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NRCC-46412

A version of this document is published in / Une version de ce document se trouve dans:
Proceedings for the First North American Green Roof Infrastructure Conference, Awards and Trade Show, Chicago, IL., May 29-30, 2003, pp. 1-10

THERMAL PERFORMANCE OF GREEN ROOFS THROUGH FIELD EVALUATION

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Abstract

Green roofs have the potential to improve the thermal performance of a roofing system through shading, insulation, evapotranspiration and thermal mass, thus reducing a building's energy demand for space conditioning. To quantify the thermal performance and energy efficiency of green roofs in Canada, the National Research Council of Canada (NRC) has constructed an experimental facility, the Field Roof Facility (FRF), in its Ottawa campus. A median divider separates the roof of the FRF in two equal areas: a generic extensive green roof and a modified bituminous roof. Both roof sections are instrumented to allow direct comparison of the thermal performance the Green Roof and the Reference Roof.

Observations from the FRF showed that a generic extensive green roof could reduce the temperature and the daily temperature fluctuation experienced by the roof membrane significantly in the warmer months (spring and summer). The Green Roof also significantly moderated the heat flow through the roofing system and reduced the average daily energy demand for space conditioning due to the heat flow through the roof in the summer by more than 75%. The Green Roof was more effective in reducing heat gain than heat loss.

Introduction

Green roofs not only add aesthetic appeal to the unused roof space that is available in most urban areas; they also provide many benefits. Green roofs can protect the roofing membrane from exposure to ultra violet radiation and hail damage. They can reduce energy demand on space conditioning, and hence greenhouse gas emissions, through direct shading of the roof, evapotranspiration and improved insulation values (1,2,3,6,7,8). If widely adopted, green roofs could reduce the urban heat island (11,12) (an elevation of temperature relative to the surrounding rural or natural areas due to the high concentration of heat absorbing dark surfaces such rooftops and pavements) which would further lower energy consumption in the urban area. They can also be used as part of the stormwater management strategy in the urban area. Part of the rain is stored in the growing medium temporarily, and to be taken up by the plants and returned to the atmosphere through evapotranspiration (2,7,10,13). Green roofs delay runoff into the sewage system, thus help to reduce the frequency of combined sewage overflow (CSO) events, which is a significant environmental problem for many major cities in North America (2). The plants and the growing medium can also remove airborne pollutants picked up by the rain, thus improving the quality of the runoff. In addition, green roofs can improve air quality, provide additional green space in urban areas, and increase property values (9).

Green roofs are found throughout many European countries such as France, Germany and Switzerland. They are rapidly gaining popularity across different parts of the world as well. In North America, Portland, Oregon has pioneered an incentive program (Clean Air Incentive and Discount Program) to encourage the installation of green roofs on commercial, industrial, institutional and residential properties, with the aim of reducing the stormwater runoff problem and relieving the loading on the sewage infrastructure (5). In Asia, Tokyo, Japan has initiated a new ordinance to install green roofs on new buildings with floor space more than 1000 m^2 (10800 ft^2) to mitigate the urban heat island effects (4).

The National Research Council of Canada (NRC), in collaboration with members of the North American roofing industry, is leading a research project to study the thermal performance and environmental benefits of green roof technology. The objectives of this project are to identify sensitivities to climate variability and to quantify the benefits of the technology under Canadian climatic conditions. This paper focuses on the thermal performance results based on data collected during the first two years of this study.

Experimental Study

NRC has constructed the Field Roofing Facility at its Ottawa campus in Canada. It provides an experimental roof area of about 72 m^2 (800 ft^2) and can represent a low slope industrial roof with a high roof-to-wall ratio. The roof is divided into two equal areas separated by a median divider: a generic extensive green roof was installed on one side and a modified bituminous roofing assembly was installed as a reference on the other (Figure 1). The surface of the roof membrane (on both roof sections) is covered with light grey coloured granules, which is intended to avoid the extreme colours of a reflective white membrane or a dark built up roof surface. While the Green Roof have the same basic components up to the membrane level, it incorporates additional elements to support plant growth. Figure 2 shows the components and configurations of the two roofing systems. In the first year of the study (2001), a wild flower meadow was established in the garden and in the second year (2002), common lawn grass (Kentucky blue grass) was planted.

Both the Green Roof and the Reference Roof are instrumented to measure the temperature profile within the roofing system, heat flow across the system, solar reflectance of the roof surface, soil moisture content, microclimate created by the plants, and storm water runoff (Figure 2). The local meteorological data such as temperature, relative humidity, rainfall and solar radiation are monitored continuously by a weather station located at the median divider on the rooftop and an additional weather station situated approximately 50 m (160 ft) from the site. All sensors are connected to a data acquisition system for monitoring.

Results and Findings

The Field Roofing Facility has been in operation since November 2000. The data collected from the first two years of operation (November 2000 to September 2002) have been analysed and are summarized below. This paper will focus on the thermal performance results only.

Temperature Profile

An exposed roof membrane absorbs solar radiation during the day and its temperature rises. The extent of the temperature increase depends on the colour of the membrane. Light colour membranes are cooler because they reflect solar radiation but dark colour membranes are hotter because they absorb much of the solar radiation. Results from the FRF show that the roof membrane on the Reference Roof experienced much higher temperatures than that on the Green Roof. Figure 3 shows the temperature profile within the roofing systems on a summer day. The membrane on the Reference Roof absorbed the solar radiation and reached close to 70°C (158°F) in the afternoon. However, the membrane on the Green Roof remained around 25°C (77°F).

Table 1 compares the number of days out of the observation period (a total of 660 days) when the maximum roof membrane temperature exceeded various levels. For example, there are 219 days out of the 660 days (i.e. 33% of the days) observed that the membrane on the Reference Roof reached a temperature above 50°C (122°F). However, the roof membrane reached above 60°C (440°F) only on 89 of the 219 days – 13% of the days observed during this period (i.e. 89 days out of 660 days). While the ambient temperature exceeded 30°C (86°F) for 10% of the days during the 22-month observation period, the membrane temperature of the Reference Roof went above 30°C (86°F) over half of the time, compared to only 3% for the Green Roof. In fact, the Reference Roof membrane reached over 50°C (122°F) about one third of the days during the observation period and reached over 70°C (158°F) in the extreme conditions. Note that the colour of the membrane was light grey, the temperature of a dark colour membrane would be expected to be even higher.

Heat exposure can accelerate aging in bituminous material, thus reducing its durability. Ultra violet radiation can change the chemical composition and degrade the mechanical properties of the bituminous materials. Although long-term durability data is not available from the study yet, the growing medium and the vegetation of the green roof can prevent the UV radiation from attacking the roofing membrane and minimize aging of the membrane from heat exposure, which might extend the life of the membrane.

Temperature Fluctuations

An exposed membrane absorbs solar radiation during the day and its surface temperature rises. It re-radiates the absorbed heat at night and its surface temperature drops. Diurnal (daily) temperature fluctuations create thermal stresses in the membrane, affecting its long-term performance and its ability to protect a building from water infiltration. Figure 4 shows the daily membrane temperature fluctuation (daily maximum temperature - daily minimum temperature) of the Reference Roof and the Green Roof and the daily ambient temperature fluctuations. The Green Roof moderated the daily temperature fluctuations that the membrane experienced during early winter (November and December), while the membrane temperature of the Reference Roof followed the daily ambient temperature fluctuations. This protection was somewhat dissipated during the accumulation of snow, and once heavy snow coverage was established (January and February) both roofing membranes were protected from temperature fluctuations. The Green Roof significantly moderated the daily temperature fluctuations experienced by the roof membrane during the spring and the summer. The daily membrane temperature fluctuations of the Green Roof were consistently lower than the diurnal ambient temperature fluctuations. The exposed membrane in the Reference Roof experienced high daily temperature fluctuation, with a median of about 45°C (81°F). However, the Green Roof reduced the temperature fluctuation in the roof membrane throughout the year, keeping a median fluctuation of about 6°C (11°F) only.

Energy Efficiency

The Green Roof was found to be effective in helping to keep the building cool in the summer. The plants and the growing medium in the Green Roof kept the roofing membrane cool by direct shading, evaporative cooling from the plants and the growing medium, additional insulation values from both the plants and the growing medium, and the thermal mass effects of the growing medium.

Heat flow through the building envelope creates energy demand for space conditioning in a building. Figure 5 shows the heat flow through the roof on a summer day as measured by the three heat flux transducers embedded in each roof section. These transducers were calibrated such that positive heat flow represents heat entering the roof at the installed location while negative heat flow means heat leaving the roof. The membrane on the Reference Roof, being exposed to the elements, absorbed solar radiation during the day and re-radiated the absorbed heat at night, creating positive heat flow in the afternoon and negative heat flow in the early morning and evening. The Green Roof significantly moderated the heat flow between the building and its surrounding through the roofing system. In the winter, data from the FRF showed that once the snow coverage was established, the heat flow through both the Reference Roof and the Green Roof became the same as snow coverage provided good insulation and stabilized heat flow through the roof.

Figure 6 summarizes the average daily energy demand for space conditioning due to heat flow through the roof ONLY. The energy efficiency of the Green Roof was slightly better than that of the Reference Roof in the fall and early winter as the green roof system acted as an insulation layer. However, as the growing medium froze, its insulation value was greatly diminished. Snow coverage provided excellent insulation to the roofing system and stabilized the heat exchange between the building and its surrounding. The snow coverage on the roof was not uniform in early winter due to the wind and the influence of the high parapet. Once snow coverage was established on the roof, heat flow through both roofs was almost the same.

The Green Roof significantly outperformed the Reference Roof in spring and summer (April to September). Solar radiation has a strong influence on the heat flow through the roof. The membrane on the Reference Roof, being exposed to the elements, absorbed solar radiation during the day and re-radiated the absorbed heat at night, creating high daily energy demand for space conditioning. On the other hand, the growing medium and the plants enhanced the thermal performance of the Green Roof by providing shading, insulation and evaporative cooling. It also acted as a thermal mass, which effectively damped the thermal fluctuations going through the roofing system. The average daily energy demand for space conditioning due to the heat flow through the Reference Roof was 6.0-7.5 kWh/day (20,500-25,600 BTU/day) as shown in Figure 6. However, the growing medium and the plants of the green roof modified the heat flow and reduced the average daily energy demand to less than 1.5 kWh/day (5,100 BTU/day) – a reduction of over 75%. Note that these values were due to the heat flow through the roof only (36 m^2 or 400 ft^2) and did not include heat flow through other parts of the building envelope.

The Green Roof was more effective in reducing heat gain in the spring/summer than heat loss in the fall/winter. This is because the green roof can reduce heat gain through shading, insulation, evapotranspiration and thermal mass. However, it can reduce heat loss only through improved insulation and decreased radiation heat losses. This is effective on summer evenings, but not in winter when the growing medium is frozen and the improved insulation and decreased radiation heat loss effects were dominated by snow coverage. Table 2 shows the total heat flow through the roof surfaces of FRF normalized with the roof area from November 2000 to September

2002. During the 22-month observation period, the Green Roof reduced 95% of the heat gain and 26% of the heat loss as compared to the Reference Roof, with an overall heat flow reduction of 47%. Since an extensive green roof was more effective in reducing heat gain than heat loss, and Ottawa is in a predominantly heating region, it is expected that its effectiveness will be more significant in warmer regions.

Conclusions

Observation from the Field Roofing Facility showed that a generic extensive green roof with 150 mm (6 in.) of growing medium could reduce the temperature of the roof membrane significantly in the summer. The exposed roof membrane on the Reference Roof was recorded to reach over 70°C (158°F) in the summer but that under the Green Roof rarely reached over 30°C (86°F). Also the Green Roof modified the temperature fluctuations the roof membrane experienced, especially in the warmer months. The median daily temperature fluctuation of the membrane on the Reference Roof in spring and summer ranged from 45°C (81°F), however, the Green Roof reduced the temperature fluctuation to 6°C (11°F). The Green Roof also significantly moderated the heat flow through the roofing system in the warmer months. The average daily energy demand for space conditioning due to the heat flow through the roof was reduced from 6.0-7.5 kWh/day (20,500-25,600 BTU/day) to less than 1.5 kWh/day (5,100 BTU/day) as measured on the Reference Roof and the Green Roof, respectively. This corresponded to a reduction of over 75%.

Implications from the Study

Analysis of the data that has been collected from the Field Roofing Facility suggests that an extensive green roof can lower the temperature and modify the temperature fluctuations that are experienced by roof membrane. The reduction in temperature reduces the effects of heat aging from natural exposure and the moderation in temperature fluctuations decreases the thermal stress on the membrane; both mechanisms can possibly extend the life of the roof membrane. The reduction in roof surface temperature can help to lower the urban heat island effects as well. Green roofs can moderate heat flow through the roof through shading, insulation, evapotranspiration and thermal mass effects. This reduces the energy demand for space conditioning, most significantly in spring and summer.

Acknowledgement

The author would like to acknowledge the members of the Rooftop Garden Consortium – Bakor, Canadian Roofing Contractors' Association (CRCA), EMCO, Environment Canada, Garland, Hydrotech, IKO, Oak Ridge National Laboratory (ORNL), Public Works Government Services Canada (PWGSC), Roof Consultants Institute (RCI), Soprema and Tremco – and the Climate Change Action Fund for providing financial support and technical expertise in this project. The author also gratefully acknowledges the assistance of W. Lei, D. Guenter, H. Shen and R. Bruce in the set up and maintenance of the Field Roofing Facility.

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Temperature Greater Than:	Reference Roof		Green Roof		Ambient	
	No. of Days	% of Days	No. of Days	% of Days	No. of Days	% of Days
30°C (86°F)	342	52	18	3	63	10
40°C (104°F)	291	44	0	0	0	0
50°C (122°F)	219	33	0	0	0	0
60°C (140°F)	89	13	0	0	0	0
70°C (158°F)	2	0.3	0	0	0	0

Table1: Statistics on the daily maximum temperature of the roof membranes on FRF during the observation period (660 days in total).

	Reference Roof	Green Roof	Reduction
Heat Gain	19.3 kWh/m^2 (5900 BTU/ft^2)	0.9 kWh/m^2 (270 BTU/ft^2)	95%
Heat Loss	44.1 kWh/m^2 (13500 BTU/ft^2)	32.8 kWh/m^2 (10100 BTU/ft^2)	26%
Total Heat Flow	63.4 kWh/m^2 (19400 BTU/ft^2)	33.7kWh/m^2 (271 BTU/ft^2)	47%

Table 2: Normalized (per unit area) heat flow through the roof surfaces of FRF during the observation period (Nov 22, 2000 – Sep 30, 2002).

Figure 1: The sod two weeks after installing on the FRF in the NRC campus in Ottawa (2002).
Note that the median divider separates the Green Roof (left) and the Reference Roof (right).
The weather station is located at the median divider.

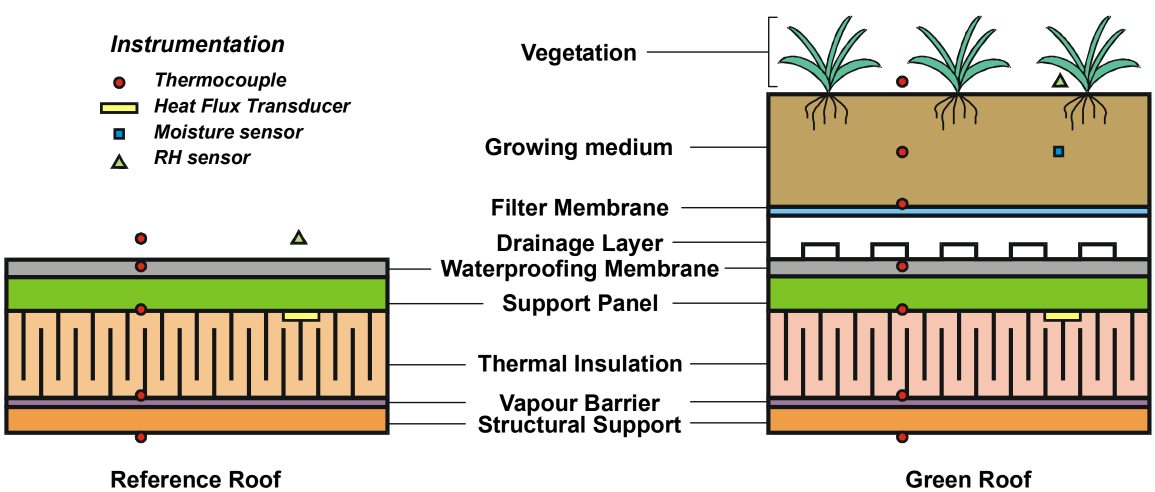

Figure 2: Major components and instrumentation location of the
Green Roof and the Reference Roof.

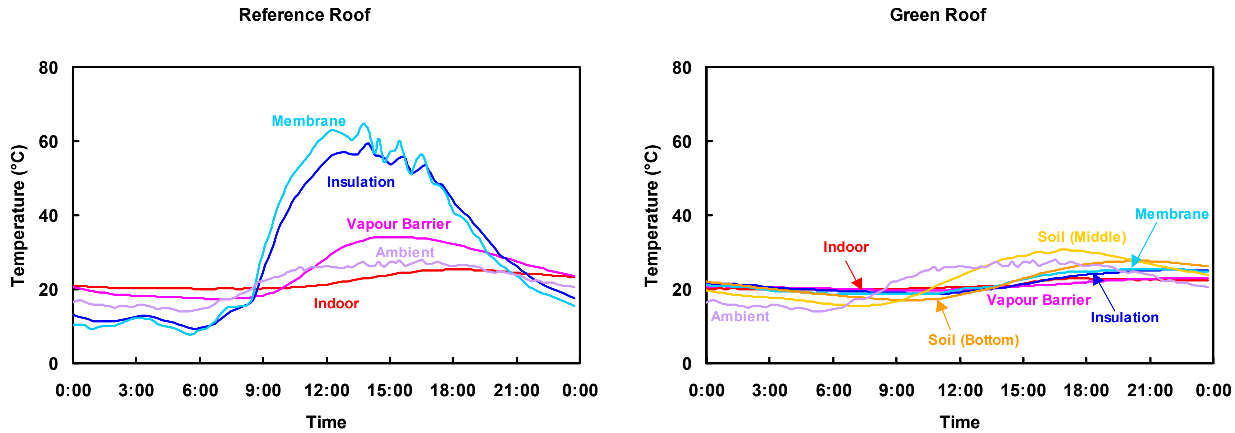

Figure 3: Temperature profile within the roofing systems on a summer day (July 16, 2001) indicating that the Green Roof reduces the temperature fluctuations within the roofing system.

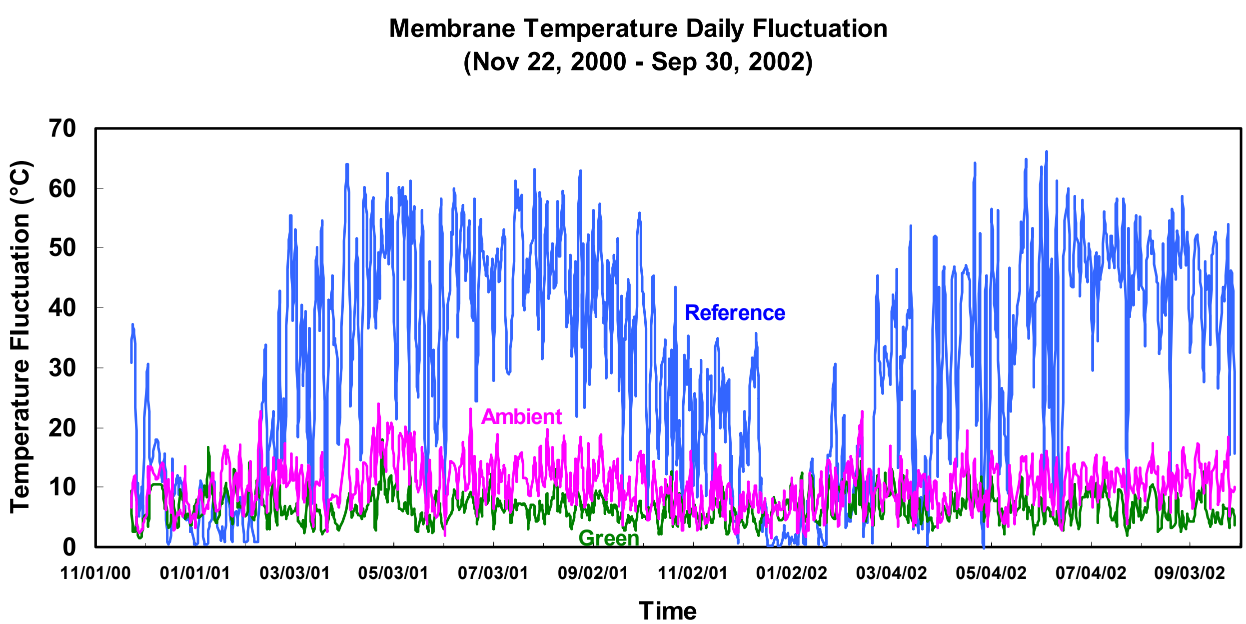

Figure 4: Temperature measurements showed that the Green Roof significantly reduced the daily temperature fluctuations experienced by the roofing membrane.

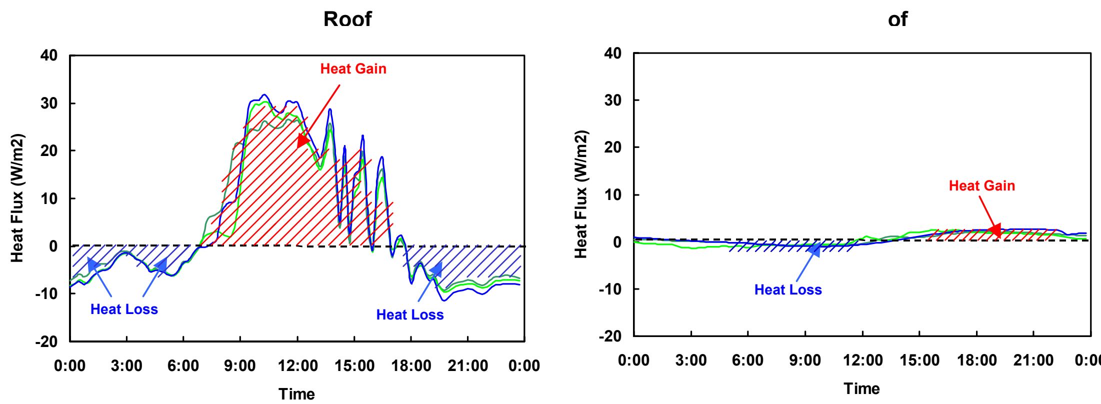

Figure 5: Heat flow through the roofing systems on a summer day (July 16, 2001) indicated that the Green Roof reduced the heat flow through the roofing system significantly.

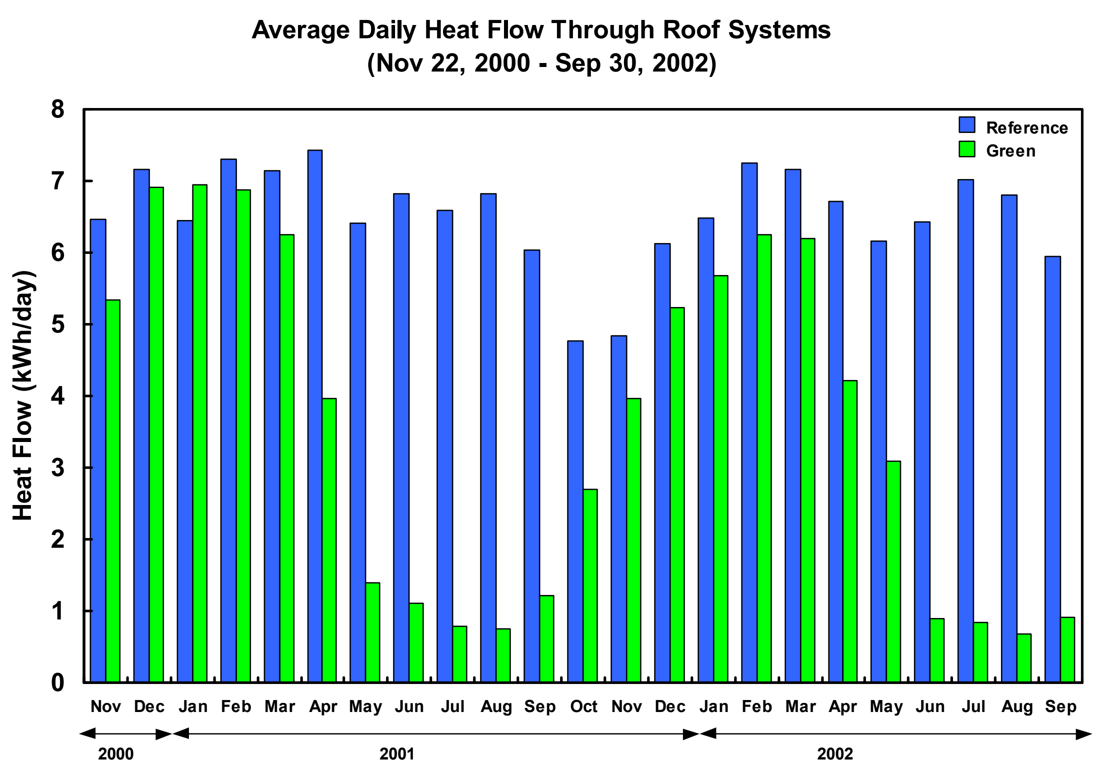

Figure 6: Heat flow measurement showed that the average daily energy demand due to the heat flow through the Green Roof was significantly less than that of the Reference Roof in the spring and summer.