



# A DECISION-MAKING APPROACH TO GREEN ROOF SYSTEM DESIGN

By Elizabeth J. Grant and James R. Jones, PhD

## ABSTRACT

Designing a green roof is a challenging proposition. Selecting an appropriate vegetated roofing system can be an exceedingly complex task due to the number of factors involved. A framework is needed to streamline this decision-making process. This paper discusses the creation of a framework describing the decision process involved in the design of vegetated roofing systems. Through a series of interviews with experts and case studies of built projects, the available knowledge is being captured and organized in order to determine the critical parameters affecting design decisions. An initial set of six case study projects in North America has been analyzed, and six critically important evaluation categories were identified: stormwater management, energy consumption, acoustics, structure, cost, and compliance with regulatory guidelines and governmental incentives. These six factors are addressed individually and in interaction with one another in the context of a decision support system for green roof designers. A weighted environmental index is used to determine the most feasible green roof systems for a particular project. The decision-making framework described in this paper will ultimately be adaptable to digital processing and a computer-based design assistance tool.

## THE DESIGN PROCESS

The demand for vegetated roofs in North America is growing. Spurred in part by the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) program and other green building initiatives, many owners and designers are looking to green roofing as a strategy to minimize the negative influence of a building project on the environment. In Germany, significant research into the performance of green roofs, and governmental and industry support of this technology, have led to its widespread use. In North America, many practitioners are now being called upon to include green roofs in their project designs. A decision support system is needed to assist these designers in comparing the suitability of various vegetated roofing systems in the context of specific projects.

When commissioned to design a green roof, design professionals rely on building codes, industry sources, local trends, and conventional wisdom, as well as their own experience. Unfortunately, many of these sources have not yet significantly incorporated green roofing technologies and do not typically represent a comprehensive picture of the information available to assist in the design process. The creation of a framework for vegetated roof system selection constitutes the first step in the effort to collect, organize, and present the available knowl-

edge on green roofing in North America in a form that is readily usable by designers of green roofing systems for a given locale and climate region. The framework will address many of the possible benefits, as well as potential pitfalls of green roofing in an effort to provide a broad view of the possibilities and limitations inherent in these systems.

Design frequently involves a series of trade-offs to obtain the "optimal" solution to a design problem. Green roofs have many different characteristics based on a variety of parameters. One of the most critical of these, depth of the system, is used to distinguish an *extensive* green roof (typically with 6" or less of growing media) from an *intensive* green roof (typically with more than 6" of growing media). In the design of green roofs, one example of a design trade-off would be balancing increased roof runoff retention, thermal mass, and sound insulation benefits gained from specifying a deeper system against the increased cost of providing adequate structural capacity in the roof deck and additional growth media.

Roof system designers typically weigh factors like these using intuition or past experience as a guide. But since vegetated roofing is a relatively complex and comparatively new technology to many practitioners, an explicit rational method to help organize and rank the tradeoffs made during the design process would be useful.

Because it evaluates green roof performance in light of multiple parameters, both in isolation and in combination, the decision-making framework will allow designers to make appropriate, informed design decisions about the type of systems to implement on building projects. They will be assisted in creating roof systems that go above and beyond the stipulations of codes and industry standards. By focusing on the environmental impact of various roofing systems, the decision-making framework for vegetated roofing system selection will help designers provide more ecologically sound solutions for building owners.

#### SUMMARIES OF SIX EVALUATIVE CATEGORIES AND CASE STUDY OBSERVATIONS

Six initial case study projects listed below were evaluated to determine key design criteria for inclusion in the framework for vegetated roofing system design. The case study projects were selected to represent a range of building types, locations, and owner considerations. Additional case studies are underway to broaden the findings.

- Montgomery Park Business Center, Baltimore, MD (2002)
- Life Expression Chiropractic Center, Hazleton, PA (2001)
- Chicago City Hall, Chicago, IL (2001)
- Ford Dearborn Truck Assembly Plant, Dearborn, MI (2002)
- Mountain Equipment Cooperative (MEC), Toronto, ON (1998)
- Jordan N. Carlos Middle School Art Building, Woodward Academy, Atlanta, GA (2004)

In order to develop a useful framework for green roofing design, it is necessary to sort the pertinent design parameters into a manageable number of elements. Six such elements have been identified based on driving concerns raised in the analysis of the case study projects and on discussions with green roof designers and building owners. The main issues relevant to each parameter are summarized here, along with available rules of thumb or other methods for evaluating vegetated roofing systems' performance relative to each parameter. This is followed by a brief discussion of how these criteria are manifested in the examined case study projects.

#### Stormwater

Vegetated roofing systems may be conceptualized as a means to replace much of

the permeable ground that has been displaced by buildings and paved surfaces. Green roofs reduce both the quantity and flow rate of water entering sewer systems, which in urban, densely populated areas, can become overtaxed during storms<sup>1</sup>. Filtration of stormwater occurs as the water slowly passes through the layers of the green roof assembly.

According to Katrin Scholz-Barth<sup>2</sup>, a typical extensive green roof retains an average of 75% of incident rainwater, while the remaining 25% is released as run-off, with a substantial time delay that effectively reduces the peak flow to be accommodated by stormwater management systems. These rule-of-thumb figures vary in response to a variety of factors, including the time of year, the duration and intensity of storms, and the moisture content of the soil prior to storm events<sup>3</sup>.

Studies are in progress, such as the Green Roof Infrastructure Technology Demonstration Project in Toronto, to determine the effects of the depth of a green roof on its efficacy as a stormwater control system. Research is also currently underway at a variety of sites to determine the water quality benefits of green roofs, and these performance criteria will be incorporated into the framework as they become available.

Several of the case study projects illustrate how green roofs are used as a component of stormwater management systems. The two green roofs at Montgomery Park were designed primarily as stormwater mit-

igation devices that reduce the impermeable area of the existing site. The same is true on a smaller scale at the Life Expression Chiropractic Center (*Figure 1*), where the green roof intercepts and delays the flow of incident rainfall, allowing it to flow through a gapped fascia at the eaves. The green roof on Ford's new truck assembly plant at the Rouge complex is also part of a comprehensive plan to manage stormwater. [Editor's Note: See "Ford Rouge Center Dearborn Truck Plant Green Roof Project, February 2004 *Interface*.] The roof is expected to prevent 447,000 gallons per year, or 50% of the rainfall incident on the roof, from entering the storm sewer<sup>4</sup>. The modular green roof installed atop the middle school art building at the Woodward Academy contributes to stormwater management on the site. The green roof slows the rate and reduces the volume of run-off to be held in a concrete tank located beneath the parking lot before it is slowly released to the city's storm sewer system.

#### Energy

Vegetated roofing systems lower the ambient temperature at the roof surface through the processes of evaporation and transpiration, as well as through air convection and shading provided by the plants. The soil medium and air trapped within the plant layer are believed to provide some degree of thermal insulation, but this effect is dependent on climate and soil moisture and is difficult to quantify. Intensive green



Figure 1 - Life Expression Chiropractic Center, Hazleton, PA.

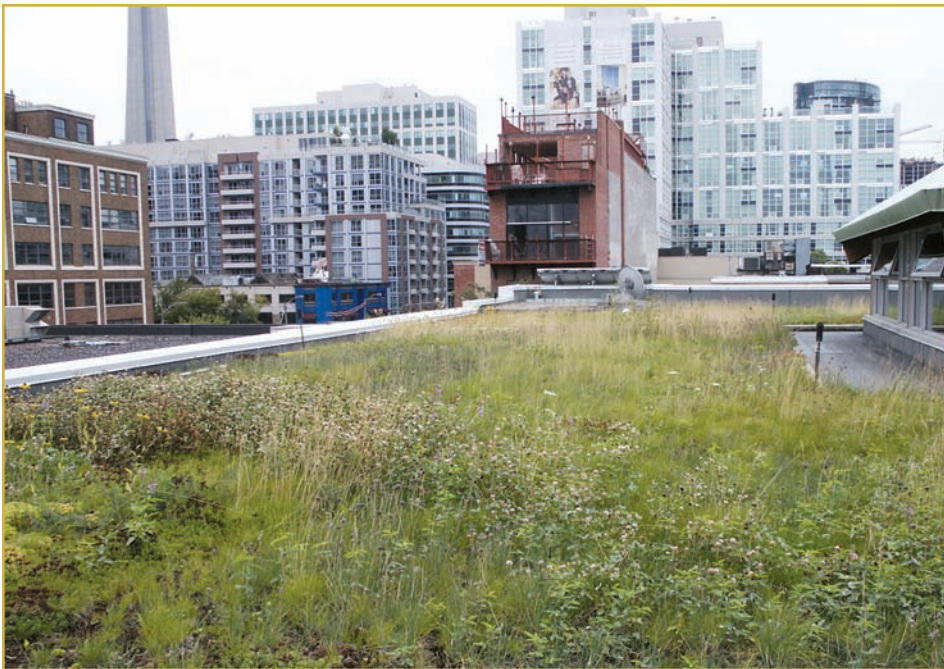


Figure 2 - Mountain Equipment Cooperative (MEC), Toronto, ON.

roofs of significant depth also possess thermal mass properties that moderate and delay the effects of outdoor temperature swings on the building's internal temperature.

Christopher Wark of SHADE Consulting, LLC<sup>5</sup> has established a method to estimate the "Q" value of green roofing systems, a calculated value that gives some indication of their overall energy performance relative to one another and to traditional roofing. A factor such as this will be a useful performance criterion in evaluating green roof systems.

The potential for energy savings also often motivates owners to install green roofs. At both the Life Expression Chiropractic Center and the Toronto MEC store (Figure 2), the green roof generally lowers air temperatures above the roof surface as compared with traditional roofing, potentially lowering temperatures at the roof membrane and inside the building. Unfortunately, it is often impossible to isolate the thermal effects of the green roof from the thermal effects of building insulation incorporated into the roof assembly. Additionally, both temperature and heat flow reduction are difficult to quantify in the absence of monitoring equipment, which was the case for most of the case study projects.

The green roof atop Chicago City Hall, however, was fitted with thermal data collection equipment. The roof garden there is projected to save the city \$3,600 in heating

and cooling per year<sup>6</sup>, or \$0.18 per square foot of green roof per year.

Vegetative solar shading at the roof and walls of Ford's new truck plant minimizes heat gain. According to Green Roofs for Healthy Cities, the project's engineers expect the green roof to reduce energy use by seven percent<sup>4</sup>. To help verify these claims, Ford has recruited experts from governmental organizations and the University of Michigan to collect and interpret building performance data<sup>7</sup>.

Daniel Bedard, construction manager at the Woodward Academy, expects the thermal benefits of the green roof on the art building to offset, at least in part, the higher cost of green power purchased by the school in the form of renewable energy certificates. These certificates support the use of wind, landfill natural gas, and solar energy sources. In all cases, further study is needed to determine the energy benefits to be derived from green roofs.

## Acoustics

In addition to providing hydrological and energy benefits, green roofs also possess certain desirable acoustical properties. Several green roofs have been implemented in the vicinity of airports to protect against noise transmission. A report by Roofscapes, Inc.<sup>8</sup>, a Philadelphia-based green roof provider, describes the use of green roofs on structures lying in the flight path of airplanes as a measure to minimize the effects of expansion at the airport in Frankfurt, Germany. Similarly, the Gap 901 Cherry project in San Bruno, California, designed by William McDonough + Partners, is claimed in the Green Roof Awards of Excellence<sup>9</sup> to attenuate noise from the nearby San Francisco airport by up to 50 decibels by virtue of the mass of its growing media. Peck, Callaghan, Kuhn and Bass<sup>10</sup> cite a German study by Minke and Witter<sup>11</sup> demonstrating that a green roof with a 12-cm (5-inch) substrate layer can decrease noise transmission by 40 decibels, while a 20-cm (8-inch) substrate layer can decrease noise transmission by 46 decibels. Peck *et al.*<sup>10</sup> also state that the growing medium dampens the effect of low-frequency noise while the plants themselves block high-frequency noise. Based on rules of thumb such as these, it will be possible to rate various green roof systems based on their ability to reduce noise.

## Structure

Structural loads frequently are controlling factors in green roof design. A variety of lightweight manufactured growing media have been developed to minimize green roof weights while providing sufficient depth to sustain plant life. Particularly with intensive systems, plant weights must also be taken into consideration when determining



Figure 3 - Chicago City Hall, Chicago, IL.

green roof system loads. In addition, green roof systems must resist the wind loads present at the roof surface. Strategies for wind resistance include parapet walls and photodegradable mesh used to protect the plants and growing media from wind scour until the plants are fully established<sup>12</sup>. Structural loads are fairly easy to quantify; lighter green roof systems are generally preferred over heavier systems due to their compatibility with typical roof construction in North America. However, any index of performance must also take into account the effects of wind on plants and the potential for roof membrane uplift. More robust, heavier systems or systems with protective meshes or other devices will likely perform better, especially during the critical plant establishment phase. A composite index reflecting both a green roof system's contribution to vertical loading and response to wind loading will need to be established.

Structure was viewed as a controlling factor in most of the case studies, limiting the weight of the green roof system and, therefore, the depth of media and type of plants selected.

At Montgomery Park, because the 20,000 s.f. green roof was installed over an existing train shed, weight considerations controlled the design and required the existing steel roof framing to be structurally augmented. The green roof system used has a saturated weight of only 18 pounds per square foot (psf)<sup>13</sup>.

The design of the roof garden at Chicago City Hall (*Figure 3*) reflects the structure of the existing roof deck. According to Kevin Laberge, environmental engineer with the city of Chicago, the trees located in the intensive planting areas (18" deep) are centered over building columns, while semi-intensive planting areas (4 - 8" deep) are situated in raised beds that coincide with former skylights. The remainder of the roof garden is extensive (3 - 4" deep). According to project specifications, the maximum allowable structural loads within these planting areas are 90 psf, 75 psf, and 30 psf, respectively. To avoid overloading the existing structure, polystyrene insulation above the roof membrane was used to create the contours of the garden.

At the Woodward Academy's new art building (*Figure 4*), load constraints on the roof structure limited the green roof load to 35 psf, according to R. Alfred Vick (personal communication, September 23, 2004), the project's landscape architect. The growing medium was saturated with water and

subjected to a load test to determine the maximum allowable depth of 6-1/2". The green roof modules were installed above 3" of gravel ballast to prevent roof membrane uplift, which is especially critical in the absence of a parapet wall at the perimeter.

### Cost

The price of green roofing varies widely, depending upon the system selected, the local availability of material and labor, and the accessibility of the project to the green roof installer, among other factors. Green roofs that are touted as economically com-

petitive are frequently proven to be so when subjected to a life cycle cost analysis that takes into account the expected longer life of the green roof when compared with a traditional system, as well as the avoided costs of energy and stormwater management and any other financial incentives. A methodology for life cycle cost analysis including initial, replacement, and maintenance costs will be included in the design of the framework.

Cost was perhaps the most complex parameter investigated in the case study projects and was often tied to compliance



RCI, Inc.  
800-828-1902  
[www.rci-online.org](http://www.rci-online.org)



Figure 4 - Jordan N. Carlos Middle School Art Building, Woodward Academy, Atlanta, GA.

with governmental or other incentives. The Ford Motor Company hired William McDonough + Partners to assist in the revitalization of the Ford Rouge complex (Figure 5), a project slated to take 20 years and cost \$2 billion. McDonough estimates that the green roof alone saved the company \$5 million by avoiding the construction of a new stormwater treatment plant, which would have otherwise been required<sup>7</sup>. In many of the projects, cost was intertwined with other factors, such as the desired thermal benefits of the system or the need to upgrade the roof structure to support a green roof. Performance goals for the green roof were often balanced with the need to specify a system that would meet budget constraints. Further investigation is needed to derive meaningful relationships between cost and other parameters.

### Compliance

When considering the viability of green roofing in North America, governmental incentives and regulatory requirements frequently become an important factor in the decision to employ vegetated roofing on a particular building. The U.S. Green Building Council's Leadership in Energy and Environmental Design program has catalyzed the use of green roofs on projects seeking certification. LEED itself is a numerical tool that can be used to rank project alternatives, but in this framework, LEED point ratings will be incorporated into a constructed attribute scale that will also

measure the capacity of green roofing to meet other governmental incentives and to meet various code stipulations.

In the case study projects, code requirements often supported the use of green roofing as a measure to improve the quality of the urban environment.

The Montgomery Park Business Center's green roof was part of a larger set of strategies that led to the project winning the U.S. Environmental Protection Agency's Phoenix award for excellence in brownfield redevelopment. The green roof met the Code of Maryland Regulations stipulating that all redevelopment projects must reduce exist-

ing site imperviousness by 20%, provide water quality control for 20% of the site's impervious area, or employ a combination of these strategies<sup>14</sup>.

The green roof at Chicago City Hall was the initial demonstration project of the Chicago Department of Environment's Urban Heat Island Initiative<sup>6</sup>. Results of the project include guidelines for future green roof projects in Chicago, a performance specification for green roofs, and data demonstrating environmental benefits.

Building codes also limit the use of green roofs as occupied space in some cases. Access to both Chicago City Hall's green roof and the modular green roof system on the art building at the Woodward Academy in Atlanta is limited to maintenance personnel and escorted visitors due to liability considerations in the absence of a parapet or railing at the roof edge of both projects.

### THE STRUCTURE OF THE FRAMEWORK

The decision-making framework is a calculation of the positive influence of various green roof systems on the environment as compared with one another and with a reference (non-vegetated) roof. Designer system inputs include specific information about the project and weight factors to account for the importance of different green roof parameters according to the perspective of the individual using the framework. For example, if the site is located near a busy airport, the acoustic performance might be given more weight than for another, more rural site. The body of the framework is a set of functions that assigns value



Figure 5 - Ford Dearborn Truck Assembly Plant, Dearborn, MI.

to the characteristics of the different green roof system types on a cardinal scale. These value functions are being drawn from available research and data collected from green roof sites in North America and from applicable industry rules of thumb such as those discussed above. Output from the framework will consist of a series of non-dominated solutions drawn from a set of green roof system types available in North America. The structure of the framework is depicted in *Figure 7* and described in more detail below.

*Figure 7* is an influence diagram of the decision situation a roof designer faces when selecting a green roofing system type for a particular project. The diagram can be divided into user inputs, framework calculations, and framework output. Inputs are represented by rectangles in *Figure 7*, with initial inputs shown in bold type. First, the project location and characteristics are determined. Project location is a key input to the decision-making framework, as it establishes the values of the climate, utility, and code variables that affect the outcome of the decision. The reference roof type and characteristics such as roof size, building use, and site classification as urban, sub-

urban, or rural are also initial inputs to the framework. The reference roof type can be defined as the green roof system minus its green roof components and most commonly consists of the layers from the roof deck up

to the waterproof membrane. Separately considering the green roof and the reference roof in this manner allows the designer to isolate the effects (both positive and negative) of the green roof system. This is partic-



*Figure 6 - Montgomery Park Business Center, Baltimore, MD.*



RCI, Inc.  
800-828-1902  
[www.rci-online.org](http://www.rci-online.org)

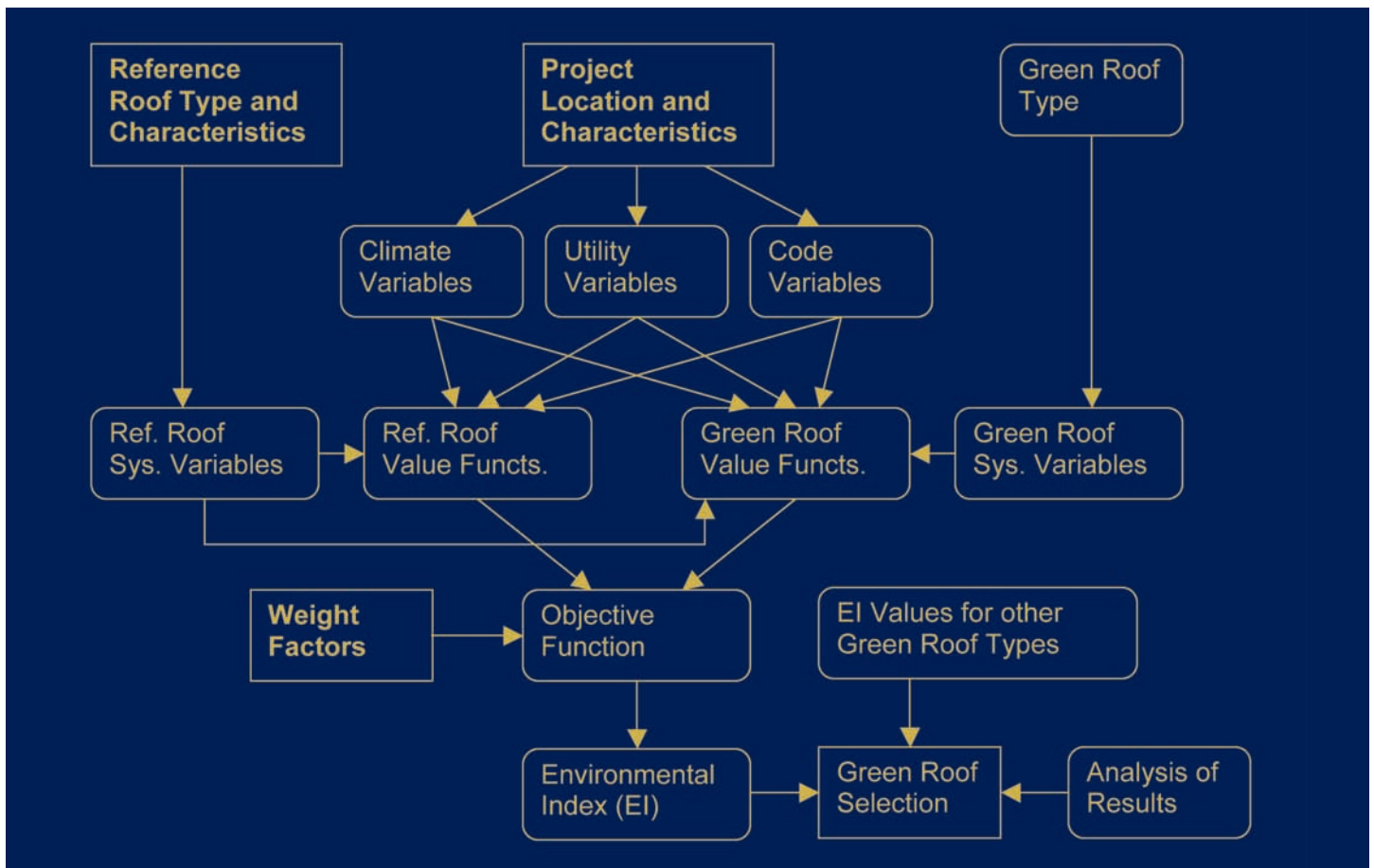


Figure 7: Influence diagram of vegetated roofing design decision process.

ularly helpful when assisting an owner in justifying the decision to use a green roof.

Finally, the designer, often in cooperation with the owner, must establish the importance of each green roof parameter by assigning it a weight factor. A library of default weight factors, determined by a survey of green roof experts, is being included in the framework. Because green roofs are considered desirable for different reasons, depending upon the perspective of the building owner and the location of the project, different sets of weight factors are

being made available for selection by the designer. The framework is also being equipped with a library of 20 to 30 green roof types representing a variety of extensive and intensive systems. Values for each of these green roof systems are automatically input into the framework.

Once these inputs are established, they are processed through a set of equations that assign a weight and a value to each parameter. These functions are represented by rounded rectangles in Figure 7. The objective function yields an environmental

index that gives a numerical value to each of the green roof types considered, as compared to the reference roof. The environmental index is based on the Battelle Method<sup>15</sup>, an evaluation system that was originally developed to rank various water resource management projects. The environmental index is calculated as shown in Equation 1<sup>16</sup>.

In this case, each environmental quality parameter is one of the six contemplated criteria: stormwater, energy, acoustics, structure, cost, and compliance. Figure 7 depicts the process whereby the framework evaluates one green roof system at a time, comparing it with the reference roof selected by the designer. The framework will reiterate multiple times, using calculated values for each of the green roof system types within its library, and yielding results for each.

The output of the framework will be a list of feasible solutions to the design problem. Because of the complexity of the analysis, it is unlikely that one solution will best satisfy all six evaluative criteria. Therefore, the weight factors assigned by the designer will be used to determine which roof system

$$EI = \sum_{i=1}^m w_i [(V_i)_1 - (V_i)_0]$$

Equation 1

where EI is the environmental index,

$w_i$  is the relative weight of parameter  $i$ ,


$(V_i)_1$  is the environmental quality of parameter  $i$  with the project,

$(V_i)_0$  is the environmental quality of parameter  $i$  without the project, and

$m$  is the total number of parameters<sup>16</sup>.

type or types will be recommended. For example, a thin extensive system might be less expensive and less structurally demanding than a somewhat thicker intensive system that provides greater run-off reduction. If the user has valued low first cost and minimal structural impact more highly than stormwater mitigation benefits, it is likely that the thinner system will be chosen in this hypothetical example.

Coupled with his or her own intuition, observations, and judgment, the results of the rational decision-making approach will guide the designer in choosing a system that will effectively meet the project's constraints and opportunities.

One future goal for the framework is to replace the library of existing green roof system types with an interface that would allow a designer to generate a fully customized roof system. Another is to add data and lessons learned from additional green roof projects to continue to refine the framework. The ultimate goal of this research into the process of green roofing design is the creation of an interactive, computerized tool to assist roof designers in the selection of vegetated roofing systems. 


#### ACKNOWLEDGEMENTS

The authors would like to acknowledge GreenTech and the National Roofing Foundation for their financial support of this research. This research is being conducted in cooperation with the Center for High Performance Learning Environments (CHPLE) at Virginia Tech.

1. Solomon, N. B., "Vegetation Systems Atop Buildings Yield Multiple Environmental Benefits," *Architectural Record*, March 2003, pp.149-152, 154, 156.
2. Scholz-Barth, K., "Green Roofs: Stormwater Management from the Top Down," *Environmental Design and Construction*, January/ February 2001, pp. 63-69.
3. Liu, K., "Engineering Performance of Rooftop Gardens through Field Evaluation," *Interface*, February 2004, pp. 4-12.
4. Green Roofs for Healthy Cities, "Green Roof Awards of Excellence: Gala Awards Program," *The Second Annual Green Roof Infrastructure Conference, Awards and Trade Show*, Portland, 2-4 June 2004, The



RCI, Inc.  
800-828-1902  
www.rci-online.org



# ROOF KNOWLEDGE ASSESSMENT

Test your knowledge of roofing with the following metal roofing questions, developed by Donald E. Bush Sr., RRC, FRCI, chairman of the RRC Examination Development Subcommittee.

The sources for this month's column are NRCAs's *Energy Manual*, and ASHRAE 90.1.

1. A new low-slope roof system is being installed with a 1/4"/ft. roof slope. The roof slopes north to south and south to north to a drain valley that equally divides the area to be drained. The drain valley is dead level and has two drains, one at each end of the drain valley. A cricket with 1/2"/ft. slope is to be installed between the drains. The cricket will be 60 ft. long and 30 ft. wide. What will the slope to drain be at the drain lanes of the cricket?
2. How many board feet of insulation are required to build a 1/2"/ft. tapered cricket that is 60 ft. long and 30 ft. wide for the roof described in Question #1? (Assume a minimum insulation thickness of zero.)
3. Determine the design temperature of the vapor retarder of a roof assembly that consists of a gravel-surfaced, built-up membrane over two layers of insulation with a total thermal resistance of 10.0 over a 5"-thick structural concrete deck (R=0.25). The design interior temperature (T) is 75°F and the design outside temperature is 0°F.

Component	ER	ER <sub>t</sub>
Outside Air Film	0.17	
Built-up Membrane	0.33	
Insulation	10.00	
Vapor Retarder	Negligible	
Concrete Deck	0.25	0.25
Inside Air Film	0.60	0.61
	<b>ER 11.36</b>	<b>ER<sub>t</sub> 0.86</b>
4. A new low-rise commercial building is being designed that will be located in Chicago, Illinois. The building will be both heated and air conditioned. Determine the required overall thermal transmittance (U<sub>oa</sub>) of the roof system according to the ASHRAE 90.1 calculation method.

For Chicago, Illinois  
HDD65 = 6151  
CDD65 = 1015  
CDH80 = 3190

Fundamental Equation - U<sub>oa</sub> = 5.3 + (0.0018 x HDD65) + (0.0013 x CDD65) + (0.00026 x CDH80)

**Answers on page 20**

# ROOF KNOWLEDGE ASSESSMENT

Answers to questions on page 19:

1.  $a^2 + b^2 = c^2$

$15^2 + 30^2 = 1125$

$\sqrt{1125} = 33.54 \text{ ft} = \text{length of drain lane}$

$1/4 \times 15 = 3.75$

$\frac{3.75}{33.5} = \frac{1}{8.9} = \text{slope along drain lanes}$

Ref: NRCA Energy Manual and basic geometry.

2. (total area of cricket) (average insulation thickness) = cubic feet of insulation

(Cubic Feet) (12) = board feet of insulation

$900 \times .625 \times 12 = 6750 \text{ board feet}$

Ref: NRCA Energy Manual

3. Fundamental Equation =

$$T_{vr} = T_i - \left[ \left( \frac{ER_1}{ER} \right) T_i - T_o \right]$$

$$75^\circ\text{F} - \left[ \left( \frac{0.86}{11.36} \right) 75^\circ\text{F} - 0^\circ\text{F} \right]$$

= 69.375 or 69°F

Ref: NRCA Energy Manual

4. 18.52° F \$ ft² \$ h/BTU

Ref: NRCA Energy Manual and ASHRAE 90.1.

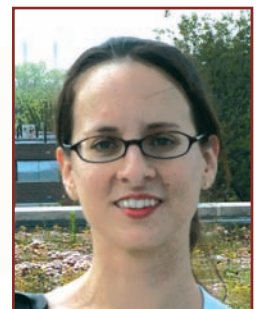
City of Portland and Green Roofs for Healthy Cities, 2004.

- Wark, C., "Finding the 'Q-value' of Your Green Roof," *The Green Roof Infrastructure Monitor*, Volume 6, Number 1, 2004, pp. 12, 18.
- Weston, *Urban Heat Island Initiative Pilot Project, City Hall Green Roof Final Report*, Roy F. Weston, Inc., 1999.
- Litt, S., "Some Sustainability Required," *Architecture*, May 2004, pp. 52-59.
- Roofscapes, Inc., "Roof Benefits," *Roofscapes, Inc.: Green Technology for the Urban Environment*, <http://www.roofmeadow.com/pdf/Benefits.pdf>, August 9, 2004, 2002.
- Green Roofs for Healthy Cities, "Green Roof Awards of Excellence: Profile of Award Winners," *The First Annual Green Roof Infrastructure Conference, Awards and Trade Show*, Chicago, May 29-30, 2003, the City of Chicago and Green Roofs for Healthy Cities, 2003.
- Peck, S. W., Callaghan, C., Kuhn, M. E., and Bass, B., "Greenbacks from Green Roofs: Forging a New Industry in Canada," *Canadian Mortgage and Housing Corporation Research Report*, 1999.
- Minke, G. und Witter, G., *Haeuser mit Gruenem Pelz, Ein Handbuch zur Hausbegruenung*, Verlag Dieter Fricke GmbH, Frankfurt, 1982.
- Miller, C., "Updating the Sod Roof: A German-style Ecoroof finds a Home in Suburban Pennsylvania," *Landscape Architecture*, Volume 92, Issue 11, 2002, pp. 30, 32.
- Maryland Department of the Environment, *Green Building Features of Montgomery Park*, MDE, Baltimore, Maryland, 2004.
- Maryland Secretary of State, "26.17.02.05: When Stormwater Management is Required," *Code of Maryland Regulations*, [www.dsd.state.md.us/comar/26/26.17.02.05.htm](http://www.dsd.state.md.us/comar/26/26.17.02.05.htm), August 10, 2005.
- Dee, N., Baker, J., Drobney, N., Duke, K., Whitman, I., and Fahringer, D., "An Environmental Evaluation System for Water Resources Planning," *Water Resources Research*, Volume 9, Issue 3, 1973, pp. 523-535.
- Dandy, G. C. and Warner, R. F., *Planning and Design of Engineering Systems*, Unwin Hyman, London, 1989, p. 138.

A version of this paper was originally presented at the Green Roofs for Healthy Cities conference, May 2005, in Washington, DC, and published in the 2005 Greening Rooftops for Sustainable Communities Conference Proceedings. It is reprinted here with permission.

## Elizabeth Grant

Elizabeth Grant is a doctoral candidate in the Environmental Design and Planning program at the College of Architecture and Urban Studies at Virginia Tech. She is a registered architect, RCI member, and the 2004 recipient of the National Roofing Foundation's William C. Cullen Research Fellowship Award for vegetated roofing research.



## James Jones, PhD

Jim Jones, PhD, is an associate professor and director for the Center for High Performance Learning Environments in the College of Architecture and Urban Studies at Virginia Tech. Professor Jones holds a Master of Architecture and PhD from the College of Architecture and Urban Design at the University of Michigan.