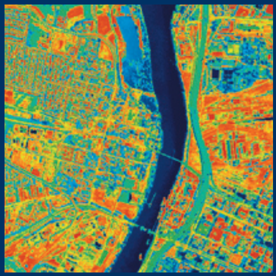
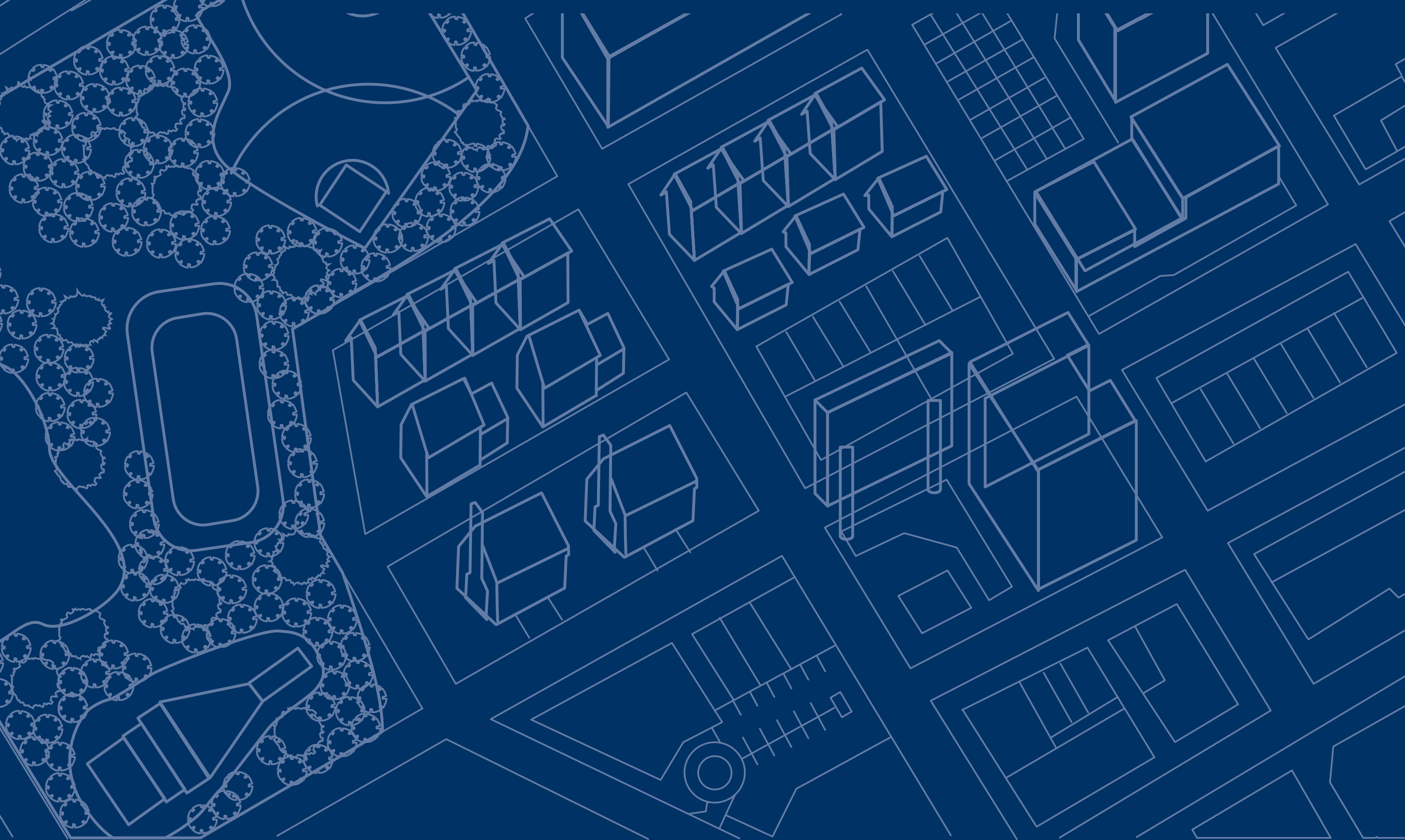
    

Reducing Urban Heat Islands: Compendium of Strategies

Green Roofs



Acknowledgements

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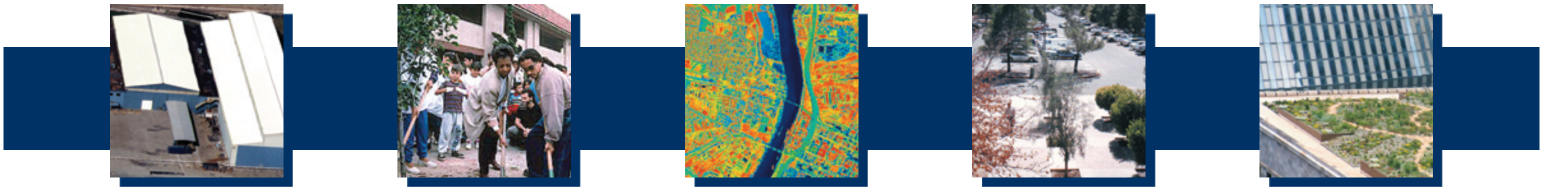


Green Roofs

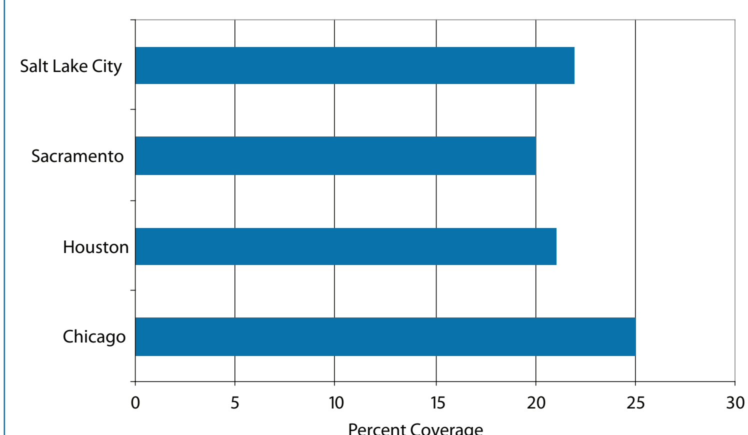
Green roofs are an emerging technology that can help communities mitigate urban heat islands. A green roof is a vegetative layer grown on a rooftop. As with trees and vegetation elsewhere, vegetation on a green roof shades surfaces and removes heat from the air through evapotranspiration. These two mechanisms reduce temperatures of the roof surface and the surrounding air. The surface of a vegetated rooftop can be cooler than the ambient air, whereas conventional rooftop surfaces can exceed ambient air temperatures by up to 90°F (50°C).[2] Green roofs can be installed on a wide range of buildings, including industrial, educational, and government facilities; offices; other commercial property; and residences. This chapter reviews:

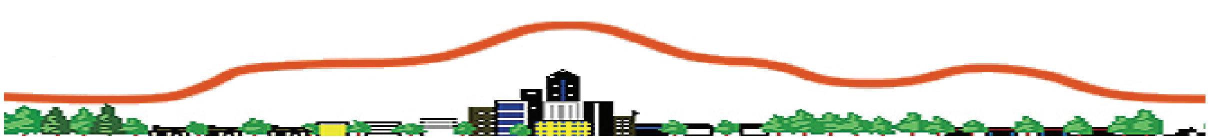
- How green roofs work to mitigate heat islands
- What types of green roofs are available
- The benefits and costs of green roofs
- Other factors to consider in using this mitigation strategy
- Initiatives used to promote green roofs
- Tools and resources to further explore this technology.

Opportunities to Expand Use of Green Roofs in Urban Areas

Most U.S. cities have significant opportunities to increase the use of green roofs. As part of EPA's Urban Heat Island Pilot Project, the Lawrence Berkeley National Laboratory conducted analyses to estimate baseline land use and tree cover information for the pilot program cities.[1] Figure 1 shows the percentage of roof cover in four of these urban areas: roofs account for 20 to 25 percent of land cover. Even though not all these areas will be likely candidates for installing a green roof, there is a large opportunity to use green roofs for heat island mitigation.

Figure 1: Roof Cover Statistics for Four U.S. Cities (Below Tree Canopy)





1. How It Works

With regard to urban heat islands, green roofs work by shading roof surfaces and through evapotranspiration. Using green roofs throughout a city can help reduce surface urban heat islands and cool the air.

Shading. The plants of a green roof and the associated growing medium, a specially engineered soil, block sunlight from reaching the underlying roof membrane. Though trees and vines may not be common on green roofs, they indicate how other vegetation on green roofs shade surfaces below them. For example, the amount of sunlight transmitted through the canopy of a tree will vary by species. In the summertime, generally only 10 to 30 percent of the sun's energy reaches the area below a tree, with the remainder being absorbed by leaves and used for photosynthesis and some being reflected back into the atmosphere. In winter, the range of sunlight transmitted through a tree is much wider—10 to 80 percent—because evergreen and deciduous trees have different wintertime foliage, with deciduous trees losing the leaves and allowing more sunlight through.[6]

Shading reduces surface temperatures below the plants. These cooler surfaces, in turn, reduce the heat transmitted into buildings or re-emitted into the atmosphere. For example, a multi-month study measured maximum surface temperature reductions due to shade trees ranging from 20 to 45°F (11-25° C) for walls and roofs at two buildings.[7] Another study examined the effects of vines on wall temperatures, and found reductions of up to 36°F (20°C).[8] Furthermore, the growing medium of a green roof itself protects the underlying layers from exposure to wind and ultraviolet radiation.

Figure 2: Intensive Green Roof in Frankfurt, Germany

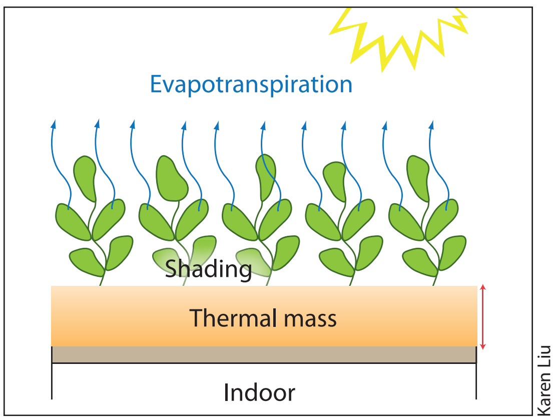
Germany has long been a leader in green roofs; an intensive green roof covers much of this building in Frankfurt.

Green Roof Market

In the United States demand and interest in green roofs has grown tremendously. A survey of Green Roofs for Healthy Cities members found that 25 percent more square feet of green roofing were installed in the United States in 2005 than in 2004.[3] A Green Roofs Project Database, available at <www.greenroofs.com/projects/plist.php>, estimated a total of 6.6 million square feet (614,000 m^2) of completed or ongoing green roof projects in the United States as of June 2007. Germany, widely considered a leader in green roof research, technology, and usage, has had decades of experience with green roofs. An estimated 10 percent of all flat roofs in Germany are rooftop gardens.[4,5]

Evapotranspiration. Plants absorb water through their roots and emit it through their leaves—this movement of water is called transpiration. Evaporation, the conversion of water from a liquid to a gas, also occurs from the surfaces of vegetation and the surrounding growing medium. Together, the processes of evaporation and transpiration are referred to as evapotranspiration. Evapotranspiration cools the air by using heat from the air to evaporate water.

Figure 3: Evapotranspiration and Shading on a Green Roof



Plant shade reduces the sunlight that reaches the roof. Evapotranspiration further cools a green roof by using heat to evaporate water from the growing medium and plant surfaces

Green roof temperatures depend on the roof's composition, moisture content of the growing medium, geographic location, solar exposure, and other site-specific factors. Through shading and evapotranspiration, most green roof surfaces stay cooler than conventional rooftops under summertime conditions. Numerous communities and research centers have compared surface temperatures between green and conventional roofs. For example:

- Chicago compared summertime surface temperatures on a green roof with a neighboring building. On an August day in the early afternoon, with temperatures in the 90s, the green roof surface temperature ranged from 91 to 119°F (33 to 48°C), while the dark, conventional roof of the adjacent building was 169°F (76°C). The near-surface air temperature above the green roof was about 7°F (4°C) cooler than that over the conventional roof.[9]
- A similar study in Florida found that the average maximum surface temperature of a green roof was 86°F (30°C) while the adjacent light-colored roof was 134°F (57°C).[10]

Reduced surface temperatures help buildings stay cooler because less heat flows through the roof and into the building. In addition, lower green roof temperatures result in less heat transfer to the air above the roof, which can help keep urban air temperatures lower as well. Some analyses have attempted to quantify the potential temperature reductions over a broad area from widespread adoption of green roof technology. A modeling study for Toronto, Canada, for example, predicted that adding green roofs to 50 percent of the available surfaces downtown would cool the entire city by 0.2 to 1.4°F (0.1 to 0.8°C). Irrigating these roofs could further reduce temperatures by about 3.5°F (2°C) and extend a 1 to 2°F (0.5-1°C) cooled area over a larger geographic region. The simulation showed that, especially with sufficient moisture for evaporative cooling, green roofs could play a role in reducing atmospheric urban heat islands.[11]

A similar study in New York City modeled air temperature reductions two meters, or 6.5 feet, above the roof surface based on a scenario assuming 100 percent conversion of all available roofs area to green roofs. The model results estimated a temperature reduction of about 0.4°F (0.2°C) for the city as a whole, averaged over all times of the day. The model projected that temperatures

Figure 4: Temperature Differences between a Green and Conventional Roof

National Center of Excellence/ASU

On a typical day, the Chicago City Hall green roof measures almost 80°F (40°C) cooler than the neighboring conventional roof.

at three o'clock in the afternoon would be reduced 0.8°F (0.4°C). The researchers also evaluated, in detail, six areas within the city. The area with the highest 24-hour average reduction in temperature had a change of 1.1°F (0.6°C), and the reductions at three o'clock in the afternoon in those six areas ranged from 0.8°F (0.4°C) to 1.8°F (1.0°C).[12]

2. Green Roof Types

A green roof can be as simple as a 2-inch (5 cm) covering of hardy, alpine-like groundcover, generally termed an "extensive" system, or as complex as a fully accessible park complete with trees, called an "intensive" system.

2.1 Extensive Green Roofs

For the simpler, lighter weight ***extensive green roof system***, plant selections typically include sedums—succulent, hardy plants—and other vegetation generally suitable for an alpine environment. The concept is to design a rugged green roof that needs little maintenance or human intervention once it is established. Plants adapted to extreme climates often make good choices and may not require permanent irrigation systems. Overall, because of their light weight, extensive systems will require the least amount of added structural support, which improves their cost-effectiveness when retrofitting an existing structure.

Extensive green roofs have been grown on roofs with slopes of 30° or more, which would equal a ratio of rise to run of 7:12 or greater. (In contrast, a low-sloped roof with a ratio of rise to run of 2:12 would have a slope of 9.5°.) The slope determines if the roof will need additional support to hold the growing medium and other parts of the vegetative layer in place. Steeper roofs may retain less stormwater than an equivalent, flatter roof.

2.2 Intensive Green Roofs

An ***intensive green roof*** is like a conventional garden, or park, with almost no limit on the type of available plants, including large trees and shrubs. Building owners or managers often install these roofs to save energy and provide a garden environment for the building occupants or the general public to enjoy. Compared to extensive green roofs, intensive green roofs are heavier and require a higher initial investment and more maintenance over the long term than extensive roofs. They generally require more structural support to accommodate the weight of the additional growing medium and public use. Intensive

Figure 5: Combination Extensive/Intensive Green Roof—The Rooftop Garden on Chicago's City Hall

J. David Mattox/City of Manhattan, Kansas

The photograph provides an example of a combination extensive/intensive green roof on Chicago's City Hall.

systems also need to employ irrigation systems, which can use rainwater captured from the roof or another source.

3. Benefits and Costs

Green roofs provide many of the same benefits that trees and other ground level vegetation provide. Green roofs have an advantage, though, in that they can be used in dense, built-up areas that may not have space for planting at the ground level. The benefits of vegetation were discussed

Green Roofs and Green Walls

In addition to green roofs, building owners can install green walls, sometimes referred to as living walls or vertical gardens. These walls can involve placing trellises or cables in front of exterior walls and allowing vines to grow up them, or can be more elaborate, with plants actually incorporated into the wall.[13]

Figure 6: Ford's Dearborn Truck Plant: An Example of an Extensive Green Roof

Green Roofs for Healthy Cities/www.greenroofs.org

Ford's Dearborn Truck Plant in Michigan covers 10.4 acres (42,100 m^2) and is anticipated to reduce the building's energy costs by 7 percent.[15]

in the "Trees and Vegetation" chapter and are briefly described here in the context of green roofs.

3.1 Benefits

Reduced Energy Use. Green roofs can save energy needed to cool and heat the buildings they shelter. When green roofs are wet, they absorb and store large amounts of heat, which reduces temperature fluctuations. When dry, green roof layers act as an insulator, decreasing the flow of heat through the roof, thereby reducing the cooling energy needed to reduce building interior temperatures. In the winter, this insulating effect means that less heat from inside the building is lost through the roof, which reduces heating needs. In the summertime, green roof vegetation reduces roof surface temperatures and ambient air temperatures, thus lowering cooling energy demand. The insulating properties of green roofs vary as they are dynamic systems that change throughout the year, particularly with regard to water storage. As with cool roofs, discussed in the "Cool Roof" chapter, green roofs should not be used as a substitute for insulation.

Figure 7: Green Wall in Huntsville, Alabama

EOA/Elmslie Osler Architect

This 2,000-square foot (190 m^2) green wall on a store in Huntsville, Alabama, is one of the largest in North America.[14]

Green Roof Types—Changing Nomenclature?

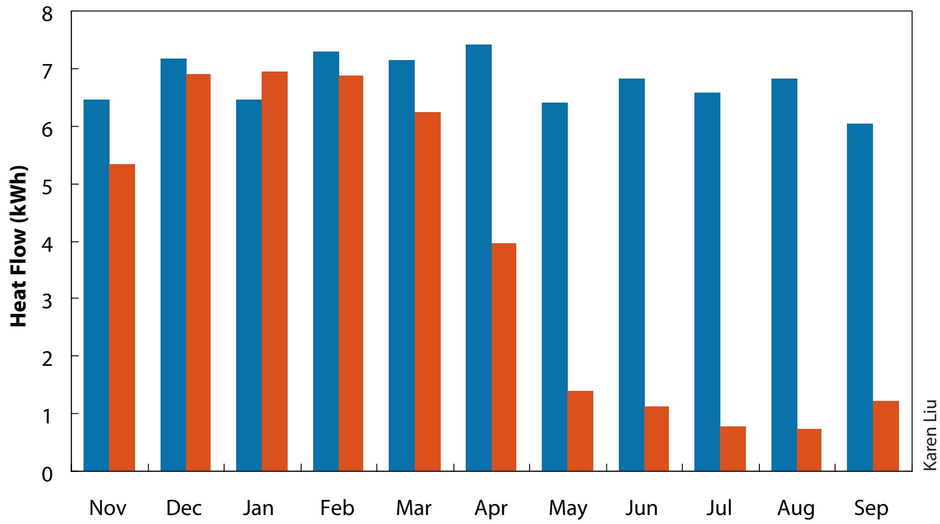
The term "low profile" has been used in place of "extensive" to describe green roofs that are lighter weight, shallower, and simpler. Similarly, "high profile" or "deep profile" has been used instead of "intensive" to describe a heavier, more complex green roof system with deeper soil.

Figure 8 compares the average daily flow of heat through a dark, conventional roof and an extensive green roof in Ottawa, Canada. During the spring and summer, from May to September 2001, the energy demand needed to remove heat that flowed through the conventional roof was six to eight kilowatt hours (kWh) a day, while the green roof's energy demand from heat flow was less than 1.5 kWh a day, a reduction of more than 75 percent. In contrast, during the fall and winter months, from November 2000 through March 2001, heat flow through the green roof was only slightly less than the reference roof in all months except January, so that the energy demand from both roofs was relatively similar. During this time, snow had accumulated, and the temperatures of both roofs stayed about the same.[16]

Although green roofs can save energy both in summer and winter, the specific savings will depend on the local climate and individual building and roof characteristics, such as size, use, and insulation. For example:

- Chicago estimates that its City Hall green roof project could provide cooling savings of approximately 9,270 kWh per year and heating savings of 740 million Btus.[18] This translates into annual, building-level energy savings of about $3,600.
- A Canadian study modeled the heating and cooling energy savings of a roughly 32,000- square foot (2,980 m^2) green roof on a one-story commercial building in Toronto.[19] The analysis estimated that the green roof could save about 6 percent of total cooling and 10 percent of heating energy usage, respectively, or about 21,000 kWh total. The study noted that the cooling energy savings would be greater in lower latitudes. For instance, when the authors ran the same simulation for Santa Barbara, California, the cooling savings increased to 10 percent.
- A study in central Florida measured year-round energy savings from a green roof. By the roof's second summer, the average rate of heat transfer, or flux, through the green roof was more than 40 percent less than for the adjacent light-colored roof. The reduced heat flux was roughly estimated to lower summertime energy consumption of the 3,300 square foot (1,000 m^2) project building by approximately 2.0 kWh per day.[20] Under winter heating conditions,

Figure 8: Comparison of Average Daily Energy Demand Due to Heat Flow Through an Extensive Green versus Conventional Roof in Ottawa, Canada[17]



This chart shows the average daily energy demand due to observed heat flow through a green and conventional roof. The period of evaluation was November 22, 2000, through September 30, 2001.

when the outdoor air temperature was less than 55°F (13°C), the heat flux was almost 50 percent less for the green roof than for the conventional roof.[21]

Reduced Air Pollution and Greenhouse Gas Emissions. As described in the "Trees and Vegetation" chapter, vegetation removes air pollutants and greenhouse gas emissions through dry deposition and carbon sequestration and storage. The reduced energy demand from green roofs also reduces air pollution and greenhouse gas emissions associated with energy production. Further, because ground-level ozone forms more readily with the rise in air temperatures, green roofs help slow the formation of ground-level ozone by lowering air temperatures. As with trees and vegetation, when selecting vegetation for a green roof, building owners in areas with poor air quality may want to consider the volatile organic compound (VOC) emissions from certain plant species, as VOCs are a ground-level ozone pre-cursor.

Plant surfaces can remove certain pollutants from the air through dry deposition. A green roof can remove particulate matter (PM) and gaseous pollutants, including nitrogen oxides (NO_X), sulfur dioxide (SO_2), carbon monoxide (CO), and ground-level ozone (O_3) from the air. Many studies have investigated the potential air pollutant removal of green roofs:

- Researchers estimate that a 1,000-square foot (93 m^2) green roof can remove about 40 pounds of PM from the air in a year, while also producing oxygen and removing carbon dioxide (CO_2) from the atmosphere.[22] Forty pounds of PM is roughly how much 15 passenger cars will emit in a year of typical driving.[23]
- A modeling study for Washington, D.C., examined the potential air quality benefits of installing green roofs on 20 percent of total roof surface for buildings with roofs greater than 10,000 square feet (930 m^2). Under this scenario, green roofs would cover about 20 million square feet (almost 2 million m^2) and remove,

annually, about 6.0 tons of O_3 and almost 6 tons of PM of less than 10 microns (PM_{10}), or the equivalent of the pollutants that could be absorbed by about 25,000 to 33,000 street trees.[24]

- A similar study for the midtown area of Toronto modeled various green roof scenarios and compared pollutant reductions with existing baseline urban tree and shrub benefits. One scenario involved green roofs on flat roof surfaces, representing 20 percent of midtown roofs in total, such as commercial, high-rise residential, and institutional buildings. In that scenario, the green roofs removed about 10 to almost 20 percent of the pollution that existing trees and shrubs remove, depending on the pollutant examined. If green roofs were added to all available surfaces across midtown Toronto, the model predicted that green roofs' collective performance would increase to between roughly 25 and 45 percent of the reductions currently obtained by existing vegetation.[25]

Vegetation and the growing medium on green roofs also can store carbon. Because many of the plants are small and the growing medium layer is relatively thin, green roofs tend not to have as large a carbon storage capacity as trees or urban forests.

Improved Human Health and Comfort. Green roofs, by reducing heat transfer through the roof of a building, can improve indoor comfort and reduce heat stress associated with heat waves. The use of cool roofs (see "Cool Roof" chapter) provides similar indoor air temperature benefits. These improvements in building comfort can yield human health benefits, particularly in non-air conditioned buildings.

Enhanced Stormwater Management and Water Quality. Another key benefit of green roofs is that they can reduce and slow stormwater runoff in the urban environment. The plants and growing medium of a green roof, in the same manner as other natural surfaces and vegetation, absorb water that would otherwise become runoff. The amount of rainfall retained by a green roof will depend primarily on the depth of the growing medium and may also be affected by the roof slope. Studies have shown that extensive roofs will typically capture between 50 and nearly 100 percent of incoming rain, depending on the amount of growing medium used, the density of vegetation, the intensity of an individual rainstorm, and the frequency of local rain events.[26] An intensive green roof, with thicker layers of growing medium, will capture more rainfall under comparable conditions than an extensive roof. Field study results below help illustrate these findings:

Figure 9: Green Roof on Seattle Public Library

Green Roofs for Healthy Cities/www.greenroofs.org

Municipal buildings, such as this public library in Seattle, have often been used to demonstrate the benefits of green roofs and the feasibility of the technology.

- A North Carolina study of actual green roof performance found that test green roofs reduced runoff from peak rainfall events by more than 75 percent and that the roofs temporarily stored and then released, through evapotranspiration, more than 60 percent of all rainfall.[27]
- A Canadian green roof demonstration

measured significant reductions in runoff over a six-month period, with steep reductions in five of the six months, and then lower reductions in one month that had many large rain events, which did not allow the growing medium to dry out between events. Overall, this project showed the green roof reduced runoff by more than 50 percent.[28]

- A green roof demonstration project in Portland, Oregon, examined runoff reductions over a 15-month period. In that study, a green roof with about four inches (10 cm) of growing medium reduced runoff by almost 70 percent.[29] In addition, the authors noted that the retention rate appeared to increase over time, which might be related to maturing vegetation. Because of the benefits in controlling stormwater, Portland has approved green roofs (or "eco-roofs") as a technique to help meet stormwater management requirements for new development and redevelopment projects. [30]

Stormwater retention will vary with local conditions, and communities generally consider this when projecting the potential stormwater benefits of green roofs in their area.

Even when a green roof does not retain all the water from a storm, it can detain runoff for later release and reduce the runoff rate. For example, the same Portland study demonstrated that the green roof reduced peak run-off rates by 95 percent during an intense storm.[31] The North Carolina study found that average peak runoff rates from the green roofs were roughly 75-85 percent less than average peak rainfall rates, so that even when rain was falling on average at about 1.5 inches/hr (42 mm/hr), it ran off the green roof at less than 0.25 inches/hr (6 mm/hr).[32] Reduced rates of runoff can help communities minimize flooding and combined sewer overflow (CSO) events.*

Various research projects are underway to continue **monitoring pollutants in stormwater runoff from green roofs,** such as those at Pennsylvania State University's Green Roof Research Center, North Carolina State University's Greenroof Research program, the Green Roof Test Plots research at the Chicago Center for Green Technology, and Portland, Oregon's Eco-Roof program.

The plants and growing medium of a green roof not only retain and delay the release of stormwater but also act as a filter. Findings from various studies demonstrate the ability of green roofs to remove pollutants and highlight the need to select growing media carefully to avoid elevated levels of certain pollutants, which may initially leach from organic materials. A 2005 Canadian report synthesized past studies on this issue.[33] It noted that several studies from Europe had found that green roofs can bind and retain significant levels of pollutants, with one study stating that green roofs could remove up to 95 percent of the cadmium, copper, and lead from stormwater runoff. The study also summarized findings from a monitoring program on a green roof in York, Ontario, which found decreased pollutant concentrations compared to a control roof. The reductions ranged from 80 to almost

* Combined sewer systems are single-pipe systems that carry sewage and stormwater runoff together; when they overflow during heavy rain, they discharge directly into surface waters.

95 percent for several pollutants, such as suspended solids, copper, and polycyclic aromatic hydrocarbons. The same study, however, found increased concentrations of nitrogen and phosphorous.

Recent research in Pennsylvania found improved pH in green roof runoff compared to a conventional roof, as well as reductions in total nitrate loadings based on the reduced amount of stormwater from the green roof. The concentration of other pollutants in the green roof runoff, in contrast, was generally higher than concentrations from a conventional roof.[34]

As with the field study in York, Ontario, research in North Carolina found increases in total nitrogen and total phosphorous, which the authors attributed to certain compost materials in the roof substrate.[35] Research in Portland and Toronto found that phosphorous levels appeared to decrease over time as the green roof vegetation matured and the phosphorous in the initial substrate leached during rainfall events.[36,37] A German study also revealed that a green roof retained more phosphate as it matured, with retention percentage increasing from about 26 percent in the first year to about 80 percent in the fourth.[38]

Enhanced Quality of Life. Green roofs can provide many of the same quality of life benefits as other urban greenery. People in taller, neighboring buildings may enjoy looking down at a rooftop garden. Allowing public access to rooftop gardens provides residents another green space to enjoy. Finally, some researchers are evaluating the potential for green roofs to provide a safe habitat for rare or endangered species, removing them from ground-level predators.[39]

3.2 Costs

The costs of green roofs vary depending on the components, such as the growing medium, type of roofing membrane, drainage system, use of fencing or railings, and type and quantity of plants. A 2001 report estimated that initial costs start at $10 per square foot (0.09 m^2) for the simpler, extensive roof and $25 per square foot for intensive roofs.[40] Other estimates assume $15 to $20 per square foot. Costs in Germany, where green roofs are more prevalent, range from $8 to $15 per square foot.[41] Prices in the United States may decline as market demand and contractor experience increase.

Initial green roof costs are more than those of most conventional and cool roof technologies (see “Cool Roofs” chapter). Green roofs have a longer expected life, though, than most roofing products, so the total annualized costs of a green roof may be closer to those of conventional and cool roofs. Los Angeles estimated that to retrofit a building with an extensive green roof would cost from $1.03-$1.66 per square foot, on an annualized basis, while a conventional re-roofing would range from $0.51-$1.74 per square foot.[42]

In addition to construction costs, a building owner incurs maintenance costs to care for the plants on a green roof. Although the level of care depends on plant selection, most of the expenses arise in the first years after installation, as the plants establish themselves and mature. For either an intensive or extensive roof, maintenance costs may range from $0.75 to $1.50 per square foot. The costs of maintaining an extensive roof decrease after the plants cover the entire roof, whereas maintenance costs will remain more constant for an intensive roof.[43]

3.3 Benefit-Cost Considerations

Although a green roof might have higher initial costs than most conventional or cool roofs, a full life-cycle analysis can identify how the roof benefits the building owner. In many cases, these benefits justify the cost of green roofs in densely populated areas. In addition, a building owner can directly benefit from reduced energy use, reduced stormwater management fees, and increased roof life. Finally, the widespread adoption of green roofs may provide significant, indirect net benefits to the community.

Although few detailed, full life-cycle analyses exist, researchers and communities are beginning to invest in these evaluations. A report on the use of green roofs in New York City outlined one framework for a cost-benefit analysis of green roofs.[44] The framework incorporates both private and public benefits and costs (see Table 1). Under most hypothetical scenarios, a green roof project yields net benefits when assessed with public benefits, such as reduced temperature and stormwater. Under a "high-performance" scenario that generally assumes reduced costs from widespread adoption of green roof technology and a mature market, an owner would achieve net benefits based on private benefits alone.

A University of Michigan study compared the expected costs of conventional roofs with the cost of a 21,000-square-foot (1,950 m^2) green roof and all its benefits, such as stormwater management and improved public health from the NO_X absorption. The green roof would cost $464,000 to install versus $335,000 for a conventional roof in 2006 dollars. However, over its lifetime, the green roof would save about $200,000. Nearly two-thirds of these savings would come from reduced energy needs for the building with the green roof.[45]

Portland, Oregon, meanwhile, has begun a comprehensive cost-benefit analysis of its current eco-roof program, as the city plans to expand green roof coverage from 6 acres (24,300 m^2) in 2007 to over 40 acres (162,000 m^2) in 2012.[46]

Table 1: Benefit-Cost Elements for Green Roofs

Benefits/Costs	Energy, Hydrology, and UHI Benefits	Other Benefits
Private Benefits	• Reduced energy use • Extended service life	• Noise reduction • Aesthetic value • Food production
Public Benefits	• Reduced temperature • Reduced stormwater • Reduced installation costs (from widespread technology use)	• Reduced air pollutants • Reduced greenhouse gases • Human health benefits
Private Costs	• Installation • Architecture/Engineering • Maintenance	N/A
Public Costs	• Program administration	N/A

Cool and Green Roofs: Different Options for Different Motivations

Cool and green roofs both help to mitigate urban heat islands. The two technologies have different cost and performance implications, though, and the motivations for selecting one or the other are typically different.

Cool roofs generally have a minimal incremental cost compared to their conventional equivalent. Depending on the type of product (e.g., asphalt shingle, concrete tile), costs can range roughly between $0.50 to $6.00 per square foot. Costs can vary greatly, though, depending on the size of the job, ease of access to the roof, and local market factors. The initial cost of a green roof, on the other hand, is much higher, starting from $10 per square foot for the basic, extensive green roof.

Both cool and green roofs lower surface and air temperatures and reduce summertime peak and overall energy demand. The extent of the energy savings varies depending on factors including the local climate, attic ventilation and insulation levels, and—particularly for green roofs—the design and maintenance of the roof.

Green roofs provide additional benefits, including reducing and filtering stormwater runoff, absorbing pollutants and CO_2, providing natural habitat and a sound barrier, and potentially serving as a recreational green space and having aesthetic value.

Communities or building owners with limited budgets, who are primarily interested in energy savings or reducing peak energy demand, generally focus on cool roofs. Whereas others, who can consider life-cycle costs and public benefits, and who are interested in broader environmental impacts, particularly improving stormwater management, may choose to install green roofs.

Sustainability leaders, such as Chicago, recognize the value and opportunity for both cool and green roof technologies and are supporting efforts to encourage both options.

Energy Savings and Green Roofs

For building owners and communities primarily interested in saving energy, cool roofs and other energy efficiency measures are generally more cost-effective than green roofs. (See the "Cool Roof" chapter and the ENERGY STAR website <www.energystar.gov> for information about a wide array of cost-effective energy efficient products and practices.) Green roofs provide benefits beyond energy savings, though, which is why they are attractive to diverse interest groups and sustainability advocates.

Figure 10: Green, or Eco, Roof in Portland, Oregon

Portland Bureau of Environmental Services

This apartment building in Portland, Oregon, is among the 6 acres (24,300 m^2) of green roofs in the city, as of 2007. Many roofs remain candidates to become green roofs.

4. Other Factors to Consider

4.1 Site Characteristics

Recommendations for ideal site characteristics vary and often depend on project or program objectives. For example, Chicago and New York City are focusing on "hot spot" areas, which are often found in dense, built up urban cores. Green roofs may be the only option to provide an effective amount of vegetation in these older city centers that have vast amounts of impervious cover and few opportunities to retroactively plant shade vegetation. Further, entities interested in providing recreational space or improving aesthetics may also focus on high density areas that are visible from adjoining or near by buildings.

On the other hand, stakeholders focused on saving energy and managing stormwater often target low-to-medium rise buildings that have a large roof area. These sites, such as the Ford's Dearborn Truck Plant in Michigan, may be found in less developed areas.

From a structural standpoint, existing roofs with concrete structural systems likely will require the least amount of intervention; roofs with steel deck can require the most. Installing a green roof on a flat or low-sloped roof generally will be easier than installing one on a steep-sloped roof. Also, green roofs tend to be easier to design into new rather than existing buildings, given that loads and other requirements can be included in the design process. However, retrofit installations are becoming increasingly common in the expanding green roof market. Many existing buildings, such as low-sloped residential and commercial buildings with large roof areas, can be modified without significant disruption when replacing an old roof. For example, projects at Carnegie Mellon University, Tobyhanna Army Depot, and the Albemarle

The Green Roof Continuum

The decision to install an extensive or intensive green roof depends on available resources and the building owner's goals for how the roof will be used. For example, someone with a limited budget who desires minimal maintenance and is mainly interested in the energy and environmental benefits of a green roof, would most likely install an extensive green roof. On the other hand, someone who wants to create an accessible garden and is able to maintain the green space, will probably install a more intensive green roof. Many green roofs incorporate a combination of extensive and intensive green roof features. These "semi-extensive" or "semi-intensive" green roofs lie within the continuum of green roof types, with "extensive" and "intensive" at each end of the spectrum.

County, Virginia, office building have highlighted the ease of replacing stone-ballast on existing roofs with vegetative layers.[47]

4.2 Installation and Maintenance

Whether extensive, intensive, or somewhere in between, green roofs generally consist of the same basic components.[48] From the top layer down (see Figure 12), these include:

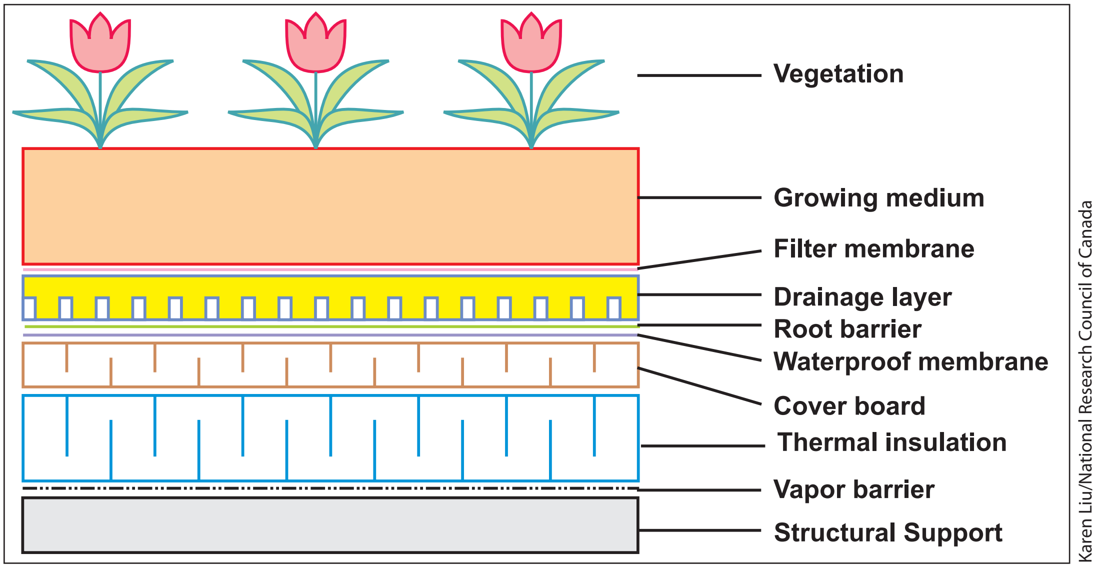
- ***Vegetation.*** The choice of vegetation depends on the type of roof (extensive or intensive), building design, local climate, available sunlight, irrigation requirements, anticipated roof use, and similar factors:
  - Extensive green roof plants are typically hardy perennials. They are preferably shallow-rooting, self-generating plants that spread rapidly and require minimal nutrients. They should tolerate sun, wind, and extreme temperature fluctuations. Succulents, such as sedums, are well adapted for green roofs because they are drought-resistant and their high water content makes them fire resistant. Sedums come

Figure 11: A Green Roof Replaces a Stone Ballast Roof

Albemarle County, Virginia, replaced the stone ballast roof on its county office building with a green roof in 2005. The project received money from the Chesapeake Bay Program through the Virginia Department of Conservation and Recreation.

Gregor Patsch/Albemarle County

Figure 12: Typical Layers of a Green Roof



in a wide variety of sizes, textures, and colors. Building owners also can ensure that the selected plants suit USDA plant hardiness zones for their area.[49]

– Intensive green roofs have deeper growing media, which allows them to incorporate larger plants, including shrubs, bushes, and trees, in their design. Most intensive green roofs also have irrigation systems that can support a wide variety of plants.

- A lightweight, engineered ***growing medium*** may or may not include soil as the primary organic matter. The planting media used in green roof systems are usually engineered to provide the best support for plants with the lightest weight and can be tailored to maximize water retention without water-logging the plants. A growing medium should ideally last as long as the roof it will cover. Typically, the growing medium will consist primarily of lightweight inorganic mineral materials (at least 80 percent) and up to 20 percent organic materials like topsoil.[50] Extensive green roofs use up to roughly 6 inches (15 cm) of growing medium[51] while intensive green roofs use 8 inches (20 cm) or more.[52]
- A ***filter membrane*** is usually a geotextile that allows excess water from the growing medium to flow out, while preventing the fine particles from washing away and clogging the roof drain.
- A ***drainage layer*** helps the excess water from the growing medium to flow to the roof drain, which prevents overloading the roof and provides a good air-moisture balance in the growing medium. Some drainage layers take the form of egg crates to allow for some water storage.
- A ***root barrier*** can protect the roof membrane from aggressive plant roots, which may penetrate the waterproofing layer and cause leaks.
- A ***waterproofing/roofing membrane*** protects the building from water penetration. Any roofing membrane can be used in green roofs, although single-ply waterproofing membranes are generally thicker and more durable on green roofs than on conventional ones. Some

membranes are naturally protected from root penetration, while others require a root barrier.

- A ***cover board*** is a thin, semi-rigid board that provides protection, separation, and support for a roofing membrane.
- ***Thermal insulation*** can be installed either above or below the membrane of a green roof. The insulation value of the growing medium in a green roof increases as its moisture content decreases. However, green roofs are not a substitute for conventional insulation; using the recommended insulation levels for one's local climate helps conserve energy.
- A ***vapor barrier*** is typically a plastic or foil sheet that resists passage of moisture through the ceiling.
- ***Building and roof structural support.*** The components of a green roof weigh more than conventional roofing materials, and thus the roof requires support panels. Not only are the roofing membranes and other materials heavier on a green roof, but the roof design also must account for the weight of water-saturated plants and growing medium. An extensive roof typically weighs from 15-30 pounds per square foot, although the range will depend on the depth of the growing medium and other site-specific factors.[53] An intensive roof can weigh much more, with significantly greater depth of growing medium, more extensive vegetation, and people using the space. Building owners must ensure that the structure can support the green roof even when fully saturated, in addition to meeting building code requirements for snow and wind loads. Reinforcing roof supports on existing buildings adds to the project cost but can usually be worked into building retrofit or renovation plans. It is often easier to put green roofs on new buildings, as the requirements for the added roof load can be included as part of the initial design parameters, and the cost for the upgrade is usually minimal.

Inverted Roof Membrane Assemblies (IRMAs) and Green Roofs

Inverted roof membrane assemblies (IRMAs) have insulation above the waterproofing membrane, as opposed to conventional roofs, which have insulation below the membrane. This design protects the membrane and prolongs the life of the roof. A green roof that has insulation between its vegetative layer and the waterproofing membrane is an IRMA, with the vegetation protecting the membrane and weighing down the insulation. More conventional IRMAs use concrete pavers or stones for ballast. These IRMAs often make good candidates for green roof retrofits, as the conventional ballast can be replaced with the necessary green roof layers.

Although both extensive and intensive green roofs share these basic components, their characteristics vary (see Figure 13). Most important, the intensive green roofs are likely to require more structural support and enhanced irrigation systems to support the wider variety of plants, increased weight loads, and desired public access. However, intensive roofs will probably also retain more rainfall and support more species.[54]

In addition, any green roof generally will require some ongoing maintenance. Extensive green roofs not designed for public access have fewer obligations. For an intensive roof, maintenance can be continuous, similar to a traditional garden, because aesthetics will be more important.

For either roof, early weed control is important to ensure that the installed plants have a chance to spread and to minimize the opportunity for invasive weeds to take root. According to a federal guide on green roofs,[55] weeding might be necessary monthly or quarterly for the first two years and might be reduced to only once a year in many cases after the plants have fully covered the roof. The guide also lists other important maintenance activities including:

- ***Fertilize.*** Given the thin layer of growing medium, building owners or managers might need to apply a slow release fertilizer once a year to avoid soil acidity, especially when the plants are first establishing themselves.
- ***Irrigate.*** An ideal green roof could rely on natural irrigation, especially for extensive roofs. However, some green roofs might require irrigation based on local climate and the stage of plant growth for a particular project. Irrigation might also be needed to reduce fire risks or to increase evaporative cooling. Almost all intensive green roofs need irrigation systems. Extensive green roofs, however, may only need them during plant establishment. For large, extensive green roofs, building owners often install a drip irrigation system, which is generally inexpensive and saves the time and effort of having someone manually water the roof.
- ***Replant.*** Over time, some level of replanting or addition to the growing medium might be necessary.

Figure 13: Comparison of Common Features of Extensive and Intensive Roofs

Extensive (Low-Profile/Ecoroofs)	vs.	**Intensive** (High-Profile/Roof Gardens)
Low growth media: 2 – 6"		> 6"-15" and deeper
Lightweight: 13 – 50 lbs/sf		Heavier weights: 50+ lbs/sf
Low growing plants: 1"– 24" H		Trees, shrubs and more
Less variety of plants: Alpine types, succulents, herbs, some grasses and mosses		Huge variety of plant selection/ architectural features depending on loads, design & budget
Usually non-accessible and non-recreational		Designed for human recreation: gardening, socializing, etc.
Slopes up to 30° & higher		Relatively flat
Less expensive: $5-$25/sf		More expensive: $25-$40+/sf
Low water requirements		Irrigation usually necessary
Low maintenance		Higher maintenance

Linda Velasquez

There is no official definition of an extensive or intensive green roof. This chart is not meant to strictly define these green roof types and instead aims to describe the general characteristics of roofs at each end of the continuum.

Figure 14: A Modular Green Roof on a Sloped Residential Roof

Greenroofs.com and Kelly Luckett/Green Roof Blocks

This home in Arizona shows a modular green roof on a steep-sloped roof.

Modular Green Roof Systems

Some green roof systems use modular components. These components are generally plastic trays a few feet long (~0.5-1 m) on each side and several inches (~10-20 cm) deep. They are filled like flowerpots with growing media and the desired plants and placed directly on top of the existing roof. The grid of trays covers the roof's surface to provide benefits similar to built-in green roofs. Moving or replacing individual modules is potentially easier than changing or repairing parts of a non-modular green roof. Modular roofs, however, are relatively new, and have not been as widely studied as non-modular roofs.

- ***Clean Gutters.*** Similar to conventional roofs, clean gutters decrease the risk of standing water and leaks. It is also necessary to keep drains and gutters clear of plant growth to prevent blockage.

In addition to routine maintenance, green roofs may require repairs over time, although the expected life of a green roof is about twice that of a conventional roof.[56] If correctly installed, the membrane under the vegetation of a green roof is expected to last 30 to 50 years.

4.3 Fire Safety

Green roofs, when saturated with water, can retard the spread of fire,[57] but dry plants on a green roof can be a fire hazard. The most common ways to increase fire safety are to:

- Avoid grasses and plants that could dry up in summer and instead use fire resistant plants, like sedums, and a growing medium that is low in organic material content.
- Construct fire breaks on the roof—2-foot (0.6 m) widths of concrete or gravel at 130-foot (40 m) intervals.

Another precaution that some practitioners recommend is to install sprinkler irrigation systems and connect them to a fire alarm.

5. Green Roof Initiatives

Green roof research efforts are growing with an increasing number of universities offering courses or developing centers focused on improving our understanding of green roof technology. Many communities are also taking action by encouraging or sponsoring green roof projects. These initiatives are typically motivated by various environmental concerns, mainly stormwater management, but also the desire to reduce urban heat islands and enhance the urban ecosystem. Many of these efforts involve a single demonstration or showcase project as a highly visible means to promote green roof technology, such as the green roof on Atlanta's City

> Many green roof projects are motivated not by government policies but by a desire to show a **commitment to sustainable design and the environment.**

Hall patio. Some cities such as Chicago, Portland, Seattle, and Toronto have been developing more coordinated programs and policies to promote green roofs. The "Heat Island Reduction Activities" chapter provides many examples demonstrating the wide range of green roof efforts. Table 2 identifies some of the research activity and options available for taking action to advance green roofs.

Green building programs in many communities provide another opportunity to encourage green roof installation. The U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) Rating System (see <www.usgbc.org>) and Green Globes operated by the Green Building Initiative (GBI) in the United States (see <www.thegbi.org>), are two rating systems that communities are using. These and other systems give credit for a broad range of building and development techniques that save energy and protect the environment. Green roofs can achieve credit under multiple categories—such as stormwater management, heat island mitigation, water efficiency, energy and atmosphere, materials and resources, and innovation and design—depending on how they are constructed.

Figure 15: A Newly Installed Green Roof in New York City

©2008 J. Burling Chase for Sustainable South Bronx

Initiatives to install green roofs in urban areas reduce urban heat islands and can help to create jobs in the local economy, such as this roof installed by graduates of Sustainable South Bronx's Bronx Environmental Stewardship Training (BEST) program.

Table 2: Examples of Green Roof Initiatives

Type of Initiative	Description	Links to Examples
Research	University programs	**<www.hrt.msu.edu/greenroof>** - Michigan State University began its Green Roof Research Program in 2000 to assist with the design and study of Ford's Rouge Plant. The program has since expanded and now investigates green roof plant selection among other topics.
		<http://hortweb.cas.psu.edu/research/greenroofcenter> - Penn State University's Center for Green Roof Research studies the energy savings, stormwater retention and filtration, and other benefits of green roofs.
		<www.bae.ncsu.edu/greenroofs> - North Carolina State University has extensive green roof test sites in Goldsboro and Kinston, North Carolina, as part of the Biological and Agricultural Engineering Program.
		<www.stormwater.ucf.edu/> - The University of Central Florida focuses primarily on stormwater management, which has led to its investigations of green roofs.
		<http://commons.bcit.ca/greenroof/> - The British Columbia Institute of Technology's Centre for the Advancement of Green Roof Technology collaborates with industry to support and improve the deployment of green roofs.
Voluntary efforts	Demonstration projects	**<www.chicagogreenroofs.org>** - For background information on Chicago City Hall's green roof, see the "Links" section of this site.
		<www.atlantaga.gov/mayor/energyconservationgreenroof.aspx> - This site provides an overview of the Atlanta City Hall green roof demonstration project.
	Incentives	**<http://egov.cityofchicago.org>** - Chicago has sponsored a green roof grant program for several years. Grants of up to $5,000 each were available in the application cycle that ended in January 2008. See the Department of Environment page and browse under "Initiatives and Programs."
		<www.toronto.ca/greenroofs/incentiveprogram.htm> - Toronto's green roof incentive program offers grants of Canadian $50 per square meter for eligible projects, up to a total of $10,000 for single-family homes and $100,000 for all other buildings.

Table 2: Examples of Green Roof Initiatives (Continued)

Type of Initiative	Description	Links to Examples
Voluntary efforts	Incentives	**<www.portlandonline.com/bes/index.cfm?c=43077>** - Portland, Oregon, offers grants, workshops, and other technical assistance to support green roofs.
		<www.houstondowntown.com/Home/Business/DoingBusiness/DevelopmentAssistance/Development%20Assistance.PDF> - The Houston Downtown Management District (HDMD) Vertical Gardens Matching Grant initiative is intended to assist in the facilitation of wall cover plantings and exceptional landscaping on blank walls, parking garages, and sidewalks; improving overall aesthetics, pedestrian comfort, and air quality; and reducing the heat island effect.
	Outreach & education	**<www.epa.gov/heatisland/>** - EPA's Heat Island Reduction Initiative provides information on the temperature, energy, and air quality impacts from green roofs and other heat island mitigation strategies.
		<http://cfpub.epa.gov/npdes/home.cfm?program_id=298> - EPA's Office of Water highlights design options, including green roofs, that reduce stormwater runoff and water pollution.
		<www.greenroofs.org/> - Green Roofs for Healthy Cities hosts a series of green roof design and implementation workshops throughout North America.
Policy efforts	Density bonus provisions in zoning codes	**<http://commons.bcit.ca/greenroof/publications/2006_regulations.pdf>** - Document that highlights efforts of Chicago; Seattle; Portland, Oregon; Toronto; and Waterloo, Ontario, to encourage green roof installations by offering density bonus incentives in their zoning codes.

6. Resources

Table 3 lists some guidance documents and organizations that promote green roofs.

Table 3: Green Roof Resources

Name	Description	Web Link
	Guidance Documents	
U.S. Department of Energy Federal Technology Alert: Green Roofs	DOE's Energy Efficiency and Renewable Energy program publishes technology alerts and developed this primer on green roof technology.	<www.nrel.gov/docs/fy04osti/36060.pdf>
Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services	The journal *Bioscience* November 2007 issue contains this comprehensive article summarizing the research on green roofs and their costs and benefits.	<www.aibs.org/bioscience-press-releases/resources/11-07.pdf>
National Roofing Contractors Association Green Roof Systems Manual	The NRCA has recently released a guidebook for sale that focuses on the waterproofing needs of green roofs.	<www.nrca.net/rp/pubstore/details.aspx?id=450>
Los Angeles Green Roof Resources Guide	The City of Los Angeles developed this guide as a resource for individuals and groups interested in developing green roofs in Los Angeles. This guide includes information on how to plan, design, and maintain a green roof.	<www.fypower.org/pdf/LA_GreenRoofsResourceGuide.pdf>
	Other Resources	
Green Roofs for Healthy Cities	Green Roofs for Healthy Cities offers resources on green roof installation, benefits, projects, and training. This group also publishes the *Green Roof Infrastructure Monitor*.	<www.greenroofs.org>
Greenroofs.com	Greenroofs.com provides green roof industry resources, including how-tos, plant lists, references, and an international database of green roof projects.	<www.greenroofs.com>
Chicago Green Roof Program	Chicago's Green Roof Program has online information on building green roofs in Chicago, including an aerial map of completed and planned projects, frequently asked questions, featured projects, and links to other resources.	<www.chicagogreenroofs.org>

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