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Standard Guide for Vegetative (Green) Roof Systems[1]

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1. Scope

1.1 This guide identifies terminology, principles and fundamental concepts including those related to sustainability, technical requirements of construction, and types of vegetative (green) roof systems used on buildings.

1.2 The considerations for sustainable development relative to vegetative (green) roof systems are categorized as follows: environmental, social, and economic as consistent with Guide E2432. (See Appendix X1.)

1.3 This guide discusses technical requirements for vegetative (green) roof systems pertaining to the following categories: plants, media, wind scour resistance, soil reinforcement, separation or filter layers, drain layers, water retention layers, protection layers, and root penetration barriers.

1.4 This guide addresses intensive and extensive vegetative (green) roof systems for roofs up to 15 % slope. Roofing/waterproofing membranes and insulation are key components of vegetative (green) roof systems, but technical requirements regarding their role in such roof systems is beyond the scope of this guide.

NOTE 1—ASTM Technical Committees D08 and C16 have jurisdiction over the development of standards for roofing/waterproofing membranes and insulations, respectively. Some of their existing standards may be helpful in the evaluation of membranes and insulation used in vegetative (green) roof systems. As these two committees develop standards for such roofs, this guide will be revised appropriately.

1.5 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2,3]

C88 Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate
D1079 Terminology Relating to Roofing and Waterproofing
D1987 Test Method for Biological Clogging of Geotextile or Soil/Geotextile Filters
D2974 Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils
D3786/D3786M Test Method for Bursting Strength of Textile Fabrics—Diaphragm Bursting Strength Tester Method
D4354 Practice for Sampling of Geosynthetics and Rolled Erosion Control Products(RECPs) for Testing
D4439 Terminology for Geosynthetics
D4491 Test Methods for Water Permeability of Geotextiles by Permittivity
D4595 Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method
D4716/D4716M Test Method for Determining the (In-plane) Flow Rate per Unit Width and Hydraulic Transmissivity of a Geosynthetic Using a Constant Head
D4751 Test Method for Determining Apparent Opening Size of a Geotextile
D4759 Practice for Determining the Specification Conformance of Geosynthetics
D4873 Guide for Identification, Storage, and Handling of Geosynthetic Rolls and Samples
D5262 Test Method for Evaluating the Unconfined Tension Creep and Creep Rupture Behavior of Geosynthetics
D5617 Test Method for Multi-Axial Tension Test for Geosynthetics
D5818 Practice for Exposure and Retrieval of Samples to Evaluate Installation Damage of Geosynthetics
D6637 Test Method for Determining Tensile Properties of Geogrids by the Single or Multi-Rib Tensile Method
D7361 Test Method for Accelerated Compressive Creep of Geosynthetic Materials Based on Time-Temperature Superposition Using the Stepped Isothermal Method

[1] This guide is under the jurisdiction of ASTM Committee D08 on Roofing and Waterproofing and is the direct responsibility of Subcommittee D08.24 on Sustainability.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Whenever a specific version of a standard is not identified, the most recent edition of the standard shall apply.

E108 Test Methods for Fire Tests of Roof Coverings
E136 Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C
E631 Terminology of Building Constructions
E2114 Terminology for Sustainability Relative to the Performance of Buildings
E2396 Test Method for Saturated Water Permeability of Granular Drainage Media [Falling-Head Method] for Vegetative (Green) Roof Systems
E2397 Practice for Determination of Dead Loads and Live Loads Associated with Vegetative (Green) Roof Systems
E2398 Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Vegetative (Green) Roof Systems
E2399 Test Method for Maximum Media Density for Dead Load Analysis of Vegetative (Green) Roof Systems
E2400 Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems
E2432 Guide for General Principles of Sustainability Relative to Buildings
E2788 Specification for Use of Expanded Shale, Clay and Slate (ESCS) as a Mineral Component in the Growing Media and the Drainage Layer for Vegetative (Green) Roof Systems

2.2 *ASCE/SEI Standard:*[4]

ASCE/SEI 7 Minimum Design Loads for Buildings and Other Structures (latest edition)

3. Terminology

3.1 *Definitions:*

3.1.1 For terms related to building, refer to Terminology E631.

3.1.2 For terms related to sustainability and buildings, refer to Terminology E2114.

3.1.3 For terms related to roofing and waterproofing, refer to Terminology D1079.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *apparent opening size (AOS), n*—for a geotextile, a property which indicates the approximate largest particle that would effectively pass through the geotextile.

3.2.2 *capillary potential, n*—of geotextiles, a property that indicates the ability of a geotextile to distribute moisture.

3.2.3 *cation exchange capacity (CEC), n*—the capacity of a soil to retain and exchange the cations of nutrients, defined as the sum of exchangeable cations that a media can retain per unit weight (**1**).[5]

3.2.4 *clogging, n*—for geotextiles, the condition where soil particles move into and are retained in the openings of the fabric, thereby reducing the hydraulic conductivity.

3.2.5 *dead load, n*—for a vegetative (green) roof system, the weight of a mature vegetative (green) roof system from the structural deck up, following prolonged rainfall during which retained and captured water attain maximum levels.

3.2.6 *drain layer, n*—horizontal layer, including one or more discrete components, that has been specifically designed to convey water toward the roof deck drains, gutters, or scuppers.

3.2.6.1 *Discussion*—Drain layers may be simple, consisting of a single component, or complex, combining multiple components including: geosynthetics, geocomposites, and coarse mineral aggregate. Drain layers are not used in single-course vegetative (green) roof systems. See also *geocomposite drain layer* and *granular drain layer*.

3.2.7 *extensive vegetative (green) roof system, n*—a roof system that features plants that can be sustained in shallow media layers (with 6 in. or less of growing media), and typically utilizes non-woody, drought tolerant herbs, grass, moss, and succulents.

3.2.8 *evapotranspiration, n*—the process by which water is released to the atmosphere by evaporation from the surface of media and plant foliage, and components of the vegetative (green) roof system.

3.2.8.1 *Discussion*—Potential evapotranspiration rates can be determined using local climatic data. Specific evapotranspiration rates may vary with plant type, plant foliage density, vegetative (green) roof media composition and availability of irrigation.

3.2.9 *gap-graded, adj*—granular materials in which the particle size distribution curve is markedly discontinuous. Mixtures containing particles of both large and small sizes, in which particles of certain intermediate sizes are wholly or substantially absent. See *particle size distribution curve*.

3.2.10 *geocomposite, n*—a product composed of two or more materials, at least one of which is a geosynthetic.

3.2.11 *geocomposite drain layer, n*—drain layer composed of a synthetic sheet, mat, or panel.

3.2.11.1 *Discussion*—Geocomposite drain layers may include absorptive drain mats whose principle function is drainage, but which will also contribute to water retention. Some geocomposite drain layers may incorporate reservoirs on their upper surfaces that will capture water. See also *granular drain layer*.

3.2.12 *geosynthetic, n*—a planar product manufactured from polymeric material used with soil, rock, earth, or other geotechnical-engineering-related material as an integral part of a vegetative (green) roof system [as described in Practice D4354, Practice D4759, Guide D4873, Test Method D5617, and Practice D5818].

3.2.13 *geotextile, n*—any permeable textile used with foundation, soil, rock, earth, or any other geotechnical–engineering-related material as an integral part of a man-made project, structure, or system.

3.2.13.1 *Discussion*—Geotextiles perform several functions in geotechnical engineering applications, including: separation; filtration; drainage; reinforcement; and protection.

3.2.14 *granular drainage media, n*—coarse aggregate applied in a layer at the base of the vegetated vegetative (green) roof system profile or filled into the upper face of a reservoir

[4] Available from American Society of Civil Engineers (ASCE), 1801 Alexander Bell Dr., Reston, VA 20191, http://www.asce.org.

[5] The boldface numbers in parentheses refer to the list of references at the end of this standard.

sheet to provide a horizontal plane for free drainage of the vegetative (green) roof system.

3.2.15 *granular drain layer, n*—a drain layer composed entirely of granular drainage media.

3.2.16 *hardscape, n*—non-vegetated surfacing on vegetative (green) roof systems, used in place of soil at walkways, plazas, maintenance areas, or at staging areas for mechanical equipment and façade access.

3.2.17 *hydraulic transmissivity, n*—for a geosynthetic or geocomposite, the volumetric flow rate per unit width of specimen per unit gradient in a direction parallel to the plane of the specimen; also referred to as in-plane flow, and, for a granular drainage media, saturated water permeability multiplied by the layer thickness [as determined using Test Method D4716/D4716M].

3.2.18 *intensive vegetative (green) roof system, n*—intensive vegetative (green) roof systems feature large perennial plants or turf grass.

3.2.18.1 *Discussion*—The use of large plants generally requires media thicknesses in excess of 6 in. (15 cm), and in most instances, irrigation. Intensive vegetative (green) roofs will require levels of maintenance similar to onground gardens. See also extensive vegetated (green) roof system.

3.2.19 *maximum media density, n*—the density of a granular drainage media or vegetative (green) roof media determined after they have been subjected to a specific amount of compaction and hydrated by immersion to simulate prolonged exposure to both foot traffic and rainfall.

3.2.19.1 *Discussion*—The maximum media density applies to drained conditions.

3.2.20 *module, n*—pre-manufactured unit containing some of the functional elements of a vegetative (green) roof system.

3.2.20.1 *Discussion*—Independent modules are designed to be placed adjacent, and sometimes linked to one another, in order to cover roof surfaces.

3.2.21 *open-graded, adj*—granular materials that contain relatively few fines in order to leave fairly large spaces between particles when compacted. See particle size distribution curve.

3.2.22 *organic matter, n*—material in a soil or vegetative (green) roof media that volatilizes from a dry sample when heated in an oven to 824°F (440°C).

3.2.23 *particle size distribution curve, n*—curve, based on sieve and hydrometer analysis that describes the relative quantities of particles of different sizes in a mixture.

3.2.23.1 *Discussion*—For planting media, this descriptor is limited to the non-organic fraction.

3.2.24 *permittivity, n*—of geotextiles, the volumetric flow rate of water per unit cross sectional area per unit head under laminar flow conditions, perpendicular to the plane of the geotextile.

3.2.25 *permeability, n*—see *saturated water permeability*.

3.2.26 *phytotoxic, n*—poisonous to plants.

3.2.27 *protection layer, n*—any continuous layer that is intended to protect the roofing/waterproofing membrane from damage and which is placed in direct contact with the roofing/waterproofing membrane.

3.2.27.1 *Discussion*—Agents for damage may include abrasion, puncture, UV exposure, and temperature fluctuation. Protection layers may include of additional layers of material (as recommended by the membrane manufacturer), coatings, geosynthetic materials, geotextiles, geocomposites, tiles, and insulation.

3.2.28 *reservoir sheet, n*—a shaped plastic membrane containing receptacles on its upper surface to capture and retain water.

3.2.28.1 *Discussion*—In some vegetative (green) roof systems, these receptacles are filled with granular drainage media.

3.2.29 *root penetrability, n*—of a geotextile, a property that indicates the ease with which plant roots can penetrate a geotextile.

3.2.30 *root penetration barrier, n*—continuous layer incorporated in a vegetative (green) roof system to prevent damage to the roofing/waterproofing membrane system caused by root growth.

3.2.31 *root resistance, n*—ability of component to prevent penetration by roots as measured in a long-duration test that simulates field conditions (2).

3.2.32 *saturated water permeability, n*—for vegetative (green) roof media, the coefficient which when multiplied times the hydraulic gradient yields the apparent velocity with which water at 68°F (20°C) moves through a cross-section of fully submerged media.

3.2.33 *soundness, n*—for granular drainage media, the capacity to resist freezing without fracturing.

3.2.34 *thermal capacitance, n*—a property of a material that determines how readily it absorbs and releases thermal energy (3).

3.2.34.1 *Discussion*—Heat capacity, or specific heat, is the measure for thermal capacitance. Heat capacity of a material is determined by measuring the increase in temperature that attends the addition of thermal energy. In vegetative (green) roof systems, the material with the highest heat capacity is usually water.

3.2.35 *underflow, n*—water derived from rainfall or irrigation that percolates to the base of the vegetative (green) roof system profile and then flows horizontally through the drain layer toward roof discharge facilities such as area drains, scuppers, and gutters.

3.2.36 *vegetated (green) roof covering, n*—see *vegetative (green) roof system*.

3.2.37 *vegetative (green) roof media, n*—materials that fulfill the role that natural soil would fulfill in at-grade landscape.

3.2.37.1 *Discussion*—To achieve specified requirements for weight, drainage, fertility, saturated water permeability, density, etc. vegetative (green) roof media is typically prepared as mixture of fine and coarse mineral aggregate, organic materials, and admixtures.

3.2.38 *vegetative (green) roof system weight, n*—see *dead load*.

4. Significance and Use

4.1 *Intended Use*—The intended use of this guide is to provide general information to practitioners in the fields of vegetative (green) roof design and construction. The guide encourages innovative but responsible vegetative (green) roof design, with a focus on performance and quality assurance. Numerical ranges, practical minimums, and benchmarks that are incorporated in the guide are intended for reference. Design requirements for specific projects vary and therefore qualified professionals may prepare designs with features that may vary from the recommendations contained in the guide. In all instances, vegetative (green) roof system designs shall conform to the applicable code requirements of Federal, State, Provincial or local agencies with jurisdiction.

4.2 *Users*—Users of this guide include: planners, developers, architects, landscape architects, engineers, general contractors, subcontractors, owners, facility managers, financial organizations related to building industry, building materials and product manufacturers, government agencies including building officials, and other building professionals.

5. Principles Relative to Vegetative (Green) Roof Systems

5.1 *Design Intent and Building Function*—Vegetative (green) roof systems should contribute or enhance, or both, a building‘s function/purpose. The design of the vegetative (green) roof system should be responsive to the project objectives.

5.2 *Sustainability*—vegetative (green) roof systems should improve the sustainability of a building including: environmental, social, and economic impacts. Appendix X1 provides a review of potential contributions that vegetative (green) roof systems may make toward achieving sustainability objectives.

5.3 *Design Considerations:*

5.3.1 *Maintenance*—All vegetative (green) roof systems shall be accompanied by a detailed written maintenance procedures manual, provided by the design professional, vegetative (green) roof installation company or system manufacturer. Maintenance manuals should include instructions for operation of irrigation systems, where relevant, and directions for proper weeding and fertilization. These documents should also include methods for recognizing and dealing with commonly encountered problems, including: insect infestations, weed infestations, bare spots, wet spots or areas with perennial surface water ponding. Depending on the vegetative (green) roof system and site conditions, provisions for employing temporary irrigation should also be addressed. Manuals should also include instructions for inspecting exposed elements of the roofing/waterproofing membrane system, most notably the drains. Minimum requirements for site visitations should be provided.

5.3.2 *Performance*—The design professional working on a vegetative (green) roof system shall convey to the owner a written description of the system, showing conformance with the specified performance characteristics. Depending on the purpose of the vegetative (green) roof system and the provisions of the construction specifications, these descriptions include at minimum: *1*) maximum or minimum associated dead load, *2*) moisture retention capacity per hydrology study by the manufacturer, *3*) assurances of the longevity of the vegetative (green) roof system, *4*) assurances of the survival of the plant foliage cover, *5*) assurances that the roofing/waterproofing membrane is compatible with the selected vegetative (green) roof system and suitable for the application. Written descriptions of vegetative (green) roof system performance characteristics, typically emanate from, and will be supported by, the manufacturer or provider of the vegetative (green) roof system.

5.3.3 *Longevity*—The longevity of vegetative (green) roof systems can be limited by: *1*) degradation or loss of function of components of the vegetative (green) roof system, or *2*) premature failure of the roofing/waterproofing membrane system. Consideration should be given to locating leaks and repairing the membrane. For novel designs or large-scale projects, mock-ups of vegetative (green) roof systems may be advisable. Exposed surfaces of the roofing/waterproofing membrane system (for example, flashings and penetrations) may become the most important factor in determining the longevity of an installation. Consideration should be given to providing protection for all surfaces of the roofing/waterproofing membrane system. For instance, flashings should be protected with a durable and UV-resistant protection layer or counterflashing.

5.3.4 *Structural Loads*—The introduction of a vegetative (green) roof system to a new or existing structure has an effect on the live, dead and seismic loads. The addition of materials associated with vegetative (green) roof systems usually increases the dead load in varying amounts based on the number, composition and thickness of the layers of the system. Because of the transient water retention capacity of vegetative (green) roof systems, the live loads may increase as well. In accessible roofs, the live loads created by human occupants, should be taken into account. Minimum live load allowances for access by pedestrians, as well as by maintenance personal apply in most jurisdictions. Consideration of appropriate loads is the responsibility of the design professional and shall be addressed before the vegetative (green) roof system is designed.

5.3.4.1 Take into account all components in the vegetative (green) roof system profile and include the weight of matured plants and retained moisture.

5.3.5 *Roof Access*—Building maintenance and other personnel shall be provided with a safe means of accessing the roof.

5.3.6 *Equipment Access*—When mechanical equipment is located on the roof, accommodations shall be made to provide safe access to that equipment. Determination shall be made that the vegetative (green) roof system will not interfere with equipment operation. Allowances shall be made for required clearances for working around and under the equipment. Hardscape may be used in these spaces to provide working areas. Measures shall be included to prevent damage to the vegetative (green) roof system caused by wash-down, ‘blow down' or other discharges of fluids associated with operation or maintenance of mechanical equipment. Chemicals used in the operation or maintenance of mechanical equipment located in the field of a vegetative (green) roof system should not be phytotoxic to any of the designated plant varieties or damaging to the components of the vegetative (green) roof system.

5.3.7 *Facade Access*—In many instances, the roof serves as the primary point of façade access. Consideration should be given in vegetative (green) roof system design for access to façade rigging equipment including the use of temporary equipment (beams and weights). If walkways and staging areas for façade maintenance are not provided, damage to the vegetative (green) roof system may result. Chemicals used for window and façade cleaning and maintenance should be reviewed periodically to determine if they are phytotoxic and may inhibit plant growth in areas affected by façade maintenance. Materials that will be phytotoxic to plant varieties designated for the vegetated (green) roof system should be replaced by alternative materials that are benign toward these plants.

5.3.8 *Wind Resistance*—Damage by wind is a concern with vegetative (green) roof system installations, particularly along perimeters and corners, at obstructions such as mechanical equipment, and adjacent to penthouse structures. The potential for damage by wind will vary with building height, building geometry, geographic location, and local topography. Probability of wind damage is greatest with high winds immediately after installation and diminishes as the vegetative (green) roof matures. With many vegetative (green) roof systems methods for temporarily protecting the media prior to establishment of a mature plant ground cover may be advisable. This may include mats or mesh fabricated from organic fibers or geosynthetics, tackifying agents, or the installation of pre-grown mats or modules. Various permanent stabilized leading-edge systems may be viable for a particular project, including: gravel or stone margins, unit pavers, strapped or bolted pavers, reinforced media layers, and buried ballasts in conjunction with reinforcing geotextiles. The width of stabilized leading-edge systems depends on the local wind environment, which is specific to each building and geographic setting. Measures shall comply with requirements of Federal, State, Provincial, or local entities with jurisdiction. Methodologies for determining ballast requirements often rely on estimates of wind velocities and uplift pressures based on ASCE/SEI 7. The dry weight should be used when evaluating the ballast weight of a vegetative (green) roof system In some jurisdictions upper limits on basic wind speed (3 s gusts) may apply to inclusion of gravel or stone ballast, due to the risk of these becoming windborne missiles.

5.3.9 In regions where brush fires are an identified threat, it is recommended that designs emphasize foliage cover consisting of succulent plants (for example, Sedum, Senecio, Delosperma, Graptopetalum, Echeveria, etc.), and the vegetative (green) roof system should be maintained to regularly remove dead or dormant grass and shrubs. Non-vegetated margins, consisting of coarse stone, gravel, concrete pavers, or stone pavers can be used to set back foliage-covered areas from critical surfaces. Specifically, setbacks for plant foliage are recommended in the following situations: *1*) walls immediately beneath the sills of operable windows, and *2*) adjacent to hatchways, thresholds, and mechanical equipment. Non-vegetated set-backs are recommended for boundaries with roofing/waterproofing membrane systems that are not classified Test Methods E108 Class A and from building surfaces constructed using materials that have not been successfully tested in accordance with Test Method E136. For vegetated (green) roof systems that are not rated Class A or B based on Test Methods E108, additional precautions are recommended, including providing breaks in the vegetative (green) roof system that will limit the area of any contiguous foliage-covered roof zone. Breaks may consist of concrete or masonry curbs that are taller than adjacent plant foliage or non-vegetated strips. Non-vegetated strips may consist of either: *1*) coarse stone, gravel, concrete pavers, or stone pavers, or *2*) Class A roof covering, as determined by Test Methods E108. All vegetative (green) roof systems should be provided with access to hose-bibs faucets, or an irrigation system that can provide sufficient to water to allow the entire vegetative (green) roof system to be thoroughly soaked within an elapsed time of 2 h. Provisions for introducing fire resistance measures shall comply with requirements of Federal, State, Provincial, or local entities with jurisdiction.

5.3.10 *Flashing*—To minimize the opportunity for water to gain entry through the roofing/waterproofing membrane system, minimum vertical isolation distances between the upper surface of the vegetative (green) roof cover and the top of the flashing is advised. These vertical isolation distances may vary with manufacturer and flashing type, some manufacturers require a minimum vertical isolation of 8 in. Vegetative (green) roof system profile thicknesses must be adjusted accordingly. If the recommended vertical isolation distance cannot be satisfied, then the vegetative (green) roof cover should be set back from the flashing using rigid edging.

5.3.11 *Leak Detection*—Design of the vegetative (green) roof system should include consideration of how leaks can be located and repaired. Expedients for consideration include: *1*) ensuring that both the roofing/waterproofing membrane system and other components of the system are compatible with use of low-voltage electrical methods of leak detection, and *2*) always using fully adhered membranes.

5.3.12 *Drainage*—Vegetative (green) roof systems can be adversely affected by either excessive or insufficient drainage capacity. The first concern of the designer when addressing drainage, should be to insure that the vegetative (green) roof system can efficiently percolate and discharge the underflow associated with mandated design storms. Unless specifically designed to generate surface runoff, vegetative (green) roofs systems should not experience ponding or surface flow when subjected to rainfall events that would be normal for a typical year. All drains and scuppers should be isolated by a filter fabric, or other appropriate means, to protect from clogging caused by the accumulation of foliage or debris. Conventional 'beehive' or 'bonnet' strainers are not suitable for this purpose. Chambers with removable lids are recommended for use at all drains and scuppers. Surrounding all drains and scuppers and along depressions where underflow concentrates, coarse stone aggregate should be placed to facilitate percolation and horizontal flow toward the drainage facilities. The designer should avoid excessive drainage of the vegetative (green) roof system which may lead to perennially stressed conditions for the plants and, in extreme conditions, plant mortality.

6. Quality Assurance

6.1 *Specifications*—Specifications should clearly define the performance requirements for the vegetative (green) roof system, identify the relevant properties of constituent components, identify hazardous conditions, and include appropriate procedures to monitor construction, provide a safe working environment, and provide on-going maintenance.

6.1.1 *Performance Requirements*—Performance requirements may vary. However, where vegetative (green) roof systems have been selected with specific objectives in mind, these should be included in the specification. Where specific energy conservation or stormwater control objectives are important, civil engineering reports, supporting computations, field data, or computer simulations should be required of providers of vegetative (green) roof systems.

6.1.2 *Submittals*—Properties cited in specifications should be relevant to the successful performance of the vegetative (green) roof system. To the extent practical, specifications should provide ranges of acceptable performance, or design minimums and maximums.

6.1.2.1 For materials and components that are unique to vegetative (green) roofs, contractors should provide certifications by manufacturers that any tests have been successfully performed by an independent laboratory and that their products comply with the specification.

6.1.2.2 For vegetative (green) roof media, samples should be accompanied by certified statements by the manufacturer/blender – or recent tests by an independent laboratory -- demonstrating compliance with the specifications. Since the characteristics of feed stocks, such as ESCS and compost, may vary over time, tests for specific media formulations should be conducted on a periodic basis.

6.1.3 *Maintenance Program*—Contract documents should be specific concerning the maintenance requirements and responsibilities of the vegetative (green) roof system installer or system manufacturer. For example:

6.1.3.1 Procedures for leak detection and repair, as necessary, for the roofing/waterproofing membrane.

6.1.3.2 Requirements for minimum foliage cover prior to acceptance by the owner. Specify remedies if the cover requirement is not satisfied at the end of the designated establishment period.

6.1.3.3 Requirements for continued performance, including effective drainage, soil thickness, horticultural viability, etc., provided the maintenance program is followed.

6.1.4 Required longevity for constituent components.

6.2 *Project Check List*—The following project check list includes recommended activities to achieve successful outcomes with vegetative (green) roof system installations.

6.2.1 Determine the projects priorities, including sustainability goals.

6.2.2 Determine dead load and live load allowances.

6.2.3 Evaluate regional climate and microclimatic conditions.

6.2.4 Select vegetative (green) roof system(s) that can best achieve project priorities.

6.2.5 Coordinate vegetative (green) roof system details and requirements with the roofing/waterproofing membrane system manufacturer.

6.2.6 Prepare detailed specifications and address whether all components (membrane up to and including plantings) should be furnished by one manufacturer, or that the responsibility for same rest in one contractor.

6.2.7 *Implementation:*

6.2.7.1 Maintain the completed roofing/waterproofing membrane system in a protected condition.

6.2.7.2 Consider testing delivered vegetative (green) roof media in order to confirm compliance with the specification.

6.2.7.3 Monitor vegetative (green) roof system installation.

6.2.7.4 Document vegetative (green) roof system performance during the establishment period [typically two to three years are required for a vegetative (green) roof system to attain a stable condition].

6.2.7.5 Conduct regular on-going maintenance, as directed in the maintenance program, and document activities to the owner.

7. Technical Requirements

7.1 This section addresses technical requirements associated with plants, media, wind scour resistance, soil reinforcement, separation or filter layers, drain layers, water retention layers, protection layers, root penetration barriers, and membranes.

7.2 *Plants*—Refer to Guide E2400.

7.3 *Media*—Detailed specifications should be written around tests that can be conducted on samples of the final planting mixture. To ensure compliance with the performance requirements, testing of the final mixture should be considered. The purpose of the planting media is to sustain the life of the plants over an extended period of time, function as moisture reservoir, support efficient drainage during rainfall events, and protect the underlying components of the vegetative (green) roof system. Planting media is typically formulated from a mixture of component ingredients and is designed to satisfy specific performance requirements. In order to reduce dead load to roofs, many vegetative (green) roof systems utilize planting media that incorporate lightweight mineral aggregates as their principal constituent. Vegetative (green) roof planting media should exhibit a well-graded character. Gap-graded materials are not recommended for use as planting mixtures, as these tend to separate and lose saturated hydraulic permeability over time. In order to minimize the potential for compression over time, vegetative (green) roof planting media should contain a more or less continuous range of particle sizes that imparts a stable structure to the media layer. The choice of which ingredients to use in a planting mixture may depend on factors such as: performance specification, regional availability, cost and allowable dead load. Most mineral aggregates are provided in many gradations. The grain-size distribution curve for the mineral fraction should be selected with the goal of providing sufficient pore space for air, water, and the exchange of gases. Mixes with finer particles generally have higher surface areas and smaller pores, which enhance water retention capacity and capillarity of the planting mixture. However, too many fine particles may lead to clogging and loss of drainage properties over time. The silt-size fraction (material passing the #200 US sieve (.075 mm)) should be closely monitored, since excessive quantities of silt may lead to clogging of fabrics and stratification of the media. Under most circumstances the silt content of media should not exceed 15 %. Clay-size material should be avoided, except as top-dressing in some intensive vegetative (green) roof systems. In general, planting mixtures require a blend of different sizes and types of mineral ingredients. Natural topsoil should be used with caution, due to their clay and silt content, as well as the potential burden of unwanted seeds, rhizomes and potential pathogen inoculation. Natural soils are prone to compaction when installed in thin layers as part of a vegetative (green) roof system. Sandy loam soils may be suitable as amendments for some intensive planting mixtures. In anticipation of thinning of the media over time due to compaction and winnowing by wind, it is advisable to place the media with an initial thickness that is 10 to 20 % thicker than the specified thickness, after moistening and rolling.

7.3.1 *Classes of the Planting Media:*

7.3.1.1 *Planting Media for Intensive Roof Systems*—Intensive systems have a deeper media layers, typically ranging from 6 to 48 in. (15 to 120 cm). Relative to extensive planting mixtures, intensive planting mixtures are generally characterized by finer particle sizes, lower air-filled porosity, lower saturated water permeability, and higher water retention capacities. Intensive vegetative (green) roof systems are designed to support a wide variety of plants. Depending on the cultural requirements of the plants, the planting media may vary with respect to pH, saturated water permeability, moisture retention capacity, organic content, etc. As a general observation, on-going addition of amendments to intensive vegetative (green) roof systems as part of the maintenance program are suggested to insure optimum growing conditions. The type of plants that can be grown may depend on the thickness of the vegetative (green) roof planting media (including granular drainage media, in dual media vegetative (green) roof systems), drain layer type, and the intended use and function of the system. The system requirements vary with climate and level of irrigation. In deep intensive systems, the upper layers of media may incorporate relatively more fine particles and organic matter.

7.3.1.2 *Planting Media for Multi-Course Extensive Vegetative (Green) Roof Systems*—Multi-course extensive vegetative (green) roof systems usually have a shallow media layer. Extensive vegetative (green) roof systems can be designed to support succulents, grass, and wide range of herbaceous perennial and annual plants. Plant selections may be influenced by the intended use and function of the vegetative (green) roof system, climate, degree of exposure of the roof surface to wind and sun, and availability of irrigation. Many plants that are adapted to extensive vegetative (green) roof systems have shallow root systems or, in the case of sedums, are adversely affected by long periods of summer heat and night time temperatures above 25°C. Therefore, increasing the media layer may not improve plant performance but instead create adverse conditions that may prove to be detrimental to the plants in some instances.

7.3.1.3 *Planting Media for Single-Course Extensive Vegetative (Green) Roof Systems*—Single-course extensive vegetative (green) roof systems are rarely thicker than 4 in. (10 cm). To provide sufficient drainage, the media is generally coarser than that used in multi-coarse extensive vegetative (green) roof systems, and exhibits have higher air-filled porosity and saturated hydraulic permeability.

7.3.1.4 *Granular Drainage Media*—In some vegetative (green) roof systems profiles the drain layer consists of coarse mineral aggregate, separated from the overlying planting media by a separation geotextile. Other systems incorporate a coarse granular material as part of a complex drain layer; often including a reservoir sheet. This material should be coarse and porous enough to promote drainage. To minimize the potential for the development soil pathogens, the material should contain no organic matter.

7.3.2 *Functional Properties of the Planting Media:*

7.3.2.1 *Mineral Contents*—The mineral fraction of the planting media provides a durable structure to the soil, furnishes surface areas for moisture retention and nutrient exchange with the plants, and provides a permanent substrate for beneficial micro-biota to colonize. Under most circumstances, the mineral fraction of planting media should fall within a range of 85 to 97 % (dry weight basis) [Test Methods D2974, method C]. Specialty extensive media mixtures with a mineral content less than 85 % may be specified in some instances. However, care should be exercised in using organic-rich media, since these materials may biodegrade and may also be combustible when dry. Mineral materials with low bulk densities are recommended for use in vegetative (green) roof planting media mixtures where dead load is an important design consideration. Examples of suitable low-density materials include: expanded shale, clay, and slate (ESCS) [see Specification E2788], sintered (vitrified) diatomaceous earth, expanded perlite, crushed lava rock (scoria) and crushed pumice. These low-density materials are also characterized by high surface areas and porosity, which improve the horticultural performance of the planting mixtures. Where dead load is not an over-riding concern, other materials such as sand, gravel, and crushed shale may be introduced. Where a reliable source of clean, crushed and classified demolition material is available, crushed brick or terra cotta can be also be used to advantage. Extreme care should be taken when considering any recycled building products for use as an aggregate or vegetative (green) roof media amendment should be tested to determine if it harbors any toxic materials. Carbonate materials should be avoided since these frequently result in carbonate minerals precipitating on fabrics and in drainage facilities.

7.3.2.2 *Nutrient Retention Capacity/Cation Exchange Capacity (CEC)*—The mineral fraction of a planting mixture serves additional functions for sustainability such as providing cation-exchange capacity (CEC) and pH buffering. Cation exchange capacity of the media is a measure of the soils ability to attract and hold cations. Cations are positively charged ions like Ca++, Mg++, and K+ which are also essential plant micro-nutrients. In most naturally occurring soils this role is fulfilled by clay minerals. In vegetative (green) roof planting media mixtures clay and loam is avoided due to the threat of fabric clogging and reduced drainage capacity. Therefore, other mineral components may be selected that can contribute CEC capacity to a vegetative (green) roof planting media mixture. Laboratory testing of candidate materials and amendments is necessary to determine the CEC potential. [To insure ample nutrient reserves in vegetative (green) roof media an initial CEC of at least 25 meq/lb (6 meq/100 g) is recommended.]

7.3.2.3 *Longevity*—In temperate climates, the mineral fraction of the planting media and the granular drainage media, if present, should be frost resistant based on Test Method C88 in order to resist breakdown over time. In conditions where plant fibers are expected to biodegrade (for example, climates with seasonally wet conditions or irrigated vegetative (green) roof systems), the organic matter fraction should be kept to a minimum. The ideal planting media should sustain plant life with little breakdown or compaction over a period of decades.

7.3.2.4 *Retained Water*—Water retention is an important requirement of the media and vegetative (green) roof system. The mix should be able to retain water without becoming waterlogged. Rainfall retention is generally improved with thicker media layers and water retention components. However, storm runoff peak rate reductions are not well correlated with media depth. Water retention capacity is strongly influenced by the water retention components as well as media grain size distribution curve, particle surface area, and effective air-filled porosity of the planting mixture. Some media formulations include polymer gel amendments for the purpose of boosting moisture retention. Typical maximum media water retention falls in the range of 30 to 45 % based on Test Method E2399.

7.3.2.5 *Permeability and Drainage*—The media should be permeable in order to provide good drainage and aeration. The media should drain well while at the same time retain water in order to reduce or eliminate irrigation requirements. The saturated water permeability of the vegetative (green) roof planting media can be adjusted by modifying the gradation of the mineral fraction of the planting mixture. Typical saturated water permeability, measured according to Test Method E2399, falls in the ranges of:

Vegetative (Green) Roof System Category	Saturated Water Permeability
Intensive	0.01 to 0.25 in./min (4×10^{-4} - 1×10^{-2} cm/sec)
Multi-Course Extensive	0.025 to 0.75 in./min (1×10^{-3} - 3×10^{-2} cm/sec)
Single-Course Extensive	> 2 in./min (8.5×10^{-2} cm/sec)

7.3.2.6 *Porosity*—The measure of porosity of interest is the air-filled porosity when the media is at the maximum media density measured according to Test Method E2399. The air-filled porosity contributes to aeration of the plant roots and uniform drainage. For two-course extensive vegetative (green) roof systems, with separate drain layers, the recommendation for minimum air-filled porosity is 7 %. For single-course extensive vegetative (green) roof systems, where media drainage is critical, the recommendation is for a minimum air-filled porosity of 20 %.

7.3.2.7 *pH*—Many mineral aggregates are neutral in pH, although the pH can vary somewhat higher to 8.5 with some materials. In some climates which are favorable to Sedum-based extensive vegetative (green) roof systems, planting mixtures with a higher pH can be beneficial to buffer the lower pH of acidic rainwater. The recommended stable range of pH for the planting mixtures in most applications is 6.5 to 8.5. Exceptions apply to some plant communities that are adapted to acidic or basic soil conditions.

7.3.2.8 *Salt Content*—Excess soluble salts can be phytotoxic to plants. Media with excessive salt levels should be irrigated (leached) and retested prior to planting, to ensure that it falls within an acceptable range using the Saturated Paste Method Procedure. This is especially important in southern or arid climates when irrigating with municipal water supply in conjunction with any water retention apparatus.

7.3.2.9 *Organic Matter Content*—In most cases the climate of the roof location should determine the organic matter content. In arid climates decomposition may be slower. In temperate regions or localities with seasonal rainfall, however, excess organic matter may decompose rapidly, leading potentially to problems associated with loss of media thickness, reductions in saturated hydraulic permeability and airfilled porosity, and migration of fines to separation geotextiles. The introduction of irrigation in arid and semi-arid climates may also promote biodegradation. Once settled on a geotextile, organic fines may decompose and promote the development of a bioslime and impede drainage. In extensive vegetative (green) roof systems mature vegetative (green) roof media tends to stabilize at organic matter contents below 10 %. Initial organic matter content (dry weight basis, using Test Methods D2974, method C) of between 3 and 15 % is recommended for vegetative (green) roof planting media mixtures in temperate regions. Depending on local availability the type of the organics can vary but may include: peat, coir (coconut fiber), compost, and biosolid compost. Certain composts may be derived from feed stocks that may include bio-solids from municipal sewage treatment facilities. These sources may contain very fine particulates, fine flocking materials, heavy metals and pathogens. Any bio-solid compost shall satisfy all Federal, State, Provincial or Local requirements for use as a soil amendment. Compost can be derived from many sources including sawdust, bark, mushroom bedding, manure, and leave litter. Compost derived from lawn wastes should be tested for the presence of residual herbicides. Compost should be fully mature with a negligible residual respiration rate. (See also *Mineral Content*.)

7.3.2.10 *Density*—The bulk density of the planting mixture will vary with the mix design. A media cannot be too lightweight to avoid wind erosion or floating in heavy rain.

7.3.2.11 *Depth*—The choice of plant type will influence the depth of the planting media. The structural system of the building that supports the vegetative (green) roof system and the budget for the project are also factors in determining the depth of the planting media.

7.3.2.12 *Capillary Potential*—Vegetative (green) roof media varies in the amount of capillary rise that it can support. Media with high capillary potential can be advantageous in irrigated projects, where it can assist in equalizing moisture conditions. However, in un-irrigated projects or projects in arid regions, media with low capillary potential can minimize losses to direct evaporation. As a general observation, vegetative (green) roof media has low capillary potential.

7.3.2.13 *By-Product Constituents*—By-product materials considered for inclusion in planting mixtures should be rigorously tested to insure that leaching of deleterious constituents cannot lead to problems.

7.3.3 *Functional Properties of Granular Drainage Media*—Granular drainage media should be hard, frost resistant, non-carbonate mineral aggregate. Hydraulically transmissive granular drain layers should be composted of open graded granular drainage media, with most particles having diameters falling within a narrow range. For example, ASTM ⅜ in. #8 gradation which represents a common lightweight aggregate gradation, contains 50 % of particles between ¼ and ⅜ in. (6.0 and 9.5 mm) diameter (Specification E2788). The fraction of the aggregate passing the #200 sieve (0.075 mm) should be less than 2 % to minimize the potential for clogging or silting of down gradient drainage facilities. The saturated water permeability of the media should be evaluated at low hydraulic gradients that reflect field conditions using Test Method E2396.

7.4 *Wind Scour Resistance*—Some winnowing of fine particles from the surface of vegetative (green) roof systems should be anticipated when establishing media thicknesses. Some vegetative (green) roof media cannot resist wind scour unless stabilized by a uniform vegetative ground cover. Therefore, rapid establishment of ground-covering plants is an essential consideration when addressing the longevity of a vegetative (green) roof. Where protection of exposed media is of concern, techniques for wind stabilization should be introduced. Depending on the severity of the condition, these may include: temporary mats composed of biodegradable/photodegradable materials, permanent polymeric meshes or nets, and tackifying agents. Pre-grown mats or linked modules can also be used to create a wind-stabilized surface.

7.5 *Soil Reinforcement*—There are several reasons why soil reinforcement might be introduced as part of a vegetative (green) roof system. Soil reinforcement may be used to prevent damage caused by extreme rainfall and wind events, or to protect areas of a vegetative (green) roof where outwash from downspouts occurs. Also, soil reinforcement can be used to stabilize turf grass that will be subjected to heavy recreational use. The appropriate test for evaluating the usefulness of soil reinforcing layers are Test Method D4595, for geotextiles, and Test Method D6637 and Test Method D5262, for geogrid.

7.6 *Separation or Filter Layers*—The purpose of a filter layer is to prevent fine soil media particles from migrating into the drain layer causing clogging or reduction of the drainage capacity of the drain layer. Fabrics used as filter layers should have sufficiently high permittivity to allow water to percolate rapidly into the underlying drain layer. Vegetative (green) roof media should be matched to the fabrics to minimize the potential for clogging.

7.6.1 *Classes/Components of Filter Layers*—The filter layer may be independent of the drain layer or an integral part of a geocomposite drain layer. The filter layer of woven or non-woven fabric should typically be installed parallel with the drain layer.

7.6.2 *Functional Properties for Filter Layers:*

7.6.2.1 *Burst Strength*—Burst strength, measured according to Test Method D3786/D3786M is particularly useful when assessing the suitability of geotextiles that will be used to separate media from gravel or ballast.

7.6.2.2 *Tensile Strength*—Depending on the application, filter layers may be called upon to resist tensile forces. However, many vegetative (green) roof systems are designed to encourage root growth through filter layers. In these cases, the filter layers should not be so strong as to exclude plant roots. The appropriate test to determine the suitability with respect to tensile properties is Test Method D4595.

7.6.2.3 *Root Penetrability*—Root penetrability is desirable in many, but not all, vegetative (green) roof systems.

NOTE 2—There is, at present, no approved test for this property.

7.6.2.4 *Apparent Opening Size (AOS)*—The AOS of geotextiles used for separation layers should be selected on the basis of the particle-size distribution curve of the vegetative (green) roof planting media determined according to Test Method D4751.

7.6.2.5 *Permittivity*—Filter layers should allow good water flow perpendicular to the plane of the filter while inhibiting the migration of soil media particles into the drain layer. In most applications a permittivity, measured according to Test Methods D4491, of at least 1.5 sec^{-1} is recommended for filter layers.

7.6.2.6 *Clogging Potential*—The potential for geotextiles to become clogged by fine particles and lose permittivity is addressed in Test Method D1987 and Terminology D4439.

7.6.2.7 *Chemical and Microbial Resistance*—Geotextile filter layers should have sufficient resistance to anticipated soil borne chemicals or microbial growth.

7.6.2.8 *Specific Functional Properties to Classes/Component of Filter Layer.*

7.7 *Drain Layers*—The primary purpose of the drain layer is to remove excess water from the roof and maintain aerobic conditions in the vegetative (green) roof media. In some vegetative (green) roof systems, secondary functions may include providing a suitable horizon for introduction of irrigation or increasing the root-volume available for the plants. For a drain layer to be effective it should allow water to percolate vertically into the layer and also provide sufficient hydraulic transmissivity to convey the underflow horizontally to the discharge facility (for example, area drain, scupper, and gutter). Properly designed vegetative (green) roof systems should not result in surface flow or ponding during the designated design storm. Vegetative (green) roof planting mixtures are sufficiently permeable to promote rapid percolation to the drain layer. Also, it is common practice to provide direct access for surface water to the vegetative (green) roof system drain layer via stone margins, strips, or columns. Depending on climate, thickness of the vegetative (green) roof system, efficiency of the drain layer, geometry of the roof, and the density and spacing of the drainage facilities, the roofing/waterproofing membrane system may require little or no pitch to drain efficiently.

7.7.1 *Classes/Components of Drain Layers*—The choice of drain layer is an important factor influencing a vegetative (green) roof system's impact in reducing peak rainfall runoff rates from vegetative (green) roofs. This is because the hydraulic transmissivity of the drain layer is correlated to the time of concentration for the roof runoff function. The efficiency of the drain layer can also affect how rapidly the overlying planting mixture will dry out during drought conditions. Drain layers divide into two basic classes: granular drain layers and geocomposite drain layers.

7.7.1.1 *Granular Drain Layer*—Granular drain layers utilize coarse aggregate to create a zone of horizontal drainage. A number of granular materials may be considered. See 7.7.2.1 for a discussion of appropriate mineral aggregates.

7.7.1.2 *Geocomposite Drain Layers*—Drain layers composed of two or more materials one of which is a geosynthetic. Many geocomposite drain layers have a geosynthetic filter fabric adhered to one or both sides. See 7.7.2.2 for a more detailed discussion.

(1) Entangled Polymeric Filament Mats—These mats are composed of entangled filaments of different polymers which allow water flow from any direction. Typically mats have a geosynthetic filter layer attached to one or both sides.

(2) Shaped Plastic Sheet—These drain layers are made of continuous polymeric sheets that are deformed to three-dimensional layers with studs, pegs, cups, or dimples (often arranged in an egg-carton-like surface). Some varieties, like the dimpled egg-carton sheets, are transmissive on both sides. Others, like stud- or peg-style drain layers can be installed with the transmissive side up or down. When installed with the transmissive side facing down, it is usually to take advantage of water retention on the opposing face; that is, where the inverted studs or pegs form water-retaining reservoirs. In this configuration, consideration should be given to how rapidly water can percolate to the underside of the sheet. Typically these sheets include perforations for this purpose. Where the vertical permeability of a sheet is low, the selection of the vegetative (green) roof media should anticipate the potential for horizontal flow to develop above the drain layer; that is, soil properties should be consistent with single-course extensive vegetative (green) roof systems. There is great variety in the type of shaped plastic sheet components. Designers should consult product manufacturers regarding the performance characteristics of specific products and their appropriate use.

(3) Porous Synthetic Mats—These drain layers are made from fabrics or non-rigid foam. Some of these drain layers have a filter fabric bonded to the upper face.

(4) Rigid Grooved or Deformed Foam Boards—These drains are formed from rigid foam boards with grooves or deformations on one side to allow drainage. As with shaped polymeric sheet drain layers, consideration should be given to the how rapidly water can percolate to the underside of the boards where drainage occurs. Vertical flow may be at board seams or via perforations provided for this purpose. Some of these components are available with filter fabric pre-bonded to the upper face.

7.7.1.3 *Runoff Discharge Facilities*—Consist of any structure that conveys accumulated runoff off the roof. These include area drains, gutters, scuppers and associated piping. These structures receive both surface water and underflow from the drain layers. As with normal roofing practice, overflow drainage method should be provided for water removal in event of blockage of the primary system. Drain outlets should be located so they are remain accessible after anticipated vegetation growth and are protected so as to prevent vegetative growth from impairing their function. Additional internal drainage networks of perforated piping that reside in the aggregate/granular drain layer or on top of a geocomposite drain layer can be used to enhance drainage. These function to carry excess water directly to drain outlets.

7.7.2 *Functional Properties of Classes/Components of Drain Layers:*

7.7.2.1 *Granular Type Drain Layers:*

(1) Hydraulic Transmissivity—A reliable method for estimating the hydraulic transmissivity of a granular drain layer under field conditions is Test Method E2396. Flow rate in the layer can be estimated using the saturated water permeability of the granular drainage media, the thickness of the drain layer and the expected hydraulic gradient.

7.7.2.2 *Geocomposite Drain Layers:*

(1) Compressive Strength—Drain layers should withstand reasonable overburden pressures without sustaining reductions in their design hydraulic performance. Compressive strengths, used in conjunction with the measurement of hydraulic transmissivity, should exceed the expected overburden pressure, including the maximum dead load of the vegetative (green) roof system, snow loads, and ancillary landscape components. In critical applications, geocomposite drain layers should be evaluated for long-term mechanical creep, using Test Method D7361.

(2) Hydraulic Transmissivity—A reliable method for estimating the hydraulic transmissivity of a simple geocomposite drain layer under field conditions is Test Method D4716/D4716M. Flow rate in the layer can be estimated using the hydraulic transmissivity of the sheet and the expected roof gradient. Tests using Test Method D4716/D4716M to obtain hydraulic transmissivity should be conducted using hydraulic gradients that approximate, as closely as possible, the roof pitches and overburden pressures of the vegetative (green) roof system. Typical hydraulic gradients encountered in the field range from 1 to 10 %. Measurements made at higher hydraulic gradients can result in significant under-estimates of flow capacity under field conditions, possibly resulting in assembly designs that are excessively drained.

NOTE 3—Some complex drain layers incorporate reservoir sheets, in which the upper surface of reservoir sheets are intended to be filled with granular drainage media. This is done to support the weight of the overburden, improve access by the plant roots to the retained water, and increase the layer's water retention capacity. Other complex drain layers may incorporate dense geotextiles for purposes of moisture retention. Complex drain layers should be evaluated as a single system when assessing vertical permeability and hydraulic transmissivity.

7.8 *Water Retention Layers*—The purpose of the water retention function is to allow water to be stored for use by plants and to benefit stormwater infrastructure by reduction of runoff. This section specifically addresses water that is retained in addition to moisture absorbed by the vegetative (green) roof planting media.

7.8.1 *Classes/Components of Water Retention Layers*—The primary function is to retain water following irrigation or rainfall events. Water retention capacity can be separated into two forms: transient water retention capacity for water held for a certain number of hours or days before it begins draining away and long term water retention capacity for water that is only removed through plant transpiration or evaporation. Water retention may occur in multiple layers simultaneously, which is the method that provides the most reliable long term performance.

7.8.1.1 *Reservoir Sheets*—The drain layer can store water in receptacles formed into geocomposite drain layers. Comparison of water retention among these layers should be determined using Test Method E2398. Typical examples are inverted stud or peg-type sheets and dimpled egg-carton-type sheets. Reservoir sheets are frequently used to improve moisture retention capacity without adding significant additional weight to the vegetative (green) roof system.

7.8.1.2 *Restricted Drainage*—Collars or other devices can be installed at the runoff discharge facility to hold water to a pre-selected depth in the drain layer.

7.8.1.3 *Capillary Geotextile Layers*—This layer can be dense non-woven geotextiles, pads, or mats of non-rigid foam. While these function independently of drain layers they are sometimes bonded to a geocomposite drain layer in the manufacturing process.

NOTE 4—When capillary geotextile layers intervene between the vegetative (green) roof media and the drain layer, consideration should be given to how rapidly water can percolate through the water retention layer and into the drain layer below. The appropriate test is permittivity of the water retention layer, determined using Test Methods D4491. When low permittivity fabrics are used in this configuration, the selection of vegetative (green) roof media should anticipate the potential for horizontal flow to develop above the capillary geotextile layer; that is, soil properties should be consistent with single-course extensive vegetative (green) roof systems.

7.8.1.4 *Polymer Gels*—Some vegetative (green) roof systems exploit absorbent polymer gels to enhance the water retention capacity of the vegetative (green) roof system. The polymer gels can be contained in a non-woven fabric or, in some instances, bonded to the roof membrane in the manufacturing process.

7.8.2 *Functional Properties of Water Retention Layers*—Methods to estimate the water retention properties of the media in some vegetative (green) roof systems are provided in Test Method E2398 and Practice E2397.

7.9 *Protection Layers*—The purpose of the protection layer is to protect the roofing/waterproofing membrane system from damage.

7.9.1 *Classes/Components of Protection:*

7.9.1.1 *Tiles or Cement Boards*—In instances where there is a severe threat of penetration from surface activities, tiles or cement boards can be applied over the roof membrane to form a continuous protection layer. These should be compatible with prolonged exposure to moisture.

7.9.1.2 *Geotextiles*—Non-woven geotextiles.

7.9.1.3 *Polymeric Sheets*—Sheets or panels made of thermoplastic, rubber, or other polymers. This may include extruded foam insulation products.

7.9.1.4 *Geocomposite Layers*—Geocomposite products can be used as protection layers. In some instances, the geocomposite can be identical with the drain layer.

7.9.2 *Functional Properties of Protection Layers*—Roofing/waterproofing membranes require the use of a protection layer. Some protection layers may also function as the root-penetration barrier. The primary purpose of the protection layer is to protect the roofing/waterproof membrane from physical abuse during the installation of the vegetated (green) roof system components, from other trades, as well as from activities associated with long-term care and maintenance. The individual waterproofing/roofing manufacturer should be consulted with respect to its choice of protection layer for use in combination with its roofing/waterproofing membrane system. In order to evaluate a protection layer under specific field conditions, the designer may require that tests be conducted using the same roofing/waterproofing membrane system proposed for the application. Where future use of electrical methods of leak detection is desired, protection layers should be selected that do not inhibit or adversely affect the accuracy of the leak detection method.

7.10 *Root Penetration Barriers*—The purpose of a root penetration barrier is to prevent plant roots from growing into or through the roofing/waterproofing membrane system. The root penetration barrier should be positioned so it allows plant roots access to retained water. Any product that is to be considered for use as a root penetration barrier should pass a long-term test that replicates field conditions (**2**). Root penetration barriers should be continuous layers. The seams between adjacent sheets should provide the same level of root resistance as the field of the root penetration barrier layer. Roof systems that are identified as root-resistant and warranted against rootpenetration by the manufacturer may be installed without supplemental root penetration barriers.

7.10.1 *Classes/Components of Root Penetration Barrier:*

7.10.1.1 *Polymeric Sheet Material*—Membranes made of thermoplastic, rubber, or other polymers. These include, but are not limited to, membranes made of highdensity polyethylene (HDPE), low-density polyethylene (LDPE), chlorosulfonated polyethylene (CSPE), polypropylene (PP), thermoplastic polyolefin (TPO), polyvinyl chloride (PVC), Ketone Ethylene Ester (KEE), and ethyl-propylene diene terpolymer (EPDM). The designer should inquire into potential chemical incompatibilities between the roofing/waterproofing membrane and the root penetration barrier. If appropriate supply a suitable separation fabric to prevent direct contact between incompatible membranes.

7.10.1.2 *Herbicide or Root Growth Inhibitors*—Until a suitable test is available to evaluate the long-term effectiveness of root penetration barriers that rely on root repellant chemical compounds these products should be used with caution.

7.11 *Modules*—Design considerations for the waterproofing membrane dead load, plants, media, filter layers, drainage, water retention capacity, protection, and root penetration barriers are the same when addressing vegetative (green) roof systems that employ modules.

7.12 *Warranties*—There are a wide variety of warranties available from manufacturers. Read all provisions closely and insure that maintenance requirements are met to protect the owner‘s rights.

NOTE 5—The most comprehensive warranties available from some manufacturers will cover the costs of labor and material to remove and replace the full system including the defective components and overburden furnished for up to 20 years: from the waterproofing membrane up to and including the plantings. Other warranties may only require that the manufacturer furnish replacement for one component of the system within the first year.

8. Keywords

8.1 sustainability; vegetative (green) roof; vegetative (green) roof system; vegetative roofing/waterproofing membrane system

APPENDIX

(Nonmandatory Information)

X1. REVIEW OF POTENTIAL CONTRIBUTIONS OF VEGETATIVE (GREEN) ROOF SYSTEMS TOWARD ACHIEVING SUSTAINABILITY OBJECTIVES

X1.1 Environmental Impacts

X1.1.1 *Air Quality*—Vegetative (green) roof systems capture particulates and slows volatile organic compound (VOC)/nitrogen oxides (NOX) reaction rates that produces ground level ozone (that is, smog).

X1.1.2 *Carbon Sequestration*—Vegetative (green) roof system plants sequester atmospheric carbon. The effect is limited to the permanent biomass added to the vegetative (green) roof system by the foliage.

X1.1.3 *Stormwater Management*—Vegetative (green) roof systems intercept rainfall in media and plants and return a portion of this water to the atmosphere through evapotranspiration. This effect, which reduces runoff volume, is most prominent in warm months. Vegetative (green) roof systems can also influence peak runoff rates from roofs by introducing stormwater detention storage and by lengthening the times of concentration. These later effects are dynamic properties that are strongly dependent on internal drainage properties. Benefits are specific to different vegetative (green) roof systems. Therefore, with appropriate selection of drain layers, moisture retention layers, media, and plants, vegetative (green) roof systems may provide significant benefits by reducing both rate and quantity of stormwater runoff from roofs.

X1.1.4 *Runoff water quality management*—The potential for vegetative (green) roof systems to improve runoff water quality depends on site conditions, such as the rate of atmospheric deposition of particulate pollutants, rainfall distribution patterns, and the presence, or absence, of combined sewer systems. The concentration of chemical constituents in the underflow from vegetative (green) roof system can also be influenced by the choice of components and materials used in the vegetative (green) roof system. By reducing both the volume and the rate or runoff from roof surfaces, vegetative (green) roof systems can play an important role in reducing combined sewer overflows (CSOs), a major source of water pollution in many American cities. Vegetative (green) roof systems can also be relied on to buffer acidic rainfall that discharges to sensitive outfalls. The benefit in reducing the concentration and mass of pollutants washed from roof surfaces may vary depending on the background airborne pollutant deposition rates and the maturity of the vegetative (green) roof systems. It has been demonstrated that the ability of vegetative (green) roof systems to sequester and metabolize airborne nutrients and pollutants improves with maturity of the installation (**4**).

X1.1.5 *Noise/Acoustics Management*—Plant media, plants and vegetative (green) roof system structures may reduce both sound reflection and sound transmission The influence on sound reflection is likely to be a function of surface roughness and mostly independent of system thickness or mass.

X1.1.6 *Urban Heat Island Effect Mitigation*—Evaporative cooling reduces the temperature of vegetative (green) roof system surfaces and therefore can influence outdoor temperatures in the near vicinity. Also, by improving the energy efficiency of building envelopes, warming of ambient outside air through the discharge of waste heat from HVAC systems can be reduced.

X1.1.7 *Energy Efficiency*—The latent heat of evapotranspiration cools the surfaces of vegetative (green) roof systems during warm months. Conversely, thermal energy is released as water retained in vegetative (green) roof systems freezes in cold months. Vegetative (green) roof systems also stabilize the temperatures of roofing/waterproofing membrane systems through the property of thermal capacitance. The combined effects of these processes may act to reduce the rate at which thermal energy flows through the underlying roofing/waterproofing membrane system (**5, 6**). Insulation added as a component of a vegetative (green) roof system also contributes to the overall thermal performance.

X1.1.8 *Wildlife Habitat Creation*—Vegetative (green) roof systems may provide habitat to local and migratory wildlife. However, vegetative (green) roof systems should not be regarded as a method of replacing or preserving lost natural habitat. With few exceptions, vegetative (green) roof habitat differs in character and quality from native habitat. Generally, the types of animals that benefit from urban vegetative (green) roof habitat 'archipelagos' cannot be anticipated. This does not diminish the potential of vegetative (green) roof systems to enrich the biology of urban areas where natural habitat is not available.

X1.2 Social Impacts

X1.2.1 *Access to Vegetative (Green) Space*—In urban areas, some vegetative (green) roof systems offer improved access to landscaped areas for both passive and active recreational activities.

X1.2.2 *Therapeutic Environments*—Vegetative (green) roof systems have been used to provide therapeutic environments in medical facilities (7).

X1.2.3 *Community Organizing*—Vegetative (green) roof systems have been used as focal points to organize neighborhood communities around goals of education, food security, and nature conservation.

X1.3 Economic Impacts

X1.3.1 *Costs/Benefits*—Under certain circumstances, a present-value economic analysis of development plans that incorporate vegetative (green) roof systems may show an advantage over alternative plans. However, the realization of a net financial benefit for the property owner may often be dependent on incentives and subsidies offered by government. In municipalities with combined sewer systems, the saving associated with reductions in infrastructure upgrades may justify the cost to the community of providing incentives for vegetative (green) roof installations.

X1.3.1.1 Particularly in dense urban areas, the incorporation of vegetative (green) roof systems may offer a cost-effective approach for complying with stormwater management programs. In some instances direct or indirect subsidies, such as tax abatements, may also be offered by municipalities to implement stormwater management practices that can reduce stormwater runoff. Countervailing costs that may add to first costs include: *1*) required upgrades to roofing/waterproofing membrane systems, *2*) supplemental construction quality assurance activities, and *3*) structural enhancements to support the weight of the vegetative (green) roof system.

X1.3.1.2 Financial benefits of vegetative (green) roof systems may be realized in lower operating costs associated with reducing HVAC demand. Also, in some municipalities, entities that install vegetative (green) roof systems may benefit from lowered sewer fees. Costs associated with annual vegetative (green) roof system maintenance, represent a countervailing cost.

X1.3.2 *Building Longevity*—Vegetative (green) roofs offer protection to the underlying roofing/waterproofing membrane system similar to conventional protected roof assemblies. As a result, roofing/waterproofing membrane systems covered with a vegetative (green) roof assembly should have a longer service life than an exposed roofing/waterproofing membrane system.

X1.3.3 *Salvage and Re-Use Options*—Vegetative (green) roof systems can be designed with salvage value in mind. In particular, media and modules may be reusable for other landscape applications. Plants can be salvaged and sold.

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