Hindawi
Geofluids
Volume 2021, Article ID 2023393, 12 pages
https://doi.org/10.1155/2021/2023393

Research Article

Latent Heat Flux (Evapotranspiration) in Summer Season on Rooftop Greening Soil with Bamboo Charcoal Sublayer at a Building in West Japan

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Received 16 April 2021; Revised 16 June 2021; Accepted 28 June 2021; Published 23 July 2021

Academic Editor: Xudong Zhang

The effect of a thin and light greening system with bamboo charcoal layer for water retention on heat fluxes, in particular latent heat flux (evapotranspiration rate), under no irrigation condition, on the rooftop of a building in Higashi-Hiroshima, West Japan, was investigated. In April 2019, lawn seeds (Zoysia tenuifolia) were sown which were germinated, reached a height of 70 mm by May when 100% of the vegetation area was covered. The air temperature and humidity at two different heights (0.3 m and 1.8 m) above greening soil surface, latent, and sensible heat fluxes were estimated. Bowen ratio was employed to collect the data on surface heat balance and soil water content during the summer season (June to September) in 2019 on the rooftop of a building in Higashi-Hiroshima, West Japan. The latent heat during daytime for a week without rainfall in each month was compared with the evapotranspiration rate. Owning to the vegetation development, the ground heat flux on greening soil surface decreased from -400 W/m^2 to -200 W/m^2 (flux from air to soil) during sunny daytime in July, and it was less than -100 W/m^2 in August, although net radiation was maintained around 800 W/m^2 over the season except in September. The monthly net radiation flux for an entire day (daytime and nighttime) ranged between 55 and 125 W/m^2 (average: 95 W/m^2) for the summer season of which 32-66% (average: 48%) was occupied by latent heat. Evapotranspiration from greening soil ranged between 1.24 and 1.82 mm/day, averaged at 1.51 mm/day throughout the season, which corresponded to about 26% of total rainfall over the season ($r^2 = 0.88$, $p < 0.01$; S.E = 0.06) between the estimated and measured values. These observations suggested that the thin and bamboo coal light soil layer greening system, even without constant irrigation, could maintain the development of lawn grass and transformed more than half of net radiation to latent heat, i.e., evapotranspiration, insulating most ground heat in midsummer, which may be mostly due to bamboo charcoal sublayer.

1. Introduction

With the rapid development of urbanization, more than half of the world's population live in cities [1]. According to a report by the Intergovernmental Panel on Climate Change of 2014, human activities are almost certainly the cause of global warming [2]. The heat island phenomenon, accelerated by global warming, has become a serious problem in major cities around the world, recently [3, 4]. It is particularly severe in the metropolitan area of Tokyo in Japan [5]. Natural greening systems such as growing grass and plants on rooftops can convert the heat into latent heat (evapotranspiration). It is one of the attractive ways to reduce heat island phenomena and can also contribute to a substantial reduction in electric power consumption to cool the house in urban areas [6–11].

However, the hot air temperatures during summer months are harsh on plants on rooftops [8, 12]. The weight load restriction on rooftops also prevents the addition of thick layer of soil to grow vegetation [13, 14]. Since there is no water retention, the soil on rooftops tends to dry out, and this requires frequent watering to take care of the plants

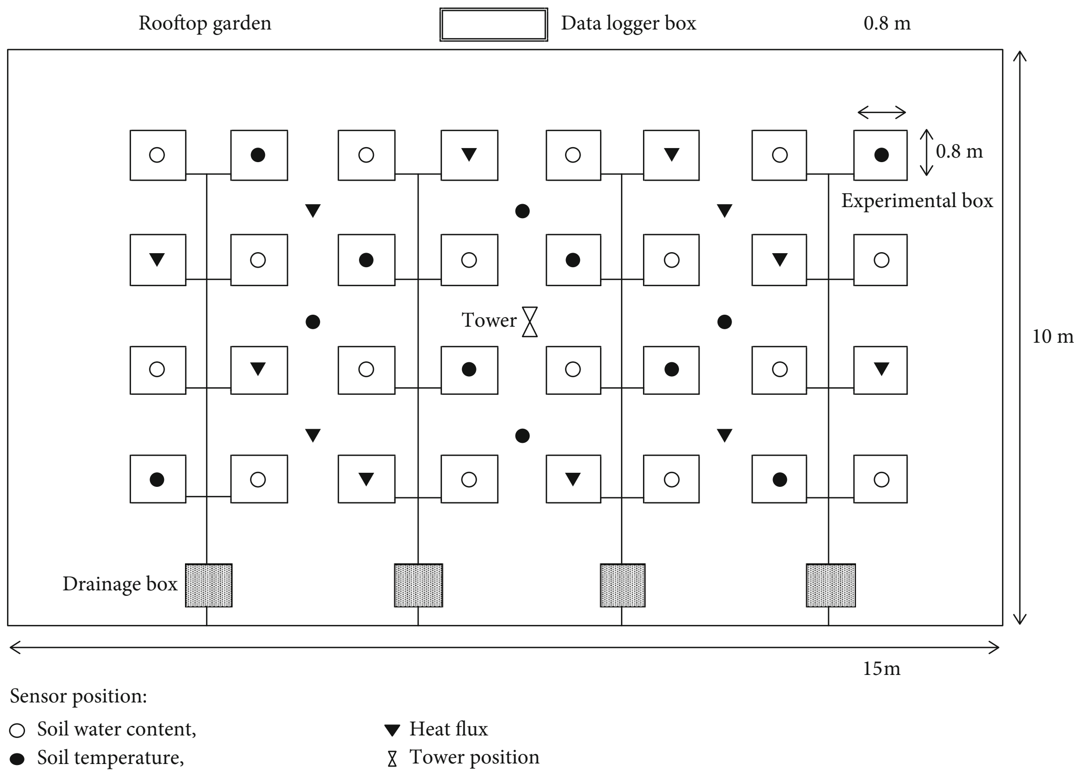

Figure 1: Arrangement of thirty-two experimental boxes (0.8 m × 0.8 m) and position of sensors (soil water content, soil temperature, and ground heat flux) and tower for measuring solar radiation, air temperature, and humidity on the rooftop greening system (10 m × 15 m).

during summer months and dry seasons [15, 16]. The type of soil, plant species and vegetation depth for water retention (hydrological performance), thermal/heat insulation efficiency, etc., are known to affect the rate of water loss, shading, and the subsequent cooling effect. All these play a role in controlling the microclimate on rooftop greening systems to balance the heat transfer [17–21].

There are so many types of rooftop greening systems. Coutts et al. [22] indicated that the function for controlling rooftop surface energy (heat) balance, i.e., rooftop microclimate, may depend on hydrological performance, for instance, substrate type and depth (i.e., water retention capacity and heat or thermal insulation efficiency) [8, 22–24] and plant species or vegetation type [16, 25], which affects not only the rate of water loss from green roofs through transpiration and the subsequent cooling effect but also shading on roof surface.

It is useful to examine the effectiveness of a different, thin, and light rooftop greening system to mitigate the heat on rooftops in summer season. In this study, we have tested a novel greening system on rooftops which has the potential to resolve the problems mentioned above. It is based on reusable and lightweight material for water retention, viz., bamboo charcoal as a substitute for soil. Compared with other types of charcoal (such as wood and activated charcoals), bamboo charcoal has higher water retention capacity, retains more water, and releases it slowly [17, 18]. Thus, even a thin layer of such greening system can promote better growth of most plants [19] and effectively control soil temperature and surface heat flux [20, 21]. Hence, we tested a charcoal-based greening system to grow vegetation on the rooftop of a building in Hiroshima, Japan, and the evapotranspiration rate (latent heat flux without watering) during summer season was estimated.

2. Materials and Methods

2.1. Study Site and Rooftop Greening System. The study was carried out from February to September (a warm-temperate moist season), using the rooftop of the five-storied building of Graduate School of Biosphere Science, Hiroshima University, in Higashi-Hiroshima, Hiroshima Prefecture, West Japan, which is known as a warm-temperate and moist zone. A sectional schematic diagram of the experimental set-up and all the measurements made are indicated in Figures 1–3. The 10 m × 15 m rooftop area was covered with lightweight plastic board (TECO form). Thirty-two bottomless boxes (16 experimental and 16 control), each measuring 0.8 × 0.8 × 0.2 m height, were placed on the plastic board and sealed tightly using a sealing bond to prevent water loss from the boxes. In the bottom of each box, a 5 cm thick bamboo charcoal layer was built in the center of the boxes in March to measure air temperature and humidity and to monitor solar radiation, as shown in Figure 3. The average temperature and precipitation were 14.0°C and 1,690 mm, respectively, which were near the average values of the preceding decade.

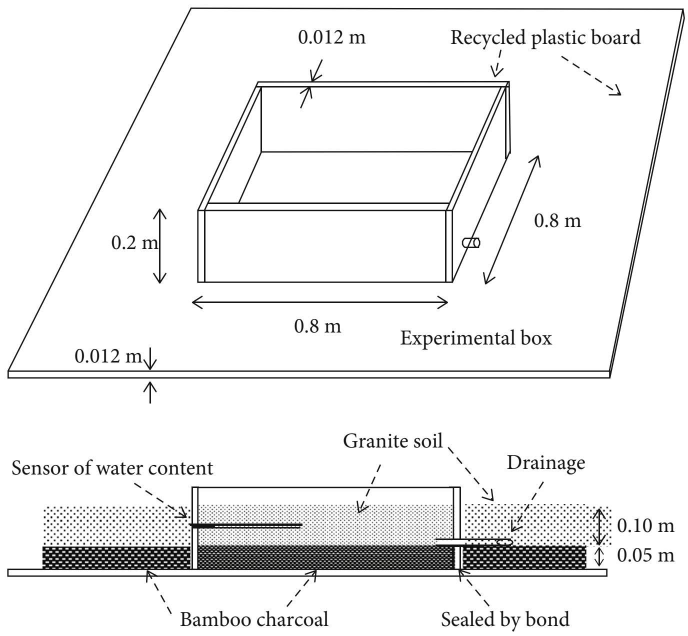

Figure 2: Cross-sectional schematic diagram of greening system. A plastic board (brand name: TECO form) was used for the bottom plate, on which was placed a 5 cm bamboo charcoal sublayer for water retention, followed by a 10 cm layer of soil (well weathering granite). Lawn grass seeds (Zoysia tenuifolia) were sowed on the soil two months before starting the measurement.

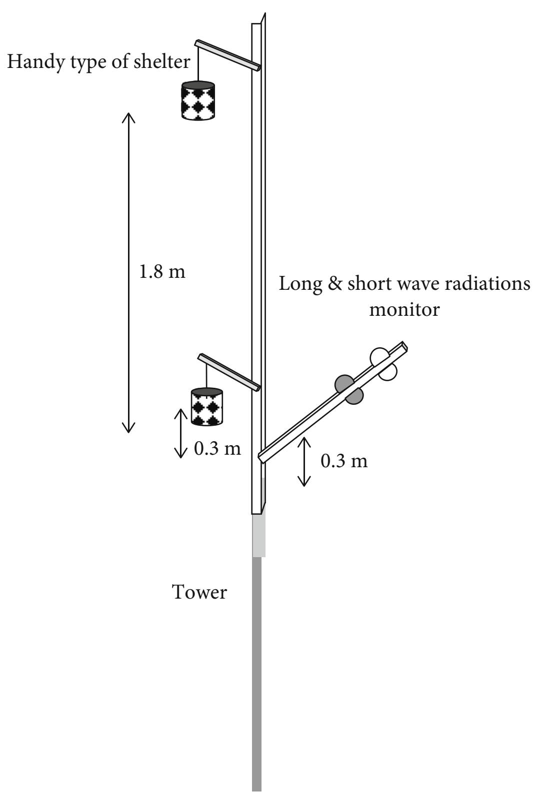

Figure 3: Schematic diagram of the tower (height: 2 m) built up at the central position of rooftop garden for measuring air temperature and humidity and monitoring up- and downwards of short- and long-wave solar radiation.

2.2. Methods

2.2.1. Vegetation Census. The charcoal and the soil in experimental boxes were dried at 70°C for a week and then covered with vinyl sheets until late March. The same in control boxes were left undried. In April, lawn seeds (Zoysia tenuifolia) were sown in both experimental and control boxes. The experimental boxes were watered only for the first two months while control boxes were watered as in normal routine practice. Every month (from June to September 2019), the area of lawn development (%) and growth/height of the grass (m) were measured at 10 different points in each box to obtain average values. The grass biomass index was calculated by the coverage $(\%) \times \text{height}\,(\text{mm})$ for each box and then the average in experimental and control boxes.

2.2.2. Measurement of Temperature, Moisture, Heat Flux and Radiation, and Precipitation. The details of parameters for microclimate measurements on the rooftop greening, including the instruments, location, and sensor points mentioned above, are given in Table 1. The details of parameters for microclimate measurements on the rooftop greening, including the instruments, location, and sensor points mentioned above, are given in Table 1. The following measurements were made to evaluate the usefulness of light weight bamboo charcoal soil in experimental boxes (compared with control boxes) for rooftop greening system. The temperature and ground heat fluxes out on the surface and inside at 5 cm depth of sixteen points of greening soil were measured using a thermometer (TR-81/Pt-100, T&D Co.) and a heat flow meter (MP-75/MF1810M, EKO Co.), respectively (Figure 1). The water content in the soil was measured at 5 cm depth by TDR (C-CS-615, CLIMATEC Co.) (Figure 1). The temperature and

Table 1: Temperature, humidity (water content), heat flux, and solar radiation measurement parameters.

Element	Measuring equipment	Location	Point	Output interval
Temperature in air lagoon	TR-72U, T&D Co.	0.3 and 1.8 m height above	30 minutes	Greening soil surface 1
Humidity in air	TR-72U, T&D Co.	0.3 and 1.8 m height above	30 minutes	Greening soil surface 1
Soil temperature	TR-81/Pt-100, T&D Co.	On the surface and 5 cm depth	30 minutes	Greening soil in boxes 8 Out of boxes 8
Oil water content	C-CS-615, CLIMATEC Co.	At 5 cm depth of greening soil	60 minutes	In boxes 16 Out of boxes 4
Ground heat flux	MP-75/MF1810M, EKO Co.	On the surface of greening soil	10 minutes	In boxes 8 Out of boxes 8
Radiation (up- and downwards, short and long waves)	MR-50, EKO Co.	0.3 m height above greening soil	1 minute 10 minutes	

relative moisture content were measured (TR-72U, T&D Co.) both at 0.3 m and 1.8 m above the greening soil surface along the tower (Figure 3). Short and long waves of solar radiation up- and downwards were monitored at 0.3 m above greening soil surface (MR-50, EKO Co.) (Figure 3). The temperature in the soil and air and humidity (water content) were recorded at 30-minute intervals and radiation and heat flux at 10-minute intervals from June to September 2019. The relationship between sensor and actual values of soil water content was obtained by pumping water gradually into the dried up soil and charcoal in each box in February but shutting out rainfall (Figure 4). Calibration curves for soil water content in each box were made and used to estimate the evapotranspiration rate for a week with no rainfall in each month. The average of evapotranspiration rate of sixteen boxes was determined each week.

The average of the measured values at all points in experimental boxes compared with control boxes was determined and reported here. The precipitation values reported here were taken from the meteorological station in Hiroshima University campus.

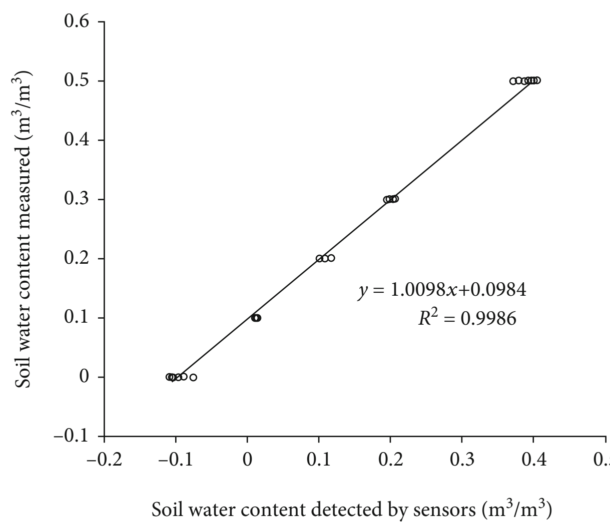

Figure 4: The examples of the relationship between soil water content measured directly and detected by sensor. The calibration was conducted for each box, i.e., each sensor.

2.2.3. Estimation of Latent Heat (Evapotranspiration) by Bowen Ratio. The latent heat, i.e., evapotranspiration, was estimated by Bowen ratio [26] based on the data of net radiation and ground heat flux on the greening soil as follows:

The net radiation (Rn) is described as

$$\mathrm{Rn} = ((\mathrm{SW}\downarrow) + (\mathrm{LW}\downarrow)) - ((\mathrm{SW}\uparrow) + (\mathrm{LW}\uparrow)), \quad (1)$$

where SW and LW are short and long waves and arrows $(\downarrow, \uparrow)$ are down- and upward waves, respectively. Rn is also described as

$$\mathrm{Rn} = G + H + lE. \quad (2)$$

Thus,

$$H + lE = \mathrm{Rn} - G, \quad (3)$$

where G is ground heat flux (from air into greening soil), H is sensible heat, and lE is latent heat fluxes from soil to air.

When Bowen ratio $(\beta : H/lE)$ is obtained, each H and lE can be estimated as

$$H = \beta \frac{(\mathrm{Rn} - G)}{(1 + \beta)}, \quad (4)$$

$$lE = \frac{(\mathrm{Rn} - G)}{(1 + \beta)}. \quad (5)$$

Bowen ratio (β) is derived from following equations

$$\beta = \gamma \frac{(T_h - T_l)}{(P_h - P_l)}, \quad (6)$$

where T_h and T_l and P_h and P_l are air temperature (°C) and water vapor pressure (P : mb) at high ($_h$) and low ($_l$) position above greening soil surface, respectively. γ is a parameter (=0.67 mb °C^{-1}).

Water vapor pressure (P) at each height level is obtained as

$$P = \frac{\mathrm{RH} \times \mathrm{PS}}{100}, \tag{7}$$

$$\begin{aligned} \mathrm{Log}_{10}\mathrm{PS} = {} & 10.79574\left(1 - \left(\frac{T_i}{T}\right)\right) - 5.02800 \times \log_{10}\left(\frac{T}{T_i}\right) \\ & + 1.50475 \times 10^{-4}\left(1 - 10^{-8.2969(T/Ti)}\right) \\ & + 0.42837 \times 10^{-3}\left(10^{4.76955(1-Ti/T)} - 1\right) \\ & + 0.78614, \end{aligned} \tag{8}$$

where PS is saturated water vapor pressure (mb), RH is relative air humidity (%), and $T_i = 273.16(K)$ and $T = +273.15(K)$.

The Bowen ratio was calculated at 30-minte interval throughout the season. The mean values of radiation and heat flux data during 30 minutes, which were originally obtained at 10-minute intervals, were calculated and employed. The latent heat flux (100 W/day) was converted in terms of evapotranspiration (3.53 mm/day) based on $l(\text{latent heat} : \text{MJ/kg}) = 2.5 - 0.0024t$, where t is air temperature (°C). The fluxes of G, H, and lE from soil to air are represented as plus (+), and from air to soil are done as minus (-) in this paper.

3. Results and Discussion

3.1. Vegetation Development. The lawn seeds started to germinate two or three weeks after sowing seeds in early of April and covered with 20% of greening surface and grew up to 10 mm in height by middle of June. By the middle of August, 100% of the lawn was covered and grew 70 mm height (Figure 5). The grass biomass index expressed as coverage × height increased exponentially from June to July and reached maximum level in August (Figure 6) indicating a logarithmic growth of the lawn grass and also suggested that greening of lawn grass was complete in July or August. There were no significant differences between experimental and control boxes despite the initial drying and watered only for the first two months.

3.2. Air Temperature and Humidity. Figure 7 shows the change in air temperature and relative humidity at 1.8 m height above the greening soil surface from June to September. The air temperature increased from June to August and decreased in September. Except on rainy days, the daily temperature fluctuation was between 15 and 20°C; it rapidly increased during the daytime and fell at nighttime. The maximum air temperature on sunny days is around 30°C in June and September, 35°C in July, and >35°C in August. At nighttime, the humidity was increased to nearly 100% in all months except in rainy days. Similar changes in temperature and fluctuations in humidity on a thin rooftop garden in the summer in Tokyo were reported by Yamaguchi et al. [27].

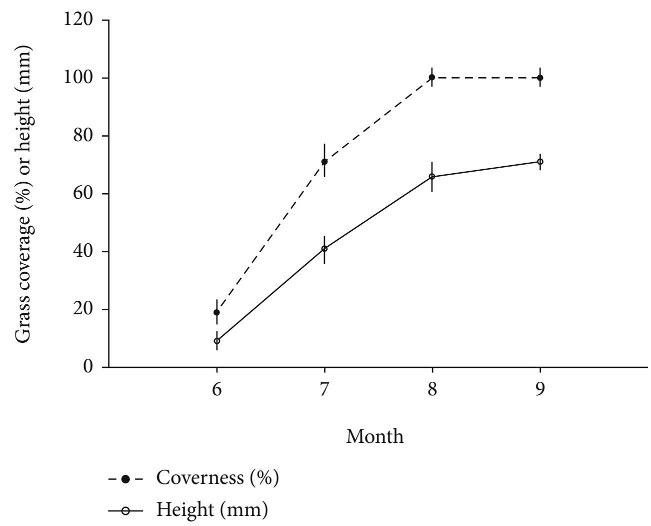

Figure 5: Change in the coverage (%) and height (mm) of lawn grass during summer season. Bar: standard deviation (S.D.).

3.3. Soil Temperature and Water Content. Temperatures at the surface and at 5 cm depth showed similar changes, i.e., the daily fluctuation in temperature was larger on soil surface than at 5 cm depth, particularly on sunny days in June (Figure 8). Larger daily fluctuation of soil temperature in June might have been caused by the slower development of lawn grass. Soil surface temperature reached around 40°C in the daytime in sunny days in midsummer while the temperature at 5 cm depth remained around 35°C suggesting that temperature at 5 cm depth is always near to air temperature in daytime and night time through the season.

Figure 9 shows the change in mean soil water content from June to September, measured in sixteen experimental boxes by a lysimeter. After heavy rainfalls, e.g., in late of June or early of August (Figure 10), soil water content increased and arrived at around 0.45 m^3/m^3, which is nearly maximum water holding capacity (0.5 m^3/m^3). The soil water content thereafter decreased gradually to 0.15 m^3/m^3 in the middle of July or August due to little or no rainfall in the later weeks. The soil water content was very sensitive to rainfall. Therefore, the peak soil water content was recorded just after the rainfall (Figure 10). The minimum value (0.15 m^3/m^3) of soil water content over the season was sufficient for most planted species to maintain growth on rooftop garden in Japan and other warm-temperate climate zones [19, 28].

The total precipitation over the seasoning was 720 mm which is near to the average (670 mm) for the preceding decade. Precipitation pattern over the season in 2019 was also similar to the usual one for the decade except during heavy rainfall in early August indicating that the soil water over the summer season was less than the average for the decade.

3.4. Net Radiation (Rn) and Ground Heat Flux (G). The net solar radiation (Rn) reached to around 800 W/m^2 during daytime on sunny days from June to August to 600 W/m^2 in September. However, Rn in rainy days was less than 300 W/m^2 even in daytime from June to August and 200 W/m^2 in September, as shown in Figure 11. The Rn was minus (-50 to

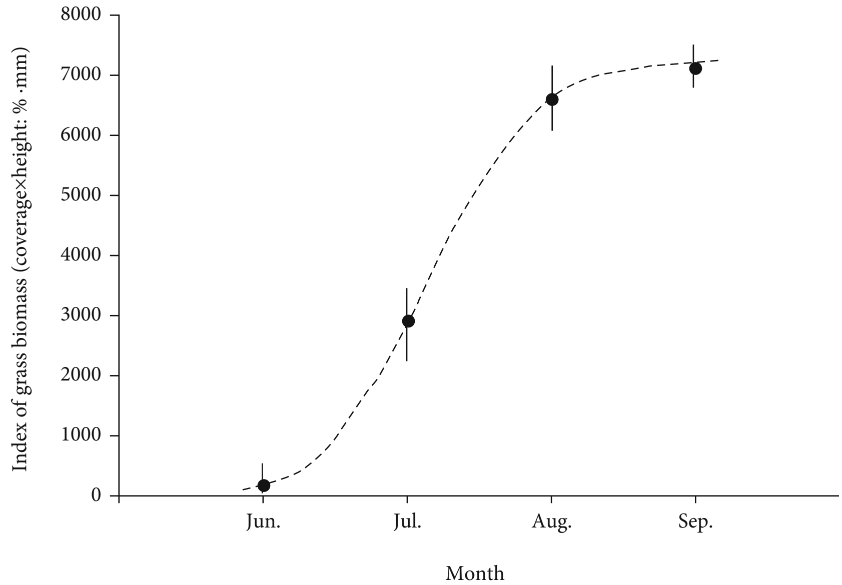

Figure 6: Development of index of grass biomass (coverage × height, % mm) during summer season. Bar: standard deviation (S.D.).

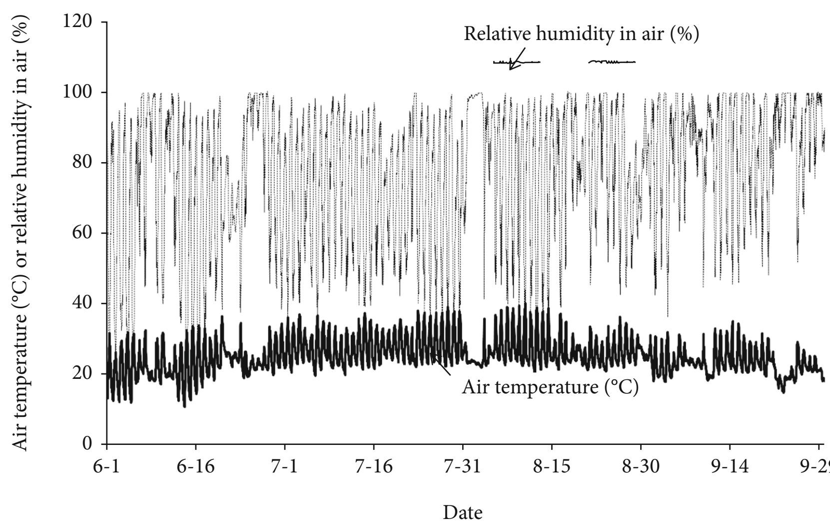

Figure 7: Change in air temperature (°C) and relative humidity (%) during summer season observed at 1.8 m height of the tower above greening soil surface.

-100 W/m^2) at nighttime on sunny or cloudy days throughout the summer season, suggesting that the radiation output from greening soil to air became lager than the input from air to soil, due to no sunshine (Figure 11). These Rn values observed over the summer season were similar to those reported earlier on rooftop gardens in the temperate climate zone [22, 27].

The ground heat flux (G), which is represented as minus (-) in the case of flux from air to soil, reached around or more than -300 W/m^2 during daytime on sunny days from June to early July owing to the strong net radiation, but the later (mid of July to September) G flux diminished to less than -100 W/m^2 during daytime even on sunny days (Figure 11). This might have been caused by the development of lawn grass (Figures 5 and 6). Vegetation cover can insulate of Rn and shade the soil surface of rooftop greening. Thus, the G was decreased more on rooftop greening soil than on rooftop without vegetation cover [22, 27, 29].

3.5. Sensible Heat Fluxes (H) and Latent Heat (lE) Estimated by Bowen Ratio. Sensible heat fluxes (H) and latent heat fluxes (lE) estimated by Bowen ratio for a week without rainfall in each month are shown with net radiation (Rn) and ground heat (G) in Figures 11–14. The balance between Rn (net radiation) and G (ground heat), i.e. H (sensible heat) + lE (latent heat), as indicated by Eq. (3), in daytime on sunny or cloudy days occupied about the half of Rn in June to early of July. However, the occupation of $H + lE$ in Rn increased the later (from mid-July to September), owing to the decrease occupation of G in Rn with development of the lawn grass.

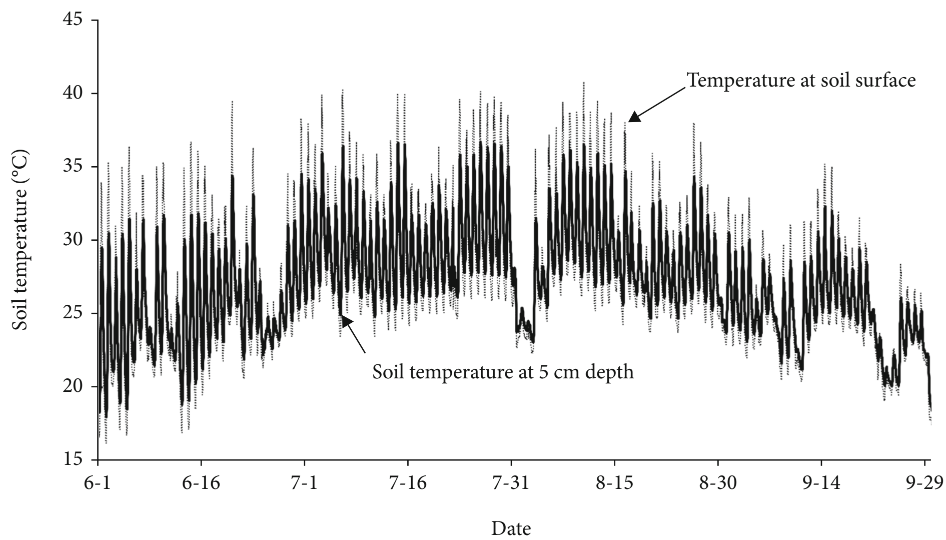

Figure 8: Change in temperatures at soil surface and 5 cm depth during summer season.

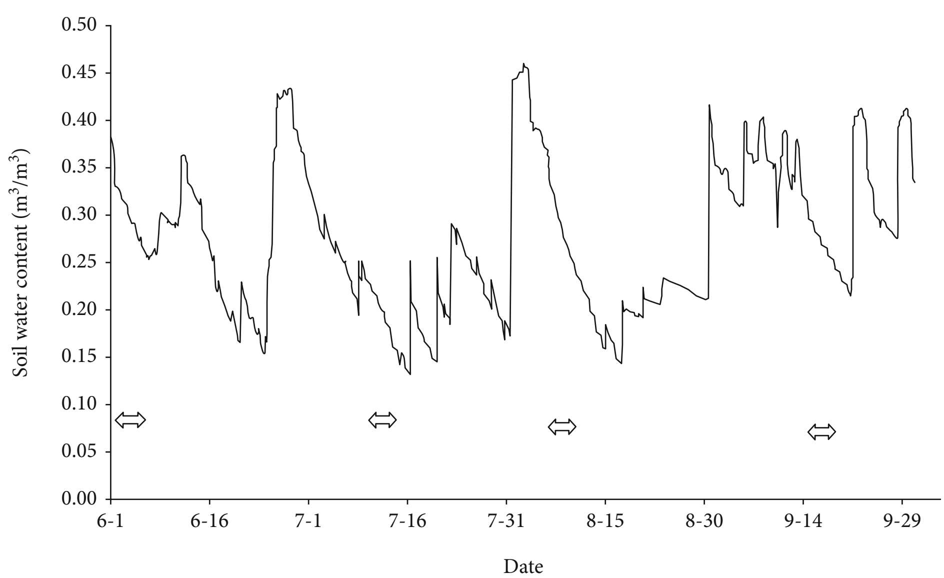

Figure 9: Change in averaged soil water content observed at one hour interval during summer season. Arrows: periods of measuring and estimated evapotranspiration during the week without rainfall in each month.

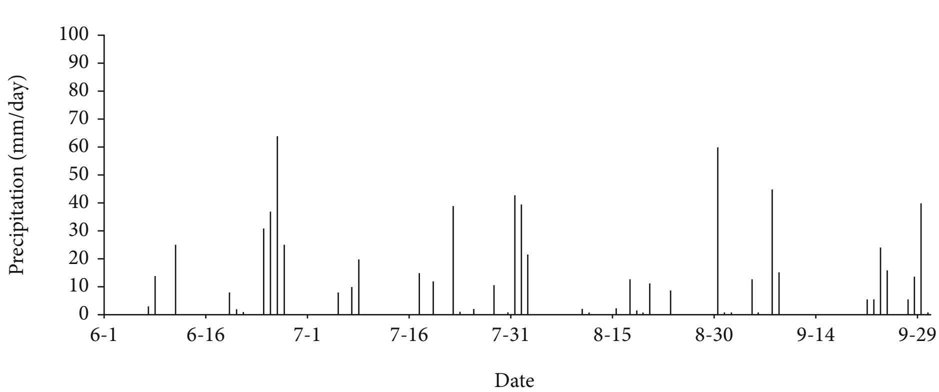

Figure 10: Precipitation (mm/day) during summer season.

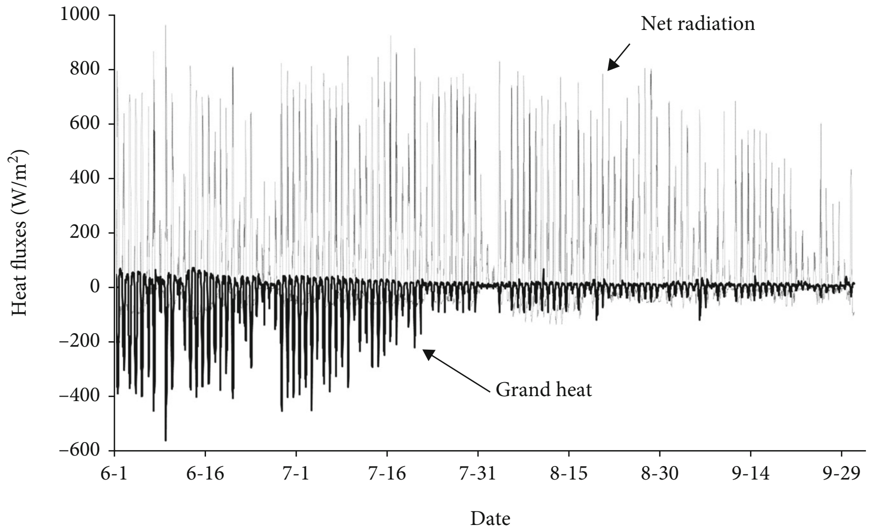

Figure 11: Net radiation (Rn) and ground heat flux (G) during summer season. The flux (G) from air into soil is represented as negative (-).

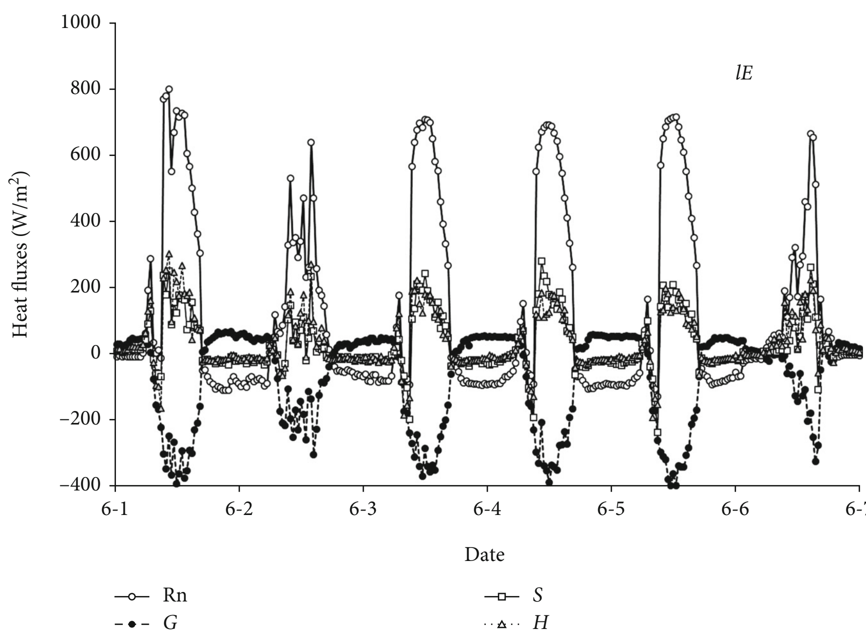

Figure 12: Fluxes of net radiation (Rn), ground heat (G), latent heat (lE), and sensible heat (H) during the week without rainfall in June 1-6th. lE and H were estimated by Bowen ratio.

Each H (sensible heat) and lE (latent heat) during daytime occupied about 1/4 of Rn (net radiation) in June, 1/3 of Rn in July, and 1/2 of Rn in August and September, respectively. Thus, there was a small difference between lE and H during daytime throughout the season, but lE was somewhat larger than H in August to September, which may be due to the development of the lawn grass. There were reports indicating relatively higher ratio (73%) of lE to Rn during daytime on sunny day in midsummer than that observed (ca. 50-60%) in this study [27]. The difference may be due to the lack of irrigation on greening soil except rainfall through the summer season in this study. Coutts et al. [22] reported increase in latent heat flux from around 100 W/m^2 to more than 200 W/m^2 just after irrigation on an experimental vegetated roof. Matsushita et al. [30] also reported that the maximum latent heat during daytime decreased from 500 W/m^2 to 300 W/m^2 on four sunny days after the last rainfall at the rooftop greening (Hedera herix) at 20 cm depth soil substrate. The reason for the differences in greening system in this study and others mentioned above could be due to maintenance of vegetation growth and considerable latent heat flux (evapotranspiration), even without irrigation and also due to the function of bamboo charcoal sublayer acting as the higher soil water retention agent [18].

Both H and lE were very low (nearly zero) in nighttime through the season except for August, when lE was

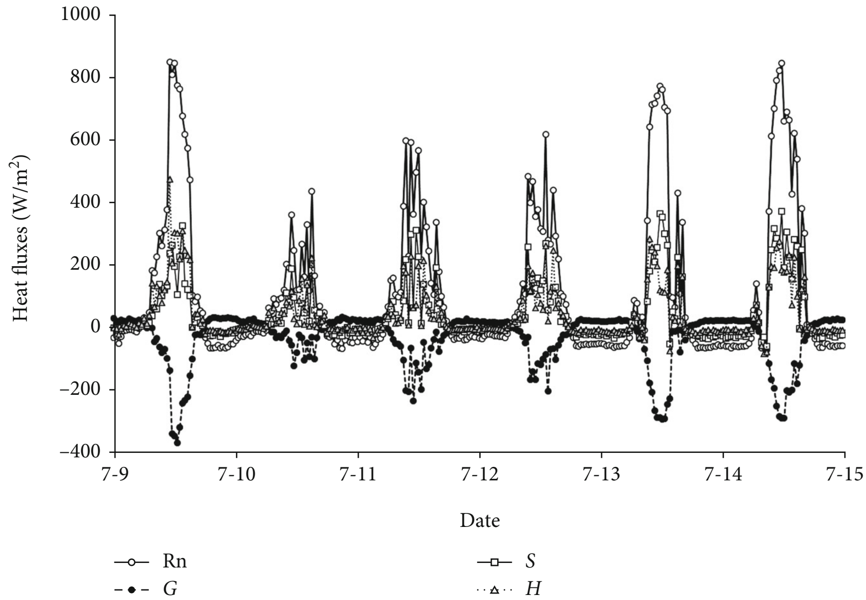

Figure 13: Fluxes of net radiation (Rn), ground heat (*G*), latent heat (*lE*), and sensible heat (*H*) during the week without rainfall in July 9-14th. *lE* and *H* were estimated by Bowen ratio.

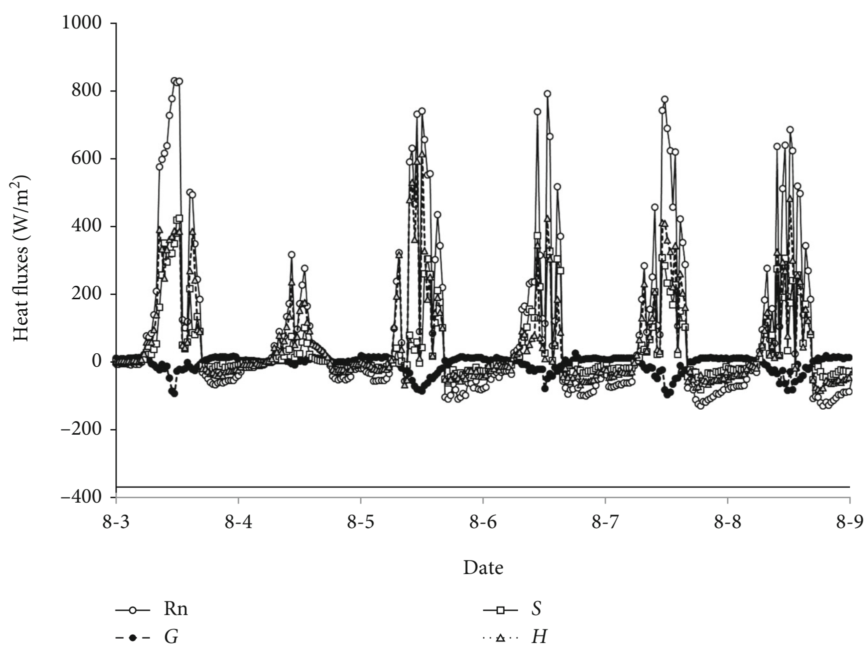

Figure 14: Fluxes of net radiation (Rn), ground heat (*G*), latent heat (*lE*), and sensible heat (*H*) during the week without rainfall in August 3-9th. *lE* and *H* were estimated by Bowen ratio.

minus (below zero, i.e., flux from soil to air) which may cause the dew to drop from air to soil and vegetation surfaces (Figure 13).

3.6. Relation between Latent Heat Fluxes (lE: Evapotranspiration Rate) Estimated and Measured. The relationship between latent heat flux (*lE*), i.e., evapotranspiration rate (mm/day), estimated by Bowen ratio and measured directly by the boxes by the lysimeter for each daytime (6:00 AM–6:00 PM) in the week without rainfall in each month throughout the season is presented in Figure 15. The regression relationship between evapotranspiration rates estimated and measured was significant (ANCOVA; $r^2 = 0.88$, $p < 0.01$). The error, i.e., difference between *lE* estimated and measured, was 0.012 for the mean relative error or 0.06 for the standard error (S.E.), and mean values estimated and mean relative error or 0.06 for the standard error (S.E.), and mean values estimated and measured in the four

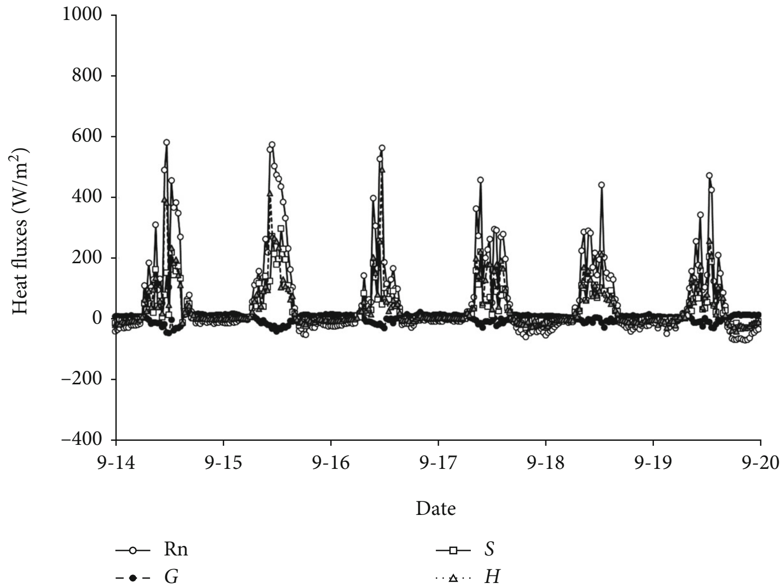

Figure 15: Fluxes of net radiation (Rn), ground heat (*G*), latent heat (*lE*), and sensible heat (*H*) during the week without rainfall in September14-19th. *lE* and *H* were estimated by Bowen ratio.

weeks throughout the season were 1.616 and 1.623 mm/day, respectively, without consideration of *lE* at nighttime, which seemed to be small or negative. The largest difference between *lE* estimated and measured was found in the case of maximum *lE* on August 3rd (Figure 16), suggesting that Bowen ratio might be overestimated at high evapotranspiration condition by the effect of the surround dry area of non-greening rooftop.

The results mentioned above also indicated that *lE*, i.e. evapotranspiration rate, can be reliably estimated on a daily basis by the Bowen ratio based on the data of Rn and *G* observed at a 10-30-minute interval. Thus, monthly evapotranspiration rate is calculated throughout the season and presented in Table 2. The monthly mean Rn for full day (daytime and nighttime) ranged 54.7–125.2 W/m^2 (average: 94.9 W/m^2) for the summer season. *lE* (latent heat) occupied 32-66% (average: 48%) of Rn, which was relatively larger than *H* (sensible heat) averaged out at 38%. The ratio of *lE* to Rn increased from June (32%) to September (66%), which may be owed to the development of the lawn grass.

The relative large proportion (66%) of Rn was converted to *lE* in September, which may be derived from negative (from soil to air) flux (-0.04%) of *G* and active photosynthesis of the lawn grass in late of summer. Evapotranspiration from greening soil ranged 1.42-1.82 mm/day (averaged: 1.51 mm/day) throughout the season, which corresponded to about 26% of total rainfall (720 mm) in the season.

Monthly Rn, *G*, *H*, and *lE* (evapotranspiration) during daytime (6 : 00 AM–6 : 00 PM) are also presented in Table 2. There was a little difference between ratio of each flux to Rn in full day and in daytime, but Rn in daytime is more than twice the value in full day. Evapotranspiration at daytime over the season was relatively larger than in a full day, in particular in August (8.8 mm/month). The relative humidity in

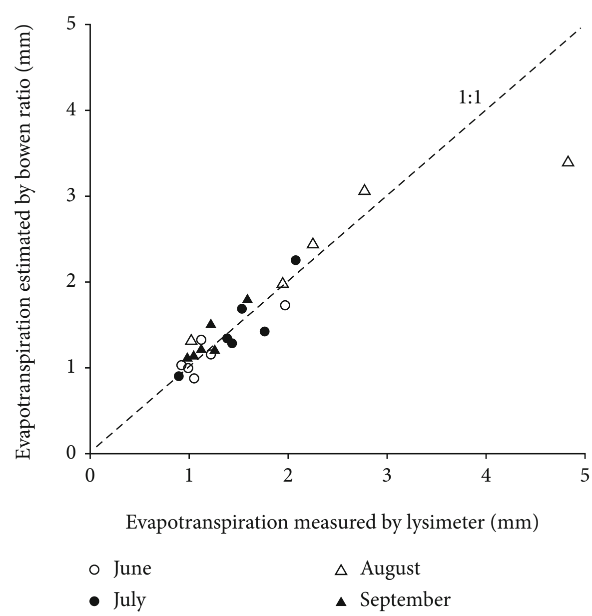

Figure 16: The relationship between evapotranspiration measured directly in the box as a lysimeter and estimated by Bowen ratio during the daytime of the week without rainfall in each month.

the air increased to 100% at nighttime on sunny days (Figure 7). The more the decrease in air temperature, the more dew dropped which caused radiative cooling. The relative large negative flux of latent heat in the nighttime in August is presented in Figure 13.

The ratio of latent heat to net radiation (50-66%) obtained in this study was comparatively smaller than reported on intensive lawn rooftop garden [6] or extensive, thin, and light greening with irrigation [27].

Table 2: Net radiation rate (Rn) and the ratio (%) of ground heat (*G*), latent heat (*lE*), and sensible heat (*H*) to Rn and evapotranspiration rate estimated by Bowen ratio over the summer season (July–September) under no irrigation on a rooftop garden of a thin and light greening substrate with bamboo charcoal sublayer.

	Net radiation (Rn) (kW/m^2/month)	Ratio to net radiation (daytime) (*G*) (%)	Latent heat (*lE*) (%)	Sensible heat *H* (%)	mm/day	mm/month
June	156	0.43	0.24	0.32	0.92	28.66
July	186	0.20	0.39	0.41	1.70	52.85
August	128	0.01	0.45	0.53	1.38	42.69
September	79	-0.04	0.38	0.66	0.73	21.98
Mean or total		0.15	0.37	0.48	1.185	146.18 (4 months)

4. Conclusion

The effect of a thin and light greening system with bamboo charcoal soil for water retention on latent heat flux (evapotranspiration rate) was investigated under no irrigation over the summer season at the rooftop of a building in Higashi-Hiroshima, western Japan. After germination in May, the vegetation (lawn grass) started to develop and reached maximum coverage (100%) and height (70 mm) in August, even without irrigation over summer, suggesting the higher water-storage ability of bamboo charcoal sublayer. The daily temperatures at soil surface and at 5 cm depth showed similar fluctuations as those in the air. The water content in the soil ranged from 0.15 to 0.45 m^3/m^3 throughout the summer season, which is neither more nor less for the growth of most species planted on rooftop gardens in Japan and other warm-temperate zones. There was good correlation between the latent heat (evapotranspiration) estimated by the Bowen ratio and measured directly by lysimeter in daytime for a week without rainfall in each month. Evapotranspiration from greening soil ranged between 1.24 and 1.82 mm/day and averaged about 1.51 mm/day, which corresponded to about 26% of total rainfall over the season. The ratio of latent heat to net radiation was relatively smaller than that reported on intensive lawn rooftop garden or extensive, thin, and light greening with irrigation.

Overall, even without irrigation, the thin and light bamboo soil layer greening system proposed here could maintain the development of lawn grass and transform more than half of net radiation to latent heat, insulating most ground heat in midsummer.

Data Availability

The data support the results of this study and are reported in the tables.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Acknowledgments

This research was financially supported by the Japanese Ministry of Economy, Trade and Industry as a project of the program entitled "Technical Seeds and Social System Development for Low Carbon Society." The authors would like to express their sincere thanks to Profs. Takayuki Nakatsubo and Hirofumi Saneoka of Hiroshima University for their advices and assistance and also thanks to Mr. Motomu Kawamura for his assistance with data collection and analysis. The article is also supported by the Science and Technology Project of Jiangxi Education Department (GJJ191057).

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