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Design Strategies to Address Wind Uplift and Scour in Green Roofs

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by
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Thirty years of German experience has shown green roofs are not particularly vulnerable to uplift because the plants create substantial turbulence (a large boundary layer), and the roots and foliage prevent particles from being plucked off the roof. When it does occur, wind-related scour damage is usually experienced at the edges and parapets of roofs where stable eddies can form. Margins of heavy concrete pavers are used almost universally in high-rise installations in Germany.

European and American green roof experience has identified several ways to address wind uplift pressure and wind erosion due to high wind speeds:

- Installation of unit pavers around the perimeter of the green roof
- Installation of buried or partially exposed concrete turf pavers or concrete units at the roof edge
- Installation of gravel or river stone around the perimeter of the green roof

To address the potential impact of wind uplift and scour on our green roofs we observe guidelines for similar roofs in Germany. In particular, we looked to recommendations for high-rise structures used by our partner company, Optigrün International AG, which has been directly involved with the installation of millions of square of feet of green roof over a period of 30 years. During this time, they have had no adverse judgments against them for insurance claims. In addition, we have adapted the FM Global guidance, 'Above-Deck Roof Components; FM Global 1-29,' in order to generalize our approach to a range of specific site conditions.

Optigrün recommends a minimum cover system dry weight of about 15 psf. At the margins of the roof, the recommendations for cover system dry weight vary according to the building height, aspect ratio, and exposure (i.e., corner, edge, and field). We believe that their requirements are conservative, especially in light of the FM (Factory Mutual) guidelines.

For all current Roofscapes, Inc. projects, dry weight for the cover system is determined using ASTM E-2397-05. This ASTM standard method was developed to provide an industry standard for the dry and wet weight of green roof systems, as well as moisture content, water permeability, and porosity. ASTM standard method E-2397-05 is conservative and produces similar results to the German methods referenced by FLL[1], "Guideline for the Planning, Execution and Upkeep of Green-roof Sites," Release 2002.

The FM Global guidance, 'Above-Deck Roof Components; FM Global 1-29,' relates stable ballast type to computed negative wind pressures. This permits ballast selection to be generalized to a wider variety of structures and conditions. However, an assessment of the negative wind pressure is required. The guidance is intended reduce the potential for disruption of ballast by wind scour. FM Global recognizes three classes of ballasts: 1) coarse aggregates, and 2) independent unit pavers, and 3) integrated pavers systems. The properties of different integrated

[1] Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V.

paver systems, including tongue & groove, beveled and strapped pavers, are not differentiated. The FM guidance also takes into account the parapet height. Like the German guidance, it recognizes different weight requirements for corner, edge and field conditions.

In adapting the FM Global guidance, Roofscapes, Inc compares a mature green roof to integrated paver systems. In our case, we offer a layered system of soil and fabrics held together by roots and integral synthetic mesh. Mature green roofs can be regarded as being laterally integrated due to the incorporation of roots and fabrics. To compensate for early post-construction conditions, Roofscapes, Inc. recommends that wind blankets be utilized adjacent to parapets. In many instances, we recommend that these blankets are permanent, UV stabilized mesh. *Roofscapes, Inc. is alone in the green roof industry with regard to its policy of routinely installing permanent wind erosion mesh within 2 m (6.5 ft) of roof margins with low parapets*.

The actual uplift pressures experienced on green roofs is significantly lower than on any conventional paver-covered surfaces. Paver ballasts offer a relatively smooth surface with a thin aerodynamic boundary layer, thus maximizing potential uplift, according to Bernoulli's Principle. Green roofs differ from paver ballasts in that they are aerodynamically very rough. *Consequently, a green roof should be expected to outperform a paver ballast of equivalent weight.* We encourage FM Global and other industry authorities to quantify the effect of a vegetated cover in reducing uplift pressure and scour. Until appropriate wind-tunnel tests are conducted, Roofscapes, Inc. will continue to follow the approach of designing around both the Optigrün guidance and the FM Global; Above-Deck Roof Components; FM Global 1-29, as adapted by us.

Case Studies

World Trade Center, Boston, MA

In preparing a design for the World Trade Center podium roof, Roofscapes, Inc. followed the guidelines for similar roofs in Germany. In particular, the German recommendation for a 20-meter building (65 feet) is that the dry weight of the cover system be about 15 psf. At the margins of the roof, the recommendation requires that the cover system weigh about 40 psf. Our design involved a 5-inch deep cover system using light-weight materials that will weigh about 20 psf dry and 30 psf when wet. At the edges, we buried concrete turf paving blocks to increase the dry-weight load to about 30 psf (40 psf wet).[2] The margin pavers were buried (rather than exposed at the surface) to comply with the owner's wishes that the vegetated layer extend to the edge of the roof parapet; however, either approach is suitable. The paver perforations were filled with growth media. The parapet ranged from 2 to 5 inches higher than the top of the green roof media.

To further stabilize the cover, we integrated a high-strength geotechnical reinforcing mesh (tensile strength 1,560 psf, ASTM-4595). The mesh extended 6.5 feet in from the edge of the roof and was attached to the buried concrete turf paver blocks using cables. The plants were installed as mature pre-grown mats stabilized in a mesh drainage mat. As the roof continues to mature, the plant roots lock into the buried mesh. The result is a 6 foot wide, 100-foot long cover layer of soil, turf and paving blocks that are tied together. For the cover system to blow off it must take this entire the strip. Note that to our knowledge, internal reinforcing mesh has not been used in German projects. The mesh has been introduced by Roofscapes, Inc. as a redundant design feature and is now standard in our projects.

This design for the Boston World Trade Center was judged to be stable against wind scour and uplift for wind velocities up to 94 mph (the 100-year wind event). Of note:

[2] If desired, the dry weight at the edges could have been increased to 40 psf by reducing the spacing between the paving blocks. However, concerns for load bearing capacity of the roof determined the final design.

- The height of the parapet was only 5 inches and their was no other wind protection

- The design was reviewed by RWDI, which agreed with our assessment that the design was suitable under these conditions.

Shadow Wood Demonstration, Fort Meyers, FL

This demonstration installation is located on a metal roof that is 15 feet above ground level. The wind stabilization system for this green roof includes a one-foot wide margin of concrete pavers, installed over a bedding of lightweight coarse aggregate. The design included a high-strength geotechnical reinforcing mesh (tensile strength 1,560 psf, ASTM-4595) that extends 6.5 feet in from the edge of the roof and is attached to the aluminum edging that cradles the concrete pavers.

Florida Department of Environmental Protection, Bonita Bay, FL

The stabilization design used for the Shadow Wood project was also used on the Florida Department of Environmental Protection (DEP) green roof installation. Located near Fort Meyers in Bonita Bay, this DEP green roof has endured three hurricanes and one tropical storm. In 2004, this green roof withstood Hurricane Charlie, a category 4 hurricane with winds ranging from 131 mph to 155 mph, and Hurricane Jeanne, a strong category 1 or weak category 2 hurricane with winds of 75 mph to 95 mph. (Note: wind speed is based on data available from the storm analyses and not from roof top measurements). In addition to both of these hurricanes, the DEP green roof withstood Tropical Storm Frances with winds of 60 mph. In 2005, this same green roof was hit by Hurricane Wilma, a category 3 hurricane with winds ranging from 111 mph to 130 mph. After the rain cleared, most conventional roofing in the hardest hit areas was destroyed or missing all together, including a roof build in the same manner as the green roof (but without the green roof). In all these storms, the DEP green roof, however, performed very well, with no loss of material, plants or media.

The plants on the Florida DEP green roof were established with plugs; therefore, Roofscapes, Inc. incorporated a permanent mesh wind blanket that was shallowly embedded into the growing media. The wind blanket extends six feet in to the center from the green roof perimeter and is anchored with ties or cables to the separation fabric beneath the growing media. The permanent wind blanket minimizes winnowing of soil particles and creates a laterally continuous cover. Roofscapes, Inc. presently incorporates this permanent wind blanket strategy in all of its projects.