Exploring Tomorrow's Technology in Roofing

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Abstract

Extensive greenroof technology has been tried and proven in Europe more than 30 years but has not been fully developed for North American climates. Perennial plant ground covers and shallow growing substrates on roofs: 1) improve energy efficiency by reducing interior temperature fluctuations, 2) significantly extend roof membrane life, 3) ameliorate storm water run off, 4) provide beauty & wildlife habitat, 5) reduce pollution and the heat-island effect, 6) are used as a place for advertising, recreation, herb & food production, education, physical and mental therapy and treatment of gray water.

Biography

Dr. John W. White is Professor Emeritus and former Associate Director of The Office of Industrial Research and Innovation at The Pennsylvania State University, University Park, PA. He currently is Horticulture Consultant for The Garland Company, Inc. an industrial roofing company with corporate offices in Cleveland, OH.

Introduction

A building's footprint, parking lots and roadways sealed with concrete or asphalt prevent or slow water infiltration into the ground, alter weather, take away green space in metropolitan areas and increase temperatures in urban environments. Dark-colored building roofs contribute to temperature increases that lead to the "urban heat-island effect" by absorbing and reradiating heat.

Greenroofs provide solutions to these problems and offer new and innovative uses for rooftops. The cost of a greenroof can be recovered in a short time with only the value of energy savings. Roof system life can be extended because roofing membranes are protected from heat load, ultraviolet rays, sun, wind and hail damage. Storm water management can result in tax savings or permit a building to have a larger footprint or more floor area. The technology is available to use extensive greenroofs to grow herbs and food and provide a place for beauty, relaxation and therapy, advertising and to recycle gray water.

What is a greenroof?

Intensive and extensive are the two basic kinds of greenroofs. Intensive greenroofs cover smaller areas, have deeper and heavier substrate and are planted with trees, shrubs and more large perennials than extensive greenroofs. There are many examples in most major metro areas. Extensive greenroofs, sometimes called ecoroofs or living roofs, are typically used on large commercial roof areas. Substrates are typically 2-inches (in) to 6-in (5-cm –15-cm) deep and weigh from 10 pounds per square foot (lbs/ft^2) to 25lbs/ft^2 (49 kg/m^2 –123 kg/m^2), compared to 12-in to 24-in (30-cm – 60-cm) deep and weights of 50 lbs/ft^2 to 150 lbs/ft^2 (246 kg/m^2 – 738 kg/m^2) for intensive greenroofs. Xerophytes, low growing ground covers and sun, wind and heat tolerant perennials, are the best type of plants for extensive greenroofs.

Construction Materials (Layers)

1. Waterproof roof membrane is the most critical component of a greenroof system. If all of the plants die, we can replant. If the plants thrive but the roof leaks, there is a major problem. Therefore, we should install the longest lasting/best roof system available. There are various types of roof systems available in the commercial roofing industry. The most common are built-up roofs, modified bitumen, single-ply, fluid-applied and metal. Bituminous roof systems have the longest history of successful roof performance. Built up roofs and modified bitumen roof systems consist of alternating plies of bitumen and reinforcement. Modified bitumen roof membranes can also incorporate post-consumer recycled tires into the waterproofing system. Bitumen-based roof systems have been successfully used in North America for over 150 years. The redundancy provided by the multiple plies provides inherent reliance on the roof system and is less dependant on the workmanship of the laborer installing the roof. The premier roof system in Germany, for use under greenroofs, is multi-ply modified bitumen systems. The most historical greenroof, the hanging gardens of Babylon, used reeds and bitumen as the waterproofing membrane. (Lambert, B., 2002)

Thermoset (EPDM) and Thermoplastic (PVC & TPO) single ply membranes are plastic or rubber membranes which are typically 39 mils to 60 mils thick. These single-ply membranes provide for quick installation of the waterproofing system; however, they tend to rely upon the expertise of the craftsman who is installing the roof to provide its watertight integrity. Fluid applied systems are typically installed on structural concrete decks. These systems consist of hot or cold applied waterproofing materials applied directly to the substrate. These field-constructed systems are subject to poor application techniques and the relative smoothness of the substrate to achieve its desired monolithic appearance.

The key to guaranteeing a waterproof roof system is choosing a well known, financially stable, reputable contracting company, that provides high quality materials, detailing, excellent workmanship and on-site manufacturer's rep supervision. Poor quality installation, construction damage and lack of supervision can undermine the most detailed and well-prepared specifications.

2. Underlayment is composed of layers of insulation (optional), a root penetration barrier, drainage and filter fabric, and growing substrate stabilization. Insulation may be used under a roof membrane, over a membrane or both. Insulation placed over a membrane must absorb little or no water over the 35-year to 40-year life of the greenroof system. The long-term water absorption characteristics of insulation have not been thoroughly researched because most traditional roof systems are not expected to last that long. Ask insulation manufacturers for accelerated weathering studies and water vapor absorption quantities of various insulation materials over a 40-year period.

A **root penetration barrier** is required for most roof systems. A root barrier provides extra assurance for clients requesting it. Thick high-density polyethylene (HDPE), chlorosulfonated polyethylene (CSPE) such as Hypalon, thermoplastic polyolefin (TPO) or ethyl-propylene diene monomer (EPDM) can serve as a root penetration barrier over built-up, single-ply or fluid-applied membranes.

Some manufacturers offer water storage reservoirs made of expanded polystyrene (EPS) or synthetic fabric or use polyacrylimide gels. A properly formulated growing substrate (soilless media) can provide all the water storage capacity necessary and can be supplemented with irrigation. Adding water storage seems counterintuitive to creating a lightweight greenroof. These reservoirs are redundant, have limited life and add extra weight & cost.

A **drainage layer** is needed to prevent water from accumulating on the roof or in the substrate. Good roofing practices require no water ponding. Greenroofs are no exception. In Europe, crushed roofing tiles are recycled and used as a drainage layer. In North America, synthetic erosion-control fabrics are more likely to be chosen. Erosion-control fabrics come in many forms and may be a single three-dimensional matrix or have a filter fabric fastened on top and used as a two-ply sandwich. A drainage expert should be consulted regarding the physical characteristics of the drainage and filter fabric layers to assure they provide adequate water flow for peak rainstorms. The filter fabric prevents small particles of growing substrate from being flushed out but should not be so fine that it is clogged by fine humus particles.

A **growing substrate stabilization layer** is probably necessary only when the roof pitch is 3:12 (14 degrees) or greater. Then, battens or various types of erosion control systems can be used to keep the substrate from slipping or eroding off the roof. Extra precautions for safety are necessary when constructing and maintaining 3:12 to 6:12 roof slopes. Building codes in Europe require safety-rope tie-downs and lightening rods on all greenroofs.

3. Substrate (engineered soilless media): The most important substrate properties are stability, saturated weight, depth, drainage, readily available water, and cation exchange capacity (CEC) for nutrient availability and pH and soluble salt buffering.

Substrate stability is critical to long-term success of a greenroof. Substrates with high percentages of organic matter are prone to shrinkage and compaction. Mineral aggregates of various sizes and types provide this stability. Expanded clay, shale and slate, volcanic rock (scoria), pumice, zeolite and vitrified diatomaceous earth are examples of stable aggregates. Perlite is relatively stable but also brittle and easily crushed during mixing, hauling and loading. These aggregates also provide good drainage and some of the smaller aggregates hold available water in their interstices.

Organic materials such as sphagnum moss peat, coir (coconut pith), composted barks, composted municipal and yard wastes, and pasteurized manures provide CEC and help hold readily available water. Some organic materials contain poisons. Mixtures of mineral aggregates and organic materials provide all necessary characteristics for drainage and growing plants. However, extensive greenroofs have special limitations not found in ground level or even intensive greenroof sites. Maximum saturated weight loads for extensive greenroofs on steel and wood decks are usually in the range of 10 lbs/ft² to 25 lbs/ft² (49 kg/m² - 122 kg/m²) with the average being about 15 lbs/ft² (73 kg/m²) (similar to a ballasted single ply systems' maximum weight). This weight must include all system components including the substrate during a soaking rain, long-term water vapor accumulation in the insulation and plants at full maturity.

The15 lbs/ft² (73kg/m2) is easily achieved with a one-inch (2.54-cm) substrate depth. The problem is that most plant roots need a minimum of three inches (7.6-cm) or more of substrate depth to sustain good growth and to survive drought and freeze/thaw cycles. The trick in developing an extensive greenroof substrate is providing all of the essential depth and plant growth characteristics, while keeping the maximum load within the structural engineer's specifications. The ingredient component combinations for achieving this goal are often proprietary secrets.

A professional structural engineer must determine and certify the buildings maximum load capacity so that the greenroof system stays below this maximum throughout its life. Lack of quality control in a substrate's analysis and maximum saturated weight could lead to overloading and roof deck collapse.

4. Plants: Low-growing, shallow-rooted, perennial plants that are heat, sun, wind, drought, disease and insect tolerant are preferred for extensive greenroofs. Low-growing plants or ground covers resist drying out and being blown over by wind. Evergreen plants and seasonally flowering plant make good combinations for providing aesthetical pleasing roofs year-round.

Plants must be matched to the roof location for both macroclimatic and microclimatic conditions. A professional horticulturist, landscape architect or local nursery business should be consulted for this information and to help select plants that meet the clients needs. Some client's may want only native plants; however, many native plants are tall and have deep root systems, which excludes them as good candidates for greenroofs. But there are native plants that fulfill all the best extensive greenroof plant criteria.

Most commonly used are rock garden succulents and alpine xerophytes such as Antennaria, Armeria, Aubrieta, Allium, Dianthus, Phlox, Sedum, Sempervivum and Thyme. Grasses and mosses are best avoided because at certain times of year their shoots turn straw-colored and die, making them both unsightly and flammable.

Plants can be started by hydroseeding and hydrosprigging, transplanting small plant or plugs and laying out mats and carpets. Hydroseeding and hydrosprigging are the least expensive but have the highest risk of not becoming established and the slowest rate of surface coverage. Plugs or small plants are easiest to establish, if irrigated the first growing season. Their rates of coverage and cost will depend on the size and spacing of plants. Mats can provide the fastest total surface coverage, if planted solidly, but are the most expensive. Mats are not generally available from traditional nursery plant growers.

5. Irrigation: During the first growing season all species will require irrigation until roots are well established. After initial plant establishment, it may be possible to stop irrigating but it is best to keep the irrigation system available in case of unusual weather patterns. It would be costly to have plants die because of a lack of sufficient water. Subirrigation systems direct the water only to plant roots, lose less water to evaporation and are not visible. Weed seeds are unlikely to germinate if the substrate surface is dry.

Applications

All types of commercial buildings with large, low-slope roofs are ideal candidates for greenroofs. Roofs of hospitals, schools, park pavilions, colleges, casinos, manufacturing facilities, shopping malls, apartment buildings and even multiple-story buildings are suitable for greenroofs. Sloped roofs from 1:12 to 6:12 (27 degrees) have been covered with plants in Europe.

Advantages of Greenroofs

1. Energy efficiency: Greenroofs significantly reduce a building's heat gain and loss. Evapotranspiration from substrate and plant leaves dissipates up to 50 percent of the sun's heat, thus cooling the surrounding air. Air temperatures above a black roof system in summer can be 95° F (35° C) or higher, with the roof surface reaching 176° F –190° F (80° C - 88° C). The daily variation in temperature in spring and summer on a black roof can be as much as 90° F (50° C) while temperature variation under a greenroof system is only about 22° F (12° C). The K-value of a roof in summer can be reduced between 52 percent and 72 percent. (W. Kolb et. al. 1986-87)

Research studies in Canada and the United States have shown 22° F (12° C) average lower building temperatures in a 24-hour cycle, leading to a potential reduction in the "urban heat-island effect". Additional savings include less air conditioning equipment and lower cooling costs. (Liu, K., 2002)

Reduction of heat loss also depends on substrate depth, moisture content, and the depth and density of hydrophobic insulation used as part of a greenroof system. Greenroof systems alone can have R-values of 10 or higher, reducing traditional insulation needed to meet building heat loss codes and specifications.

When architect William McDonough designed an extensive greenroof for The Gap Inc. in San Bruno, Calif., he anticipated a payback of about eight years for the added costs of the greenroof. Paul Kephart, horticulture consultant for the project, said “after five years the air conditioners have not been used”. “The energy saved on air conditioning costs alone could pay for most of the cost of the greenroof.” (Kiers, H., 2002)

2. Extended roof life: Greenroofs significantly extend the life of roof membranes by blocking the sun’s ultra-violet rays, and preventing physical abuse from wind, heat load, air pollution and hail based on many years of observations in Europe. Climates in Europe are wetter and milder and there is less heat load and hail damage on average than in most of North America.

3. Stormwater management: Boston, New York, Seattle, Portland, Ore. and Washington D.C. are served by sewer systems with limited capacity that carry both city sewage and storm-water. During peak storms, raw sewage may be discharged into urban waterways and eventually pollute streams and rivers. Greenroofs can help reduce the effects of pollution and associated costs of building new storm water systems.

Rainwater run-off studies are being conducted in Philadelphia, Portland, Ore., Toronto, Canada and Germany to determine the effects of different substrate depths and plant species mixtures on attenuation of heavy rains. Results in Portland, Ore. have shown that greenroofs can slow the rate of storm water run-off, which allows storm water from streets to dissipate before roof water reaches the system. (Lambert, B., 2001)

Philadelphia is an example of an older American city where storm water flooding overloads available sewer systems. In a Philadelphia research project, a 3000 ft^2 (279 m^2) low-slope, demonstration roof, 3.4-in (8.6-cm) deep was used in a rainwater attenuation study. A German computer model predicted 48 percent to 54 percent reduction in total annual rainwater run-off for the Philadelphia research roof. Empirical data produced 40 percent attenuation in run-off. (Miller, C., 1998)

In a German research project, run-off from a low-slope roof was reduced by 99 percent during a light rainfall of 0.08-inches (5-mm). After a strong rainfall of 0.79-in (20-mm) in 15 minutes, run-off was 70 percent less from a greenroof than from a gravel roof. In each case, the moisture content of the soil was not reported. Forty seven percent maximum water storage was obtained with a vegetated roof. (Kolb,W., et al.,1986-87).

In another low-slope roof German greenroof study, only 20 percent of applied irrigation water reached the drain with a very dry substrate while with almost saturated substrate, the run-off water was 48 percent of that applied. The average maximum reduction in run-off water was 70 percent. (Kolb, W., et al., 1986-87)

Excess rainwater percolates through greenroof substrate when it’s fully saturated, but it can be several hours, after the peak of a rainstorm, before the excess begins to reach the drainage system. This attenuation of water reaching the central storm water system can allow the system to evacuate water from streets and parking lots before rain from an extensive greenroof reaches the system. (Peck, S., et al., 1999)

Some local German land development and city ordinances allow greenroof building owners to be compensated for lost open space by allowing their buildings to have a 50 percent to 70 percent larger footprint than buildings without greenroofs. This subsidy is especially attractive in areas with high real estate values. Portland, Ore. has implemented a floor area ratio bonus greenroof incentive.

4. Sound attenuation: Studies have shown that a 5-in (12.5-cm) deep substrate can attenuate sound transmission by at least 40 decibels, a significant factor when planes are taking off and landing near buildings. Workers at the Gap Building, just a few miles from the airport, said that they don't notice the sound of airplanes taking off and landing less than a mile away. (Peck, S. et al., 1999)

5. Psychological and physical therapy: Psychologists associate natural settings with numerous health benefits. Greenroofs in the workplace provide natural landscape views for office workers. Greenroofs, in combination with patios and walkways, could result in potentially happier, more relaxed and more productive workers and managers.

Studies have linked natural settings to lower levels of stress and decreased hospital recovery times. Patients in confining institutions, characterized by high levels of stress, such as mental hospitals, prisons, and drug and alcohol recovery facilities, could benefit from physical therapy workshops conducted on greenroofs. (Ulrich, R., 1982)

6. Aesthetics: Vegetated roofs can provide natural beauty year-round and help blend rigid buildings and other structures into natural surroundings. New growth and changing patterns of color and texture add seasonality to an urban setting, keeping city dwellers more in tune with biological cycles of nature.

7. Ecology & wildlife habitat: Plants can provide habitats for birds, butterflies and bees and create biodiversity of plant life including providing a sanctuary for endangered species. The ecology of a greenroof can be as diverse as the imagination of the designer and can be an ecological experiment of significant value for generations to come.

8. Urban heat-island effect: On warm summer days, the temperature difference between a city and surrounding natural vegetation can be 8° F(4.4° C) or more. Plants absorb the sun's rays and use this energy to transpire moisture and cool the air. Studies have shown that a reduction of just one degree to two degrees F (0.56° C – 1.1° C) outside a building can reduce the cooling load by 8 percent. (Peck et al., 1999)

9. Pollution reduction: Warmer temperatures also contribute to deterioration of air quality. Photochemical reactions of airborne pollutants create urban smog. These reactions are more intense at higher temperatures. Studies in Los Angles showed a 3 percent increase in smog for every degree of temperature rise above 70° F (21° C)

(Akbari, H., 2002). Plant leaves absorb carbon dioxide and capture particulates. Greenroofs can reduce particulates as much as 75 percent and for each 16 ft² (4.9 m²) of surface area supply enough oxygen for one person for a whole year. The growing substrate can absorb sulfur dioxide, ozone and nitrous oxides, air pollutants from car exhausts and industrial wastes found in urban environments. (Colorado Tree Coalition, 2002)

10. Recreation: Golf putting greens and children's fenced play areas with sand boxes can be created on greenroofs. If basketball, badminton and volleyball courts can be built on a luxury cruise ship, then you can also build them into a greenroof design.

11. Advertising: Company logos, mosaic designs and even photo images of the CEO could be created with plants of different colors and textures. A casino is considering having a royal flush designed with plants on its greenroof. These designs seen from surrounding buildings or helicopters would generate lasting impressions. Also, a greenroof is a good way for companies to show their dedication to improving the environment. Greenroofs are like billboards demonstrating environmental commitment to the "**building green movement"**.

12. Increased property values: In Germany, land is scarce in urban areas resulting in high real estate values. In most German cities, building codes require the footprint of a building to be replaced by vegetation. If you purchase a building without a greenroof, any new codes are retroactive requiring the addition of a greenroof to the old building, which is more expensive than adding one to a new building. The only place this can be done is on the roof. Buildings with greenroofs sell at a premium compared to buildings without greenroofs or to land requiring new building permits.

13. Herb & food production: Many herbs fit the criteria for extensive greenroof plants, especially Thyme. Roofs of restaurants would make ideal sites for herb production. Food crops, especially tomatoes and peppers, can be produced on greenroofs providing food and jobs for people who live inside the city or urban area.

14. Gray water treatment and recycling: Detention ponds and wastewater treatment are not always feasible in urban areas where open space is expensive and scarce. A new, all-glass, 15-story, oval-tower building in Germany has a large pond in front that acts as a reservoir for storm water and gray water management. The gray water is first filtered through the greenroof substrate, which removes nitrates and phosphates for plant growth, then the filtered water circulates through a constructed wetlands and mixes with stormwater in a large aerated pond and is finally recycled as toilet flush water. The greenroof, pond and constructed wetlands are major aesthetic landscape features.

Overcoming Myths

The greatest myth about greenroofs is that they leak. This is a misconception based on unfavorable stories of early conventional greenroofs. In the 1970s, during the so-called energy crisis, sod roofs were not properly installed and leaks developed. This should not happen today because of improved waterproof roof membranes and superior installation technology.

Myth: Greenroof systems are too heavy to retrofit on existing older buildings with steel and wood roof decks. New technology and better substrate ingredients have proved that this concern is unfounded.

Myth: Slopes greater than 3:12 (14 degrees) can't support a greenroof because it will slide off. Actually flat roofs can be more of a problem than sloped roofs because excess rainwater may pond on a flat roof and cause floating of the greenroof components or damage to the plant's root system. A roof slope of at least 1:12 (5 degrees) allows water to drain properly to in-roof drains or perimeter scuppers. A roof slope between 1:12 (5 degrees) and 5:12 (23 degrees is best because excess water easily drains from the pull of gravity. Roofs up to a 10:12 pitch (40 degrees) have been greened in Europe, but slopes greater than 23 degrees present significant maintenance and safety concerns; these concerns, however, are manageable.

Myth: Greenroofs are fire hazards. This is not totally a myth because it is possible for dead vegetation to catch on fire from a smoldering cigarette or lightning. However, there are many techniques for preventing fires on greenroofs and for using greenroofs to reduce the danger of fire on a building's roof. Plants with high moisture content such as sedums and most succulents, especially those that are evergreen, are fire retardant. Evergreen shrubs with high volatile oil content, seasonally dead vegetation with dried flower stalks, grasses and mosses should be avoided unless surrounded by fire retardant plants or by nonflammable firebreaks and paths. Moist, mainly mineral-based substrates with succulent vegetation will reduce the chances of fire spreading on a roof.

Myth: Greenroofs require a lot of maintenance. Customer's requirements determine how much maintenance is required. The more important aesthetics, the more maintenance required. The correct selection of plant species usually reduces maintenance to a minimum of twice per year. Low growing ground covers spread horizontally forming mat-like covers that do not need regular mowing or cutting. If the species has a flower stalk, it will need to be removed with a weed cutter once yearly. If irrigation is needed after the first season of plant establishment, time clocks and solenoid valves can be used to automate irrigation cycles. Once in the spring and once in the fall, the irrigation system will need attention. At the same time the irrigation system is being activated or winterized, weeding and fertilization can be accomplished.

Installation

There isn't space in this paper to describe detailed installation procedures. We soon will be publishing a book on greenroofs that will address installation and other important greenroof subjects in more detail.

Cost

The cost of a greenroof can be recovered in less than its expected life but many building owners and investors consider only initial costs. Typically, a five-year or less payback period is expected. Long-term lifecycle accounting probably is not used in North America as much as it is in Europe or Japan, where greenroof installations have a long history and are increasing yearly.

A properly designed and maintained greenroof should last 30 years to 40 years compared with 10 years to 20 years for traditional roof system. The average cost of an extensive greenroof including the waterproofing membrane, greenroof system and plants in North America is currently $10/ft² to $20/ft² ($108/m² to $216/m²) compared to $3/ft² to $6/ft² for a conventional roof.

Life-cycle cost analyses have shown that greenroofs are less expensive than conventional roof systems based on replacement and maintenance costs alone over a 30-year period. (visit http:www.ecoroofsystems.com/c_cost.html)

Funding & Incentives

Federal, state and local funding programs can provide financial assistance for greenroof projects. Funding can be obtained under EPA's Clean Water Act –Section 10 (non point source pollution). Greenroofs are credited within the U.S. Green Building Council's Leadership in Energy and Environmental Design certification program, which offers tax credits for sustainable building practices. Greenroofs qualify in the following areas: surface water, energy efficiency & sustainability.

Installation of greenroofs in Chicago, Portland, Ore. and Seattle and the state of Maryland can earn tax credits. Developers in Portland, Ore. that incorporate greenroofs in their designs can qualify for floor area bonuses. Seattle, Wash. has a similar density bonus system providing a maximum 30 percent increase in lot area in exchange for roof vegetation, but only if the roof garden is accessible to the public. (Beatley,T., 2000).

Recommendations

Cities and urban areas in North America are faced with major problems of growth and economic development. Population growth projections suggest these problems will only get worse in the years ahead. This means that the urban heat-island effect, microclimate weather changes, air pollution, loss of green space and storm water management problems will escalate.

Greenroofs can provide partial solutions for these problems. The International emphasis on building green has opened new doors for potential funding and other incentives for greenroofs. The European and Japanese experiences have shown what is possible and that North America is many years behind in following their leadership. We need to encourage policy makers, the mass media, building contractors and owners, landscape architects and the general public to learn about the advantages and benefits of greenroofs.

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