**9.7** ANALYSIS OF LONG-TERM OBSERVATIONS OF URBAN SURFACE-ATMOSPHERE ENERGY EXCHANGE

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## 1. Introduction

Urban patterns of land-surface modification and energy consumption contribute to distinct urban climates by altering surface - atmosphere exchange processes. Better understanding of local-scale urban meteorology is necessary in order to develop numerical climate models and to address a range of applied questions of concern to the health, comfort and safety of citizens. To date studies of the energy, mass and momentum exchanges have been conducted at a relatively limited range of urban sites. Since November 2000 we have been making eddy-covariance (EC) flux measurements in downtown Łódź, Poland. These measurements are a unique dataset due to the climate, urban structure, wintertime anthropogenic heating, and the duration of measurements. Here we review the measurements in Łódź for 2001 including an evaluation of the effects of surface characteristics.

## 2. Methods

### 2.1 *Study Site*

Łódź, the second largest city (population ~800,000) in Poland, is located in topography that is relatively flat (180 to 235 m from W to E). Building heights within central Łódź (19$^{o}$ 26' 54" E 51$^{o}$ 45' 46" N) range from 15 – 20 m with little variation. The long-term observational site is located within the relatively homogeneous urban core. The majority of roofs are either flat or slightly pitched. Within 500 m of the tower, buildings and pavement dominate the surface cover (Fig. 1). To the south and west, within a 1 km distance, there is considerably more vegetation.

### 2.2 *Instrumentation and operations*

The instrumentation was mounted 37 m above ground level on a tubular tower (top diameter 8 cm) on YD 2000/307. An ATI K-type sonic anemometer is used to measure 3-d wind velocities and virtual temperature. A fast-response (~ 1 Hz) thermocouple is installed within the sampling volume of the sonic to provide an alternative method to calculate heat fluxes. A krypton hygrometer (KH2O, CSI) measures water vapor fluctuations. The instruments are mounted on booms extending approximately 1 m from the tower, oriented eastward toward the most built fetch. In addition net radiation, air temperature, relative humidity, atmospheric pressure, precipitation, soil heat flux, temperature, and moisture are measured. The fast response data are stored at 10 Hz and all other measurements as 15 minute averages.

Sensible ($Q_H$) and latent heat fluxes ($Q_E$) and turbulence statistics were computed at half-hour intervals. This time period provides a balance between stationarity and sampling rate to reduce measurement uncertainty. An oxygen absorption correction (Tanner *et al.* 1993) was applied to $Q_E$, and the Webb *et al.* (1980) density correction was applied to $Q_H$ and $Q_E$.

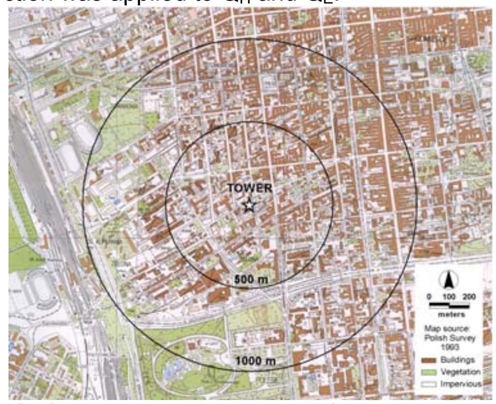


Fig. 1: Surface cover within the vicinity of the long-term tower site in Łódź, Poland

## 3. **Results**

### 3.1 *Stability and roughness*

The Monin-Obukhov stability parameter (z'/L) was calculated for half-hourly fluxes (N=14999). Daytime periods tended toward unstable conditions, with neutral to weakly stable stratification at night (Fig. 2). In wintertime stability tended toward more neutral conditions (not shown). Roughness length ($z_{0m}$) was determined for near-neutral conditions ($-0.05 \le z'/L \le 0.01$) using the log wind profile with a displacement height of 13 m (N=1828). The overall mean $z_{0m}$ was 1.8 m ($\sigma$=1.1 m). Figure 3 shows these observations by wind direction, for winter (Nov 15 – Mar 15) and summer (May 15 – Aug 31). The peak at 135$^{\circ}$ is likely due to the influence of much taller buildings about 1 km from the tower (Fig. 3).

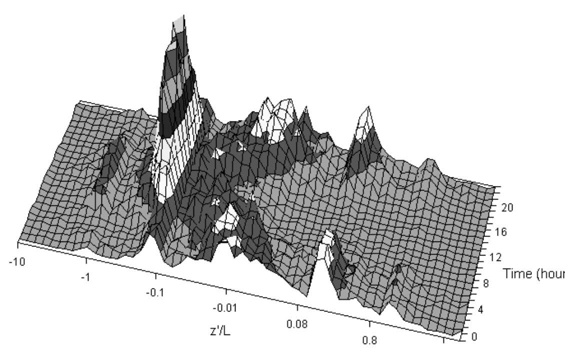


Figure 2: Relative frequency of Monin-Obukhov stability parameter (z'/L) as a function of time of day (not adjusted for seasonal changes in sunrise/sunset). Data were separated into unevenly spaced bins for better resolution near neutral (9 bins between tick marks). Scale limited to $|z'/L| \le 10$.

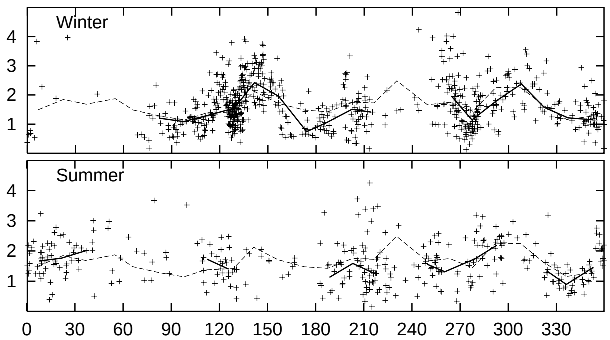


Figure 3: $z_{0m}$ (m) by wind direction and season. The solid line is the seasonal median for 15° bins with a minimum N=10, and the dashed line the annual median.

3.2 *Source area surface characteristics*

The characteristics of the surface are an important control on energy partitioning. For example, Grimmond & Oke (1999a) find vegetative fraction shows a relation with Bowen ratios (β) in different cities. The fractions of surface cover (vegetated, impervious, buildings) have also been used to estimate heat storage (Grimmond & Oke 1999b), which in turn limits the Q* available to drive turbulent fluxes. Further, materials and geometry determine effective albedo and emissivity, and thus Q*, and turbulent exchange is affected by roughness lengths for momentum, heat and water vapor.

To determine the surface fractions of vegetation, buildings, and pavement within the source area, 1:10,000 scale maps (Główny Geodeta Kraju, 1993) were digitized to create a raster GIS ( a 2 x 2 km area centered on the tower). Representative source area weights (90% probability) were determined for neutral, unstable and stable conditions using FSAM (Schmid, 1994). These grids (10 m resolution) were rotated in 30° increments and multiplied by the raster GIS to produce surface cover fractions representative of the three stability conditions. For the neutral case, only 75% of the source area fell within the GIS domain. As the stable case was < 40%, these results are not presented. For unstable conditions, there is little variation in surface cover fraction with direction (Table 1). The influence of the park and other vegetation to the west is evident under neutral stability.

Table 1: Source area surface cover fraction statistics (30° bins). The maximum water cover is less than 0.005.

| | | Mean | Max | Min | SD |
|---|---|---|---|---|---|
| Neutral | Pavement | 0.56 | 0.62 | 0.48 | 0.045 |
| | Buildings | 0.32 | 0.48 | 0.16 | 0.102 |
| | Vegetation | 0.12 | 0.31 | 0.03 | 0.088 |
| Unstable | Pavement | 0.58 | 0.63 | 0.53 | 0.031 |
| | Buildings | 0.35 | 0.43 | 0.27 | 0.053 |
| | Vegetation | 0.08 | 0.16 | 0.04 | 0.039 |

*3.2 Fluxes*

Diurnal patterns in fluxes and daytime partitioning were fairly consistent throughout 2001 (Fig. 4,5 note $Q_E$ was not available until mid-March). $Q_H$ remains positive into the evening, due to release from heat storage (Grimmond and Oke 2002). β peaks during times of little or no rain (e.g. May). Daytime peaks in β are much less pronounced during the summertime, and there is less variance. This may be attributable to the greater role of vegetation (Fig. 4, 5). Daily totals of $Q_H$+$Q_E$ begin to exceed Q* in November, this corresponds to the time of increased heating demand.

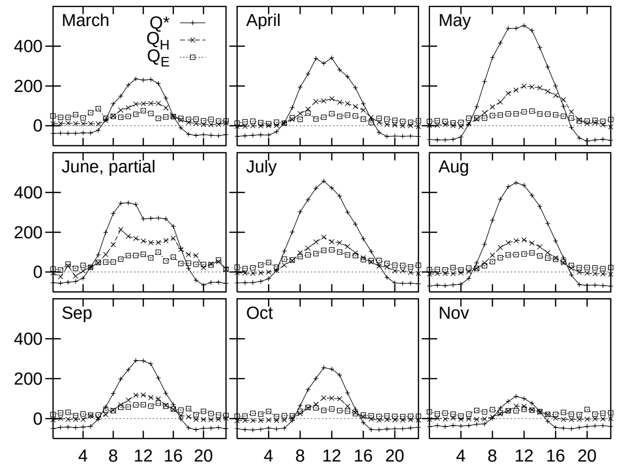


Figure 4: Mean diurnal (local time) fluxes (W m$^{-2}$) by month.

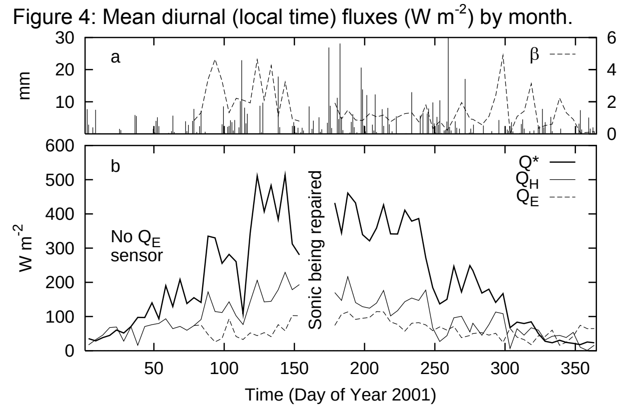


Figure 5: a) Daily precipitation & Bowen ratio b) 5-day mean fluxes for midday hours (10 -16 h local time).

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