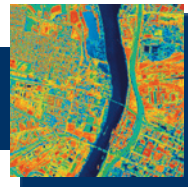




Green Roofs

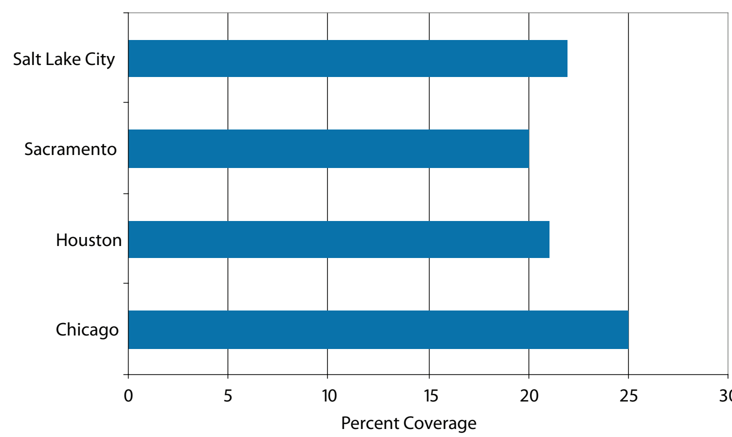
Green roofs are an emerging technology that can help communities mitigate urban heat islands. A green roof is a vegetative layer grown on a rooftop. As with trees and vegetation elsewhere, vegetation on a green roof shades surfaces and removes heat from the air through evapotranspiration. These two mechanisms 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]

Figure 2: Intensive Green Roof in Frankfurt, Germany

Wikimedia Commons

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

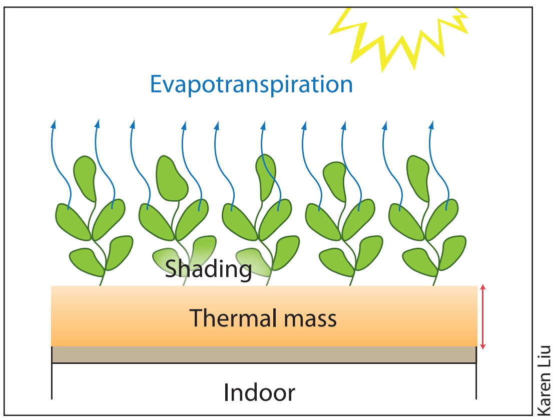
Shading reduces surface temperatures below the plants. These cooler surfaces, in turn, reduce the heat transmitted into buildings or re-emitted into the atmosphere. For example, a multi-month study measured maximum surface temperature reductions due to shade trees ranging from 20 to 45°F (11-25° C) for 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.

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.

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]

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

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]

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?

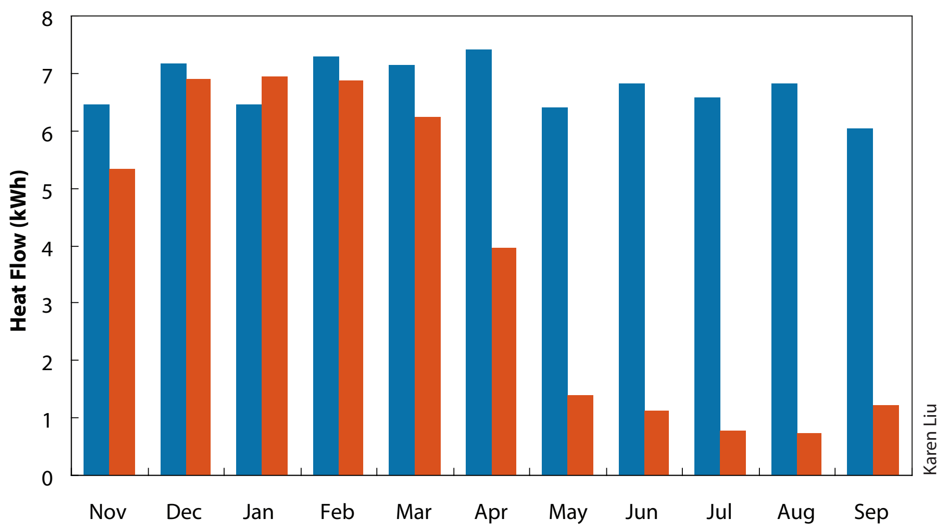
The term "low profile" has been used in place of "extensive" to describe green roofs that are lighter weight, shallower, and simpler. Similarly, "high profile" or "deep profile" has been used instead of "intensive" to describe a heavier, more complex green roof system with deeper soil.

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,