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Green Roof Design Considerations

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Presented by: LiveRoof Global, LLC
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Description: With a focus on hybrid green roof systems, this course provides an overview of green roofs, including system options and design and specification considerations such as plant selection, irrigation, mitigation of wind pressure and fire risk, sloped applications, and warranty options.

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Purpose and Learning Objectives

Purpose: With a focus on hybrid green roof systems, this course provides an overview of green roofs, including system options and design and specification considerations such as plant selection, irrigation, mitigation of wind pressure and fire risk, sloped applications, and warranty options.

Learning Objectives:

At the end of this program, participants will be able to:

- define and compare the various green roof system options in terms of performance, cost, maintenance, etc.
- state the recommended types of plants, plant designs, and irrigation methods that help reduce energy consumption and allow the green roof to be fully optimized
- discuss how to properly design and engineer the green roof so that it retains its integrity during high winds and mitigates fire risks, and
- review the design and specification considerations to avoid problem areas and facilitate a successful green roof installation.

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Introduction

As energy demands rise and smog and other pollution impacts our cities, many cities and states are encouraging green building methods, including green roof systems. Cities also encourage green roofs to reduce storm water surges; to protect the groundwater, lakes, and streams; and to conserve energy.

This course was developed to provide the best practices for designing green roofs and includes design-related issues which may not be obvious, but can have a large impact on the success of your project.

Presented in this first section is a review of the various types of green roof system options that are available.

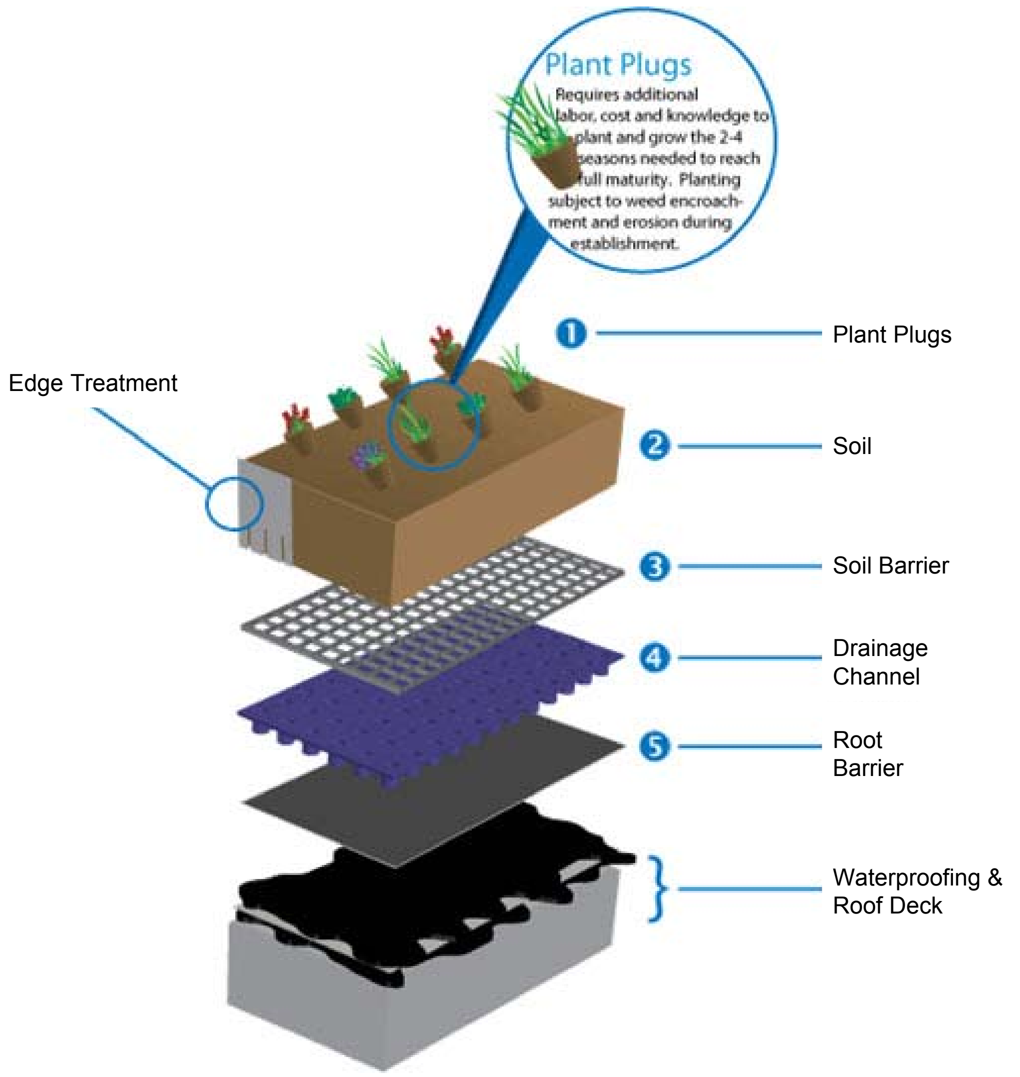
- Built-in-place
- Sod and tile
- Traditional modular
- Hybrid systems

Built-in-Place Systems

All vegetated roofing assemblies consist of a roofing system (the waterproofing component) and a vegetated system (consisting of drainage, root barrier, soil, and plants).

The roofing system may be a single-ply, modified bitumen, BUR, or fluid-applied roofing system.

The root barrier is a plastic or rubber sheet or film (approved by the roofing system manufacturer) that functions as a protection layer for the roofing system against root penetration and physical abrasion.



Built-in-Place Systems

As the name implies, built-in-place green roof systems are constructed on-site using a drainage layer, filter fabric, root barrier, soil, and plants. In effect, you start with a brown roof and try to get it to turn green.

These systems have a low acquisition price and natural function, as water and beneficial organisms can be shared across the entire surface of the continuous soil layer.

Built-in-place systems require high costs to ensure maturation of the green roof. The level of lifetime costs depends upon plant selection, density, soil quality, and expertise of the maintenance staff. During the maturation period (approximately three years), the maintenance costs are significant and the system may be prone to soil and wind erosion and weed encroachment.

Sod and Tile Systems

Sod and tile systems are composed of lightweight sods, grown upon plastic or coco fiber netting.

Generally, they are 1" (or thinner) in thickness, with mostly organic soil, and set upon a built-up soil profile.

These systems have modest front-end costs, and if properly maintained, irrigated, and installed during the right time of year, can become established more quickly than built-in-place systems. Sod and tile systems are limited to low-growing, moss-like species. Frequent irrigation is required during establishment, and systems are not wind-resistant until their roots knit into the growing medium.

Traditional Modular Systems

Traditional modular systems are typically delivered pre-planted in containers made of plastic or metal, and most commonly have a 4" soil depth.

Occasionally, they are available in shallower depths of 3.3", and these systems have reduced storm water absorption capacity compared to the 4" systems.

Pre-grown modular systems typically have higher front-end costs, but depending on the level of maturation at delivery, can save money on initial maintenance. They offer increased plant options over sod and tile systems, and they allow for more efficient installation.

Traditional Modular Systems

The soil is compartmentalized, therefore stopping the flow of nutrients, beneficial organisms, and water between modules.

Edges may be exposed, creating hot surfaces that hinder plant growth, creating unattractive grid lines, and in plastic systems, making them susceptible to photodegradation and cracking. At minimum, the perimeter should be surrounded by edging to shield it from the sun. Many systems may not be custom cut, so flexibility is limited.

Durability, aesthetics, and function are variable with these systems, and some systems may produce relatively high lifecycle costs.

Hybrid Systems

A hybrid system is designed to package all of the advantages of the various green roof systems and to leave out the drawbacks.

- **Built-in-Place**
  - Interconnected soil without extensive ongoing costs of maturation and maintenance
- **Sod and Tile**
  - Pre-vegetated without plant limitations, or excessive watering and maintenance required for establishment
- **Modular**
  - Ease of installation, without exposed edges or soil compartmentalization

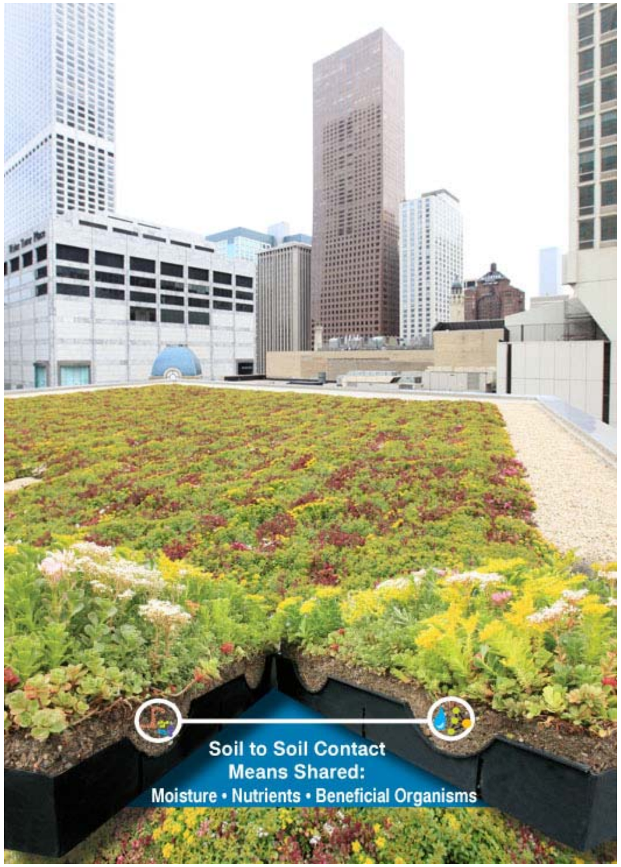
For the purposes of design recommendations, this presentation draws largely upon examples of hybrid systems.

Hybrid Systems: Benefits

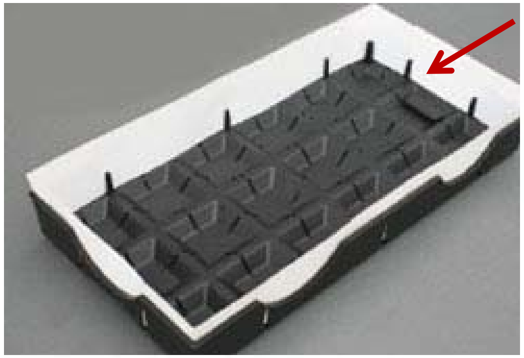
Hybrid systems offer unrestricted, interconnected soil for natural function and sharing of moisture, nutrients, and beneficial organisms across the roof strata. In general, the systems are fully grown to maturation under care of local horticulturalists and thus eliminate the lengthy and expensive establishment period of other systems.

Plant selections are broad, and systems may be available in depths of 2.5" to 8" in modules with subterranean edges that are protected from sun and sight under a continuous layer of soil.

Hybrid systems offer optimal wind and fire resistance, storm water absorption, and thermodynamic performance. These systems are designed to provide lowest overall lifecycle costs as they eliminate maturation costs, minimize ongoing maintenance costs, and maximize longevity and aesthetic and/or marketing value.



Non-Compartmentalized Hybrid Systems: Process



First, the grower inserts the soil elevator (riser) into the module.

Installer sets modules tightly in place on the roof.

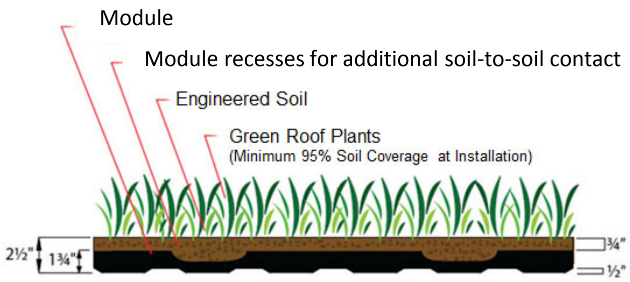
Module is filled with locally sourced engineered growing medium.

The soil riser is removed for a seamless, instantly mature green roof.

Plants are grown to maturity under care of local professional growers.

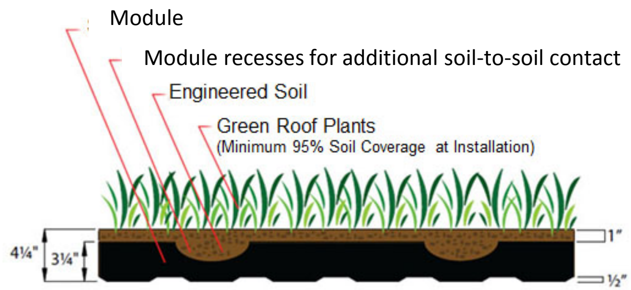
Water is applied to settle growing medium.

Non-Compartmentalized Hybrid Systems: Options



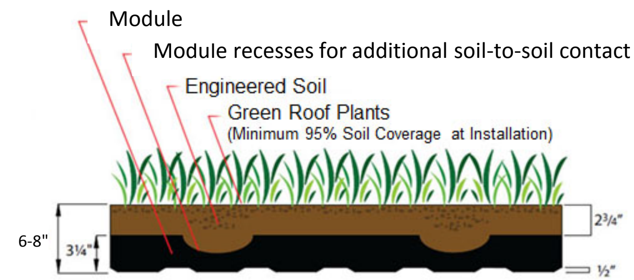
Hybrid Extensive Systems: 2-1/2" Deep

- Can be used on many retrofit projects where load limitations exist.
- Succulent ground covers, water-conserving accent plants, hardy spring-blooming bulbs.
- Not recommended for hot climates.



Hybrid Extensive Systems: 4-1/4" Deep

- Suited for new construction and existing buildings.
- Succulent ground covers, water-conserving accent plants, hardy spring-blooming bulbs.
- Maximizes storm water management.



Hybrid Intensive Systems: 6" and 8" Deep

- Intensive systems are available in 6" and 8" depths.
- Used mostly with highly drought-tolerant native and adapted perennials, grasses, and vegetables.
- 8" system provides greater perimeter ballast, can be used to optimize biodiversity and meets local storm water codes in some municipalities.

Plant Selection and Design

Water-Sourcing Plants vs Water-Conserving Plants

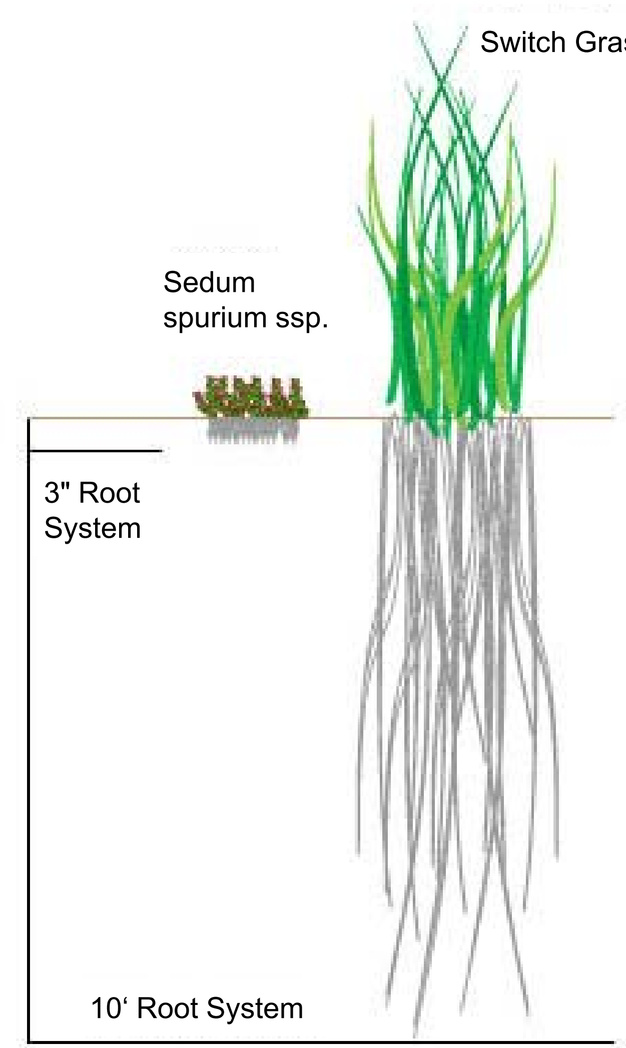
Now that we have discussed the green roof system options, we'll move on to review the design considerations of green roofs, beginning with plant selection and design.

Extensive green roof systems have a soil depth of less than 6". While extensive green roof systems optimize evaporative cooling and storm water management (in part because they can dry down between rain events), their shallow substrate depth means that the plants they can support must be extraordinarily drought-resistant. Practically speaking, the plants that work best in extensive green roofs must be exceptional "water conservers" as opposed to "water sourcers."

Water-Sourcing Plants vs Water-Conserving Plants

Water conservers are plants that store copious amounts of water in their fleshy stems and leaves. Cacti and *Sedums* are an excellent example of water conservers. They absorb water when available and conserve it by closing their leaf pores during the day.

Water sourcers, on the other hand, are plants that have extensive and deep root systems that go deep into the earth in search of water. Good examples of water sourcers are prairie plants, such as switch grass, purple coneflower, and prairie dock.



Recommended Plants

In temperate and mild climates, extensive green roof systems are typically vegetated with a palette of deciduous, semi-evergreen, and evergreen base mix and accent plants that are exceptional water conservers. These include succulent, water-holding plants like *Sedums*, *Alliums*, *Sempervivums*, *Euphorbias*, *Delospermas*, and other species.

Base plants consist of easily propagated *Sedums* that range from ¼" to 4" tall. They are used to create an attractive “living mulch” that protects the system from erosion, provides year-round coverage, provides colorful flowers and foliage, and serves as a backdrop to any taller accent plants used in the assortment.

Accent plants are often included in mixes at a density of ½ to two plants per square foot to add interesting color splashes, vertical dimension, and unique floral and foliar highlights.

Recommended Plants

The best green roof plants both store water and have a special type of metabolism called Crassulacean acid metabolism, CAM for short.

CAM plants are unique in that under drought conditions their stomates (leaf pores) are open at night rather than during the day (as is the case with most plants).

CAM plants exchange gasses (oxygen and carbon dioxide) in the dark when it is cooler and less windy, and therefore conserve water. And CAM plants are up to ten times more efficient with water conservation than non-CAM plants.

Climate and Plant Selection

Prolonged high humidity combined with high nighttime temperatures (constantly above 70°F at night) may disrupt Crassulacean acid metabolism, keeping the stomates (plant pores) closed, impairing metabolism, and leading to metabolic fatigue. When this happens, the CAM plants can become susceptible to disease and fungal infections.

In temperate or mild climates, prolonged spells of high humidity and high nighttime temperatures are uncommon. When they occur, metabolic fatigue can be lessened with regular irrigation (3/4" per week applied early morning is helpful). Plants that are weakened prior to the onset of such weather due to drought stress and/or low fertility hold up worse during these conditions.

In climates where high humidity and high nighttime temperatures are commonplace, CAM plants will have to be carefully chosen (some perform better than others) and oftentimes will be supplemented or replaced with climate-appropriate grasses and herbaceous perennials supplemented with regular irrigation. When designing green roofs in these climates, it is critical to consult an experienced local horticulturist for plants tried and proven for local rooftops.

Native Plants on Green Roofs

While it is popular to say that native plants are better adapted because they evolved here, this notion is not necessarily true.

A plant’s toughness or suitability, is dependent upon genetics and ecological and environmental adaptation (evolving with time and exposure). There is nothing magical about latitude and longitude, as there may be similar or more demanding environmental conditions on the other side of the globe.

In reality, some native plants are tough, some aren’t, and a few will grow in an extensive green roof without frequent irrigation. The list, however, is quite short, as the native ecosystem parallel would be a giant rock covered in 2" to 4" of gravelly soil with loads of reflected light from bordering rocks. Such “real world” parallels are few and far between.

Even though there is not a long list of native plants for use in extensive green roofs (unless one plans to frequently irrigate), there are some good ones to choose from.

Native Plants on Green Roofs

Species such as shade-loving white flowered sedum (*Sedum ternatum*), prickly pear cactus (*Opuntia humifusa*), and nodding onion (*Allium cernuum*) are such plants that are ideal for extensive systems.

With regular and frequent irrigation, many others can be sustained, and plants that fall into this category include prairie dropseed (*Sporobolus heterolepsis*) and little bluestem (*Schizachyrium scoparium*).

These plants are very drought-resistant in conventional landscape settings because they are great water sourcers. On a rooftop with 4" of soil, however, they won't survive for long unless regularly irrigated. Such plants are better suited to a 6" or 8" intensive system.

It is recommended to work with an experienced, local horticulturist to select plants that will be successful, regardless of regional nativeness.

Intensive Green Roof Plants

A broad range of hardy perennials may be used in intensive green roof systems, provided irrigation is ample. Keep in mind, however, that not all perennial plants will work on a rooftop in 6"–8" of soil. A 10' tall grass may not be happy in 6"–8" of soil, and neither will plants that are marginally cold-tolerant.

The best plants for use in these systems are smaller to midsized perennials and grasses that are extremely tolerant of cold, drought, and heat.

Many selections of *Geranium*, daylilies (*Hemerocallis*), *Nepeta*, thyme (*Thymus*), feather reed grass (*Calamagrostis*), and fescue (*Festuca*) are well suited to irrigated intensive green roofs.

Natives, such as butterfly milkweed (*Asclepias tuberosa*), spike gayfeather (*Liatris*), blue grama grass (*Bouteloua gracilis*), northern sea oats (*Chasmanthium latifolium*), and indian grass (*Sorghastrum nutans*) have also been successfully used on green roofs in northern temperate climates.

Intensive Green Roof Plants

Numerous vegetables, herbs, and select fruits (such as strawberries and melons) may be grown on intensive green roofs that receive frequent watering, have ample sunlight, and have proper soil.

Edible plants require sufficient nutrients to support their rapid growth cycle and the energy needed to bear fruit.

When growing produce on green roofs, a blend of organic soil and traditional green roof growing media yields the best results; however, the soil will need annual amendments to maintain volume and provide sufficient nutrition.

Plant Adaptation and Evolution

All plants are unique and are opportunistic in one way or another. Practically speaking, some species tolerate heat better than others, some endure cold better than others, some flourish in dry conditions, and others prefer moist conditions.

By combining species of varying growth characteristics, one strives to design plant assortments which are beautiful and effective in all seasons.

Over time, depending upon the particular plant assortment, geographic site, climate, and microclimate, the plant assortment will adapt and evolve. One species will increase its presence while another decreases its presence, from season to season, and from year to year. This evolutionary "dance" helps to make an extensive system fresh and appealing now and in the future.

Hybrid Green Roof System: Grand Haven, Michigan, August 2007 (day of installation)

Hybrid Green Roof System: Grand Haven, Michigan, June 2008

Mixed vs Monoculture Plantings

While monoculture plantings (those with only one plant type) may seem like an effective way to create patterns on a green roof, areas with only a single plant selection lack biodiversity and are more susceptible to the weaknesses and seasonal characteristics of that particular plant (all plants have their high and low seasons in regards to growth and aesthetics).

Mixed vs Monoculture Plantings

Contrasting blends of complementary species with different strengths can be used to create interesting designs that promote biodiversity, optimum aesthetics, and long-term health. Within the *Sedum* genus alone, there are hundreds of varieties with unique characteristics whose combinations provide for unlimited creative expression.






Mixed vs Monoculture Plantings

By selecting a palette with a mix of deciduous and evergreen species, you improve biodiversity and add value to the system.

Deciduous plants drop their leaves, and often their stems, during the winter months. Dropped leaves and stems decompose to nourish the soil and provide ongoing nutrition.

Evergreen plants hold on to their leaves year-round and blanket the soil 12 months out of the year. They provide winter color and interest, act as a living mulch to help prevent weed encroachment during all seasons, and sequester carbon as they hold on to their leaves and stems indefinitely.

Plant Specification

The climate in Texas is quite different from that of Minnesota. It should be no surprise that the appropriate plants for green roofs will be quite different as well. Therefore, thoughtful climate-specific plant selection is not only important for the functionality of a green roof system, it is critical for aesthetic qualities as well.

Whether you endeavor to have plants that will survive 50 stories high, or to use the rooftop as a canvas to “paint with plants,” you will need the right plants.

Because green roof plants are not one-size-fits-all, local professional horticulturists, experienced in green roofs, should be involved in the plant selection process to help choose the plants that best complement the architecture and suit the microclimate of each project. It is recommended to request a selection of rooftop tried-and-proven plant options appropriate for each project.

To price and plant projects according to your design intent, contractors need to have accurate information when preparing estimates. Therefore, it is important to detail selected plant mix(es) in the drawings and specifications.

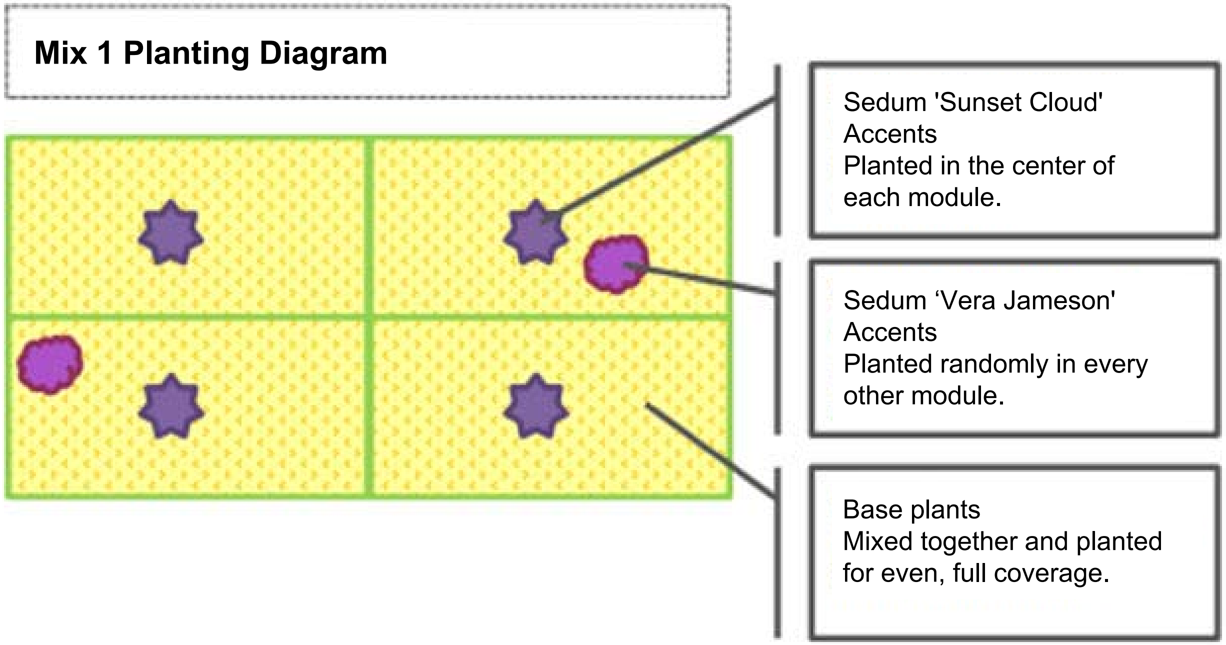
Plant Specification: Example, Mix 1

Base Plants (randomly mixed)

- *Sedum acre* ‘Aureum’
- *Sedum album* ‘Chloroticum’
- *Sedum reflexum* ‘Sunsplash’
- *Sedum reflexum* ‘Moonshine’

Accent Plants (planted as diagrammed)

- *Sedum cauticola* ‘Sunset Cloud’
  - 1 per module, *planted in the center of each*
- *Sedum* x ‘Vera Jameson’
  - ½ per module, *planted randomly to look natural*



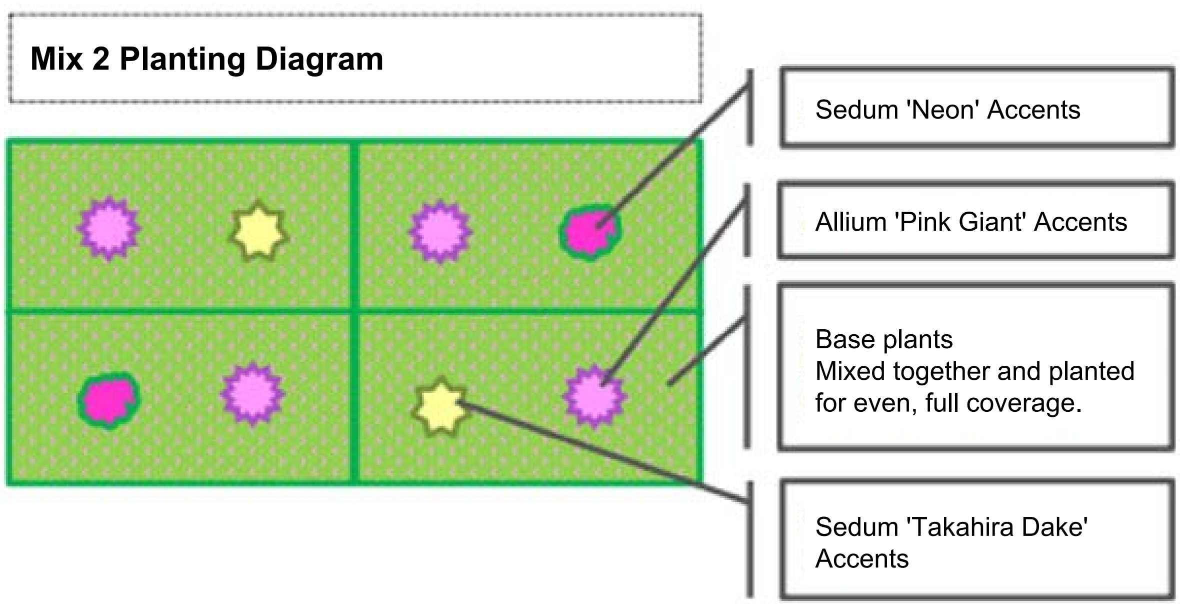
Plant Specification: Example, Mix 2

Base Plants (randomly mixed)

- *Sedum aizoon* 'Euphorbiodes'
- *Sedum hybridum* 'Immergrunchen'
- *Sedum spurium* 'Green Mantle'
- *Sedum spurium* 'Pink Jewel'
- *Sedum takesimense*

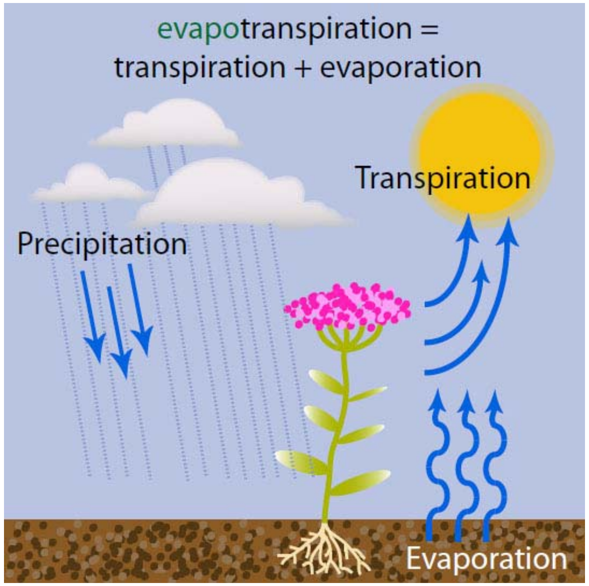
Accent Plants (planted as diagrammed)

- *Allium schoenoprasum* var. *sibiricum* 'Pink Giant' one per module, *alternate left and right sides with one of the following accents:*
- *Sedum kamtschaticum* 'Takahira Dake', ½ per module
- *Sedum spectabile* 'Neon', ½ per module



Irrigation

Effects of Supplemental Irrigation



While irrigation may only be needed during protracted hot, dry weather (to sustain the plants), there are other reasons to install an efficient means of irrigating a green roof.

Irrigating during hot, dry weather allows for the optimization of the green roof's cooling ability, saving money on air conditioning.

Water liberates 8000 BTU of energy during evapotranspiration, which is the combined release of energy (heat) from the evaporation of water from the soil, and the transpiration of water through plant roots and out the stomates (pores).

Pumping water is efficient and cheap, whereas running air conditioners is inefficient and expensive. The cooling effect derived by irrigating allows for the conservation of energy in comparison to the energy wasted on cooling by less efficient methods.

Effects of Supplemental Irrigation

According to some authorities and dependent upon the particular climate, during the cooling season, the temperature in the room below an irrigated green roof may be reduced 16 to 27ºF compared to a reduction of about 11–13ºF for a non-irrigated green roof. This difference is substantial and can mean considerable savings on air conditioning costs. Estimates of cost savings for air conditioning range from 25% to 50% for the floor under the green roof.

In rough figures, when an extensive irrigated green roof shows an average summertime temperature of 80ºF, the same roof without irrigation will average about 100ºF. Similarly, the membrane below the irrigated roof might fluctuate an average of only 7 or 8ºF during a 24-hour period, while the same green roof without irrigation may fluctuate ± 20 degrees. Less fluctuation may mean less wear and tear via micro-tearing on membranes, and therefore, potential extension of the lifetime of the waterproofing membranes.

Save Water, Irrigate

In his paper, “How Green Roofs Partition Water, Energy and Costs in Urban Energy-Air Conditioning Budgets,” Paul S. Mankiewicz, PhD, illustrated the hidden relationship of water and energy when he asked the question, “*Is it more cost-effective to utilize potable water for cooling than electrical air conditioning*?”

He found that the cost of electricity for a ton of air conditioning in New York costs $13.50, while the evaporation of 33 gallons of water produces an equivalent ton of air conditioning for only 26 cents.

Central to his comparison is the fact that virtually all electricity has substantial water cost for its production. Each ton of air conditioning requires 84 kilowatt-hours to produce.

In four major cities, this quantity of electricity takes between 24 and 89 gallons of water to generate. On the average, each gallon of water used to cool a structure will save 1.7 gallons of water used to produce the equivalent cooling using air conditioning.

Effects of Supplemental Irrigation

Judicious irrigation also keeps the green roof plants fat, full, and beautiful. This means better coverage, fewer weeds, less labor, and happier owners, occupants, and visitors.

It also means lower maintenance costs and safeguards one's investment in the green roof.

Finally, judicious irrigation should not significantly impact storm water management, as irrigation typically occurs only during low rain/low runoff periods when the roof will dry out quickly from evapotranspiration.

Overhead Spray Rotor vs Drip vs Sub-Irrigation

Overhead, matched-precipitation rotor systems are the best for irrigating green roofs, and they do a better job with less water than drip or sub-irrigation methods.

In 2013, Ecological Engineering published a study from MSU Plant Science Greenhouses by Dr. Bradley Rowe and others, comparing water efficiency and plant health of overhead spray rotor, drip, and sub-irrigation for green roofs. Substrates that were watered with overhead spray rotor irrigation retained more of the water dispersed with less waste than sub-irrigation and drip systems. This is because green roof substrates are designed with coarse textures for drainage, and therefore do not wick water upward or move it horizontally very well.

Additionally, measured plant health was greatest with overhead spray rotor irrigation and lowest with sub-irrigation systems.

Overhead irrigation systems (above) waste less water and grow healthier plants than drip and subsurface irrigation systems (below).

Understanding and Mitigating Wind Pressure

Wind Pressure

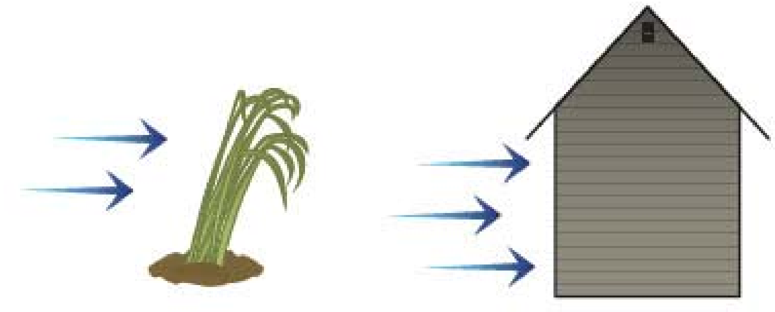
As with any roof, high winds can pose a threat to the security of green roofs, and care must be taken to properly design and engineer the green roof so that it retains its integrity during high winds.

To do this, consideration of wind pressure and associated variables such as the building's geographic location, surrounding terrain, shape, slope, height, building openings, parapet design, and other features is essential. At the tip of the iceberg of wind pressure, one must consider the typical high wind speeds for that region.

Consulting ASCE 7.95 Figure 6-1 "Basic Wind Speed" or "Factory Mutual Global Property Loss Prevention Data Sheet 1-28" is a good first step. In addition, the engineer must consider the surrounding terrain; for example, is the building situated along water, mountains, or open field, or surrounded by tall trees or taller buildings? Of course the building design itself is very important. Low-rise buildings (generally regarded as 75' and lower) are less affected than high-rise buildings (76' and taller), which in addition to direct (positive) wind pressure, are more greatly affected by negative wind pressure, often referred to as uplift or suction. Note that the National Fire Protection Association (NFPA) defines a high-rise building as a building more than 75 feet in height (roughly seven stories).

Positive Wind Pressure

Positive wind pressure is the force exerted by the wind as it strikes an object or building. For example, positive wind pressure is evident when a tree (or other object) moves or bends over in a strong wind.



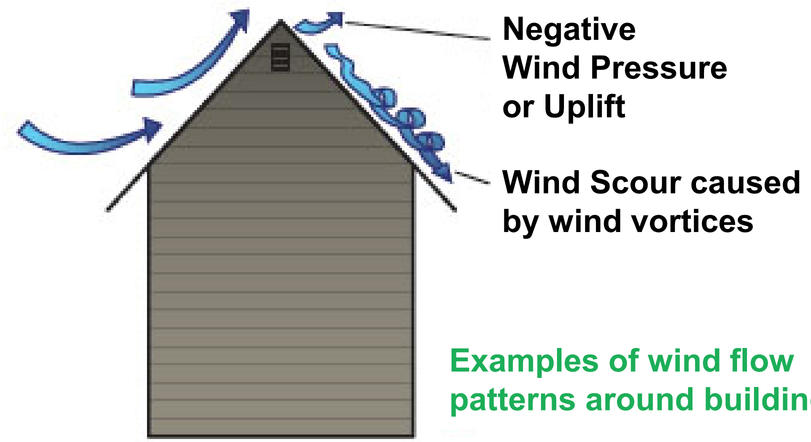
In 2008, a hybrid modular system, fully vegetated with a base mixture of flexible-stemmed hardy *Sedums*, was tested against wind speeds exceeding 110 MPH according to method ASTM D3161.

The 4' x 5' plot was surrounded with aluminum edging and first exposed to ten minutes of wind at 95 MPH, followed by one hour and 50 minutes at 110+ MPH. The wind was impinged directly upon the surface of the planting as would be the case when testing other roof coverings. Remarkably, at the end of the test period, there was no loss of growing medium and all plants remained well rooted and intact. Throughout the test, the plants simply arched over, held in place by their root systems. This test demonstrated the value of installing and maintaining a green roof with full, mature plant coverage as a means of stabilizing the green roof system against wind pressure.

Negative Wind Pressure (Uplift)

Negative wind pressure is what causes airplanes to fly, and it's what causes roofs to want to fly.

Negative wind pressure occurs when wind passes over an object that causes the wind to redirect and accelerate. This in turn creates a pressure differential that can be substantial.



Examples of wind flow patterns around buildings

In the case of roofs, wind accelerates as it passes over the roof edge or parapet, causing a pressure differential and lifting force, uplift, that is exerted upon the rooftop. Redirected winds of this nature tend to whirl and swirl, often in cone-shaped vortices which can aggressively scour roof surfaces and components. Such forces are typically greatest in the corners of the roof, secondarily along the parapet walls, and to a lesser degree in the "field" or center part of the roof. Uplift forces vary with the building shape and height, parapet shape and height, overall exposure, size of openings, etc.

How Much Uplift?

In 2010, the American National Standards Institute (ANSI) accepted RP-14, “Wind Design Standard for Vegetative Roofing Systems,” as an American National Standard. This document provides design and installation recommendations to mitigate the risk of wind uplift on green roofs in high areas.

In 2012, a team of code officials and engineers from the U.S. and Canada performed the first full-scale dynamic wind uplift test on a hybrid green roof system, producing empirical data on the system performance against uplift. Using specialized disc connectors, the modules remained connected across the green roof surface with an upper limit set at 200 PSF. As an example, the tested system is expected to be in full compliance with the code on any building in all areas (field, perimeter, corner) that is 90 feet tall in a 115-mph wind zone in Exposure B (e.g. Chicago or Las Vegas).

ASCE 7 serves as a reference, and a qualified engineer should evaluate the actual uplift on each project, as unique building features and surroundings may influence wind pressure.

How Much Uplift?

This testing has demonstrated that green roof uplift resistance can be measured. The uplift resistance is a result of pressure equalization between the top and bottom of the green roof system: the more equalization, the less chance of uplift, even at very high uplift pressures. Equalization is variable-based on specific system attributes, and the findings would only apply to the system tested and could not be universally accepted as a standard for other types of green roofs.

In 2013, under the leadership of the Canadian Roofing Contractors Association, a consortium of green roof manufacturers retained the services of the Building Envelope Laboratory at the National Research Council of Canada to develop a dynamic wind uplift testing standard for green roof systems. The draft testing standard was submitted to the Canadian Standards Association for review and public comment period in March 2014.

Mitigation Through Parapet Design

Low-rise buildings in areas of moderate exposure may present fewer challenges in regard to positive or negative wind forces.

Taller buildings may cause one to have to be more creative. Design strategies that moderate wind uplift forces and disrupt the formation of surface-scouring wind vortices may be employed in the overall green roof design.

On low-rise buildings, a lower parapet design may avoid potential air turbulence and help to minimize uplift forces. For buildings containing only a single parapet, as is commonly used as a facade for aesthetic purpose, one should keep in mind that the parapet may dramatically increase the uplift pressures in the corner regions.

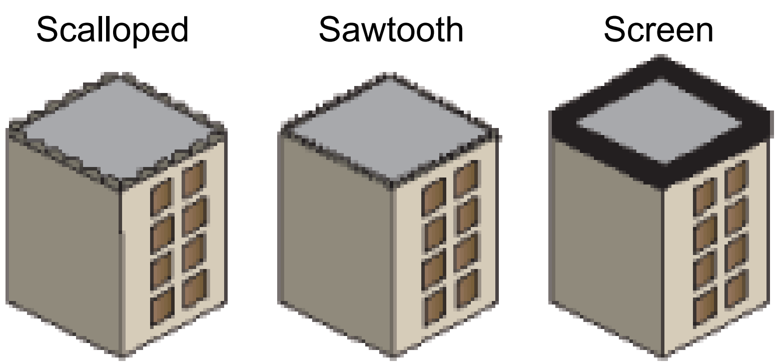
Conversely, on high-rise buildings (over 76'), higher parapet height can be an effective tool in moderating uplift forces. Studies on parapet height typically indicate that parapets over 3' tall can moderate uplift pressure in the corners of the roof on high-rise buildings.

Mitigation Through Parapet Design

Likewise, the use of a partial parapet with attached porous screen may be used to reduce uplift pressures and expand design options for taller buildings.

Parapets of different shapes, e.g., saw-tooth configuration, rounded vs. sharp edges, or the application of spoilers are sometimes used.

Keep in mind that the taller the parapet, the more positive wind pressure against the parapet itself, both windward and leeward sides.

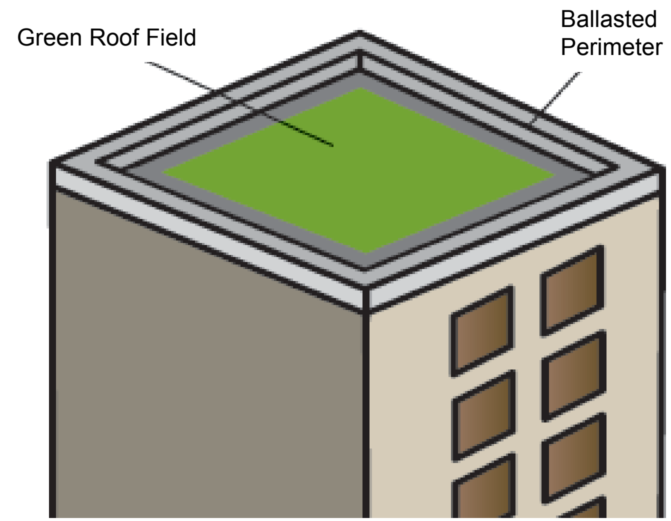


Special parapet designs to reduce uplift

Wind-Challenged Applications

In very challenging applications, an engineer may have to direct the architect to:

- forego using the shallow, lightweight extensive green roof systems in favor of deeper substrates.
- limit the green roof to the center field of the rooftop and use heavier ballast in the corners and along the parapet edges. Such ballasted perimeter design is referred to as a vegetation-free zone. Vegetation-free zones will vary with the parapet height and geometry.
- use tested and proven connector systems to join modules in most uplift prone areas.



Tall Buildings: How High Is Too High?

Tall buildings present three substantial challenges for green roofs.

The first is wind uplift, as previously discussed.

The second issue for tall buildings is wind scour, which refers to the physical displacement of soil and/or plants due to the force of the wind. The best defense against wind scour is full vegetation.

It is also important to remediate any bare patches that might arise in the future. Bare patches may be caused by weed encroachment, nesting, birds, or physical damage.

After a year of growing a plug-planted system (left) next to a pre-vegetated hybrid green roof system (right), the comparison demonstrated that wind scour is minimized and plant health is optimized by fully mature vegetation at the time of installation.

Tall Buildings: How High Is Too High?

The third challenge involves the plants and their ability to resist the wind and cold at high building elevations.

Consequently, the answer to the question, “How high up can green roof plants survive?” is not well understood, at least not at this time.

Very tall buildings, for example over 20 stories tall, are subject to virtually constant wind. With appropriate plant selection, this in itself is not a problem, as most green roof plants hail from alpine environments where there is also a lot of wind.

The problem seems to be an issue of dehydration and wind chill, particularly in areas of persistently cold winter temperatures. In such cases, the soil will be frozen for prolonged periods of time, and therefore, the plants cannot extract water from the soil to replace the moisture lost from wind desiccation. If this occurs for too long, the plants essentially become freeze-dried and their tissue dies.

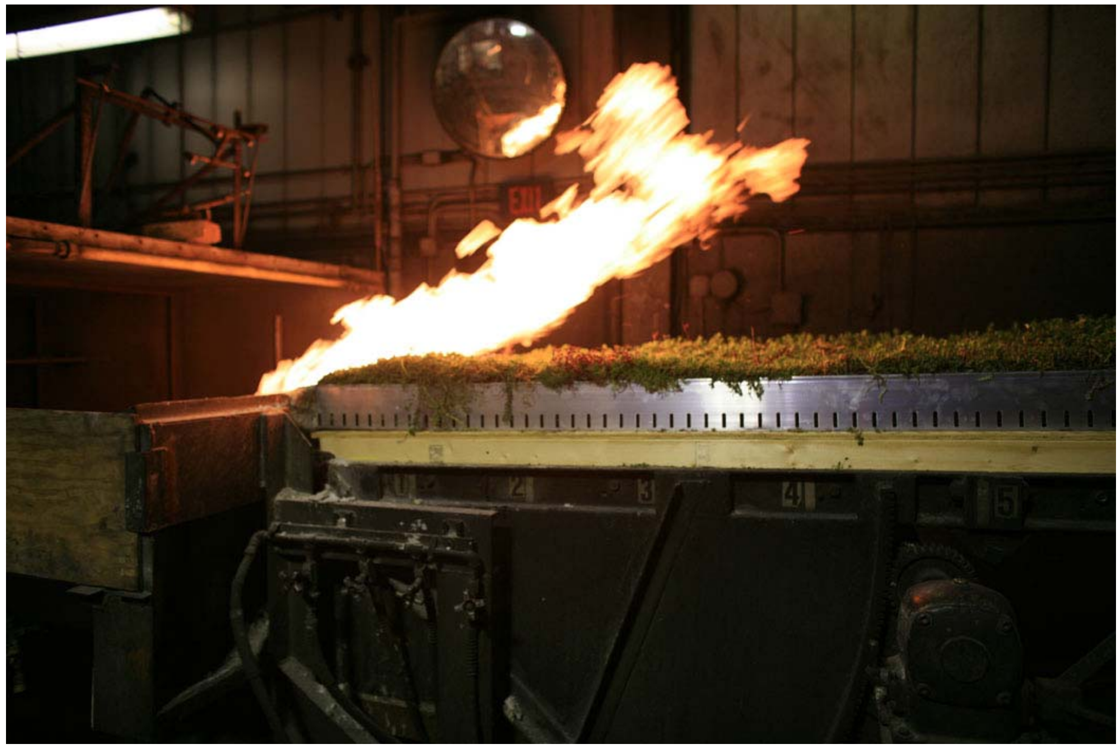
Common Sense Considerations

Currently, the level of experience and bona fide research with this problem is not sufficient to be able to quantify the effect in such manner that makes it simple to properly plan and design for tall building applications. No one can say, "*On the 35th floor in New York City, you can effectively grow these five species of plants.*" Therefore, at present, we must rely upon anecdotal experiences and upon common sense.

- <u>The issue will likely be more significant in colder climates than mild or hot climates</u>.

- <u>Deciduous plants</u>: Plants that drop their leaves are likely better equipped to resist the rigors of constant winter chilling winds. This is because they present less surface area for chilling.

- <u>Irrigation helps</u>: In areas where the winters tend to be dry, providing the plants periodic irrigation can help them to resist dehydration during cold spells.



Understanding and Mitigating Fire Risk

Fire/Spread of Flame

FLL (Forschungsgesellschaft Landschaftsbau Landschaftsentwicklung, English translation: The Landscaping and Landscape Development and Research Society) refers to the German granulometric standards, a professional association that researches various topics concerning green roof design.

Green roof systems planted with succulents and in FLL-compliant growing media are naturally fire-resistant.

The reason for this is two-fold: succulents actually hold significant amounts of water within their foliage; plus, FLL-compliant growing media has high percentages of inorganic content that is relatively inert, such as expanded shale, pumice, or even recycled brick waste.

FLL-compliant growing media helps to mitigate fire risks.

Fire/Spread of Flame

The ANSI/SPRI VF-1, “External Fire Design Standard for Vegetated Roofs,” will be included in the 2015 International Building Code. This document provides design and installation recommendations to help eliminate the risk of fire on green roofs.

As part of FM Approvals Standard 4477, manufacturers may now test their green roof systems according to ASTM E108, “Standard Test Methods for Fire Tests of Roof Coverings,” and be granted a fire resistance classification.

In September 2009, the FM Approvals lab successfully tested a non-compartmentalized hybrid green roof system planted with succulents according to this standard and granted it a Class A Fire Rating.

Sedums and other succulent plants are naturally flame-resistant as they store water inside their foliage.

Sloped Applications

Downward Force Against Parapet

The combination of a green roof (unaffixed object), slope, and gravity implies the need to address physical containment and resistance to downward pressures exerted by the green roof against the parapet and mechanical fixtures of the roof, especially in cold climate areas where ice crystals may form on the slip sheet/root barrier surface during winter.

Therefore, the slope and size of the roof should be assessed in regard to force that will be exerted against the parapet or other mechanical features of the roof.

For long roofs, and roofs with great slope, it may be appropriate to incorporate “stops” or buttresses in the design to prevent all of the load from being exerted against the parapet on the low side of the roof.

In all cases, it is important to realize that the low side parapet must be built in such manner as to have the structural integrity to resist whatever forces exist, given the design of the particular roof.

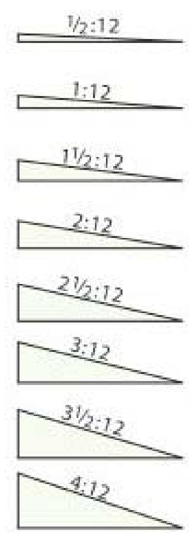
End Force Loading Tables

This table assumes zero friction and presents a conservative model based upon the assumption of ice between the membrane and green roof system during the winter months.

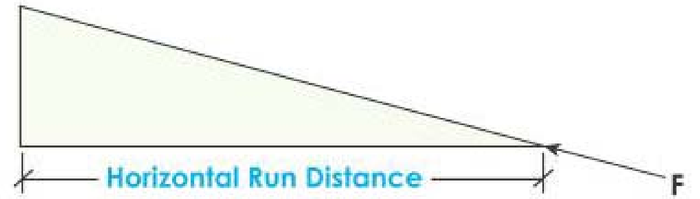
Obviously, this may not be appropriate for frost-free zones, but one must realize that certain roofing membranes are coated in talc, or other lubricants, to prevent sticking. Other membranes may be slippery when wet. Therefore, even in frost-free zones, one should assume a degree of downward force on sloping applications.

Force Against Roof Edge for 30 PSF
Plus 30 PSF Snow Load Expressed in Pounds per Lineal Foot.

Coefficient of friction (μ) assumed to equal zero



Roof Slope			Force Against Roof Edge, F (plf) Horizontal Run Distance (ft)				
			10	20	30	40	50
½:12	4.20%	2.4°	26	50	76	100	126
1:12	8.30%	4.8°	50	100	152	202	252
1½:12	12.50%	7.1°	74	150	224	298	374
2:12	16.70%	9.5°	100	200	302	402	502
2½:12	21.00%	11.8°	126	250	376	502	628
3:12	25.00%	14.0°	150	300	448	598	748
3½:12	29.20%	16.3°	176	350	526	702	878
4:12	33.30%	18.4°	200	400	598	798	998



How Much Slope Is Too Much?

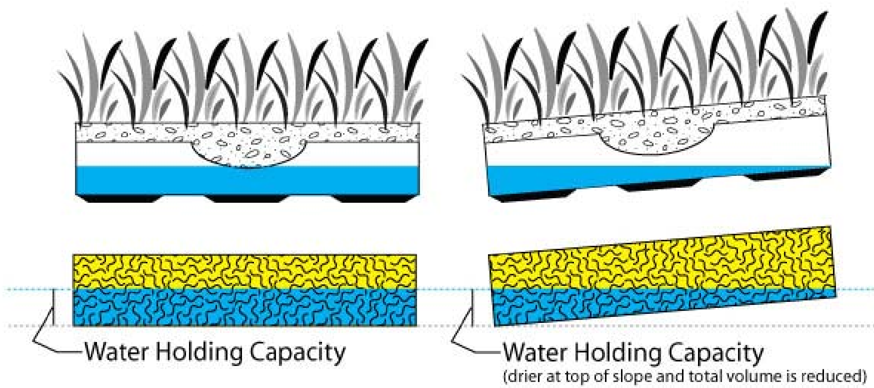
Both of the main international green roof organizations, the German FLL and North America's Green Roofs for Healthy Cities, caution against green roofs with slope of greater than 40 degrees (10:12 pitch). This stems from challenges with both containment and the extreme difficulty in managing soil moisture on a roof of such pitch.

How Much Slope Is Too Much?

You may be familiar with the properties of a wet sponge that will hold so much water when lying on its side, but after you prop it up on its end, even more water runs out.

Soil acts the same way, and as the pitch of the roof increases, there is a greater tendency for the water to want to run out of the system.

Green roofs above 9-½ degrees (2:12 pitch) are commonly dry at the top and moist at the bottom. And while the segmental or baffled characteristic of some non-compartmentalized hybrid green roof systems may help to mitigate this phenomenon, pitched roofs will certainly require more irrigation than low-sloped green roofs.



How Much Slope Is Too Little?

While the question, “How much slope is too little?” is seldom asked, it is important to design for adequate drainage.

Most authorities state that a roof needs 1/4:12 slope to provide sufficient drainage. Without this, water may accumulate and damage the health of the green roof plants.

Even “flat” roofs need minor slope underneath the green roofs to prevent standing water.

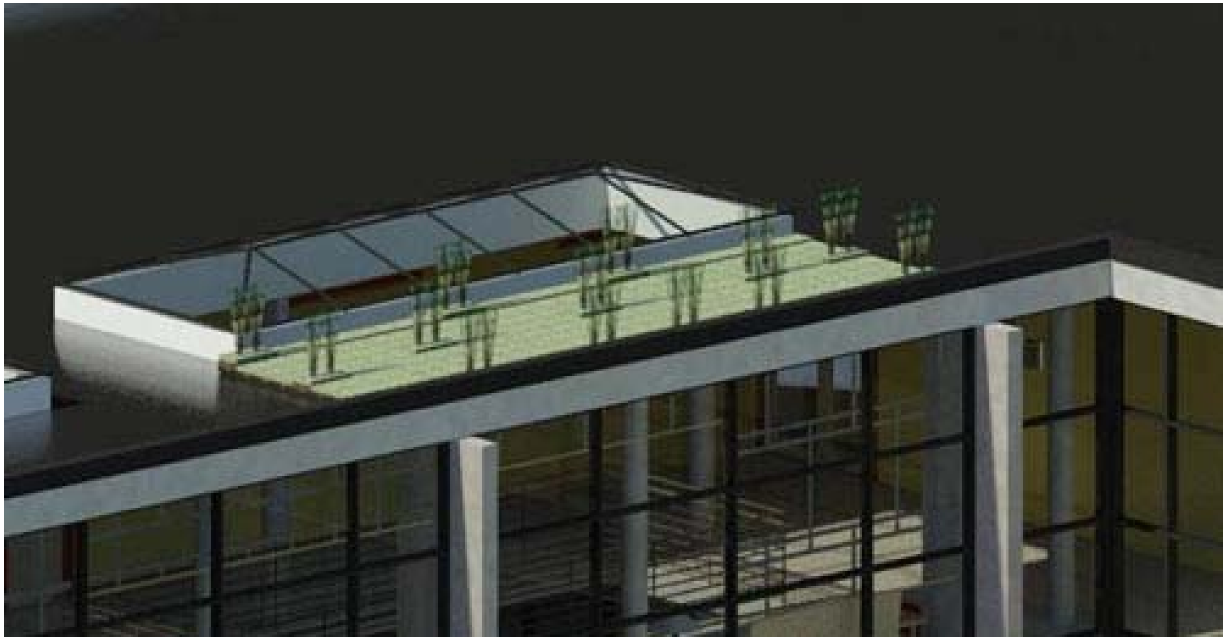
Level or Gently-Rolling?

Most non-compartmentalized hybrid green roof installations simply follow the contour of the roof for an aesthetically pleasing, gently-rolling, meadow-like appearance.

A dead-level green roof system can be realized by applying a tapered closed-cell foam to the roof above the waterproofing layer.

If this is done, be sure to specify that the closed-cell foam allow for adequate water drainage.

Slightly undulating green roofs have a natural, meadow-like look.



Additional Design Considerations

Additional Design Considerations: Introduction

This presentation concludes with a discussion on additional design considerations, including:

- retrofit roof applications
- warranty options, and
- a designer's checklist.

Retrofitted Roofs

Retrofit projects are exciting as they represent a tremendous upgrade to aesthetics and environmental quality. Of course, they bring their own particular challenges that need to be addressed from an architectural and engineering standpoint. Listed below are some of the main considerations for retrofit green roofs.

- Determination of the construction, condition, and load capacity of the pre-existing roof and suitability to accept a green roof.
- Determination of the condition of the remaining roof warranty lifetime, and terms or warranty of the existing membrane as it pertains to being retrofitted with the new green roof system.
- Compatibility of the existing roof system with the proposed slip sheet.
- All the same issues regarding positive and negative wind pressure, slope, and forces against the parapet as they relate to new construction also apply to retrofit roofs.

Roof Warranty Options

When it comes to physical and chemical compatibility, with limited exception, just about any green roof system currently on the market is compatible with almost any membrane type on the market.

As the green roof market has grown, so have the numbers of membrane manufacturers who own and sell their own green roofing systems.

Some membrane manufacturers have sought to limit the design options of specifiers, owners, and contractors to the products they sell. Most frequently, they do this through strategic warranty offerings. The most common are different types of overburden removal and single-source warranties.

Roof Warranty Options: Overburden Coverage

Overburden coverage is a warranty to remove and replace whatever is sitting on top of a rooftop membrane in the event of a leak. Overburden can consist of pavers, gravel, or the green roof system.

The question of "Do I need it?" is an interesting one, with people advocating both perspectives and with the answer being as much philosophical as logical—not unlike an extended warranty for an appliance or car, some people advocate them and others abhor them. Here are two ways of looking at it:

- If the membrane is tested for watertightness prior to green roof installation via flood testing, then the chance of a roof leak is greatly minimized. This is because the green roof shelters the waterproofing system from common causes of roof leaks, i.e., dropped sharp objects, environmental damage, and hail. So, once the green roof is in place above a watertight membrane, the need for overburden coverage is minimized and overburden coverage may be an unneeded cost.

- If there is a leak, then it would be nice to not have to worry about the cost of overburden removal and replacement. For those who advocate this perspective, ask your green roof system supplier about available options.

Roof Warranty Options: Single-Source Warranties

Presented below are the pros and cons of single-source warranties.

Pros

- The owner has a single point of contact to call if there are any issues with the green roof system (including plants, drainage, membrane).
- A single company is responsible for response.

Cons

- Green roof system and design options are typically limited to the products sold by membrane manufacturers.
- Independent green roof products would be excluded at bidding.
- Membrane manufacturers often have limited horticultural experience or staff and may provide limited support should plant concerns arise.
- In the event of a leak, warranty exclusions may place the responsibility on the owner for repair anyway.

Designer’s Checklist

To facilitate a successful installation and avoid common mistakes, it is important to be proactive and specific when designing and specifying a hybrid green roof system.

Following are considerations as part of a green roof designer’s checklist, a valuable resource that identifies problem areas and provides helpful specification considerations.

For a print-friendly version, please refer to the link on the References and Resources slide at the end of this presentation.

Avoid placing plants within roof lines that overhang the plant area.

Avoid placing plants within the airstream of roof vents.

Designer's Checklist

System Specifications and Drawings

- Check if supplier offers a web-based specification program to help you create custom specifications for your projects.
- Choose sole specification option to protect design integrity.
- Use performance specification for public jobs if they will not allow sole specification.
- Be sure to overlay the green roof design over other rooftop design elements (such as lighting, electrical conduits, drains, mechanicals, etc.) to ensure compatibility.

Plant Material Specifications and Drawings

- Plant material is integral to the functional, visual, and maintenance characteristics of the hybrid green roof system. Choose wisely and consult with your local grower for advice on pairing the plants with the particular rooftop environment. Ask your local grower to assist with and to review your plant list so as to make the best choices based upon such variables as: colors and patterns, sun and shade exposure, reflected light, strong winds or dead air, building height, climate, soil depth, irrigation, desired winter colors, etc.

Designer's Checklist

Plant Material Specifications and Drawings, cont'd

- Call out the plant selections, regardless of the system (extensive, intensive), specify the particular base plant material and accent plants. Craft the plant selections in regard to light exposure and account for the specific exposures if there are multiple roofs. If there are accent plants in the mix, specify the density and position of the plants with a visual diagram so that bidders know what is required and growers know what to grow.

Irrigation

- Ensure sufficient water volume and pressure are available on the rooftop.
- If no irrigation, be sure to provide sufficient spigots so that a 50' hose can easily be manipulated to reach the various areas of the green roof.
- If a built-in irrigation system is part of the design (a good idea for many installations), specify placement and type of system.

Designer's Checklist

Bidding Contractors

- Check if a local green roof grower can provide referrals for trained and experienced installers.
- Require contractors to adhere to design and specifications. Disallow substitutions.

System Protection and Worker Safety

- Specify and follow all safety, code, wind uplift, structural loading, and other important considerations. Be sure to have these items developed or reviewed by a structural engineer if needed.

Watertightness

- If overburden removal warranty is required, verify that the membrane manufacturer provides this, or specify that overburden warranty is to be sourced from the green roof system supplier at nominal cost.
- Call out electronic leak detection or flood testing to ensure watertight membrane prior to placement of green roof.

Designer's Checklist

Avoid Plant Material in the Following Locations:

- Within the airstream of roof air intake units or vents.
- Underneath roof lines unless there is built-in irrigation.
- Within 2' of south facing walls, unless irrigated, as reflected light will cause excessive loss of soil moisture.
- Underneath downspouts and drip lines.
- In shady areas, those that get less than three hours of direct sunlight per day (too shady for *Sedums*). Such locations require a 6"+ deep system and shade-tolerant perennials, such as *Hosta*, *Epimedium*, etc.
- Locations with constricted air movement.
- Areas where there is reflected light from white membrane, glass, and skylights, unless there is a built-in irrigation system and access to water at least once per week.
- Areas where there is excessive heat below the roof deck, such as from steam or hot water pipes. Use pavers or stone ballast in such areas.
- Any area where water pools on the roof.

Designer’s Checklist

Avoid Plant Material in the Following Locations, cont’d:

- Within 10' of the leeward side of wind screens, unless they extend to the ground. If there is a gap, the wind will blow under it, accelerate, and dry out the plants.
- Under landscape lighting that is close enough to plant material to throw heat onto the plant material.

Design for Longevity

- Cover up all membrane so that it is protected from sunlight and will wear at a similar pace. It is suggested that flashing cover the membrane on the parapet and extend to 2" or 3" above the roof deck. Similarly, membrane around drains should be covered with a drain box or 2" to 4" of round river rock to shelter it from sun.
- Slip sheet should extend from underneath the green roof to drain box areas for full membrane protection.

Designer’s Checklist

Edging

- Make it clear on the drawings where edging needs to be used (e.g., around drains, mechanical units, conventional paver/pedestals, etc.). If the plant material runs from parapet to parapet, then edging is not required along parapet.

Traffic Areas

- Pavers are recommended for pathways and patios following the contour of the roof.
- Provide for a landing area of pavers so that visitors and maintenance workers may avoid trampling plants. A 10' x 10' area is suggested immediately bordering the roof access point.
- If the roof serves as a means of egress during the winter months, specify that no de-icing chemical or salt be used. Instead, specify that cat litter or sand be used for traction. Alternatively, an appropriate heat cable may be installed under the paver.

Designer's Checklist

Pavers

- If pavers with an integrated plastic base are used, they require no pedestals or edging between paver and plant materials; however, if they are used in a perimeter application, specify integrated pavers to be surrounded with edging to shield their bases from sunlight.

Installation

- Require installation contractor to flood test roof and verify it is watertight prior to green roof installation.
- Require adherence to manufacturer's/supplier's installation protocol.
- Require installation contractor and general contractor to prevent foot traffic, trampling, and equipment storage upon plants.
- Require that irrigation protocol (how often/how much) be approved by local green roof grower.

Designer's Checklist

Maintenance

- Specify who will maintain the green roof system immediately after installation.
- Require adherence to specified maintenance protocol beginning at the time of installation. If one year of maintenance is required as part of the installation package, state so definitively.
- Provide sufficient tie off anchors for future maintenance if roof design or OSHA/CanOSH policy requires such safety measures for maintenance workers.
- Provide for easy access by maintenance workers. Remember, maintenance personnel will at times need to access the roof with equipment, fertilizer, hoses, possibly even a lawn mower.

★ Please remember the **exam password HYBRID**. You will be required to enter it in order to proceed with the online examination.

References and Resources

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Conclusion

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