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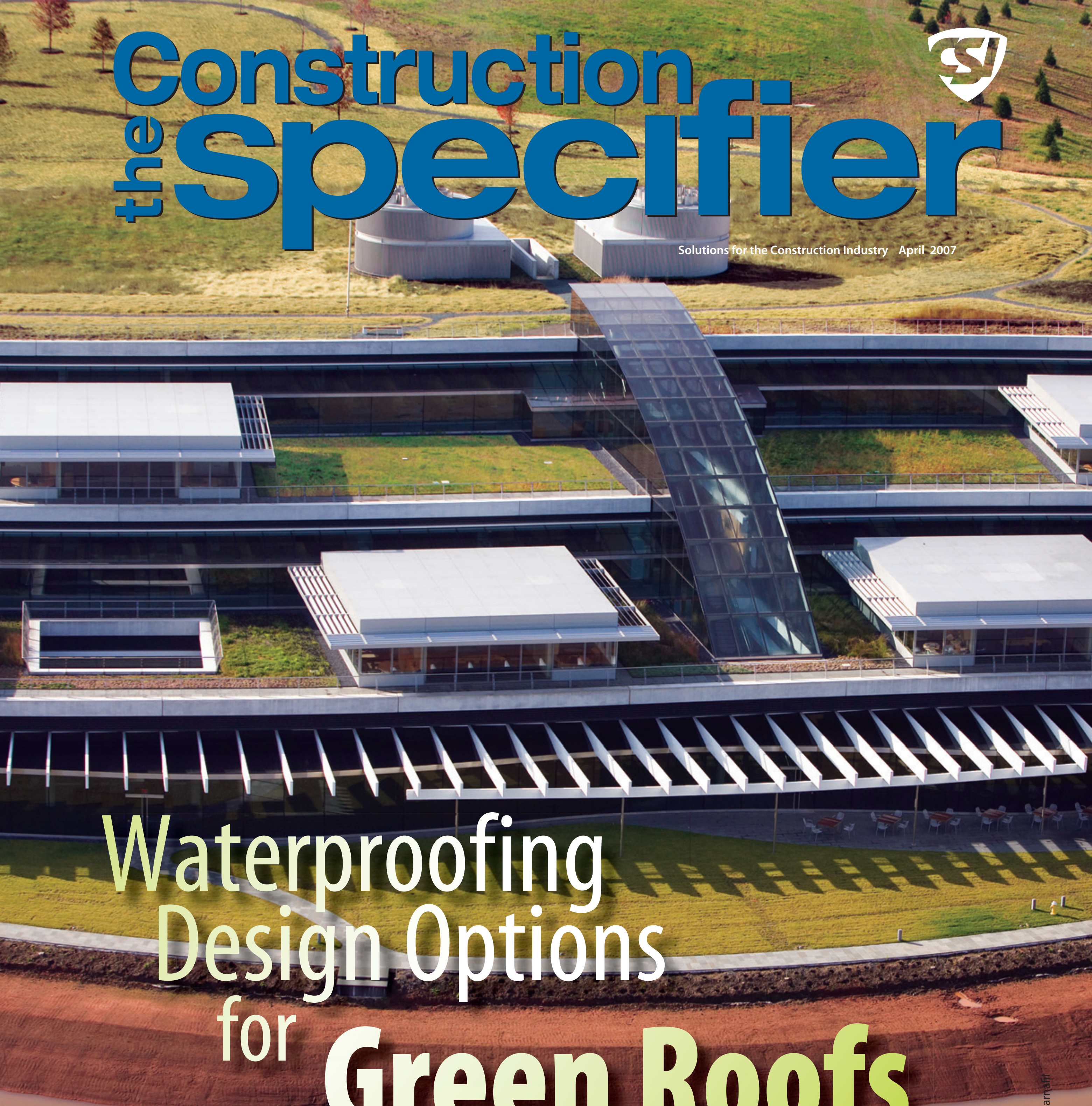

Waterproofing Design Options for Green Roofs

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by Gary W. Whittemore, CDT

With the increased desire for high-performance buildings and sustainable products, green roofs have become a 'growing' option in North America. Also known as eco-, garden, or vegetated roofing, these assemblies are simply a planted area on a flat or sloped roof. While conventional rooftop gardens usually consist of a few pots and planters, a green roof system can cover the whole roof area with the cultivation of plant life.

In Europe, extensive research and testing on how to waterproof green roofs started in the early 1970s. This work resulted in today's waterproofing solutions, allowing durable and sustainable green roofs to increase in popularity. Although each green roof is unique and designed to meet multiple design and performance criteria, they all contain the same basic components. The challenge for specifiers and designers is to determine which components are necessary and where they should be located within the green roof assembly.

Figure 1 Green Roofs for Healthy Cities Survey Results

Green Roof Type	North America 2005	North America 2004	United States 2005	United States 2004
Extensive	165,809 m^2* (1,784,755 sf)	85,171 m^2** (916,776 sf)	145,891 m^2 (1,570,352 sf)	72,190 m^2 (777,052 sf)
Intensive	45,347 m^2 (488,109 sf)	37,697 m^2 (405,762 sf)	44,254 m^2 (476,359 sf)	37,697 m^2 (405,762 sf)
Mixed/ Semi-Intensive	18,459 m^2 (198,686 sf)	458 m^2 (4,924 sf)	9,557 m^2 (102,874 sf)	365 m^2 (3,924 sf)
Total	**229,615 m^2 (2,471,550 sf)**	**123,325 m^2 (1,327,462 sf)**	**199,703 m^2 (2,149,585 sf)**	**110,252 m^2 (1,186,738 sf)**

*Includes seven projects with no assigned category of green roof type.
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A budding green roof market

In early 2006, Green Roofs for Healthy Cities (GRHC) embarked on the first industry-wide survey to develop data on the size, composition, and geographic distribution of the green roof industry in North America.[1] A partial summary of the findings is found in Figure 1.

The survey indicates that in 2005, nearly 230,000 m^2 (2.5 million sf) of green roofs were planted in North America. This is an increase of 86 percent compared to 2004. Approximately 87 percent of the green roofs planted in North America in 2005 were located in the United States, with Chicago, Washington, D.C., and New York City leading the way.

These numbers are said to be understated, as several GRHC corporate members were unable to collect and report the data at the time of the survey. However, members believe such dramatic growth is sustainable as policies are implemented across North America to encourage green roof construction. GRHC is in the process of collecting data for the 2006 market and expects to release this information in 2007.

It is the 'look' that counts

The first consideration that needs to be addressed when designing a green roof is the client's aesthetic requirements. The following are several factors affecting the final plant selection.[2]

Client-dependent factors

1. Capital and maintenance budgets in regard to the cost of plants, which includes shipping, installation method, species, and care. Mats, trays, and plugs provide immediate results, but are more expensive than cuttings and seeds.
2. Aesthetic desires, meaning the vegetation's color, style, and seasonality.
3. Functionality, which refers to the intent of the green roof to reduce stormwater, noise, or energy consumption. Additionally, design professionals must consider whether the area is accessible to pedestrians.

Climate- and weather-related factors

1. Macroclimatic zones—maps of low- and high-temperature hardiness zones based on 25- to 30-year averages are available from the U.S. National Arboretum (USNA).[3]
2. Microclimatic zones—climates outside the normal zone affected by mountains, valleys, seacoasts, urban centers, structures, and surrounding buildings. Additionally, the amount and direction of sunlight, seasonal temperature, rainfall, wind, humidity, and soil type create unique rooftop microenvironments.

Structure-dependent factors

1. Composition and depth of growing medium.
2. Roof slope.
3. Transmission of heat through steel, wood, HVAC vents, etc.
4. Areas of shade, partial shade, full sun, wind flow, building height, parapet walls.

Plant-dependent factors

1. Growth rate.
2. Sensitivity to airborne pollutants.
3. Ability to withstand wind.
4. Sensitivity to light.
5. Tolerance to drought.
6. Fire resistance.

Supply and scheduling

1. Availability of required plants.
2. Planting methods.
3. Timing of installation.

Figure 2 Plant Type and Minimum Growing Medium Depth

Plant type	Minimum growing medium depth	Green roof type
Sedums	25 mm to +75 mm (1 in. to +3 in.)	Extensive
Groundcovers and grasses	150 mm to +250 mm (6 in. to +10 in.)	Extensive/intensive
Shrubs	450 mm to +600 mm (18 in. to +24 in.)	Intensive
Large shrubs and small trees	600 mm to +900 mm (24 in. to +36 in.)	Intensive
Trees	+900 mm (+36 in.)	Intensive

Plants determine the growing medium depth

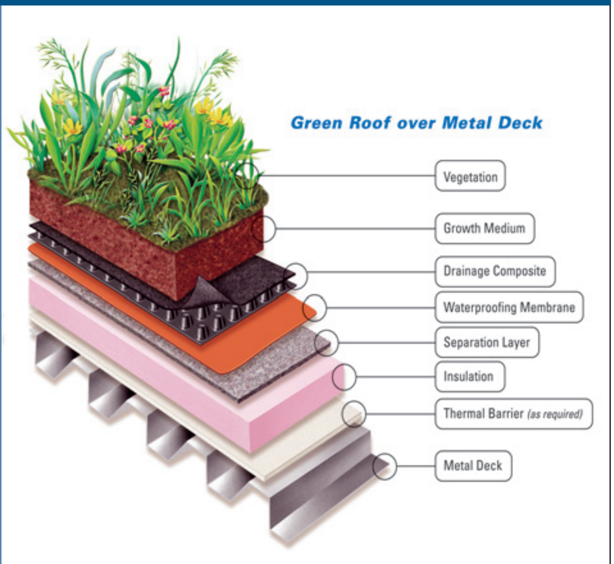
Once the plant selection is established, the green roof design process can begin. The growing medium depth necessary to sustain plant growth depends on the species and maintenance practices. Figure 2 is a rule-of-thumb guideline for general species and green roof type.[4]

The terms 'extensive' and 'intensive' green roofs were adopted from the German FFL *Green Roof Guidelines*. While there can be some variations in definition, the main distinction between the two types is the depth of the growing medium and the maintenance required to sustain the system.

Extensive green roof systems

Extensive green roofs use a narrower range of species limited to herbs, grasses, mosses, and drought-tolerant succulents such as sedum, a plant known for its tolerance for extreme conditions. These types of plants can potentially be sustained without automatic irrigation in a growing medium layer as shallow as 25.4 mm (1 in.). Therefore, they can often be installed on buildings without the cost of major structural alterations.[5] The fully saturated weight of an extensive green roof system can range from 58.8 to 171.5 kg/m^2 (12 to 35 lb/sf).[6]

Figure 3



Extensive green roofs are generally inaccessible to the public and have lower input requirements for resources. They require less maintenance and are usually less expensive to install. Annual maintenance consists of a general inspection, removal of weeds and unwanted vegetation, and a nutrient check of the growing medium. If a grass-based system is used, it requires more frequent mowing and nutrient inspection.

Intensive green roof systems

Intensive green roofs use a wide variety of plant species that may also include trees and shrubs. Using large plants requires deeper growing medium layers, usually 152 mm (6 in.) or more, which results in additional weight and a need for an increased structural load capacity of the building. The fully saturated weight of an intensive green roof system ranges from 245 to 1470 kg/m^2 (50 to 300 lb/sf).[7] Intensive green roofs are often accessible to the general public and can create a park-like atmosphere. Higher input requirements for water, labor, and other resources are standard and regular care and upkeep is required, similar to that of an ornamental garden.[8]

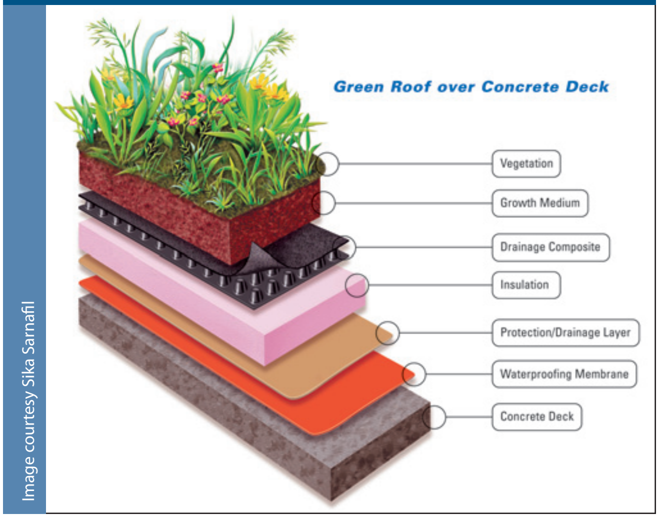
Typical maintenance for this type of green roof includes:

- weeding and removal of unwanted vegetation;
- cutting and trimming;
- preventative measures to protect plants from pests and diseases;
- fertilization; and
- watering.

Structural substrate influences the design of the roof

The weight of a green roof assembly influences the selection of a structural substrate, the most common of which are metal decks and structural concrete decks. The substrate selection directly impacts the green roof assembly.

Figure 4



Metal deck and conventional green roof designs

Figure 3 illustrates a typical green roof assembly over a metal deck. The most frequently chosen design approach over a metal deck is to build a 'conventional' roof assembly. Typical components starting at the deck are:

- metal deck;
- thermal barrier (if required by code);
- rigid insulation;
- waterproofing membrane;
- drainage composite;
- growing medium; and
- vegetation.

The thermal barrier is rigid, fire-tested hardboard mechanically attached to the metal deck. It is moisture-resistant and available in 6-mm (0.25-in.), 13-mm (0.50-in.), and 16-mm (0.625-in.) thicknesses.

The rigid insulation material is typically extruded polystyrene (XPS), which is resistant to moisture absorption and has been used in green roof applications for decades. It is available in 280 kPa (40 psi), 420 kPa, (60 psi), and 700 kPa (100 psi) compressive strengths so it will not crush during construction or under load after placement. Local building codes usually require the installation of a thermal barrier over the metal deck prior to installing the XPS insulation board.

Rigid polyisocyanurate (polyiso) foam insulation is sometimes used in conventional green roof applications. One benefit of using this material is that it does not require a thermal barrier. However, since polyiso foam is typically manufactured with a 140 to 175-kPa (20 to 25-psi) compressive strength, a rigid hardboard should be installed over the insulation to protect it from damage during the vegetated cover installation. Like XPS, polyiso is mechanically attached to the metal deck and the hardboard is glued to the isocyanurate with a cold-applied adhesive. Adhering the hardboard to the insulation is the preferred method since it eliminates fastener heads and plates under the waterproofing membrane.

The waterproofing membrane is installed over the insulation. It is usually loose-laid, but can be mechanically fastened or adhered if required. Some waterproofing membrane manufacturers require a separation layer (*e.g.* felt) between the insulation and membrane.

The most common type of waterproofing membrane in the conventional green roof design is a thermoplastic sheet, which is typically formulated from polyvinyl chloride (PVC). PVC sheets have a long track record in green roof applications in Europe and the United States. Both the Swiss and German governments closely regulate waterproofing membranes used in green roof construction.

The Swiss Society of Engineers and Architects (SIA) 280 standard for concealed roofing (*i.e.* waterproofing membranes) and German FLL are regarded as the most stringent and meaningful green roof membrane test protocols.[9] This author recommends that designers specify waterproofing membranes that meet both protocols to ensure product suitability. SIA- and FLL-certified membranes can provide an impermeable barrier against aggressive root growth and ponded water. The laps and flashings are hot-air welded, providing permanent seaming.

Other sheet waterproofing membrane options include thermoplastic polyolefin (TPO) and ethylene-propylene-diene-monomer (EPDM).[10] TPO is a newcomer to green roof applications, but since this material is thermoplastic, it offers the security of hot-air welded seams. EPDM has been used for years in waterproofing applications, such as plaza decks. These sheets are available in various thicknesses depending on the depth of the green roof and the length of the manufacturer's warranty. Additionally, they may require root barriers to protect waterproofing membrane from root growth.

Built-up (BUR) and modified bitumen (mod-bit) roofing systems are used less frequently in green roof applications because of concerns among specifiers of the long-term performance of bitumen in such harsh, buried, living environments. With these systems, the drainage composite is placed over the waterproofing membrane. (There are several types of drainage composites available.) Drainage structures vary from entangled filaments to thermoformed dimpled cups to geonets. Some drainage composites also serve as the protection layer for the waterproofing membrane. A separate protection layer can be specified over the waterproofing membrane and under the drainage composite for added protection and security, especially on projects anticipating significant construction traffic.

Benefits of conventional roof designs

Conventional roof designs are most common in extensive green roof systems. Since these systems are relatively lightweight, steel decking is typically used as the substrate. Although conventional roof designs are common for exposed and ballasted systems, the following additional benefits can be realized when using green roofs.

1. Insulation is protected and dry. Since the insulation is under the membrane, it is not subjected to rain, moisture, plant roots, microorganisms, and the like found within the vegetated cover.
2. Insulation does not interfere with water retention systems. Some green roofs are designed to retain water at the membrane level to sustain the vegetated cover. If insulation is introduced above this barrier, it will interfere with the water retention system. Additionally, ponding ridges—when incorporated into the system—can be easily secured directly to the waterproofing membrane.
3. Insulation remains in place. If the insulation is placed above the waterproofing membrane, it may become buoyant and float during severe rain events, likely displacing the vegetated cover above.
4. Tapered insulation is an option. The designer has the flexibility to incorporate tapered insulation into the design since it is under the waterproofing membrane and creates slope to facilitate drainage.

Concrete deck and protected membrane design

Due to the heavy loads associated with intensive green roofs, the most common substrate is structural concrete with a 'protected membrane' roof assembly. Figure 4 illustrates a typical green roof assembly over a concrete deck. Starting at the deck, standard components are:

- structural concrete deck;
- leveling layer (if required by membrane manufacturer);
- waterproofing membrane;

Installation of waterproofing membrane and flashings in a 'conventional' green roof assembly.

- protection/drainage layer (optional);
- XPS insulation;
- drainage composite;
- growing medium; and
- vegetation.

With this design, the waterproofing membrane is installed over the concrete deck and insulation is placed above this barrier. The waterproofing membrane can be adhered or 'compartmentalized' in a containment grid configuration to localize water migration under the barrier in the event of a leak.

The most common types of waterproofing membranes for the protected membrane assembly are thermoplastic sheets, self-adhering bituminous sheets, and hot liquid-applied rubberized asphalt. Thermoplastic sheets are versatile since they can be adhered directly to the concrete substrate or installed in a containment grid configuration. Self-adhering bituminous sheets and hot liquid-applied rubberized asphalt systems bond directly to the deck.

Adhered system

Adhered systems are most commonly used in new construction projects where a smooth concrete finish can be specified and achieved in the field. Most waterproofing membrane manufacturers require a magnesium float or steel-trowel finish. The concrete should be cured for 14 to 28 days and surface-dry for the membrane application. Additionally, curing compounds must be compatible with the waterproofing membrane and should not interfere with the membrane bond to the concrete substrate. Adhered systems typically have installation temperature limitations because adhesives tend to lose their tack in cold temperatures (*i.e.* approximately –4 to 4 C [25 to 40 F]), or may become too sticky to work with in high temperatures (*i.e.* approximately 32 C [90 F]).

Sheet systems can provide factory-controlled uniform thickness through-out the waterproofing membrane. The materials can be adhered with specially formulated, compatible field-applied adhesives. Some membrane manufacturers offer 'self-adhered' membranes incorporating a pressure-sensitive adhesive that is factory-applied onto the waterproofing membrane during manufacture. This adhesive is protected by a release liner that is removed during the installation. The concrete substrate is conditioned or primed prior to the membrane installation to bind residual dust that can interfere with the membrane's adhesion.

Hot liquid-applied rubberized asphalt systems have been used over concrete decks in green roof applications for a number of years. This material shipped as a solid and heated on-site in a double-jacketed melter between 176 to 190 C (350 to 375 F). It is installed in a two-coat liquid application with a reinforcing fabric placed between each coat. A surface conditioner is sprayed to the concrete deck prior to installing the rubberized asphalt and allowed to dry. The first coat of rubberized asphalt is a minimum 2.3-mm (90-mil) thick. A layer

Plant selection depends on several factors, including aesthetics, maintenance budgets, climate and weather, and roof slope.

of spun bonded polyester fabric reinforcing sheet is embedded into the first coat, followed by a second layer with an average thickness of 3.2 mm (125 mil). The total membrane thickness is an average of 5.46 mm (215 mil) with a minimum thickness of 4.57 mm (180 mil).

A root barrier protection course is embedded into the rubberized asphalt while the material is still hot. This layer is required to protect the waterproofing membrane from the aggressive roots of the vegetated cover. It also provides installers with a walking surface.

Containment grid system

The containment grid system is an option with thermoplastic sheets. It combines the performance benefits of the adhered system with the application benefits of a loose-laid system. In this design, the area to be waterproofed is segmented into smaller waterproofed grids. If there is a leak in the system, water cannot migrate from one grid to another, making it easier to locate the source.

The above photo depicts a completed green roof installation at Save the Bay, located in Providence, Rhode Island.

Containment grids are created by bonding 305-mm (12-in.) wide thermoplastic grid strips to the concrete deck with a specially formulated adhesive. The grid strips are installed around the deck's perimeter, projections, at the base of walls, and at the high points of the sloped areas. The waterproofing membrane is loose-laid over a geotextile fabric and welded to the grid strips. Since the waterproofing membrane is loose-laid between the grids, it can be installed at any temperature and even over damp surfaces. This provides a significant benefit to the construction schedule since it will limit the number of no-work days.

The grid system is frequently used on renovation projects where significant time and money may be spent preparing the entire concrete deck to receive an adhered system. Instead, surface preparation is limited to the areas receiving the grid strips. The geotextile fabric provides a cushioning layer and separates the existing waterproofing system from the new waterproofing membrane.

Insulation

As the insulation is atop the waterproofing membrane in a protected membrane roof assembly, XPS should be specified since it is designed for moist, buried environments. Polyiso insulation boards are only intended for 'conventional' roof designs.

Drainage and water retention

Prefabricated drainage composites or granular drainage systems are placed over the XPS insulation in protected membrane assemblies.

A garden roof tops Chicago's City Hall. The city has several initiatives aimed at sustainability.

This allows excess water to evacuate the system quickly. In some cases, an additional layer of drainage composite may be installed under the insulation to prevent floatation. As a rule of thumb, this layer is required if the thickness of the growing medium is less than 1.5 times the thickness of the XPS.

Some green roofs are designed to retain as much water as possible to provide nourishment for the vegetated cover. Since the waterproofing membrane is at the deck level, a secondary membrane (*e.g.* PVC thermoplastic sheet) is needed above the insulation to hold water. Water retention can also be achieved by installing specially designed panels that incorporate molded water retention cups and drainage channels.

Waterproofing quality assurance

A leak in the waterproofing system can be catastrophic, making this the most critical component of a green roof. There are several options available to ensure a watertight system before the vegetated cover is planted. One option is to hire a monitor to observe the waterproofing and vegetated cover installation. He or she should be trained in the membrane application and flashing details. A careful eye can detect application deficiencies and membrane breaches.

A flood test is the most common method for determining watertightness after the waterproofing is installed and prior to the vegetated cover installation. The area is 'flooded' with 51 mm (2 in.) of water for 48 hours, after which an inspector checks the inside of the structure for signs of water leakage. If an area is wet, he or she looks for a breach in the waterproofing system, which can be a challenge to detect. Once the breach is found, it is repaired and the area is flood-tested again.

Electric field vector mapping (EFVM) is a technique to detect breaches in the waterproofing membrane that are not easily observed by the human eye or are missed during flood tests. This technique is cost-competitive to traditional flood tests. Although it has been used for a number of years in Europe, it is now gaining acceptance in North America. EFVM has several benefits, including:

- locating membrane breaches with pinpoint accuracy;
- providing the ability to re-test membrane repairs immediately;
- facilitating re-testing of permanently installed EFVM components throughout the membrane's lifecycle;
- the ability to be used before and after vegetated cover is installed; and
- eliminating unnecessary and costly removal of the vegetated cover.[11]

It is important to specify compatible protection and/or drainage layers when using EFVM, since some types of protection layers and drainage panels may interfere with the test.

Conclusion

There are currently no design standards for green roof systems and designers are challenged to develop their own designs and specifications with limited information and resources. As a result, waterproofing manufacturers are becoming more involved in the design process to ensure proper selection and placement of green roof components.

In an effort to simplify the design and delivery process, some waterproofing manufacturers have partnered with vegetated cover providers to offer single-source warranties. Such partnerships leverage the expertise and experience of each to deliver technically sound, time-tested, cost-effective green roof solutions. Single-source responsibility drives the parties to become engaged

Additional Information

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Abstract

Selecting and locating the various components of a green roof can be challenging. This article focuses on the various waterproofing design options as they relate to the type of green roof and structural deck selected for the project.

early in the design phase through the installation and beyond. Coordination and cooperation of the waterproofing manufacturer and vegetated cover provider will ensure high-performance, long-lasting green roofs.

Notes

[1] See "First Annual Green Roof Industry Survey Shows Significant Growth in North America," *The Green Roof Infrastructure Monitor*, Volume 8, No. 1 (Fall 2006).

[2] See Green Roofs for Healthy Cities, Green Roof Design 101 Introductory Course, *Participant Manual* (2004).

[3] For more on macroclimatic and microclimatic zones, see the U.S. National Arboretum (USDA) Plant Hardiness Zone Map at www.usna.usda.gov/Hardzone/hrdzon3.html.

[4] See C.R. Friedrich's "Principles for Selecting the Proper Components for a Green Roof Growing Media," presented at the Third Annual Greening Rooftops for Sustainable Communities Conference in Washington, DC (May 2005).

[5] See ASTM International's WK575 Subcommittee E06.71 2002-2-7 on the Practice for Assessment of Green Roofs.

[6] See Green Roofs for Healthy Cities, Green Roof Infrastructure: Design and Installation–201, *Participant Manual* (2006).

[7] See note 6.

[8] See note 5.

[9] See P.J. D'Antonio's "Thermoplastic Waterproofing Membranes in Green Roof Construction 2004," *RCI Interface*, February 2004.

[10] See A.P. Bailey's "So You Want to Roof Green?" *Professional Roofing*, April 2006.

[11] See EFVM Benefits at the International Leak Detection Web site at www.leak-detection.com.