Roofscapes inc.
Green Technology for
the Urban Environment

7114 McCallum Street
Philadelphia, PA 19119
215 247-8784 phone
www.roofmeadow.com

Design Strategies to Address Wind Scour in Green Roofs in Extreme Wind Areas

by
Charlie Miller, P.E.

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 cover materials are air-permeable. Consequently, uplift pressures estimated using standard procedures for roofing materials (e.g. ASCE 7) are not actually realized on green roofs. When it does occur, damage is results from wind-scour. Problems can be experienced at the edges and parapets of roofs where stable eddies can form. For this reason, margins of heavy concrete pavers are used almost universally in high-rise installations in Germany.

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 and pressure is quickly dissipated because the cover can 'breath.' *Consequently, a green roof should be expected to outperform a paver ballast of equivalent weight.*

We look forward to the results of wind tunnel tests and field monitoring that will lead to practical design algorithms for green roofs. In the meantime, we follow a conservative approach for design in high wind areas. This approach is two-fold. First, at margins and corners we advocated installing concrete pavers that are tethered with cables to a wide sheet of high-strength geogrid. The width of this margin will coincide with the area in which the traditional uplift computations result in a negative pressure that exceed 45 psf. In some cases, the client may choose to leave this margin without a cover or to pour a topping slab. Second, where the uplift computations result in negative pressures less than 45 psf, we consult FM Global guidance for the weight of ballast. We consider beveled pavers to represent a reasonable surrogate for a mature green roof cover.

The FM Global guidance, 'Above-Deck Roof Components; FM Global 1-29,' relates stable ballast type to computed negative wind pressures. The guidance is intended to reduce the potential for disruption of ballast by wind scour. Minimum ballast weights are related to uplift potential. For all Roofscapes, Inc. projects, dry weight for the cover system is determined using ASTM E-2397-05.

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*.

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).[1] 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:

- 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.
- Through the use of geotechnical methods this design allows the planted cover to extend to the perimeter of the roof

This project has experienced no wind-related damage or disruption in the five years since it was built.

Florida Department of Environmental Protection, Bonita Bay, 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.

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

[1] 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.

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.

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.