J7.4 MEASUREMENTS OF NET RADIATION, GROUND HEAT FLUX AND SURFACE TEMPERATURE IN AN URBAN CANYON

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1. INTRODUCTION

The Joint Urban 2003 (JU2003) field study was conducted in Oklahoma City in July 2003 to collect data to increase our knowledge of dispersion in urban areas. Air motions in and around urban areas are very complicated due to the influence of urban structures on both mechanical and thermal forcing. During JU2003, meteorological instruments were deployed at various locations throughout the urban area to characterize the processes that influence dispersion. Some of the instruments were deployed to characterize urban phenomena, such as boundary layer development. In addition, particular sites were chosen for more concentrated measurements to investigate physical processes in more detail. One such site was an urban street canyon on Park Avenue between Broadway and Robinson Avenues in downtown Oklahoma City.

The urban canyon study was designed to examine the processes that control dispersion within, into and out of the urban canyon. Several towers were deployed in the Park Avenue block, with multiple levels on each tower for observing the wind using sonic anemometers. Infrared thermometers, net radiometers and ground heat flux plates were deployed on two of the towers midway in the canyon to study the thermodynamic effects and to estimate the surface energy balance. We present results from the surface energy balance observations.

2. INSTRUMENTATION

Park Avenue is a two-way street that runs east-west with one lane in each direction, parallel parking and broad sidewalks on both sides. Our sensors were collocated with two towers fielded by the University of Oklahoma. The towers were situated in parking spaces on both sides of Park Avenue. Each tower held five anemometers in a vertical line from 1.5 to 15 meters above the road surface.

We fielded three types of sensors at this location: two ground-heat-flux plates, two net radiometers and six infrared thermocouples.

The ground-heat-flux plates were encapsulated thermopiles (Radiation and Energy Balance Systems, Bellevue, WA). Placement of the plates was difficult in the hardscape of downtown Oklahoma City. There was no possibility to dig the plates under a soil surface. We decided to cover the plates with a rock-less concrete mix that would simulate the existing surfaces in the area. Care was taken to insure that the top and bottom of the plates were in full contact with the concrete matrix. One plate was placed on the base for the tower under a 1.5-cm-thick layer of concrete. The tower bases were large blocks of concrete, 1-meter high and 2-meters in length and width, sufficiently heavy to ballast the 15-meter towers. We did find a crack in the road surface large enough for the other plate. The roadway is estimated to be 10-cm thick.

The net radiometers (model Q6.71, REBS) were recently refurbished and calibrated. Both net radiometers were about 4 meters above the road surface. The downward field of view for the net radiometers was primarily over the asphalt roadbed, and included the north-side sidewalk, the tower base, and both ground-heat-flux plates. The sensors were about one meter apart on a north-south line.

We deployed six model IRTS-P infrared thermocouples (Apogee Instruments, Logan UT). These sensors measure the average temperature of the surface that is in its field of view. For 90% of the signal the full-angle field of view is 39^{o}. Four of these sensors were pointed horizontally at the exterior walls of the buildings along Park Avenue; two to the north, two to the south. All four building sensors were pointed 10 meters above the street level. Two IRTS-P sensors were pointed downward at the road surface.

The ground heat flux plates and net radiometers were connected to a CR10 logger (Campbell Scientific Inc., Logan, UT) recording 1-minute averages. We called this logger the Energy Budget System (EBS). The infrared thermocouples were connected to two CR21X loggers (CSI) that recorded 5-minute averages.

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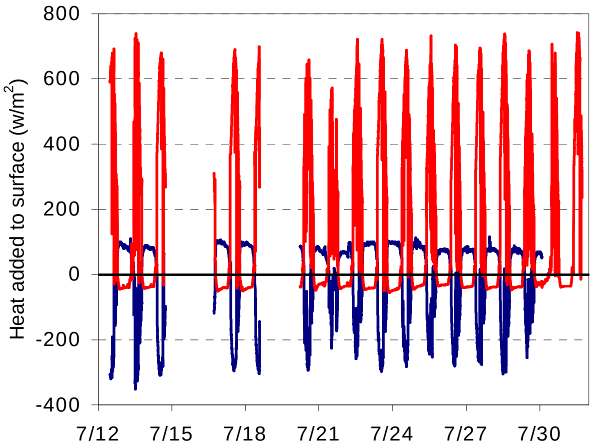

Figure 1: Time series of ground heat flux (blue) and net radiation (red) over the period of high data recovery. Data from only one of each sensor is presented.

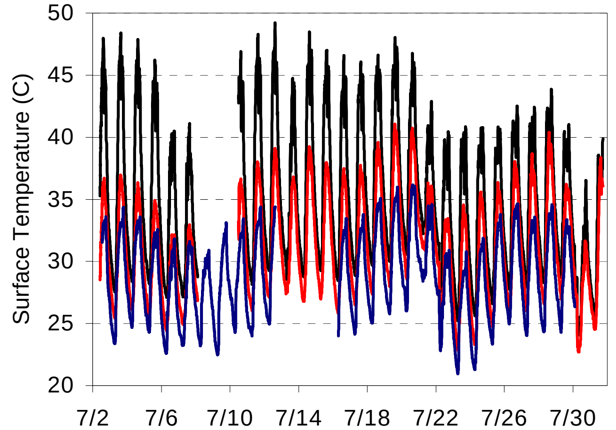

Figure 2: Time series from three of the surface temperature sensors showing one each from the street (black), building to the north (red), and building to the south (blue).

The longer averaging rate was necessary due to the limited memory of the CR21X loggers. All sensors were sampled at 1 Hz.

The EBS was started on 6 July and stopped on 31 July. Battery and download problems for the EBS made for very low data recovery until 12 July. After that date the recovery was 73% for the ground flux plates and 81% for the net radiometers. The two thermocouple systems were more successful returning 89 and 95% of the possible data from 2 July through 31 July.

3. TIME SERIES

Figure 1 shows the time series of ground heat flux and net radiation from representative sensors from the EBS. The days from 12 through 31 July were very similar with few cloudy days, most notably 21 July.

The time series of the thermocouple data appears as Figure 2. This figure shows data from only three of the six sensors we deployed. The other three traces were omitted for clarity.

The IRTS-P thermocouples were very accurate and responsive. Although we did not save the 1-second data from these sensors, we periodically reviewed the samples in real time on a laptop computer. Individual automobiles traversing a sensor's field of view would cause brief decreases or increases in the trace. The negative changes were associated with air-conditioned automobiles; positive changes were associated with cars with no air conditioning. Relatively large negative changes occurred when large refrigerated beverage trucks drove by.

4. DIURNAL AVERAGES

Detailed examination of the time series data shows that there is a strong diurnal pattern to all the energy and temperature traces. The same diurnal pattern is evident every day and even during the few cloudy days with some modification.

Diurnal averages were computed using all data. No attempt was made to exclude incomplete days or times with invalid data from any of the sensors.

Figure 3 shows the diurnal averages for the two ground heat flux plates. Although one was

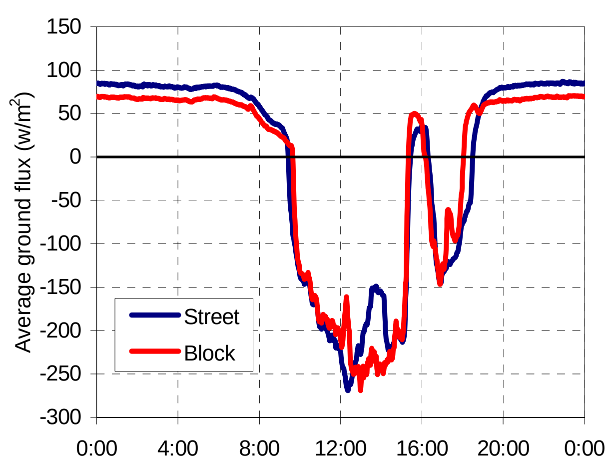

Figure 3: Diurnal average of data from the two ground-heat-flux plates on Park Avenue. One plate was located in the street, the other on the block used to ballast a 15-meter tower.

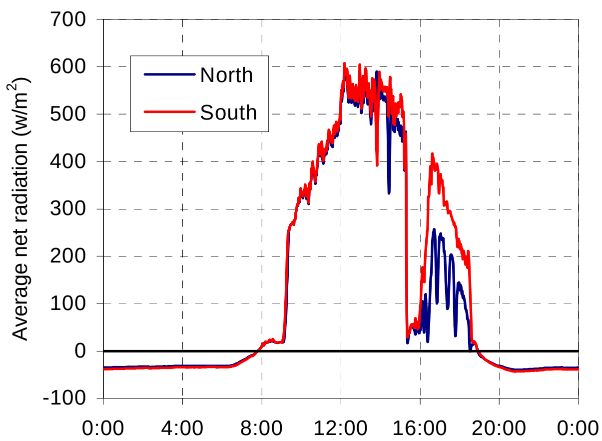

Figure 4: Diurnal average from the two net radiometers. The sensors are about 1-m apart.

installed atop a large block of concrete and the other was in a filled crack in the street, they are both surprisingly similar in shape and magnitude. At about 9:30 AM there is a sudden increase in heat going into the ground. This occurs when the sun is almost in line with the street. Before this sudden increase there is a slow reduction in heat going into the ground that may be due to advection of warm morning air into the street canyon. The series of small variations between 10 and 12 AM are due to shadows of overhead lines. Shading from the buildings on the south side of Park Avenue caused the two large decreases at 2 and 4 PM. The last increase in downward heat flux occurs when the sun's rays come down the street from the west.

At night there is a slight difference of about 10 to 20 w/m^2 between the two sensors. This may be due to the fact that the block is a smaller heat sink than the ground under the street.

The diurnal averages from the two net radiometers (Fig. 4) exhibit some of the same features found in the ground heat flux data. There is a rapid increase solar radiation at 9 AM when the sun strikes the radiometers directly. Since the radiometers are high above the ground heat flux sensors, they receive direct rays from the sun earlier. The sudden and narrow decreases at 1:30 and 2:30 PM are caused by the shade from the same overhead cable. The northern radiometer is in the shadow of the tower in the afternoon.

The surface temperatures also show strong diurnal patterns (Fig. 5). The coolest surfaces we measured are the north-facing exteriors of the building on the south side of Park Avenue. The small increases in temperature of these surfaces just after 8 AM and 7 PM are caused by brief direct exposure to the sun. The temperature of these north-facing surfaces is primarily driven by the ambient air temperature and ventilation in the street canyon, and secondarily by reflection from the opposing wall and street. Although both sensors are pointed at different buildings with different characteristics, the surface temperature is very close in magnitude.

The temperature of the southern exteriors of the northern buildings predominantly responds to the direct rays from the sun. The two sensors are pointed at different buildings, which accounts for the temperature difference of about 3°C in the afternoon.

The proportion of sun and shade within the sensor's field of view affects the temperature of the street surface. We estimate that the thermocouples measure surfaces of about 20 to 30 meter in diameter.

5. RESIDUAL HEAT

Although the environment of Park Avenue is inhomogeneous, we will make an attempt to estimate the energy balance terms using traditional methods,

$$RN + GF = -(H + LE),$$

where *RN* is net radiation, *GF* is ground heat flux, *H* is sensible heat flux, and *LE* is latent heat flux. Figure 6 shows the most representative diurnal averages of the measured terms and the arithmetic residual that represents the sum of sensible and latent heat. The dry surfaces of Park

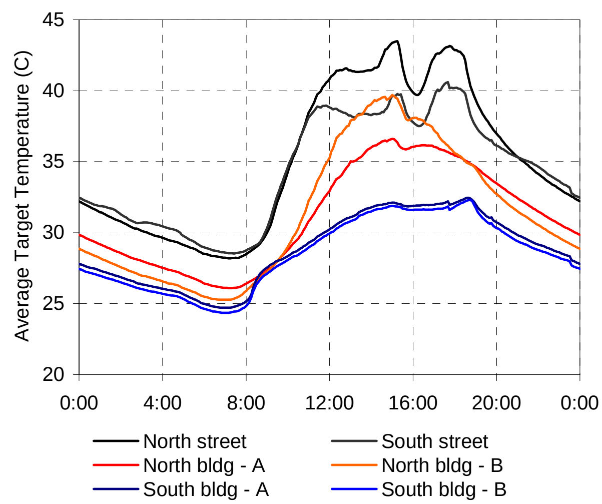

Figure 5: Diurnal averages from the six thermocouple sensors. The north building (bldg) sensors are pointed at the southern-facing exteriors of the buildings north of Park Avenue.

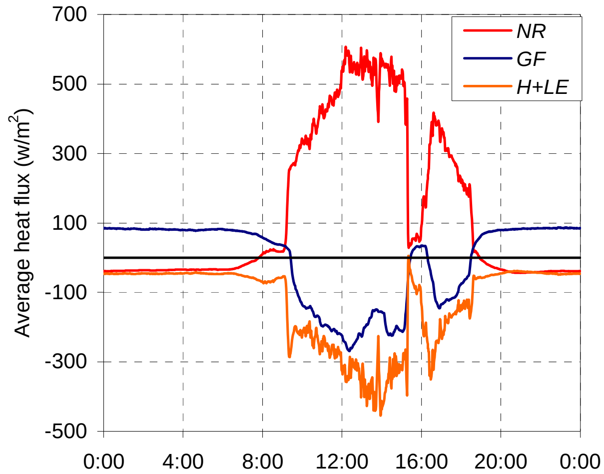

Figure 6: Diurnal averages of the measured terms, *NR* and *GF*, and the computed term (*H+LE*).

Avenue yield very little moisture; therefore sensible heat dominates the residual term.

At night, the residual term is approximately equal to the net radiation. GF is between 80 and 85 w/m^2 and fairly constant throughout the night from 8 PM to almost 8 AM.

6. SUMMARY

These measurements of ground heat flux, net radiation, and surface temperature are unique. Combined with other measurements, they will help us to determine the relative role of thermodynamic forcing in circulation development, turbulence production and dissipation and dispersion in a street canyon. These processes determine the exchange of air and material from within the urban canopy layer and the urban boundary layer above. Ultimately, the increased knowledge will lead to improved atmospheric dispersion modeling by incorporating these processes in the models.

7. ACKNOWLEDGEMENTS

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