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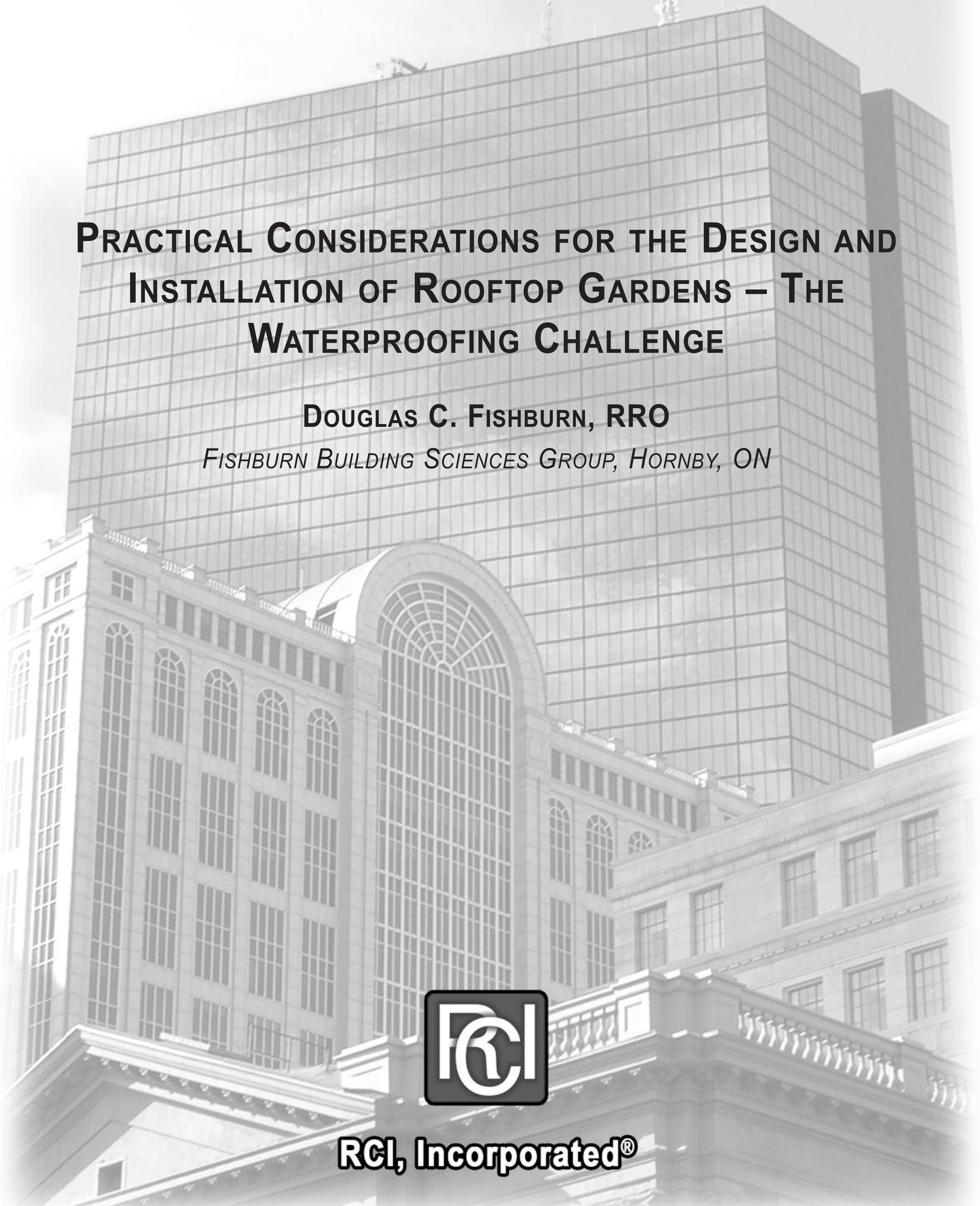

PRACTICAL CONSIDERATIONS FOR THE DESIGN AND INSTALLATION OF ROOFTOP GARDENS – THE WATERPROOFING CHALLENGE

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ABSTRACT

Roof gardens, commonly referred to today as “green roofs,” have been used in Mexico for centuries. Sod roofs were introduced in Canada by the Vikings and later by the French colonists in Newfoundland and Nova Scotia. Earth dwellings have been used in the southwest by Native Americans, and sod roofs on homesteads were used during the settling of western North America.

Over the last 40 or 50 years, roof landscaping has been used over parking decks and podiums to improve aesthetics and create market appeal for both commercial and residential buildings. A green roof does not demand an entirely different roof design approach. The sound principles involved in the design and construction of a conventional or protected roof membrane can be modified and/or adapted to green roofs. Green roofs offer many operational, financial, environmental, and social benefits. These benefits can be short lived if the waterproofing assembly fails to provide its principal function: a waterproof environment.

The environment to which it is exposed, its design, its method of construction, and the frequency of maintenance can impact the durability of any waterproofing system. Improper design, poor construction practices, and lack of proper maintenance have been found to result in premature roof failure. There is no reason to think that such factors would have a different impact on green roof applications. In order to mitigate the risk of failure and to improve long-term performance, specific considerations must be paid to load requirements, slope and drainage, thermal performance, design of the details, waterproofing membrane, testing, and requirements for maintenance.

This paper focuses on some of the factors impacting the design of waterproofing for green roofs, particularly intensive green roofs, and suggests methods of design and construction that can help achieve long-term watertight service.

SPEAKER

Douglas C. Fishburn, RRO — Fishburn Building Sciences Group, Hornby, ON

Acknowledged as an expert in his field, DOUG FISHBURN has investigated numerous roofing, waterproofing, and building-envelope failures and has appeared as an expert witness in many high-profile litigation cases. Considered a leading authority on green-roof waterproofing and design, he has authored and presented papers addressing green-roof design and waterproofing issues for the NRC and RCI at numerous conferences throughout Canada and the U.S. Fishburn is a member of the Professional Engineers of Ontario (PEO), National Roofing Contractors Association (NRCA), Toronto Construction Association (TCA), Construction Specifications Canada (CSC), Ontario Industrial Roofing Contractors, Concrete Institute of Canada, Ontario Building Envelope Council (OBEC), Canadian Government Specifications Board, RCI, and Green Roofs for Healthy Cities.

Practical Considerations for the Design and Installation of Rooftop Gardens – The Waterproofing Challenge

Green roofing can range from a carpet of flowers to grasslands to woody shrubs. Green roofing has been refined over the years and is generally divided into three types: intensive, semi-extensive, and extensive.

Intensive green roofing is characterized by its higher weight, which is due to the depth of growing medium (150 mm/6 in) or more required to accommodate larger shrubs and trees. These systems weigh 290 to 967 kg/m^2 (50 to 200 lb/ft^2).

Semi-extensive green roofing is characterized by a depth of growing medium of approximately 150 mm (6 in). The weight of a semi-extensive system can vary from 169 to 290 kg/m^2 (25 to 50 lb/ft^2).

Extensive green roofing is characterized by its lower weight, which is due to reduced depth of growing medium (150mm /6 in or less), saturated weights between 72 and 169 kg/m^2 (12 to 25 lb/ft^2), and the use of smaller plants.

The following are the major benefits and disadvantages of green roofing compared to traditional conventional roofing applications. Note: Most tangible benefits are project-specific.

TANGIBLE BENEFITS

- May expedite municipal approvals
- Increases the roof membrane life expectancy
- Decreases maintenance of the membrane and membrane flashing
- Reduces cooling costs
- Food production
- Increased market value

INTANGIBLE BENEFITS

- Reduced heat-island effect
- Reduced water run off
- Aesthetic appeal
- Improved air quality
- Reduced sound transfer
- Qualifies for LEED[1] points

DISADVANTAGES

- Higher cost of construction due to increased load capacities and increased height of flashing
- Higher cost of construction due to landscaping and planting requirements
- Higher operation cost due to landscape maintenance
- Higher cost of roof replacement
- More difficult and costly to find and repair leaks
- Repairs' impact on the aesthetics, since mature trees and shrubs are typically replaced with immature ones

In general terms, roofs can be classified as water-shedding, weatherproof, or waterproof. Water-shedding roofs use gravity to keep water out. Weatherproof and waterproof systems employ waterproof membranes to provide this function. The prime difference between weatherproof and waterproof membranes is that waterproof membranes must remain watertight when exposed to hydrostatic pressure. Trade associations such as the Canadian Roofing Association (CRCA) and the National Roofing Contractors Association (NRCA) recommend that only waterproof membranes be used in the construction of green roofs.

Low-slope roofs are divided into three types: conventional, where the roof membrane is placed above the roof insulation; protected, where the roof membrane is placed below the insulation; or cold (vented) roofs, where the insulation is located under the roof deck.

While conventional roofs can employ extensive green roof technology, typically intensive green roofs incorporate protected-roof-membrane designs.

PROTECTED ROOF MEMBRANE

In a protected-roof-membrane design, the roof membrane is placed on the deck or overlay under the insulation. With this configuration, regardless of the roof finish (gardens, pavers, or gravel), the roof membrane is shielded from temperature extremes of the environment and protected from roof traffic following construction.

In a protected-roof-membrane design, the membrane serves the functions of waterproofing, air barrier, and vapor barrier. An example of a protected membrane roof is shown in *Figure 1*.

CONVENTIONAL ROOF MEMBRANE

In a conventional roof, the membrane is placed above the insulation and provides

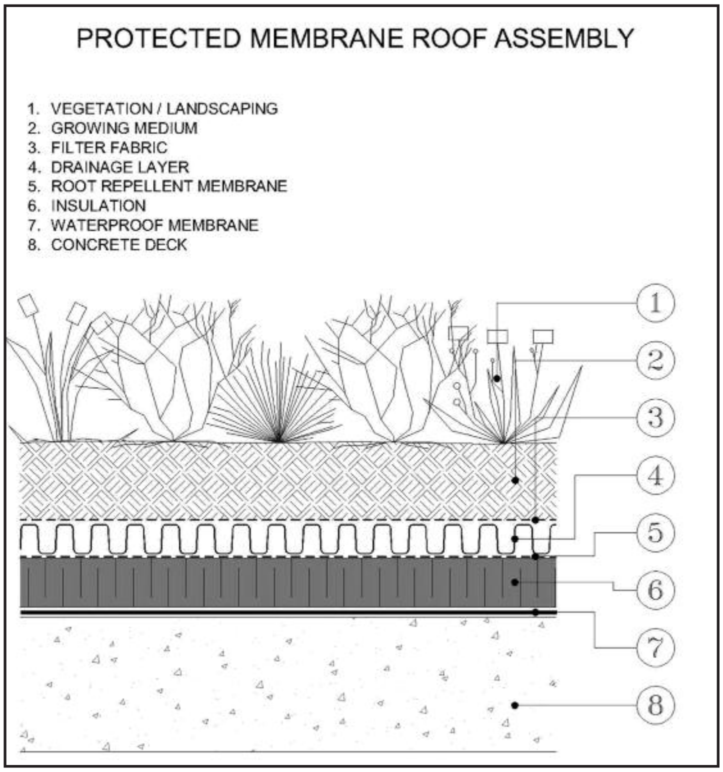

Figure 1

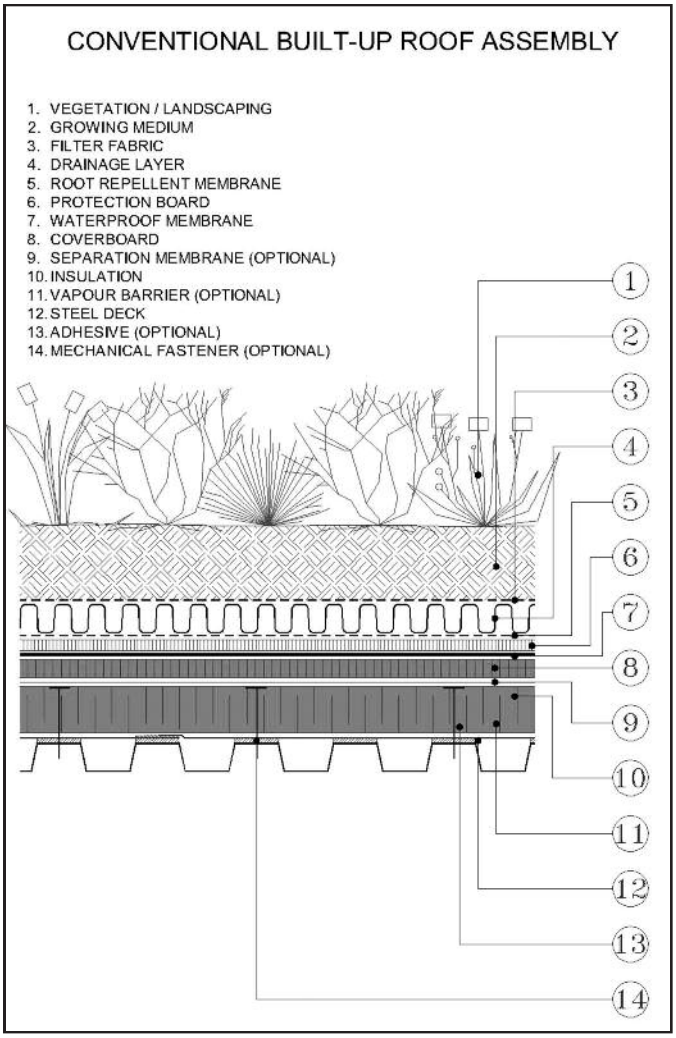

Figure 2

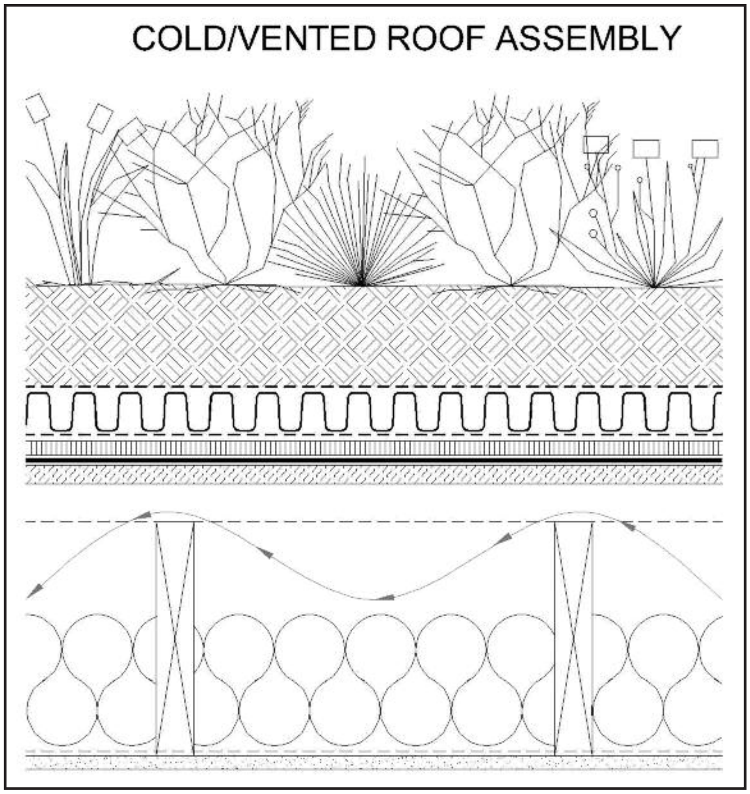

Figure 3

the function of waterproofing. When green roofs utilize a conventional roofing system, once protection boards, growing medium, and plants are in place, they have many of the features and benefits of protected roof membrane assemblies. An example of a conventional roof is shown in *Figure 2*.

COLD (VENTED) ROOF ASSEMBLY

In cold or vented roofs, the insulation is located below the roof deck. A cold (vented) roof assembly is not recommended for a green-roof application unless a detailed building-science and engineering review is completed.

These systems are typically not designed with the load-carrying capacity to support green roofs and are subject to creep deflection that results in ponding water.

The lack of a proper air/vapor barrier and inadequate ventilation of the roof cavity leads to a moisture build-up that can result in deterioration of the wood framing and mold growth. Converting cold/vented roofs to conventional or protected roof assemblies is recommended as a way to mitigate the risk of failure. An example of a cold/vented roof assembly is shown in *Figure 3*.

ROOF DECK AND LOAD REQUIREMENTS

The roof deck must be designed to carry the anticipated dead and live loads, including temporary loads imposed by construction equipment and stockpiling of materials. A number of roof-deck types such as concrete, steel, or wood planks can be utilized in the construction of both intensive and extensive green roofing, provided they are designed to carry the anticipated loads. Poured-in-place or precast cellular concrete decks typically do not have the structural capacity or robustness to accommodate the installation of green roofs.

When structural concrete decks are left

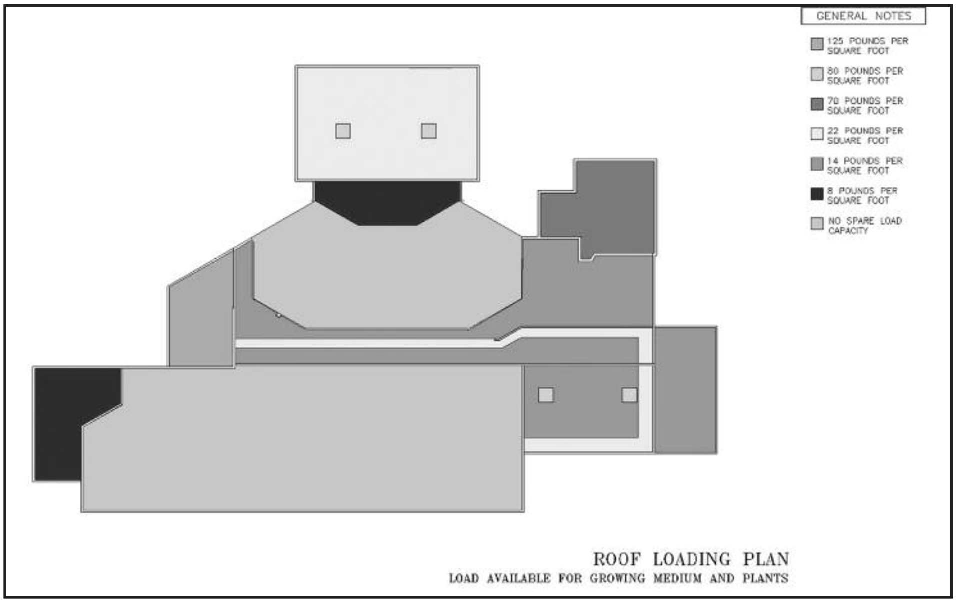

Figure 4

Figure 5 – Courtesy of the Bank of Canada, Ottawa, Ontario.

exposed and used as staging areas, consideration should be given to using additives in the concrete mix (to reduce water absorption) or the use of epoxy-coated rebar (to reduce the risk of corrosion of the steel reinforcement).

It is recommended that the preparation of a loading plan that shows the spare load capacity of various areas of the deck be completed early in the design stage. An example of a loading plan is shown in *Figure 4*.

The use of lightweight materials in the design of green roofing increases the potential for having green roofs on both new and existing buildings. Building up the planting area with polystyrene insulation in lieu of a full depth of growing medium, using drainage panels in lieu of a heavy layer of gravel, and using plant varieties that can grow in a minimum depth of growing medium will contribute to reduced weight.

If larger trees are incorporated into the design, one solution to address dead loads is to use planter boxes for larger shrubs and locate them over columns or at the roof perimeter, as shown in *Figures 5* and *6*.

Concrete-topped insulation, rubber walkway pavers, stepping stones, or wood or plastic walkways in traffic zones are all designed to reduce the dead loads on the roof assembly. An example of stepping-stones used to reduce weight is shown in *Figure 7*.

If wood walkways or paving stones are incorporated in the design, they should be installed to allow easy removal in order to gain access to the waterproofing system. The greater weight of green roofs compared to conventional roofing systems can be a major limitation from both a cost and a functional point of view.

While the structural requirements can be easily accounted for during initial construction, owners may not be willing to pay the additional costs to upgrade the structure to carry the additional load capacity required for green roofs.

Figure 6 – Courtesy of the Minto Hotel, Ottawa, Ontario.

While existing protected-membrane roofs may be viewed as good candidates for green roofing, the load capacity needs to be carefully considered. Many protected-membrane roofs that are more than 20 years old could have the necessary spare load capacity to install extensive green roofing. This is due to the fact that these roofs were typically designed with the insulation being bonded to the roof membrane. These roofs were positively ballasted to prevent insulation flotation.

The weight of the gravel ballast was typically installed at a minimum of 48.8 kg/m^2 for 50 mm of insulation or less. The weight was increased at a rate of 24.4 kg/m^2 for every 25 mm of additional insulation. Roofs installed with 100 mm of insulation are typically ballasted at 107 kg/m^2.

Within the last 15 years, many protected roofs were designed as lightweight systems. With protected lightweight systems, the insulation was loose-laid with a water-permeable fabric installed over the insulation. While greater ballast weights were required at the roof perimeters and corners to offset wind loads, the ballast in the field of the roof was typically installed at a weight of 48.8 kg/m^2. The insulation was expected to float under ponding water conditions and the water-permeable fabric was expected to keep the insulation boards in alignment like a raft floating on water if the roof periodically ponded water.

Designers and contractors must proceed with caution when substituting the gravel ballast on lightweight protected-roof membrane assemblies and installing an extensive green-roof cover, since the weight of the growing medium and plants may be insufficient to prevent flotation, and, as a result, the insulation may become dislodged.

National and regional building codes are not static and change periodically to reflect increases or decreases in live loads imposed by rain or snow. A reduction may, in some cases, allow additional load capacity for the installation of green roofs. The replacement of a built-up gravel roof with a lighter modified or single-ply membrane will also provide additional spare capacity.

The weight of a built-up roof membrane can be reduced to approximately that of a modified-roof membrane by substituting the bitumen and gravel surfacing with a ply of modified-membrane cap sheet. Depending on the design of the system, this reduction in weight is approximately 25 kg/m^2. These systems are generally referred to as hybrid roof membranes and are reviewed elsewhere in this paper.

FIRE RESISTANCE

Building codes require that roofs meet UL or ULC (in Canada) requirements for external fire resistance. The risk of external fire propagation will increase with roof slope. Due to insufficient test data, it is recommended that local fire marshals and insurance underwriters approve designs early in the design stage. Tall grasses and

Figure 7 – Courtesy of the Minto Hotel, Ottawa, Ontario.

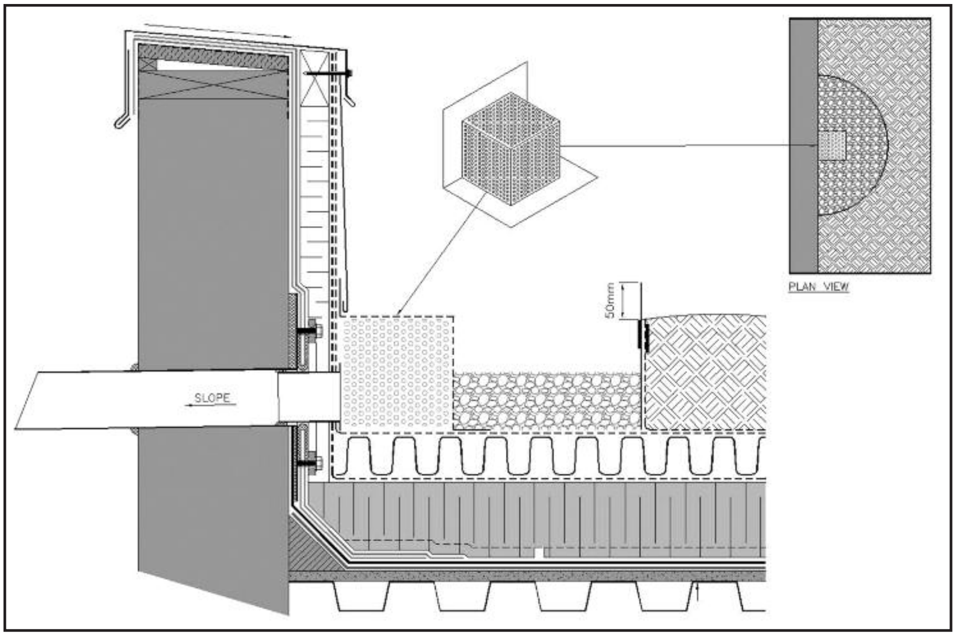

Figure 8

woody shrubs and trees pose an elevated fire risk in comparison to low-growing plant material such as sedums.

Where there is an elevated risk of fire, consider providing firebreaks or firewalls within the green-roof system. Increasing the height of firewalls above that required by regulatory requirements will provide additional protection. The location and width of the fire breaks will depend upon the fire risk imposed by plant material.

On large continuous roof areas, firebreaks of 1200 mm (4 ft) at approximately every 30 m (100 ft) may be used as a rule of thumb.

Providing and increasing the width of vegetation-free zones (0.9 m or 3 ft wide) adjacent to walls and openings in the roof (such as drains, skylights, rooftop equipment, etc.), providing sprinkler irrigation, and dead-heading vegetation will assist in minimizing the risk of fire. Hot exhaust from production equipment, kitchen hood exhausts, and equipment that expel material onto the roof (such as lint from dryer vents) also pose higher fire risk.

Increasing the size of the vegetation-free zones, together with the use of fire-resistant materials such as concrete curbs vs. wood curbs, would increase the margin of safety.

It is important to review increased risk potential with owners and end-users and establish maintenance procedures to ensure leaves and other debris are cleaned from vegetation-free zones around equipment on a regular basis. The maintenance plan should include regular inspection and maintenance of grease traps and cleaning of the interior of ducts that can carry fire-hazardous materials onto the roof.

When the roof is required to accommodate a concentration of mechanical equipment that would require extensive coverage of vegetation-free zones to provide adequate fire protection, provide a roof divider and use a standard (non-vegetative) conventional or protected membrane roof in these areas. Roofs covered with vegetation can be tested for interior fire exposure according to current prescribed test procedures.

SLOPE AND DRAINAGE

Green roofs have demonstrated the ability to control stormwater runoff through absorption, the slow release of water into the storm drainage system, or evaporation. In colder regions, a buildup of snow on the roof will retard surface drainage, and increased water runoff may occur when the soil becomes frozen and snow cover is minimal.

Water-retention drainage panels and water-retention mats installed under the growing medium will further reduce water runoff. Water-retention drainage panels not only promote drainage, but also allow water vapor to migrate out of the system after water has receded. The use of controlled flow drains and ponding of water under drainage panels should be avoided, due to the risk imposed by increased loads, potential wash-out of growing medium and plants, and floating insulation on protected-membrane roofs.

A minimum of one drain plus one overflow drain or scupper is recommended for each roof area. There is a higher risk of roof collapse, should blockage of the drainage system occur. The prudent design decision may be to install drains at closer intervals rather than providing a few large ones.

The installation of green roofs on buildings that do not have adequate slope-to-drain could result in ponding water, particularly during severe rain events. Regular inspection and maintenance must be provided to keep drainage paths and drains in good operating condition.

Due to reduced water flow at scuppers, scupper outlets should be designed larger than internal drains by a factor of three. Larger screens designed to maximize water flow are recommended for both scuppers and internal drains. An example of a larger

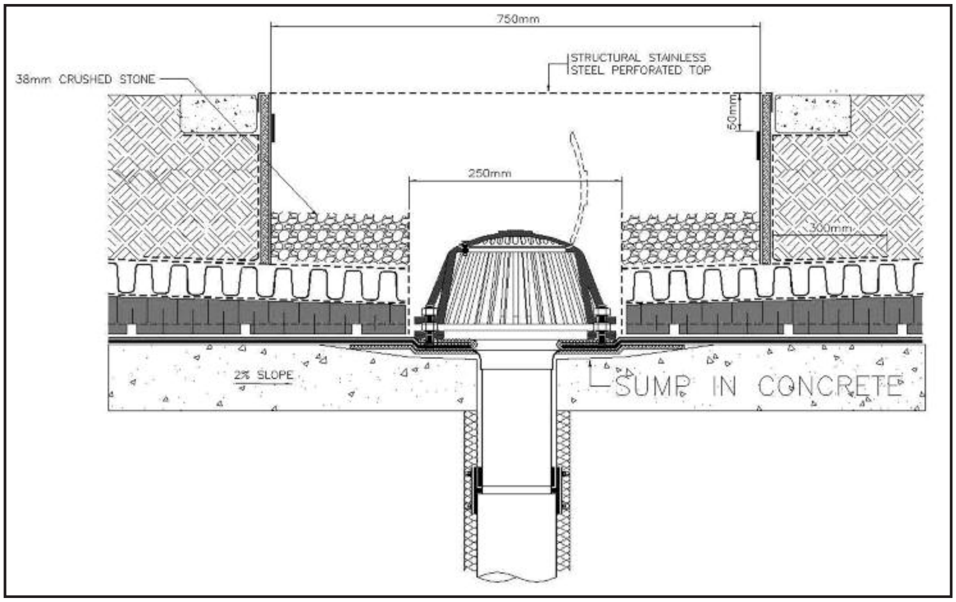

Figure 9

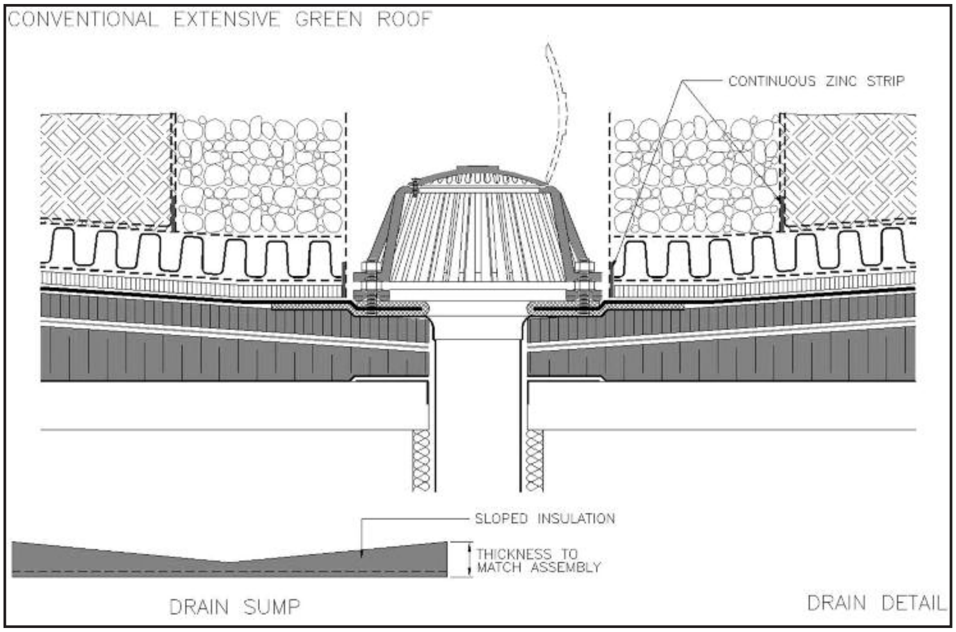

Figure 10

screen for a scupper is shown in *Figure 8*.

Roof decks should be designed to shed water effectively. A slope of 2 percent or a quarter-inch fall per linear foot should be considered the minimum requirement. Stabilization measurements are required on roof slopes exceeding 16 percent to keep the roofing system and landscaping in place in order to prevent shear failure. Do not rely on friction or adhesive alone. A restraint system must transfer the gravity load to the structure. Restraint systems can be installed at the eaves, at the ridges, or within the field of the roof.

If insufficient slope is provided, long-term creep deflection of the structure or oversights in construction can collect silt that washes out of the growing medium and collects at low points, thereby blocking drainage paths.

To aid in obtaining positive roof drainage in addition to positive slope, roof drains should be installed in a sump that will allow them to be set below roof level. Drainage sumps on concrete decks should be a minimum of 1200 mm x 1200 mm and should slope gradually from general roof level to a minimum of 19 mm at the roof drain. An example of a sump found in a concrete deck on a protected-membrane roof is shown in *Figure 9*. An example of a roof drain for a conventional roof is shown in *Figure 10*.

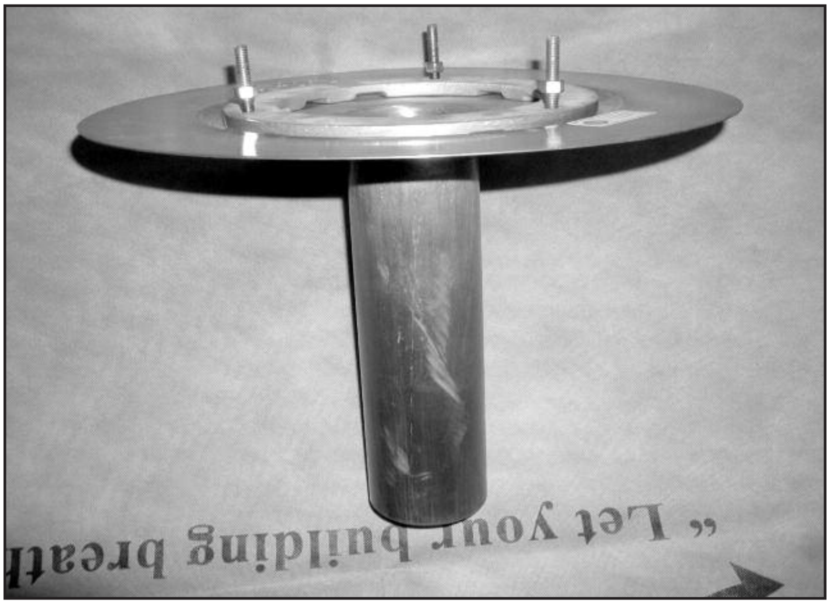

Figure 11

Excessive slope at the drain sump can cause wrinkling of the roof membrane and break adhesive bonds between membrane layers. The sump should be designed to accommodate variations in construction and ensure clamping rings do not restrict water flow. Clamping rings with drainage slots on the underside of the clamping ring are preferred, as shown in *Figure 11.*

Most landscape architects are well aware of the requirements for irrigation and drainage for plant survival; however, often little consideration is paid to the impact of water on the performance and durability of the waterproofing system.

In some cases, landscape architects may attempt to minimize the impact of ponding water on plants by installing a thicker (50 mm to 100 mm) drainage layer. The impact of ponding water as it relates to live loading and the impact on the performance of the membrane cannot be ignored.

Typically, an increase in the moisture content of the membrane will erode its performance characteristics and shorten its life expectancy. Increased rainfall, low temperatures, and slow drying conditions characterize late fall days in most of the northern states and Canada. Wet soil will become frozen during long periods of freezing temperatures, a development that will prevent topside drying.

Good slope and drainage will minimize the impact of moisture on the surface of the roof membrane. The installation of water-retention drainage board immediately above the membrane on a conventional roof will increase drainage and promote drying at the membrane level, thereby improving the system's response to moisture control. This is achieved by providing continuous drainage and venting paths at flashings and roof drains.

The drainage paths can be vented to the roof surface at vegetation-free zones, thereby promoting drying. Providing insulation with drainage grooves has the same effect and allows drainage and venting at the membrane level on protected membrane roof assemblies. Additional information on the use of drainage grooves is provided in the section addressing insulation. At the bottom of slopes and when relatively thin drainage panels are installed, a drainage pipe is required to collect and move water to the drain.

Three types of drainage pipes are available: round, square, and triangular. The latter two are preferred, due to their ability to evacuate water and increase water-carrying capacity at a lower drainage plane.

Due to their exposure to moisture and to the corrosive nature of some fertilizers, the use of drains that are made of corrosive-resistant material, such as copper or stainless steel, should be considered. If corrosive-resistant drains are not available, preference should be given to fitting drains with stainless-steel bolts, clamping rings, and strainers. Roof drains must be accessible for regular inspection and maintenance. Roof drains in intensive landscaping may be located a meter or more below the surface, and access wells need to be provided, as shown in *Figure 9*.

Access wells also serve as relief for ventilation. Roof drain strainers should be designed to facilitate inspection and cleaning. If traditional cast-iron drains are used, they should be painted or coated to improve their durability. The coating must be compatible with the roof membrane.

Bolts used to secure strainers should be stainless steel wiped with Teflon Dope to minimize rusting and to make future removal easier. Attention to these details will increase strainers' durability and minimize the need to replace roof drains at considerable risk and cost when the waterproofing system is eventually replaced.

Heat loss and the collection of silt due to soil wash-out can result in retained moisture around drains, providing an ideal environment for vegetation growth, as seen in *Figure 12*.

The use of zinc strips at drain screens will retard moss and other vegetation growth and assist in keeping drainage paths open. Underscoring the insulation to provide routes for drainage and reducing the insulation thickness at the drains will also improve drainage and drying of the subsurface components. This subject is reviewed in more detail under the heading of "Roof Insulation."

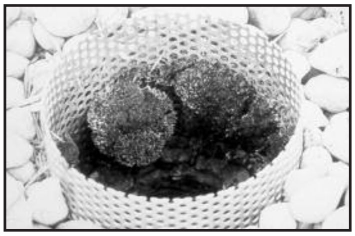

Figure 12

ROOF INSULATION

Dry growing medium has a higher R-value than growing medium saturated with water or frozen material. Saturated growing medium provides a greater heat sink than dry, which may reduce cooling loads. The geographic location of the building, type and depth of growing mediums, and moisture content of the growing medium are factors that will impact heating and cooling loads.

In addition, the type of vegetation will impact heat gain or loss. It has been stated that the evaporation from one gallon of water equals 8,000 BTU.[2] The effectiveness of plants to provide cooling should not be underestimated.

Given the number of variables, it is recommended that the calculation of heating and cooling loads be based primarily on the insulation component of the roof assembly, a factor that can be easily calculated. A design professional should determine the requirements for cooling and heating. The thermal resistance of common construction materials should be calculated based on information provided by ASHRAE.

Green roofs designed with a protected membrane place great demands on the insulation component of the system. The type of insulation used must have good physical and moisture-resistant properties. Extruded polystyrene with a minimum density of 40 PSI is recommended. Use of a high-density, 60- or 100-PSI material should be considered when the roof is to be subjected to increased loads such as roof planters, waterfalls, or heavy traffic during or following construction.

It is recommended that the insulation be looselaid. Loose-laid insulation will speed construction and allow for salvage and reuse when repair or replacement is required, thereby reducing cost and lessening the impact on the environment.

While the drainage from protected membrane roofs covered with vegetation has not been extensively analyzed, on protected membrane roofs covered with gravel ballast, it is believed that approximately 80 percent of water drains above the insulation and 20 percent at the membrane level. Drainage under the insulation is a slower process and is retarded by the offset of insulation boards one to another, water tension, and irregularities in the membrane (including side laps in membrane running across the slope) causing water to dam.

Where possible, side laps of single-ply membranes should be laid with the slope in order to improve drainage. The use of insulation with drainage grooves will improve drainage at the membrane level.

Drainage grooves should be installed around the perimeter and in the field of each insulation board. The drainage grooves can range from 13 mm to 19 mm wide and deep and can be installed by the insulation manufacturer or contractor.

Polystyrene insulation manufacturers do not recommend the use of a drainage mat or protection board under the insulation, since convective currents could reduce the effectiveness of the insulation and change the location of the dew point. Depending upon the construction schedule and anticipated loads from construction traffic, the underscoring of insulation may eliminate the requirements for a drainage mat and protection board on some systems. An example of drainage grooves is shown in *Figure 13*.

In order to promote drainage, reducing the thickness of the insulation at roof drains is recommended, since more water is shed from the surface of the roof insulation than below it. Reducing the insulation thickness and increasing the thickness of gravel ballast at the drains will tend to offset flotation forces at the low points of the roof.

This will also increase the heat loss adjacent to the roof drains, an increase that will assist in keeping drainage paths open in the winter months. An example of reducing the insulation at roof drains for landscape roofing is shown in *Figure 14*.

When the roof membrane is installed above the insulation, such as in a conventional roof assembly, the insulation should be installed with a high-density cover board in order to improve the roof-membrane resistance to damage from construction traffic.

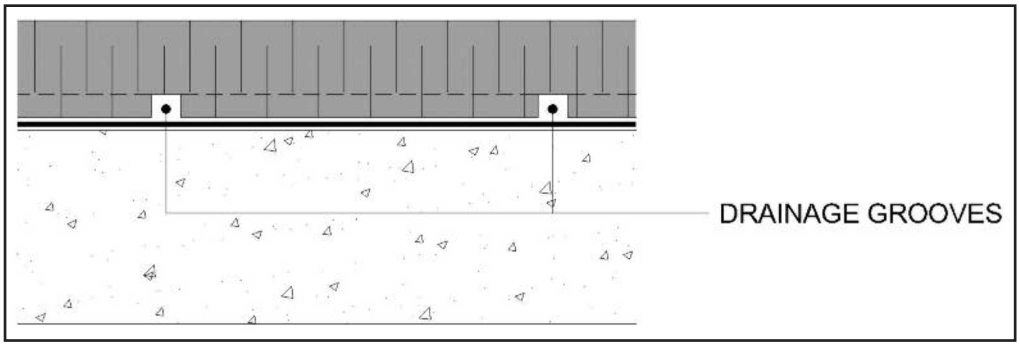

Figure 13

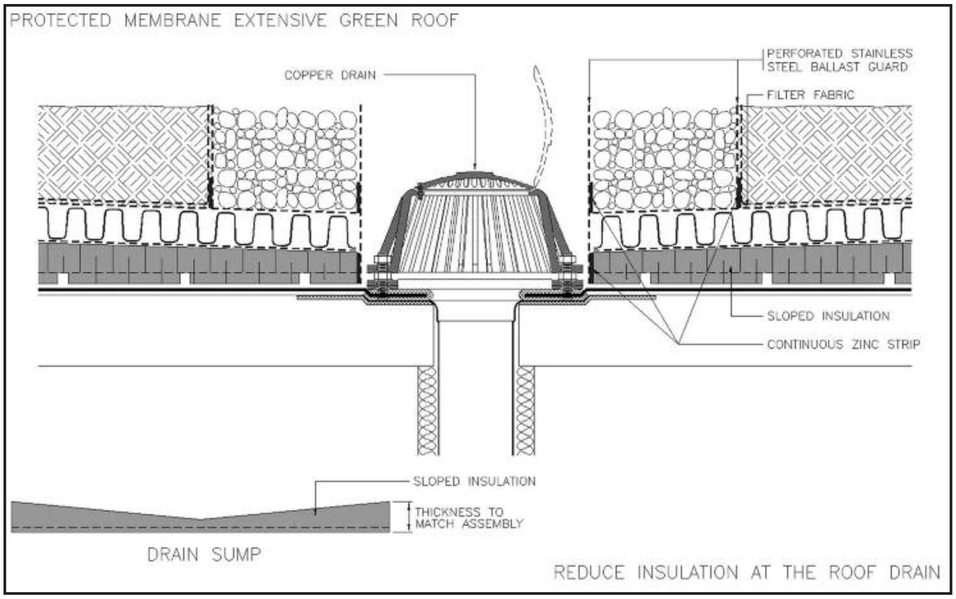

Figure 14

WATERPROOF MEMBRANE

The incorporation of a root barrier was not generally included in most early landscape roofing designs. The need for protection of the waterproofing membrane from root penetration is now receiving general acceptance.

Some membranes, such as polyvinyl chloride (PVC) and thermoplastic polyolefin (TPO), provide a natural root barrier. Waterproof membranes incorporating organic material such as asphalt-based products are susceptible to micro-organic activity and root penetration.

Roots can infiltrate small deficiencies in the membrane and lap joints, resulting in a breach of the waterproof membrane. Protection from root penetration can be provided with sheet root barriers. Other membranes, such as modified membranes, can be manufactured with copper films or be chemically altered to deter root penetration.

To prevent roots from plugging drains and drainage pathways on protected-membrane roofs, a root barrier should be used above the insulation, as shown in *Figure 15*.

The root barrier must be of a type to allow the passage of water vapor. The installation of a polyethylene sheet to provide this function is not recommended, since it will prevent topside venting of the insulation and may cause the polystyrene insulation to absorb water. Water-retention mats installed directly in contact with the topside of the insulation are not recommended for the same reason.

The level of protection against root penetration must be assessed with each project, since some plant varieties have more aggressive and deeper root systems than others. Planting shrubs and trees that have aggressive root systems in concrete planters is one approach to root containment.

To be effective, a sheet root barrier must be sealed at overlap and around penetrations (such as vent pipes) and carried up flashings at parapets, walls, and curbs. During the design stage, chemically altered membranes or root barriers must be verified to be compatible with other components, such as metal flashings built into the membrane layer. They must also address environmental concerns. *Figures 15* and *16* provide examples of where to terminate the root barrier at a parapet wall and vent pipe.

Countries such as Germany have adopted standardized membrane testing for root penetrations. For example, root penetration is tested under the German FLL green-roof guidelines over a three- to five-year period.

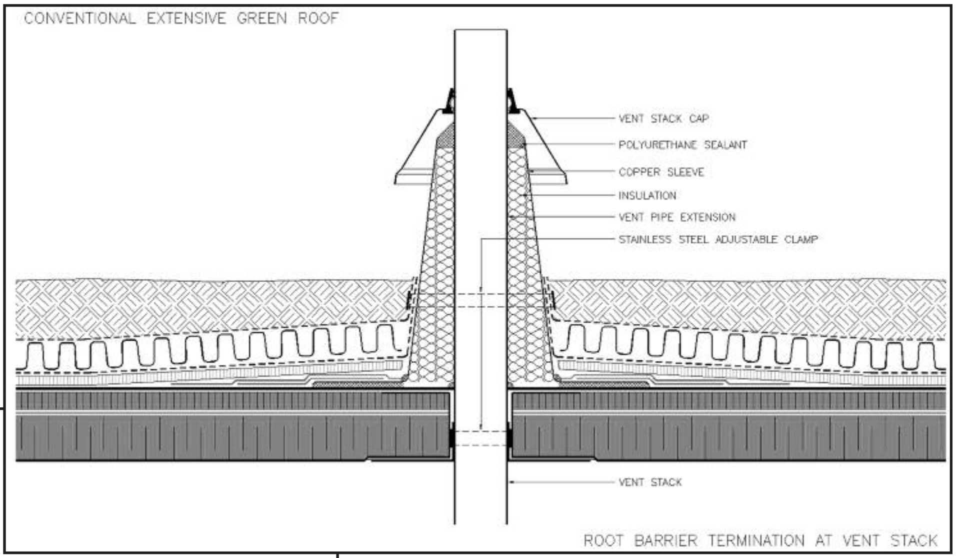

Figure 16

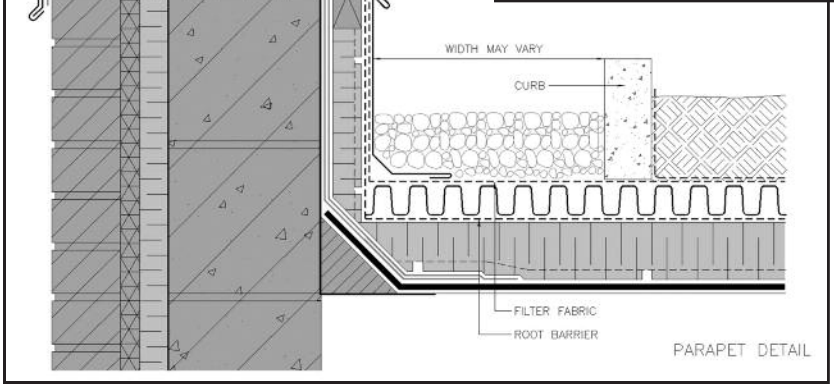

Figure 15

While testing for root membrane penetrations is now under review by ASTM, to date there is no Canadian test standard.

MEMBRANES

While most single-ply membranes, such as loose-laid thermoplastic or elastomeric sheets, have been used for green roofs, great care must be employed in their design and application. These systems do not have the same redundancy offered by multi-ply systems, and they have a tendency to be more easily damaged by construction traffic.

Because single-ply membranes characteristically do not have the mass of multi-ply membranes, defects in the deck, such as trowel ridges in concrete decks or small stones tracked onto the working surface can puncture the membrane from below. If a loose-laid, single-ply system is used on a concrete surface such as in a protected-roof assembly, it should be installed over a moisture-resistant underlay such as polyester felt to protect the membrane.

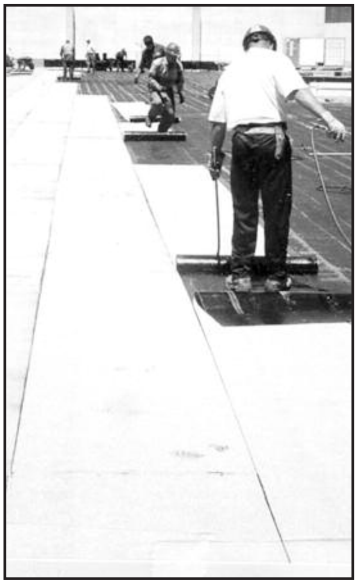

Figure 17

Thicker single-ply membranes have improved physical characteristics and may carry longer manufacturers' warranties. Single-ply membrane should be a minimum of 60 mils thick; 80-mil thermoplastic and 90-mil elastomeric sheets are also available. In short: the thicker, the better. While changes in technology have improved the performance of field seams in elastomeric membranes, the use of a cover strip over the seam is recommended for green roofs.

Single-ply membranes can be solidly bonded to the substrate or installed with water cut-off to limit the spread of water under the membrane, should a leak occur; however, field experience has shown that single-ply membranes have only limited success unless increased care is provided. Not all solidly bonded membranes have the same ability to restrict the flow of water under the membrane, should a leak occur.

Multiple-layer systems that are solidly bonded to the deck, such as a hot-rubber, built-up membrane using kettle-modified SEBS mopping asphalts, or prefabricated modified asphalt membranes, offer good under-membrane resistance to water flow.

In multiple-layer systems, additional layers of membrane can be added if needed to build up low points to eliminate or reduce water ponding on the membrane surface. Should a leak occur, the disruption and cost to remove the landscaping in order to gain access to the roof membrane could be substantial. To avoid this, it is prudent to increase the number of plies of membrane beyond that normally recommended for conventional roofing use. Increasing the number of plies will have a minor impact on cost but can have a major impact on long-term performance and waterproofing service life.

When constructing a built-up membrane, the use of fiberglass or polyester felts is recommended. In addition, the installation of a cap sheet, such as 250 gm/m^2 or 350 gm/m^2 over a bituminous built-up or hot-rubber membrane, will improve the membrane crack-bridging ability, tensile strength, and puncture resistance.

The use of a granule-surfaced cap sheet as compared to a smooth-surfaced sheet also provides a slip-resistant work surface, prevents the insulation from becoming adhered to the membrane, and aids in drainage by reducing water film tension. Due to the ability to spot physical damage, should it occur, light-colored cap sheets are recommended.

Because asphalt-based products such as membranes constructed with asphalt or hot rubber are subject to root penetration, the use of a modified cap sheet that has been chemically formulated to deter root penetrations as the top layer will substantially improve the durability of the system. *Figure 17* shows a modified cap sheet being installed over a built-up membrane.

In order to restrict drainage, should a leak occur, large areas of the roof and high-risk areas such as water features should be separated from one another with the use of area roof dividers.

The separation allows for precise moisture control, according to the requirements of any given section, and enables a wider variety of plants to be successfully established, which can add to overall aesthetics. On conventional roofs, dividing large roof areas into smaller sections can reduce the total thickness of insulation required to achieve the required slope within each section, thereby reducing the cost of insulation and the need to raise the height of parapet walls. In addition, this approach will reduce the cost of repairs, should the need arise, since the leaks would be contained within smaller areas.

When incorporating ponds and waterfalls into landscape roofing designs, an additional, independent waterproofing system should be installed. The use of a protected membrane roof is not recommended when constructing water features.

While drainage mats and root barriers are important elements in a landscape roofing design, they can also contribute to trapping moisture in the roof assembly.

Trapped moisture within protected-roof assemblies due to restricted topside venting can increase the moisture content of the insulation, even if extruded polystyrene insulation is used. Good drainage and topside venting are prerequisites if long-term performance is to be achieved.

More study on the negative impact of root barriers and drainage mats on topside venting is required.

FLASHING- AND VEGETATION-FREE ZONE

Flashings typically represent 70 percent of all waterproofing problems. The detailing of flashings on roofs or podiums often poses increased challenges. In addition to landscaping, flashings often incorporate rooftop mechanical equipment and may also incorporate conduits for electrical and mechanical services, lightning protection, railings, fall arrest systems, and davit arms for window-washing equipment.

Because rooftop equipment penetrates the moisture and thermal plane, flashings must be designed not only to be watertight, but also to prevent condensation and air leakage and to be insulated to provide thermal continuity.

Flashings at roof access points are of particular concern. Either flashing heights must be raised to accommodate the depth of growing medium, or curbs must be provided to separate the flashings from plantings or patio areas.

The use of curbs can allow deeper depths of growing medium without sub-

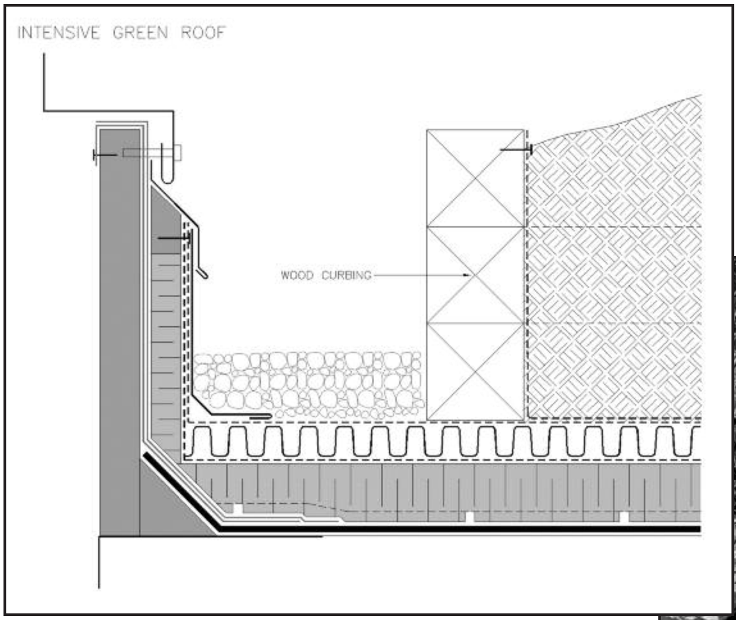

Figure 18

Figure 19 – Courtesy of the Minto Hotel, Ottawa, Ontario.

stantially increasing flashings heights, examples of which are shown in *Figures 18* and *19*.

The *Forschungsgesellschaft Landschaftsentwicklung Landschafts bau ev* (F.L.L.) guidelines as used in Germany typically provide a horizontal (vegetation-free) zone between the curbs and flashings. This separation allows for phased construction and prevents conflict among the trades during initial construction. The separation can be designed to allow for drainage, provide a fire barrier, and allow for foot traffic to gain access to the flashings and plant areas. The width of the gravel bed can be tailored to each project, but it is typically 500 mm.

When a parapet wall is provided at perimeters, the height of the parapet and the type of material used in the vegetation-free zone must be sufficient to prevent the roof system and roof gardens from being dislodged by the wind. Wind problems have not typically occurred when roof gardens have been constructed at or near grade level; however, when roof gardens are placed on taller structures, wind is more of a concern. Building code and Factory Mutual requirements (if applicable) must be considered early in the design stage. A wind-protection mat may be used to keep the growing medium in place in high-wind zones until the plants are established.

F.L.L. recommendations in regard to providing vegetation-free zones adjacent to flashings have merit. However, typically, parking decks in North America are designed with the landscaping carried up to the flashings, with good success.

Given specific requirements of the design, the width of the vegetation-free zone could be reduced partially at interior or high-parapet walls if a vertical and horizontal drainage plane is provided adjacent to all flashings to encourage drainage away from these critical points. An example of a wall detail with a vertical drainage plane as an alternative to a vegetation-free zone is shown in *Figure 20*.

The drainage plane at flashings can also be used to vent moisture out of the system and minimize the impact of the local environment on the membrane and flashings. The drainage plane can be provided by grooved insulation, protection drainage board, or stone.

It is also recommended that root barriers, drainage mats, and insulation a minimum 1,200 mm from the roof perimeter be installed in the direction of the parapet. This will facilitate ease of finish and access, should a leak occur. An example is shown in *Figure 21.*

Where possible, membrane flashings should be carried over and turned down the outside face of the building. A minimum flashing height of 200 mm (8 in) above the

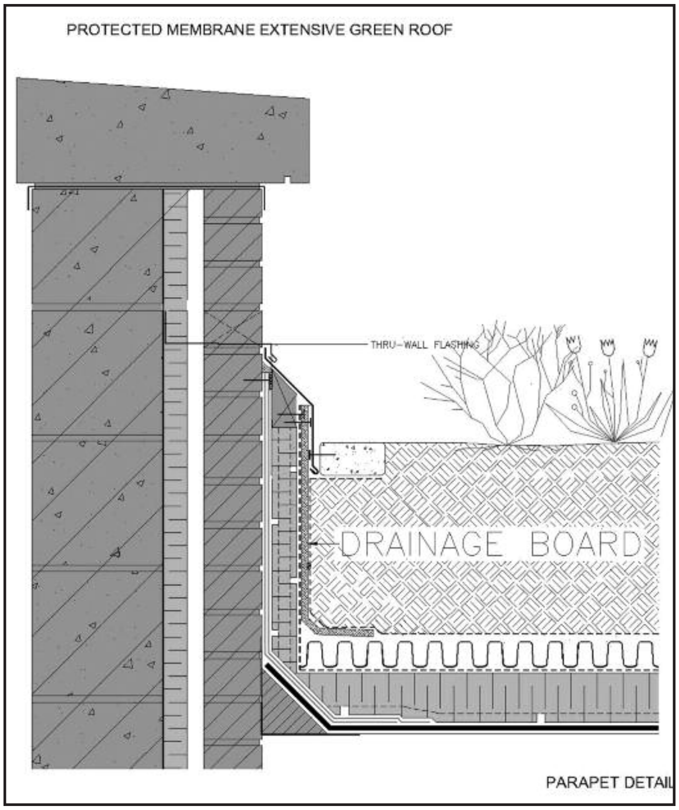

Figure 20

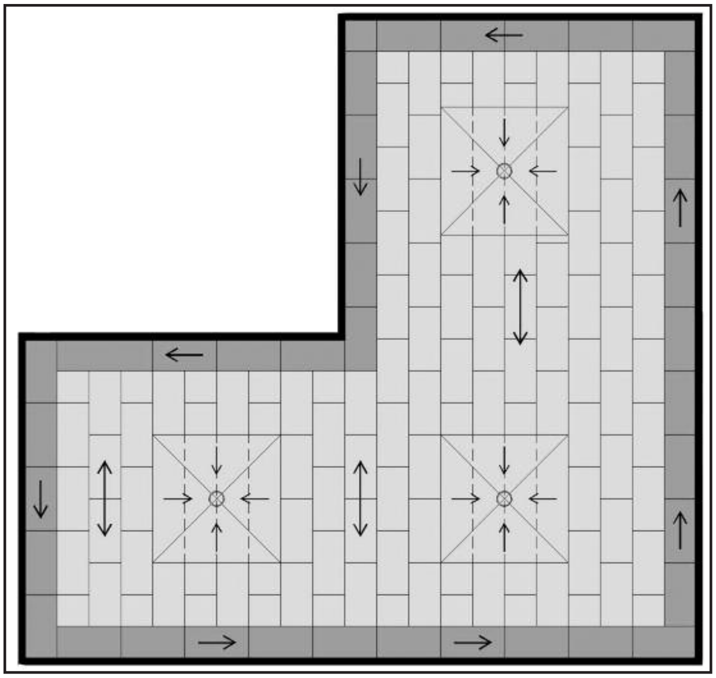

Figure 21

finished surface is recommended. The top of all flashings should be sloped to drain to the building interior. Depending on the type of membrane flashing, between 4 and 8 percent slope is recommended.

In order to improve long-term performance, covering the vertical portions of the roof flashing with insulation is recommended. This approach will not only reduce the impact of roof traffic and the external environment on the performance of roof flashings; it improves the overall thermal performance, helps to eliminate condensation traps, and reduces the need and frequency of maintenance. The benefits of insulating flashings have been published in a previous paper by this author, titled "Improving the Performance of the Protected Membrane Roofing Systems."[3]

In order to meet minimal height standards, membrane flashing can be carried up the walls and hidden behind siding or pavers, as shown in *Figure 22*.

While tradeoffs are common in design and construction, water-tightness should not be sacrificed for aesthetics. Due to their resistance to corrosion, copper or stainless steel materials are recommended to flash roof penetrations such as soil pipes or exhaust stacks that are built into the waterproofing membrane.

Depending upon their location, high-grade, pre-finished metal, copper, or stainless sheet counterflashings are also recommended for the same reasons. Light-gauge aluminum flashings are not recommended, due to poor performance when exposed to some fertilizers, as well as to their high thermal coefficient of expansion.

While this article primarily reviews the application of landscape roofing on protected-membrane roofs, the application of extensive green roofs is also finding acceptance on conventional roofs.

When a landscape roof is installed on a conventional roof assembly, many of the benefits normally associated with protected-roofing systems (e.g., shielding the membrane from environmental extremes) can also apply to the conventional roof. There are, however, exceptions. Flashings on conventional roofing have typically been the "weak link." Many of the problems associated with flashings can be mitigated on conventional roofs by insulating them similarly to protected membrane roofs, as reviewed earlier in this paper and covered in a previously published paper, titled "Protected Membrane Flashings Designed to Work."[4] A comparison of a typical conventional roof design at a parapet wall is shown in *Figure 23*.

While some membrane manufacturers may not be in agreement, an alternate approach as suggested in this paper is shown in *Figure 24*.

TESTING

Leaks in green roofs can be costly to investigate and repair. Most membrane manufacturer warranties include clauses that state the cost of removal and replacement of the overburden in order to gain access to their membrane is not covered by the warranty.

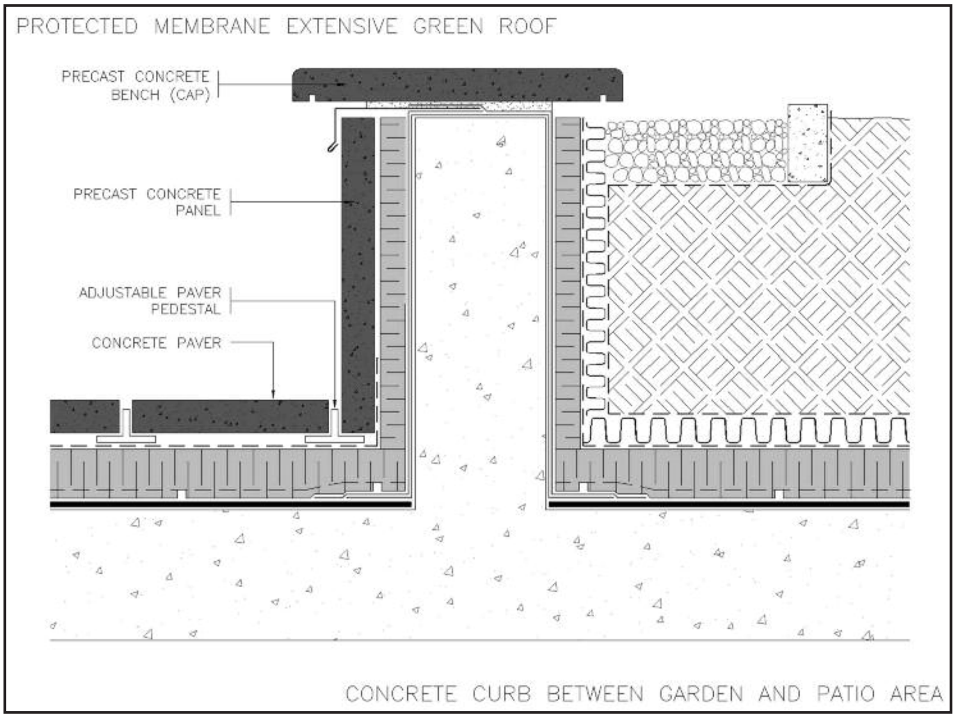

Figure 22

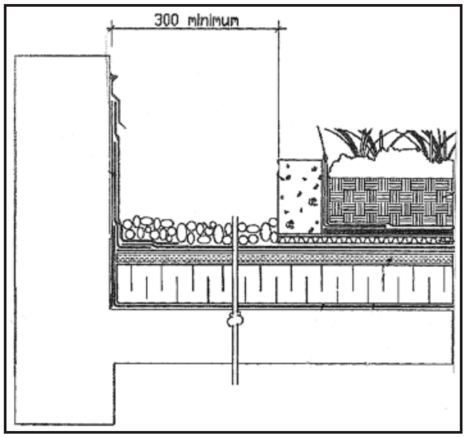

Figure 23 – From a report on environmental benefits and cost of landscape roofing technology for the city of Toronto, Ontario.

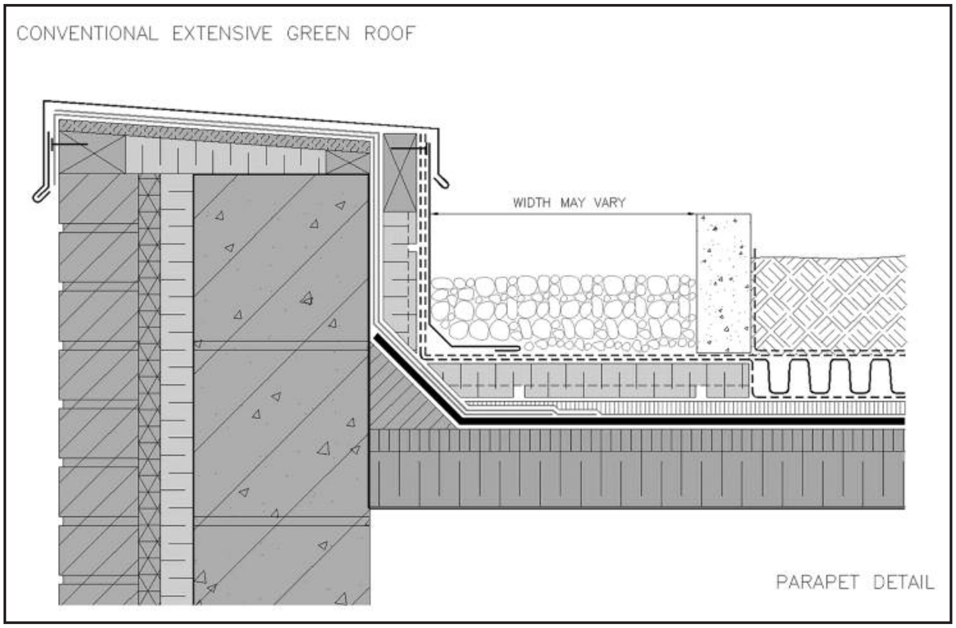

Figure 24

Some warranties also give the manufacturer the right to claim against third parties to recover the cost to investigate and remove the overburden, should it be proven that the leak was not the result of defects in the membrane. This could apply to leaks that result from damage caused by others or to leaks in walls or windows that eventually find their way to the building interior and are incorrectly assumed to be breaches in the waterproofing membrane.

While the use of modular systems may make the green roof more accessible and reduces the time and cost of investigating and repairing leaks, testing of the membrane system to ensure it is defect- and leak-free should be incorporated into all landscape roofing construction prior to installation of the overburden. Compared on a per-square-meter basis, repairs due to leaks after landscaping and planting is completed can be four to ten times greater than the cost of repair at time of initial construction. In order to minimize in-service problems, some form of testing is recommended.

Although visual inspection during construction provides useful information, testing can also include water testing, infrared, nuclear, capacitance, electronic field-vector mapping, moisture sensors, and air pressure. These test methods are often used in concert with one another.

This paper does not review the features and benefits of the particular test methods, but it is intended to highlight some of the systems available.

When flood/water testing is employed, the test is completed on the exposed waterproofing membrane by dividing the roof into zones, capping the roof drains temporarily, and flooding the roof surface with water to a depth of approximately 100 mm.

The water is left over a 24- or 48-hour period. The water-tightness of the membrane is determined by a visual inspection of the building interior. In the case of new construction, the test should be conducted prior to the completion of interior finishes to reduce the possibility of damage, should a leak occur (both the NRCA and CRCA do not endorse flood testing). A water spray test of flashings at walls, windows, and roof openings to ensure that seals are intact has merit and can often pinpoint latent construction defects that are incorrectly assumed to be roof leaks.

The use of electronic field vector mapping to test the continuity of the membrane is relatively new and has proven to be beneficial in detecting leaks in the waterproof membrane. The grid wire, if required with this system, can be left in place to allow for future in-service monitoring. Electronic field-vector mapping cannot be used on all systems. Consult the manufacturer for recommendations. During construction, wireless electronic moisture sensors with an alarm and a telephone interface can also be installed in a grid pattern under the roof membrane to monitor performance.

MAINTENANCE

While both quality control and quality assurance measures implemented during construction will have a positive impact on the performance of the roof, when the architects and contractors have left the site, the roof becomes the owner's responsibility

Regardless of the type of system (intensive or extensive) or membrane installed, all green roofs require periodic inspection and maintenance. This section addresses the maintenance of the waterproofing system, but not the plant material. Experience has shown that it is less expensive to provide periodic maintenance in order to maximize the system's service life than it is to have it fail from neglect.

While there is, in this author's experience, usually great care taken in the design and installation of a green roof, this same care is not often afforded to roof modifications (such as the installation of new roof openings) after the architect, engineers, and contractors have left the site. To aid in the maintenance and modification of the roof, information on the roof construction, together with the recommended maintenance procedure, need to be provided to the owner or building operator at the end of the project. On larger projects, these records can be incorporated into the building-commissioning process.

A maintenance inspection is recommended during both the spring and the late fall, as well as prior to the lapse of the contract or manufacturers' warranties. Most roofing trade organizations, such as the CRCA and NRCA, provide information on the frequency and type of maintenance required for roofs in general.

The maintenance for green roofs (excluding plants and growing medium) should include:

1. An inspection and cleaning of roof drains, scuppers, and accessible drainage paths
2. Investigation of areas that appear to pond water
3. Inspection and removal of all debris, including dead plant material and spills of contaminants that can increase the risk of fire or block drainage paths
4. Identification and inspection of all modifications made to the roof since last inspected, to ensure that the work has been completed to good trade practices and does not negatively impact the performance of the roof

5. Inspection of all drains, drain screens, flashings built into membranes, and counterflashings for signs of movement or corrosion; replacement of any dislodged or damaged material
6. Inspection and replacement of any areas or materials that have become dislodged due to floating, wind, or system failure
7. Inspection and reseal of all broken or deteriorated caulking joints or seals
8. Inspection and repair of leaks when reported; failure to act in a timely manner will escalate cost

Additional maintenance information is available and may form part of most extended-warranty agreements available from membrane manufacturers.

CONCLUSION

Green roofs can provide aesthetic appeal and improved moisture, thermal, and sound control. However, the benefits of green roofing will not be achieved if the waterproofing system leaks prematurely, requiring its removal and replacement.

Depending upon its design and accessibility, the cost of replacement can be four to 10 times the cost of original construction.

While other types of roof assemblies can be used, roofs of protected-membrane design provide the best chance of success, due to the fact that the insulation covers and protects the roof membrane.

The roof deck must be designed to carry the anticipated structural loads and must be sloped to achieve positive roof drainage. A minimum slope of 2 percent is recommended. Steeper slopes need to be given careful design consideration to avoid slippage or system failure.

Roof drains must be installed below roof level and be corrosion resistant. Access to drains must be provided to allow for inspection and maintenance. A means of improving drainage and drying, the subsurface system at the insulation and membrane level needs to be implemented. This can be completed by underscoring the insulation, providing drainage mats, and installing vent pipes.

Designs should include continuous drainage and venting systems adjacent to the flashings and drains. Extruded polystyrene insulation provides good service in green roofs, due to its physical characteristics and moisture-resistant properties. Where possible, insulation should be installed in one layer.

The waterproofing membrane serves more than one function. Membranes that are solidly adhered to the deck will limit the spread of water, should a leak occur. Multilayer systems provide the benefit of redundancy. The installation of a cap sheet on hot-rubber or built-up roof membranes will improve the durability of the membrane and long-term service. A root-resistant membrane and/or root barrier that facilitate topside venting of the insulation is required.

Special considerations need to be implemented when using single-ply membranes; the thicker the membrane, the better. Double welds or cover strips will improve the seam's ability to provide long-term service. Large areas should be compartmentalized to reduce the spread of water, should a leak occur.

Flashings typically represent 70 percent of all problems. Flashings should be designed of sufficient height and durability to survive in the environment to which they are exposed. Designs must include continuity of the moisture/air/vapor barrier and thermal barrier. The flashings should be designed to provide accessibility for inspection and maintenance. The continuity of the waterproofing membrane needs to be tested during initial installation.

Systems are available to monitor in-service performance. In-service inspection and maintenance are important and should be completed on a regular basis. Failure to do so will increase the risk of leaks, will shorten the life expectancy of the system, and may nullify long-term warranties.

Green roofs need increased inspection and maintenance to ensure drains and drainage paths are kept open and working.

In summary, design of green roofs must focus on providing long-term service, making provisions for structural load, thermal efficiency, and moisture control. Designs must provide for inspection and maintenance. Aesthetics should not override function.

With attention to these factors, the benefits of roof gardens can be realized, and their contribution toward the improvement of the urban environment will be long lived.

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