THE SUBURBAN ENERGY BALANCE IN SHUNYI, BEIJING CITY

Dou Junxia*, Liu Weidong, Su Chen, Wang Yaoting, Miao Shiguang
Institute of Urban Meteorology, China Meteorological Administration, Beijing 100089

Abstract
This paper discusses the results of measurements of energy balance fluxes for Shunyi, a suburb of Beijing City, conducted from July 2007 to February 2008. Ensemble diurnal patterns and ratio of fluxes for clear sky condition in summer and winter are presented and discussed.

Keywords: Surface energy fluxes, Eddy covariance, Suburb

1. INTRODUCTION
Most study about surface energy flux by using (EC) techniques has been initiated in European and North American cities (Grimmond et al., 1995, 2002a,b, 2004, 2006; Offerle et al., 2005, 2006; Oke et al., 1999). It is rarely done in Chinese cities. However, Beijing city has its distinct architectural styles, building materials, climatic settings and energy use/emission patterns. The aim of this study was to understand the sensible heat, latent heat and momentum exchanges at various locations within Beijing City urban land-cover mosaic. In this paper we report the findings at Shunyi, a suburban location recently impacted by rapid urban sprawl.

2. MATERIALS AND METHODS
2.1. Site description
This study was conducted in Shunyi observatory station (116°37'N, 40°08'E, elevation 28.6 m). Shunyi is part of greater Beijing city, which has experienced tremendous growth in recent years. The fractional land cover of the surface at this suburban site is approximately 52% of vegetated, 36.4% roofs, 11.6% impervious grounds such as roads, sidewalks and driveways.

2.2. Instruments and measurements
The height of the meteorological tower at the observation site is 45 m. The CO2 fluxes, water vapor and sensible heat were quantified using tower-based eddy covariance. The flux measurement system consisted of a fast-response three-dimensional sonic anemometer-thermometer (CSAT3, CAMPBELL, USA) and a fast-response open-path infrared gas analyzer (LI-7500, LI-COR, Inc., Lincoln, NE, USA) for measuring the mean and fluctuating quantities of wind speed and temperature, and CO2 and H2O vapor, respectively. The sensors of eddy fluxes were installed at 36 m above the ground level. The dominant diurnal and nocturnal wind directions above the canopy were North (NNE) both in summer and winter. So, the sensors of eddy fluxes were oriented in the direction of the mean wind on the upwind side of the tower in order to minimize the potential for flow distortion from the tower. In addition, one routine meteorological gradient system was installed on the tower with 5-level air temperature, and relative humidity sensors (HMP45C) with the heights of 4.5, 9, 18, 36, and 42 m. Net radiation was measured with a 4-component method (CM11, KIPP&ZONEN, the Netherlands) at 36 m above the ground. These factors were sampled at 0.5 Hz and the data were stored in the data loggers.

The CO2 fluxes, water vapor and sensible heat were recorded at 10 Hz in two CR5000 data loggers (Model CR5000 and Campbell Scientific) and 30 min mean values were calculated. The affiliated meteorological variables above the ground, including wind speed, air temperature, humidity and net radiation, are all measured simultaneously. The thirty-min average of each factor was also calculated by the data loggers and then stored.

* corresponding author’s address: Institute of Urban Meteorology, No.55, Beiwaxili Road, Haidian District, Beijing, 100089 P. R. China
Since only the net all-wave radiation and turbulent fluxes were measured directly, the storage heat flux (ΔS) was calculated as a residual, assuming both horizontal advection and the anthropogenic heat flux were negligible. These measurements were started since June 2007, and the data for clear sky condition from July 1 2007 to February 20 in 2008 were used in this paper.

3. RESULTS AND DISCUSSION

3.1. Net radiation

The net radiation presented one peak tendency during a day in the summertime, with values ranging weakly in the nighttime (Fig. 1b). After 06:00 AM, the values of net radiation were changed from negative to positive and increased gradually, with the peak of 622.0 W/m² at 12: 30 AM; later, net radiation decreased gradually and approached zero at 18: 30 PM. Moreover, net radiation continued to decrease after 18: 30 PM, associated with values ranged from -55 to -44 W/m².

Although daily variation of net radiation for clear sky conditions in wintertime was similar to that for summertime (Fig. 1a), net radiation is only positive during the period from 09:00 AM to 17:00 PM, with a maximum value of 227.5 W/m² occurring at 13:00 PM. Moreover, daytime values of net radiation in wintertime was generally 200-400 W/m² lower than those in summertime. Net radiation was also characterized by a weak range in the nighttime, with values mainly remaining around -55 W/m² in the winter.

Mean daytime values were 378.5 and 160.9 W/m², respectively for the summer and winter. Mean daily values were 155.8 for summer and 16.1 W/m² for winter, respectively (Figure1, Table.1).

3.2. Latent and Sensible Heat Fluxes

The mean ensemble daytime values of latent heat flux reached a maximum of 215 W/m², occurring at the same time as the net radiation (12:30 AM) in the summer. Moreover, latent heat flux was always positive in summer, with a mean nighttime value of 26.9 W/m². Although latent heat fluxes were almost above zero in winter, the greatest value was only 22.5 W/m² due to vegetation dormancy. Values of latent heat flux mainly ranged from 0 to 2 W/m² during nighttime in winter (Figure1, Table 1).

Sensible heat flux presented one peak tendency during a day both in the summer and winter, although the maximum value of sensible heat flux was occurring earlier for summer and later for winter than that of net radiation,
respectively. The mean ensemble daytime values reached a maximum of 166.8 and 161.7 W/m² for summer and winter respectively. It was for both summer and winter that sensible heat flux were negative in the nighttime in Shunyi station, with mean values of -8.2 and -9.2 W/m² respectively. This result was different from that surface energy flux observations of central business district in European or North American cities (Grimmond et al., 1995, 2006; Offerle et al., 2006).

3.3. Energy partition

During the clear sky conditions in summer, $\Delta S$ absorbed 44% (daytime) and 29% (daily) of the net radiation, respectively. The fraction of net radiation used to latent heat was 36% (daytime) and 51% (daily), respectively. Sensible heat accounted for 20% (daytime) and 21% (daily) of net radiation respectively (Table 1).

The partitioning of net radiation for winter showed that the fraction of net radiation convected away as sensible heat was the greatest, with the values of 60% (daytime) and 149% (daily) respectively. Latent heat accounted for 9% (daytime) and 34% (daily) of the net radiation. $\Delta S$ occupied 31% of the net radiation for the daytime, while daily fraction was -82% due to effects of underlying surface releasing heat in the nighttime.

The mean daytime and daily Bowen ratio values are 0.56 and 0.41, and 6.70 and 4.43 respectively for the summer and winter, which indicated that available energy partitioning was dominated by latent heat in summer but sensible heat in winter respectively.

Table1 Daytime and daily mean values of energy fluxes and mean ratios of energy fluxes normalized by the net radiation

<table>
<thead>
<tr>
<th></th>
<th>Rn</th>
<th>LE</th>
<th>H</th>
<th>S</th>
<th>LE/Rn</th>
<th>H/Rn</th>
<th>S/Rn</th>
<th>H/LE</th>
<th>(H+LE)/Rn</th>
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</thead>
<tbody>
<tr>
<td>Daytime</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Summer</td>
<td>378.5</td>
<td>135.7</td>
<td>76.0</td>
<td>166.8</td>
<td>0.36</td>
<td>0.20</td>
<td>0.44</td>
<td>0.56</td>
<td>0.56</td>
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<tr>
<td>Winter</td>
<td>160.9</td>
<td>14.5</td>
<td>96.9</td>
<td>49.5</td>
<td>0.09</td>
<td>0.60</td>
<td>0.31</td>
<td>6.70</td>
<td>0.69</td>
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<tr>
<td>Daily</td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>155.8</td>
<td>79.2</td>
<td>32.2</td>
<td>44.5</td>
<td>0.51</td>
<td>0.21</td>
<td>0.29</td>
<td>0.41</td>
<td>0.71</td>
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<tr>
<td>Winter</td>
<td>16.1</td>
<td>5.4</td>
<td>24.0</td>
<td>13.3</td>
<td>0.34</td>
<td>1.49</td>
<td>-0.82</td>
<td>4.43</td>
<td>1.82</td>
</tr>
</tbody>
</table>

4. CONCLUSION

Energy partitioning was dominated by latent heat in summer but sensible heat in winter, the mean daytime and daily Bowen ratio values are 0.56 and 0.41, and 6.70 and 4.43 respectively for the summer and winter. The fraction of net radiation used to latent heat was 36% (daytime) and 51% (daily), to heat storage was 44% (daytime) and 29% (daily), to sensible heat was 20% (daytime) and 21% (daily) respectively in summer. These fraction values about sensible heat are lower than the values reported for some suburban areas in North America.

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References


