

Green Roofs

Restoring Urban Landscapes One Roof at a Time



October 9, 2014

Overview

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

1

Civil Engineering Crossroads



2









Sites to Mimic Nature

Source: Magnusson Klemencic Associates

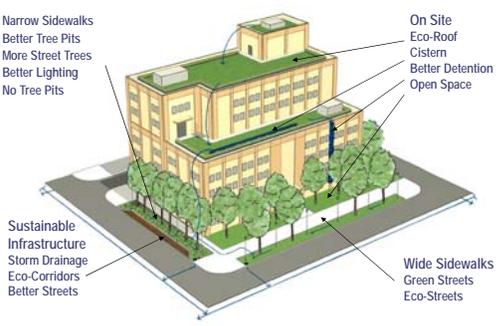
7

Civil Engineering Crossroads

Pre-Settlement Conditions Historical Urban Development Green Stormwater Infrastructure

8

Urban Green Stormwater Strategies 



Left Side Labels:
 Narrow Sidewalks
 Better Tree Pits
 More Street Trees
 Better Lighting
 No Tree Pits

Right Side Labels:
 On Site
 Eco-Roof
 Cistern
 Better Detention
 Open Space

Bottom Left Labels:
 Sustainable Infrastructure
 Storm Drainage
 Eco-Corridors
 Better Streets

Bottom Right Labels:
 Wide Sidewalks
 Green Streets
 Eco-Streets

Source: Magnusson Klemencic Associates

Green Roofs... 



Source: www.roofscapes.com

...aka... 



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

Source: www.roofscapes.com

Benefits



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

12

Ecology: Habitat & Biodiversity



Laban Dance Centre, London

- Wildlife habitat
- Demonstrated success when targeted to species



Black Redstart

Source: www.greenroofs.com

13

Ecology: Habitat & Biodiversity



Killdeers

Source: www.roofscapes.com



Birdhouse with Green Roof

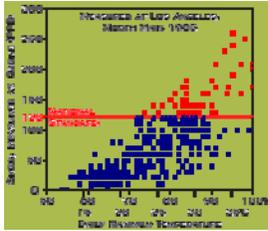
Source: Barry Taylor



Ladybug

14

Ecology: Air Quality



- Particulates trapped
- Secondary benefits from reduced temperature



Increased temperature = increased smog

Social



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

Green roof at nursing home

Source: www.greenroofs.org

Social



Life Expression Wellness Center
Sugarloaf, Pennsylvania

Source: www.roofscapes.com

Noise Reduction amec



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



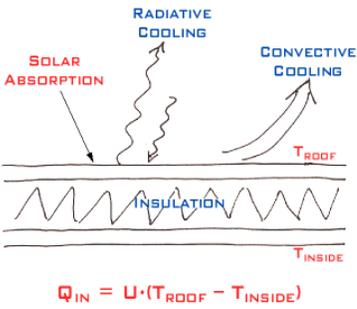
Howard Hughes Medical Center
Dulles, Virginia

Source: Roofscapes.com Source: www.greenroofs.org

18

Energy & Heat amec

- Roofs have major role in building energy consumption



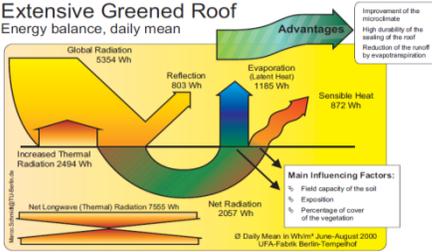
$Q_{IN} = U \cdot (T_{ROOF} - T_{INSIDE})$

19

Energy & Heat amec

- Evapotranspiration affects global energy flux

Extensive Greened Roof
Energy balance, daily mean



Advantages:

- Improvement of the microclimate
- High durability of the sealing of the roof
- Reduction of the runoff by evapotranspiration

Main Influencing Factors:

- % Field capacity of the soil
- % Exposition
- % Percentage of cover of the vegetation

© Daily Mean in Wh/m² June-August 2000
UFA-Fabrik Berlin-Tempelhof

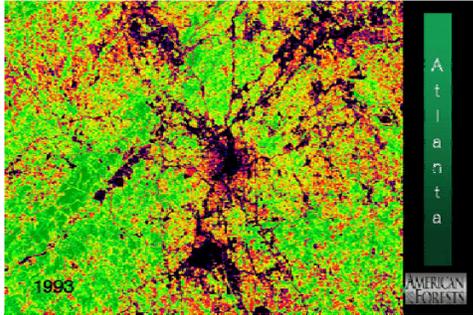
Fig. 4 Extensive greened roofs transfer 58% of net radiation into evapotranspiration during the summer months, UFA-Fabrik in Berlin, Germany

20

Energy & Heat



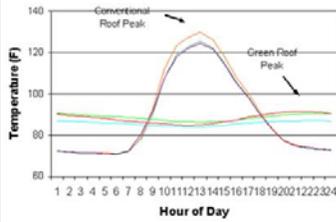
- Traditional roofs & pavements contribute to urban heat island



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

Energy & Heat



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



Source: www.roofscapes.com

Source: U.S. EPA Region 8

Economic



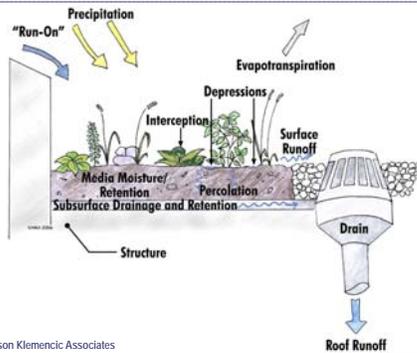
- Reduce size of HVAC equipment
- Extend roof membrane life
- Higher lease rates
- Higher productivity
- Incorporate function...
 - Water treatment
 - Food production



Source: www.greenroofs.com

24

Green Roof Hydrologic Processes



Source: Magnusson Klemencic Associates

25

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

26

Green Roof Categories



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

Source: Green Roofs for Healthy Cities
30

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
31

Green Roof Categories: Intensive



Millennium Park, Chicago

Source: www.greenroofs.com
32

Green Roof Categories: Intensive



Hugh Garner Housing Co-operative Source: www.greenroofs.com

33

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

34

Green Roof Categories: Semi-Intensive



Vancouver Public Library Source: www.greenroofs.com

35

Green Roof Categories: Semi-Intensive



Seattle Art Museum/WAMU

36

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

37

Green Roof Categories: Extensive



Whistler Daycare Centre, B.C.

Source: BCIT

38

Green Roof Categories: Extensive



MKA Green Roof Evaluation Test Plot

Green Roof Systems



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

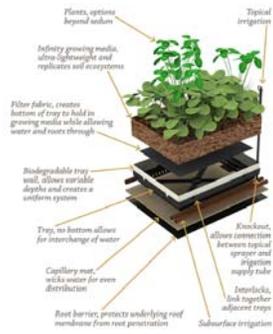


Images: www.greenroofroofs.com

Green Roof Systems



- Modular (cons)
 - Expense of modules
 - Gaps & exposed membrane
 - Weight of loaded trays
 - Irrigation constraints



Source: Omni-Ecosystems.com

Green Roof System (Modular)



Image: www.greenroofplants.com

Image: www.greenroofblocks.com

42

Green Roof System



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

43

Green Roof System (Multi-course)

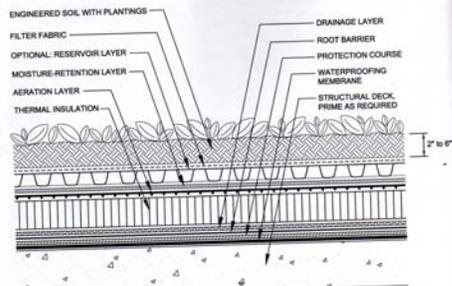


Figure 3: Extensive (shallow) green roof system

Source: NRCA Green Roof Systems Manual

44

Green Roof System (Multi-course)



Granular Drainage

Image: www.roofscapes.com

45

Green Roof System (Single-Layer)

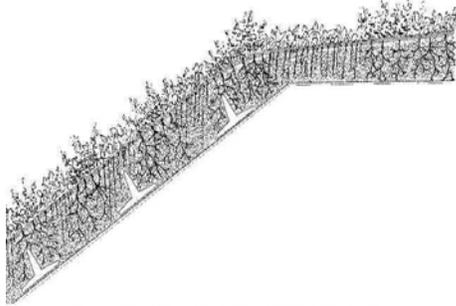


Image: www.roofscapes.com

46

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

...just about **any!**



47

"Flat" Roofs



Chicago Wal-mart
Source: www.roofscapes.com



Ford Rouge River Plant
Source: www.greenroofs.com

Sloped Roofs



California Academy of Sciences



High-rises



Chicago

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

Wood Frames



Zoomazium, Seattle

- New construction
- Native plantings

51

Bridges/Structures



52

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"

53

Green Roof Guidance & Resources



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

54

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

55

Green Roof Components

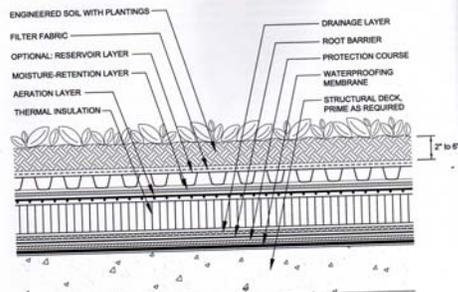


Figure 2. Extensive (shallow) green roof system

Source: NRCA Green Roof Systems Manual

56

Green Roof Components



■ Roof Deck

- Concrete, Steel, or Wood, typ.

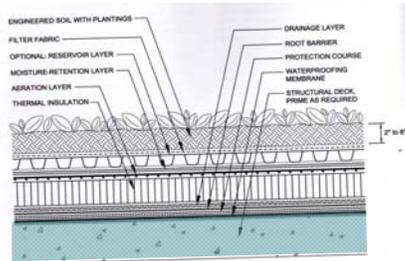


Figure 2. Extensive (shallow) green roof system

57

Green Roof Components



■ Roof Deck

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

58

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 |

59

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

60

Green Roof Components



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

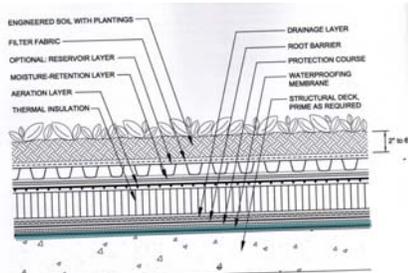


Figure 3. Extensive (shallow) green roof system

61

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

62

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



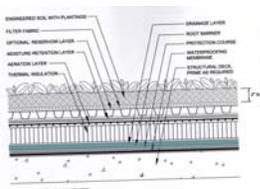
American Hydrotech
MM6125@monolithic fluid applied
rubberized asphalt membrane

63

Green Roof Components



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



64

Green Roof Components



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

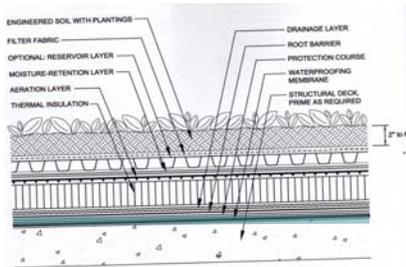


Figure 2. Extensive (shallow) green roof system

65

Green Roof Components



■ Insulation

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

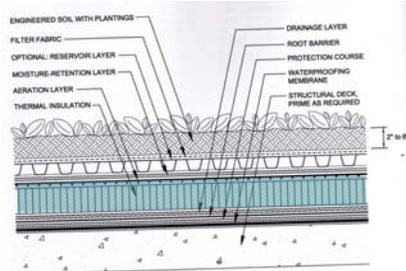


Figure 2 Extensive (shallow) green roof system

66

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

67

Green Roof Components



■ Drainage layer (Roofing perspective)

- Relieves hydrostatic pressure
- Allows insulation to breathe

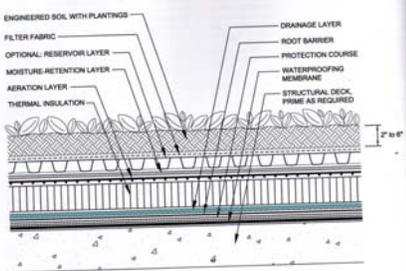


Figure 2 Extensive (shallow) green roof system

68

Green Roof Components



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

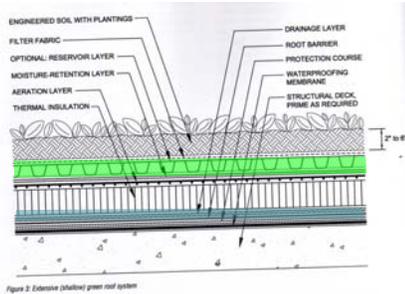


Figure 3: Shallow (shallow) green roof system

69

Green Roof Components – Drain Layer



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

70

Green Roof Components – Drain Layer



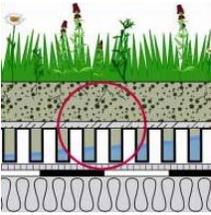
- Properties
 - Porous to permit water movement
 - Transmissivity - related to catchment area
 - Permeability - 425+ in/hr for granular media
 - Continuous coverage
 - Compressive strength for overburden and traffic

Source: Green Roofs for Healthy Cities

71

Green Roof Components – Drain Layer 

- Non-Granular "Open" Drain Layer Products
 - Transmissivity & strength
 - Moisture retention



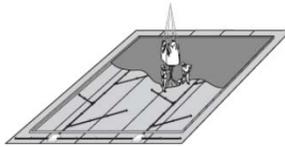



Source: www.optigreen.com

72

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

Source: www.roofscapes.com

73

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

74

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

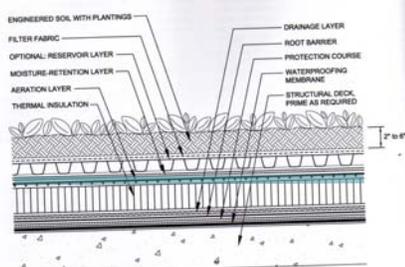


Figure 3: Extension (shallow) green roof system

76

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

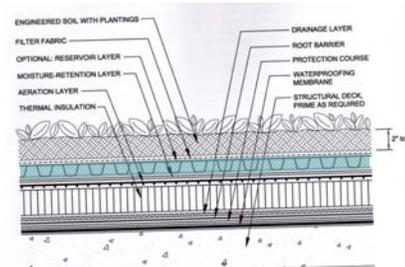


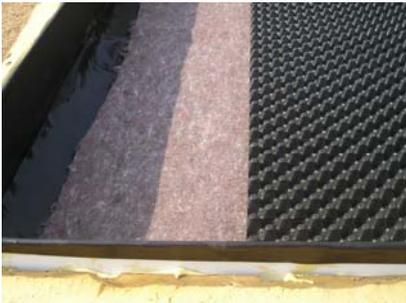
Figure 3: Extension (shallow) green roof system

76

Green Roof Components



Moisture Retention Layer



77

Green Roof Components



Filter Fabric

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

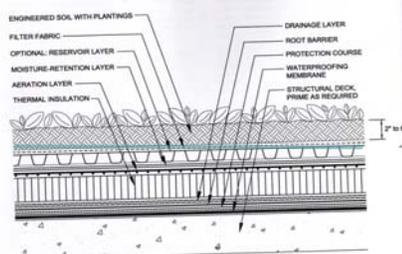


Figure 2 Extensive (shallow) green roof system

78

Green Roof Components



Growing Media

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

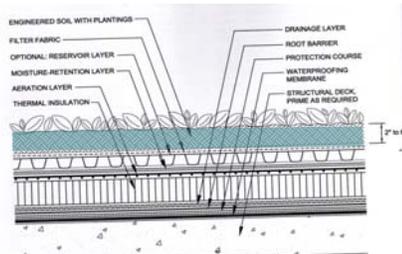


Figure 2 Extensive (shallow) green roof system

79

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



- 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

84

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)

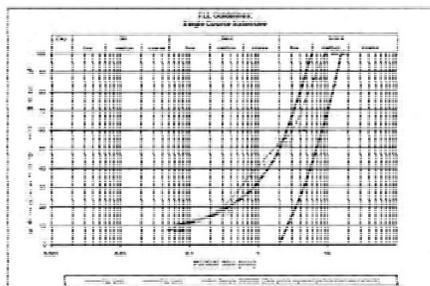
Source: FLL

85

Specifying Growing Media



FLL Particle Size Distribution Graph
For Single-Course Extensive Systems



86

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

Green Roof Components – Growing Media



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

Source: Green Roofs for Healthy Cities

Green Roof Components



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

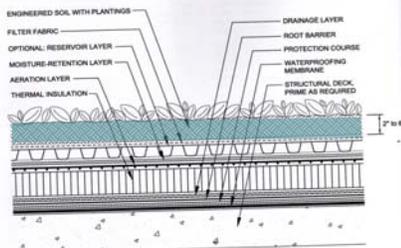


Figure 2. Extensive (shallow) green roof system

Green Roof Components



- Common Plants
 - Succulents
 - Grasses
 - Herbaceous

90

Green Roof Plants



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



91

Green Roof Plants



- Succulents also have fewer stomata
 - Sempervivum
 - Delosperma



92

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.)

Green Roof Components



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



Source: www.optigreen.com

GREP Plant Progression



May June July Sept

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

96

Green Roof Factors



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



Source: American Hydrotech

97

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

98

Green Roof Factors



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

Green Roof Factors



- Sloped roofs: Slippage restraint

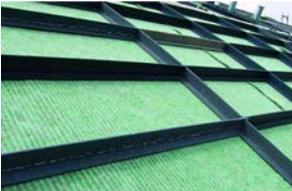


Image: www.optigreen.com



Image: www.hydrotechusa.com

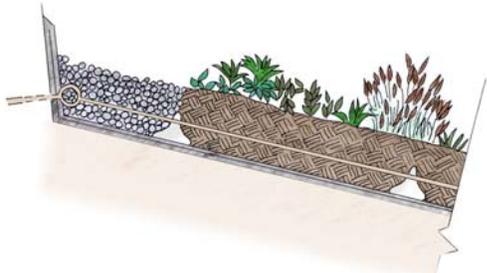
Green Roof Factors



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

Green Roof Factors **amec**¹

- Sloped roofs: Cellular confinement



MKA, 2009

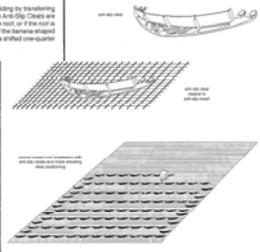
102

Green Roof Factors **amec**¹

SLOPE STABILIZATION

When roof slopes reach 2:12, or approximately 17°, special precautions must be taken to prevent soil from sliding down the roof. Non-resistant waterproofing membranes must be fully adhered to the underlying roof structure. Independent root barriers 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 2:12, or approximately 17°, it is essential to use a mechanical slope stabilization system. We offer two basic forms to accommodate different roof architecture: one system transfers soil loads to the roof and one transfers soil loads down the roof.

ANTI-SLIP-CLEATS AND MESH: This system offers a simple and inexpensive means to prevent soil sliding by transferring soil loads to 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 gabled or hipped, the mesh can be used to balance the opposite side. The new spacing of the barbed-riped plastic cleats varies from 17° to 90° depending on the roof slope. To distribute load on the mesh each row is offset one-quarter inch from the row above and below and each cleat is inserted between rows at edges to fill the voids.



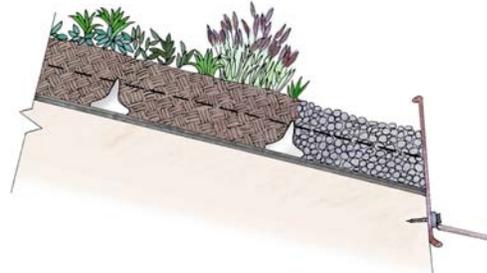
- Sloped roofs: Cellular confinement

MKA, 2009

103

Green Roof Factors **amec**¹

- Sloped roofs: Cellular confinement



MKA, 2009

104

Green Roof Factors **amec**

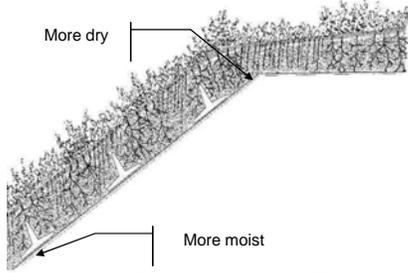
- Sloped roofs: Cellular confinement

Sloped Green Roof Case Study **amec**

Green Roof Factors **amec**

- Sloped roofs: Slippage restraint

Green Roof System (Single-Layer on Slope)



108

Green Roof Factors



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

109

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

110

Installation Considerations 

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

111

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

112

Installation Considerations 

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

113



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

114

Installation Considerations 

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

115

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

116



Pests - Birds



117

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

118

Maintenance During Installation



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

119

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

120

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

121

Find the problem #1



Source: American Hydrotech

122

Find the problem #2



Source: American Hydrotech

123

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

124

Find the problem #3



Source: American Hydrotech

125

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

Structural Considerations

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

Building Types

- Wood
- Masonry
- Steel
- Concrete

Building Types



129

Building Types



130

Building Types



131

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

132



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

133

Design Load Verification



- Snow load
- Load Swapping
- Plaza/Decks

134

Design Load Verification



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

135

Design Load Verification



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



136

Design Load Verification



- Plaza/Decks
 - Live (e.g. 100 psf) vs. dead load



Image: www.greengridroofs.com

137

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

138

Green Roof Placement 

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

139

Seismic 

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

140



Seismic 

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

141

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

142

Structural Screening Criteria 

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

143

Target Weight 

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

144

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

145

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



146

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



147

Questions?



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148
