University of Florida Research  Wind and Plant Performance Studies for Green Roof Systems in FL

Wind Resistance of Green Roof Systems in Florida –
Developing A Wind Test Protocol

Principal Investigator:  David O. Prevatt, Ph.D., P.E. (MA)
Co-Investigators: Glenn A. Acomb, FASLA
Forrest J. Masters, Ph.D., P.E. (FL)
Graduate Research Assistant: Tuan D. Vo, E.I.
Research Assistant: Nick K. Schild
Research Scope and Objectives

- **Task 2:** Investigate the performance of vegetative roof systems appropriate to Florida building for performance in hurricane wind and rain conditions.

  - (a) Capture and present the most recent research on vegetative roofs in the public domain. Catalogue and compare the vegetative roof systems (in Florida), their (wind) anchorage to the roof structures and installation and design criteria.

- Approximately 12 million sq. ft. of green roofing systems in the US.
- Nearly one-third of these are in southeastern U.S. (including Texas). Less than 2% of US green roofs are installed in Florida.
- UF Report UF04-11 (September 2011): extensive literature review.
- No Verification Test Protocol Exists for Wind Uplift Performance
University of Florida Research  Wind and Plant Performance Studies for Green Roof Systems in FL

Green Roof Design Guidelines

German FLL

ANSI/SPRI VF-1: External Fire Design Standard for Vegetative Roofs

FM Global I-35: Green Roof Systems

German FLL: Green Roofing Guideline

ASTM-E2396: Saturated Water Permeability of Granular Drainage Media
ASTM-E2397: Determination of Dead/Design Loads on Green Vegetative Roofs
ASTM-E2398: Water Capture and Media Retention of Geocomposite Drain Layers
ASTM-E2399: Maximum Media Density for Dead Load Analysis
ASTM-E2400: Selection, Installation, and Maintenance of Plants for Green Roof Systems Guide

German FLL: Green Roofing Guideline

(FLL, 2008)

(Factory Mutual Insurance Company, 2007)

(SPRI, 2010)

(SPRI, 2010)
Green Roof Standards/Guidelines

- **FLL site condition checklist:**
  - Climate and weather-dependent factors
  - Structure-dependent factors
  - Plant-specific factors for design & maintenance (not selection)

- **FM Global 1-35: most conservative guide**
  - 100 mph limit = restricts green roofs in FL
  - Commercial roofs on metal or concrete decks

- **RP-14: Prescriptive wind design guide and tables**
  - Unprotected media limit of 5” diameter (influences plant selection)
  - Design tables per ASCE 7-05 wind maps

Recommendation: Florida Green Roof Design Guide should develop from a combination of the FLL, RP-14, VF-1 and FM 1-35.
Wind Load on Green Roof Systems

Critical wind load: corner and roof edges
University of Florida Research  Wind and Plant Performance Studies for Green Roof Systems in FL

Research Scope and Objectives

• Phase 2 Tasks:

  – (b) Conduct wind uplift tests on full scale “Florida-appropriate” green roof systems and develop preliminary understanding of the performance in high winds. Evaluate minimum biomass loss, scouring characteristics, and plant damage for moderate, strong and extreme winds. Determine effect of rain on wind performance. Assess the rate of recovery of vegetation and effect of multiple wind storms.

  – (c) Conduct parametric studies of factors affecting uproot resistance and plant breakage strength of plants used in vegetative roof systems, and scour resistance for green roof systems. Develop a standardized test procedure for evaluating green roofs hurricane wind related performance and submit protocol to ASTM and the Green Roof Council to initiate national consensus standards development.
Experimental Design

- Full-scale wind uplift tests on green roofs systems (6 ft by 6 ft)
- Evaluate three growth media depths: 4 in., 6 in. and 8 in.
- Simulate modular tray and built-in-place green roof systems
- Identify appropriate plants suited to the Florida climate.
- Determine effect of water-soaked growth media on performance
- Develop test methods to evaluate wind uplift capacity of roots
Phase 1 Test Setup

- 6 tests of modular tray roofs
- 3 tests 4 in. depth, 3 test 8 in. depth
- 9 trays per test, incl. 1 unprotected module
- Wind speeds, 30, 40, 50, 70, 90, 120 mph
- 5 minutes each test
- Wind azimuth 90 degrees
- 12 in. high parapet
- 6 plant varieties mixed
4 in. module test at 120 mph
### Phase 1 Test Matrix

<table>
<thead>
<tr>
<th>Test ID</th>
<th>Wind Testing Date</th>
<th>Establishment Period</th>
<th>Plant Height</th>
<th>Parapet Configuration</th>
<th>Unprotected Module Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>4” – T1</td>
<td>08/18/2011</td>
<td>3 months</td>
<td>Mixed</td>
<td>Encompassing</td>
<td>9</td>
</tr>
<tr>
<td>4” – T2</td>
<td>08/18/2011</td>
<td>3 months</td>
<td>Mixed</td>
<td>Encompassing</td>
<td>5</td>
</tr>
<tr>
<td>4” – T3</td>
<td>08/18/2011</td>
<td>3 months</td>
<td>Mixed</td>
<td>Encompassing</td>
<td>1</td>
</tr>
<tr>
<td>8” – T1</td>
<td>08/18/2011</td>
<td>3 months</td>
<td>Mixed</td>
<td>Encompassing</td>
<td>7</td>
</tr>
<tr>
<td>8” – T2</td>
<td>10/20/2011</td>
<td>5 months</td>
<td>Mixed</td>
<td>Encompassing</td>
<td>8</td>
</tr>
<tr>
<td>8” – T3</td>
<td>02/16/2011</td>
<td>9 months</td>
<td>Mixed</td>
<td>Back wall removed</td>
<td>8</td>
</tr>
</tbody>
</table>

**Observation:**

Severe scour at corners in unprotected module trays.

8 in. depth growth media trays produce robust plants but severe dieback occurs in dry winter.
Examples: Scour at Roof Corner and Edges

Phase 1: Test Trial 1, leeward corner

Phase 2: Test Trial T7, windward corner
Phase 1 Conclusions

• 8” better for plant health than 4” (irrigation needed)
• Protection provided by parapets (but movement of media on roof)
• Dormant woody plants a fire hazard in winter unless fuel removed
• Wind speed under 70 mph not damaging in short term tests
• Limitation of test (simulator produces low turbulence wind flow ~5% TI) which is likely far less damaging than real winds
Phast 2 Test Setup
Phase 2 Test Setup
Phase 2 Test Setup

- 16 Trials; 45 degree wind azimuth; no parapets (conservative)
- 8 tests built-in-place green roof assemblies (normal vs. saturated)
- 8 tests module trays; 4 repeated and 4 6-month old
- Wind speed: 100 mph; held for 10 minutes and 20 minutes
- Trays planted in short plant species and tall species (in 6 month old trays)
### Phase 2 Test Matrix

#### Phase 2: Built-in-Place Green Roof Test Matrix

<table>
<thead>
<tr>
<th>Test ID</th>
<th>Plant Date</th>
<th>Wind Testing Date</th>
<th>Establishment Period</th>
<th>Moisture</th>
<th>Plant Height</th>
<th>20 min. test (Y/N ?)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-S1</td>
<td>04/25/2012</td>
<td>06/12/2012</td>
<td>7 weeks</td>
<td>Normal</td>
<td>Short</td>
<td>No</td>
</tr>
<tr>
<td>N-S2</td>
<td>04/25/2012</td>
<td>06/13/2012</td>
<td>7 weeks</td>
<td>Normal</td>
<td>Short</td>
<td>No</td>
</tr>
<tr>
<td>N-T1</td>
<td>04/25/2012</td>
<td>06/12/2012</td>
<td>7 weeks</td>
<td>Normal</td>
<td>Tall</td>
<td>No</td>
</tr>
<tr>
<td>N-T2</td>
<td>04/25/2012</td>
<td>06/13/2012</td>
<td>7 weeks</td>
<td>Normal</td>
<td>Tall</td>
<td>No</td>
</tr>
<tr>
<td>S-S1</td>
<td>04/28/2012</td>
<td>06/13/2012</td>
<td>6.5 weeks</td>
<td>Wet</td>
<td>Short</td>
<td>No</td>
</tr>
<tr>
<td>S-S2</td>
<td>04/28/2012</td>
<td>06/13/2012</td>
<td>6.5 weeks</td>
<td>Wet</td>
<td>Short</td>
<td>No</td>
</tr>
<tr>
<td>S-T1</td>
<td>04/28/2012</td>
<td>06/19/2012</td>
<td>7.5 weeks</td>
<td>Wet</td>
<td>Tall</td>
<td>Yes*</td>
</tr>
<tr>
<td>S-T2</td>
<td>04/28/2012</td>
<td>06/19/2012</td>
<td>7.5 weeks</td>
<td>Wet</td>
<td>Tall</td>
<td>Yes*</td>
</tr>
</tbody>
</table>

#### Phase 2: Modular Tray Green Roof Test Matrix

<table>
<thead>
<tr>
<th>Test ID</th>
<th>Wind Testing Date</th>
<th>Establishment Period</th>
<th>Media Depth</th>
<th>Plant Height</th>
<th>Continued Testing?</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2</td>
<td>06/18/2012</td>
<td>13 months</td>
<td>4”</td>
<td>Mixed</td>
<td>No</td>
</tr>
<tr>
<td>T3</td>
<td>06/18/2012</td>
<td>13 months</td>
<td>4”</td>
<td>Mixed</td>
<td>No</td>
</tr>
<tr>
<td>T5</td>
<td>06/20/2012</td>
<td>13 months</td>
<td>8”</td>
<td>Mixed</td>
<td>No</td>
</tr>
<tr>
<td>T6</td>
<td>06/20/2012</td>
<td>13 months</td>
<td>8”</td>
<td>Mixed</td>
<td>No</td>
</tr>
<tr>
<td>T7</td>
<td>06/21/2012</td>
<td>6 months</td>
<td>4”</td>
<td>Tall</td>
<td>Yes</td>
</tr>
<tr>
<td>T8</td>
<td>06/20/2012</td>
<td>6 months</td>
<td>4”</td>
<td>Short</td>
<td>No</td>
</tr>
<tr>
<td>T10</td>
<td>06/22/2012</td>
<td>6 months</td>
<td>8”</td>
<td>Tall</td>
<td>Yes</td>
</tr>
<tr>
<td>T11</td>
<td>06/22/2012</td>
<td>6 months</td>
<td>8”</td>
<td>Short</td>
<td>No</td>
</tr>
</tbody>
</table>
University of Florida Research Wind and Plant Performance Studies for Green Roof Systems in FL

Results: Short versus Tall Plants, & Duration

- RECOMMENDATION:
  Moisture content was not a major factor
  Coverage ratio reduces with time, therefore significant loss in plant coverage in a “normal” hurricane.
Green Roof Anchorage

Case 1: No Internal ties

Case 2: Internal ties provided

RECOMMENDATION:

- Anchorage is required for all green roofs to the structure/substrate
  Unprotected growth media susceptible to scour

- Parapets and sufficient dead load of green roof may minimize failure
Deeper Media Depth = Healthier Plants

4 in. deep module trays
8 in. deep module trays

RECOMMENDATION: Assume 6 in. minimum growth media depth for Florida

1. Decreases heat flux effect on roots
2. Greater dead load mitigates chance of green roof displacement
\textbf{Plant Height}

- **RECOMMENDATION**: Use low-lying plants (horizontal stem spread) to minimize wind uplift forces.

- **Lantana**
  - "wet": 94% vs. 68%
  - Tall, Lantana species prior to testing vs. Tall, Lantana species after testing

- **Portulaca**
  - "wet": 98% vs. 79%
  - Short, Portulaca species prior to testing vs. Short, Portulaca species after testing
Root Uplift Test Device

- 6” Linear Actuator
- 200 lb Load Cell
- Rubber Padded Steel Plates
Typical Force vs. Displacement Plots

Typical curve denoting 6” upheaval of binded growth media

Displacement = 5.9165 in
Peak Load = 32.2649 lbs

Typical curve denoting stem/root breakage

Displacement = 3.3192 in
Peak Load = 24.5218 lbs
University of Florida Research  Wind and Plant Performance Studies for Green Roof Systems in FL

Uproot Resistance

• Root network minimizes scour potential of growth media
• Roots fully bound the media in 6 mo. and 12 mo. modules
• Lantana species showed highest uproot resistance, showing only 1 sign of stem breakage. *Delosperma* performed the worst.
• Uproot test results suggest that given sufficient establishment, wind damage does not affect uproot resistance of a plant
Green Roof Plant Species for Florida

- Considerations:
  1. Plants must tolerate extreme heat and drought
  2. Plant root system habit and depth must be understood
  3. Plants must be hardy and low-maintenance
  4. Irrigation is needed
  5. Origin of plants should be within the region and grown to match the roof conditions
  6. Plant form and leaf area should limit uplift
  7. Plants should achieve coverage quickly
Plant Selection Performance

• Of the selected plant species, none failed excessively in comparison to each other.
• Taller plant species were more susceptible to bending and root lodging, and resulted in higher amounts of media exposure.
• The originally planted Lantana and Salvia experienced extreme stress after Phase 1, due to sporadic irrigation in the winter months and suffered many losses.
• Succulents perform better in surviving heat and dry extremes, as well as wind desiccation
Summary

• Major conclusions
  – Avoid using tall plants in significant proportions – reduced wind stresses
  – Vegetation coverage and root networks helpful to reduce scour
  – A minimum test period of 20 minute recommended (more is better)
  – Root uplift tests useful but need to be calibrated to wind uplift tests.
  – Studies are needed using high turbulence wind flows 9 (15%-25%)

• Future recommendations
  – ASTM E60 Subcommittee: Will review report for inclusion in their work
  – Wind Load on Green Roof at CitiesAlive Conference Chicago 2012
  – Currently 3 scientific papers in preparation on the work
Thank you for Your Attention!

Comments/Questions?

David O. Prevatt
dprev@ufl.edu
352-672-2660
Phase 2: Modular Tray Green Roof Systems

- Measured losses show uniform media loss across the roof surface as opposed to Phase 1’s redistribution.
- Coverage ratio losses were lower in modular trays than built-in-place assemblies.
- Modular tray green roofs display localized scour patterns.
University of Florida Research Wind and Plant Performance Studies for Green Roof Systems in FL

Phase 2: Built-in-Place Green Roof Systems

Portulaca “wet” 98% 79%

Aptenia “dry” 96% 81%
Phase 2: Built-in-Place Green Roof Systems

94% → 68%

47% → 35%
Green Roof Anchorage

Therefore, through the observed movement in Phase 1 and failures in Phase 2, as well as UCF’s documented wind-induced failure, the investigators identified that for adequate system anchorage, it was necessary to implement one (or a combination) of the following options:

- Install green roof systems with sufficient dead load to resist uplift with proper maintenance and vegetation to provide scour resistance
- Mechanically attach the green roof system to the roof deck
- Utilize a parapet of sufficient height to prevent wind flow from reaching the underside of a loosely laid green roof system