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Federal Technology Alert

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Green Roofs

Green roofs can improve the energy performance of federal buildings, help manage stormwater, reduce airborne emissions, and mitigate the effects of urban heat islands

Executive Summary

Because of their many energy-saving and environmental benefits, green roofs are a promising technology for energy-efficient buildings. In a green roof, a layer of vegetation covers the surface of a roof to provide shade, cool indoor and outdoor temperatures, stormwater management, and more. The main components are waterproofing, soil, and plants.

Katrin Scholz-Barth/PIX13397

The roof of the 12-story Chicago City Hall building has been retrofitted with a 22,000-square-foot rooftop garden. The primary goal of this installation, which was completed in 2001, was to demonstrate that green roofs help to reduce urban air temperatures.

Federal facility managers in particular might want to consider green roofs in responding to Executive Order 13123, Greening the Government through Efficient Energy Management. That order, signed in 1999, directs agencies to improve the energy performance of their buildings, reduce their use of potable water, and assist in curbing the greenhouse gas emissions associated with energy use in the United States.

Today, there are two distinct types of green roofs: extensive and intensive. An extensive green roof contains shallow soil and low-growing, horizontally spreading plants. These plants are primarily succulents that can thrive in the somewhat alpine conditions of many rooftops. In other words, there is not much water or soil, but the roof does experience a significant amount of exposure to the sun and wind.

Intensive green roofs are more complex, and they require more maintenance. They feature deeper soil (usually more than 12 inches in depth) and more diverse plants, such as shrubs and trees. They are usually not as cost-effective as extensive green roofs, and they require more structural support. They are also considered to be less environmentally effective than extensive green roofs. Therefore, this *Federal Technology Alert* focuses on the design and implementation of extensive green roofs.

This technology is especially effective in urban areas, because roofs make up such a large percentage of a city's impervious surfaces. Impervious surfaces contribute to two key problems—the urban heat island effect and urban stormwater runoff—and both affect the consumption of energy and water as well as the demand on energy and water systems.

Green roofs contribute to energy- and water-saving goals both directly and indirectly. By shading the surfaces of a roof, they reduce heat gain through it by nearly 100 percent. In addition, a green roof's soil and vegetation layer absorbs and filters rain, preventing it from quickly becoming runoff from the roof's surface. Studies have also shown that the photosynthesis process of the plants reduces the amount of greenhouse gas emissions in the surrounding air.

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Energy- and Water-Saving Mechanisms

Conventional roof surfaces absorb solar radiation, and this has an impact on both outdoor and indoor air quality. Outdoors, the absorbed radiation raises the temperature not only of the roof (and other impervious surfaces) but also of the surrounding air in densely populated urban areas; this is known as the "urban heat island effect." The result is ground-level ozone, in many cities—a temperature-dependent reaction. The higher ambient air temperature acts like a catalyst and adds to smog, making air quality problems worse.

Indoors, the higher air temperatures caused by solar gain through the roof result in greater use of air conditioning. This in turn raises electricity demand and causes additional waste heat to be emitted into the urban environment.

A green roof forms a buffer zone between the roof and the sun's radiation and shades the roof, preventing its surface from heating up and increasing outdoor and indoor air temperatures. Thus, this technology directly benefits both air temperatures and air quality and reduces the amount of energy needed for air conditioning. In addition, green roofs use rainwater for irrigation needs, reducing the demand for potable water for irrigation.

Scientists at the U.S. Department of Energy's Lawrence Berkeley National Laboratory (LBNL) have been studying the urban heat island effect. They estimate that using alternative surfaces to reduce the temperature of ambient air in cities by just 5.4 degrees Fahrenheit (3 degrees Celsius) would save up to $6 billion per year in energy costs, nationwide. Green roofs could help cities achieve these temperature reductions.

No specific studies have been done in the United States on the amount of energy saved by a green roof. However, a "cool roof" study by LNBL concluded that another alternative surface, a reflective roofing membrane, should save $65,000 over the lifetime of the roof on a 100,000-square-foot retail store.[1] And studies by the National Research Council of Canada have shown that green roofs are very effective in reducing heat transfer through a roof; one green roof reduced average daily energy demand by 75 percent in a test facility with a 400-square-foot roof.[2]

The extensive research conducted by national laboratories and others to understand the urban heat island effect and develop strategies to reduce it could be tremendously helpful in introducing green roofs into the mainstream building industry. However, the two technologies—cool roofs and green roofs—have different objectives. A highly reflective cool roof is primarily intended to reflect solar energy away from a building, whereas a living green roof absorbs solar energy but reduces heat transfer through the roof by means of biochemical processes and added mass.

These two technologies might not be suitable for every type of building, however, although they are both very effective in reducing surface temperatures. But sometimes they can be applied in tandem to maximize benefits. Because urban heat islands clearly contribute to increases in temperature, energy use, and pollution, the U.S. Environmental Protection Agency (EPA) and the Cool Roof Rating Council are preparing a guidebook on strategies for reducing the effects of these heat islands.

Green roofs are not just effective in reducing urban heat islands, however; they also provide several cumulative benefits. Stormwater management is probably the most tangible direct benefit. In urban areas, precipitation becomes runoff because impervious surfaces—such as buildings, sidewalks, parking lots, and streets—cannot absorb it.

Runoff from a rainstorm can quickly overburden an urban sewer system, especially a combined one that captures sanitary waste as well as storm water. Curbs, gutters, pipes, and gullies all direct the runoff to the same sewer system and outlets. Therefore, the first half-inch of runoff is the most challenging because of its large volume at peak flow rates. Runoff can overload sewers, cause floods, and prevent the replenishing of local aquifers. Untreated runoff also carries non-point-source pollutants—such as sediment, nutrients, oil, and grease—into sewer and water treatment systems.

Another environmental problem can occur when urban roofs heat up stormwater runoff before it reaches the receiving streams. The subsequent thermal shock to the streams can have adverse effects on the aquatic ecology. Any runoff that occurs from a green roof, however, will have a lower temperature than runoff from a conventional roof, so thermal shock is usually not a problem.

On a green roof, rain passes slowly through a layer of soil. This reduces the peak flow rate of the runoff and aids in regulating flow into sewer and water treatment facilities during periods of heavy rain. On an impervious roof, rainwater is usually conveyed quickly to gutters and downspouts as runoff and then pumped through sewers and treatment plants; a green roof, however, can absorb and use much of this rainwater. Thus, green roofs help to reduce the energy costs associated with pumping and treating stormwater runoff as well as the cost of heating and cooling buildings.

Potential Applications

Considering the vast number of federal buildings, there is great potential for green roof applications in this sector. There are good candidates in all government building categories, including office buildings, housing, and hospitals. The energy benefits of green roofs are probably greater for single-story or low-rise buildings, however.

Green roofs could also provide cost-effective stormwater management for nearly all federal facilities or housing complexes. Therefore, facility managers in areas with strict stormwater regulations should seriously consider using green roofs in lieu of conventional methods to control the quality and quantity of stormwater on site.

Nutrients stemming from urban runoff are the number one violation of National Pollutant Discharge Elimination System permits, which are issued under a federal monitoring program to protect U.S. waterways. The EPA is in the process of publishing regional criteria for total maximum daily loads of nutrients for the entire country; these criteria will be more stringent then ever before. To help cities meet the criteria, green roofs can be designed to have a specific water-retention capacity. They can then be incorporated into stormwater management plans without the need for additional land for retention basins. Federal buildings that are concentrated in a particular area, as is often the case, could realize even greater energy and environmental benefits by combining or clustering their green roofs.

Field Experiences

Green roofs technology has been a subject of great interest in business and academic communities over the past two years. However, only a few U.S. green roof applications have been monitored to provide data for future projects. Although extensive research has been conducted in Europe for many years, resources are still needed on the design, construction, and installation of green roofs in the United States, so that performance data can be collected and energy cost savings can be estimated.

Therefore, this publication is based in part on experiences in Europe and in part on anecdotal evidence from observations of green roofs in the United States. As a result, we are not yet able to calculate with precision the cost savings resulting from the energy- and water-saving features of a green roof on a federal facility. Rather, we can lay out a road map for interested facility managers who wish to become familiar with the technology and better understand its broad potential impact on buildings, regions, and resources.

Implementation Barriers

Despite the growing interest in green roofs technology, there is some resistance to applying it widely. One reason for this is that there are no consistent guidelines or standards for determining structural and load requirements and then designing and installing a green roof. However, these standards are now being developed.

Implementation barriers can be attributed in part to decision makers' experiences with poorly installed waterproofing systems and persistent leaks from conventional roofs. As a result, building and facility managers have some reservations about retaining water on their rooftops. They know that a waterproofing failure underneath a green roof's vegetation layer would mandate very expensive repairs, including the cost of removing and reinstalling vegetation. Also, decision makers sometimes fear that installing a green roof retrofit could void the waterproofing warranty of their existing roof system.

The fear of leaks thus appears to be the single greatest barrier to implementation. It can even outweigh the realization that a green roof provides numerous cumulative benefits, both direct and indirect, to facilities, occupants, and outdoor and indoor environments. The lack of data on these benefits is another hurdle that appears to be difficult to overcome. Other barriers include a lack of, and need for, the following:

- Information and familiarity with green roof technology, design, and function
- Knowledge about maintenance requirements
- Industry standards and design guidelines and specifications
- Qualified designers and contractors
- Incentives to make green roof applications more attractive
- Available funding to absorb higher first costs

These implementation barriers are reflected in the low number of installed green roofs in the United States. They also reflect the complexity of green roof designs and functions. Many industry members, researchers, and practitioners are conducting research, development, and demonstrations to address and overcome these barriers.

Conclusion

Green roof technology is emerging as an effective, practical way to increase the energy performance of buildings and limit stormwater runoff. Adapting green roofs for federal buildings can provide significant benefits, especially to low-rise office buildings and facilities in districts with strict stormwater regulations. Integrating green roofs into stormwater permitting requirements may become a realistic solution to making them financially viable.

For those who would like more information, a list of manufacturers, contractors, consultants, and additional publications is provided at the end of this publication.

Contents

Abstract

In North America, green roofs are gradually being accepted as a sustainable design practice for the environmental benefits they provide. The U.S. Green Building Council (USGBC) has adopted green roofs as an effective technology for reducing stormwater runoff and mitigating urban heat islands. The council has incorporated green roofs into the Green Building Rating System of the Leadership in Energy & Environmental Design (LEED™) program (LEED is a trademark of the USGBC).

In addition, the General Services Administration (GSA) has issued a directive that requires all new federal buildings or renovations completed after 2002 in the National Capital Region to achieve a LEED silver rating. Installing a green roof contributes to obtaining a silver rating by earning two credits in the sustainable sites section for on-site stormwater management (Credit 6: Stormwater Management) and for shading the impervious roof surface (Credit 7: Landscape and Exterior Design to Reduce Heat Islands).

A cost-benefit analysis will not favor such an installation for LEED credits, however, unless the green roof is integrated into the building design and stormwater plan. Green roofs can also be helpful in meeting Executive Order 13123, *Greening the Government Through Efficient Energy Management*, established to improve the energy performance of government buildings and reduce the use of potable water.

This *Federal Technology Alert* discusses the benefits that green roofs provide as well as the design, function, maintenance and technical issues related to green roof design and installation. It is intended to help federal facility managers determine whether or not a green roof is appropriate for their facilities and if so, what types of green roof systems are available. Energy-saving mechanisms and benefits are reviewed for inclusion in the design process in order to maximize returns on investments. Also included are architectural criteria such as additional loads, roof slopes, and equipment integration.

Finally, this publication addresses material selection, waterproofing and related warranties, codes and standards, incentive programs, and technology performance. A case study includes a cost-benefit analysis comparing initial capital costs and anticipated payback periods. There are also lists of sources of further information.

About the Technology

A green roof is a continuous layer of vegetation and soil that covers a roof's surface. The main components are waterproofing, soil, and the plants themselves. Green roofs are an important conservation technology because they increase the energy performance of buildings, improve indoor as well as outdoor air quality, and enhance the health of urban watersheds. There are two distinct types of contemporary green roofs: extensive and intensive.

An extensive green roof consists of a shallow soil profile with low-growing, horizontally spreading plants. These plants are primarily succulents that are adapted to the alpine (high-elevation) conditions that predominate on a rooftop, where there is often little water and soil but significant exposure to sunlight and wind.

Intensive green roofs are more complex systems that require greater maintenance. They are constructed with deep soil profiles (more than 12 inches of soil depth) and feature greater plant diversity, including shrubs and trees. Intensive green roofs are considerably less cost-effective than extensive green roofs are, however.

Extensive green roofs usually require less structural support than intensive ones, and they are considered to be more environmentally effective. Therefore, this publication focuses on the design and installation of extensive green roofs.

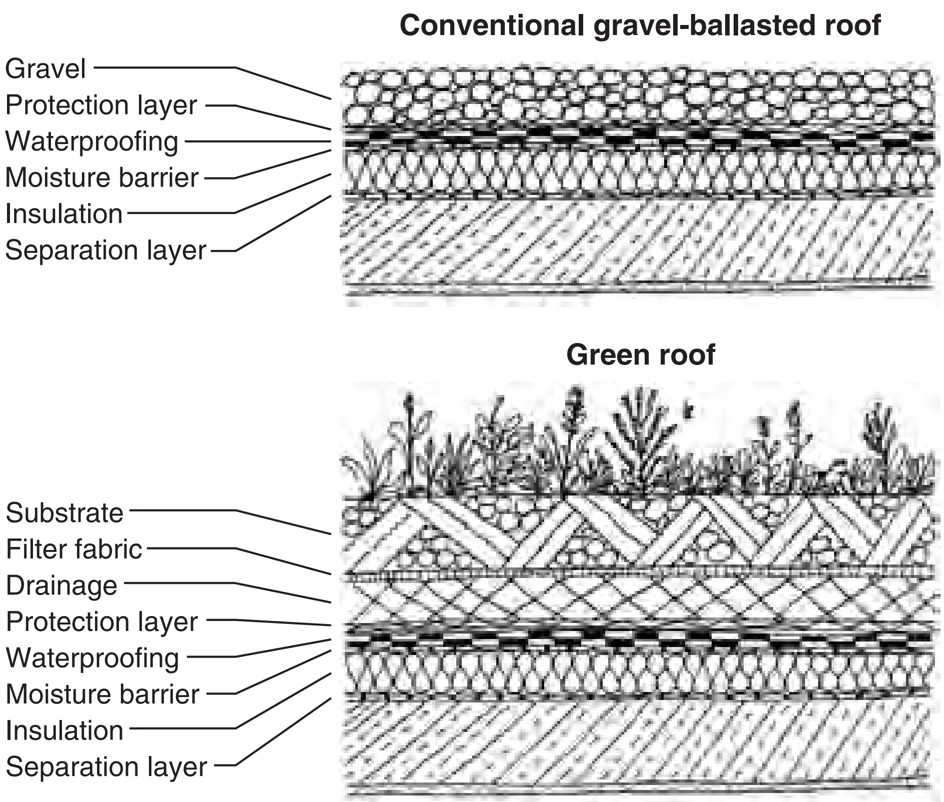
All green roofs are natural systems that effectively cool the temperature of ambient air at roof level. The vegetation layer shades the roofing membrane, thus significantly reducing heat gain through the roof. The vegetation cover itself adds green space to areas that otherwise would remain impervious and uninhabitable to birds, butterflies, and other small wildlife.

Green roofs are important to consider in designing a sustainable facility, especially in urban areas, because roofs make up such a large percentage of the impervious surfaces in cities. Thus, they contribute to two key problems: the "urban heat island" effect and urban stormwater runoff. Both problems affect the consumption of energy and water and the demand on energy and water systems.

Pavement (roadways, sidewalks, parking lots), and buildings are the predominant surface covers in urban areas. These hard surfaces absorb solar radiation and transmit heat back into the atmosphere, and they prevent rainwater from filtering down through subsoil. Green roofs technology makes use of the natural processes and functions of vegetation to minimize the adverse effects of these impervious surfaces, especially where green space is limited and there are few trees to absorb water.

Green roofs contribute to energy management and water conservation in both direct and indirect ways. They provide shade, which reduces solar heat gain through the roof by almost 100 percent and mitigates the urban heat island effect. Also, a green roof's soil and vegetation layer absorbs and filters rain, preventing it from becoming polluted runoff from the roof's surface. And the photosynthesis process in vegetation has been shown to help reduce greenhouse gas emissions.

Green roofs absorb, filter, and temporarily store precipitation. This water storage and filtration feature helps to mitigate the impacts of urban stormwater runoff. Volume, peak runoff rates, and associated non-point-source pollution—primarily sediments and nutrients such as nitrogen and phosphorus—are of great concern to the



The drawings show the general buildup of a gravel-ballasted roof and that of a green roof, in cross section. The buildup is very similar in both, but the performance of a green roof is superior to that of gravel-ballasted roofs on many levels. (Source: A. Dürr, *Roof Greening; An Ecological Balance*, 1995; reprinted with permission)

Charlie Miller/PIX

An extensive green roof by Charlie Miller, Roofscapes, Inc., for the Chiropractic Life Expression Wellness Center in Sugar Loaf, Pennsylvania.

health of watersheds, aquatic life, and air quality, especially in urban centers.

During low-intensity periods of rainfall (about one-half inch or less), green roofs have the potential to completely eliminate runoff as the soil layer absorbs the rain. During longer periods of rainfall, or rainstorms of greater intensity (1 to 2 inches or more), green roofs reduce peak flow rates and delay any runoff that might occur later, thus reducing the total volume of water that reaches sewer systems. Watersheds are also protected from non-point-source pollution, such as sediments and nutrient overload.

Green roofs are considered to be a form of low-impact development, and they are becoming more accepted as sustainable planning and design practices. Today, green roofs technology is anchored in the U.S. Green Building Council's Leadership in Energy & Environmental Design (LEED) building rating system because of the ways that green roofs help to minimize the environmental footprint of buildings and mitigate the impacts of urban runoff and urban heat islands.

The following sections provide more detailed information and criteria for federal facility managers to use in considering, evaluating, and implementing green roofs at their facilities. Note, however, that green roof technology is a general technique rather than a specific system that can be universally applied. It is thus important to understand the concept before selecting appropriate design criteria and designing a site-specific green roof. A case study is included to show how these concepts are implemented.

Energy and cost savings are difficult to predict because monitoring data are not yet available in North America. However, many research projects are under way, and several have produced data that verify the cooling effectiveness of green roofs.

Application Domain

The design intent and goals of a green roof need to be defined before the design begins. Installation techniques and material and plant selections can vary and depend on the climate zone in which the roof is installed. In general, green roof applications are appropriate for a variety of government buildings and roof types, including office buildings, housing, and hospitals in warm or cool climates throughout North America. Green roofs are particularly effective when used to increase the energy efficiency of single-story or low-rise buildings, because of the high roof-to-wall ratio. They are also very effective when used for stormwater management on large-footprint buildings.

Facilities in areas with strict stormwater regulations, and those that must meet National Pollutant Discharge Elimination System (NPDES) permit requirements and criteria for total maximum daily loads (TMDLs), should consider using green roofs in lieu of conventional systems to control the quality and quantity of stormwater. Since federal buildings are often concentrated in one area, they can combine and maximize the environmental benefits of individual green roofs.

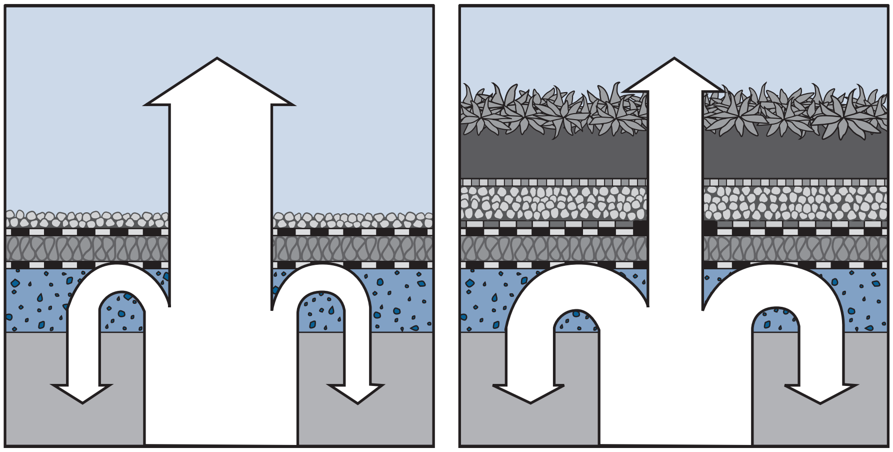
Green roofs are appropriate for both new and existing federal buildings. They can be incorporated into new building designs without much difficulty. Structural load requirements will usually need to be adjusted to accommodate the additional weight, beyond wind and snow loads, as required by building codes.

It is also possible to retrofit existing buildings with green roofs. But this requires a feasibility study to evaluate the structural integrity of the existing building and roof. Gravel-ballasted roofs are often suitable for a green roof retrofit because the gravel layer can be replaced with a green roof layer without adding much weight. It is important to protect existing waterproofing systems from root penetration, however. Tile and metal roofs are not usually suitable for green roof applications.

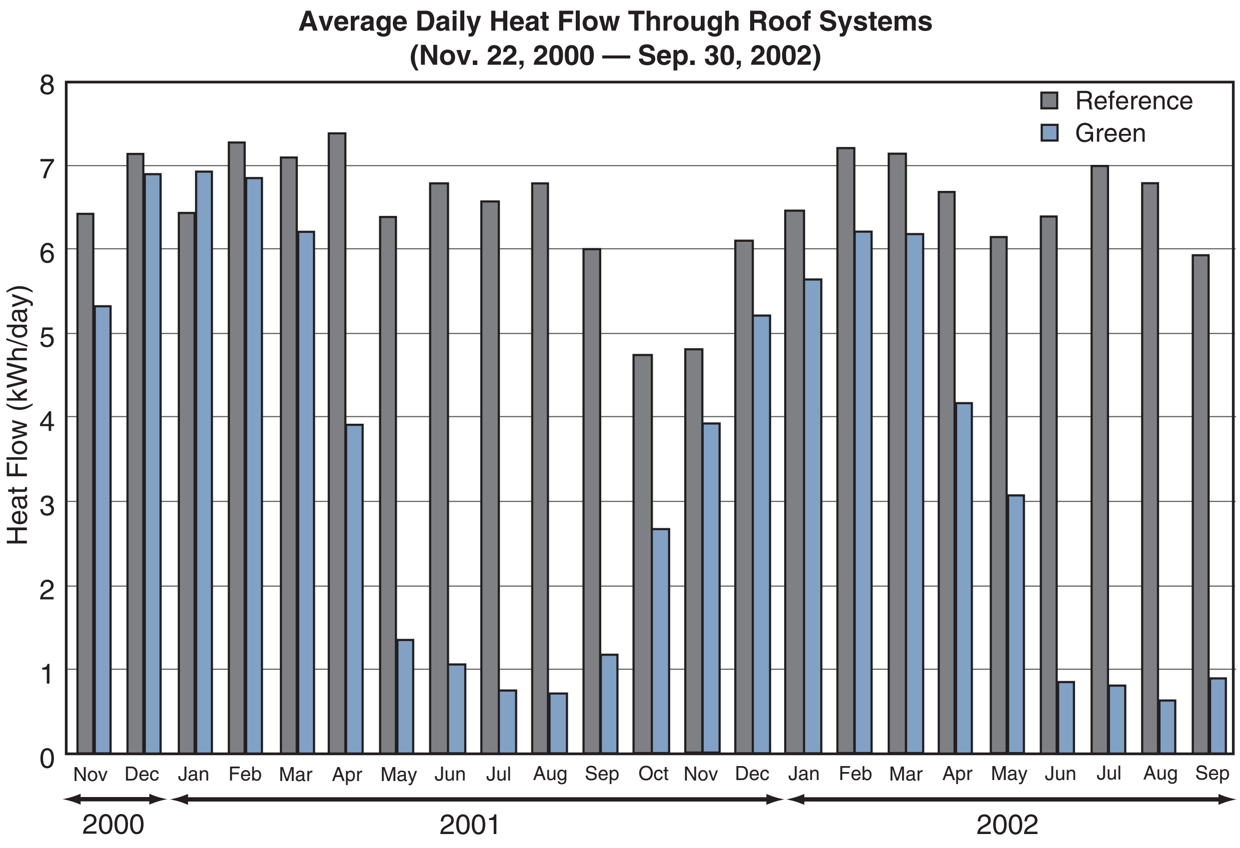
Energy-Saving Mechanism

Green roofs represent a unique, unconventional approach to increasing the energy performance of buildings through shading, insulation, evapotranspiration, and thermal mass. Measurable direct benefits are lower roof surface temperatures and reduced heat transfer through the roof, which reduce peak air-conditioning and energy demand. These energy-saving properties are different in summer and winter.

Summer energy savings. In summer, a green roof forms a protective layer over the waterproofing membrane, thereby shading the roofing system from direct ultraviolet (UV) radiation. From March to November, a chemical process occurs in plants known as photosynthesis, in which plants use the energy in sunlight to form carbohydrates from the carbon dioxide in the air and the water in the soil. Plants on a green roof thus prevent the surface of the roof from absorbing



Heat flow through a gravel-ballasted roof (left) and through a green roof. The added thermal mass of the green roof prevents a large amount of air from escaping through the roof system. (Source: A. Dürr, *Roof Greening; An Ecological Balance*, 1995; reprinted with permission)



Measurements of heat flow show that average daily energy demand for the green roof was significantly less than that of the reference roof in spring and summer. (Source: National Research Council of Canada)

Table 1. Daily Maximum Temperatures of Roof Membranes on Test Green Roof and Reference Roof during a 660-Day Observation Period

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

Source: National Research Council of Canada

Table 2. Normalized (per unit area) Heat Flow through the Roof Surfaces of the Test Roof during the Observation Period (November 22, 2000–September 30, 2002)

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

Source: National Research Council of Canada

the sun's heat energy. This has a direct impact on the temperature of the indoor air immediately beneath the roof. The plenum heat gain is reduced, and energy demand for space conditioning is correspondingly reduced.

As plants take up water from soil and transport it through their leaves to the atmosphere (transpiration), water also evaporates from the soil's surface and leaves. The total water loss—evapotranspiration—helps to effectively cool ambient air temperatures at roof level. This has a significant impact on mitigating the urban heat island effect.

Winter energy savings. In winter, plants are dormant, and neither photosynthesis nor evapotranspiration take place. During this season, the thin vegetation layer of an extensive green roof adds thermal mass and provides a barrier that prevents some of the warm air from escaping through the roof. Small air pockets in the soil and around the roots add insulation. The insulation value depends on the soil's moisture content, and it decreases with greater moisture.

The plants, with their various heights and surface textures, help to reduce the velocity of cold winter winds over the roof, preventing additional heat loss through the surface.

The National Research Council of Canada conducted a field study over a two-year period (2000 to 2002) to evaluate the thermal performance of green roofs. The test facility in Ottawa has a total roof surface of 800 square feet (72 square meters). The test roof was evenly divided into an extensive green roof (green roof) and a modified bituminous roof covered with light gray gravel (reference roof).[3]

The study found that the daily maximum membrane temperature underneath the green roof was significantly lower than the daily maximum membrane temperature of the reference roof. During a 660-day monitoring period, the temperature of the green roof exceeded 86 degrees Fahrenheit (°F) (30 degrees Celsius [°C]) on only 18 days, or 3 percent of the time.

In contrast, the ambient air temperature exceeded 86°F (30°C) on 63 days, or 10 percent of the time. The temperature of the reference roof was significantly higher throughout the monitoring period. Temperatures climbed above 122°F (50°C) on more than 219 days, or 33 percent of the time, as shown in Table 1.[4]

The data show that green roofs effectively cooled the roofing membrane underlying the green roof to below ambient air temperatures in this field study.

The study also found that the test green roof significantly reduced heat flow through the roof. It also reduced the average daily energy demand for space conditioning by 75 percent in summer. Table 2 shows heat gain and heat loss in total Btu per square foot; the graph on page 5 shows average daily heat flow through the reference roof in comparison to that of the green roof.

The green roof appeared highly effective in reducing heat gain in summer. It was less effective in winter, reducing heat loss an average of 26 percent, as compared with a reduction in heat transfer of 75 percent in summer.

Benefits

Green roofs provide a wide array of benefits:

- Shading the roof and cooling ambient air temperatures in summer
- Shielding the roof from wind and preventing heat transfer in winter
- Absorbing, retaining, filtering, and storing precipitation
- Reducing the temperature of runoff
- Minimizing the impacts of impervious surfaces on watersheds
- Extending the lifetime of roofing membranes
- Increasing the area's green space and wildlife habitat
- Enhancing the aesthetic of cityscapes
- Improving air quality
- Sequestering carbon dioxide
- Reducing traffic noise through absorption by the soil layer
- Ballasting the roofing membrane
- Mitigating floods in certain regions
- Reducing runoff and the need to expand the urban stormwater infrastructure's capacity

Table 3. Typical Surface Albedo Values

Material	Surface Albedo Value
Highly reflective roof	0.60-0.70
White paint	0.50-0.90
Grass	0.25-0.30
Brick/stone	0.20-0.40
Colored paint	0.15-0.35
Trees	0.15-0.18
Red/brown tile	0.10-0.35
Concrete	0.10-0.35
Corrugated roof	0.10-0.16
Tar and gravel	0.08-0.18
Asphalt	0.05-0.20

Source: U.S. EPA, *Cooling Our Communities. A Guide to Tree Planting and Light Colored Surfacing*.

Several of these benefits are addressed in greater detail below.

In regard to energy savings, the U.S. Environmental Protection Agency (EPA) estimates that annual U.S. energy demand for air conditioning accounts for almost one-sixth of the energy generated per year. That also represents an expenditure of approximately $40 billion to fight heat gain in buildings. Careful selection of building materials and their surface albedo (or reflectivity) values can have a significant effect on the heat gain of surfaces as well as on ambient air temperatures, which in turn can reduce the demand for air conditioning.

New studies indicate that reflective surfaces, especially those used on roofs, can help reduce cooling demand by 10 to 15 percent. This can result in direct energy savings of up to 50 percent.[5]

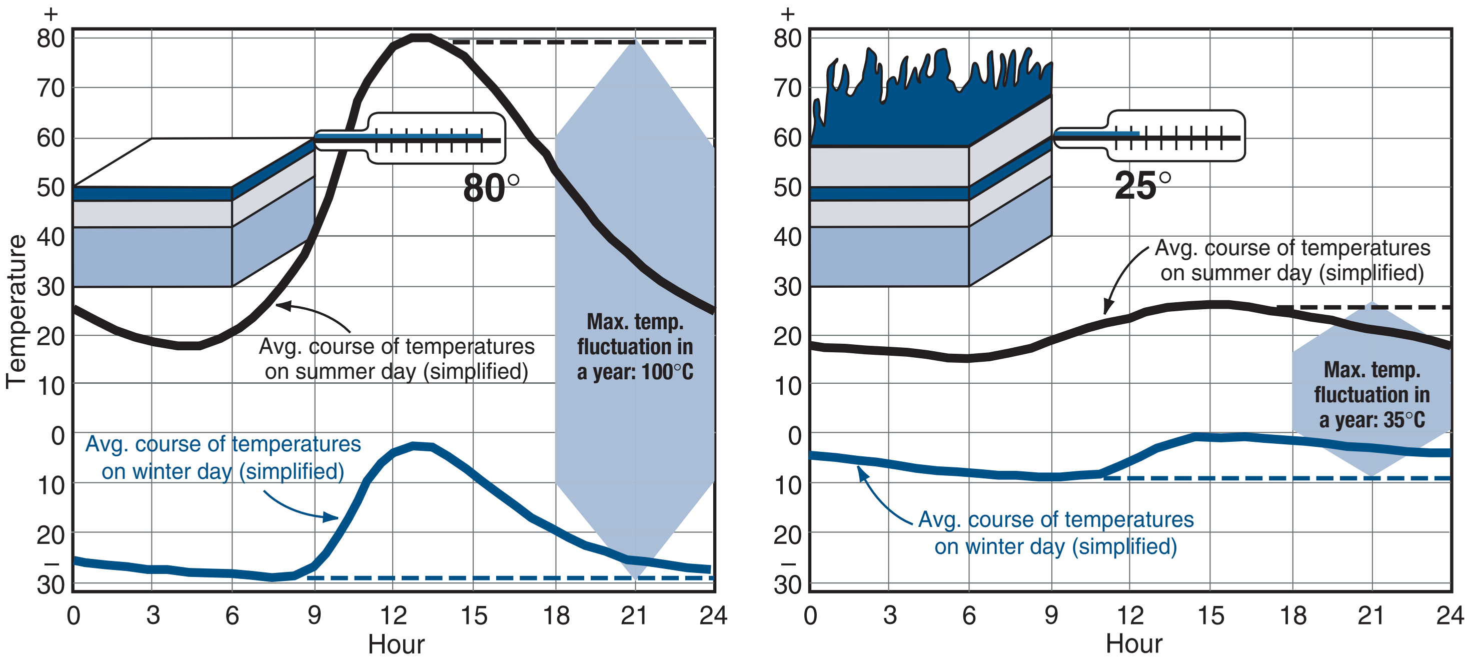
Several kinds of reflective roofing membranes have been tested. Within EPA's ENERGY STAR® Program, reflective roofs are encouraged to improve energy efficiency. Reflective roofing membranes are usually light in color; therefore, they absorb less heat from sunlight than dark, conventional roofs do. This means lower heat gain, which impacts the energy performance of a building directly.

Hashem Akbari of Lawrence Berkeley National Laboratory (LBNL) has tested and evaluated the performance of reflective roofing membranes. A 100,000-square-foot, single-story retail store in Austin, Texas, served as the test site. Energy used for air conditioning was measured before and after the installation of a reflective roofing membrane. In the test, the reflective membrane lowered the average summertime roof surface temperature from 168°F (76°C) to 126°F (52°C), a difference of 42°F.

The final report on this test states, "The total air-conditioning energy use was reduced by 11 percent and peak air-conditioning demand fell by 14 percent. The 100,000 square feet building is predicted to save $65,000 over the life of the roof."[6]

The typical albedo value for green roofs is not as high as that of the reflective roofing materials featured in the study above, which means that green roofs are not as reflective

Maximum Temperature Fluctuations for a Conventional Roof and a Green Roof



In the graph on the left, the arrow shows the maximum temperature fluctuation of a typical flat conventional roof, up to 60°C (140°F) in a single day, and up to 100°C (212°F) during the year. The graph on the right shows a significantly lower temperature fluctuation on a green roof. The protective green-roof layer moderates temperature extremes and protects the roofing membrane from accelerated aging caused by UV radiation. [7] (Source: A. Dürr, 1995; adapted with permission)

(see also Table 3). However, comparing only the reflectivity of a green roof with that of a light-colored roof surface can be misleading when determining the more energy-efficient surface. Almost all traditional building materials, regardless of color, will transmit some heat; a green roof, however, is a live ecosystem that performs natural processes. Green roofs, though darker in color and correspondingly lower in reflectivity than light roof surfaces, do not reflect solar radiation; instead, this solar energy is used by the green roof's vegetation. Almost none of the sun's heat passes into the building. The vegetation uses the solar energy to provide effective cooling through the evapotranspiration process described above.

Also, because green roofs do not reflect solar radiation, occupants of neighboring buildings do not have to restrict reflections from them by installing additional shading. Therefore, albedo value is not an effective or accurate measure for predicting the energy efficiency of green roofs.

Nevertheless, cool roofs can be very effective on some buildings. Because steeply sloped roofs can be unsuitable for cost-effective green roof technologies, a reflective roofing membrane should be considered because of its energy benefits and ability to alleviate the urban heat island problem. A cool roof should be considered when an existing roof cannot withstand the additional load of a green roof. In summary, these are some advantages and disadvantages to be aware of in choosing between the two kinds of roofs:

Some advantages of green roofs in comparison to reflective roofs:

- Besides reducing heat transfer through the roof, they are also beneficial in controlling stormwater quality and quantity and in mitigating the effects of impervious surfaces.
- They do not reflect sunlight into adjacent buildings; rather, they use radiant energy to cool ambient air.
- They are not vulnerable to UV radiation.
- They can protect the roofing membrane and increase its longevity.
- They provide green space and have aesthetic value.
- They reduce noise by absorbing sound in the soil medium.

Some disadvantages of green roofs in comparison to reflective roofs:

- They have higher first costs because of the additional material needed and high installation costs.
- They require higher maintenance for plant care and upkeep until plants are fully established and the roof is fully covered (about two years); some ongoing maintenance

is also required, such as fertilizing vegetation annually and checking on plants.

- They are vulnerable to high winds because they are not mechanically fastened to the roof.
- It is more difficult to locate any leaks in waterproofing material.
- Waterproofing must be protected from root penetration.
- They do not work well (if at all) on roofs with very steep slopes.

Note that cool roofs also tend to collect airborne dust and particulate matter. Some cool roofs, such as metal ones, are less susceptible to the elements. However, the dust that usually accumulates on light-colored roofs, and the acid rain that stains them, can darken the surface, reducing solar reflectance and infrared emittance properties by 8 to 11 percent. However, cool roofs can usually be power-washed to reinstall their reflective properties.

In comparison, airborne dust and particulate matter are usually fixed on the leaves and foliage of a green roof and do not compromise its heat-flow reduction properties or any other performance parameter. Because of the benefits a green roof provides as an ecosystem, it can outperform a reflective roof with regard to energy efficiency and mitigating urban heat islands.

The multifunctional, cumulative benefits of green roofs make them attractive and unmatched by other technologies. Therefore, designers and facility manager might select a green roof for reasons other than its energy efficiency. Besides technical performance, green roofs offer improved aesthetics and a multitude of other benefits, as listed below.

Cost: Green roofs offer direct cost benefits when the design is integrated into a stormwater management plan to offset permit fees and runoff treatment requirements. Another cost benefit is the extended lifetime of the waterproofing system. Conventional roofing systems are typically replaced every 20 to 30 years. A green roof, in contrast, protects the waterproofing membrane from UV exposure and temperature fluctuations that accelerate the breakdown of the membrane. In Europe, green roofs have extended the lifespan of a roofing membrane to two or three times that of a conventional roofing system.

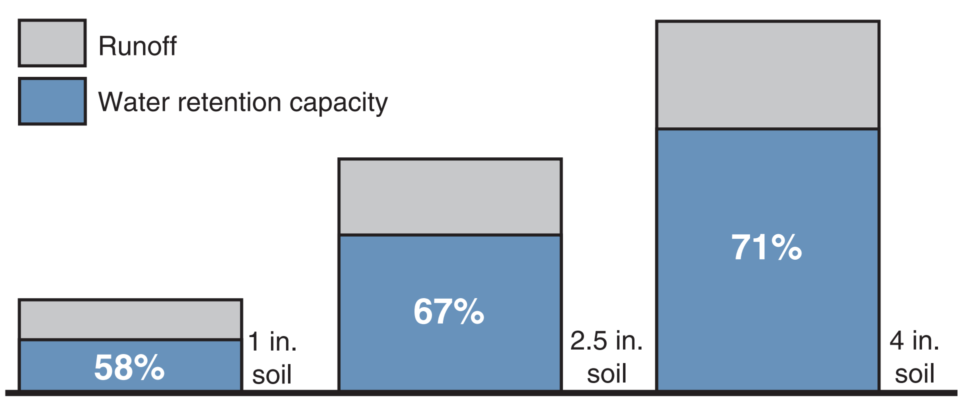
Stormwater management: Converting conventional roof surfaces to green roofs is potentially the single greatest way to reduce or delay stormwater runoff on a large scale. The stormwater benefits of green roofs are greatest in densely populated urban centers. Cities that are serviced by combined sewer networks benefit from the resulting reductions in the volume and rate of runoff. Green roofs should be incorporated into a building design in the conceptual planning phase for new construction to reduce the need for a costly stormwater retention and treatment infrastructure. Depending on the intensity of rainfall, the growing season, and the soil moisture content at the site, an extensive green roof can eliminate runoff from a building and reduce the peak flow rate and volume of the sewer system.

A layer of soil 3 to 4 inches deep in an extensive green roof can absorb about 1 inch of water. Green roofs are estimated to absorb, filter, retain, and store an average of about 75 percent of the annual precipitation that falls on them. This applies to most areas in the United States.

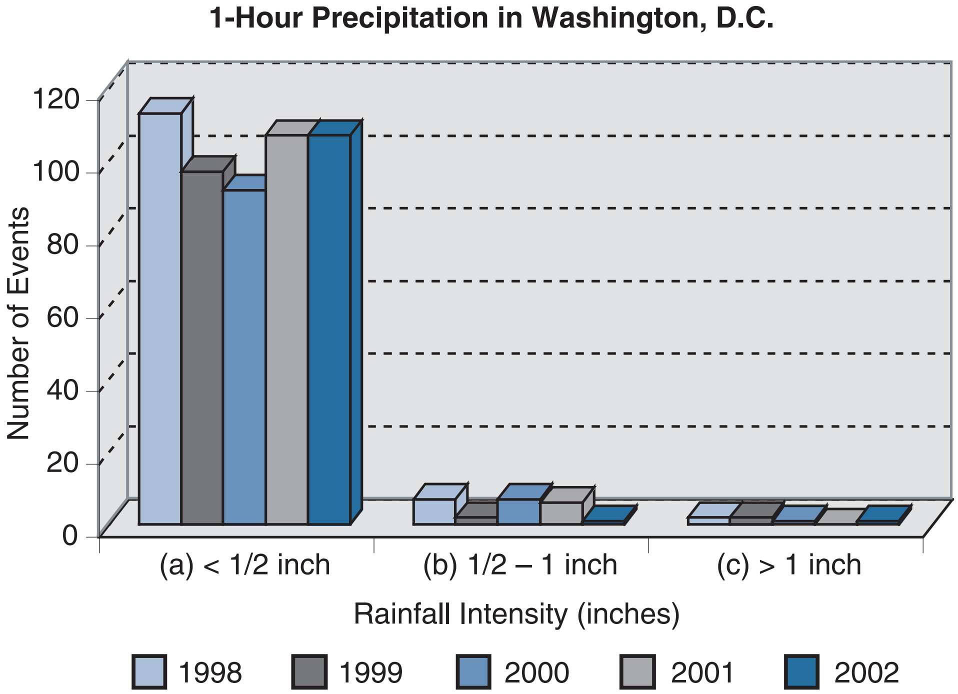
A green roof's health, durability, and return on investment increase along with the depth of the soil. Plants grow and spread more vigorously in 3 to 4 inches of soil than in more shallow soils. This depth also allows greater plant diversity and provides greater resistance to diseases.

The water-retention capacity of a green roof depends on the type of growing media used. Water retention can be increased by either mixing lightweight, water-retaining aggregate into the soil, or using this kind of aggregate for the topsoil layer. See also the sections on architectural criteria and installation for load issues associated with different growing media.

Runoff vs. Water Retention at Different Soil Depths



The graphs show runoff vs. water retention capacities of extensive green roofs at 1-inch, 2.5-inch, and 4-inch depths. The first bar represents a 1-inch deep soil and vegetation mat over a 2-inch gravel bed. This green roof can retain an average of 58% of annual precipitation. The second bar represents a 2.5-inch-deep soil and vegetation mat, which can retain an average of 67% of annual precipitation. The third represents a 4-inch soil and vegetation mat, which can retain an average of 71% of annual precipitation.[8] (Source: A. Dürr, 1995; adapted with permission)



This graph shows the total number of annual rainfall events for the District of Columbia over five years at (a) less than 1/2-inch, (b) from 1/2-inch to 1-inch, and (c) greater than 1-inch intensities. (Source: National Oceanic and Atmospheric Adiministration, National Weather Service; see www.erh.noaa.gov/box/dailystns.shtml)

Engineers who design stormwater infrastructure usually design for a worst-case scenario—urban runoff from a 100-year storm. Green roofs, however, absorb and use much of the rain that falls on them at intensities at or below 1/2 inch. The first 1/2-inch of runoff, referred to as the first flush, is of the greatest concern to municipalities because it carries the most concentrated pollutants. Extensive green roofs can absorb up to 1 inch of rain and effectively reduce storm runoff to sewer systems. Excess rainfall can them be conveyed away by a smaller-than-usual system.

Nitrogen and phosphorus stemming from atmospheric deposition become fixed in the soil and serve as plant fertilizer. Sediments are trapped as water slowly percolates through the soil medium. Green roofs reduce this non-point-source pollution, and any runoff is thus cooler and cleaner than it would be if it came from conventional roofs.

Green space and wildlife: Green roofs benefit urban areas by adding green space and offering resting places and food sources for wildlife. These elevated ecosystems are sheltered from human activities and traffic noise as well as from predators. Migratory birds and butterflies especially benefit from green roofs, because their habitat in urban areas is limited and fragmented. Studies show that butterflies will fly as high as 20 stories for access to green space.[9] Green roofs might not be able to replace ecosystems, but multiple green roof applications in urban areas may play an important role in reconnecting fragmented habitats.

Air quality: Densely built-up urban areas often lack enough green spaces and trees to enrich the urban environment and offset air pollution. Green roof plants sequester carbon dioxide like other plants do, and release oxygen back into the environment.

The annual cost of air pollution in the United States is estimated to be about $10 billion.[10] This estimate is based on the cost of health care as well as the loss of productivity. Smog accounts for about 30 percent of air pollution, or $3 billion per year.[11] Smog forms when nitrogen oxides (NO_x) react with volatile organic compounds, and it accelerates at high ambient air temperatures. Acid rain, smog-related respiratory illnesses, and impaired visibility (because of “brown clouds” over cities). Air pollution can also reduce water quality by polluting runoff, as noted earlier.

Green roofs have great potential to collectively improve air quality because they can reduce air temperatures. As evapotranspiration lowers the ambient air temperature at roof level, this slows the formation of lower atmospheric ozone, the prime component of smog. Green roofs can also improve air quality by fixing dust particles and particulate matter from the atmosphere on plant foliage. Particulate matter includes dust particles that are smaller than 10 microns and that pass right through air filters without being trapped; they can cause lung damage, respiratory illnesses, and even premature death.

Utilities burn fuels at high temperatures to generate energy, which emits 27 percent of all NO_x into the air. Nitrogen oxide emissions from motor vehicles and from combined industrial, commercial, and residential sources also generate NO_x emissions: 49 percent and 19 percent, respectively.[12] The foliage in trees and other vegetation, such as green roofs, can help to reduce these emissions in the air through pollutant fixation and uptake. Studies show that trees near streets reduce both particulate and gaseous pollution up to 90 percent. Some measurements show about 10,000–12,000 dust particles per liter of air in streets without trees and about 1,000–3,000 dust particles per liter of air in streets with trees.[13]

It is difficult to predict specific emission reductions from green roofs on a per-building basis. However, the Rocky Mountain Institute estimates that electricity demand in buildings could be reduced by 45 percent through conservation alone. This reduction in energy use could result in a 10 percent reduction in total carbon emissions, which in turn would yield a net energy cost savings of $56 per ton of carbon emission reductions associated with reductions in energy use.[14] Green roofs could help to increase this result by reducing the heating and cooling needs of spaces underneath the roofs.

Aesthetic: Green roofs can enhance urban environments by adding green space and habitat that attract wildlife. They do not reflect sunlight, and they contribute to the urban aesthetic.

Traffic noise: Green roofs also provide noise-reduction benefits. The soil layer in a green roof can absorb traffic noise. The amount of the reduction depends on the thickness of the layer. An 8-inch deep cover has been found to reduce traffic noise by as much as 46 decibels.[15]

Roof ballast: Green roofs can replace conventional gravel ballast while providing the same benefits. The sole purpose of gravel ballast on traditional roofs is to weigh down the waterproofing membrane and protect it from being uplifted by wind. The gravel ballast can easily be replaced with an extensive green roof to function as ballast.

Variations

Contractors can design and install green roofs as entire manufactured systems. Green roofs can also be designed specifically for a site by a consultant or installed as prefabricated roof modules.

Entire systems: Several American roofing companies have partnered or arranged franchise agreements with European manufacturers to offer green roof systems in North America. The advantage of these systems is that, in most cases, only one contractor will be needed to install the waterproofing and the green roof system, minimizing the number of contractors at the site and potential damage to the waterproofing. Green roof systems are most cost-effective on large surfaces, because the larger size often results in material discounts per square foot.

Because only one contractor is used, manufacturer's warranty questions and maintenance calls can be directed to a single point of contact. A disadvantage is limited design flexibility. Because they are proprietary, these kinds of green roof systems come as fixed assemblies. This makes it harder to design for specific site conditions and to meet design goals.

Design consultants: For small projects or those with restricted budgets, it might be more appropriate to work with a green roof consultant who will specify components individually. The advantages of a site-specific green roof design are greater design flexibility and better cost control. Materials and layers can be selected that perform multiple necessary functions, thus eliminating the labor and costs associated with optional layers that are unnecessary in some applications.

Modular systems: Modular green roof systems are also available for rooftop applications, and they are effective for large roof applications with uninterrupted surfaces. Traditionally used for athletic fields, modules can be pregrown as green roofs. The advantage of modular systems is that they can be installed quickly.

The modules are perforated, which permits drainage and eliminates the need for an additional drainage layer. Drainage channels on the bottom provide sufficient space for excess water to flow freely to reach gutters, drains, and other collection points. The channels can also be used for irrigation piping, if a permanent irrigation system is required. The modules interlock for greater stability.

A disadvantage is that the height of the module dictates the soil depth, and this limits design flexibility. Also, modules might not suitable for a retrofit because of load restrictions. They are very heavy and thus must be lifted onto the roof by a crane and put in place by a forklift or manual labor. Some modules are made of plastic that is not UV-resistant and can degrade over time. The coordination of preplanting and scheduling, as well as high costs, still limit wider use of modular systems.

Architectural Criteria

Loads and structural upgrades: The weight added by an extensive green roof is comparable to that of the gravel ballast on a conventional roof—about 15 to 30 pounds per square foot, depending on the soil media, the depth of the soil layer, and the weight and depth of any additional layers.

The load of the green roof must be figured in addition to snow and wind loads, as required by all applicable building codes, to ensure that it does not exceed the structural capacity of the building. The maximum weight of a green roof occurs at full saturation or supersaturation. Supersaturation, a kind of worst-case scenario, could occur if malfunctioning roof drains cause the roof to flood to a certain depth. Therefore, the design load must always be calculated at full saturation.

Structural upgrade requirements for green roofs on new buildings add a negligible increase in cost. For existing buildings, a structural analysis is necessary to determine whether structural upgrades are required. The cost benefit must be determined on a case-by-case basis.

Roof slope: Almost any roof surface can be vegetated. Typically, government buildings have flat or only slightly sloped roofs. These surfaces are the most suitable for green roof applications and retrofits, depending on the roof's structural integrity. Roofs with steep slopes can be used in some green roof applications, but they are more difficult to accommodate. The friction coefficient between two neighboring materials (for example, waterproofing and geotextile, waterproofing and root-resistant liner, or root-resistant liner and geotextile) defines the critical practical slope angle. Roofs pitched at up to a 10-degree angle (17 percent, or up to 2:12) can be greened without using special stabilization techniques.

Roofs pitched between 10 and 30 degrees (17 percent to 58 percent, or 2:12 to 7:12) require standard slope stabilization techniques, such as wooden lath grids, eave-supported frames, or ridge-supported mesh. These techniques help to form smaller fields that reduce friction forces and keep soil and vegetation in place until plants have formed a dense vegetation mat with interlocking roots. Greening or retrofitting steeper roof surfaces with an extensive green roof would be more material- and labor-intensive and thus more expensive.

Roofs with a pitch greater than 30 degrees (58 percent, or 7:12) require a mechanically fastened, pregrown vegetation mat. However, in most cases this is cost-prohibitive and will not yield substantial stormwater retention benefits.

Root barrier: In sharp contrast to conventional gravel-ballasted roofs, green roofs need a root-resistant liner as well as waterproofing. Waterproofing based on organic materials (such as bitumen or asphalt) is susceptible to root penetration. If these materials are used, a barrier will be needed to prevent roots from puncturing the waterproofing. Synthetic waterproofing membranes, such as rubber (EPDM) and polyvinyl chloride (PVC) plastic, provide a root barrier within the membrane. Thus, no additional barrier is needed.


Katrin Scholz-Barth/PIX13398

The Montgomery Park Business Center in Baltimore, Maryland, features a 20,000-square-foot extensive green roof that has a suitable slope for this technology.

Drainage: The performance and success of green roofs depend to a great extent on efficient drainage. Although green roofs are designed to retain water, they are not intended to hold water beyond the absorption capacity of the soil layer, and standing water is detrimental to the plants. Thus, flat roofs require drainage mats to allow excess water to drain away. Drainage on low-sloped roofs occurs via gravity, which eliminates the need for additional drainage mats. Along the perimeter of the roof, a gravel strip conveys water to a standard gutter system.

Federal Sector Potential

Estimated Savings and Market Potential

Improvements in energy efficiency resulting from the use of green roofs can be attributed to reductions in roof surface temperatures, in heat transfer through the roof, and in peak power demand. Reduced heat gain ultimately means lower indoor air temperatures and less need to use air conditioning for cooling. Energy savings result from these reductions in energy use.

Research and pilot studies on buildings have been conducted by SHADE Consulting, using a roofing system heat transfer analysis method. They indicate that green roofs consistently outperform cool roof systems (highly reflective roofs) in terms of energy cost savings and long-term overall savings—in some cases, by a significant amount.[16] If these data could be verified and made available to the public, green roofs could soon become another viable alternative to high-performing roofs.

Additional energy savings could be obtained by carefully locating air intake vents. Placing the air intake vent over or near a green rooftop takes advantage of the smaller temperature difference between outdoor and indoor air for a green roof than for a conventional roof. This means that less energy would be needed to cool indoor air to desired levels, and it would also improve the efficiency of the mechanical system.

It is important to note, however, that every green roof has a different thermal impact on a building. Small variations in the design, installation, components, material selection, and geographic location will affect the energy performance of the roof and the building.

Building scale: Exact energy savings are difficult to predict at this time. However, field tests[17] (see the section on energy-saving mechanisms) and research[18] have already produced data that indicate the potential of green roofs to save energy by lowering roof surface temperatures as well as energy demands.

The effects of UV radiation and heat exposure can accelerate the aging process of waterproofing systems; this can compromise the quality of the waterproofing and the durability of a roofing system. As noted earlier, green roofs shade the roofing system and protect the waterproofing membrane from exposure to UV radiation and extreme temperature fluctuations. Thus, they can be said to slow down the aging process. Long-term savings result from extending the lifetime of a waterproofing system, but they cannot be predicted because they depend on the quality of workmanship and the long-term performance of the waterproofing. In Berlin, Germany, 100-year-old green roofs have not failed,[19] and they have more than doubled the lifetime of their waterproofing systems.

The waterproofing of a roof on a GSA-managed building is typically replaced every 15 to 25 years. Even if a green roof only doubles the lifetime of the waterproofing system, the resulting savings could significantly offset the initial costs of the roof. Savings to the federal government could be considerable. For example, the federal government owns or manages more than 500,000 facilities nationwide and spends about $8 to $10 per square foot to replace a roof and dispose of old materials every 15 to 35 years.[20] Assuming that the average roof surface of each building is 10,000 square feet, the savings from green roofs could amount to $80,000 to $100,000 per building in roof replacement costs alone. This is roughly equivalent to the initial capital investment in a green roof system (see the section on costs), excluding maintenance. If only half of all government facilities were retrofitted with green roofs, the savings could be in the millions of dollars over 15 to 25 years, despite additional maintenance expenses.

To minimize extra costs, green roofs could be installed on existing buildings to coincide with the next waterproofing replacement. The potential savings and environmental impact of such a phased-in approach are significant. If only 50 percent of all buildings are suitable for a green roof application, approximately 2.5 billion square feet, or nearly 60,000 acres, of green roof installations could be completed within the next 15 to 25 years on government buildings alone. This example is based solely on the extended life cycle of the waterproofing system; it does not take energy-use reductions and savings into account.

Regional scale: Air and water quality improvements will be measurable only when enough green roof installations are completed to make measurements meaningful. Meanwhile, the green roof initiative conducted by the National Research Council of Canada, along with field studies conducted by Environment Canada, has produced data that could lead to greater acceptance of green roofs.

The Canadian study finds that if only 6 percent of Toronto's roofs, or 1,600 acres (6.5 square kilometers), were green roofs, summer temperatures could potentially be reduced by 1.8° to 3.6°F (1° to 2°C) in this urban center. These lower ambient air temperatures could help reduce energy demand by as much as 5 to 10 percent, for a direct savings of more than $1 million in annual energy costs. The study also shows that 1,600 acres (6.5 square kilometers) of green roofs could help reduce greenhouse gas emissions, particularly carbon dioxide, by an estimated 2.2 megatons and remove 30 tons of pollutants from the air.[21]

Laboratory Perspective

Laboratory testing, field-testing, and theoretical analyses are currently under way at various research universities, such as Pennsylvania State. Data could be available in a few years that will provide additional statistical and empirical evidence as to the effectiveness of green roofs and their associated cost savings.

Implementation Barriers

The fear that waterproofing will leak underneath a green roof is one implementation barrier that seems to outweigh all its benefits, for some people. They often assume that green roofs cause leaks. But actually, a watertight system is the single most important prerequisite for any effective roof, whether it is a gravel-ballasted inverted roof membrane assembly (IRMA) or a green roof. Waterproofing keeps precipitation out of the building and is the basis of a successful green roof.

Additional barriers involve a lack of the following:

- Information and familiarity with green roof technology, design, and function
- Knowledge about maintenance requirements
- Industry standards and design guidelines and specifications
- Qualified designers and contractors
- Incentives to make green roof applications more attractive

Lack of information and familiarity with green roof technology, design, and function: This lack of information, as well as inadequate distribution of currently available information, has to be overcome before green roofs can be adopted more widely. But several groups are making progress. Green Roofs for Healthy Cities, a Toronto-based organization, is advocating the technology, organizing annual green roof conferences, and helping to develop a viable industry to support the emerging green roofs market.[22] The City of Chicago hosted "Greening Rooftops for Sustainable Communities," the First North American Green Roofs Infrastructure Conference, Awards, and Trade Show in May 2003. About 500 attendees from a wide range of professions learned about green roof designs and opportunities for application. The City of Portland, Oregon, hosted the second annual conference in 2004; 512 professionals attended.

In addition, green roof consultants, roofing manufacturers, and other organizations have started offering green roof seminars nationwide to staff in government, industry, and design firms. Research is being conducted by universities, government, and the public as well as private entities,[23] but English-language publications evaluating and discussing the data usually lag months or even years behind. A number of book projects are under way, however, and publications by Schiffer Books, Timber Press, and Wiley and Sons have been scheduled for 2004 and 2005. Basic monitoring devices such as temperature gauges could also be installed easily on green roofs to collect more data for widespread use.

Lack of knowledge about maintenance requirements: People often mistakenly assume that green roofs require a lot of maintenance throughout their life cycle. Rather, case studies show that, once green roofs are established, they require only annual maintenance surveys and occasional fertilizing if the soil becomes too acidic because of nitrogen deposits. However, they should always be inspected for damage to plants and soil following severe weather (e.g., high winds, drought, hurricanes, tornadoes, or heavy snow and ice storms).

Lack of industry standards and design guidelines and specifications: The term "green roof" is not yet standard and has been criticized as misleading by some GSA consultants. For example, in terms of environmental qualities, "green" roofs could mean reflective roofs, roofs made of recycled materials, vegetated roofs, or any other sustainable type.

To address this lack, a green roof task group under the American Society for Testing and Materials (ASTM) Subcommittee E06.71 on sustainability is developing a standard practice guide. It will establish a procedure for assessing green roofs and include technical requirements as well as considerations for sustainable development. The Canadian-based Green Roofs for Healthy Cities has developd a green roof training seminar that was first presented in June 2004, during the second annual green roof conference in Portland, Oregon.

Lack of qualified designers and contractors: Designing a green roof requires knowledge of the complex interactions and performance of all its layers. Training seminars would help to offset the shortage of qualified designers. However, the practical skills and knowledge needed to install a green roof are not highly specialized. Most qualified contractors can install one successfully without special training. The industry guidelines described above should make it possible for both designers and contractors to specify green roofs with little difficulty.

Lack of incentives to make green roof applications more attractive: Green roofs have higher up-front costs than other kinds because of the additional materials and special installation required. Too often, this premium is used as an excuse to forego a green roof application without evaluating its potential for savings and amenities. Limited funding may be available for green roofs that are designed to manage stormwater and control non-point-source pollution. More readily available research data are needed to further demonstrate that an integrated green roof design pays for itself when we take into account the savings resulting from reduced energy demand, reduced stormwater management requirements (treatment and retention basin size), and extended roof life.

Application

Many governmental buildings have flat or low-sloping roofs, and some have multiple roof elevations. These types are ideally suited for green roof applications.

Where To Apply

Green roof technology can be used on most building types that have concrete, wood, or composite (wood fibers and cement) roof decks. Metal roofs expand and contract and are thus not suitable for a green roof retrofit. To maximize their benefits, green roofs should be considered for office buildings in urban areas, military facilities, and buildings along coastal areas, in areas with combined sewer systems, and in areas where green space and habitat are limited or fragmented, once microclimate and plant selection criteria are fully understood.

What To Avoid

Except for the best practice guide being developed by ASTM, there are no recognized industrywide design specifications for green roofs. Therefore, it is essential to define a primary design goal before beginning the design. This will determine what materials and layers are required to achieve your goal. Here are some general guidelines on what to do and what to avoid.

DO: Prioritize desired green roof benefits and specify one primary goal. This allows you to stay focused during the design and specification process, while still receiving additional benefits.

DON'T: Try to make every benefit a priority.

DO: Ask an experienced professional to develop or review your green roof design specifications, to avoid costly mistakes and streamline the bidding process.

DON'T: Combine the cost estimate for the waterproofing with that of the green roof. The basic waterproofing system is usually not part of the green roof bid, because waterproofing is part of the building, whether you are planning new construction or a replacement for an existing roof. Separating the cost of green roof components from that of the basic waterproofing system allows you to make a more realistic cost estimate.

DO: Coordinate the selection of a waterproofing system with your green roof application, and choose one that is suitable, such as a root-resistant synthetic membrane. Avoid asphalt-based systems for waterproofing, because they are not root-resistant.

DON'T: Choose single-ply roofing membranes with adhered seams, because there is a greater risk of leaks.

DO: Use a heat welding or vulcanizing process to adhere seams on waterproofing.

DON'T: Use grasses or sod for green roof vegetation, as they are not suitable and can be a fire hazard.

DO: Choose suitable vegetation for your extensive green roof, that can withstand the extreme sun and wind exposure on roof tops.

Installation, Integration, and Maintenance

Green roofs can be used in place of conventional gravel-ballasted roofs. All the materials needed are readily available in the United States. Aside from specific layers for the green roof, construction and *installation* processes are very similar to those for conventional roofs and do not required specialized tools or equipment.

Time: In general, installing a green roof requires more time and labor than a conventional roof needs. Additional material has to be applied according to specifications. The planting can be handled by a roofing contractor or by a contracted landscape company.

Scheduling: To ensure a high plant survival rate, green roofs should be installed in cool seasons, such as spring or fall, when natural precipitation can be utilized most effectively to establish the plants. Hot and dry seasons should be avoided. If construction schedules dictate installation and planting during hot or dry periods, plants must be watered enough to avoid damage.

The installation of the soil and the planting should coincide. This helps to stabilize the soil immediately, and it avoids exposing a barren soil layer to erosion by wind or precipitation.

Contractors: Few U.S. contractors have special experience with green roof installations. However, any roofing contractor who is committed to high-quality work should be qualified to install a green roof under the supervision of an experienced and knowledgeable consultant.

Soil media: The soil media add weight to the structure; the type and thickness of the media determine the system's water-absorption capacity. The soil has also a significant impact on how well plants will establish and how much maintenance and weeding will be necessary. Lightweight aggregate is often preferred. Pumice, lava rock, perlite, compost, peat, or sand can be added to create suitable weed-free soil media. The added weight of water in the spaces between soil particles must also be calculated.

The weight of green roof soil media is always specified at maximum water-retention capacity per inch depth. See Table 4 for examples.

Aside from weight considerations, soil media must have some very important characteristics. These include grain size, soil density, porosity, water retention capacity, pH, organic substances, and nutrients.

Table 4. Loads for Various Green Roof Soil Media or Substrates

Substrate	Load per 1-inch Depth (lb/ft^2)
Topsoil with mineral and organic content	8-10
Mineral substrate with high organic content	5-7
Mineral substrate with low organic content	5-7
Expanded clay or slate	3.5-4
Recycled aggregates (broken bricks)	5-7
Expanded clay or slate	3.5-4

Katrin Scholz-Barth/PIX13399

It is important to select the right growing media for a green roof. Selection criteria depend on the intent and desired performance of the green roof. The photo shows, from left, plant establishment in 100 percent gravel, an 80/20 mix of gravel and topsoil, a 20/80 mix of topsoil and expanded clay, 100 percent topsoil, 100 percent expanded clay, and a mix of compost, clay, and sand.

Not surprisingly, plants generally establish best in topsoil, because it provides the best environment for plants in terms of nutrients, porosity, and grain size. Plant establishment was poor in pure gravel and expanded clay aggregate and fair in the three other soil compositions shown in the photo. The disadvantage of using topsoil in a green roof is (a) its weight and (b) decomposition, because of its high organic content. In order to maintain a constant medium depth, the soil medium should have a high mineral content that does not decompose. Mixing in 15 percent compost maximizes plant establishment while maintaining the overall performance of the green roof.

Plants: Plants must withstand significant exposure to the sun and wind and thrive in both stormy and dry conditions. Alpine and rock garden types of plants are well suited to these conditions. They store water in their leaves, which makes them ideal for the often harsh environment of rooftops.

Grasses and sod are not well suited to the green roof environment. Grasses dry up during hot, dry periods and are easily ignited by summer thunderstorms; thus, they can be fire hazards. Unless they are irrigated, grasses and sod should not be considered for extensive green roof plantings.

There are important distinctions among the plants to use in different regions of the United States. The plant hardiness zones defined by the USDA should be used as a guideline for selecting green roof plants for specific regions. Zone 1 has the coldest average temperature year-round, and Zone 11 has the warmest winter temperatures. Please see Table 5 for a selected

Katrin Scholz-Barth/PIX13400

Plants growing on the Montgomery Park Business Center's roof include Sempervivum tectorum, Sedum spurium 'Roseum,' Sedum sexangulare, and Sedum album.

list of suitable plants for extensive green roofs in different zones.

Plants are a vital component of green roofs. Their hardiness, aesthetics, and survival define the success of a green roof. There are three principal ways to establish a vegetation layer:

1. Use plant plugs with established root systems,
2. Apply plant cuttings to the soil layer, or
3. Seed the soil layer.

Plant plugs have fully established root systems and thus an 80 to 90 percent survival rate. They spread their roots horizontally almost instantly after installation, helping to stabilize the soil layer. Within one to two vegetation seasons, plant plugs will grow into a dense vegetation mat and almost fully cover the designated roof surface. Because plugs are planted by hand, this is a labor-intensive option and the most expensive one of the three.

In the second method, plant cuttings (mostly from sedum) are applied directly over the soil layer and held in place by a jute fabric. They have to develop roots before they can hold soil particles together and protect the soil from erosion, which takes time. Under ideal conditions, root development and growth can take from 3 to 6 months during the growing season (e.g., between April and October). Root development usually does not occur in the dormant season (e.g., between November and March). Using plant cuttings as an installation method is cheaper than using plant plugs. But if the condition of the cuttings and the soil preparation are not optimum, the survival of the cuttings is greatly compromised.

Cuttings may appear more attractive from a first-cost perspective. However, their survival rate is only about 50 percent, compared with 80 percent for plant plugs. Initial savings on labor

Ed Snodgrass/PIX13401

Plants make up a large part of the cost of a green roof. The photo shows establishment using both plant plugs (background) and cuttings (foreground). The plant plugs are forming a dense vegetation cover, whereas the cuttings are developing slowly, leaving most of the soil exposed.

may disappear when the roof has to be replanted. The third method, seeding, is not recommended.

Green roof plants vary in appearance, depending on the time of year. Many nondeciduous plants change color as they go dormant; others remain green throughout winter.

In terms of *integration*, large, single-story buildings benefit more from installations of green roofs than tall, multistory buildings do. The large roof-to-wall ratio of single-story buildings maximizes energy savings, because total energy use has a direct correlation to roof area. Because they help to improve energy efficiency, green roofs installed along with other energy-efficient measures often allow facility managers to downsize a building's chiller capacity. An existing heating, ventilating, and air-conditioning (HVAC) system might also be able to operate less intensively and at higher efficiency.

Mechanical systems, including air intake vents for the main HVAC systems, are usually on a large building's rooftop. Green roofs can be installed to easily accommodate these systems and their maintenance requirements. To provide proper access to equipment and ensure proper airflow, the vegetation layer should be installed at least 2 feet away from mechanical systems and air intakes.

Pathways in the form of pavers or gravel can be installed along the perimeter and around equipment for access and routine maintenance. For window cleaning and repair tasks other than HVAC maintenance, facility managers might want to consider installing a walkway made of 5-foot-wide pavers or a sufficiently wide gravel path around the perimeter of the vegetation.

Historic preservation may need to be addressed in regard to green roof installations in some areas. For example, Washington, D.C., has established

Table 5. Plants Suitable for Green Roofs in Various USDA Zones

Botanical Name	Common Name	Height (Inches)	Flower Color	USDA Zone	Bloom Time
Antennaria diocia*	Pink Pussy Toes	3”	Pink		
Armeria juniperifolia*	Spanish Thrift	2”	Pink	2	June
Armeria maritima ‘Pride of Dusseldorf’*	Common Thrift	5”	Pink	2	April-June
Aubrieta ‘Argenteo-variegata’*	Rock Cress	4”	Purple	4	April-June
Campanula ‘Birch Hybrid’	Bellflower	4”	Blue	4	June-Sept
Sedum acre ‘Aureum’	Golden Stonecrop	3”	Yellow	3	June-August
Sedum aizoon		4”	Yellow	5	July-August
Sedum album ‘Murale’		1”	White	4	
Sedum cyaneum ‘Rose Carpet’		2”	Pink		
Sedum dasyphyllum		3”	White	5	June
Sedum dasyphyllum ‘Blue Cadet’		1.5”	White	5	
Sedum dasyphyllum ‘Blue Carpet’		1”	White/Pink	5	
Sedum divergens	Old Man Bones	4-6”	Yellow	5	July-August
Sedum ewersii	Pink Stonecrop	6”	Rose-Pink	3	Late Summer
Sedum ‘Jelly Bean’	Jellybean Sedum	4”			
Sedum kamtschaticum	Russian Stonecrop	6”	Yellow	3	June-July
Sedum linare ‘Variegatum’		5”	Yellow		
Sedum lineare ‘Golden Teardrop’		3”	Yellow	3	May-June
Sedum matrona		24”	Pink	6	Sept
Sedum ‘Mentha Requein’	False artillery fern	2”		4	
Sedum pinifolium ‘Blue Spruce’		8”	Yellow	4	June-July
Sedum reflexum		4”	Yellow		
Sedum sexangulare		4”	Yellow	4	
Sedum spurium ‘Fuldaglut’	Dragon’s Blood Sedum	6”	Red	3	Fall
Sedum spurium ‘Roseum’		6”	Pink	3	
Sedum spurium ‘Tri-Color’		6”	Pink	3	
Sedum spurium ‘White Form’		6”	White	3	
Sedum ternatum ‘Larinem Park’	Shale Barrens	2”	White	3	May-June
Sedum tetractinum		4”		5	
Sedum floriforum ‘Weihenstephaner Gold’			Yellow		
Sedum ‘Arthur Branch’		18”	Red	4	August-Sept
Sempervivum arachnoideum ‘Sparkle’	Spider-web Hen & Chicks				
Thymus praecox ‘Coccineus’	Red Creeping Thyme	1”	Red/Purple	2	July-August
Thymus praecox ‘Elfin’	Miniature Thyme	1/2”	Pink	2	July-August
Thymus praecox ‘Pseudolanuginosus’	Woolly Thyme	1”	Pink	2	July-August

Note: Invasive sedum species—such as Sedum sarmentosum, a native of China—should be avoided on green roof applications. Delosperma, or ice plant, is also difficult to control on some roofs.

* These require about 4 inces of soil.

some strict guidelines for historic preservation, and green roof retrofits might not be allowed on certain roofs of historic significance.

Typically, historic preservation guidelines require that the appearance of a building from street level may not be altered. However, many government-style buildings have parapet walls around the edges of the roof. These walls can ensure the continuity of a building's appearance from street level while allowing a green roof application, if desired and permitted. Specific design details would need to be addressed on a case-by-case basis.

If a green roof is installed as part of an on-site stormwater management plan, the design should be integrated with the plan early in the design process, in collaboration with site engineers. Only if the green roof becomes an integral part of the whole project can its benefits be fully realized.

In terms of *maintenance*, an immediate commitment to weed control is imperative. Although plants on extensive green roofs do not typically produce the pollen that can cause allergic reactions in people working in or around the building, during the first two years weed control is needed to prevent ragweed and other pioneer exotics from taking root. Once the plant community forms a dense mat of vegetation, the opportunity for weeds to invade is greatly reduced because the soil, where weed seeds settle and sprout, is no longer exposed. Maintenance can thus be less frequent.

In fact, extensive green roofs are designed to require very little maintenance. When they are first installed, green roofs require some care to ensure that plants take root in the new environment, remain healthy, and grow vigorously to form a dense vegetation mat. During the first two years, weed control can be done monthly or quarterly, depending on the site's conditions; this can often be reduced to once a year after the second year.

Irrigation: If natural precipitation at the site is insufficient to establish the plants at the time of installation, green roofs may need at least initial irrigation. The planting schedule and time of year can often be chosen to make use of natural irrigation. Note, however, that a permanent irrigation system that waters the plants regularly would keep the soil moist constantly and thus reduce the capacity of the green roof to retain and redirect precipitation. Therefore, permanent irrigation should be avoided unless it is required by climate conditions at the site. Selecting suitable, site-specific plants helps to eliminate this problem.

Fertilizer: A thin layer of soil can become acidic over time. Therefore, it is advisable to apply a slow-release fertilizer during an annual maintenance walk, either in spring or in fall (whichever is the drier season).

Weeding: Initially, during one to two growing seasons, weeding may be required at least quarterly. After the soil layer is fully shaded by plants, weeding may be required only annually, in conjunction with regular roof drain cleaning and maintenance.

Leaks in waterproofing: Leaks in the waterproofing can result from problems with the waterproofing itself or with quality control and workmanship during installation. These leaks are difficult to detect and repair once vegetation covers the waterproofing. Here are a few simple measures that can reduce the potential for leaks:

- Coordinate and time your waterproofing installation to prevent debris from falling onto it before the green roof is installed.
- Limit access to the roof once the waterproofing is installed to prevent workers from stepping on sharp objects like nails or glass and causing potential damage to the waterproofing.
- Flood-test the roof before the green roof installation to detect any construction-related damage while there is time to correct it fairly easily and while the membrane is accessible. Whether it is a prefabricated system or assembled with separate materials, a green roof requires care and quality control to prevent damage to the waterproofing.

Some roofing and green roof consultants offer leak detection services that will locate a leak underneath any protective roofing system, gravel ballast, IRMA, or vegetation layer. The electric field vector mapping (EFVM) technique is a method frequently used to test the water-tightness of existing roof surfaces before installing a green roof. It can also be used for annual surveys of green roofs to verify that the waterproofing system remains watertight below the vegetation. The EFVM method enables the source of any leak, even pin-hole-sized defects, to be located, but it requires that a fine grid of metal wire be installed initially within the green roof and waterproofing layers.

Occasional replanting: If large areas remain bare, replanting is recommended to stabilize soils and control erosion. If a green roof is designed for a specific performance goal (e.g., stormwater retention), the soil depth has to remain constant to ensure a certain water-retention capacity. If the growing medium compacts or decomposes to a lower depth, the green roof needs to be top-dressed with additional soil.

Gutters: These require routine cleaning, just as those of conventional roofs do, to avoid standing water and hydrostatic pressure, which could lead to leaks.

Monitoring is not a maintenance requirement. However, government agencies might want to monitor performance to quantify benefits in specific regions and to contribute to data on the most suitable green roofs for various building types.

Warranties, Standards, and Codes

Manufacturers typically guarantee waterproofing systems for 15 to 25 years. These warranties can generally be extended to the same number of years for a green roof application if the same contractor installs the waterproofing and the green roof, or if the green roof system is supplied by the same manufacturer as the waterproofing membrane. The warranty may also be extended if a representative of the waterproofing company is on site during the subsequent green roof installation to ensure that no damage was done to the waterproofing. Warranties for maintenance and repair of the waterproofing are commonly based on the condition that the building owner bears the responsibility for removing the overburden (green roof) in case of a leak.

Currently, there are no codes or standards for green roofs in the United States. The best practice guide being developed by the ASTM green roof task group will establish a procedure for assessment that includes both technical requirements and considerations for sustainable development.

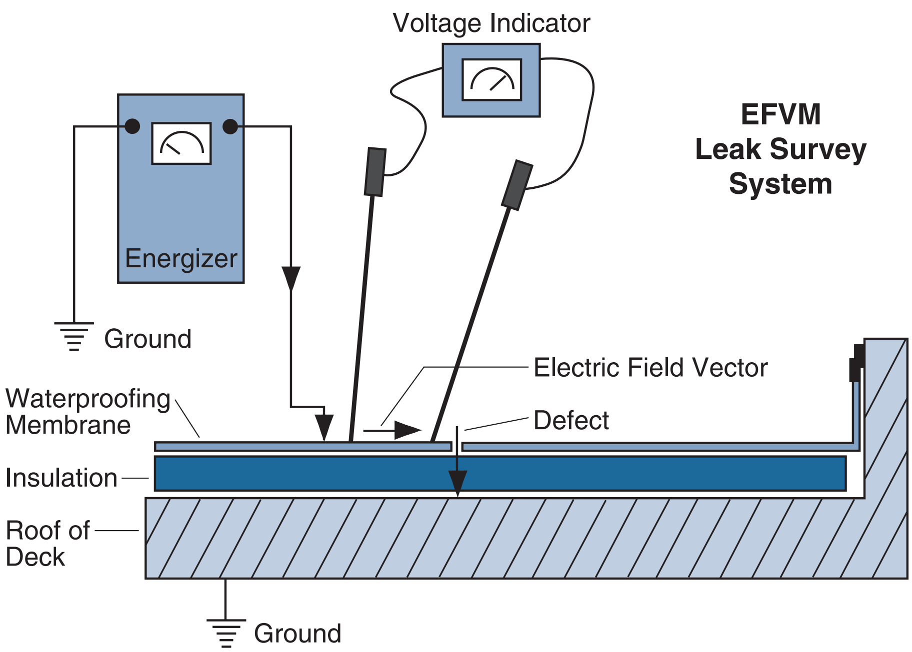
Costs

The cost of a green roof varies widely, depending on geographic area, materials used, and the contractor selected. Excluding structural upgrades, green roofs used to be widely quoted in the United States at $15 to $20 per square foot. But over the past few years, quotes have fallen to $8 to $15 per square foot. These quotes might appear high in comparison to those common in Europe. This might be due in part to contractors' unfamiliarity with the technology, to the use of imported materials from European manufacturers, and to the current lack of industry standards.

Waterproofing can cost from $3 to $6 for built-up or PVC roofs. The cost of the soil media varies, depending on its content, which can range from lightweight shale or clay aggregates mixed with topsoil to almost 100 percent expanded clay or shale aggregates. The cost of the growing media varies widely, from $1 to $5 per square foot for a 4-inch-deep layer. Plant plugs should be budgeted at a minimum of $1 per square foot, or about $0.50 per plant plus shipping and handling, not including installation. In addition, the cost of drainage mats, optional irrigation and water-retention layers, root-resistant liners, and other layers must be included in the cost estimate. In line with the overall sustainability of a project, all green roof components should be obtained locally, if possible, to reduce costs.

Retrofit costs are harder to estimate. The cost of disposing of old material, structural upgrades, and new waterproofing might have to be added to the estimate, and these can make the total cost somewhat misleading.

The payback period for a green roof is also not easy to calculate, because it depends on many variables. These include new construction versus a retrofit; the scope and cost of the green roof design; whether the roof is installed on a single or multistory building; the total energy demand of the building versus the offset in energy demand; and stormwater permit requirements. At present, no procurement information is known to be available for green roofs on government buildings.



Electric field vector mapping (EFVM) technique for detecting leaks (Sources: International Leak Detection, Ltd.; Roofscapes, Inc.).

Utility Incentives and Support

Executive Order 13123, *Greening the Government Through Efficient Energy Management*, signed in 1999, directs all federal agencies to significantly improve the energy performance of government buildings and to reduce greenhouse gas emissions. In addition, agencies have to reduce their energy consumption per gross square foot by 35 percent by the year 2010, relative to 1985[24] levels, and green roofs can contribute to all these directives. At present, no direct rebates or incentive programs support the installation of new green roofs or retrofits.

Stormwater quality and quantity requirements apply almost everywhere. However, several jurisdictions and regulatory agencies—including the Maryland Department of the Environment; the City of Portland, Oregon; the City of Seattle; and the District of Columbia—allow the runoff rates and volume of green roofs to be like those of forests or meadows. The resulting credits can help ease and speed the environmental permit process and save on construction costs for stormwater controls that would be required otherwise.

Some communities and cities in North America collect stormwater utility fees. Revisions are under way to assess how these fees can be adjusted to reflect the actual impact of impervious surfaces on sewer systems and urban watersheds, based on the actual footprint of a building rather than on a universal flat fee. This would allow the calculation of the actual amount of stormwater runoff generated by each property. Because green roofs filter, store, and absorb rainwater, buildings with a green roof do not generate the usual peak runoff rates, volume, or non-point-source pollution generally associated with urban runoff. To encourage low-impact development strategies, utilities might want to create incentive programs or provide exemptions to stormwater fees.

Many local governments in the United States have based their green building initiatives on the U.S. Green Building Council's LEED rating system, and they grant floor area ratio and height bonuses to those achieving a minimum LEED rating. However, a cost-benefit analysis would probably not support installing a green roof as a way to obtain LEED credits.

In terms of building codes, many cities and communities in North America are reviewing and revising their codes to remove barriers for green building practices and to address green roofs specifically. Landscaped roofs and roof gardens are generally allowed in building codes, as long as the roof structures are properly designed to carry the additional loads.

The City of Chicago recently updated its energy code, requiring light-colored roofs as one way to reduce the urban heat island effect. Chicago might also allow the use of green roofs that have the same benefits to meet this code. In addition, landscape ordinances throughout North America now specify minimum shading requirements for large lots to reduce urban heat islands and to meet open space requirements. Those ordinances might also allow green roofs to be used to comply with those goals, in whole or in part.

Technology Performance

Green roofs technology is not new. However, it has only recently been introduced into North America. A limited number of projects have been completed, and little performance data are available to date.

Project monitoring: The roof of the combined City Hall and Cook County building in Chicago was retrofitted with a 22,000-square-foot green roof on the City Hall side in 2001. The rooftop of the county's portion of the building remains black. These two roof surfaces are undergoing intensive monitoring programs to evaluate the green roof's performance in mitigating heat gain at the surface and thus in reducing the effects of urban heat islands. Data should be available in the near future.

Academic research: The State University of Pennsylvania, under the supervision of Dr. David Beattie in the Horticulture Department, is undertaking an extensive research project to evaluate the performance of green roofs for energy efficiency, stormwater management, and the mitigation of heat gain. The study also aims to evaluate a green roof's impacts on indoor environments and ability to neutralize acid rain, as well as to define physiological, biological, and ecological factors influencing plant survival.[25]

The research project makes use of six small structures; three of them are covered with an extensive green roof with a 4-inch thick soil layer. The other three structures have conventional black roof surfaces. All the buildings are equipped with multiple sensors and connected to an electronic data logger to continually collect and record data, including heat flux, stormwater runoff, and nutrient filtration. Each building is metered separately to evaluate its energy consumption for heating and cooling. These data will be published to aid in establishing protocols for the performance of green roofs. Note, however, that the roof-to-wall ratio in this study is not representative of a typical single-story building with a large footprint.

International performance and evaluation: In Europe, green roof technology has been applied for more than 20 years. Many projects have been monitored, and performance data are available, but not in English. Germany recently developed an evaluation matrix in an effort to quantify green roof performance. This matrix will allow comparisons of several different green roof systems, despite the broad spectrum of design parameters used, based on a point value rating system.

Performance is rated on the basis of ecological functions, ability to mitigate the effects of impervious surfaces, and economic benefits. Design parameters include the type of green roof (single- or multiple-layer construction), the use of recycled and locally available materials, soil depth, plant diversity, maintenance requirements, insulation properties, and cost-benefit ratio. However, it stops short of actually requiring monitoring the green roof's performance.

Case Study

Chicago City Hall Rooftop Garden Retrofit

Chicago, Illinois

The City of Chicago is one of five U.S. cities selected by the EPA to participate in the Urban Heat Island Pilot Project. The goal of the pilot study is to measure elevated ambient air temperatures in a metropolitan area and study the benefits of cooling urban heat islands to improve air quality.

Chicago's current Mayor, Richard M. Daley, learned about green roofs when he visited Europe. Upon his return to the United States, he decided to support a demonstration of green roof technology on the City Hall building (see cover photo) for three reasons: (1) to showcase green roof technology in Chicago and lead by example, (2) to study its effectiveness in lowering ambient air temperatures, and (3) to promote public interest in this new technology.

City Hall shares a 12-story building in downtown Chicago with Cook County's administrative offices. Each government agency is responsible for the maintenance and upkeep of its half of the building's roof. All mechanical systems are located on the roof in the penthouse. The green roof retrofit of the City Hall half—including permitting, structural, and maintenance issues—was quite a challenge for city engineers.

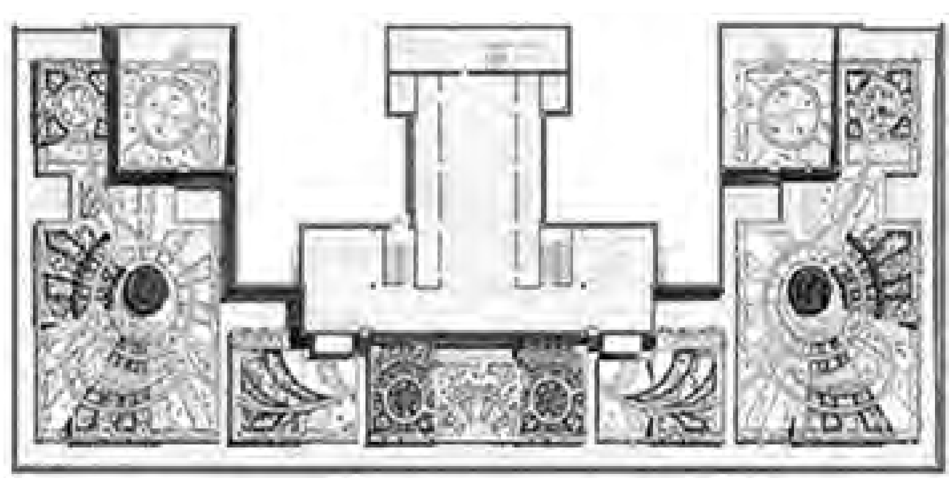
During the design process, energy modeling was conducted to predict the environmental benefits of a green roof on the City Hall roof and on those of all the buildings in Chicago, which make up about 30 percent of the city's surface area. The energy model estimated that City Hall might save $4,000 in annual energy costs from reduced heating and air-conditioning demands. The model also estimated that the entire city could reduce its energy demand by as much as 720 megawatts and thus save as much as $100,000,000 if all the buildings in Chicago were covered with green roofs. The lower energy demand would also result in a 460-ton reduction in NO_x and a 570-ton reduction in sulfur dioxide (SO_2) each year.[26]

The soil layer of the Chicago City Hall green roof was designed to have a variety of depths, ranging from 3- to 4-inch layers to semi-intensive layers of about 8 to 10 inches. Two small intensive areas contain one tree each. The initial green roof design turned out to be cost-prohibitive at $2.9 million, or about $1.5 million over budget. As a result, it was redesigned and rebid by an experienced installer. This setback shows how an unfamiliarity with green roofs can cause unnecessary, time-consuming, and expensive delays in the design process. The experienced green roof consultant was brought in too late to maximize the functionality of the roof, beyond its ability to reduce ambient air temperatures.

For construction to proceed, a building permit was required. Questions arose about how to permit a green roof and which building codes applied to the project. The design was found to not have to meet requirements for accessibility in the Americans with Disabilities Act, nor were long plumbing extensions needed. The building permit was granted in 6 weeks. However, another major setback was prompted by the extensive deterioration in the parapet walls. The brick mortar, which was susceptible to the penetration of water, had to be repaired before the installation could continue. When the waterproofing installation was completed, a flood test was conducted.

The City Hall roof measures about 38,800 square feet. The green roof now occupies 22,000 square feet of the total and consists of 156 plant varieties. Planting occurred in two stages, from September to early November 2000, and the installation was completed in spring 2001.

The first interesting effect, the reduction in heat flow resulting from the green roof, was observed during the first winter. A snowfall in late 2000 offered a protective cover for the tender plants that were feared lost because of the lateness of the



Credit: City of Chicago

Plantings for the green roof of Chicago's City Hall were done in two stages in the fall of 2000.

installation. The snow lasted for an extended period of time, as observed by engineers in the city's Environment Department, while the snow on the adjacent county building's roof melted in just two weeks, indicating reduced heat flow on the green roof.

Data loggers were used to monitor ambient air temperatures over City Hall's green roof and over the County Building's black tar roof, collecting data every 30 minutes. In August 2001, the temperature of ambient air over the County Building's black tar roof measured 114°F (45.5°C), and the temperature over City Hall's green roof measured 107°F (41.6°C). The air over the green roof was thus cooler by 7°F (3.9°C) than that over the black tar roof, which is consistent with measurements taken in a Toronto project and with estimates by LBNL.

The roof temperatures shown below were taken with an infrared thermometer on August 9, 2001. Although this method is less accurate than using a data logger, surface temperatures can be instantly measured and recorded by using a hand-held infrared thermometer. The August 2001 data are as follows:

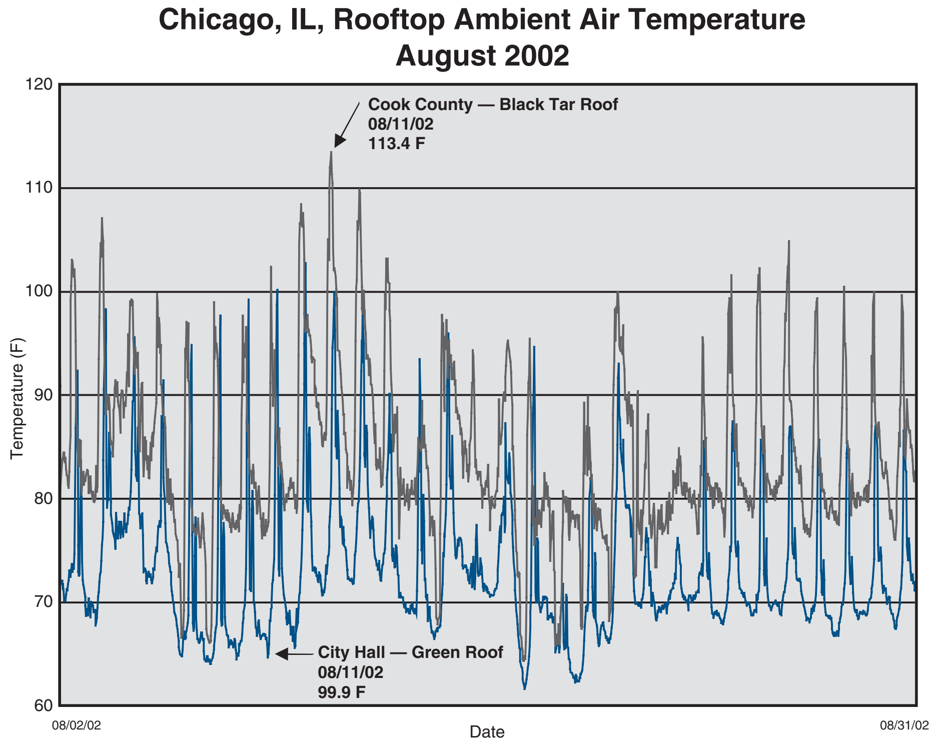
City Hall green roof paved surfaces
126°–130°F (52.2°–54.5°C)

City Hall green roof surface
91°–119°F (32.7°–48.3°C)

Cook County black tar roof
169°F (76°C)

The average temperature difference between the city's and the county's roof surfaces was thus found to be 64°F (35.5°C). This indicates the potential of green roofs to efficiently lower ambient air temperatures. The graph on this page compares cumulative data for the City Hall green roof and the Cook County black tar roof taken during August 2002.

The City Hall green roof cost $24.60 per square foot (about $500,000). The cost was higher than average because it was constructed as a combined, semi-extensive/intensive green roof. It includes the cost of irrigation and two trees, which are usually not part of an extensive green roof design. The total cost—including removal and disposal of the old roof, new waterproofing, structural upgrades, and the green roof retrofit—was $1.5 million. Actual energy savings have not yet been determined and will be needed to calculate the payback period for this retrofit.[27]



The Technology in Perspective

Technology Development

Some of the earliest known examples of green roofs—roof gardens dating back to 600 B.C. and earlier—might have been similar to the fabled Hanging Gardens of Babylon. These apparently were planted on terraced rooftops to cool the buildings underneath them.

Green roofs and traditional sod bricks have been used for many centuries in Iceland, Scandinavia, Alaska, and parts of Africa to protect inhabitants from the effects of extreme climate conditions. Both the Vikings and the French apparently brought the practice with them to areas that are now part of Nova Scotia and Newfoundland in northeastern Canada.

In modern times, the architects Le Corbusier and Frank Lloyd Wright were both notable advocates of green roof technology. In northern Europe, there has been a considerable resurgence of interest in green roofs since the 1960s for their ability to improve the environment of densely populated urban areas. Germany's interest in the technology began to surge about 20 years ago, when it became evident that stormwater runoff in densely populated areas was exceeding the capacity of the sewer systems to handle it.

In Germany, people began to realize that the capacity of the sewer infrastructure could not be expanded in many areas, so alternatives had to be found. They discovered that using green roofs in lieu of conventional roof surfaces could be the single greatest way to reduce and delay stormwater runoff and to significantly reduce the load on a sewer system. Several private companies have brought some of Europe's newest green roof designs across the Atlantic to North America.

Technology Outlook

In recent years, several research, demonstration, and test projects have been conducted in both Canada and the United States—in cities like Ottawa, Winnipeg, Chicago, and Portland, among others. Early results indicate that green roofs hold great promise as an effective way to help solve a number of modern urban problems in North America.

Recent studies conducted by the National Research Council of Canada show that green roofs are highly effective in reducing heat transfer. And extensive research is being conducted in the United States on strategies for mitigating urban heat islands; it could prove to be very helpful in introducing green roofs into the mainstream of the building industry in this country.

Because thousands of government buildings are good candidates for green roof retrofits, there is great potential for this technology in federal facilities. Green roofs could be gradually phased in as part of standard roof replacement and modernization efforts. This would also assist in extending the lifetimes of replacement roofs.

For new construction, federal agencies could make green roofs mandatory because of their energy and environmental benefits, such as stormwater management. If green roofs could be integrated into building design and stormwater permitting processes, they would be more cost-effective because the resulting cost savings would be significant.

Because they are such a beneficial, multifunctional technology, green roofs are likely to become more widely used in the United States in future years. This is particularly true in urban areas, where the need for such a benign technology is becoming more urgent all the time.

Conclusion

Green roof technology is an effective, practical way to increase the energy performance of buildings and limit stormwater runoff. Adapting green roofs for federal buildings can provide important benefits, especially to low-rise buildings and facilities in districts with strict stormwater regulations. Integrating green roofs into stormwater permitting requirements may be the most realistic way to make them more financially viable. Green roofs are also effective in reducing the effects of urban heat islands.

The lack of information and education about green roofs must be addressed, however, if they are to be used more widely. This is especially important in areas with combined sewer systems and in coastal areas where reducing stormwater runoff can be critically important to public health and to the health of our watersheds.

For More Information

The following lists include companies identified as being involved in designing, manufacturing, or installing green roofs. We made every effort to identify current manufacturers; however, this listing is not purported to be complete or to reflect future market conditions. Please see the *Thomas Register* (www.thomasregister.com) for more information.

Consultants and Designers

Charlie Miller, P.E.
Roofscapes, Inc.
7114 McCallum Street
Philadelphia, PA 19119
Phone: 215-247-8784
Fax: 215-247-4659

Katrin Scholz-Barth
Katrin Scholz-Barth Consulting
1246 Duncan Place, N.E.
Washington, D.C. 20002
Phone: 202-544-8453

Robert Hermann
Uncommon Plants
P.O. Box 493
New Hartford, CT 06057
Phone/fax: 860-379-0327

Waterproofing and Green Roof Systems Manufacturers

American Hydrotech,
in partnership with Zinco, Inc.
303 E. Ohio Street
Chicago, IL 60611
Phone: 800-877-6125
Fax: 312-661-0731

Barrett Company
P.O. Box 421
Millington, NJ 07946
Phone: 800-647-0100
Fax: 908-647-0278

The Garland Company
3800 East 91st Street
Cleveland, OH 44105
Phone: 800-741-3157

Sarnafill, Inc.
100 Dan Road
Canton, MA 02021
Phone: 781-828-5400
Fax: 781-828-5365

Suprema, Inc.
310 Quadral Drive
Wadsworth, Ohio 4428
Phone: 800-356-3521
or 330-334-0066

W. P. Hickman Systems, Inc.,
in partnership with the German firm FAMOS
30700 Solon Industrial Parkway
Solon, Ohio 44139
Phone: 440-248-7760
Fax: 440-248-6524

Modular Green Roof Systems

GreenTech, Inc.
8401-F Mayland Drive
Richmond, VA 23294
Phone: 804-965-0026
Fax: 804-965-9630

GreenGrid
20 North Wacker, Suite 1210
Chicago, IL 60606
Phone: 312-424-3306
Fax: 312-424-3330

Selected Nurseries

Emory Knoll Farms
3410 Ady Road
Street, MD 21154
Phone: 410-452-5880
Fax: 410-452-5319

North Creek Nurseries, Inc.
388 North Creek Road
Landenberg, PA 19350
Phone: 610-255-0100
Fax: 610-255-4762

ItSaul Natural
1115 West Nancy Creek Drive
Atlanta, GA 30319
Phone: 404-257-3339

Rice Creek Gardens, Inc.
11506 Highway 65
Blaine, MN 55434
Phone: 763-754-8090

Other Resources

Pennsylvania State University
Green Roof Research Center
University Park, PA 16802 http://hortweb.cas.psu.edu/research/greenroofcenter/research.html

Green Roof Innovations,
a division of SHADE Consulting, LLC
P.O. Box 2775
Carmel, CA 93921
Phone: 831-625-5625
Fax: 831-625-0525

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Osmundson, Theodore. *Roof Gardens: History, Design and Construction*. New York: W.W. Norton & Company, 1999.

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Peck, Steven, Chris Callaghan, Monica E. Kuhn, and Brad Bass. *Greenbacks from Green Roofs: Forging a New Industry in Canada*. Toronto: Canada Mortgage and Housing Corporation, March 1999. www.greenroofs.ca/grhcc/Greenbacks.pdf.

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[11] *Ibid.*

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About FEMP's New Technology Demonstrations

The Energy Policy Act of 1992 and subsequent Executive Orders mandate that energy consumption in federal buildings be reduced by 35% from 1985 levels by the year 2010. To achieve this goal, the U.S. Department of Energy's Federal Energy Management Program (FEMP) sponsors a series of activities to reduce energy consumption at federal installations nationwide. One of these activities, new technology demonstrations, is tasked to accelerate the introduction of energy-efficient and renewable technologies into the federal sector and to improve the rate of technology transfer.

As part of this effort, FEMP sponsors the following series of publications that are designed to disseminate information on new and emerging technologies:

Technology Focuses—brief information on new, energy-efficient, environmentally friendly technologies of potential interest to the federal sector.

Federal Technology Alerts—longer summary reports that provide details on energy-efficient, water-conserving, and renewable-energy technologies that have been selected for further study for possible implementation in the federal sector. Additional information on Federal Technology Alerts (FTAs) is provided below.

Technology Installation Reviews—concise reports describing a new technology and providing case study results, typically from another demonstration or pilot project.

Other Publications—we also issue other publications on energy-saving technologies with potential use in the federal sector.

More on Federal Technology Alerts

Federal Technology Alerts, our signature reports, provide summary information on candidate energy-saving technologies developed and manufactured in the United States. The technologies featured in the FTAs have already entered the market and have some experience but are not in general use in the federal sector.

The goal of the FTAs is to improve the rate of technology transfer of new energy-saving technologies within the federal sector and to provide the right people in the field with accurate, up-to-date information on the new technologies so that they can make educated judgments on whether the technologies are suitable for their federal sites.

The information in the FTAs typically includes a description of the candidate technology; the results of its screening tests; a description of its performance, applications, and field experience to date; a list of manufacturers; and important contact information. Attached appendixes provide supplemental information and example worksheets on the technology.

FEMP sponsors publication of the FTAs to facilitate information-sharing between manufacturers and government staff. While the technology featured promises significant federal-sector savings, the FTAs do not constitute FEMP's endorsement of a particular product, as FEMP has not independently verified performance data provided by manufacturers. Nor do the FTAs attempt to chart market activity vis-a-vis the technology featured. Readers should note the publication date on the back cover, and consider the FTAs as an accurate picture of the technology and its performance at the time of publication. Product innovations and the entrance of new manufacturers or suppliers should be anticipated since the date of publication. FEMP encourages interested federal energy and facility managers to contact the manufacturers and other federal sites directly, and to use the worksheets in the FTAs to aid in their purchasing decisions.

Federal Energy Management Program

The federal government is the largest energy consumer in the nation. Annually, the total primary energy consumed by the federal government is 1.4 quadrillion British thermal units (quads), costing $9.6 billion. This represents 1.4% of the primary energy consumption in the United States. The Federal Energy Management Program was established in 1974 to provide direction, guidance, and assistance to federal agencies in planning and implementing energy management programs that will improve the energy efficiency and fuel flexibility of the federal infrastructure.

Over the years, several federal laws and Executive Orders have shaped FEMP's mission. These include the Energy Policy and Conservation Act of 1975; the National Energy Conservation and Policy Act of 1978; the Federal Energy Management Improvement Act of 1988; the National Energy Policy Act of 1992; Executive Order 13123, signed in 1999; and, most recently, Executive Order 13221, signed in 2001, and the Presidential Directive of May 3, 2001.

FEMP is currently involved in a wide range of energy-assessment activities, including conducting new technology demonstrations, to hasten the penetration of energy-efficient technologies into the federal marketplace.

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

Log on to FEMP's Web site for information about New Technology Demonstrations

www.eere.energy.gov/femp/

You will find links to

- A New Technology Demonstration Overview
- Information on technology demonstrations
- Downloadable versions of publications in Adobe Portable Document Format (pdf)
- A list of new technology projects under way
- Electronic access to a regular mailing list for new products when they become available
- How federal agencies may submit requests to us to assess new and emerging technologies

For More Information

EERE Information Center
1-877-EERE-INF or
1-877-337-3463
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Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable