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Extended Abstract

DESIGN OF A GREEN ROOF WITH INTEGRATED MONITORING EQUIPMENT

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Abstract:
A green roof is planned for construction in 2005 on the south wing of Hamerschlag Hall, a historic signature building at Carnegie Mellon University in Pittsburgh, PA. A detailed monitoring plan has been developed to allow a comprehensive evaluation of green roof performance with respect to stormwater flow and quality, energy use within the building, and the urban heat island effect. The new green roof and an existing roof on an adjacent building will instrumented during construction, and data will be collected for at least one year. The results are expected to demonstrate the feasibility of the monitoring scheme for quantifying the benefits of a green roof.

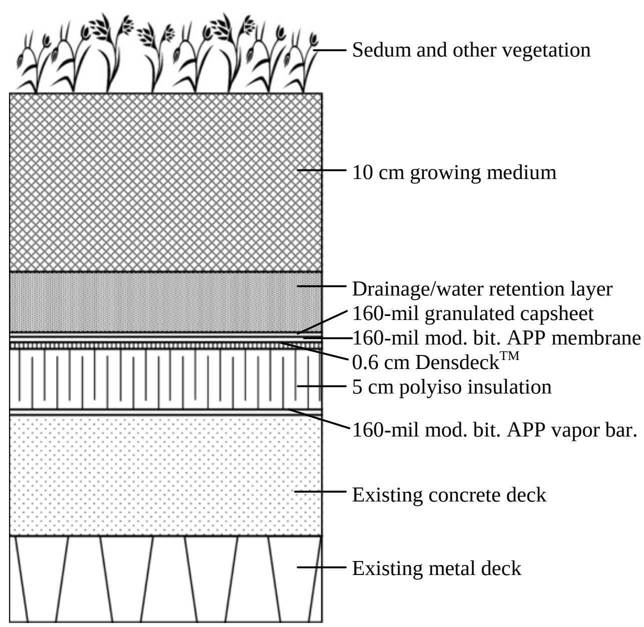
Introduction and Background:

The use of green roof systems is rather new in the U.S., and while myriad benefits have been ascribed to the technology, relatively little measured data are available to support these claims. In addition, since green roofs are dynamic ecosystems, performance can be expected to vary from one season to the next and among different locations due to differences in local climate conditions (temperature ranges, lengths of seasons, rainfall patterns, etc.). Research performed in Ottawa, Ontario by the Institute for Research in Construction (a division of the Canadian National Research Council) has provided the most comprehensive assessment of green roof performance in North America to date.

From 2000 to 2002, the Institute for Research in Construction (IRC) monitored the performance of a 36m^2 extensive green roof with 15 cm of growing medium and a control roof with light gray modified bituminous roofing (1). Both roofs were evaluated with respect to stormwater runoff, heat flow through the roof system, and membrane surface temperatures. The measured data indicate that the green roof reduced peak stormwater runoff by 85%, and reduced total runoff by 54% over a six-month period. Observation over 22 months showed that growing medium and plants of the green roof reduced heat gain by 95% and heat loss by 26% as compared to the modified bitumen roof, with an overall heat flow reduction of 47%. Finally, the green roof significantly moderated the temperature of the roof membrane: while the temperature of the control roof membrane exceeded 50°C for approximately 1/3 of the monitoring period, the temperature of the green roof membrane never exceeded 40°C (2).

By implementing comprehensive monitoring on Hamerschlag Hall, we intend to produce a complete evaluation of green roof performance similar to IRC's Ottawa experiment, but in a quite different climate condition. Hamerschlag Hall is a seven-story building that is approximately symmetric about an east-west axis. A green roof will be constructed on a flat 370 m^2 section of roof on the south wing of the building. The green roof system will be applied on top of the existing concrete and metal decking. Details of the green roof construction are shown in Figure 1.

Figure 1. Green Roof section detail



Approach / Experimental:
Measurements will be performed on an area of about $125m^2$, which amounts to approximately one-third of the green roof. A roof area of equal size on an adjacent building will be used as a control. The control roof was constructed around 1990 and consists of a ballasted rubber membrane with insulation on a concrete deck. This type of roof is typical of replacement and construction operations that are concerned only with first cost. Ambient weather conditions including temperature, solar radiation, and precipitation will be recorded by a weather station on the green roof.

Stormwater flow will be measured using instrumented flumes near two drains on the green roof and one drain on the control roof. Samples of stormwater runoff will be collected for selected storm events and analyzed for dissolved and suspended chemical species.

The effect of the green roof on energy use within the building will be assessed by measurement of heat flow through the roof systems on both the green and control roofs. Bi-directional heat flux sensors installed beneath the membranes on both roofs will measure heat loss though the roof system in the heating season, and heat gain through the roof system in the cooling season. Detailed temperature profiles for both roofs will be developed from temperature sensors installed at several locations within the green roof and at corresponding locations in the control roof, e.g., beneath the concrete deck, between the vapor barrier and insulation, between the Densdeck and membrane, between the capsheet and drainage layer, and between the drainage layer and growing medium. Finally, soil moisture sensors will be installed in the growing medium on the green roof to allow the effect of soil saturation on thermal performance of the green roof system to be assessed.

The urban heat island effect refers to an increase in air temperature in an urban area relative to the surrounding rural or natural areas due to the high concentration of heat-absorbing surfaces such as dark rooftops and pavements. The influence of the green roof on the urban heat island effect will be evaluated by measurements of roof surface temperatures and air temperatures directly above the roof surface on both roofs. Surface temperatures will be measured using non-contact, infrared thermocouples mounted above each roof. Air temperature measurements will be taken by shaded sensors located at a various heights above the roof surface. These measurements will allow us to identify the intensity of heat radiated from the surface of the roof into the atmosphere.

Results and Discussion:
Based upon the results of previous green roof research in locations with a similar amount of annual rainfall (Ottawa and Toronto, ON), we expect that the Hamerschlag green roof will reduce the total amount of stormwater runoff by roughly half over the annual cycle. Variations by season are expected. Previous research has indicated that substances present in the green roof growing medium (eg.,phosphorus, nitrogen) leach out in stormwater runoff, so we expect that runoff from the green roof will contain higher levels of these substances, at least initially.

The green roof is expected to significantly reduce the amount of summer heat gain—and as a result, cooling demands in Hamerschlag Hall—by supplying shading, insulation and evaporative cooling. The effect of the green roof in the heating season is expected to be small, but will depend upon a variety of factors such as soil saturation and consequent increases in conductivity of the growing medium as well as the freeze-thaw cycle of the medium. Similarly, the performance of the green roof in spring and fall is expected to be driven by climatic trends and events.

Since green roofs can reduce the roof surface temperature by shading and evapotranspiration, we expect that this temperature will be significantly lower on the Hamerschlag Hall green roof than on the control roof. However, it is unclear to what extent this will translate into a moderation of temperature of the air surrounding the roof. Previous research has not attempted to quantify this phenomenon in the field, but has instead relied on computer modeling to address the impact of green roofs on the urban heat island effect.

Summary and Conclusions:
Data will be collected from the green and control roofs for at least one year, yielding a dataset that will quantify the benefits of the green roof system. This data will be among the most comprehensive in the United States to date, and will support realistic life-cycle costing for green roofs. The methodology and results should prove useful to other researchers who wish to examine green roofs, whether as a monitoring standard for similar research in different climates or for research oriented toward specific aspects of green roof performance.

References:

1. Liu, K. and B. Baskaran (2003) Thermal Performance of Green Roofs through Field Evaluation. In Proceedings of the First North American Green Roof Infrastructure Conference, Awards and Trade Show, Chicago, IL, May 29-30, 2003, pp. 1-10.

2. Liu, K. (2004) Sustainable Building Envelope—Garden Roof System Performance. 2004 RCI Building Envelope Symposium, New Orleans, L.A., Nov. 4-5, 2004, pp. 1-14.