the vegetated surfaces. For Athens, these values were taken from Stathopoulou et al. (2007). Then, a composite LSE image was produced as a result of LSE images overlay and considering a mean LSE value for each pixel. In this way, a warm season LSE image of Athens was produced.

Land surface temperature (LST): A summer TM image over metropolitan Athens was acquired and analyzed for LST estimation at the 120 meter spatial resolution. After applying the calibration process of the thermal band image data (TM6) (Chander and Markham, 2003), the generalized single-channel algorithm for LST developed by Jiménez-Munõz and Sobrino (2003) was applied. The algorithm requires the knowledge of LSE for the application area as well as the atmospheric water vapor content for the observation day. Thus, the algorithm was applied using LSE values by land cover types (Stathopoulou et al. 2007) and a mean value of water vapor content for July as measured from radiosonde data in Athens (Chrysoulakis and Cartalis, 2002).

7.5 Processing of the GIS data for Athens

All processing of the GIS data was performed by using the ArcGIS software.

Planning alternatives: New vector layers were produced for describing the alternative planning scenarios for the Eleonas area, part of the municipality of Egaleo in Athens, Greece. Eleonas is a Brownfield/ industrial area of 900 hectares located at the southeastern of Egaleo having a distance of only 3 km from the center of Athens. The planning alternatives of Eleonas regard the land use change of the area from Brownfield/industrial (current state) to A) urban fabric and B) green open space. Using the vector layer of land use for Egaleo (provided by the municipality of Egaleo in a shapefile format) as a baseline, the area of Eleonas was defined. For alternative A, new building block polygons together with a new linear roadnet were created that cover the area of Eleonas, resulting thus to the development of two new vector shapefiles: ‘roadnet_eleonas.shp’ and ‘building_block_eleonas.shp’. The attribute table of the baseline land use vector file was also edited for the polygons forming the Eleonas area. In particular, the land cover type of those polygons was changed from ‘Brownfield/industrial’ to ‘Urban’. For alternative B, the land use vector layer of Egaleo was edited so as the polygons forming the Eleonas area are designated with a ‘green open space’ land cover type in the attribute table. Geographic projections of the new vectors were kept the same with the one of the baseline vector layer.

7.6 London case studies

London surface characteristics were obtained by LiDAR measurements which provided a complete description of green roof, trees and vegetation characteristics. Also, infrared thermometers and thermal cameras were used to measure the surface temperature in London. In this city, the air quality analysis was made by using both the UFORE model and infra red spectroscopy (FTIR).

A detailed description of methodology and instruments used is reported in the Deliverable 3.4. Here, a few of the lessons learnt from the BRIDGE project are identified.

From the site characterization:

- The locations of street trees in London are a very political issue (GLA 2007[1], 2011) which has meant that obtaining data about the current location of trees was very time consuming.
- The Street Tree Inventory which was obtained was incomplete so could not very reliably used as a basis for identifying where new trees could be located.
- LiDAR data provided complete data coverage. Analysis of these data using methods developed here have allowed for consistent analysis across the (Central Activity Zone) CAZ.
- Green roofs have been built in locations beyond those identified as potential locations.
- The total roof area that could potentially be retrofitted with green roofs in the CAZ is 4,987,104 m^2 (~15 % of the total CAZ area) or ~ 92 % of the total roofed area. The target increase green roofs in of 100,000 m^2 by 2012 would require the development in 2011-12 to be over five times that of the past two years.
- Currently about 0.6% of the CAZ roofs are green.

[1] http://legacy.london.gov.uk/assembly/reports/environment/chainsaw-massacre.pdf

- From comparison of field and LiDAR data, tree characteristics are well correlated with the LiDAR yielding greater diameters and very similar heights.
- Public trees are generally taller and have wider crown diameter than trees on private land.

From observations:

- Automated data archive and delivery system (KUMA) has been developed. This has facilitated the use of data and identification of potential data issues in a more rapid manner.
- Redundancy in instrumentation is extremely useful for evaluating and verifying data.
- There is the potential to use a wide range of different sources of climate data in London. However, care needs to be taken as the network have different siting, instrumentation and aims which mean that modifications to the data may be necessary to make one consistent data set.
- Data once ratified will provide new insight into a range of processes occurring in the central part of a European mega-city.
- The data collected will be used to evaluate models which are used within the Decision Support System.

8 Socioeconomic analysis

8.1 Methods applied for choosing the sustainability objectives and socio-economic indicators

During the Bridge project there were organized two CoP meetings in every case study city. Short summary of the meetings is presented in a table below.

CoP Meetings	**Date**	**Number of participants**
1st CoP Meeting in Gliwice	October 20th 2009	26
2nd CoP Meeting in Gliwice	Janary 28th 2010	26
1st CoP Meeting in London	August 24th 2009	25
2nd CoP Meeting in London	April 1st 2010	10
1st CoP Meeting in Firenze	October 16th 2009	18
2nd CoP Meeting in Firenze	December 3rd 2009	14
1st CoP Meeting in Helsinki	June 15th 2009	21
2nd CoP Meeting in Helsinki	January 20th 2010	13
1st CoP Meeting in Athens	October 8th 2009	51
2nd CoP Meeting in Athens	February 18th 2010	29

The sustainability objectives and socioeconomic indicators were derived in a series of discussions that took place in the organised CoP- meetings. In the meetings representatives from the city planning department and public works department of the cities, environment centers, energy companies, economic and planning center along with the Bridge researchers and the CoP organisers from Bridge participated.

The BRIDGE project uses models and data on energy, water and air into a DSS (Decision Support System). This DSS can evaluate planning alternatives. BRIDGE mixes science and planning by incorporating objectives and indicators, proposed by end users, in the models. Therefore, the ideas of the first CoP meeting fed into the DSS as planning priorities, objectives and indicators. A *planning priority* is a key issue for a specific city (for example: air quality). For these issues there were formulated aims for improvement, which are *the objectives* to make the city more sustainable. The objectives were selected in a process of brainstorming and then discussions on what participants considered to be objectives and which ones they selected. For example, an objective is to improve air quality. Finally the participants tried to find *indicators* to measure progress towards the established objectives. For the *objective* of improving air quality, an *indicator* could be: the amount of particulate matter.

The first CoP –meetings usually initiated the work with a walking tour. This enabled the participants to make explicit comments and/or find out about strengths and weaknesses in the current planning practices from a sustainability point of view. Moreover, it helped to discuss a number of challenges for a more sustainable planning. This was followed by open discussion that allowed participants to establish the planning priorities. Based on these priorities, and taking into account the previously defined challenges, the core sustainability objectives were established for the city by the participants. The discussion was followed by the evaluation round which showed what went well during the meeting and what needs to be improved.

The sustainability objectives and indicators were revisited in the second CoP-meetings. Before the meeting, the participants were asked to bring forward the currently utilised planning tools in the cities. In the discussion the current planning tools and the sustainability objectives and indicators currently utilised were brought forward. After that the objectives and indicators determined in the first CoP- meeting were discussed and modified accordingly.

After the second CoP- meetings in some of the case studies some more CoP meetings were organised where case-study alternatives were introduced and the sustainability objectives and indicators were concretized and their relative weight were determined. These were further commented and modified in the international Bridge-meetings in Athens and London where also representatives of the cities planning departments participated.

8.2 Lessons learned

Participation of a wide range of relevant stakeholders is necessary when the sustainability objectives are determined and it helps to stress the important role of democration. In that a process like CoP is important. Number of discussions are needed but it is also very difficult to maintain the continued interest of stakeholders if the concrete utilization of the sustainability objectives and indicators cannot be demonstrated. Discussions at concrete cases (as during the first CoP-meeting walking tour and the Bridge case study evaluation) are necessary to make general outlines more concrete. In Gliwice case study the collaboration between Bridge researchers and scientists of the Silesian University of Technology was very fruitful and has brought tangible benefits. This cooperation made possible the reduction of costs associated with the task of reading and transmitting data and enabled the preparation of the next research project.

Moreover the presentation of future sceneros was very interesting part in a process of chosing the test site. Initially in Gliwice there were two districts – Kopernik (housing district) and the Polytechnic District, that might have been useful as a the test site in Gliwice case study since it was possible to apply BRIDGE project DSS base on both districts. Then participants' discussion focused on probable future scenarios for both districts. It was concluded that Polytechnic District seems more suitable for BRIDGE project taking into account creation of future scenarios, availability of data for this area and benefits for the city of Gliwice.

Also the development of sustainability objectives and indicators is linked to the DSS-tool for which they are developed and the interaction between the DSS- development and the definition of the objectives and indicators should happen as an interactive process. In such a scheme, the initiation and maintenance of CoP activity is a very important part.

One more thing very important in the BRIDGE project was the differences between case studies that enabled for the international exchange of experiences and different points of view. The international Bridge-meetings in Athens and London where the representatives of the city planning departments of all case studies participated enabled learning some new approaches and then their application in every case study.