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Publisher's version / Version de l'éditeur:

Construction Technology Update, 2005-09-01

Construction Technology Update No. 65

Using Garden Roof Systems to Achieve Sustainable Building Envelopes

By K.Y. Liu and A. Baskaran

There is increasing interest in the garden roof system as a sustainable building design option in North America today. This Update reports the results of a field study to evaluate the thermal performance of this technology, as well as its potential to retain storm water runoff.

Garden roofs, sometimes known as green roofs or rooftop gardens, are specialized roof systems that support vegetation growth. With technical advances in roofing materials and components, garden roof systems can now be successfully installed in most climates, providing an attractive design option, especially in urban areas where land available for parks and green space is limited. As well, concern about sustainability and climate change have led to increased interest in garden roofs as a possible means of helping address these issues. However, while garden roofs are increasing in popularity, there is little information on their performance in cold climates.

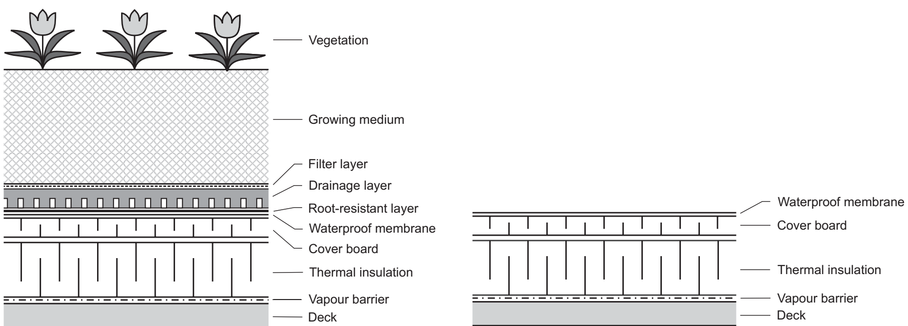

Figure 1. Conventional roofing system (a) with and (b) without a garden roof system.

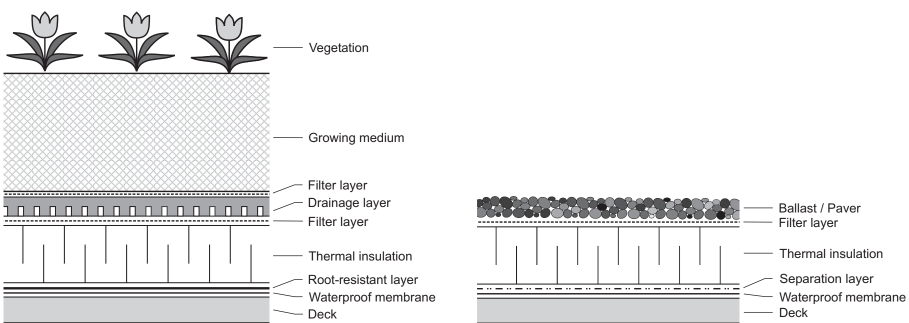

Figure 2. Protected membrane roofing system (a) with and (b) without a garden roof system.

What Constitutes a Garden Roof?

Garden roofs, which can be installed on both conventional and protected-membrane roofing systems (see Figures 1 and 2), require additional components, such as a root-resistant layer, a drainage layer, a filter membrane and a growing medium, to support the growth of vegetation. Typical components and their functions are summarized in Table 1. Garden roofs are generally considered to be "intensive" or "extensive," based on the weight of the system (Table 2).

Published by
Institute for Research in Construction
IRC

Table 1. Typical additional components and their functions in a garden roof system.

Component	Function
Root-resistant layer	To minimize root damage to the membrane. This could be a chemical agent incorporated into the membrane or a physical root barrier, which can be a layer of PVC, polyester or polyethylene.
Drainage layer	To remove excess water from the growing medium. This can be a layer of gravel, specialized polymer foam panels or a highly porous polymeric mat.
Filter layer	To prevent fine particles in the growing medium from clogging the drainage layer. It is a geotextile material.
Growing medium	To support plant growth. The composition and depth depend on the vegetation selected. Artificial lightweight growing media are typically used to replace regular soil in order to reduce structural loading.
Vegetation	Plants should be selected for their adaptability to local climate conditions. An irrigation system might be needed, depending on the specific plants and climate.

Table 2. Classification of garden roof systems by loading requirements.

	Loading				
Classification	Typical weight of system	Typical depth of growing medium	Features and functions	Level of maintenance	Accessibility
Extensive	<300 kg/m^2	<200 mm	Provides ecologically beneficial setting; can be viewed from above or from surrounding buildings.	Low maintenance—little or no irrigation needed when plants have been established.	Limited—seldom entered except for maintenance purposes.
Intensive	>300 kg/m^2	>200 mm	Provides complete garden or park-like features	High maintenance—irrigation and regular garden maintenance required	Accessible—provides green spaces for occupants

Intensive garden roof systems are relatively heavy, with deep soil to support a wide variety of small trees and shrubs. They require a high level of maintenance. Because of the high structural loading involved, intensive garden roofs are normally incorporated into the original building design.

Extensive garden roof systems have a shallow, lightweight growing medium, which can support only small plants such as herbs, grasses and wild flowers. They are intended to be low maintenance, and therefore require plants that are hardy, draught tolerant and preferably self-generating. Because the structural loading demands are low, many existing buildings can be retrofitted to accommodate extensive systems.

Experimental Study

In order to learn more about the performance of garden roofs, NRC-IRC constructed a field roofing facility at its Ottawa campus. This facility is a low-slope industrial roof of about 72 m^2. The roof is divided into two equal sections with an extensive garden roof with grass growing in 150 mm of lightweight growing medium on one half and a modified bituminous roofing assembly on the other (the reference roof). The two sections have the same basic components up to the membrane level, representing a conventional roofing system commonly used in Canada; however, the garden roof incorporates additional elements to support plant growth (Figure 1).

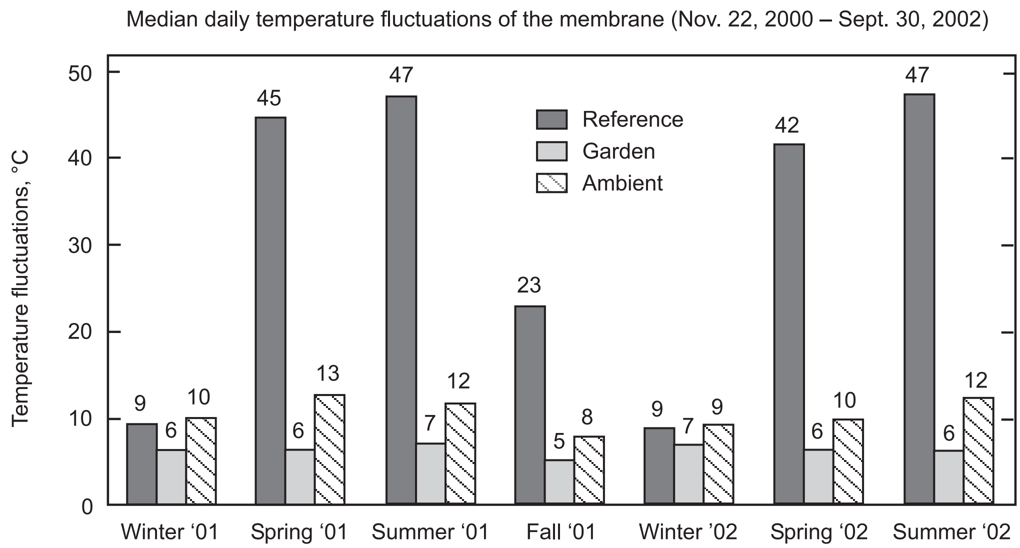

Figure 3. Temperature measurements at the NRC-IRC roofing facility showed that the garden roof significantly reduced the daily temperature fluctuations experienced by the roofing membrane.

Both the garden roof and the reference roof are instrumented to measure the following:

- storm water runoff
- temperature (measured at different layers within the roof system and growing medium)
- heat flow across the roof system
- solar reflectance of the roof surface
- soil moisture content
- rooftop microclimate

Local meteorological conditions such as temperature, relative humidity, rainfall and solar radiation are also monitored continuously by one weather station located on the median divider on the rooftop and another situated approximately 50 m from the site. All sensors and instrumentation are connected to a data-acquisition system.

Results, Findings and Implications

The data collected at the research facility during the first 22 months (November 2000–September 2002) of operation have been analyzed and are summarized below.

Temperature Profiles and Fluctuations

Roofing membranes can be negatively affected by heat exposure, which can accelerate aging in the roofing materials, reducing their durability. Temperature fluctuations can induce thermal stresses in these materials, thus affecting the integrity of the roofing system. In addition, ultra violet radiation can alter their chemical composition and degrade their mechanical properties.

The membrane of the reference roof experienced significantly higher temperatures than the one on the garden roof, especially in the warmer months. On a typical summer day, the exposed membrane on the conventional roof reached 70°C in the afternoon while the membrane of the garden roof remained at around 25°C. In the winter, the temperature profiles for the two roofs were similar because of the insulating effects of the snow coverage.

The membrane of the garden roof experienced significantly smaller daily temperature fluctuations in the warmer months than the conventional roof. During spring and summer, the median daily temperature fluctuation of this membrane was 6°C compared to 45°C for the conventional roof membrane and was consistently lower than the median daily temperature fluctuation of the ambient air (Figure 3).

Clearly, garden roofs can lower the temperature and modify the temperature fluctuations experienced by the roofing membrane. The reduction in temperature can decrease the effects of heat on the roofing materials (premature deterioration), and the moderation in temperature fluctuations can decrease the thermal stress on the membrane. This slower rate of deterioration can

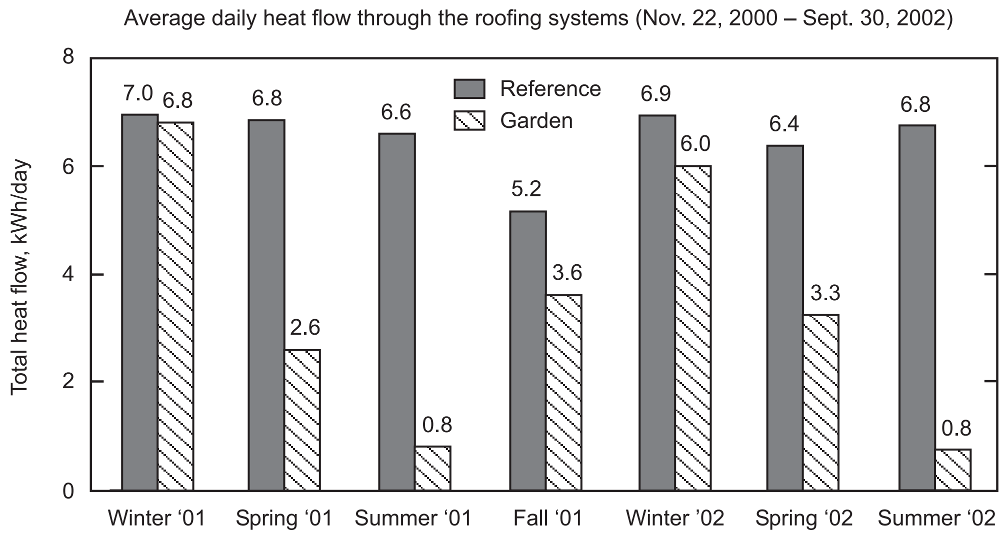

Figure 4. Energy measurements at the NRC-IRC roofing facility showed that the garden roof significantly reduced the average daily heat flow through the roof in the spring and summer.

mean greater durability and an extended service life for the roof membrane. In addition, garden roofs can protect the roofing membrane from exposure to ultra violet radiation and hail.

Heat Flow and Energy Efficiency

During the spring and summer, heat enters a building through the roof in the afternoon as a result of solar radiation and doesn't leave the building until the evening or early morning. This creates a demand for cooling in the building.

In the summer, the heat flow through the reference roof created an average daily energy demand for space conditioning of 6.5–7.0 kWh/day (Figure 4). However, this energy demand was reduced to less than 1.0 kWh/day in the garden roof—a reduction of over 75%, which can be attributed to the presence of the growing medium and the plants.[1-3] These heat-flow values are for the roof only and not for other building envelope components.

The garden roof was more effective in controlling heat gain in the spring and summer than in reducing heat loss in the fall and winter because of the various thermal mechanisms involved—shading, insulation, evapotranspiration and thermal mass. During the observation period, the garden roof reduced heat gain by 95% and heat loss by 26%, with an overall reduction in heat flow of 47% compared to the conventional roof.

Because Ottawa is in a region where the need for heating rather than cooling predominates, the energy savings derived from the use of garden roofs are likely to be relatively small. However, in warmer regions where cooling rather than heating is the main concern, they could be significant.

In general, the energy savings realized with garden roof technology would depend on the climate, the type of heating/cooling mechanisms used in the building, and their particular efficiencies, and the energy sources, which are site specific. However, any reduction in energy demand means a reduction in the green house gas emissions associated with the production of that energy, resulting in positive effects on climate change and the environment.

Retention of Storm Water Runoff

During a rain storm, water rushes off impermeable surfaces such as rooftops and pavements into the storm sewers, causing a sudden surge in the storm water infrastructure. When the amount of runoff exceeds the capacity of the storm sewers, flash floods, and sometimes combined sewage overflows (where water from the storm sewers overflows into the sanitary sewers), can occur, causing environmental and health problems.[4]

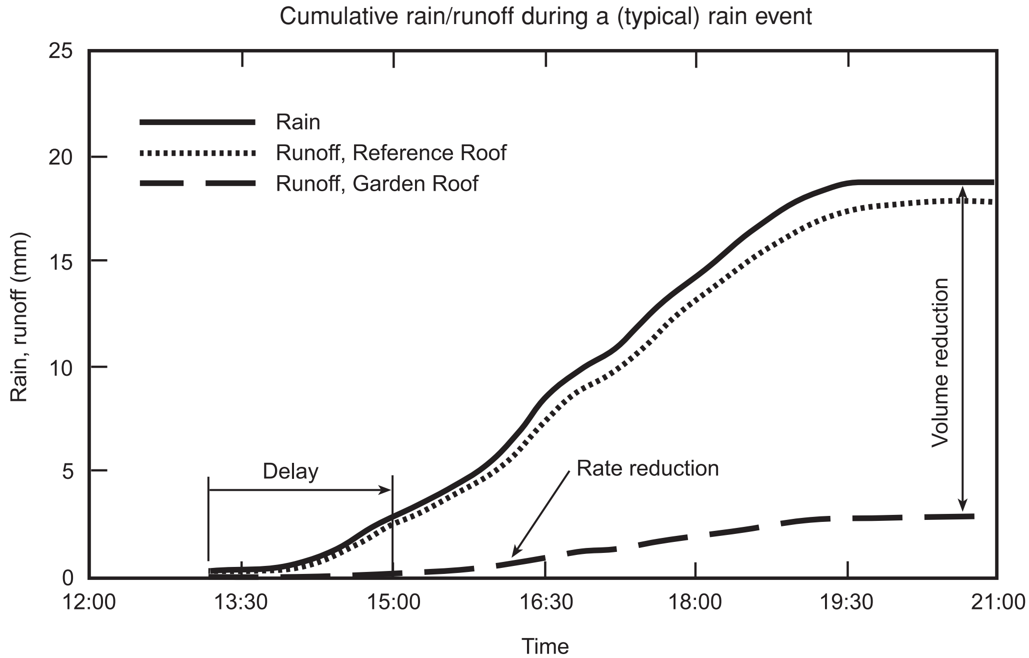

Figure 5. Runoff recorded at the NRC-IRC roofing facility during a rain event showed that the garden roof delayed the runoff, and reduced the flow rate and total discharge volume.

The garden roof delayed storm water runoff, and reduced the peak runoff rate and volume. Figure 5 shows the runoff from both roof areas during a rainfall of 19 mm over 6.5 hours. On the garden roof, the delay in runoff was 95 minutes and the runoff volume was 2.9 mm, a reduction in volume of 85%. Over the course of a year (2002), the garden roof retained (and diverted through evaporation and evapotranspiration) 245 mm of the 450 mm of rain that fell from April through September, an overall reduction in runoff of 54%. It is likely that garden roof systems designed with deeper and more absorbent soil, as well as more vegetation, would retain even more storm water than the system tested by the NRC-IRC researchers.

If the impermeable rooftop of a conventional roof were covered with a permeable layer, this would delay runoff, and reduce the peak flow and total volume going into the sewage system. Thus the "rush hour" in the storm sewer at the beginning of the storm would be avoided, while the reduction in total volume would lessen the load on the sewage infrastructure. The extent of the reduction of storm water runoff when garden roof systems are used depends on many factors such as the intensity of the rain and its duration, and the moisture content of the growing medium before the rain started.

Summary of Potential Benefits

Analysis of the data collected from the roofing facility demonstrated that garden roofs:

- can lower the temperature and modify the temperature fluctuations experienced by the roofing membrane, thereby prolonging its service life.
- can modify heat flow, thereby reducing energy demands for space conditioning, through direct shading of the roof, evapotranspiration and the improved insulation values provided by the growing medium and vegetation.[1-3]
- are more effective in reducing heat gain in the summer than heat loss in the winter because of the thermal mechanisms involved (shading and evapotranspiration), thereby offering the potential of energy savings in climates where cooling is required.
- can delay storm water runoff, thereby reducing peak flow and total volume going into the storm sewers.

Garden roof systems are specialized systems that must be carefully designed. During their construction it is important to coordinate among the various trades. As well, it is recommended that a leak detection test be performed on the membrane both before and after the installation of the overburden (the growing medium and vegetation). Building owners also need to be aware of and committed to the work and costs required to maintain such a system.

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Rooftop Garden Consortium at NRC

The members of the Rooftop Garden Consortium, who have provided financial support and technical expertise in this study, are: Bakor, Canadian Roofing Contractors' Association (CRCA), EMCO, Environment Canada, Garland, Hydrotech, IKO Industries, Public Works and Government Services Canada (PWGSC), Roof Consultants Institute (RCI), Soprema Inc., Tremco; Oak Ridge National Laboratory (ORNL) and the Climate Change Action Fund (CCAF).

September 2005
ISSN 1206-1220

"Construction Technology Updates" is a series of technical articles containing practical information distilled from recent construction research.

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