GREEN ROOF SYSTEMS

Table of Contents

List of Figures

1.0 SCOPE

This data sheet provides general guidelines for green roof systems. The green roof systems addressed in this data sheet are typified by a top layer of living plant material and soil (growth media or engineered soil) supported on the roofing assembly below. Green roof systems are also referred to as greenroofs, roof gardens, eco-roofs, landscaped roofs, and vegetated roof covers.

This data sheet is not intended to address or include information on roofing components or other materials that are sometimes referred to as “green” based on recycled material content, environmentally sustainable manufacturing methods, or reduced environmentally damaging disposal effects.

1.1 Changes

April 2011. Made changes to Section 2.2.2 regarding wind speed restriction; and Sections 2.1.2.2 and 2.2.16 regarding FM Approved roofing assemblies.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

The following sections provide recommendations for reducing exposures to natural hazards, fire, and excessive loads.

2.1.1 Types of Green Roofs

Green roofs can be categorized into three types:

- Extensive
- Intensive
- Simple Intensive

Each type is defined primarily by the depth of the growth media layer, but also by the kind of vegetation.

2.1.1.1 Extensive Green Roofs

Growth media is less than 6 in. (150 mm) in depth, but typically ranges from 3 to 4 in. (80 to 100 mm).

Extensive green roofs require minimal maintenance once the vegetation has become well established (usually after two or three growing seasons).

Extensive green roof vegetation typically consists of low-growing, herbaceous (non-woody) plants, including succulents, mosses, and grasses. Ideal plants are those that are tolerant to drought and temperature extremes, exhibit good growth and survival rates, demonstrate successful self-propagation, provide good groundcover density, and have a strong horizontal root system but a non-aggressive vertical root system. These qualities are most often possessed by succulent plants, particularly those from the Sedum family. Sedums are hardy alpine plants that are well-suited to many green roof environments and are commonly specified for that use.

Extensive green roofs are the least costly and most common of the green roof systems.

2.1.1.2 Intensive Green Roofs

Growth media is 8 in. (200 mm) or more in depth, but can be well over 12 in. (300 mm).

Intensive green roof systems require substantial maintenance at regular intervals, including irrigation, mowing, fertilizing, and weeding.

2.1.1.3 Simple Intensive Green Roofs

Growth media is generally from 6 to 8 in. (150 to 200 mm) in depth.

This is a hybrid system, composed of both Extensive and Intensive green roof characteristics in varying degrees.

2.1.2 Roofing Assembly

2.1.2.1 A green roof system consists of two major groups of components:

1. Above-membrane vegetated roof system. These components include the vegetation, growth media, moisture retention mat, geotextile filter fabric, drainage / retention panel, protection fabric, and root barrier. For systems with deep layers of growth media (i.e., Intensive systems), a layer of rigid insulation is often added below the root barrier (bearing directly on the roofing membrane). The above-membrane components typically are loose-laid.

2. Roofing base assembly. These components include the waterproofing roof membrane, protection board, rigid insulation, thermal barrier, and the supporting structural roof deck. The components can be fully adhered, mechanically attached, or loose-laid and ballasted. See section 2.1.2.2 for recommendations regarding FM Approved assemblies.

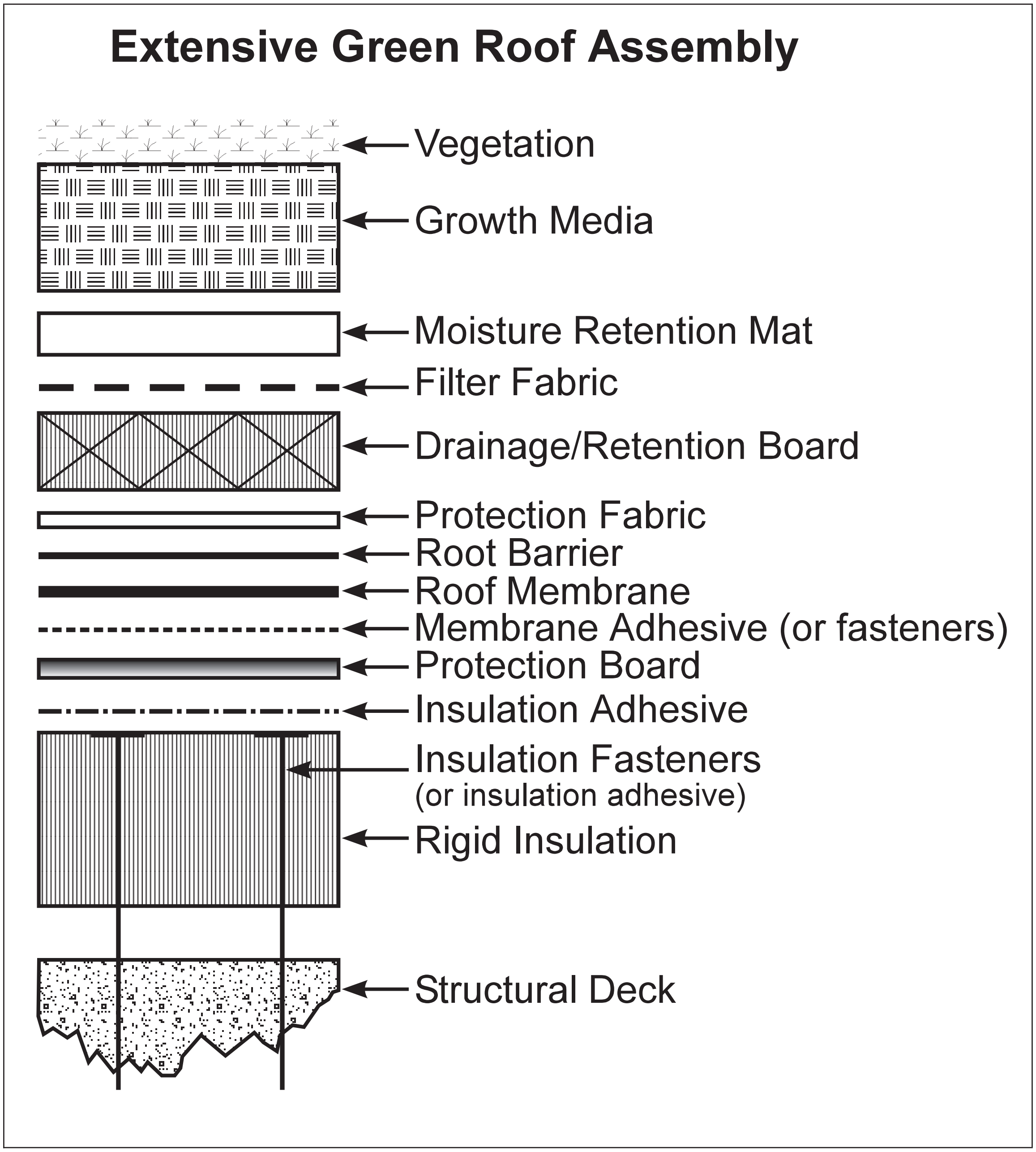

Fig. 1. Sample Extensive green roof assembly

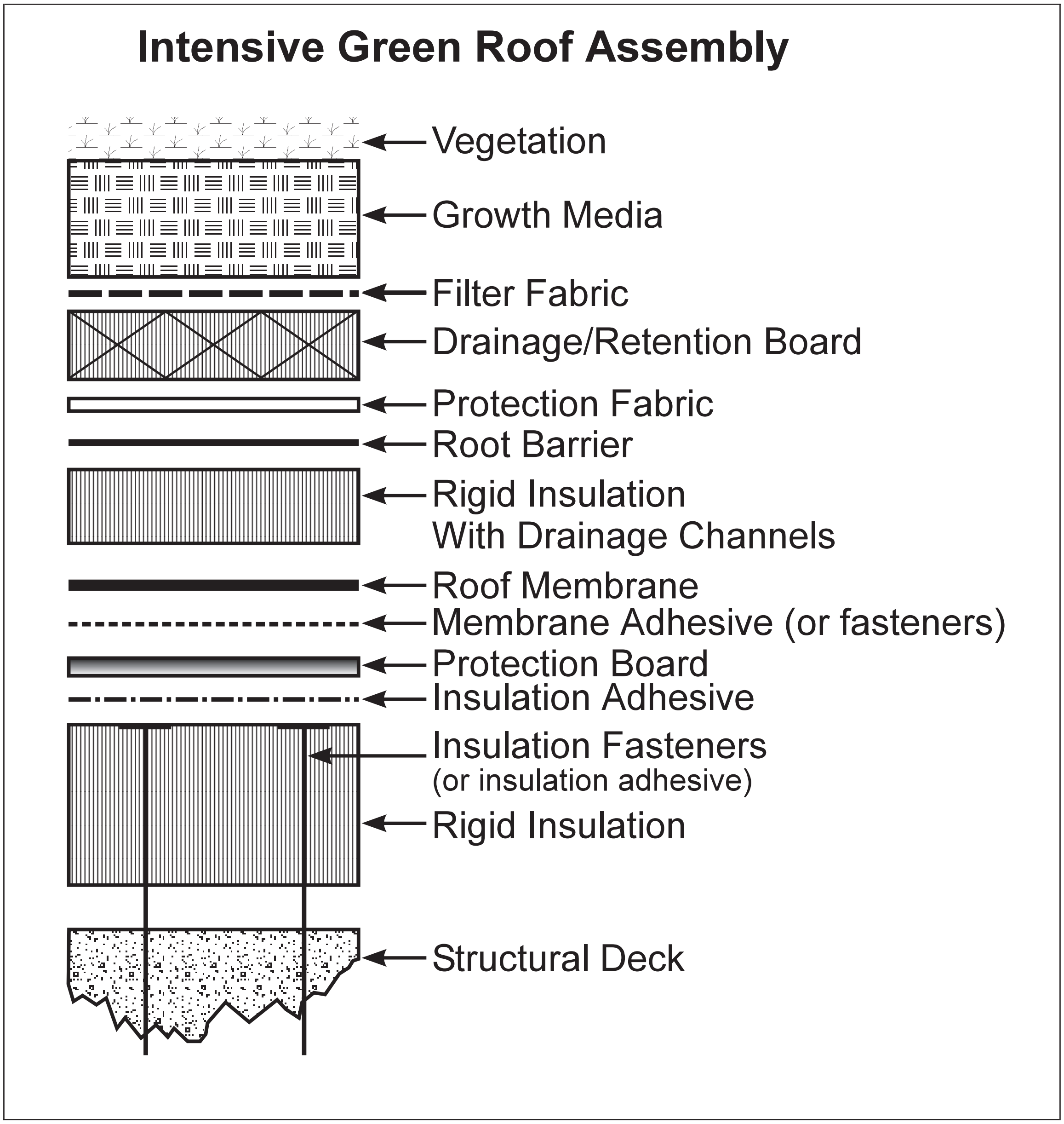

Fig. 2. Sample Intensive green roof assembly

2.1.2.2 **FM Approved** Roofing Assemblies

Use an FM Approved roof tested per FM Approval Standard 4477,*Vegetated Roof Systems.*

2.2 Construction and Location

2.2.1 Building Height Restriction

For green roof systems on buildings over 150 ft (46 m) high, use concrete pavers in non-vegetated border zones; do not use roof gravel or stone ballast. Also, see Section 2.2.14.3.3 for parapet wall provisions when building heights exceed 150 ft (46 m).

For building heights not exceeding 150 ft (46 m), stone ballast or concrete pavers may be used in non-vegetated border zones. Ensure installations are in accordance with Section 2.2.7 of Data Sheet 1-29, *Roof Deck Securement and Above-Deck Roof Components.*

2.2.2 Wind Speed Restriction

Install green roof systems only in geographical locations where the basic wind speed (3-second gust), as determined from Data Sheet 1-28, *Wind Design*, is less than 100 mph (45 m/s). This applies to all building heights.

2.2.3 Wind

2.2.3.2 Wind Uplift, Roof Ballast, and Safety Factor

2.2.3.2.1 Use a mechanically attached or fully adhered roof membrane system based on appropriate wind uplift design pressures and wind rating pressures as determined from Data Sheet 1-28, *Wind Design*. For ballasted roof systems, see additional recommendations contained in section 2.2.3.2.

2.2.3.2.2 Use growth media (engineered soil) as ballast against wind uplift for the roofing membrane and other waterproofing elements only where a uniform depth of 8 in. (200 mm) or more is provided; when this is the case, use a minimum **safety factor** of **1.7** for wind uplift calculations based on appropriate wind uplift design pressures as determined from Data Sheet 1-28, *Wind Design* . Calculate the safety factor based on a dry condition (no water present in the growth media, retention mat, drainage panel, etc.) and without the presence of any vegetation load.

2.2.3.2.3 Use a minimum of 3 in. (76 mm) of stone ballast unless greater depths are recommended either in Data Sheet 1-29, *Deck Securement and Above-Deck Roof Components,* or by the manufacturer or installer. Use clean, smooth, well-rounded stone ballast that conforms to the gradation requirements of Standard Size No. 3 Course Aggregate per ASTM D 448 (nominal 1 to 2 in. [25 to 50 mm] in diameter).

2.2.3.2.4 Growth media may be used as a secondary ballast material; that is, it may be used to ballast the loose-laid roofing components above the waterproofing membrane (i.e., drainage panel, retention mat, root barrier, and insulation board), but not the membrane itself. Use wind uplift design pressures (as determined from Data Sheet 1-28*, Wind Design*), a dry condition (no water present in growth media, retention mat, drainage panel, etc.), no vegetation, and a minimum **safety factor** of **0.85** for wind uplift calculations where growth media is used to ballast the loose-laid above-membrane components. See Section 2.2.16.2, Growth Media, for additional minimum depth requirements of growth media.

2.2.3.2.5 Pre-cultivated vegetated mats (rather than direct planting of plugs or cuttings) are sometimes used for green roofs. Where vegetated mats are installed, anchor them until the mat's root growth has achieved sufficient attachment into the growth media to adequately resist wind action (at least one full growing season). Ensure vegetated mats are properly anchored or ballasted against wind forces based on a **safety factor** of **1.0**. If pre-cultivated vegetated mats are to be used as ballast for the roofing membrane or other waterproofing elements - refer to section 2.2.3.2.2 for safety factor requirements.

2.2.3.3 Wind-Borne Debris

Do not use woody vegetation on a green roof when the wind uplift pressure at the roof elevation is equal to or greater than the uplift pressure at an elevation of 15 ft (4.5 m) or less for ground roughness B and a basic wind speed (3-sec gust) of 110 mph (49 m/s).

2.2.4 Hail

Hail can accumulate at roof drains and prevent proper drainage from melting hail and subsequent or concurrent precipitation. Conduct a roof inspection as soon as practicable following a hail storm. Inspect and clear drains as necessary. Inspect exposed roofing membrane for broken blisters or cracks. Repair any damage to the roofing membrane as necessary. Refer to Data Sheet 1-28R/1-29R*, Roof Systems,* for recommendations regarding FM Approved roof coverings for hail impact.

2.2.5 Gravity Loads

Ensure the supporting roof structure is designed to properly support the loads associated with the green roof system in a fully-saturated condition, as well as any additional supported environmental loads (e.g., snow, rainwater, ice), suspended or supported dead loads (e.g., rooftop equipment, suspended interior finishes, piping, ductwork, roofing assembly), and superimposed roof live loads. In addition, ensure the roof structure can adequately support the hardscape roof features such as stone ballast, pavers, and curbing. See Section 2.2.9, Roof Drainage, for minimum standing water load requirements based on drainage configuration. Refer to Section 2.2.15, Roofs at Grade, for additional load requirements.

2.2.5.1 Dead Loads

Ensure that the design dead load of the green roof system has been determined in conformance with ASTM E2397 and ASTM E2399 or equivalent rigorous test standards. If conformance with these test standards cannot be verified, then base the design dead load of growth media on a saturated density of not less than 100 lb/ft^3 (134 kg/m^3) for maximum gravity load combinations. In addition to the typical components comprising the dead load, consider captured and retained water to be part of the dead load.

2.2.5.2 Live Loads

Sometimes green roof systems are incorporated into roof areas where people are expected or encouraged to congregate; in such assembly areas (similar to balconies, terraces, etc.), ensure the supporting roof structure is designed to support a minimum roof live load of 100 psf (4.8 kPa).

Determine minimum design roof live load requirements in accordance with Data Sheet 1-54*, Roof Loads for New Construction,* with the following restrictions:

- For Extensive green roofs, ensure the minimum roof live load is no less than 12 psf (0.58 kPa), even when considering live load reduction.
- For Intensive and Simple Intensive green roofs, ensure the minimum roof live load is no less than 20 psf (0.96 kPa), even when considering live load reduction.

2.2.5.3 Environmental Loads

Refer to Data Sheet 1-54*, Roof Loads for New Construction,* for minimum design snow load and rain load requirements. Consider transient water to be part of the total rain load.

2.2.6 Future Load Allowances

To account for future additions of growth media and inconsistencies in grading, increase the specified depth of saturated growth media by not less than 15% for the purpose of structural load calculations.

Do not use future load allowances in calculations when these loads counteract any uplift or overturning forces.

2.2.7 Design Surface Loads of Vegetation

Surface loads of vegetation are provided by the green roof supplier or installer. The following can be used as reasonable minimum design loads:

Succulents (Sedums), herbs, grasses	2 psf (10 kg/m^2)
Grasses and bushes up to 6 in. (150 mm)	3 psf (15 kg/m^2)
Shrubs and bushes up to 3 ft (1 m)	4 psf (20 kg/m^2)

2.2.8 Seismic Loads

When calculating maximum seismic base shear, and maximum seismic overturning and uplift, evaluate the following conditions when determining the dead loads used in the most stringent design load combinations:

a) Include the full weight of the entire green roof assembly (including fully-saturated growth media with retained and captured water).

b) Exclude the full weight of the above-membrane green roof components (assume a conventional roof cover).

In the first condition, consider the effects of localized removal of green roof assembly or hardscape components where the result would constitute a more stringent design condition for the structural support system.

Refer to Data Sheet 1-2*, Earthquakes,* for additional seismic load guidance.

2.2.9 Roof Drainage

2.2.9.1 Provide a primary roof drainage system capable of removing rainwater from the roof at a rate equal to or greater than that resulting from the 60-minute duration, 100-year mean recurrence interval (MRI) rainfall event.

2.2.9.2 Provide a secondary drainage system completely independent of the primary drainage system. Ensure the secondary drainage system is capable of removing rainwater from the roof at a rate equal to or greater than that resulting from the 15-minute duration, 100-year MRI rainfall event.

Ensure the base (invert) of the secondary drainage inlets are at least 2 in. (50 mm), but no more than 6 in. (150 mm), in elevation above the base of the primary drainage inlets.

2.2.9.3 Include the weight of rainwater (based on the depth required to achieve the secondary drainage design capacity) in roof design load. Consider potential ponding resulting from roof deflections.

2.2.9.4 Provide drainage systems designed to conform to the more stringent of the following conditions:

a) The green roof system as proposed

b) The roof with a traditional roof cover (i.e., without the above-membrane green roof assembly)

2.2.9.5 Provide drains and outlets that have inspection chambers with removable covers, allowing for easily accessible inspections to ensure plants, growth media, and gravel do not restrict or reduce flow.

2.2.9.6 In addition to horizontal roof surfaces, ensure the drainage design accounts for vertical sheet flow from large façades due to wind-driven rains.

Refer to Data Sheet 1-54, *Roof Loads for New Construction,* for additional information regarding design rainfall intensity and duration.

2.2.10 Roof Slope

2.2.10.1 Provide a minimum roof slope of 2% (¼ in./ft or 1.1º) for all green roofs supported by structural concrete decks. For green roofs supported by other structural systems (e.g., metal roof deck), provide a minimum roof slope of 3% (⅜ in./ft or 1.8º).

2.2.10.2 For roof slopes greater than 20% (11º) but less than 40% (22º), provide additional anti-shear stability layers or anchorage, and erosion control. Do not use roof slopes greater than 40% (22º) as they will pose a significant challenge regarding stability and erosion.

2.2.10.3 Ensure shear loads induced by the roof slope do not damage any underlying layers (e.g., the drainage panel, protection fabric, root barrier, or membrane). Ensure growth media is placed and cultivated in such a way as to protect against sliding in both dry and saturated conditions. This may be achieved by the use of crushed aggregate (e.g., brick, expanded shale, pumice) in the mineral soil, which will provide good shear resistance due to the rough angular nature of the particles. Limiting fine aggregate content in the growth media, combined with good root penetration, will also promote stability and limit wash-out.

2.2.11 Supporting Structure

2.2.11.1 Use structural concrete deck for all green roofs with over 6 in. (150 mm) of growth media. Acceptable structural concrete deck includes cast-in-place concrete, post-tensioned concrete, pre-cast concrete, and structural concrete on metal deck. Ensure concrete has a 28-day compressive strength of no less than 3,000 psi (21,000 kPa), and a density of no less than 110 lb/ft^3 (1,760 kg/m^3).

2.2.11.2 For green roof systems with less than 6 in. (150 mm) of growth media, structural concrete deck or metal roof deck is acceptable.

2.2.11.3 Provide a galvanized finish for all exposed steel elements, steel anchors, and steel deck. Provide minimum G90 galvanizing (0.90 oz/ft^2 [275 g/m^2] zinc coating, per ASTM standard A653 or equivalent) for steel deck. Provide concrete cover for top reinforcing based on permanent exposure to weather, according to ACI standard 318 or equivalent.

2.2.11.4 Do not install green roof systems on structural deck materials other than structural concrete or metal.

2.2.11.5 Ensure the supporting structure has been designed and checked by a registered structural engineer to properly support all dead, live, and environmental loads (e.g., snow, rain, ice, flood, wind, seismic) associated with green roof systems, including the effects of ponding.

2.2.12 Fire Exposure

2.2.12.1 Exterior Fire Exposure

Due to the many variables (including plant type, plant condition, depth of growth media, combustibility of roofing assembly materials, and installation details) and the lack of sufficient experience and test data, classification of exterior fire exposure cannot be made with certainty at the present time.

2.2.12.2 Interior Fire Exposure

Evaluate green roof systems for interior fire exposure (as regards to a Class I or Class II rating) in the same manner as for conventional roofing systems on metal deck.

For green roof systems on concrete deck, assume the assembly is non-combustible with regard to interior fire exposure.

2.2.13 MFL Fire Walls

Provide areas free of vegetation and growth media adjacent to MFL walls in conformance with the minimum setbacks as defined in Data Sheet 1-22, *Maximum Foreseeable Loss*. Extend vegetation-free border zones not less than 50 ft (15 m) on each side of an MFL wall and cover with stone ballast, concrete paver blocks (refer to Data Sheet 1-29, *Roof Deck Securement and Above-Deck Roof Components*), or a gravel-surfaced roof cover as noted in Data Sheet 1-22. Refer to Data Sheet 1-22 for additional provisions regarding roof surfacing and parapets at MFL walls.

2.2.14 Non-Vegetated Border Zones, Fire Breaks, and Parapet Walls

Provide stone ballast or concrete paver blocks to cover all border zones that are designated to be free of vegetation and growth media. Refer to Data Sheet 1-29, *Roof Deck Securement and Above-Deck Roof Components,* for minimum recommendations regarding ballasted systems; note that the provision for increased minimum dimension (8.5 ft [2.6 m]) of perimeter and corner areas as described in Section 2.2.10.17.6 of Data Sheet 1-29 need not apply to green roof systems unless the roofing membrane relies on ballast to resist wind uplift pressures.

2.2.14.1 Perimeter and Corner Zones

Ensure border zones (as defined by perimeter and corner zones in Data Sheet 1-28, *Wind Design)* are free of vegetation and growth media.

2.2.14.2 Rooftop Structures, Penetrations, and Joints

2.2.14.2.1 Provide a minimum 1.5 ft (0.5 m) wide continuous border zone (free of vegetation and growth media) surrounding all rooftop equipment, penetrations (e.g., ducts, drains, pipe, conduit), skylights, solar panels, antenna supports, expansion joints, roof area dividers, and interior parapet walls (unless part of an MFL Fire wall; refer to Section 2.2.13, MFL Fire Walls**,** for additional requirements). Consider wider vegetation-free zones in cases where HVAC intake or exhaust could be expected to affect or be affected by plant growth; for instance, where taller plant growth might restrict intake, or high velocity exhaust emissions could cause plant damage.

2.2.14.2.2 Provide a minimum 3 ft (0.9 m) wide continuous border zone (free of vegetation and growth media) around rooftop structures, including but not limited to mechanical and machine rooms, penthouses, and adjacent façade walls.

2.2.14.2.3 Provide 3 ft (0.9 m) wide continuous border zone strips (free of vegetation and growth media) to partition the roof area into sections not exceeding 15,625 ft^2 (1,450 m^2), with each section not exceeding 125 ft (39 m) in length. Incorporate the border zones into expansion joints or roof area dividers wherever possible.

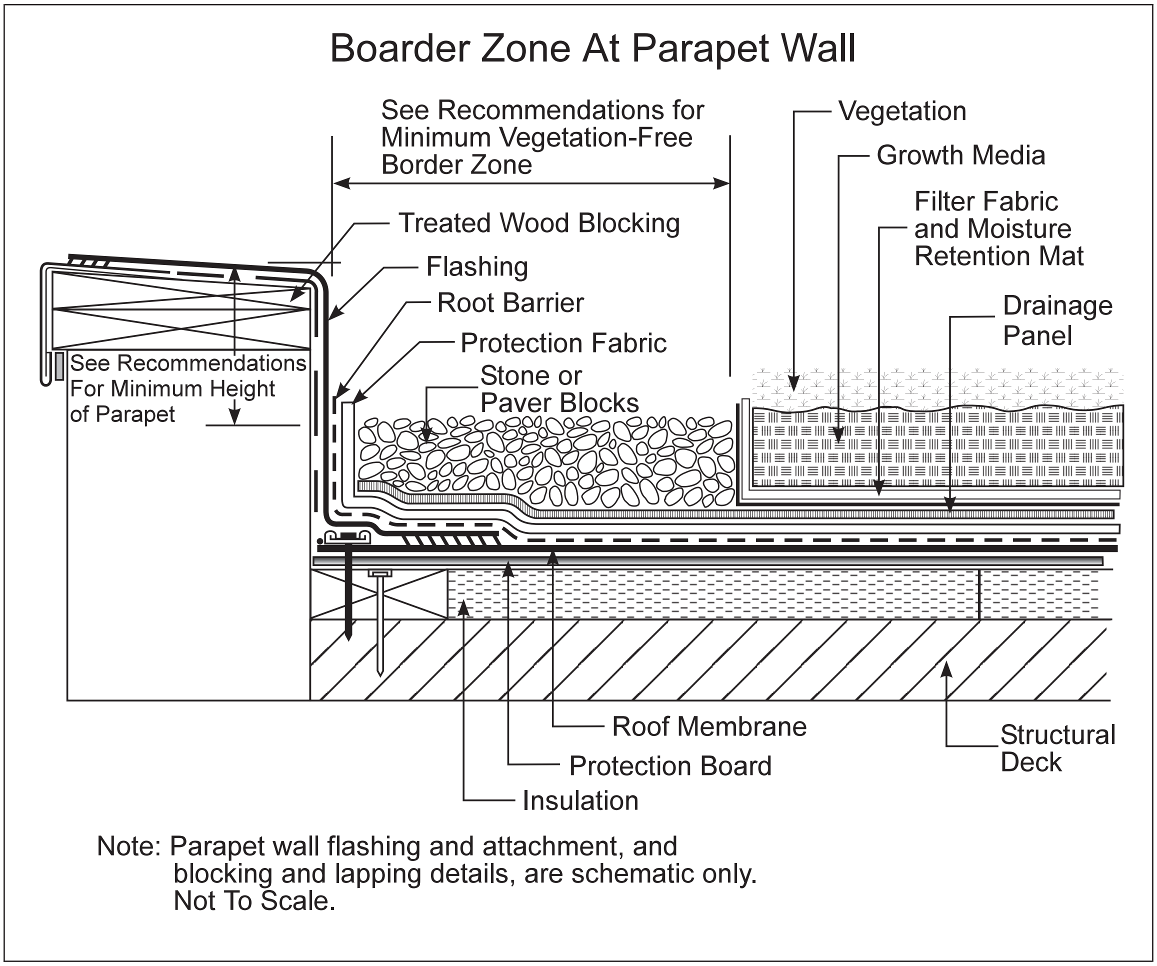

Fig. 3. Sample non-vegetated border zone detail at parapet wall

2.2.14.3 Parapet Walls

2.2.14.3.1 Provide perimeter parapet walls for all green roof systems.

2.2.14.3.2 Provide parapet walls that extend at least 6 in. (150 mm) in elevation above the top of the growth media, stone ballast, or concrete pavers.

2.2.14.3.3 For roof elevations above 150 ft (46 m), provide a perimeter parapet wall not less than 30 in. (760 mm) in height.

2.2.14.3.4 Where parapet walls 30 in. (760 mm) in height or greater are provided, the adjacent border zones specified to be free of vegetation and growth media (see Section 2.2.14.1, Perimeter and Corner Zones) may be reduced to not less than 3.0 ft (0.9 m) wide.

2.2.15 Roofs at Grade

2.2.15.1 Use a minimum 100 psf (4.8 kPa) roof live load for roofs located at or below grade, or transitioned into a sloping grade (e.g., partially built into a hillside). For roofs where vehicle access is feasible (commercial trucks, fire brigade tankers, or similar), use appropriate vehicle loads, with maximum axle loads of not less than 32,000 lb (14,500 kg) or equivalent uniform surcharge loads of not less than 250 psf (12 kPa). Where roofs are not designed to support vehicle loads, provide permanent physical barriers (e.g., bollards, guard rails) along with appropriate signage to restrict vehicular access.

2.2.15.2 Provide a continuous vegetation-free border zone break at least 3 ft (0.9 m) wide to separate the green roof system from adjacent at-grade vegetation or materials. If the surrounding grade materials are deemed to pose a fire hazard (e.g., forest, grass, or brush fires) refer to Data Sheet 9-19, *Bushfire Exposure*. Evaluate other potential fire exposure hazards on a site-specific basis.

2.2.15.3 For roofs built into a sloping grade, ensure that the structural engineer and geotechnical engineer have evaluated the roof structure and site conditions for potential mudslide or landslide hazards. Also, ensure the building official has been consulted regarding local historical occurrences relating to soil stability.

2.2.15.4 Evaluate roofs at or below grade (e.g., below-grade parking facility with landscaped green roof) for flood loads. Use the 500-year flood elevation as a basis for the evaluation.

2.2.16 Green Roof Components

Use an FM Approved roof tested per FM Approval Standard 4477, *Vegetated Roof Systems.*

2.2.16.1 Vegetation

Among the many characteristics required of green roof plants, the most critical are good fire resistance, good drought resistance, and a non-aggressive vertical root system that will be unlikely to penetrate and compromise underlying waterproofing layers. Consult a landscape or horticultural professional familiar with green roof systems regarding the selection of an appropriate comprehensive vegetation system.

2.2.16.1.1 Use plants generally accepted as appropriate for green roof applications, the local climate, and the rooftop microclimate.

2.2.16.1.2 Avoid the use of grasses and mosses, which can dry out and create a potential fire hazard.

2.2.16.1.3 Include no less than 60% of vegetation from the Sedum family for groundcover plantings. Use at least three different species of Sedums, generally in equal quantities.

2.2.16.1.4 For groundcover plantings, sow seeds at a rate of not less than 3,000 seeds per 100 ft^2 (325 per 1 m^2), distribute cuttings at not less than 2.5 lb per 100 ft^2 (12 kg per 100 m^2), or install pre-grown plugs at the rate of not less than 100 plugs per 100 ft^2 (11 plugs per 1 m^2).

2.2.16.1.5 When propagating from cuttings or dry seed, use non-combustible photo-degradable mesh ‘‘wind blankets’’ to protect against erosion until the plants are sufficiently established as ground cover. Typically, this takes from two to three growing seasons.

2.2.16.1.6 Limit plantings such that the full-grown, mature height of the vegetation (small trees, bushes, shrubs, etc.) will not exceed 3 ft (0.9 m).

2.2.16.2 Growth Media (Engineered Soil)

2.2.16.2.1 Provide no less than 3 in. (80 mm) of uniform depth growth media in its installed (compacted) condition.

2.2.16.2.2 Do not substitute standard landscaping soil or loam for growth media. Growth media contains porous aggregate materials, such as crushed clay brick, expanded shale, and crushed pumice, that are specifically designed to retain water, provide aeration, and allow for proper drainage.

2.2.16.2.3 Provide growth media in conformance with the manufacturer’s or landscape / horticultural professional’s specifications. See Section 3.12.1 for typical requirements regarding air and salt content, pH, and water content and permeability.

2.2.16.3 Moisture Retention Mat

Provide a moisture retention mat that conforms to the requirements of the green roof system. Typically, a water retention capacity of not less than 0.2 in./ft^2 (0.12 gal/ft^2 [5.0 l/m^2[) will be necessary.

2.2.16.4 Drainage Panel and Filter Fabric

2.2.16.4.1 Provide drainage panels with a compressive strength sufficient to properly support the required loads (saturated overburden of growth media and vegetation, roof gravel, and pavers in hardscape areas, roof live loads, and any required environmental loads) according to the manufacturer’s specifications.

2.2.16.4.2 Ensure the filter fabric will allow for unimpeded root penetration and provide a minimum vertical capillary rise of 4 in. (100 mm) in five minutes. Take particular care to ensure properly detailed filter fabric terminations are used around drainage fixtures to prevent erosion of growth media and clogging of drains.

2.2.16.5 Protection Fabric

Provide a durable water-permeable protection fabric of no less than 0.75 lb/yd^2 (285 grams/m^2).

2.2.16.6 Root Barrier

2.2.16.6.1 For systems with asphalt-based or bituminous waterproofing membranes and materials, provide a root barrier not less than 0.03 in. (0.8 mm) in thickness, and continuously seal (heat weld or solvent weld) all root barrier seams.

2.2.16.6.2 For all systems with over 6 in. (150 mm) of growth media, provide a root barrier not less than 0.03 in. (0.8 mm) in thickness, and continuously seal (heat weld or solvent weld) all root barrier seams.

2.2.16.6.3 When the seams of waterproofing membranes are not designed to be heat-welded (e.g., EPDM membranes), provide continuous heat-welded root barrier seams.

2.2.16.6.4 Lap all root barrier seams to be sealed at least 6 in. (150 mm). Use welded seams not less than 1.5 in. (38 mm) wide in order to create a watertight seal. Test welded seams for integrity by either air lance or hand scribe techniques.

2.2.16.7 Waterproofing Membrane

For systems with asphalt-based or bituminous waterproofing membranes or materials, ensure an appropriate root barrier is provided (see Section 2.2.16.6, Root Barrier).

2.2.16.8 Protection Board

Provide protection board of sufficient strength and durability to adequately protect the waterproofing membrane during construction and in the permanent fully assembled condition. Avoid materials that will loose effectiveness with prolonged exposure to moisture.

2.2.16.9 Insulation Board

2.2.16.9.1 Use insulation board with adequate compressive strength and durability to support the weight of the saturated green roof hardscape materials, such as roof gravel and pavers, roof live loads, and environmental loads, according to the manufacturer's specifications.

2.2.16.9.2 If also using above-membrane insulation board, provide boards with integral drainage channels to facilitate drainage.

2.3 Operation and Maintenance

2.3.1 Irrigation

2.3.1.1 For green roof systems designed to be self-sustaining without regularly scheduled irrigation (i.e., most Extensive systems), provide rooftop hosebibs to allow for irrigation during initial stages of plant propagation and during occasional drought conditions.

2.3.1.2 For green roof systems that require regular irrigation (i.e., Intensive and Simple Intensive systems) ensure that a permanent irrigation system is provided.

2.3.2 Fertilization, Pesticides, and Plant Care

2.3.2.1 Fertilization will most likely be necessary during the initial establishment of the vegetation over the first and second growing seasons; after that time, occasional fertilization, perhaps once or twice annually, might be necessary. Consult the roofing manufacturer in order to determine which chemical fertilizers and pesticides, if any, are acceptable and will not damage the waterproofing assembly or void the warranty.

2.3.2.2 Include inspections and selective weeding as part of the regular maintenance work; provide these at least twice annually.

2.3.3 Leak Test and Inspection

Prior to the installation of the above-membrane components (drainage panel, growth media, vegetation, etc.), the contractor will conduct a standing water leak test (also known as a flood test). The test will involve flooding the entire green roof area with not less than 2 in. (50 mm) of standing water for a period of at least 24 hours with drains and scuppers blocked. Ensure drains or scuppers allow for emergency overflow if the water level exceeds the specified test level (for instance, due to an overnight rain). Ensure the structure can adequately support the hydrostatic load encountered during the flood test, including the effects of ponding.

Prior to draining the standing water, the owner's representative, manufacturer's representative, and contractor will inspect the roof for leaks from below, and from the roof surface; this will include walking all membrane seams. Once the standing water has been drained, inspect the roof and walk all membrane seams again. If areas are found that are suspected of leaking, the contractor will perform test cuts according to the manufacturer's directions. If test cuts are determined to be wet, the contractor will patch the test cut per the manufacturer's specifications and the flood test will be repeated. In addition to leak detection, include inspection for adequate slope to drain.

2.3.4 Warranty

If the entire system (waterproofing assembly as well as vegetated roof cover, including vegetation and growth media) is provided by a single source, ensure the manufacturer's warranty includes the initial vegetation viability. In addition to the standard waterproofing warranty, ensure the warranty states that the proposed vegetated roof cover is completely compatible with the waterproofing assembly. Also, ensure the warranty for the vegetated roof cover states that the proposed waterproofing system is compatible with the vegetated system (including plant climate zone, roof slope, and irrigation and maintenance requirements).

If the waterproofing and vegetated roof cover are not provided by a single source, ensure the waterproofing assembly will be warranted separately, independent of any warranty for the vegetated roof cover.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Wind Speed Restrictions

The geographic locations of green roof systems are limited based on wind speed (3-second gust, as determined by Data Sheet 1-28, *Wind Design*) in order to eliminate or reduce the likelihood that growth media and/or roof gravel will become wind borne debris. The limitation is also intended to reduce the effects of wind-induced scour of growth media and the resulting loss of ballast of above-membrane components, as well as potential damage to the vegetation.

3.2 Wind

The growth media on a green roof system can be prone to scour from wind and water action and therefore may not be a reliable source of uniform ballast for waterproofing components when provided in shallow depths.

Refer to Data Sheet 1-29*, Roof Deck Securement and Above-Deck Roof Components,* for stone ballast requirements in non-vegetated border zones. Note that stone ballast is not to be used on roofs greater than 150 ft (46 m) in height.

3.3 Wind-Borne Debris

Growth media typically contains aggregate materials, including crushed porous rock (e.g., pumice, expanded shale) or crushed clay brick, that can create a potential source of wind-borne debris similar to roof gravel. Although vegetation will provide a certain amount of wind shelter and the plant roots will help anchor the surrounding growth media, it can take several growing seasons for the vegetation to become sufficiently established to protect the growth media from wind action.

3.4 Hail

The above-membrane components (including growth media, drainage board, and protection fabric) will provide substantial protection to the waterproofing membrane from hail exposure. However, areas of exposed membrane will be subjected to hail damage. Refer to Data Sheet 1-34, *Hail Damage*, for recommendations regarding FM Approved roof coverings for hail impact.

3.5 Gravity Loads

Gravity loads include dead loads, live loads, and some environmental loads (e.g., snow, rain, ice).

For structural design and analysis using Load and Resistance Factor Design (LRFD) or ultimate limit states design methodologies, it is necessary to properly classify the various loads associated with code-required factored load combinations. Load factors are determined by the classification of the load and can vary by code. For example, the factor for dead load could be 1.2, while the factor for roof live load, rain load, or snow load could be 1.6.

The green roof assembly (including vegetation, saturated growth media, and all captured and retained water) is classified as dead load. Transient water is considered roof rain load. Note that live load reduction is not applicable to environmental loads such as rain and snow.

3.6 Seismic Loads

Green roof systems can add a substantial amount of mass to the roof of a building. Since the mass of a building is one of the factors that controls the seismic (earthquake) loads induced into a building's lateral load-resisting system, the increased mass of a green roof system will cause an increase in seismic load. The weight of a building that is used when calculating seismic load typically includes the total dead load, a percentage of the storage live load and snow load, and a minimum allowance for moveable office partitions (where applicable).

Seismic design and analysis involves examining various load combinations to achieve the following conditions:

1. Maximum seismic base shear

2. Maximum seismic overturning and uplift

For the first condition, the greatest base shear loads are achieved under a maximum gravity load condition. Therefore, when considering a green roof system, include the full weight of the entire roofing assembly, including the fully-saturated growth media and captured water, when determining the dead load used for maximum seismic base shear seismic calculations. Transient water, which is considered part of the roof live load, need not be included when calculating seismic loads.

For the second condition, the greatest overturning of uplift loads can be achieved when the counteracting dead loads are minimized in a reasonable fashion. Therefore, exclude the entire weight of the above-membrane green roof system when determining the dead load used for maximum seismic overturning and uplift calculations. This provision is intended to address a potential future condition where the green roof system has been replaced with a conventional roof system.

3.7 Roof Drainage

The provision for more stringent drainage design (green roof system as proposed, versus a roof with a traditional roof cover) is intended to address the risk of insufficient drainage capacity for a roof that was originally designed as a green roof system but is either partially or completely replaced with a traditional roof cover at some time in the future.

Easily accessible inspection chambers in drainage outlets are an important part of ensuring the drainage system will function at capacity as designed. Root growth, displaced growth media and stone ballast, dead foliage, and general debris can act to substantially reduce the discharge capacity, allowing water to pond and create a collapse potential.

The provision for the differential in the elevation between primary and secondary drainage inverts (2 to 6 in. [50 to 150 mm]) is intended to ensure that the primary and secondary drains will not become clogged by debris concurrently. Also, that the maximum depth of retained water will be kept to a level that will not overload the supporting structure nor create a mechanism for ponding water.

3.8 Roof Slope

Structural concrete deck is preferred over steel roof deck to support green roof systems. Structural concrete deck has more strength and stiffness, and better resistance to water ingress and corrosion, than steel roof deck. Given the nature of green roof systems, which includes relatively large dead loads due to saturated growth media and retained water, these properties (strength, stiffness, and leak resistance) are of particular importance. When using steel roof deck, the minimum slope is increased (from 2% to 3%) in order to minimize the likelihood of ponding water and the subsequent potential for progressive deflection and collapse.

3.9 Supporting Structure

Due to the nature of green roof systems, particularly Intensive systems (which include a deep layer of growth media), the associated dead load can be substantial. Particular care must be taken to coordinate the supporting structural components with the drainage system in order to avoid excessive deflection and localized ponding. Some structural materials, such as concrete, are prone to long-term deflection (creep) when subjected to sustained loads over a long period of time.

3.10 Non-Vegetated Border Zones

Non-vegetated border zones are recommended for several reasons: (1) to provide maintenance access because green roof vegetation is not intended to support foot traffic, (2) to provide additional resistance to high wind uplift pressures, (3) as a means of reducing scour of growth media, (4) to reduce the potential generation of wind-borne debris at roof perimeters and corners, and (5) to provide a fire break at rooftop equipment, penetrations, and structures.

3.11 Vegetation

3.11.1 Climate

In the United States, vegetation can be selected based partly on the USDA Plant Hardiness Zone Map; however, the effects of solar radiation, wind, and frost can create a microclimate that will be more challenging for vegetation on a roof than for the same plants at grade level. The existence of a distinct microclimate is one of the reasons native vegetation frequently does not thrive on a green roof.

3.11.2 Extensive Green Roof Vegetation

Extensive green roof vegetation typically is limited to a few families of specialized hardy plants that can thrive in shallow soil. Extensive green roofs usually are not intended as accessible roofs since the vegetation does not support foot traffic.

Plants used successfully on an Extensive green roof system have characteristics such as wind resistance, frost resistance, drought resistance, resistance to radiation, a shallow root system, and good regenerative capabilities. As noted above, the microclimate on a green roof may exhibit significant differences from the local climate at grade. The combination of direct and reflected radiation, as well as higher wind velocity, can create a challenging environment above grade. The lack of such things as ground water (accessed through capillary action), natural soil aeration devices, and a deep thermal mass also can create a difficult environment for plant growth. For these reasons, planting Extensive green roofs with local native vegetation is frequently unsuccessful. However, specialty plants, such as Sedums, have exhibited good success rates due to their hardiness.

Sedums are succulent alpine plants that are regenerative, have shallow, non-aggressive root systems, are drought- and wind-resistant, and are relatively resistant to fire. Fire-resistant plants have foliage with a high moisture / low resin content; this is exhibited by supple leaves with watery sap. Sedums can be propagated using seeds or cuttings. Sedums can also be cultivated off-site, then planted in the form of plugs or pre-vegetated mats. Plugs have a higher up-front cost, but are preferred over cuttings and seed due to a better propagation success rate (roughly 80% for plugs, 50% for cuttings) and the resulting enhancement of erosion control against wind and water.

3.11.3 Intensive Green Roof Vegetation

Intensive green roof vegetation typically is more diverse and less specialized than Extensive green roof vegetation. Intensive green roof vegetation includes ground covers, grasses, shrubs, and even small trees.

3.12 Growth Media (Engineered Soil)

Growth media is the material that supports and nourishes the green roof vegetation; it provides water and nutrients to the plants, as well as anchorage for the root system.

Growth media consists of two components: mineral soil and organic soil. The proportions of mineral and organic soils varies significantly depending on the manufacturer; the organic content can range from 8% to 25% for Extensive green roof systems. The organic content for Intensive green roof systems is up to 50% greater than for Extensive systems. The mineral and organic soils usually are pre-mixed prior to placement on the roof. The depth of growth media usually ranges from 3 to 6 in. (75 to 150 mm) for Extensive systems, and from 8 to 24 in. (200 to 600 mm) for Intensive systems. Simple Intensive systems typically are classified by a depth of growth media from over 6 in. (150 mm) to less than 8 in. (200 mm). Growth media has an as-installed density of 5.5 to 6.0 psf/in. (1.1 to 1.2 kg/m^2 per mm) when dry, and 7.5 to 8.0 psf/in. (1.4 to 1.5 kg/m^2 per mm) when saturated.

Wind action can cause significant scour of the growth media, depriving the vegetation of moisture and nutrients, exposing plant roots and underlying roofing materials to UV radiation, and removing the ballasting effect the growth media may provide for the above-membrane roofing components.

3.12.1 Typical Specifications for Growth Media

The following are typical conditions specified for growth media:

- Soluble salt content no greater than 0.34 oz per gal (2.5 g/l) of extracted water for Extensive green roof systems, and 0.48 oz per gal (3.5 g/l) for Intensive systems.
- A pH within the following ranges: 6.5 to 8.0 for Extensive systems, and 5.5 to 8.0 for Intensive systems.
- Fully-saturated air content of not less than 10% by volume.
- Water storage capacity (by volume) in its installed, compacted state: from 25% to 65% for Extensive systems, and 45% to 65% for Intensive systems.
- Rate of water permeability in its installed, compacted state: not less than 0.12 in. per minute (3 mm/min) for systems with up to 6 in. (150 mm) of depth, and not less than 2.4 in. per hour (60 mm per hour) for systems with over 6 in. (150 mm) of depth.

3.13 Roofing Components

3.13.1 Moisture Retention Mat

A moisture retention mat is used to provide moisture to the growth media and the plant roots. The moisture retention mat typically is made of recycled polypropylene fibers stitched to a needle-punched, thermoplastic fabric sheet carrier, and is installed loose-laid. The moisture retention mat is designed to allow for unimpeded root penetration.

In some green roof assemblies, the moisture retention mat is designed to also serve as the protection fabric for the waterproofing membrane.

3.13.2 Drainage Panel and Filter Fabric

Drainage panels, also known as drainage / retention panels, have a two-fold purpose: (1) they allow for proper drainage of water from the overlying saturated growth media, and (2) they retain water to provide the root system with access to moisture during dry periods.

The drainage panel typically is molded from rigid thermoplastic (usually polyethylene or polystyrene) with “domes” and “cups” impressed into the shape. The domes are perforated to allow for air circulation to, and water drainage from, the growth media. The cups are designed to capture water, which can then be transferred to the growth media and root system through capillary action and absorption.

Filter fabric is used to retain growth media and prevent fine particles from being washed out of the growth media into the underlying drainage panel. Filter fabric typically is a non-woven geo-textile fabric made from thermoplastic (e.g., polyethylene or polypropylene) fibers.

3.13.3 Root Barrier

Root penetration into membrane laps and seams is one of the most common ways in which the integrity of the waterproofing system can be compromised. Root barriers are designed to provide protection from plant root migration under waterproofing membranes.

Green roof systems contain microorganisms in the growth media and root system that can attack and degrade bituminous and asphalt-based roofing products. Root barriers are used to protect underlying waterproofing materials from harmful microbial activity. Root barriers often are required to have heat welded lap seams; therefore, thermoplastics such as PVC, TPO, and polyethylene are commonly used. Root barrier sheets typically are installed loose-laid.

3.13.4 Protection Fabric

Protection fabric is used to protect the root barrier and waterproofing membrane from damage due to growth media aggregate, hardscape materials, drainage panel edges, and damage during installation. Protection fabric is a water-permeable, durable synthetic fiber material with good resistance to puncture. The protection fabric is sometimes provided as an integral part of the drainage panel.

3.13.5 Waterproofing Membrane

Green roof systems can be specified with fluid-applied asphalt-based membranes, torch-applied bitumen membranes, thermoplastic (PVC or TPO) single-ply membranes, or thermoset polymer-based (EPDM) single-ply membranes. Asphalt-based and bituminous membranes and materials are subject to attack and premature degradation from soil-borne microbial activity; therefore, root barriers are necessary to protect these membranes.

3.13.6 Protection Board

Fire and thermal barrier properties of protection board is of particular importance given the presence of several layers of combustible material associated with typical green roof assemblies.

3.13.7 Insulation Board

Rigid insulation board must have adequate compressive strength to properly support the weight of the saturated green roof, hardscape materials (such as roof gravel and pavers), superimposed roof live loads, and environmental loads. For systems with over 8 in. (200 mm) of growth media, two separate layers of insulation typically are provided. In addition to the below-membrane insulation, an above-membrane layer of insulation boards is provided as additional protection for the waterproofing membrane.

3.14 Irrigation

Extensive green roofs are designed to be viable without supplemental irrigation. However, during the first one or two growing seasons, and at times of extreme drought, access to irrigation (such as rooftop hose-bibs) will be necessary.

Intensive green roofs are not expected to be viable without regular irrigation and maintenance.

3.15 Leak Testing

Leaks in the waterproofing system can be difficult to detect and locate in a conventional roofing system. Leaks in green roof systems are particularly troublesome due to the covering of growth media and vegetation. In addition to the flood test described in Section 2.3.3, a method of leak detection called electric field vector mapping (EFVM) is available.

4.0 REFERENCES

4.1 FM Global

Data Sheet 1-2, *Earthquakes*

Data Sheet 1-22, *Maximum Foreseeable Loss (MFL)*

Data Sheet 1-28, *Wind Design*

Data Sheet 1-28R/1-29R, *Roof Systems*

Data Sheet 1-29, *Roof Securement and Above-Deck Roof Components*

Data Sheet 1-34, *Hail Damage*

Data Sheet 1-54, *Roof Loads for New Construction*

FM Approval Standard 4477,*Vegetated Roof Systems*

4.2 Other

ASTM International. E2397-05 Standard Practice for Determination Dead Loads and Live Loads associated with Green Roof Systems.

ASTM International. E2399-05 Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roof Systems.

ASTM International. *Hot Dip Galvanized Coils and Sheet—Quality Norms*. ASTM A653.

American Concrete Institute (ACI). *Building Code Requirements for Structural Concrete and Commentary*. ACI 318.

Forchungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. (FLL). *Guidelines for the Planning, Execution, and Upkeep of Green-Roof Sites*.

United States Department of Agriculture. "USDA Plant Hardiness Zone Map." The United States National Arboretum. Available online at http://www.usna.usda.gov/Hardzone/ushzmap.html (accessed February 2006).

APPENDIX A GLOSSARY OF TERMS

ACI: American Concrete Institute

ASTM: American Society for Testing and Materials

Border zone: An area without vegetation and growth media, surfaced with hardscape materials, and typically located at roof perimeters and corners, roof penetrations, rooftop equipment, skylights, and expansion joints.

Captured water: The quantity of water retained in the drainage layer of a green roof system (once new water addition by rainfall or irrigation has ceased) that cannot escape except through evaporation or plant transpiration. Captured water contributes to the dead load of the system.

Dead load: Loads consisting of the weights of all materials of construction, building finishes, and fixed service equipment. In the case of green roof systems, the entire roof assembly (including growth media, roofing materials, and captured water) is considered dead load.

Drainage panel/drainage layer (drainage/retention panel): Panel typically molded from rigid thermoplastic in a corrugated "egg carton" profile that provides for water retention, root aeration, and overflow drainage from the growth media. Some drainage panels are supplied with an integral filter fabric. In lieu of a drainage panel, systems can consist of a layer of granular material (expanded slate and clay, pumice, crushed brick) to perform the same functions. The granular media used for the drainage layer is typically required to meet specific requirements for gradation, porosity, hydraulic conductivity, and alkalinity.

EFVM: Electric Field Vector Mapping. A method of leak detection based on the electrical conductivity of a moist cover material (growth media) and the electrical insulating properties of the waterproofing membrane.

Environmental load: Variable loads due to earthquake, flood, wind, snow, rain, and ice. These loads are not typically subject to reduction in the same manner as live loads.

EPDM: Ethylene propylene diene monomer (or ethylene propylene diene terpolymer). A thermoset elastic monomer commonly used for single-ply roofing membranes.

Extensive green roof: Classification of a green roof system where vegetation typically consists of low-growing ground cover such as mosses, herbaceous plants, and hardy alpine succulent plants from the Sedum family. Extensive green roof systems are intended to be self-propagating and require little or no maintenance once established. Growth media for Extensive systems is less than 6 in. (150 mm) in depth.

Growth media (mixed media, media, or engineered soil): The material used to support the growth of vegetation

Hardscape: Materials and features, such as stone ballast (roof gravel), concrete pavers, gravel stops, curbs, and grating used for bordering or enclosing vegetated green roof areas and intended to support foot traffic

HDPE: High-density polyethylene. A thermoplastic material typically used for root barriers, and sometimes for drainage panels.

Heat welded: A process of bonding two layers of thermoplastic material together, typically using hot air or heated platens, to form a watertight seam.

Intensive green roof: Classification of a green roof system where vegetation can consist of a large range of plants types, including ground cover, herbaceous plants, grasses, woody shrubs, and small trees. Intensive green roof systems are intended to simulate landscaped park facilities and typically require continuous maintenance, including irrigation and fertilization. Growth media for Intensive systems is greater than 8 in. (200 mm) in depth.

LEED: Leadership in Energy and Environmental Design. A green building rating system sponsored by the U.S. Green Building Council (USGBC).

Live load: Variable loads produced by the use and occupancy during the life of the structure. Live loads on a roof include those loads produced by people, moveable maintenance materials and equipment, and other moveable object such as planters. Occupancy loads (produced by people) are typically subject to live load reduction based on the size of the contributing (tributary) area. The reduced occupancy live load can be as low as 40% of the full live load. However, governing building codes, model codes, and FM Global Data Sheets place several exemptions and restrictions on the level of live load reduction based on the structural properties and use of the building, and on the magnitude of the code-required minimum live load.

Maximum media density: The density of growth media after it has been subjected to a specific amount of compaction and hydrated by immersion to simulate prolonged exposure to both foot traffic and rainfall

Maximum media water retention: The quantity of water held in growth media at the maximum media density

Media: See growth media

Permeability: The coefficient which, when multiplied by the hydraulic gradient, will yield the apparent velocity with which water (at 68ºF or 20ºC) will move through a cross-section of growth media

PVC: Polyvinyl chloride. A thermoplastic polymer commonly used for single-ply waterproofing membranes and root barriers.

Retained water: The quantity of water that is retained, typically for several hours to several days, once new water additions by rainfall or irrigation have ceased, and that will eventually diminish primarily by gravity runoff. Retained water is that quantity of water that remains on the roof after the passage of transient water, minus the quantity of captured water. Retained water contributes to the dead load of the system.

Saturation point: The moisture content at which the tension in a growth media is zero, but a free water surface has not developed.

Simple Intensive (semi-Intensive): Classification of a green roof system where vegetation typically consists of low-growing ground cover, herbaceous plants, grasses, and small shrubs. Simple Intensive systems require maintenance programs similar to those required for Intensive systems. Growth media for Simple Intensive systems is generally from 6 to 8 in. (150 to 200 mm) in depth.

TPO: Thermoplastic polyolefin (or flexible polyolefin). A thermoplastic polymer-based material commonly used for single-ply waterproofing membranes.

Transient water: The quantity of water required to completely fill the drainage layer, minus the quantity of captured water, when new water additions by rainfall or irrigation are actively occurring. Transient water can be held for only a period of minutes and begins to drain once the saturation point of the growth media has been reached and the drainage layer has reached its captured-water capacity. Transient water contributes to the rain load of the system.

USDA: United States Department of Agriculture

APPENDIX B DOCUMENT REVISION HISTORY

April 2011. Made changes to Section 2.2.2 regarding wind speed restriction; and Sections 2.1.2.2 and 2.2.16 regarding FM Approved roofing assemblies.

January 2007. Made clarifications to Sections 2.1.2 and 2.2.16 regarding FM Approved roofing assemblies; to Section 2.2.3 regarding wind uplift; and to Section 2.2.5 regarding ASTM test procedures for load calculations.

September 2006. New reference was added to the section C.2, Some Green Roof Internet Sites.

May 2006. This is the first publication of this document.

APPENDIX C SUPPLEMENTARY INFORMATION

C.1 Background and Benefits

Vegetated green roof systems have been in use for approximately forty years in Europe. Outside Europe, however, green roofing is considered a relatively new technology. There are very few complete standards for green roof systems currently available. The standard most often referenced is the FLL standard (see Section 4.2 for complete reference). The FLL standard was developed in Germany and is considered to be the most established and comprehensive resource for technical guidance and specifications for the above-membrane assembly (including vegetation, growth media, and drainage portions) of green roof systems.

The use of green roof systems in the United States has been encouraged by the Leadership in Energy and Environmental Design (LEED) green building rating system developed by the United States Green Building Council (USGBC). The USGBC is a coalition of building owners, developers, manufacturers, design professionals, environmental groups, public and private utilities, educational institutions, and government agencies.

The LEED program has been developed to promote environmental sustainability in building construction through the use of design practices and building materials. The program involves a point-rating system intended to measure the level of environmentally sustainable site planning, as well as energy efficiency, conservation of building materials, reduction in the use of environmentally hazardous materials or processes, improved indoor air quality and environment, water conservation, and improved storm water surface run-off and filtration methods. The LEED rating system awards points on a project-specific basis, with point distribution based on the following categories:

- Sustainable sites
- Water efficiency
- Energy and atmosphere
- Materials and resources
- Indoor environmental quality
- Innovation and design process

The USGBC reviews projects and awards various levels of certification based on a comprehensive point tally as follows:

- LEED Certified (26 to 32 points)
- LEED Silver (33 to 38 points)

- LEED Gold (39 to 51 points)
- LEED Platinum (52 to 69 points)

Up to three points toward the LEED score can be earned for providing a green roof system. Green roof systems offer the following environmental benefits recognized by the LEED system:

- Storm water management and water quality. The primary goal is to reduce storm water run-off and improve the water quality of discharge water bodies. Green roofs decrease storm water runoff intensity, and therefore reduce peak floodwaters, by retaining rather than directly shedding and draining precipitation. The retention of precipitation moderates the runoff to storm sewers and reduces the potential for overtaxing the local wastewater treatment system, which can result in the release of untreated wastewater to outflow water bodies. Typical green roofs can retain over 60% of the initial precipitation they receive. Mitigating the storm water runoff is generally thought to be the primary justification for the use of green roofs in Europe.
- Urban “heat island” effect. In large, densely developed, industrialized cities, roof areas can comprise 30% of the total land area and 50% of the total impervious surface area (the balance being made-up of paved roads, parking lots, etc.). As dark, impervious roofs and bituminous pavement absorb solar radiation, they combine to create an urban microclimate (a heat island) that can cause ambient air temperatures to be 5ºF to 10ºF (3ºC to 6ºC) warmer than the surrounding suburban and rural areas. Green roof surfaces generate lower ambient air temperatures than conventional roofing by absorbing less direct solar radiation and through the cooling effect of evapotranspiration. Mitigating the urban heat island effect is generally thought to be the primary justification for the use of green roofs in North America and Japan.
- Energy conservation. A green roof reduces the transfer of heat from exterior to interior space by means of its thermal mass and by evapotranspiration. Tests conducted at the National Research Council of Canada and Pennsylvania State University have indicated that, when compared to a flat black roof, a green roof can reduce interior building temperatures by several degrees, with energy savings of up to 10% during peak ambient summer temperatures.

In some Western European countries, governments assess a rain tax on property owners based on the amount of impervious surface cover on their property that contributes storm water runoff to the local storm sewers; impervious surfaces include paved roads and parking lots, and roof covers such as single-ply membranes and bituminous / asphaltic built-up roofs. Vegetated green roof systems retain a significant amount of precipitation, reducing the amount of runoff to local storm sewers, and therefore are not considered impervious surfaces. Thus, the use of green roofing allows property owners to reduce the rain tax on their property. Over 75 European municipalities offer subsidies and tax incentives to encourage green roof installations. The use of tax incentives is beginning to take hold in the United States, albeit only at lower municipal levels so far.

Legislative efforts to improve storm water management and reduce urban heat island effects through the use of green roofs include the following examples:

- The city of Stuttgart, Germany requires that a substantial portion of new flat-roofed commercial buildings include green roofs. Approximately 12% of all flat roofs in Germany are covered with green roof systems.
- The city of Portland, Oregon, USA allows developers a planning density bonus of 3 ft^2 for every square foot of green roof.
- In Tokyo, Japan, the local government requires that 20% of new commercial construction incorporate green roof systems.
- In Cook County, Illinois, USA an ordinance is proposed requiring a LEED Certified rating for all newly constructed county-owned buildings.
- The state of Michigan in the USA is requiring all major, state-funded projects to attain a LEED Silver rating.

C.2 Some Green Roof Internet Sites

Colorado State University Cooperative Extension Service/ Colorado State Forest Service
Fort Collins, Colorado
www.ext.colostate.edu

Green Roofs for Healthy Cities
www.greenroofs.org

The Greenroof Industry Resource Portal
www.greenroofs.com

Landscaping and Landscape Development Research Society (FLL)
Bonn, Germany (German language only)
www.f-l-l.de

Michigan State University
Horticulture Teaching and Research Center
East Lansing, Michigan
www.hrt.msu.edu/greenroof

North Carolina State University
BAE Green Roof Research Center
Raleigh, North Carolina
www.bae.ncsu.edu/greenroofs

Nottingham Trent University
Green Roofs and Earth Sheltered Buildings
Nottingham, England
www.construction.ntu.ac.uk/staffwebs/greenroofs

Pennsylvania State University
Center for Green Roof Research
University Park, Pennsylvania
www.hortweb.cas.psu.edu/research/greenroofcenter

U.S. Green Building Council (USGBC)
Washington, DC 20036
www.usgbc.org

U.S. Department of Energy
Federal Energy Management Program
Federal Technology Alert
DOE / EE – 0298 Green Roofs
www.eere.energy.gov/femp/pdfs/fta_green_roofs.pdf

University of Applied Sciences
Green Roof Centre
Neubrandenburg, Germany
www.gruendach-mv.de/en/index.htm

University of Georgia
Institute of Ecology
Athens, Georgia
www.rivercenter.uga.edu/research/stormwater/greenroof

APPENDIX D BIBLIOGRAPHY

Bass, Brad, and Bas Baskaran. *Evaluating Rooftop and Vertical Gardens as an Adaptation Strategy for Urban Areas.* NRCC-46737. Project no. A020. CCAF Report B1046. National Research Council of Canada, 2003. Available online at http://irc.nrc-cnrc.gc.ca/fulltext/nrcc46737 (accessed February 2006).

Dennis, F. C. "Fire Wise Plant Materials." Colorado State University Cooperative Extension Service. Publication 6.305. Available online at http://www.ext.colostate.edu/PUBS/natres/06305.html (accessed February 2006).

"Federal Technology Alert: Green Roofs." DOE / EE-0298. U.S. Dept. of Energy, Office of Energy Efficiency and Renewable Energy (EERE). Federal Energy Management Program, 2004.

Liu, K., and Bas Baskaran. *Thermal Performance of Green Roofs through Field Evaluation.* NRCC-46412. Institute for Research in Construction, National Research Council of Canada, 2003. Available online at http://irc.nrc-cnrc.gc.ca/fulltext/nrcc46412 (accessed February 2006).

Peck, Steven, and Monica Kuhn. *Design Guidelines for Green Roofs*. Canada Mortgage and Housing Corporation and the Ontario Association of Architects, 2003.

Scholz-Barth, Katrin. ''Green Roofs: Stormwater Management from the Top Down.'' *Environmental Design & Construction* (January/February 2001).

Wark, Christopher G., and Wendy W. Wark. "Green Roof Specifications and Standards." *Construction Specifier* (August 2003).

APPENDIX E SAMPLE GREEN ROOF PROJECT PHOTOS

Fig. 4. Extensive green roof, Chicago City Hall, Chicago, Illinois, USA (C 2005, Roofscapes, Inc., used by permission; all rights reserved)

Fig. 5. Extensive green roof with sedums (courtesy of Genzyme Corp.)

Fig. 6. Extensive green roof Life Expression Wellness Center, Sugar Load, Pennsylvania, USA (C 2005, Roofscapes, Inc., used by permission; all rights reserved)

Fig. 7. Extensive green roof at time of installation; Montgomery Park Business Center, Baltimore, Maryland, USA (Courtesy of Katrin Scholz-Barth).

Fig. 8. Extensive green roof 10 months after installation; Montgomery Park Business Center, Baltimore, Maryland, USA (Courtesy of Katrin Scholz-Barth and Kai-Henrik Barth)

Fig. 9. Extensive green roof 2 years after installation; Montgomery Park Business Center, Baltimore, Maryland, USA (Courtesy of Katrin Scholz-Barth)