

## Green Roofs

Restoring Urban Landscapes One Roof at a Time

October 9, 2014




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### Overview

- Introduction
- Green Roof Benefits
- Types of Green Roofs
- Design & Installation
  - Components
  - Factors & Considerations
- Post-Installation
- Retrofits

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### Civil Engineering Crossroads



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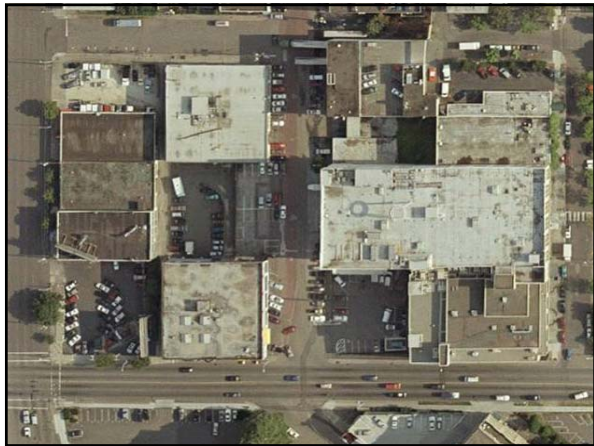
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Sites to Mimic Nature



Source: Magnusson Klemencic Associates

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Civil Engineering Crossroads







Pre-Settlement Conditions

Historical Urban Development

Green Stormwater Infrastructure

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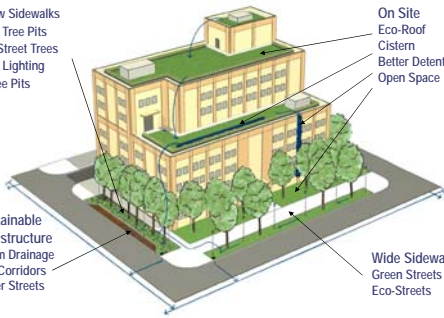
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## Urban Green Stormwater Strategies



Narrow Sidewalks  
Better Tree Pits  
More Street Trees  
Better Lighting  
No Tree Pits



On Site  
Eco-Roof  
Cistern  
Better Detention  
Open Space

Sustainable  
Infrastructure  
Storm Drainage  
Eco-Corridors  
Better Streets

Wide Sidewalks  
Green Streets  
Eco-Streets

Source: Magnusson Klemencic Associates

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## Green Roofs...



Source: www.roofscapes.com

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## ...aka...



- "Living Roofs"
- "Vegetated Roofs"
- "Eco-roofs"
- "Roof gardens"

Source: www.roofscapes.com

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## Benefits



- Ecology
- Social
- Noise Reduction
- Energy and Heat
- Economy
- Stormwater

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## Ecology: Habitat & Biodiversity



Laban Dance Centre, London

- Wildlife habitat
- Demonstrated success when targeted to species



Black Redstart

Source: [www.greenroofs.com](http://www.greenroofs.com)

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## Ecology: Habitat & Biodiversity

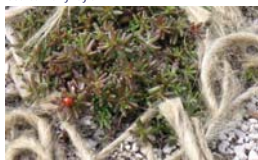


Killdeers

Source: [www.roofscapes.com](http://www.roofscapes.com)



Birdhouse with Green Roof  
Source: Barry Taylor



Ladybug

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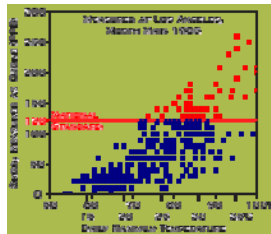
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## Ecology: Air Quality



Increased temperature = increased smog

- Particulates trapped
- Secondary benefits from reduced temperature



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## Social



Green roof at nursing home

- Faster healing
- Happier, more content, less stressed
- Increased productivity
- Reduced sick days

Source: [www.greenroofs.org](http://www.greenroofs.org)

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## Social



Life Expression Wellness Center  
Sugarloaf, Pennsylvania

Source: [www.roofscapes.com](http://www.roofscapes.com)

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## Noise Reduction



Howard Hughes Medical Center  
Dulles, Virginia

Source: Roofscapes.com

- Reduce noise up to 50 decibels
- Effective for low-frequency sounds



Source: www.greenroofs.org

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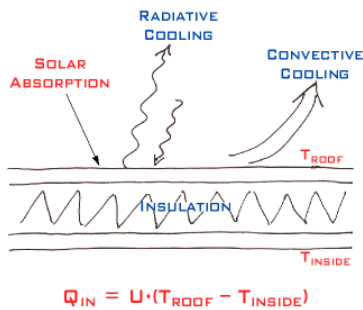
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## Energy & Heat



- Roofs have major role in building energy consumption



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## Energy & Heat



- Evapotranspiration affects global energy flux

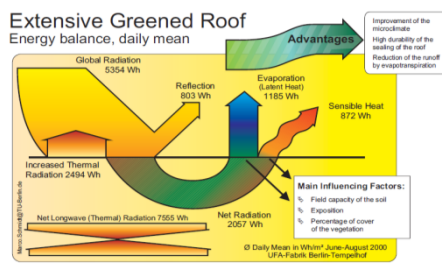


Fig. 4 Extensive greened roofs transfer 58% of net radiation into evapotranspiration during the summer months, UFA-Fabrik in Berlin, Germany

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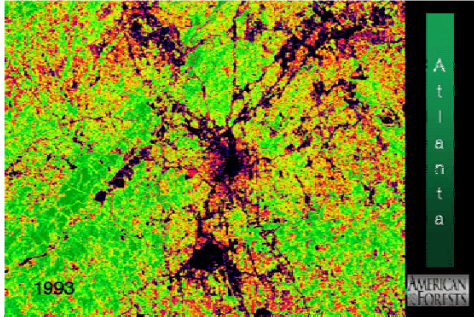
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## Energy & Heat



- Traditional roofs & pavements contribute to urban heat island



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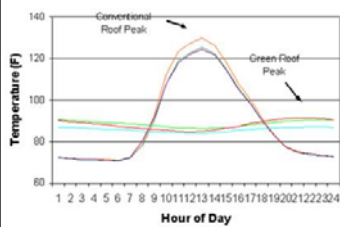
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## Energy & Heat



**UCF Green Roof**  
Roof Surface Temperature Comparison  
Average Day: July 4, 2006 to Sep. 1, 2006



- Moderate roof temperature
  - Thermal mass
  - Evapotranspiration
- Reduce heat stress on roof membrane
- Reduce ambient air temperature

Source: Jeffrey K. Sonne, Florida Solar Energy Center

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## Energy & Heat



- Improve mechanical efficiency
- Improve solar efficiency
- Reduce greenhouse gases from heating/cooling



Source: www.roofscapes.com



Source: U.S. EPA Region 8

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## Economic



- Reduce size of HVAC equipment
- Extend roof membrane life
- Higher lease rates
- Higher productivity
- Incorporate function...
  - Water treatment
  - Food production



Source: www.greenroofs.com

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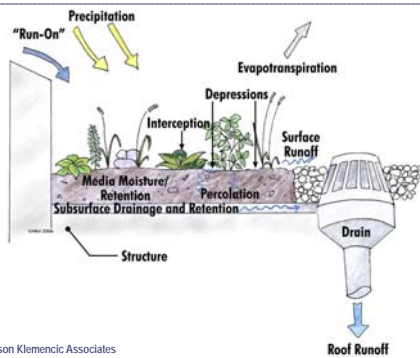
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## Green Roof Hydrologic Processes



Source: Magnusson Klemencic Associates

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## Stormwater Control Factors



- Thickness of media
- Media hydraulic properties
- Type of drainage layer used
- Properties of drainage layer
- Vegetation
- CLIMATE!
  - Micro-climate
  - How much time is available to "recharge" media
  - Evapotranspiration rates driven by temperature, humidity, windspeed, and solar radiation

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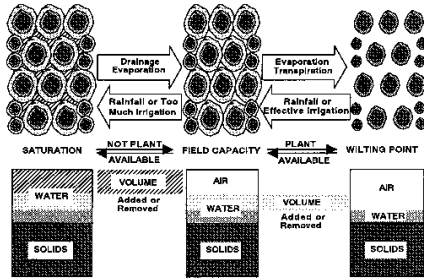
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## Green Roof Components – Growing Media



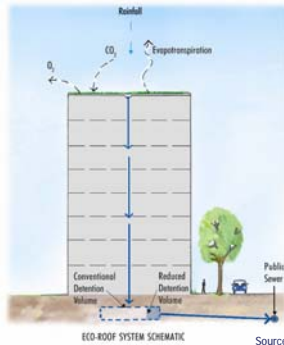
### Moisture retention & plant water availability



Source: [www.bae.ncsu.edu](http://www.bae.ncsu.edu)

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## Stormwater



Source: Magnusson Klemencic Associates

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## Green Roof Components – Overview

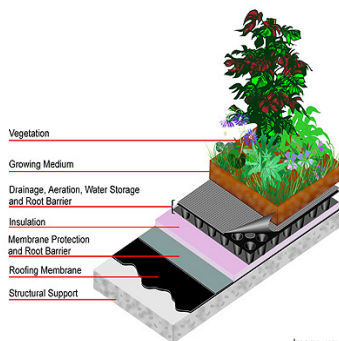


Image: [www.lowimpactdevelopment.org](http://www.lowimpactdevelopment.org)

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### Green Roof Categories



- Intensive: 6" or thicker
- Semi-intensive: 25% above or below 6"
- Extensive: up to 6"

Source: Green Roofs for Healthy Cities

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### Green Roof Categories: Intensive



- "Roof garden" with trees, shrubs, etc
- Often accessible
- 50+ psf
- Expanded planting palette
- Highest cost \$25+/sf
- Highest maintenance

Source: Green Roofs for Healthy Cities

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### Green Roof Categories: Intensive



Millennium Park, Chicago

Source: [www.greenroofs.com](http://www.greenroofs.com)

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### Green Roof Categories: Intensive



Hugh Garner Housing Co-operative

Source: [www.greenroofs.com](http://www.greenroofs.com)

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### Green Roof Categories: Semi-Intensive



- May be turf/lawn
- May be accessible/partially accessible
- 35-50 psf
- Moderate planting palette
- Take advantage of roof capacity
- Moderate cost (\$16-25/sf)
- Moderate maintenance

Source: Green Roofs for Healthy Cities

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### Green Roof Categories: Semi-Intensive



Vancouver Public Library

Source: [www.greenroofs.com](http://www.greenroofs.com)

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### Green Roof Categories: Semi-Intensive



Seattle Art Museum/WAMU

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### Green Roof Categories: Extensive



- Lightweight
- Larger areas
- 10-40 psf (allow 40 psf for 6-inch)
- Somewhat limited planting palette
- Typically inaccessible
- Lowest maintenance
- Lowest cost (\$12-20/sf)
- Amenable for retrofits

Source: Green Roofs for Healthy Cities

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### Green Roof Categories: Extensive



Whistler Daycare Centre, B.C.

Source: BCIT

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## Green Roof Categories: Extensive



MKA Green Roof Evaluation Test Plot

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## Green Roof Systems



### ■ Modular

- Trays or "bags"
- Can pre-plant off-site
- Quick installation, simpler coordination
- Easier roof repairs



Images: www.greenroofroofs.com

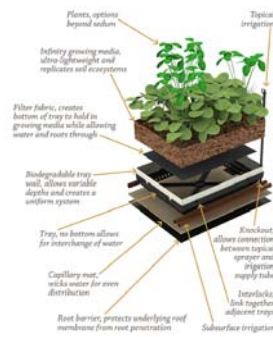
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## Green Roof Systems



### ■ Modular (cons)

- Expense of modules
- Gaps & exposed membrane
- Weight of loaded trays
- Irrigation constraints



Source: Omni-Ecosystems.com

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### Green Roof System (Modular)



Image: [www.greenroofplants.com](http://www.greenroofplants.com)

Image: [www.greenroofblocks.com](http://www.greenroofblocks.com)

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### Green Roof System



- Loose-laid or Built-Up
  - Established practice
  - Amenable for new construction
  - Likely to provide enhanced benefits
  - Horticultural benefit

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### Green Roof System (Multi-course)

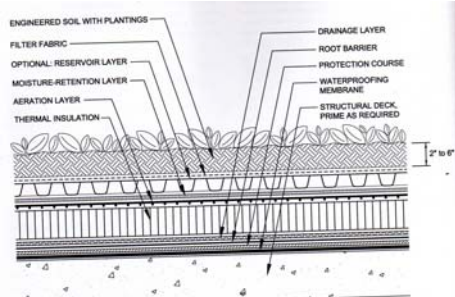


Figure 3: Extensive (shallow) green roof system

Source: NRCA Green Roof Systems Manual

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### Green Roof System (Multi-course)



Granular Drainage

Image: www.roofscapes.com

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### Green Roof System (Single-Layer)

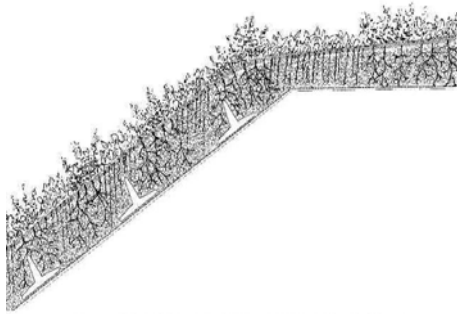


Image: www.roofscapes.com

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“What **kind** of roof can be  
**vegetated?**”

...just about **any**!



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## "Flat" Roofs



Chicago Wal-mart  
Source: [www.roofscapes.com](http://www.roofscapes.com)



Ford Rouge River Plant  
Source: [www.greenroofs.com](http://www.greenroofs.com)

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## Sloped Roofs



California Academy of Sciences

Source: [www.calacademy.org](http://www.calacademy.org)



Source: [www.roofscapes.com](http://www.roofscapes.com)

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## High-rises



Chicago

- 111 S. Wacker
- 51-story bldg
- High wind

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## Wood Frames



Zoomazium, Seattle

- New construction
- Native plantings



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## Bridges/Structures



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## Green Roof Standards



- U.S.
  - ASTM tests for media properties
  - The National Roofing Contractors Association (NRCA) Green Roof Systems Manual
- International (Germany)
  - F.L.L. (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau)
  - "Guideline for the Planning, Execution and Upkeep of Green-Roof Sites"

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Green Roof Guidance & Resources



- Green Roofs for Healthy Cities
  - Conference
  - Training workshops
  - Designer certification
- Experienced practitioners
  - Vendors
  - Consultants
- Greenroofs.com website
- Conservation Technology, Inc.

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Green Roof Design Teams



- Architect
  - Roofing & flashing details
  - Building integration
- Green roof/landscape designer
  - Green roof components & plants
- Growing media consultant
- Roofing consultant/building envelope specialist
  - Waterproofing design
- Engineers
  - Structural, Mechanical, Civil
- Leak Detection Specialist
- Irrigation Specialist

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Green Roof Components

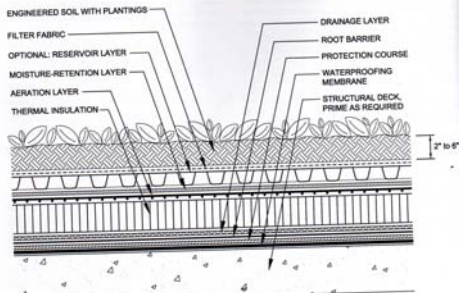


Figure 2: Extensive (shallow) green roof system

Source: NRCA Green Roof Systems Manual

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Green Roof Components



- Roof Deck
  - Concrete, Steel, or Wood, typ.

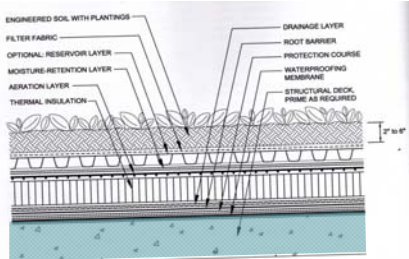


Figure 2 Extensive (shallow) green roof system

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Green Roof Components



- Roof Deck
  - Structural -
    - Extensive green roofs 10-50 psf
    - 6-inch extensive say 40 psf typ.
    - Structural Engineering Analysis critical

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Green Roof Weight



Thickness	Weight (psf)
1-in (vegetated mat)	8-15
2-in	10-22
4-in	22-34
6-in	33-51
8-in	47-65
Compare:	
Gravel ballast	10-15

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## Green Roof Components



- Roof Deck
  - Insulation above or below waterproofing membrane
  - Coordinate architectural details with green roof assembly (insulation, vapor barrier locations, and venting)
  - Building Envelope consultant

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## Green Roof Components



- Waterproofing membrane
  - Loose laid (ballasted)
  - Bonded (adhered)
  - Mechanically attached

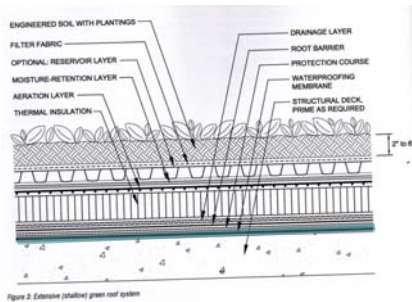


Figure 3: Extensive (shallow) green roof system

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## Green Roof Components



- Waterproof membranes
  - Waterproof vs. water-shedding
  - Use a quality membrane
  - Proven track record
  - Durability, UV resistance
  - Root resistance varies
  - Puncture resistance
  - Retrofit compatibility

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## Green Roof Components



### Types of membranes

- Built-up (layers of felt/fabric & bitumen)
- Fluid applied
- Elastomeric – EPDM (sheets of rubber-like material)
- PVC/TPO
- Others



American Hydrotech  
MM6125 monolithic fluid applied  
rubberized asphalt membrane

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## Green Roof Components



### Protection Course

- Protects membrane from damage
- Boards, sheets, mats
- Sometimes insulation used

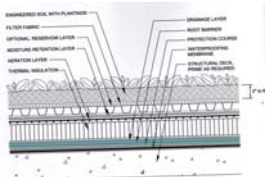


Figure 2: Extensive (shallow) green roof system

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## Green Roof Components



### Root Barrier

- Polyethylene sheets (10 mil min.)
- HPDE boards
- Some EPDM, PVC, TPO membranes
- Root inhibitors

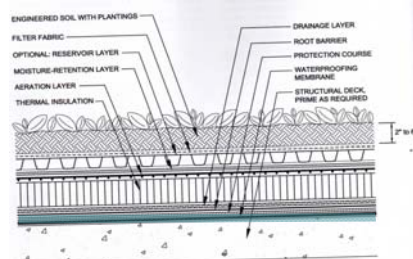


Figure 3: Extensive (shallow) green roof system

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## Green Roof Components



### ■ Insulation

- Reduces heat transfer through roof
- May be inside building beneath deck

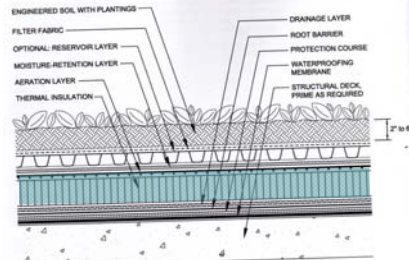


Figure 2 Extensive (shallow) green roof system

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## Green Roof Components



### ■ Insulation

- Protects membrane from damage
- Compressive strength for overburden (40 psi min.)
- Sloped for drainage on flat decks or green roof form
- NRCA recommends XPS insulation for green roofs

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## Green Roof Components



### ■ Drainage layer (Roofing perspective)

- Relieves hydrostatic pressure
- Allows insulation to breathe

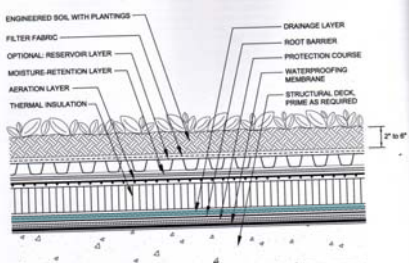


Figure 2 Extensive (shallow) green roof system

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## Green Roof Components



- Drainage layer (vegetated roof perspective)
  - Prevents over-saturation of growing media
  - Detains storm runoff

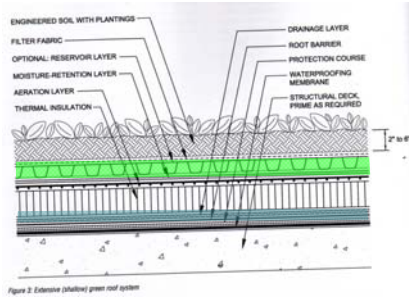


Figure 2 Extensive (shallow) green roof system

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## Green Roof Components – Drain Layer



- Two Basic Options: Granular and Non-Granular
  - Non-granular: mats, boards, & modules
- Factors
  - Slope
  - Weight
  - Compressive strength
  - Site conditions

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## Green Roof Components – Drain Layer



- Properties
  - Porous to permit water movement
  - Transmissivity - related to catchment area
  - Permeability - 425+ in/hr for granular media
  - Continuous coverage
  - Compressive strength for overburden and traffic

Source: Green Roofs for Healthy Cities

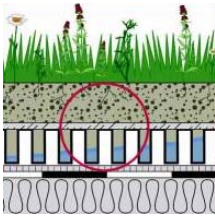
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### Green Roof Components – Drain Layer



#### ■ Non-Granular "Open" Drain Layer Products

- Transmissivity & strength
- Moisture retention



Source: [www.optigreen.com](http://www.optigreen.com)

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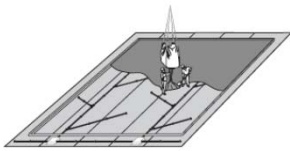
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### Green Roof Components – Drain Layer



#### ■ Granular Drainage

- Light weight aggregate (e.g. pumice)
- Open graded (highly porous)
- Refer to FLL for info



Source: © [www.conservationtechnology.com](http://www.conservationtechnology.com)



Source: [www.roofscapes.com](http://www.roofscapes.com)

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### Green Roof Components – Drain Layer



- Internal drains and retention edges
- Refer to NRCA for flashing and retention edge placement details
- See Conservation Technology, Inc.'s Green Roof Manual for additional information



Source: Conservation Technology, Inc.



Source: [www.optigreen.com](http://www.optigreen.com)

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## Green Roof Components



### ■ Aeration Layer

- Required when insulation is above the waterproof membrane to retain R-value
- Similar to, or integrated with, drainage/moisture retention mat

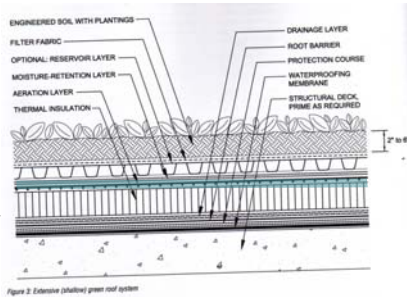


Figure 3: Extensive (shallow) green roof system

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## Green Roof Components



### ■ Moisture Retention Layer

- Waffle boards or mats
- Similar benefit can be achieved by using more growing media
- Often integrated with drainage or protection layers

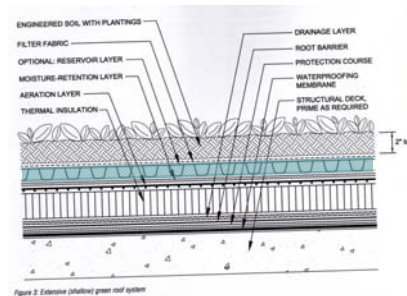


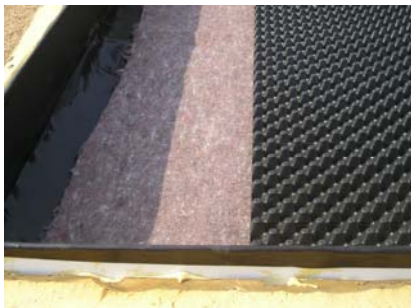
Figure 3: Extensive (shallow) green roof system

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## Green Roof Components



### ■ Moisture Retention Layer



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## Green Roof Components



### ■ Filter Fabric

- Geotextile fabric placed beneath growing media to retain fine particles
- Resistant to weathering and puncture

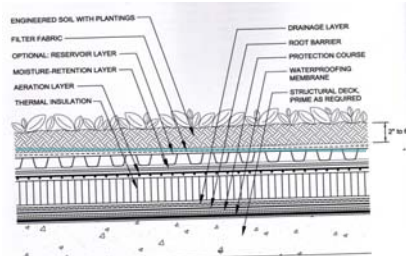


Figure 2: Extensive (shallow) green roof system

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## Green Roof Components



### ■ Growing Media

- Light-weight mineral components
- FLL guidelines: low organic
- Sustains vegetation
- Retains moisture

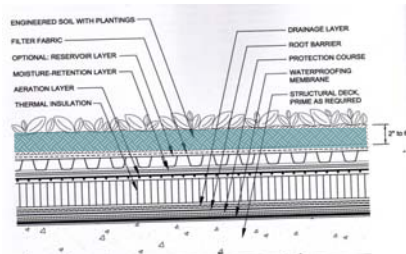


Figure 2: Extensive (shallow) green roof system

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## Green Roof Components – Growing Media



### ■ Requirements

- Permeable (to prevent over-saturation)
- Light-weight (to reduce roof load)
- Fire-resistant
- Stable versus sliding & slumping
- Frost-resistant
- Compression resistant
- Nutrient and chemical properties proven compatible with horticultural growth (ph 6.5-8.0, etc)
- Free of foreign substances

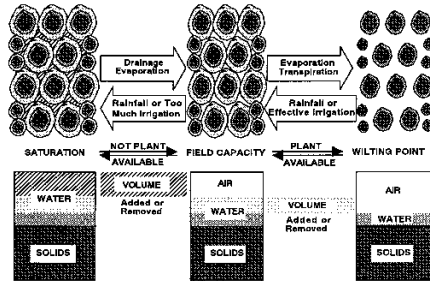
Source: FLL

80

## Green Roof Components – Growing Media



### Moisture retention & plant water availability



Source: [www.bae.ncsu.edu](http://www.bae.ncsu.edu)

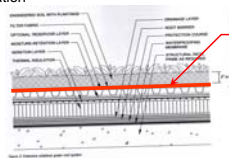
81

## Green Roof Components



### Why not use topsoil?

- Light-weight mineral components
- Permeable (to prevent over-saturation)
- Stable versus sliding & slumping
- Free of foreign substances
- Sustains vegetation



Fine particles can seal filter material

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## Specifying Growing Media



### Example of an Extensive Growing Media Blend

- Coarse lightweight aggregate: 40-80%
- Organic material: 0-25%
- Sand or fine lightweight aggregate: 0-35%
- Air content at max. water capacity: 15% at 45%

### Example of an Intensive Growing Media Blend

- Coarse lightweight aggregate: 35-60%
- Organic material: 5-20%
- Sand or fine lightweight aggregate: 25-50%
- Air content at max. water capacity: 10% at 35%

Source: Green Roofs for Healthy Cities, as adapted from Friedrich 2005

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## Green Roof Components – Growing Media



- Organic Content (FLL Guidelines)
  - Depends on the weight of materials and type of roof
  - Intensive lightweight <12% by mass
  - Extensive lightweight <8% by mass
  - Extensive single course <4% by mass

Source: FLL

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## Green Roof Components – Growing Media



- Granular Distribution
  - FLL is common standard for inorganic component of media blend
  - Different blends for intensive, multi-course extensive, & single-course extensive
  - Sand & gravel size, typ.
  - Refer to FLL or media supplier (Roof-lite, Roofscapes, American Hydrotech, etc)

Source: FLL

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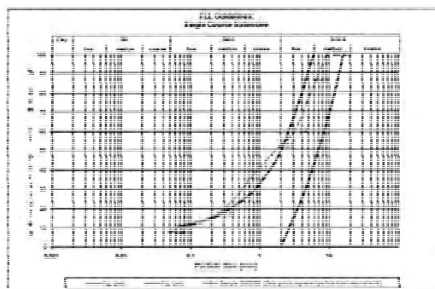
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## Specifying Growing Media



FLL Particle Size Distribution Graph  
For Single-Course Extensive Systems



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## Green Roof Components – Growing Media



- Water Holding Capacity
  - Field capacity, "Maximum Water Capacity" (ASTM test): moisture retained by saturated media after free-draining, 40-60% typ.
  - Wilt point: moisture retained by media that cannot be removed (aka wilt point), 12-18% typ.
  - Available moisture for plants is the difference
- Pore volume: allows movement and temporary storage of moisture, 10% min.
- Permeability 3+ in/hr

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## Green Roof Components – Growing Media



- Other Properties
  - Void Space
  - Cation Exchange Capacity
  - Carbonate Content
  - pH
  - Nutrients
  - Salts

Source: Green Roofs for Healthy Cities

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## Green Roof Components



- Plants: Planting conditions
  - Extensive: harsh environment for plants; wind, exposure; often not irrigated
  - Intensive: deeper soil enables large plants; typically irrigated

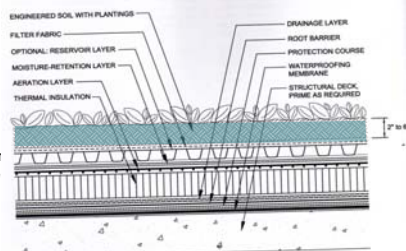


Figure 2: Extensive (shallow) green roof system

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## Green Roof Components



- Common Plants
  - Succulents
  - Grasses
  - Herbaceous

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## Green Roof Plants



- Succulents use crassulacean acid metabolism (CAM) to minimize water loss
  - Sedums



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## Green Roof Plants



- Succulents also have fewer stomata
  - Sempervivum
  - Delosperma



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## Green Roof Components



- Proven Pacific Northwest Plants (unirrigated)
  - Sedum (S. album, S. acre, S. urvillei, S. kamtschaticum, 'Autumn Joy', 'Purple Emperor')
  - Sempervivum
  - Delosperma (D. cooperii)
  - Coastal Strawberry (Fragaria chiloensis)
- Plant resources
  - Etera.com (green roof plant supplier for PNW, located in Marysville, WA)
  - Ed Snodgrass, "Green Roof Plants: A Resource & Planting Guide"
  - Green roof suppliers (American Hydrotech, Roofmeadow, etc.)

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## Green Roof Components



- Planting Methods
  - Vegetated mats
  - Pre-planted modules
  - Seeding
  - Cuttings
  - Plugs
  - Container Plants (small!)



Source: [www.optigreen.com](http://www.optigreen.com)

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## GREP Plant Progression



May

June

July

Sept

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## Green Roof Components



- Plant Irrigation
  - Required until establishment (3 yrs)
  - Drip or sub-surface recommended
  - Capillary systems available
  - Decrease frequency over time - example:
    - First month: multiple waterings/week
    - Second month: weekly
    - Third month: every 2 weeks
    - First year: monthly
    - Second year: as needed

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## Green Roof Factors



- Layout
  - Gravel border
  - Take advantage of structural capacity
  - Window-washing
  - Wind & micro-climate



Source: American Hydrotech

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## Green Roof Factors



- Sloped roofs
  - Greater than 2:12 requires analysis
  - Engineer media for steeper condition
  - Use structural restraining system
  - Terrace the roof
  - Consider soil moisture & plants

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## Green Roof Factors



- Sloped roofs: specialty geotextiles
  - Example: "EnkaRetain"
  - Consider geotextiles for slopes 2:12 to 3:12

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## Green Roof Factors



- Sloped roofs: Slippage restraint

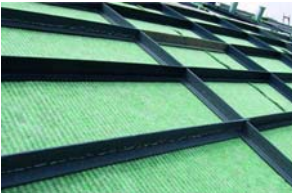


Image: [www.optigreen.com](http://www.optigreen.com)

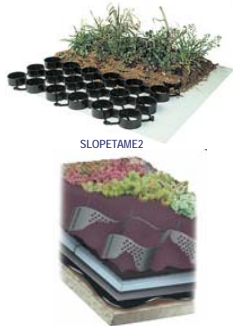


Image: [www.hydrotechusa.com](http://www.hydrotechusa.com)

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## Green Roof Factors



- Sloped roofs engineering
  - Avoid slip-plane failures:  
*Be careful what kind of drainage is used*
  - Where is the slippage being resisted structurally?

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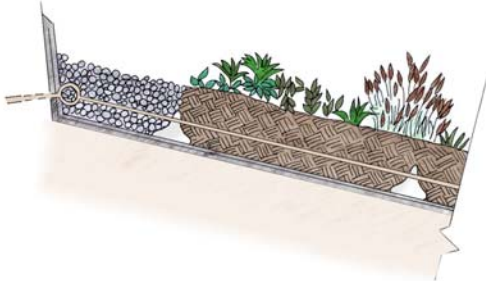
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## Green Roof Factors



- Sloped roofs: Cellular confinement



MKA, 2009

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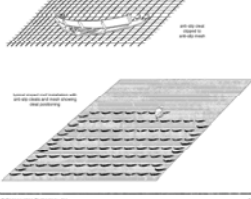
## Green Roof Factors



### SLOPE STABILIZATION

When roof slopes reach 2:12, or approximately 10°, special precautions must be taken to prevent soil from sliding down the roof. Root-resistant waterproofing membranes must be fully adhered to the underlying roof structure. Independent rootbarriers or floating membranes are not recommended. Outgreen Drainage Mat is used in place of Drainage Plates or other plastic drainage substrates that cannot withstand the shear stresses on slopes. When slopes reach 3:12, or approximately 13°, it is essential to use a mechanical slope stabilization system. We offer two basic forms to accommodate different roof architecture: one system borders and leads up the roof and one borders and leads down the roof.

**ANTI-SLIP CLEATS AND MESH:** This system offers a simple and inexpensive means to prevent soil sliding by transferring soil loads at the roof. Outgreen Anti-Slip Mesh is simply laid over Outgreen Drainage Mat and Outgreen Anti-Slip Cleats are clipped onto the mesh. The high-strength structural plastic mesh is mechanically fastened at the top of the roof, or if the roof is pitched to horizontal one side of the roof can be used to fasten the opposite side. The new spacing of the barbed-ripout plastic cleats varies from 12" to 36" depending on the roof slope. To distribute load on the mesh each row is offset one-quarter cleat from the row above and below and anti-cleats are inserted between rows at edges to fill the voids.



- Sloped roofs: Cellular confinement

© Comapcon Technology, Inc.

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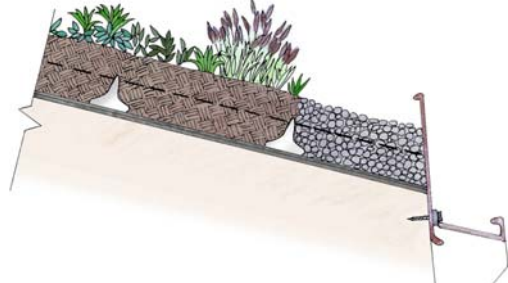
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## Green Roof Factors



- Sloped roofs: Cellular confinement



MKA, 2009

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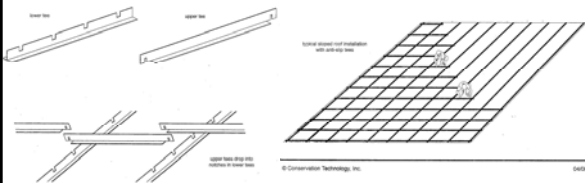
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Green Roof Factors



- Sloped roofs: Cellular confinement



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Sloped Green Roof Case Study



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Green Roof Factors



- Sloped roofs: Slippage restraint



Image: www.hydrotechusa.com

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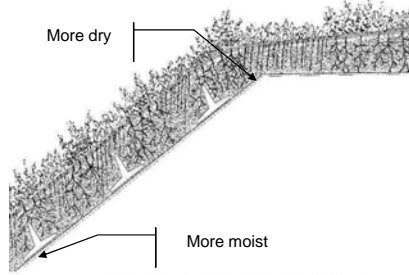
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### Green Roof System (Single-Layer on Slope)



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### Green Roof Factors



- Warranty
  - Dialogue with waterproofing contractor/supplier
  - May affect choice of system

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### Green Roof Costs



- Always use a quality waterproofing membrane (est. \$5-\$10/sf)
- Allow \$7-\$20/sf additional for the extensive or semi-intensive green roof
- Economy of scale

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### Installation Considerations



- Coordination of trades is critical
  - Waterproofing installer
  - Landscape crew
  - Mechanical equipment
  - Access to cranes/elevators
  - Mandatory Pre-Bid conference
- Pre-qualifying & bonding

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### Installation Considerations



- Allow time for test plots and material testing
- Pre-construction meeting
  - Address sequence & coordination needs
  - Identify when flood-testing to occur
  - Mechanical equipment
  - Access to cranes/elevators

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### Installation Considerations



- Safety
  - Trained crew / personnel
  - Fall protection systems (temporary & permanent)

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## Installation Considerations



- Material Handling
  - On- vs. off-site media blending
  - On- vs. off-site planting
  - Staging/stockpiling (do not exceed roof capacity)
  - Control moisture of media
  - Protect installed materials

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## Installation Considerations



- Media Conveyance & Handling
  - Prevent contamination
  - Prevent separation
  - Super-sacks (1.5 CY)
  - Small sacks
  - Blown
  - Evaluate media after placed, before planting

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## Installation Considerations



- Mulch/matting
  - Prevent wind erosion
  - Discourage weed germination
  - Reduce soil moisture loss
- Pests
  - Birds – bird netting, fake owls, scare crows, reflective streamers
- Access paths

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## Pests - Birds



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## Maintenance (Typical)



- Have a plan
- Provide for worker safety
- Provide access
- Types of maintenance
  - Maintenance during installation
  - Maintenance during the plant establishment period
  - Maintenance post-establishment

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## Maintenance During Installation



- Care for plants during transportation
- Care for plants upon arrival through installation
  - Shading
  - Watering

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### Maintenance During Establishment Period



- Expect 2- to 3-yr establishment period (80-90% coverage)
  - Watch for over-/under-compacted areas
- Weeding
- Deadheading
- Replanting
- Irrigation
  - Only during drought? or...
  - Critical to achieving target coverage
- Monitor & repair steep slope sloughing
- Temporary mulch/matting

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### Maintenance Post-Establishment



- Weeding – depends on aesthetic and desired biodiversity
- Deadheading
- Removing dead leaves and biomass
- Replanting
- Irrigation – reduced frequency
  - Only during drought
- Monitor & repair steep slope sloughing
  - Redistribute growing media
- Fertilization
  - Slow-release
  - May not be needed after first 5 years

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### Find the problem #1



Source: American Hydrotech

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### Find the problem #2



Source: American Hydrotech

123

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### Diagnosing Unusual Problems



- What is the problem? Clarify owner expectations
- Collect information
  - Age of roof
  - Plants used, locations
  - Identify micro-climates (shading, heat reflection / glare, wind)
  - Assess drainage
  - Verify irrigation is functioning
- Evaluate remedial actions
  - Testing the growing medium to determine composition and nutrient levels
  - Changing or amending growing medium
  - Weeding
  - New, more appropriate plantings
  - Repairing irrigation systems
  - Cleaning drains and border areas
- Leak detection

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### Find the problem #3



Source: American Hydrotech

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“What types of **existing** buildings are suitable for green roof **retrofits**?”

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#### Structural Considerations

- Building type overview
- Capacity per design load validation
- Building height
- Green roof placement
- Seismic

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#### Building Types

- Wood
- Masonry
- Steel
- Concrete

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Building Types



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Building Types



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Building Types



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Capacity for Additional Roof Load (per typical design methods & procedures)



- Wood: worst
- Masonry: poor, maybe if seismically upgraded
- Steel: fair (newer) to best (older)
- Concrete: best

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“How much **green roof** could be put onto an **existing** roof?”

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Design Load Verification



- Snow load
- Load Swapping
- Plaza/Decks

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## Design Load Verification



- Snow load
  - Drifting
  - True ground load:  $20 \pm$  vs.  $25 \text{ psf design}$

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## Design Load Verification



- Load Swapping
  - Ballast typically  $10 \text{ psf} \pm$
  - Concrete Sloping Slabs say  $10$  to  $50 \text{ psf} \pm$
  - Tiles



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## Design Load Verification



- Plaza/Decks
  - Live (e.g.  $100 \text{ psf}$ ) vs. dead load



Image: [www.greengridroofs.com](http://www.greengridroofs.com)

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## Building Height



- Steel & Concrete...
  - Higher buildings (6 stories +) more likely to have capacity for extra load
- Designed for extra floors
  - Very likely to have spare capacity
- Wind
  - Over 10 stories - GR design modifications

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## Green Roof Placement



- Edges
  - Greater capacity in structure
  - More snow drift
  - Interferes with window washing
  - *Parking garages*
- Over load-bearing truss / column

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## Seismic



- 2006 Seattle Bldg Code
  - Increase base shear >10% triggers seismic analysis
  - Expect to trigger seismic upgrade when adding green roof to URM

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## Seismic



- Seismic upgrade
  - Improve roof-wall connections
  - Parapet bracing
  - Additional expense

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## Structural Screening Criteria



- Favorable
  - Steel / concrete framed
  - 6 to 10 stories
  - Large roof
  - Design for extra stories (e.g., cardeck)
  - Exist., removable topping (e.g., ballast, tiles)
  - Existing plazas

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## Structural Screening Criteria



- Unfavorable
  - URM, wood frame
  - Less than 6 stories
  - Small roofs, parapets
  - No previous seismic upgrade

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### Target Weight



- CASE-BY-CASE
- Likely 5-20 psf
- Assume 2-4 inch green roof thickness

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### Additional Retrofit Screening Criteria



- Access
  - Constrained access favors modular systems
- Waterproofing system
  - Metal and asphalt tar built-up roof unfavorable
- Insulation
  - Compressive strength
- Safety
- Flashing and drain locations

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### Example: Park Place Building, Seattle



- Structural system
  - Concrete moment frame
  - Reinforced concrete slab roof
  - 10-ft beam spacing
- Design capacity
  - 60 psf live load (exist per design)
  - 25 psf snow load
- Safety
  - Exist parapets



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Example: Park Place Building, Seattle



- Green roof
  - 4-inch extensive; 9,656 sf
- Proposed Loads
  - Mechanical: 30,000 lbs
  - Green roof: 40 psf
  - Live load: 20 psf
  - Snow load: 25 psf
- Overlay existing



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Questions?



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brian.l.taylor@amec.com

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