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Green Roofs: Stormwater Management From the Top Down
By Katrin Scholz-Barth

Green roofs are an innovative stormwater management solution that can improve the energy performance of buildings, air quality and the urban ecology.

The US population is forecast to increase by 50% over the next 50 years,1 yet cities are already struggling to cope with growth and economic development. Open spaces and undisturbed land have given way to buildings and roads. Sealed with concrete and asphalt, these surfaces no longer allow water to infiltrate the ground. Dark rooftops and pavement absorb and store energy from the sun during the day and reflect it at night. The results are increased stormwater runoff; greater temperature differences between urban areas and open, undisturbed land (known as the urban heat island effect); altered weather patterns; and a loss of greenery in metropolitan areas.

Green roofs can provide a solution to these problems. What could be more inventive and resourceful than using plants to adorn our dusty metropolitan roof surfaces? Green roofs are an innovative stormwater management solution that can simultaneously improve the energy performance of buildings, air quality and the urban ecology — all without taking up additional land.

What is a Green Roof?
There are two distinctly different types of green roofs: intensive and extensive. Intensive green roofs require a minimum of one foot of soil depth to create a more traditional roof garden, with large trees, shrubs and other manicured landscapes. They are multi-layer constructions with elaborate irrigation and drainage systems. Intensive green roofs add considerable load (from 80 to 150 pounds per square foot[lbs/sf]) to a structure and require intensive maintenance. These roof gardens are, however, designed to be accessible and are used as parks or building amenities.

In contrast, extensive green roofs range from as little as 1 to 5 inches in soil depth. Depending on the soil depth and type of substrate, loads can vary from 15 lbs/sf to 50 lbs/sf. For instance, historic green roofs in Berlin, Germany, built around 1900, weigh about 42 lbs/sf. Extensive green roofs are not designed for public use but can be accessed for routine maintenance walks, generally performed once per year. Extensive green roofs are primarily built for their environmental benefits.

Although everything from earth-bermed houses to balconies with potted plants has conveniently been termed a "green roof" at one point or another, this article strictly defines extensive green roofs as elevated roof surfaces that are entirely covered with a thin soil and vegetation layer. They are not necessarily sod or grass roofs because various geographic areas require different roof plantings. Additionally, the term eco-roofs is not used in this context because products such as wood shingles are also made of natural, renewable materials, and would thus qualify as an eco-roof.

Construction Materials
A green roof is constructed of waterproofing, soil and plants. While this might not sound difficult, the secret to a successful green roof lies in understanding the complexity of and interaction among these layers.

In Europe, where green roofs are quite common, installers use 60- to 80-mil PVC single-ply roof systems for the most efficient, cost-effective construction. Reinforced PVC works well for waterproofing because it is heat-seamed, which reduces the risk of potential leaks, and it also provides protection against root penetration. While PVC is not a sustainable material due to its manufacturing process and lack of recyclability, it performs multiple functions and thus eliminates the need for additional materials and costs.

Other suitable materials for waterproofing and root protection include rubber membrane (EPDM) or hypolan (CSPE). The disadvantage with EPDM is that seams need to be bonded with adhesives or tape (glued together), which might present a higher potential risk for leaks. Thermoplastic polyolifins (TPOs) are also specified for green roof base waterproofing and are often considered more environmentally acceptable. However, TPO has not been on the US market as long as it has in Europe, and thus is not as well tested. Additionally, US manufacturers of TPO often add bromides (fire retardants) to meet the more stringent US fire codes, and these bromides can interfere with the long-term performance of the membrane.

An asphalt-based roofing system must be covered with a high-density polyethylene (HDPE) membrane to prevent root penetration, since asphalt is an organic product and is thus food for organisms.

The soil substrate is the next layer in a green roof, and selecting the type of soil can be challenging. Since the soil provides the growing media for the plants, organic materials are the best option. For new green roof projects, using on-site quality topsoil that was stockpiled prior to construction can be very cost-effective. To improve water retention capacity, the topsoil can be mixed with expanded clay or slate. Often, however, the structural loading capacity of a building determines the type of substrate. An extensive green roof should be designed with a minimal critical weight of approximately 15 pounds per square foot to withstand wind loads.

The third layer - vegetation - is the most important layer of a green roof. Plants add aesthetics and also determine the success or failure of the project, depending on their hardiness. Most commonly used are succulents and other low growing plants that are capable of storing water in either fleshy leafs, bulbs or roots. Plants successfully used in shallow soil beds on roof surfaces include various species of sedum, sempervivum, creeping thyme, allium, phloxes, anntenaria, armeria and aubrieta, as well as numerous others. What makes these plants good green roof candidates is their ability to adapt to alpine conditions with little soil, no water, high winds and high sun exposure. It is essential to select alpine natives for a successful green roof project because conditions on top of a roof are harsh and quite different from conditions on the ground. These plants have to be real "survivors."

Although plants are the most vital component of an extensive green roof, they are often the most neglected due to cost concerns. Plant plugs with fully established root systems quickly spread out their roots horizontally and form a dense vegetation mat in a few growing seasons. Plant cuttings (mostly from sedum) can also be spread over the soil layer, but while these cuttings may eventually form roots, it can take twice as long before the roots can actively hold the soil in place, prevent wind erosion and use up water. From a first-cost perspective, plant cuttings are more economical because they are less labor intensive to install. However, the survival rate of cuttings is only about 50%, compared to 80% for plant plugs with established root systems. If half the plants need to be replaced within the first year, the first cost advantage quickly erodes.

It is advisable to apply native grass seeds over a newly planted roof because the seeds will sprout quickly and stabilize the soil layer until the green roof plants start to spread. The appearance of the vegetation cover will fluctuate seasonally based on wet and dry periods. Grasses will grow during wetter periods, and the alpine natives will flourish and display their flowers during long hot and dry summers.

Sod is not used for extensive green roof applications because it is maintenance-intensive, requiring constant irrigation and cutting, and it provides only very limited ecological benefits. Mosses are also best avoided as green roof vegetation. While their sponge-like forms do soak up and retain a lot of water, they can pose a fire hazard in a drought.

Maintenance Requirements
Aside from initial watering and occasional fertilization, a properly designed green roof does not require much maintenance. The plants need to be irrigated until they are fully established. Thoroughly watering the plants once per week provides enough soil moisture for them to grow. If natural precipitation is sufficient during that time, no supplemental irrigation is required. Once the plants are healthy and established (usually within six months), extensive green roofs no longer need to be irrigated.

On a large green roof, it may prove economical to lay drip tubing during the green roof installation. This permanent drip irrigation system will allow for uniform watering of the green roof for the first few months and occasionally during extremely dry summers. Drip irrigation directly targets the root zone while keeping the soil surface dry, discouraging weeds from taking root.

Occasional weeding in the beginning and regular fertilization to prevent acidification of the thin soil layer are the only other maintenance requirements. Applying a slow release fertilizer twice a year is sufficient.

One great misconception about green roofs is that they need be cut or grazed by goats, neither of which is true for an extensive green roof. In fact, the vegetation mat does not grow vertically but spreads horizontally because the thin soil layer does not support tall vertical growths.

Advantages of Green Roofs
Plants provide a broad range of benefits, whether on the ground, submerged in water or on a rooftop. We are still exploring the natural processes of vegetation and how best to use it in the urban environment. In photosynthesis, for example, plants use energy from the sun to turn carbon dioxide into oxygen and chlorophyll. Leaves collect dust, transpire moisture in the air and provide shade. Roots hold soil in place and prevent erosion, thus preventing sedimentation of nearby waterways. Plant roots, and their attached enzymes and micro-rhyzal fungi, filter and treat rainwater as it percolates through the ground. All of this makes our environment more resilient. Transferring these processes to roofs can provide viable stormwater management, energy efficiency, urban ecology and aesthetic benefits.

Stormwater Management
When rain falls on forested and open, undisturbed land, water goes through its natural cycle. About 30% of the water reaches shallow aquifers that feed plants, another 30% percolates and nourishes deeper aquifers, and approximately 40% is almost immediately returned into the atmosphere through plant evaporation and transpiration. There is rarely any surface runoff. In metropolitan areas with buildings and streets comprising 75 to 100% impervious surface cover, rainwater is distributed much differently. Only 5% infiltrates to shallow and deep groundwater aquifers and 15% evaporates into the air through vegetation. A staggering 75% of the rainwater becomes surface runoff.2 (See Figure 1.) To offset these reversed stormwater runoff patterns, communities build costly sewer systems. While costly stormwater collection, storage and treatment systems deal with the impacts of sealed surfaces, they fail to address the source of the problem. In many cases, runoff is directly drained — untreated — into open water bodies and receiving streams. This runoff pollutes our rivers and streams. Studies show a direct link between runoff from impervious surface coverage and degradation of water quality in streams. Even relatively low levels of impervious surface cover (10 to 15% of total land area) in a watershed can make it difficult to maintain stream quality.

Greater impervious surface coverage (15 to 20% of the total land in a watershed) has been linked to dramatic changes in shape of streams, water quality, water temperature, and the health of the insects, amphibians and fish that live in these streams.3 Green roofs can help ease this problem because they absorb and recycle rainwater. The soil layer and plants soak up water that would otherwise immediately run off into storm sewer. On average, 75% of water is retained on an extensive green roof, stored in plants and the soil layer. Only about 25% of water becomes runoff, but this occurs several hours after the peak flow. When the green roof reaches full saturation, excess water slowly percolates through the vegetation layer to a drainage outlet. The soil layer traps sediments, leaves and other particles, treating runoff before it reaches the outlet. Of course, different soil substrates and vegetation provides different water retention capacities. On average, a 1-inch deep moss and sedum layer over a 2-inch gravel bed retains about 58% of water, a 2.5-inch deep sedum and grass layer retains about 67%, and a 4-inch layer of grass and herbaceous vegetation retains about 71% of water.4 In a major 2-inch rainstorm, generating about 1.25 gallons of water per square foot, a 2.5-inch thick extensive green roof would retain approximately 0.5 gallon of water per square foot, or 40%.5 The greatest cost benefit is provided by the first inch of soil and vegetation cover. However, it is recommended to install a 2.5 to 3-inch soil cover to support and maintain a diverse and healthy plant community.

Energy Efficiency

Green roofs also slow building heat gain and loss. In warm climates, when air temperatures can reach 95°F or higher during the summer, roof surface temperatures can reach 175°F.6 These high temperatures directly impact both the indoor and outdoor environment of a building. The increased outside air temperature over roof surfaces contributes to and speeds the chemical reaction that creates low atmospheric ozone, the primary component of smog.7 Inside the building, more air conditioning — and therefore more energy — is required for cooling. With a green roof, the vegetation layer and the trapped air prevent rapid air exchange, which improves the energy performance of a building. Plants transform heat (energy from the sun) and soil moisture into humidity through evapotranspiration processes, thereby naturally cooling the building. This can result in a reduced cooling load inside the building, reduced heat reflection into the atmosphere, a healthier microclimate over the roof surface, and an extended lifespan for the roofing system. In cold climates, the rate of heat loss through the green roof depends on the moisture level of the substrate. On average, extensive green roofs provide an additional 25% insulation at dry and slightly moist soil conditions. When the substrate is wet, the insulation value becomes negligible. However, heat loss due to wind can be reduced by 50% with a green roof cover. Friction slows wind down and reduces the air and heat exchange. Contrary to what is widely believed, the air exchange and heat loss is mostly prevented through air pockets between material layers and is only minimally affected by air trapped within the root zone of the vegetation. Improved energy efficiency is not the only advantage of green roofs. Green roofs also reduce the urban heat island effect, the phenomenon of thermal gradient differences between developed and undeveloped areas.8 by aiding in the vertical mixing of air. Since plants transpire moisture, the air above the green roof surface is much cooler than the hot air rising from surrounding hard surfaces. The hot air is replaced with cooler air from the vegetation, and thus limits the urban heat island effect and the chemical reactions that produce lower atmospheric ozone.

Urban Ecology

Cities often effectively exclude greenery and nature — to the detriment of their residents. While green roofs are no substitute for open space and simply cannot replace the significant functions of forests, prairies and open parkland, they do provide green space and wildlife habitat from which both urban and suburban areas can greatly benefit. Green roofs can make an area much more pleasant, beautiful and relaxing, while creating additional habitat for birds and butterflies. Green roofs also improve air quality. The air in inner cities is usually hot and dry, and the limited number of trees cannot transpire nearly enough water into the air to keep it cool and fresh. The foliage of trees also fulfills another function — filtering the air. For instance, in a tree-lined street only 1,000 to 3,000 dust particles exist per liter of air. The amount of dust in the air in non-vegetated areas can be three to four times as high, with approximately 10,000 to 12,000 dust particles per liter of air.9 Extensive green roofs have the potential to amend the lack of evaporation and filtration through plants. The air quality improvements are true for outdoor as well as indoor environments. Outdoor air improvements go hand in hand with the moderated surface temperature of a roof. The positive effect on the indoor environment is less obvious but has been documented in several cases. Pacific Telephone and Telegraph (PT&T) in Sacramento, CA, for instance, constructed a half-acre roof garden on its building in 1962. The constant indoor air environment provided by the green roof helps protect the company’s sensitive telephone computer equipment, which requires a perfectly humidified environment.

Suitable Applications
Manufacturing facilities, single-story office buildings, shopping malls, churches and other buildings with a wide roof area are all potential applications for green roofs. With a green roof, manufacturing companies could offer their community an amenity that might help establish a strong and mutual beneficial relationship.10 Schools, another potential for green roofs, have the power to convey a message to young people who will learn about these multi-functional roofing systems and increase their environmental awareness and sensitivity.

Potential Limitations
The greatest concern about green roofs is leaks. However, this is merely a perception originating from unfavorable memories of conventional green roofs. During the first wave of energy efficient building practices during the 1970s, the first green roofs - then called sod roofs - were not properly insulated, and leaks were widespread. Many of such roofs were simply removed because of the high maintenance required.

Today the situation is much different. While quality control during the waterproofing stage is still essential for a successful green roof, manufacturers have greatly improved the quality of waterproofing membranes.

In retrofit applications, load restrictions are usually the main limitation. Load reserves of at least 15 pounds per square foot beyond snow load requirements are needed to install a green roof.

Roof slope can also be a challenge for retrofits. Contrary to common opinion, flat roofs are not the ideal surface for a green roof. A flat roof requires an additional layer to drain excess water away from the root zone. A roof slope between five degrees (1:12) and 20 degrees (4:12) works best because water drains naturally due to gravity (see Figure 2). Roofs with up to a 40-degree slope can be greened, but slopes greater then 20 degrees (4:12) require a wooden lath grid that forms small fields to hold soil substrate in place until plants form a thick vegetation mat.

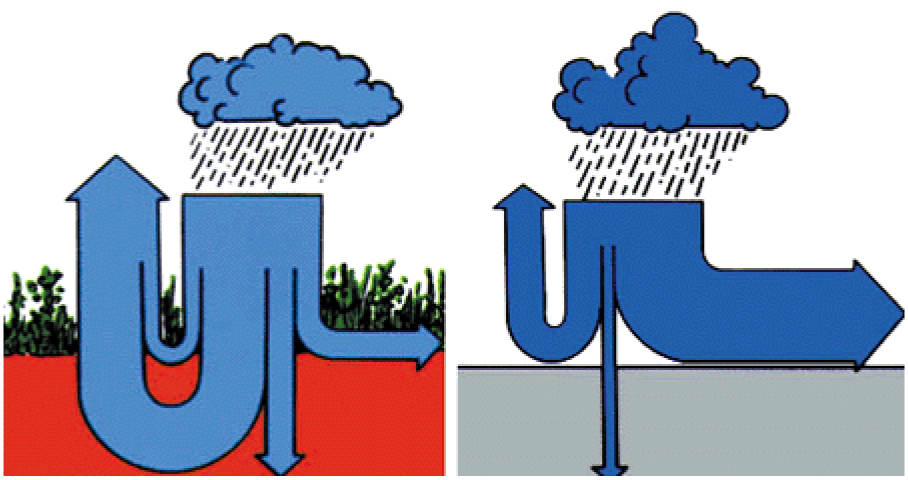

Figure 1: When rain falls on forested and open, undisturbed land, about 30% reaches shallow aquifers, another 30% nourishes deeper aquifers, and approximately 40% is returned into the atmosphere. There is rarely any surface runoff. In metropolitan areas, a staggering 75% of the rainwater becomes surface runoff. Illustration courtesy of Bauverlag GmbH, Germany.*

Cost Considerations
Despite improved manufacturing and installation methods, increased first costs still limit the use of green roofs. Realistic costs for extensive green roofs in the US currently range from $15 to $20 per square foot, including everything from waterproofing to plants. These costs stem mainly from the additional materials comprising a green roof. While green roof construction is very similar to a conventional gravel-ballasted

roof (see Figure 3), the soil substrate and plants are expensive and need to be lifted onto the roof with a crane. The use of plant plugs increases labor costs because every plug must be individually planted.

In Germany an entire service industry has formed around green roof installation, significantly reducing the first costs of a green roof. Vacuum trucks are used to blow or pump the dry soil substrate very efficiently onto a roof, and pre-grown vegetation mats, similar to sod, are simply rolled out over the soil. It is quite possible that costs for extensive green roofs in the US may soon be adjusted to between $8 and $15 per square foot, based on the demand of installation as well as the availability of the soil substrate and plants.

Anyone considering a green roof should take into account the cost savings it provides. The high temperature levels often reached by unused roof surfaces in the summer create high levels of stress on the roofing system and materials.11 Vegetation cover moderates the temperature extremes of the roof surface and prevents the roof from being exposed to the ultraviolet (UV) radiation and cold winds that accelerate the breaking down of the roofing membranes. The result is an extended life span of a roofing system. If installed correctly, a vegetated roof can outlive a conventional roof at a minimum threefold.12

The challenge is to look beyond the first cost comparison between conventional waterproofing and green roofs. The most significant benefits of green roofs, such as stormwater retention and a healthier micro-climate - especially in urban areas - are hard to quantify because a dollar value cannot be placed on them. However, these benefits, combined with the improved roof longevity and thermal insulation of a green roof, can easily outweigh the increased first costs for most installations.

For example, a developer in northern Germany considered a green roof for a single story shopping mall purely motivated by economic reasons. He wanted to save the costs for a central air system. In this case, a 6-inch thick extensive green roof was sufficient to maintain comfortable temperature levels throughout the single-story building interior without central air. The added cost benefit to this developer, even without his initial consideration, is the extended life expectancy for the roofing system. He will save the costs for an otherwise needed new roof every 15 years.

It might be worth mentioning that this project is located in an urban mixed-use area. The residents and office employees took a very active role in the public commenting and permitting process. The developer did not experience any public objection to the project because the green roof added aesthetic value.

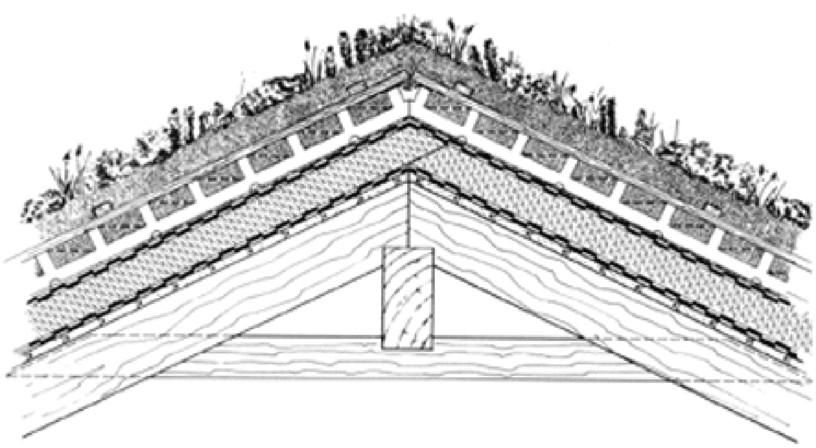

*Figure 2. A roof slope between five and 20 degrees is ideal for a green roof because it allows the water to drain naturally. Illustration courtesy of Bauverlag GmbH, Germany.**

Funding and Incentives

Germany and other European counties have responded to development and the disappearance of open space with regulations that require mitigation for open space and pervious surfaces that are disturbed by construction to reduce runoff and avoid overloading storm sewers. Mitigation requirements vary from state to state, but almost everywhere new commercial developments are obligated to green their roof surfaces. New residential developments include extensive green roofs on garages, carports and porches. Additionally, many incentive programs encourage homeowners to consider a green roof with an added benefit of exemption from the "rain taxes" — taxes collected for the amount of impervious surface cover on the property that generates runoff and contributes to the local storm sewer.

In the US, opinions vary about such taxes and regulations. However, construction of storm sewers and other utilities is financed with tax dollars, and the calculations are simple: the more rainwater that is caught and kept as a resource where it falls, the less runoff there is to convey. Less runoff allows smaller storm sewers, which, in turn, saves construction and maintenance costs.

Funding for green roofs can be obtained through EPA's Clean Water Act Section 319 (non-point source pollution) grant program, and local funds may be also available. For instance, the Critical Areas Program in Baltimore, MD, collects fees for impervious surface cover on new developments that occur within close proximity to the Inner Harbor. The money can then be redistributed to projects that engage in ecological site planning and design, including green roofs. Power companies or sewer authorities could create incentive programs that partly pay for green roof installations. Such programs could prove profitable by helping to reduce sewer pipe sizes and maintenance costs, and could also decrease power demand during hot summer days, thereby preventing blackouts.

Existing incentive programs could also easily be adapted for vegetated roof surfaces to reduce urban runoff. One such example is the reduced property tax assessments law for vegetative filter strips in the State of Illinois. This voluntary program, initiated by the Illinois Department of Agriculture, Office of Soil and Water Conservation, provides a tax reduction up to five-sixth of the land value (the land owner pays only one-sixth of the taxes) in exchange for the development of vegetated filter strips, a proven conservation practice that can aid in reducing soil erosion, improve water quality and provide significant habitat for grassland wildlife.13 Green roof technology aligns with all those goals and could form a logical extension to this existing program.

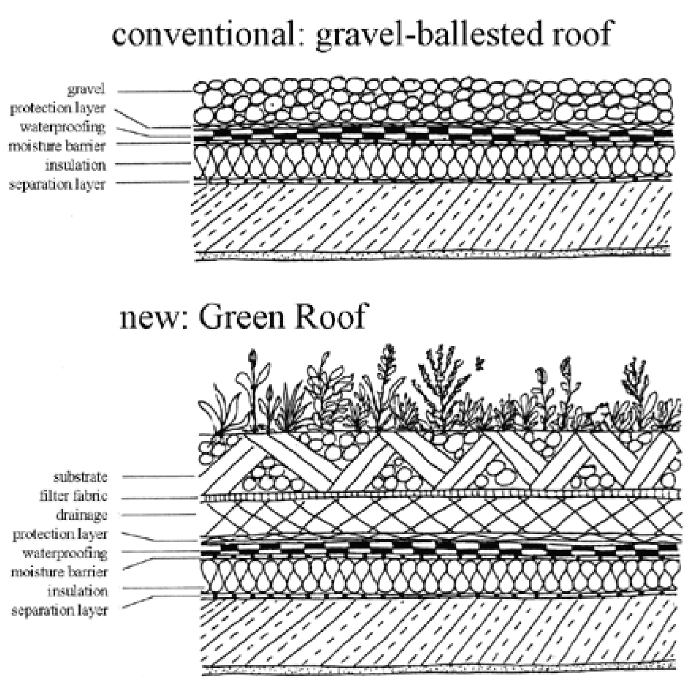

Figure 3. Green roof construction is very similar to a conventional gravel-ballasted roof. Illustration courtesy of Bauverlag GmbH, Germany.*

Bringing Cities to Life

Extensive green roofs are the single most effective solution to stormwater management. Vegetation layers are installed over impervious roof surfaces and do not take up additional land. They are economical and widely adaptable. Additionally, they do not compromise contemporary architectural design — almost every building design leaves out its fifth facade, the roof's surface.

Green roofs present a unique business opportunity to bring cities to life by combining stormwater management, energy efficiency, and the urban ecology through plants, water and landscaping. But in the end it is not the technical argument that will lead the charge for more green roofs. It must be the stakeholders, architects, planners, regulators and society, who collectively have the capacity to change the environment in which we lead our daily lives.

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Editor's note: All illustrations from Bauverlag GmbH were used with permission from the book Dachbegrünung: Ein Okologischer Ausgleich (Green Roofs: An Ecological Balance), by Albrecht Dürr, Bauverlag 1995. The photos on pages 63-64 in the print edition of this article were provided by re*natur company, Germany.

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References

1. U.S. General Accounting Office, Community Development: Local Growth Issues – Federal Opportunities and Challenges," GAO/RCED-00-178 (September 2000); this report is available at www.gao.gov/special.pubs/lgi or at www.gao.gov/new.items/rc00178.pdf.

2. City of Olympia, Public Works Department, Water Resources Program, Impervious Surface Reduction Study, Final Report, (May 1995).

3. Ibid.

4. Albrecht Dürr, Dachbegrünung: Ein Ökologischer Ausgleich translated: Green Roofs: An Ecological Balance. (Bauverlag, GmbH, Wiesbaden and Berlin, Germany, 1995).

5. Ibid.

6. The New York Times, "Scientists Watch Cities Make their Own Weather," August 15, 2000.

7. Ibid.

8. The Urban Heat Island effect was discussed in The New York Times and CBS Television.

9. Jacklyn Johnston and John Newton, Building Green: A Guide to Using Plants on Roofs, Walls, and Pavements. (The London Ecology Unit; London. 1992).

10. Matthew B. Arnold and Robert M. Day, The Next Bottom Line: Making Sustainable Development Tangible (Washington, D.C.: World Resources Institute, 1998).

11. The New York Times, "Scientists Watch Cities Make their Own Weather," August 15, 2000.

12. Re*natur, company, Germany. 1996 to 2000. Interviews conducted by the author.

13. Vegetated Filter Strip Reduced Property Tax Assessment Law (Public Act 89-606). For more information contact Terry Donohue at 217-782-6297.

Green Roof Resources

Green roofs provide a wealth of benefits. They assist in stormwater management, increase the energy efficiency of buildings, reduce the urban heat island effect, beautify cities and clean the air. However, many technical issues are involved with planning and installing a green roof. As with any green design, you should do your research before you decide whether a green roof is or isn't suitable for your project. Following are some resources that can help you learn more about green roofs:

Suppliers

American Hydrotech, Inc.
312-337-4998
http://www.hydrotechusa.com/

Barrett Co.
800-647-0100
http://www.barrettroofs.com/

Garland Co., The
800-321-9336
http://www.garlandco.com/

Roofscapes Inc., Charlie Miller, principal 215-247-8784
Cmiller@roofmeadow.com
http://www.roofmeadow.com/

Sarnafil
781-828-5400
www.sarnafilus.com/GreenRoofs.htm

Soprema, Inc.
800-356-3521

Other Resources

Bialek, Janna. "Greening Our Cities from the Rooftops Down," Audubon Naturalist, July/August 2000.

Chicago City Hall rooftop Kevin Laberge, project manager
312-742-0463

The Green Roof Monitor, published by Canada's Office of Urban Agriculture
cityfarmer.org/GreenRoof.html

Green Roofs for Healthy Cities, a Toronto-based organization that promotes green roofs
www.peck.ca/grhcc/main.htm

Osmundson, Theodore,
Roof Gardens, New York, W.W. Norton & Co., 1999.

www.greenroofs.com, a website developed by Linda Velazquez while a student in landscape architecture at the University of Georgia.

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