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Energy Efficiency and Environmental Benefits of Rooftop Gardens
By Karen Liu

Vegetation, primarily forests, has been identified as an important component of any strategy to reduce greenhouse gas (GHG) emissions, through the sequestration of carbon in the woody biomass of trees. Given the limited space available for additional trees in many North American metropolitan cities, new adaptation strategies such as placing the vegetation directly on building roofs (rooftop gardens) become especially attractive. Rooftop gardens or green roofs are found throughout Europe. Germany, in particular, has carried out a significant amount of technical research to improve the various roofing components. Here at home, Canada has agreed to reduce GHG emissions by six per cent relative to 1990 levels by 2008-2012. Rooftop gardens may be a part of the solution.

Rooftop gardens offer many benefits to an urban area. They can reduce energy demand on space conditioning, and hence GHG emissions, through direct shading of the roof, evapotranspiration and improved insulation values. If widely adopted, rooftop gardens could reduce the urban heat island, which would decrease smog episodes, problems associated with heat stress and further lower energy consumption. They could also help to improve storm water management if sufficiently implemented in an urban area. Part of the rain is stored in the growing medium temporarily, and will be taken up by the plants and returned to the atmosphere through evapotranspiration. Rooftop gardens delay run-off into the sewage system, thus helping to reduce the frequency of combined sewage overflow events, which is a significant problem for many major cities in North America. The plants and the growing medium can also filter out airborne pollutants washed off in the rain, thus improving the quality of the run-off. In addition, rooftop gardens can increase membrane durability, provide additional green space in urban areas, and increase property values.

Even though rooftop gardens represent an inexpensive adaptation strategy, technical information on their thermal performance and environmental benefits, in a Canadian context, is not available. The National Research Council of Canada (NRC), in collaboration with Environment Canada, the Climate Change Action Fund and members of the Canadian roofing industry, is leading a research project to study the various benefits of this 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.

Experimental study

NRC has constructed a field roofing facility at its Ottawa campus (Figure 1). It has an experimental roof area of about 70 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 parapet: a generic extensive rooftop garden was installed on one side and a conventional roofing assembly was installed as a reference on the other. While the reference roof and the rooftop garden have the same basic components up to the membrane level, the rooftop garden incorporates additional garden components (root repellent on the membrane, drainage layer, filter membrane and growing medium) to support plant growth. The garden has a wildflower meadow growing in 150 mm (6 in.) of lightweight growing medium. Figure 2 shows the components and configurations of the two roofing systems. The roof is surrounded by a 1-m (3-ft.) parapet and each section is structurally sloped at two per cent toward a central drain. Any run-off from one section flows through the central drain in that section into an individual flow meter in the building. There the run-off from each roof can be measured and compared.

Both the rooftop garden 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 run-off (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 parapet on the rooftop and an additional weather station situated approximately 50 m (150 ft.) from the site. All sensors are connected to a data acquisition system for monitoring.

Results and findings

The field roofing facility has been monitored continuously since its commissioning in November 2000. The data collected from the rooftop garden and the reference roof have been analysed and compared to assess the thermal performance, energy efficiency and storm water retention.

Thermal performance

The plants and the growing medium in the rooftop garden kept the roofing membrane cool in the summer by shading, insulating and evaporative cooling. Figure 3 shows the temperature profile within the roofing systems on a hot, sunny summer day. The outdoor temperature peaked at 35 C (95 F) in the afternoon. The membrane on the reference roof absorbed the solar radiation and reached approximately 70 C (158 F) while the membrane on the rooftop garden remained around 25 C (77 F).

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 minus daily minimum temperature) of the reference roof and the rooftop garden and the daily ambient temperature fluctuations. The rooftop garden 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 rooftop garden significantly moderated the daily temperature fluctuations experienced by the roof membrane during spring and summer. The daily membrane temperature fluctuations were consistently lower than the diurnal ambient temperature fluctuations. The median daily membrane temperature fluctuations were 46 C (83 F) and 12.5 C (22 F) for the reference roof and the rooftop garden, respectively.

Energy efficiency

Heat flow through the building envelope creates energy demand for space conditioning in a building. Solar radiation and snow coverage have a strong influence on the heat flow through the roofs. Figure 5 compares the average daily energy demand for space conditioning due to heat flow through the rooftop garden and the reference roof. The energy efficiency of the rooftop garden was slightly better than that of the reference roof in fall and winter as the growing medium 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. Once snow coverage was established on the roof, heat flow through both roofs was almost the same.

The rooftop garden significantly outperformed the reference roof in spring and summer. 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 rooftop garden by providing shading, insulation and evaporative cooling. It acted as a thermal mass, which effectively damped the thermal fluctuations going through the roofing system. The average daily energy demand for space conditioning in the case of the reference roof was 6.0-7.5 kWh (20,500-25,600 BTU). However, the growing medium and the plants modified the heat flow and reduced the average daily energy demand to less than 1.5 kWh (5,100 BTU)—a reduction of more than 75 per cent.

Stormwater retention

The rooftop garden delayed run-off and reduced the run-off rate and volume. Figure 6 records the rain events that occurred in a period of 12 hours. The rooftop garden delayed run-off by 45 minutes and absorbed at least 2 mm (0.1 in.) of it before run-off occurred. It reduced the run-off rate by 75 per cent during the first event and retained 45 per cent of the rain with a relatively moist growing medium. These data clearly showed that the rooftop garden replaced the otherwise impermeable roof surface by a permeable substrate, which effectively delayed peak flow and reduced the rate and volume of run-off.

As cities grow, permeable substrates are replaced by impervious structures such as buildings and paved roads. Storm water run-off and combined sewage overflow events are now major problems for many cities in North America. A key solution is to reduce peak flow by delaying (e.g., control flow drain on roofs) or retaining run-off (e.g., rain detention basins). Rooftop gardens can delay peak flow and retain the run-off for later use by the plants.

Conclusions

The initial analysis of the data that has been collected from the field roofing facility suggests rooftop gardens modify temperature fluctuations experienced by roof membranes. This moderation in temperature fluctuations reduces stress on the membrane and can possibly extend its life. Rooftop gardens can also moderate heat flow through the roof through the effects of shading, insulation and evaporation. This reduces the energy demand for space conditioning significantly in spring and summer. In addition, rooftop gardens delay run-off and reduce the run-off rate and volume. These qualities are important in storm water management strategies in big cities. The findings are significant under the current climate regime and they may prove to be of even greater significance in the future when increased variability from climate change is manifested at the regional scale.

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[Small font size, please, for acknowledgments.]

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[Note: Photos courtesy the National Research Council]

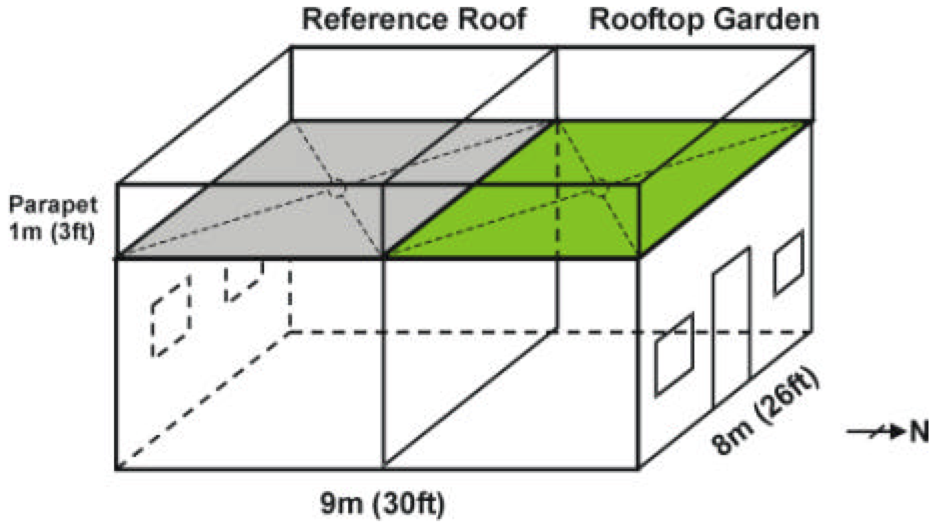


Figure 1 – Schematics of the Field Roofing Facility (FRF) at the NRC campus in Ottawa. Each roof section is structurally sloped at two per cent to a central drain so that run-off can be collected and compared.

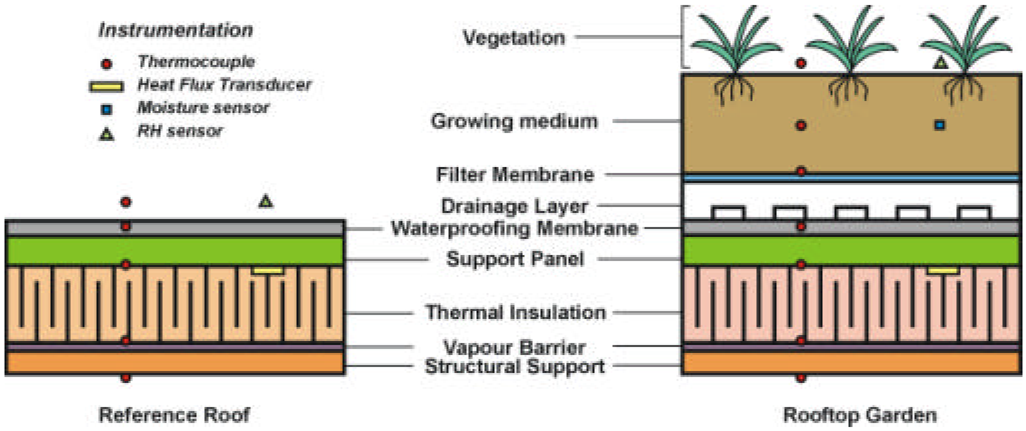
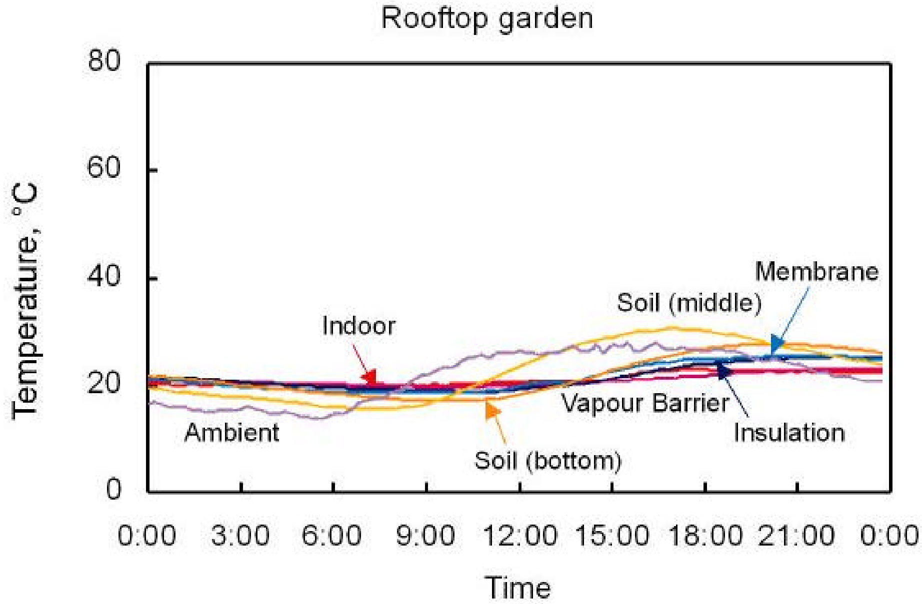


Figure 2 – The components and instrumentation of the rooftop garden and the reference roof.



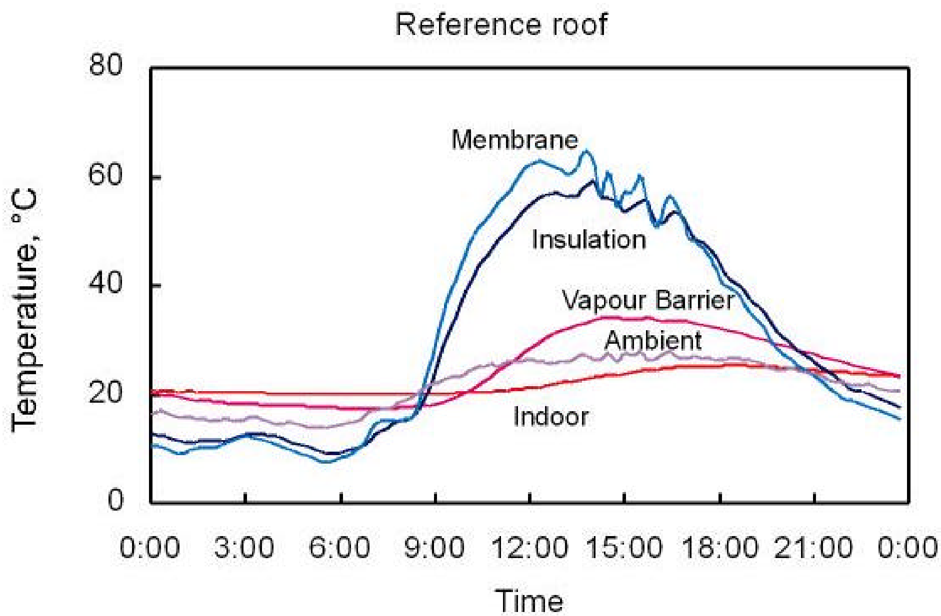


Figure 3 – Temperature profile within the roofing systems on a hot, sunny summer day indicated that the rooftop garden reduced the temperature fluctuations within the roofing system.

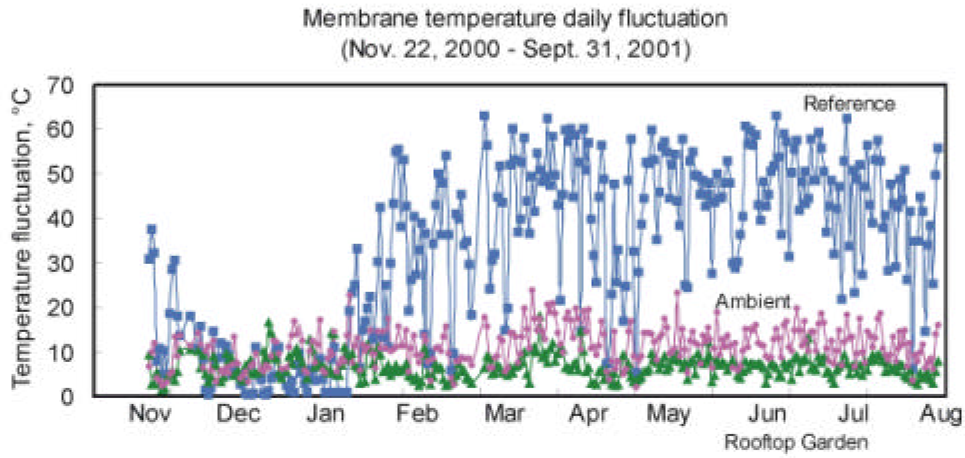


Figure 4 – Temperature measurements showed that the rooftop garden significantly reduced the daily temperature fluctuations experienced by the roofing membrane.

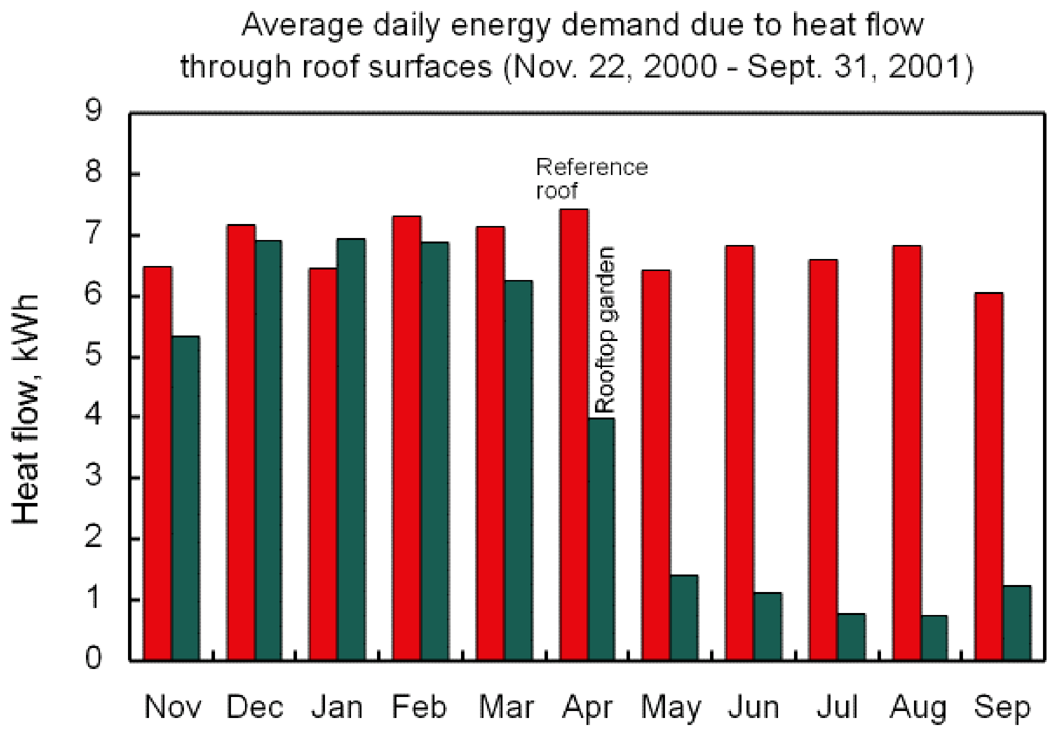


Figure 5 – Heat flow measurement showed that the average daily energy demand due to the heat flow through the rooftop garden was less than that of the reference roof in the spring and summer.

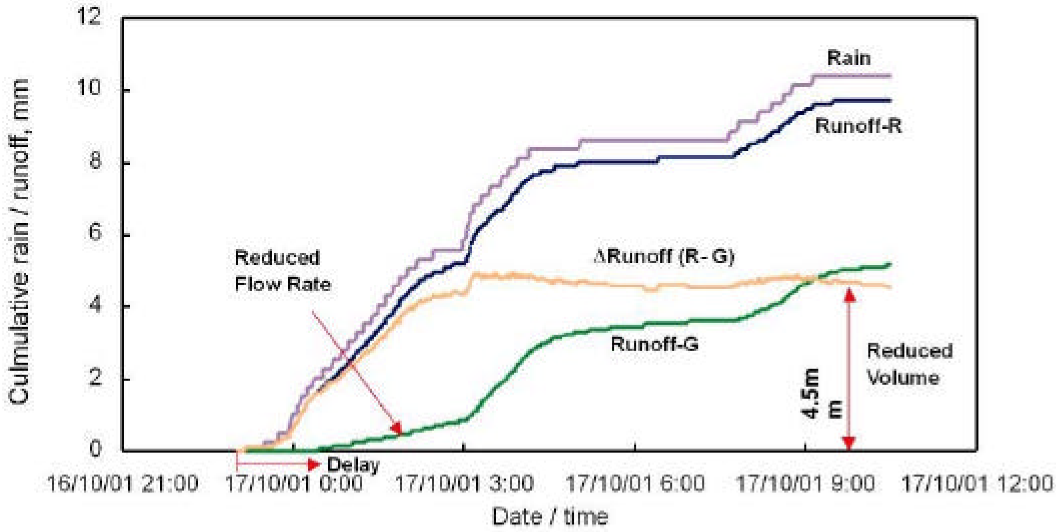


Figure 6 – Measurements during a rain event showed that the rooftop garden delayed run-off and significantly reduced the flow rate and volume of the run-off.

The Field Roofing Facility at the NRC campus in Ottawa. The median divider separates the Green Roof (left) and the Reference Roof (right). The weather station is located at the median divider.

The wildflowers growing on the rooftop garden are either native to Ontario or adapted for the climate zone. Some sedum species were also planted.