Effect on Rooftop Temperatures and Heat Fluxes of a Bamboo Charcoal Sublayer in Rooftop Greening Soil at a Factory Office

Ling PI [#1], Motomu KAWAMURA[#2], Kaneyuki NAKANE [#3]

[#] *Graduate School of Biosphere Science*
Hiroshima University
Higashi-Hiroshima, Japan
[1]first.hirei1112@yahoo.co.jp
[3]third.knakane@hiroshima-u.ac.jp

Abstract- **The effect of using a thin layer of greening material on temperatures and heat fluxes recorded on the roof of a single-story factory office in Higashi-Hiroshima, Japan, was investigated from May to November, 2006. In the study, the roof was divided into two sections. One area was a non-greening control area. The other area was a greening area, which consisted of a thin layer of soil with a bamboo charcoal sublayer spread over a plastic board. The temperature of the non-greening area was the higher of the two areas during the day in all seasons, especially in August when it was mostly around 60°C, while the temperature of the greening area was maintained at below 35°C, which helped control the temperature of the garret. Likewise, the heat fluxes from the non-greening rooftop area to the building during the day, and from the rooftop to the external environment at night were higher than that for the greening rooftop, which were reduced to less than 10%, even during summer. The monthly total heat fluxes suggest that the heat balance for the greening area during the day was negative (rooftop to external environment), and at night in August it was positive (rooftop to garret), which was contrary to the fluxes for the non-greening rooftop. Our novel greening system using bamboo charcoal and a plastic board effectively controlled the temperatures and reduced heat fluxes on the rooftop, and showed the potential to contribute greatly to regulating room temperatures.**

Keywords- **Bamboo charcoal; Heat island phenomena; Heat flux; Shallow-soil rooftop greening; Temperature**

I. INTRODUCTION

The heat island phenomenon has become a serious problem in cities recently, and it is particularly severe in the Tokyo metropolitan area [1]. Rooftop greening is one of the main measures being used for countering the phenomena and reducing energy (electric power) expenditure for cooling purposes in urban areas [2]. However, the environment on a rooftop is very harsh for plants because of the high air temperatures and dry conditions during summer, and during the dry season in tropical to temperate zones [3]. In addition, the weight load for rooftops is usually restricted, thus, a thick layer of soil cannot be used in rooftop gardens [4]. Most of the existing systems for rooftop greening in buildings in Japan and other countries require a great deal of plant care (such as frequent watering during summer and the dry season) because there is little storage of rainwater in the soil, and thus the soil readily dries out [5]. The novel system we propose for rooftop greening uses bamboo charcoal (to aid water retention in the soil) and a plastic board (to act as a waterproofing material), both of which are light, reusable materials, and have the potential to resolve the problems mentioned above. Bamboo charcoal stores more water and releases it into the soil slower than other types of charcoal (such as wood and activated charcoals), and maintains the quality of the water. Thus it promotes plant growth, instead of causing damage to the roots of plants [6, 7]. Even with only a thin layer of soil, our proposed system effectively controls soil temperature by means of active evaporation and transpiration (latent heat) without the need for watering, due to the higher water-storage ability of bamboo charcoal. These facts, however, had not been proved on an actual rooftop of a building except for an ATM booth in Hiroshima.

The number of convenience stores has increased to around 45,000 in the urban and suburban areas of Japan. Most of the stores are single-story structures with flat roofs made of corrugated-steel sheets, which are similar with structure of ATM, thus they consume a great deal of electric power for temperature control. The rooftops of these convenience stores would be ideal targets for our novel greening system.

The first test to quantitatively evaluate the performance of our proposed lightweight, shallow-soil rooftop greening system was made over the spring to the autumn of 2006 using a rooftop garden we created on the rooftop of a factory office. The results of the performance of our system with respect to controlling the temperature and the heat-insulation factor were compared with those of foregoing studies on the effects on temperature regulation and heat insulation by previous greening systems [4, 5, 8].

II. Study Site and Methods

A. Study Site and Rooftop Greening System

The study was carried out on the rooftop of the factory office of TERAL Co. Ltd., which is single-story structure with a flat roof made of corrugated-steel sheets, in Higashi-Hiroshima Industrial Park, Hiroshima Prefecture, in western Japan. In the experiment, the majority (97%) of the rooftop total area (98 m^2) was covered with a lightweight, shallow-soil rooftop greening system. Work on installing the system, dubbed "Bamboo TECO Garden" [9], commenced in March, 2006. "Bamboo TECO Garden" consisted (bottom to top) of a plastic board, a bamboo charcoal sublayer, soil (compost ＋decomposed granite) and a top lawn layer. A sectional schematic diagram is shown in Fig. 1. In detail, a plastic board (brand name: TECO form) was used for the bottom plate, on which was placed a 4-cm bamboo charcoal sublayer for water retention; followed by a 4-cm layer of light soil, which was then sown with grass seeds (*Zoysia tenuifoli*) in April, 2006. The lawn was watered just for the first two months, and cut at regular intervals to keep the grass length to less than 5 cm. The mean temperature and precipitation in 2006 were 14.0°C and 1,690 mm, respectively, which was near the average for the preceding decade.

B. Methods

The temperatures and heat fluxes were measured at 30- and 10-minute intervals, respectively, on the surface of the greening soil, the rooftop, the garret floor, and the non-greening rooftop from May to November, 2006. The air temperature in the garret was also monitored, as shown in Fig. 1. The temperature sensors were shielded from direct solar radiation by covers. Identical or similar sensors and data-loggers for measuring temperature and heat flux have been employed in many previous studies (e.g.[8], [10]), however, the methodological design of observing the vertical change in temperature and heat flux from a greening rooftop surface to a garret in a single-story structure with a flat, corrugated-steel roof had not, to the best of our knowledge, been hitherto attempted.

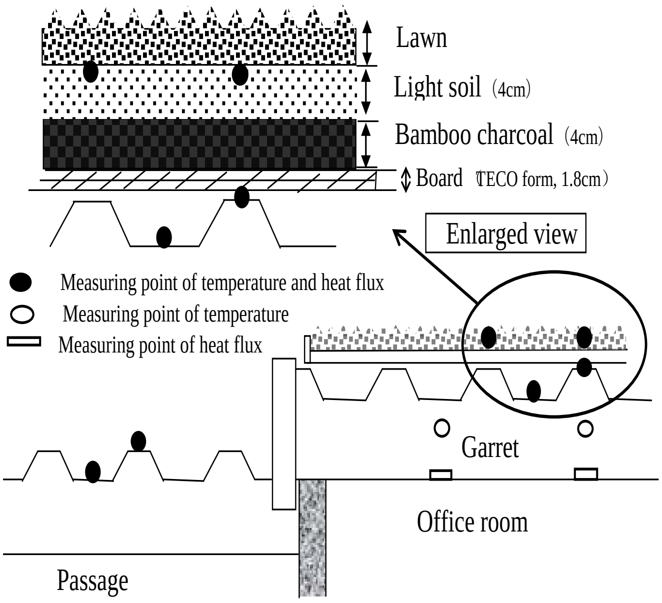

Fig. 1 Cross-sectional schematic diagram of greening system (Bamboo TECO Garden) and locations of measuring points.

Table 1 Temperature and heat flux measurement parameters.

Element	Measuring equipment		Location(surface)	Point	Output Interval
Temperature	Thermometer	TR-81:T&D.Co.	on greening rooftop	2	30 minutes
			on non-greening rooftop	2	
			on greening soil	2	
			in garret	2	
Heat flux	Heat flow meters	MP-75：EKO.Co	on greening rooftop	2	10 minutes
			on non-greening rooftop	2	
			on greening soil	2	
			on garret floor	2	

There was little difference between the data observed at two points for each temperature and heat flux measurement ($p>0.1$, two-way ANOVA), thus the average for the two points was used. The daily change in each data set was compared among the measurement locations on weekends and holidays in May, August and October when the air conditioning in the room was not operating and thus had no affect on the temperature in the garret and the heat flux for the garret floor. The total value for heat fluxes during the day (6:00-18:00) and at night (18:00-6:00) through a month (kWh/m^2month) was calculated for May, August and October.

III. RESULTS AND DISCUSSION

A. Monthly change in temperatures and heat fluxes

The temperatures and heat fluxes, respectively, on the surface of the greening and non-greening rooftops and of the greening soil in May, August and October are shown in Figs. 2 and 3.

The temperature on the non-greening rooftop repeated a large daily fluctuation (30-40^{o}C) by rapidly increasing during the day and falling at night for all months, while the fluctuation on the greening rooftop diminished to only 5-10^{o}C, due to the slow increase (lower by 30^{o}C than on the non-greening rooftop) and decrease, and that on the greening soil was 10-20^{o}C. However, the daily fluctuation on both the greening and non-greening rooftops became relatively smaller on rainy or cloudy days because their maximum and minimum temperatures were moderated, due to less solar radiation during the day and little radiative cooling at night. Even if the weather is fine, the fluctuation on the greening rooftop with a bamboo charcoal sublayer is controlled to a large extent by the far greater water content of the soil, which transforms heat into latent heat by means of evapotranspiration. Pi and Nakane (2008) [6] charted the effects of bamboo charcoal buried in soil on soil temperature and water content through a growing season in the boxes with 0-cm, 2.5-cm, 5-cm and 10-cm layers of charcoal in an environment set up on the rooftop of a building in Hiroshima University. They reported that the soil temperature during the day was regulated lower, especially during summer, in the boxes with charcoal than in the boxes without charcoal. There was little difference in soil water content between boxes with and without charcoal during and just after rainfall. However, later the soil water content in the box without charcoal decreased rapidly, while the decrease in soil water content was smaller the thicker the layer of charcoal.

Heat on the non-greening rooftop penetrated into the garret during the day as flux (+, input) and was emitted into the environment at night as efflux (-, output) in all seasons. For example, a flux of 150-400 W/m^2 (more than 300 W/m^2 in August) during the day, and an efflux of -20 to -50 W/m^2 (around -50 W/m^2 in August) during the night were observed throughout the seasons. On the other hand,

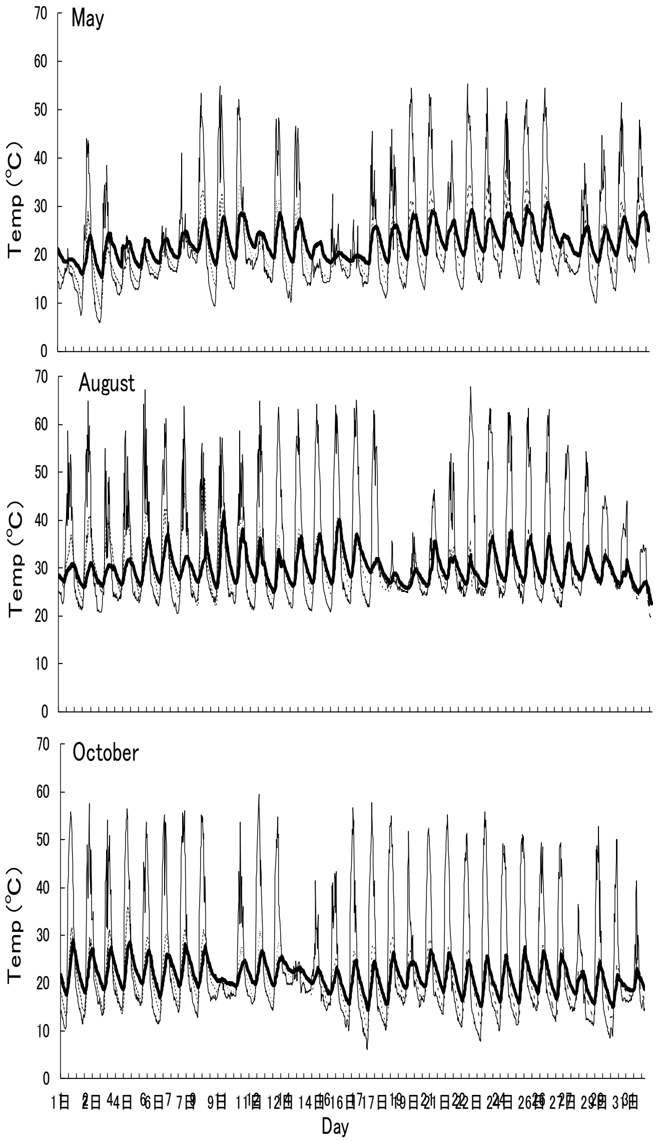

Fig. 2 Monthly change in temperature on measured surfaces in May, August, October. —: non-greening rooftop, ▬: greening rooftop, ---- : greening soil.

the input (flux) during the day was less than 10 W/m^2 on the greening rooftop and 100 W/m^2 on the greening soil, and the efflux during the night was very slight or positive (flux) on the greening rooftop and relatively small on the greening soil. The fact, that a reverse tendency of heat fluxes, i.e. output (negative) during the day and input (positive) during the night was observed sometimes on the greening rooftop, indicates a strong heat-insulation effect from a greening system incorporating bamboo charcoal and a plastic board,

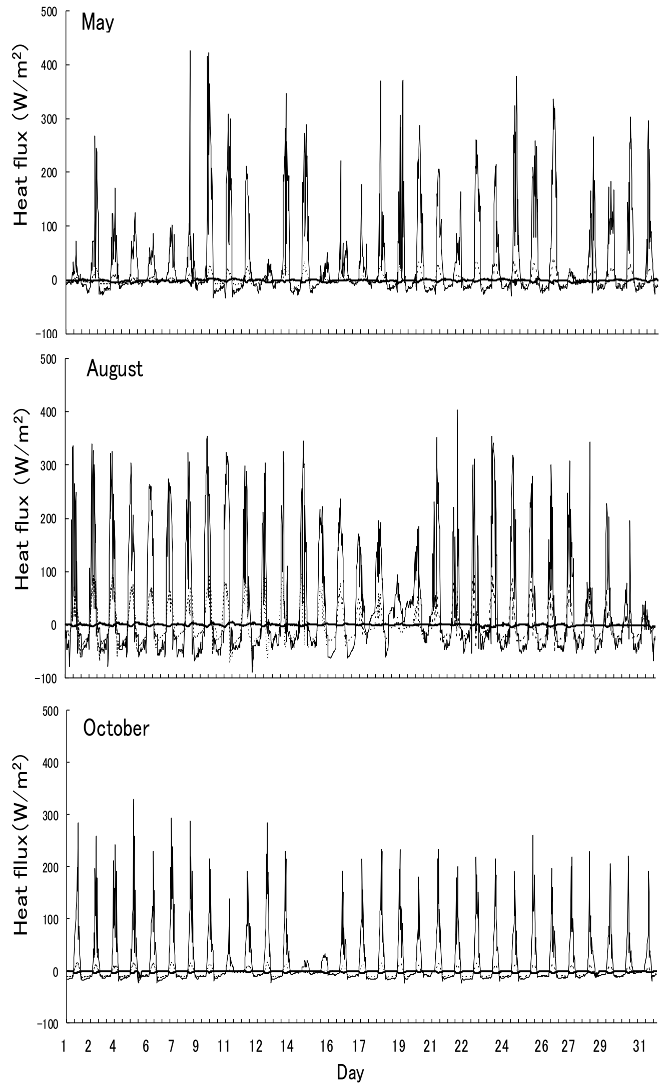

Fig. 3 Monthly change in heat fluxes on measured surfaces in May, August, and October. — : non-greening rooftop, ▬ : greening rooftop, ┄ : greening soil.

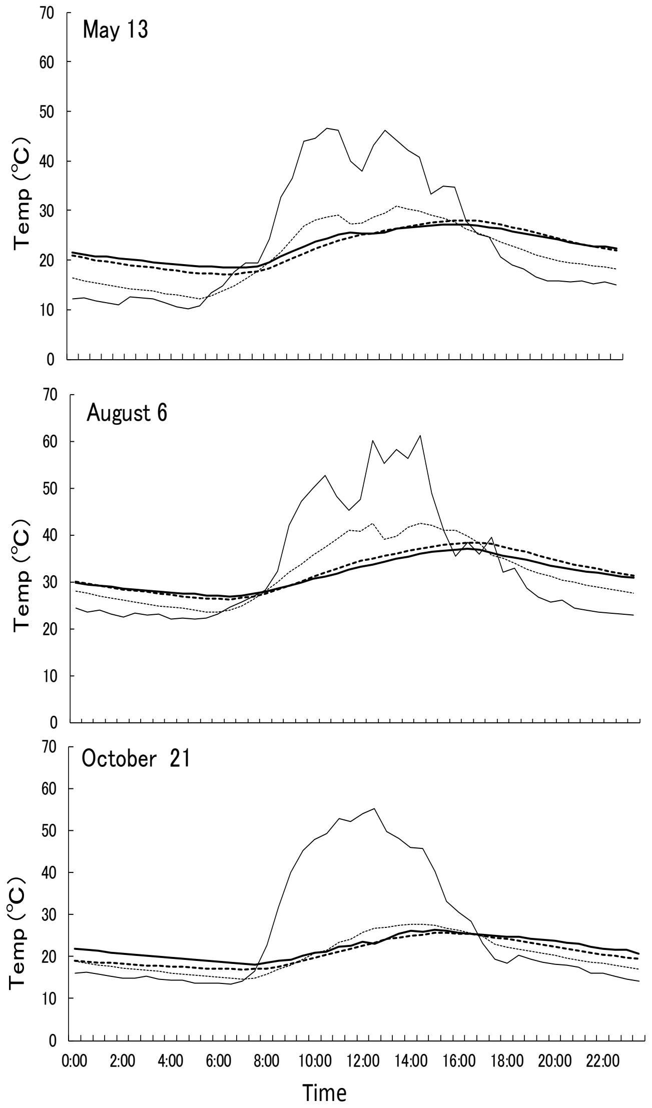

Fig. 4 Daily change in temperatures at each point on weekends and holidays in May, August, October. —: non-greening rooftop, ┄: greening soil, ▬: greening rooftop, ···· : in garret .

both of which have low heat conductivity .

B. Daily change in temperatures and heat fluxes

Daily changes in temperatures and heat fluxes on typical on weekends and holidays in three seasons are shown in Figs. 4 and 5, which include the temperature in the garret and the heat flux for its floor.

The daily changes in temperature on the greening soil in particular, and on the rooftop were markedly controlled comparing with that on the non-greening rooftop during any day. They increased to around 60^{o}C during the day and fell to 20-25^{o}C at night on the non-greening rooftop on August 6, but, increased to 40^{o}C on the greening soil and 35^{o}C on the greening rooftop during the day and fell to 25-30^{o}C on both rooftops at night on the same dates (Fig. 4). The same tendency was observed in May and October, nevertheless their values dropped by 10^{o}C compared with August. Through the period May to October, the daily difference in temperature between the peak during the day and the lowest value at night was frequently around 40^{o}C on the non-greening rooftop, 10-20^{o}C on the greening soil, and only 5-10^{o}C on the greening rooftop. The temperature in the garret showed a similar degree and fluctuation pattern to that on the greening rooftop, however, it was

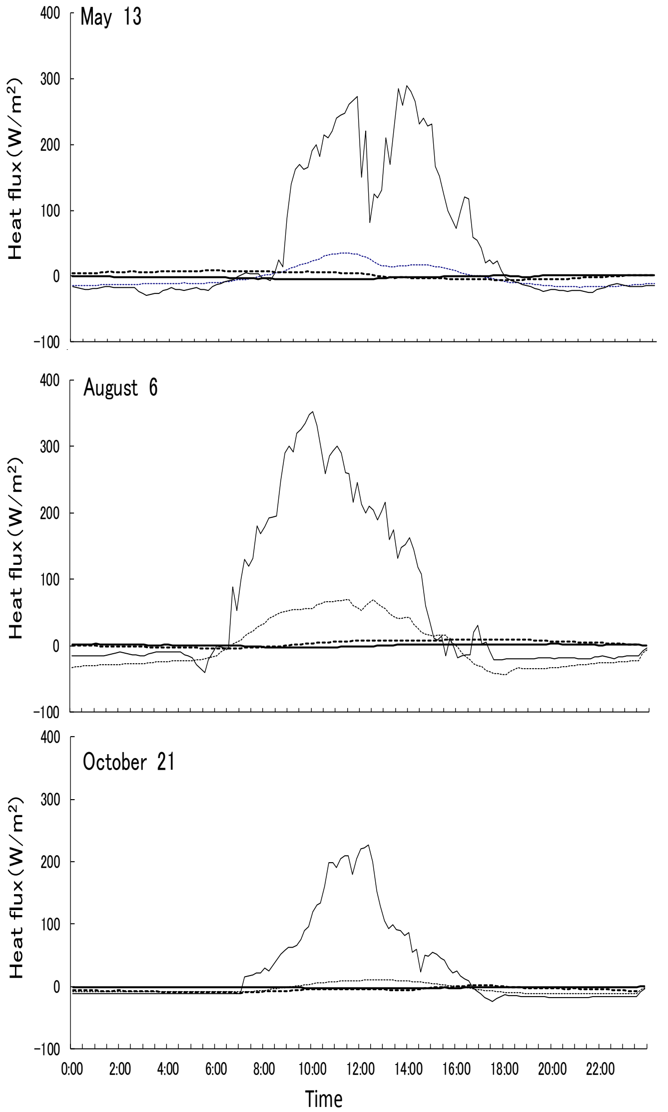

Fig. 5 Daily heat fluxes on measured surfaces on weekends and holidays in May, August and October. —: non-greening rooftop, —: greening soil, ━ : greening rooftop, ····: garret floor.

slightly higher during the day and lower at night than on the greening rooftop, due to the effect of heat flux from or to the walls and the room beneath. A heat flux of 200-400 W/m^2 from the non-greening rooftop to the garret occurred during the day throughout this period, while a heat flux of only 15-50 W/m^2 from the greening soil to the rooftop, and just a few W/m^2 —or even 0 W/m^2 — from the greening rooftop to the garret was observed during the same period (Fig. 5). The heat efflux from the non-greening rooftop to the environment at night ranged between -20 and -50 W/m^2, and the same or a greater efflux was observed on the greening soil; however, little efflux or flux was indicated on the greening rooftop at night. The heat flux or efflux for the garret floor was small—the same as for the greening rooftop, however, a flux of 5-10 W/m^2 to the room beneath during the day may have been caused by the heat flux from the wall to the garret.

Nevertheless, the rooftop greening system in this study is lightweight and has a shallow depth, and it demonstrated the function of controlling temperatures and heat fluxes on a rooftop surface, due to the bamboo charcoal sublayer with rich water retention and a plastic board, both of which have low heat conductivity. It may be made clear if the rooftop greening system can better control the temperature in a room when the heat flux to the walls is eliminated by a greening wall.

C. Monthly total heat fluxes during the day and at night

Total heat fluxes during the day and at night for each month on the greening rooftop and on the greening soil, and on the non-greening rooftop, which were not markedly affected by the air conditioner in the room, are shown together with the heat fluxes of the garret floor in Fig. 6.

The largest values for total heat flux during the day and for efflux at night were found on the non-greening rooftop throughout the three months, suggesting a significant positive balance between flux and efflux. The smaller total values for the greening soil than for the non-greening rooftop indicate a good balance between flux and efflux. The smallest total flux and efflux were observed for all months on the greening rooftop, which showed reversed heat fluxes, i.e., an efflux during the day and a flux at night in August. The reason the reversed heat fluxes occurred may be a result of heat fluxes from or to the non-greening wall via the garret. This suggests that the new rooftop greening system greatly reduced heat fluxes, e.g. the most flux during the day and more than 90% of efflux at night, on a rooftop throughout a day—even in summer . The effect is not at all inferior to that observed in earlier greening systems [4, 5].

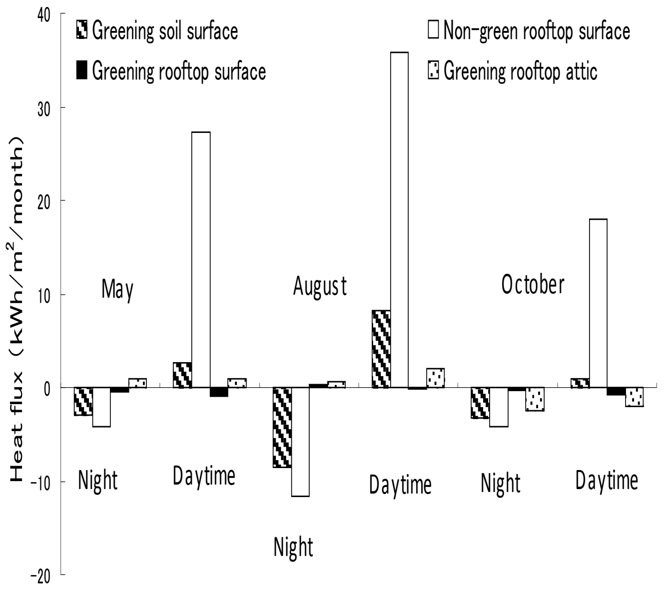

Fig. 6 Total heat fluxes on measured surfaces during the day and at night over the months of May, August and October.

IV. CONCLUSIONS

Investigations into rooftop temperatures and heat fluxes with and without a lightweight, shallow soil rooftop greening system with a bamboo charcoal sublayer spread over a plastic board were conducted on the rooftop of a factory office in Higashi-Hiroshima, western Japan, from May to November, 2006. The temperature of the non-greening area was the higher of the two areas during the day in all seasons, especially in August when it was mostly around 60˚C, while the temperature of the greening area was maintained at below 35˚C, which helped control the temperature of the garret. Likewise, the heat fluxes from the non-greening rooftop area to the building during the day, and from the rooftop to the external environment at night were higher than that for the greening rooftop, which were reduced to less than 10%, even during summer. The monthly total heat fluxes suggest that the heat balance for the greening area during the day was negative (rooftop to external environment), and at night in August was positive (rooftop to garret), which was contrary to the fluxes for the non-greening rooftop. This indicate that our novel greening system using bamboo charcoal and a plastic board effectively controlled the temperature and reduced heat fluxes on the rooftop, and showed the potential to contribute greatly to regulating room temperatures.

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