



MAGNUSSON
KLEMENCIC
ASSOCIATES

Green Roofs: Restoring Urban Landscapes One Roof at a Time

Brian Taylor, P.E.
March 2010

WSU
LID Workshop, Puyallup



Overview

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

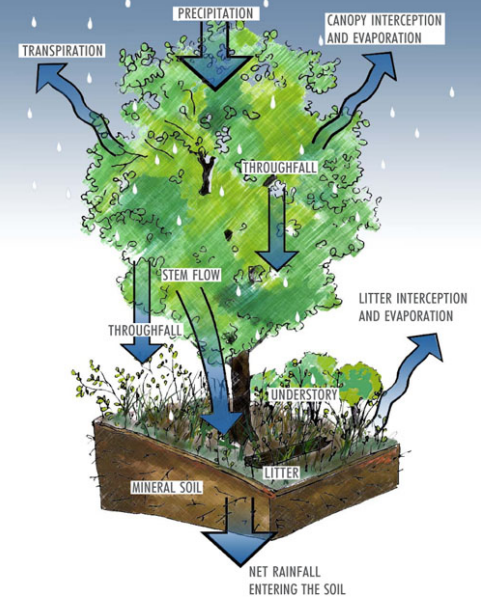
Architecturally Focused Civil Engineering



Architecturally Focused Civil Engineering



Sites To Mimic Nature



Urban Green

Narrow Sidewalks

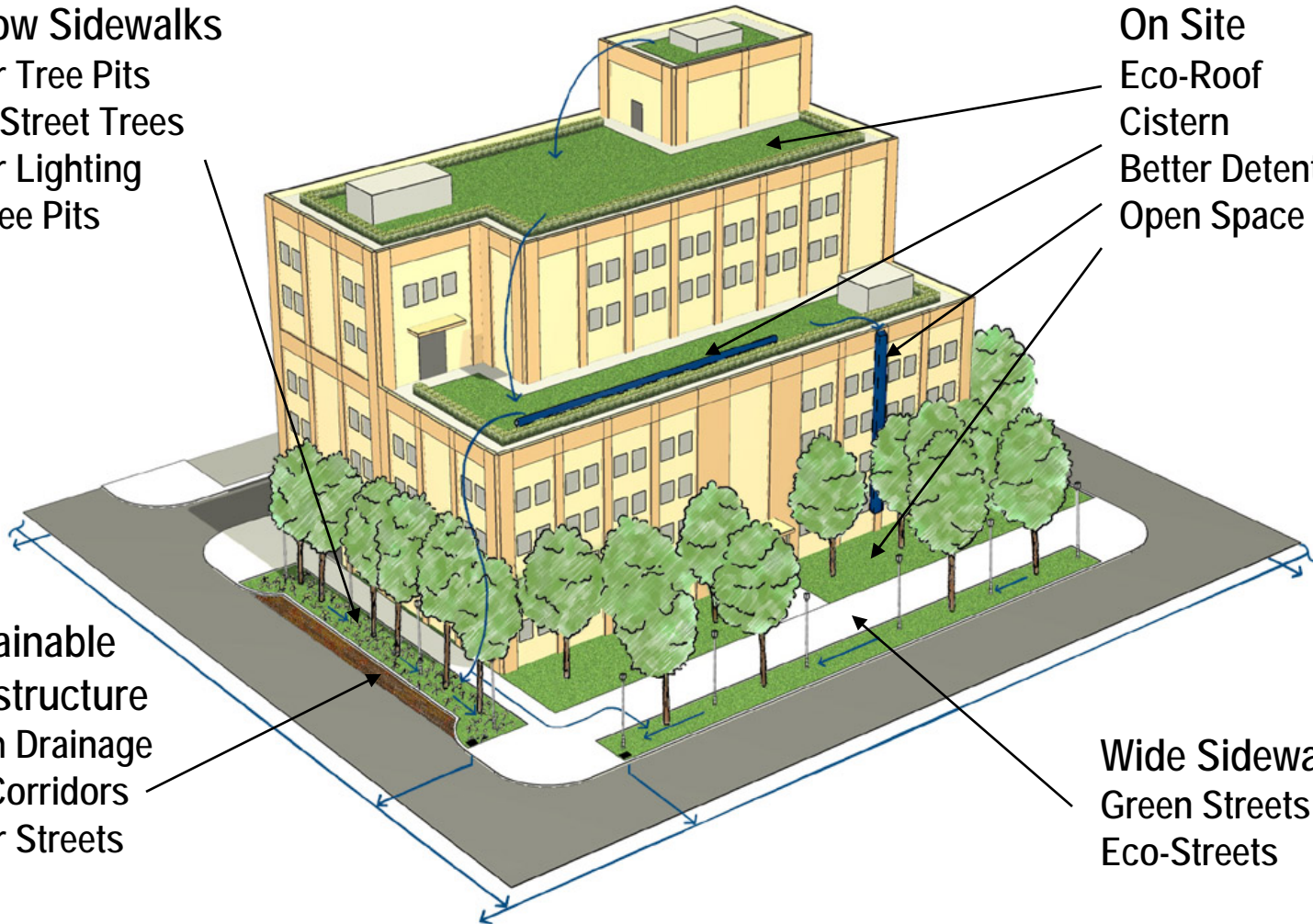
Better Tree Pits
More Street Trees
Better Lighting
No Tree Pits

On Site

Eco-Roof
Cistern
Better Detention
Open Space

Sustainable
Infrastructure
Storm Drainage
Eco-Corridors
Better Streets

Wide Sidewalks
Green Streets
Eco-Streets



Green Roofs



Source: www.roofscapes.com

...aka...



Source: www.roofscapes.com

“Living Roofs”

“Vegetated
Roofs”

“Eco-roofs”

“Roof gardens”

Green Roof Components - Overview

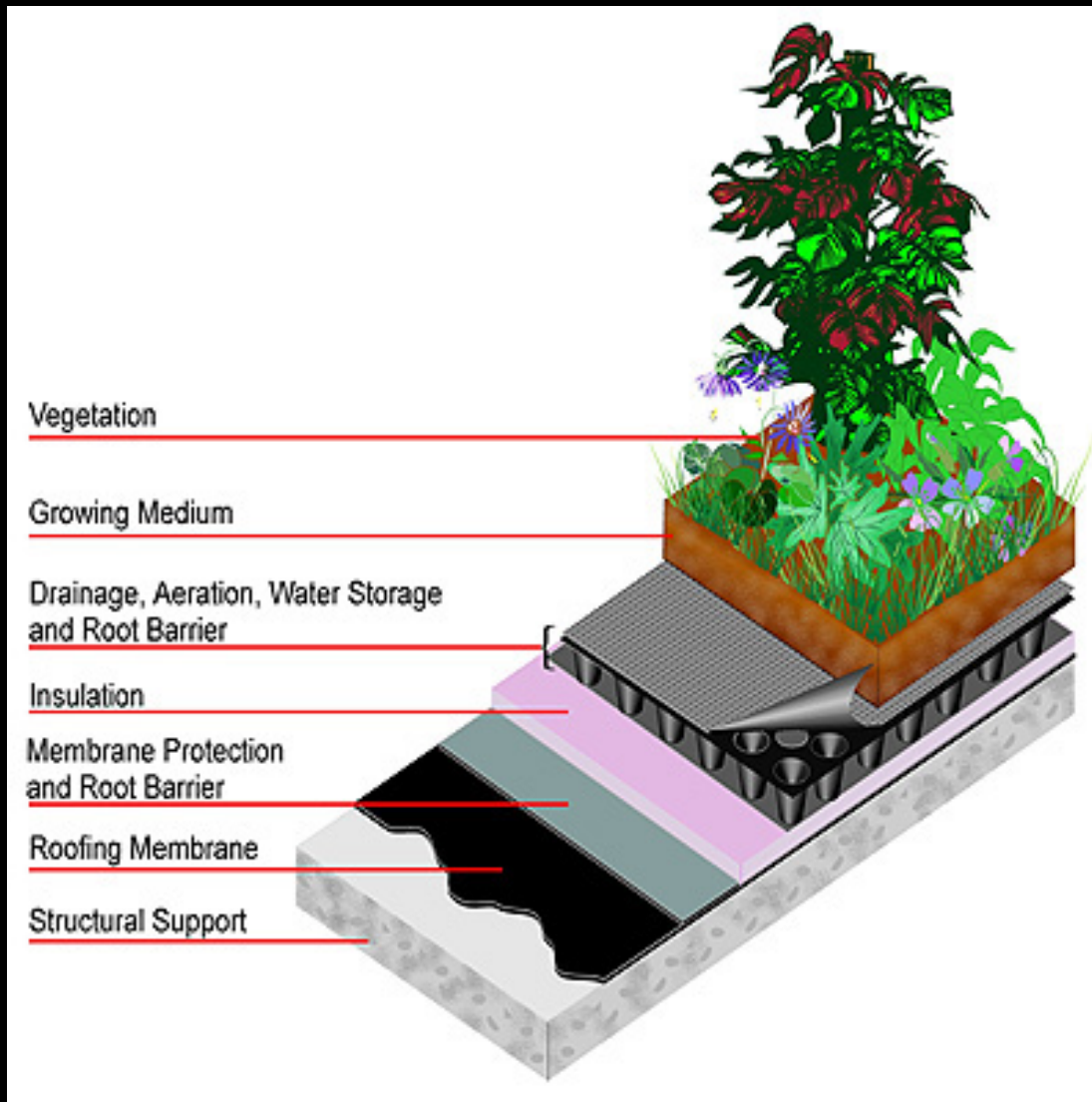


Image:
www.lowimpactdevelopment.org

Benefits



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

Ecology: Habitat & Biodiversity



Laban Dance Centre, London

Source: www.greenroofs.com

- Wildlife habitat
- Demonstrated success when targeted to species



Black Redstart

Ecology: Habitat & Biodiversity



Killdeers

Source: www.roofscapes.com



Birdhouse with Green Roof

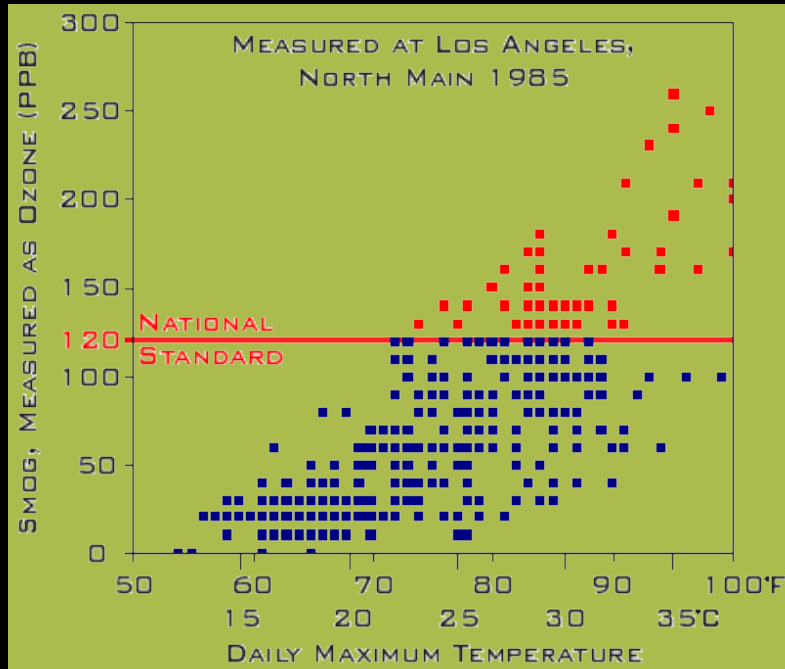
Source: Barry Taylor



Ladybug

Ecology: Air Quality

- Particulates trapped
- Secondary benefits from reduced temperature



Increased temperature = increased smog



Social



Green roof at nursing home

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

Source: www.greenroofs.org

Energy & Heat

- Roofs have major role in building energy consumption

Extensive Greened Roof Energy balance, daily mean

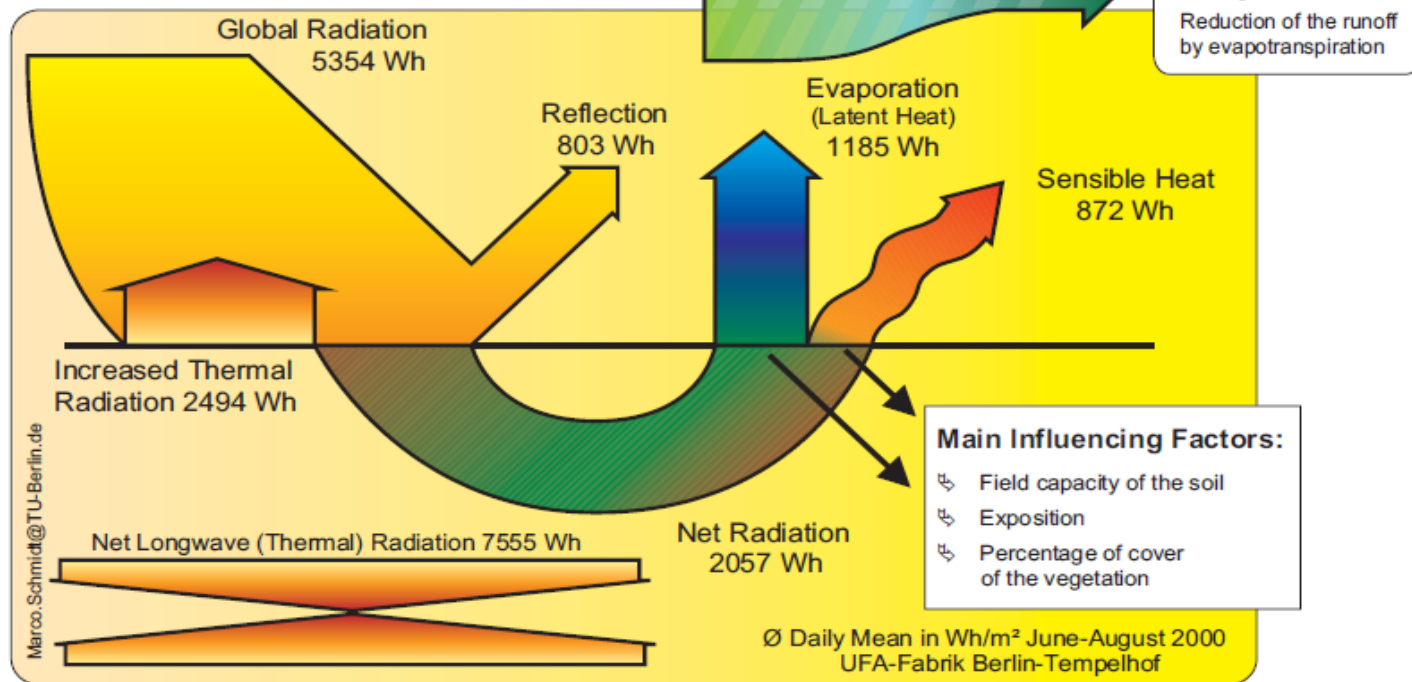
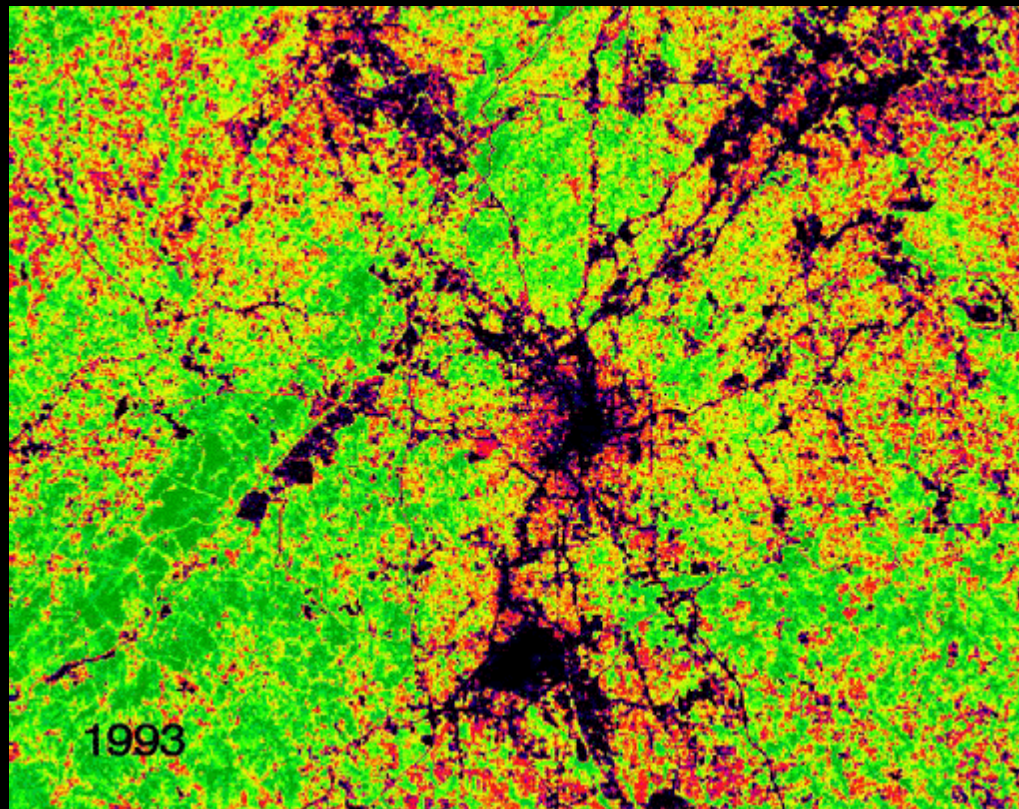


Fig. 4 Extensive greened roofs transfer 58% of net radiation into evapotranspiration during the summer months, UFA Fabrik in Berlin, Germany

Energy & Heat

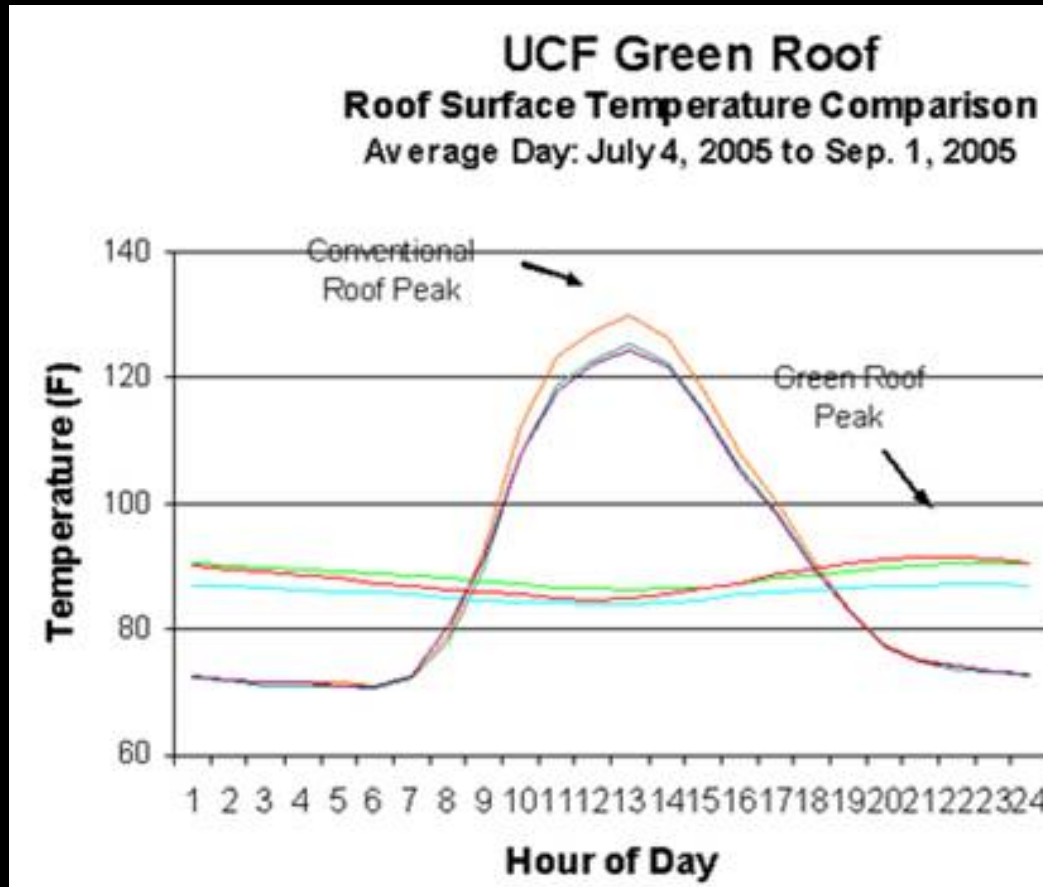
- Traditional roofs & pavements contribute to urban heat island



A
t
l
a
n
t
a

AMERICAN
FORESTS

Energy & Heat



Source: Jeffrey K. Sonne, Florida
Solar Energy Center

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

Energy & Heat

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



Source: www.roofscapes.com



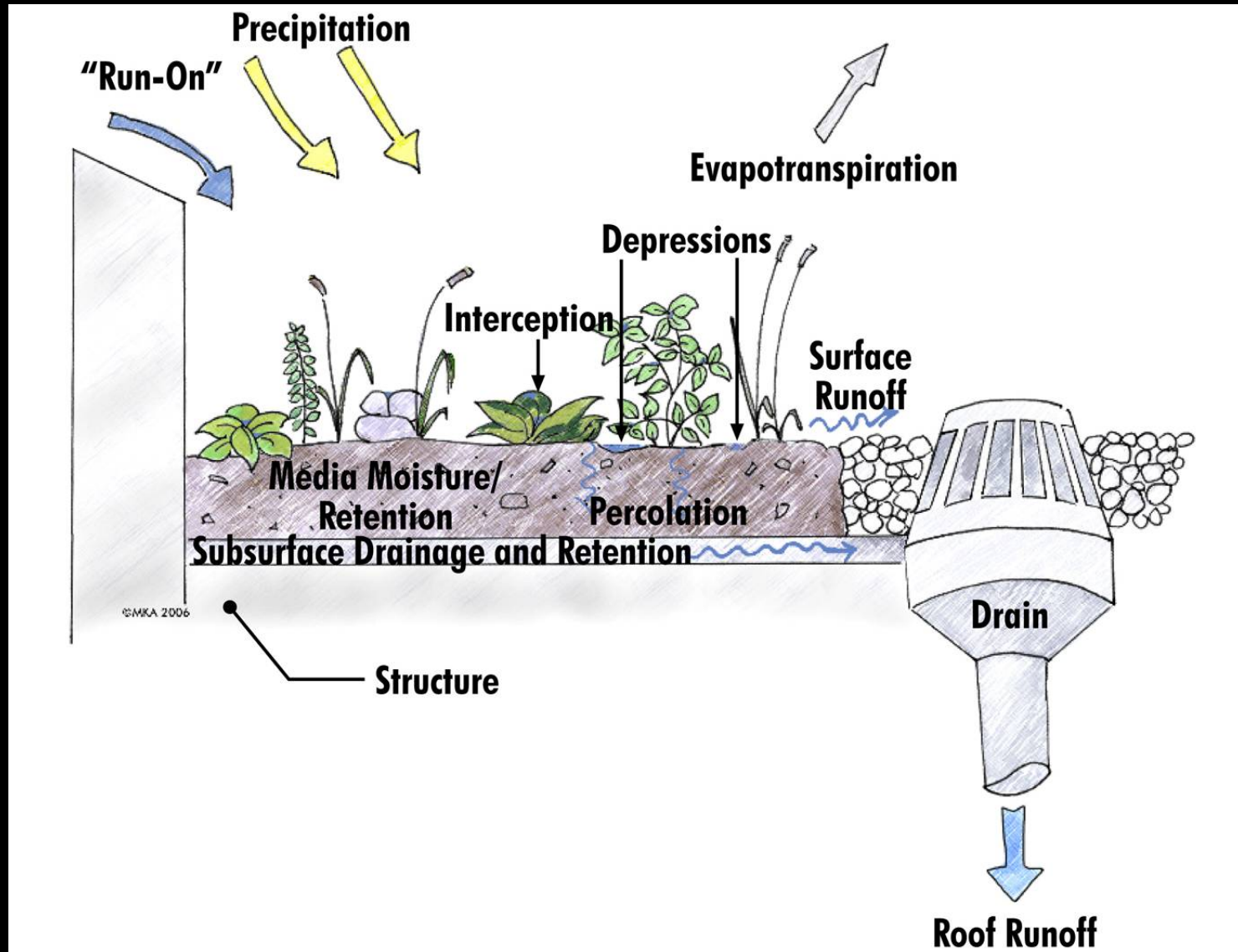
Source: U.S. EPA Region 8

Economic

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



Green Roof Hydrologic Processes

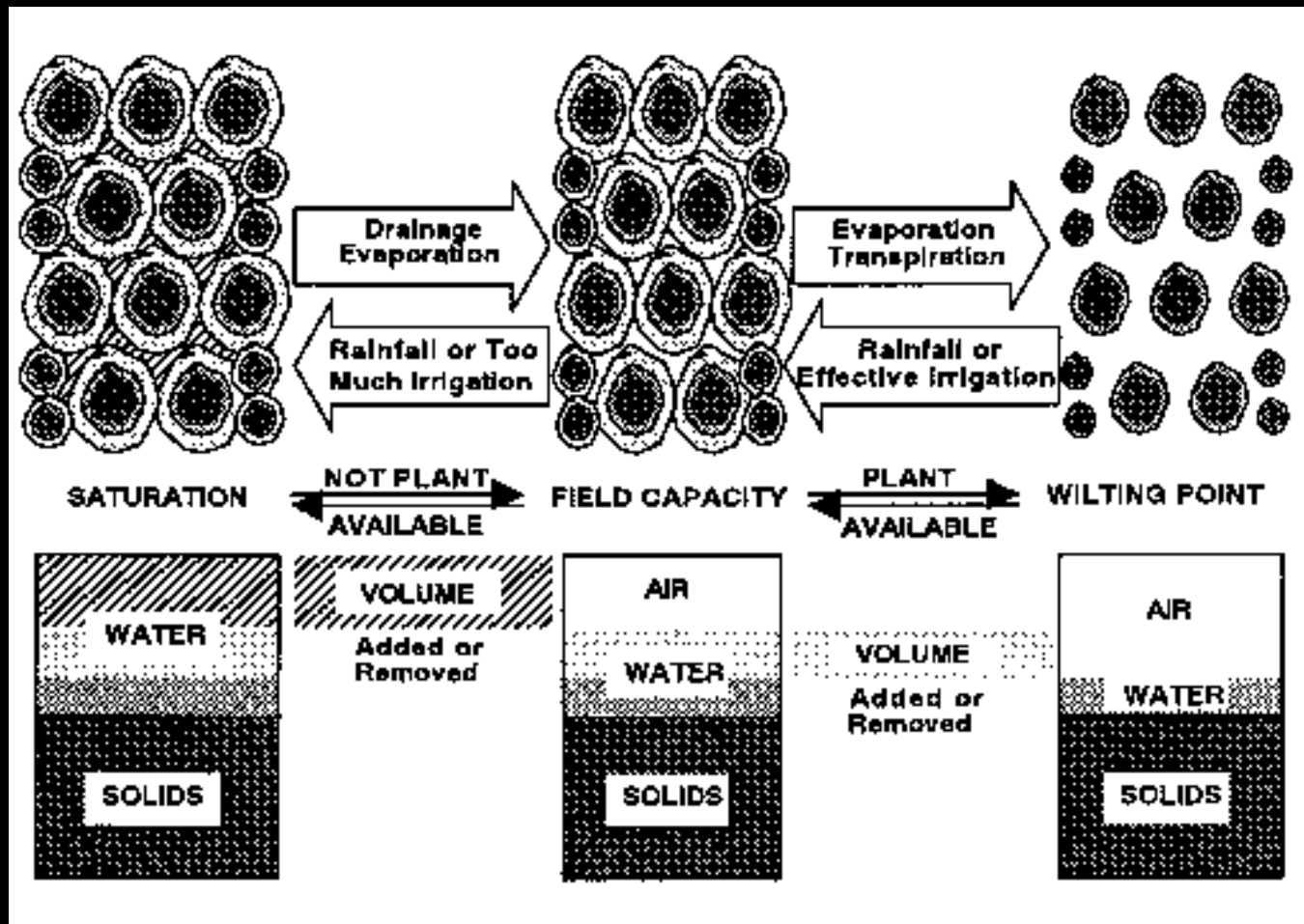


Stormwater Control Factors

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

Green Roof Components – Growing Media

- Moisture retention & plant water availability



Green Roof Categories

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

Source: Green Roofs for Healthy Cities

Green Roof Categories: Intensive

- “Roof garden” with trees, shrubs, etc
- Often accessible
- 50+ psf
- Expanded planting palette
- Highest cost
- Highest maintenance

Source: Green Roofs for Healthy Cities

Green Roof Categories : Intensive

- Millennium Park, Chicago



Source: www.greenroofs.com

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/maintenance

Source: Green Roofs for Healthy Cities

Green Roof Categories : Semi-Intensive

- Vancouver Public Library



Source: www.greenroofs.com

Green Roof Categories : Semi-Intensive

- Seattle Art Museum/WAMU



Green Roof Categories : Extensive

- Lightweight
- Larger areas
- 12-35 psf
- Somewhat limited planting palette
- Typically inaccessible
- Lowest maintenance & cost
- Amenable for retrofits

Source: Green Roofs for Healthy Cities

Green Roof Categories : Extensive

- Whistler Daycare Centre, B.C.



Source: BCIT

Green Roof Categories : Extensive

- MKA Green Roof Evaluation Test Plot



Green Roof System (Modular)



Image: www.greenroofplants.com

Image: www.greenroofblocks.com



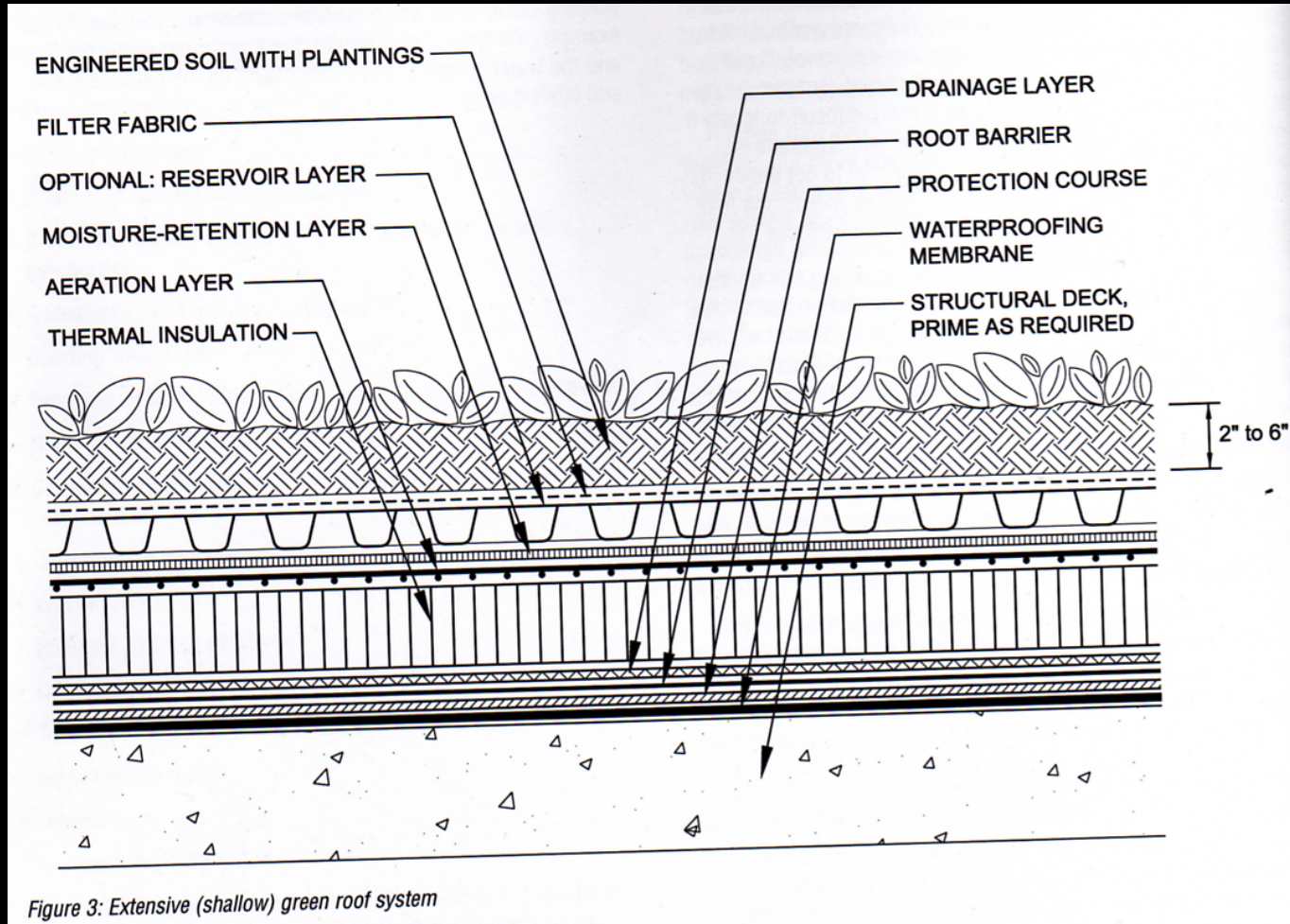
Green Roof Systems

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

Green Roof Systems

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

Green Roof System (Multi-course)



Source: NRCA Green Roof Systems Manual

Green Roof System

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

Green Roof System (Multi-course)

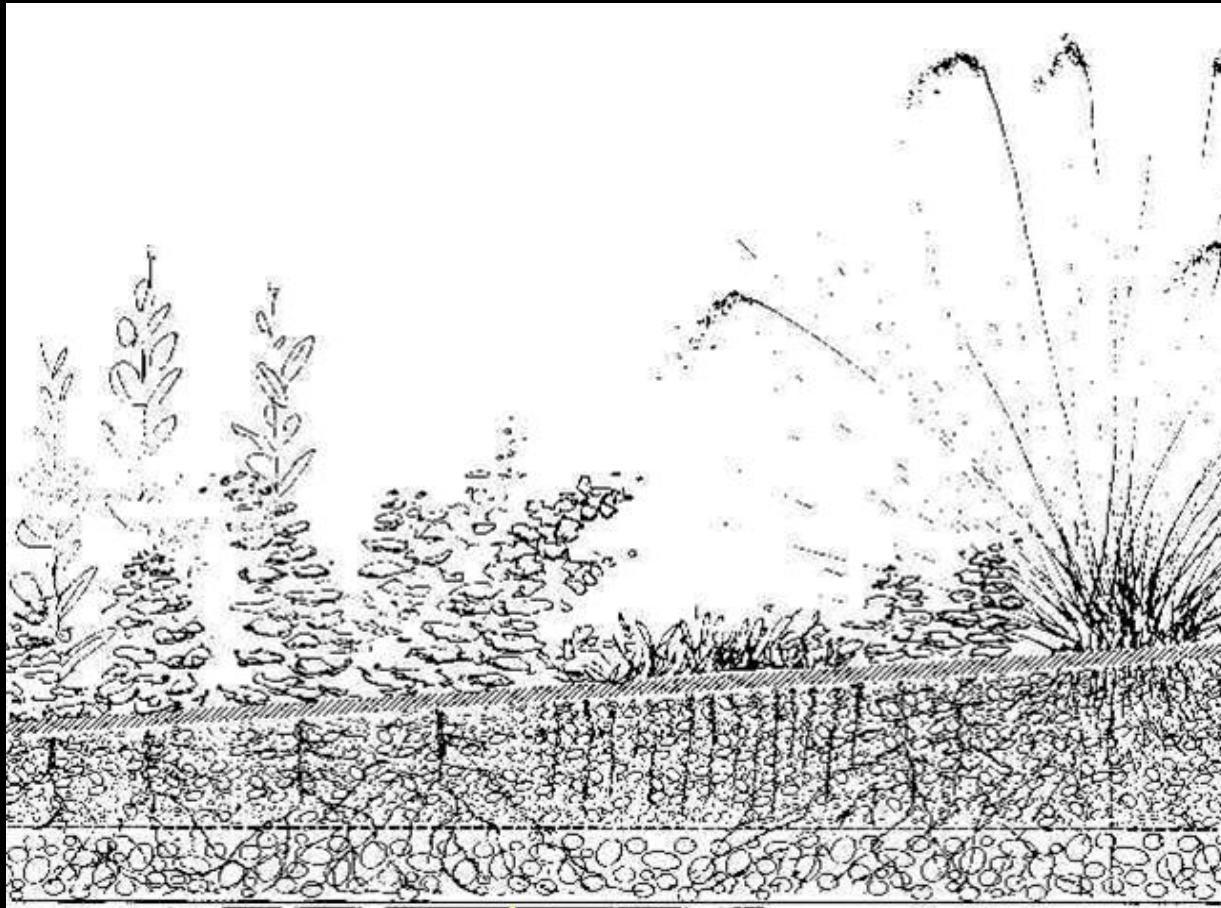
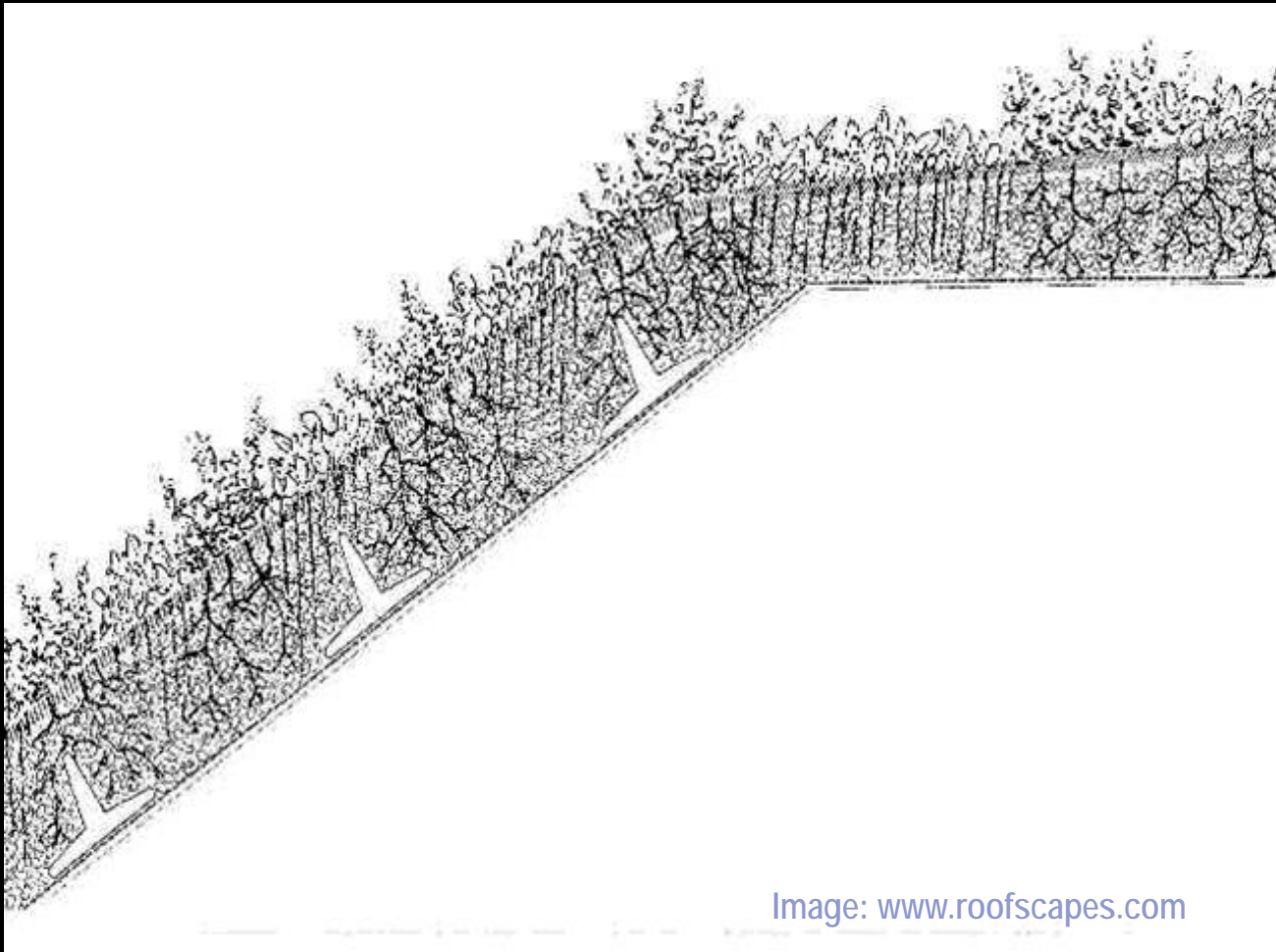


Image: www.roofscapes.com

Granular Drainage

Green Roof System (Single-Layer)



“What kind of roof can be vegetated?”

.....just about any!

“Flat” roofs



Chicago Wal-mart
Source: www.roofscapes.com



Ford Rouge River Plant
Source: www.greenroofs.com

Sloped roofs



California Academy of Sciences
Source: www.calacademy.org



Source: www.roofscapes.com

High-rises



Chicago

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

Wood frames



Zoomazium, Seattle

- New construction
- Native plantings



Bridges/structures



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”

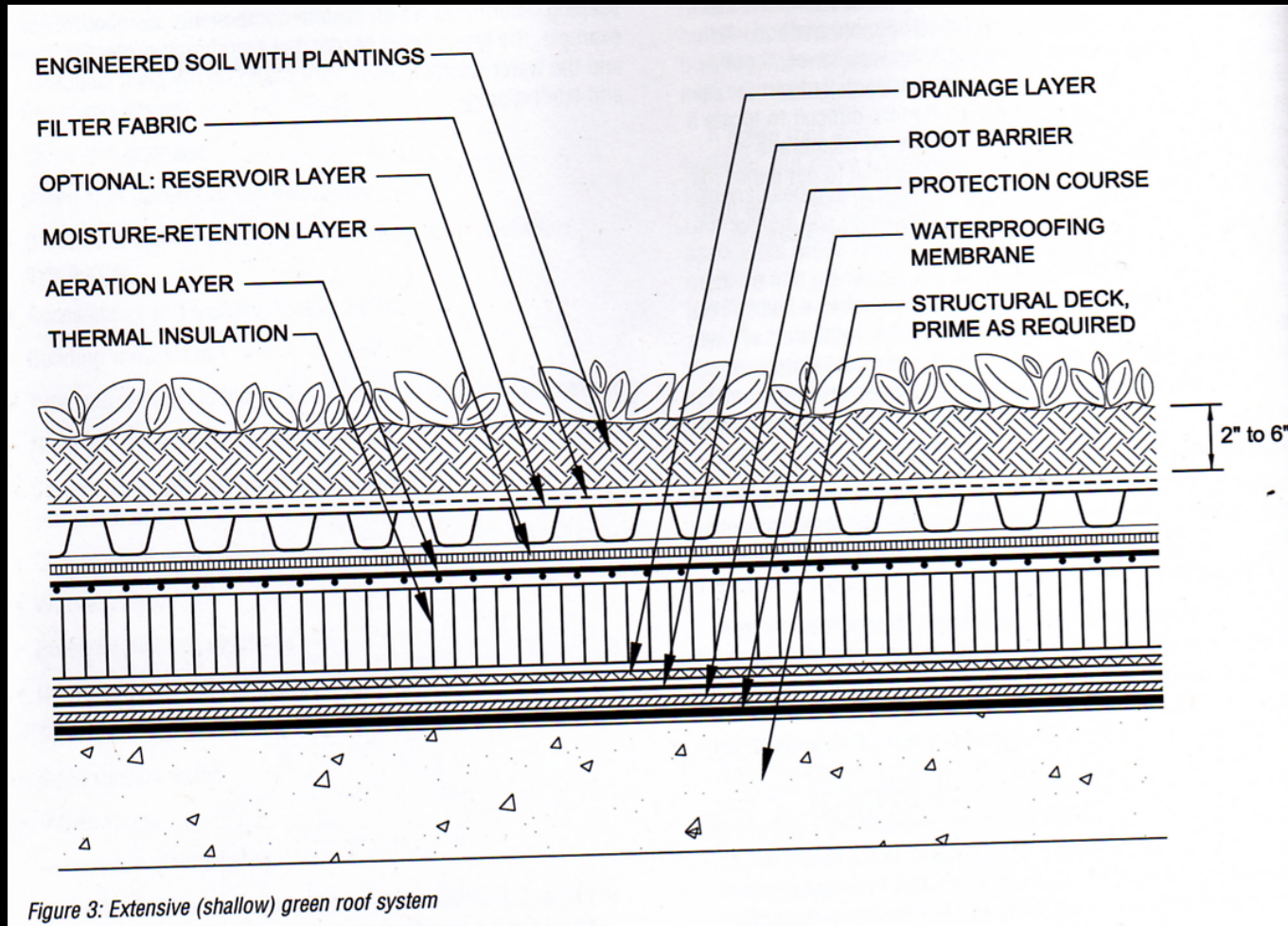
Green Roof Guidance & Resources

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

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

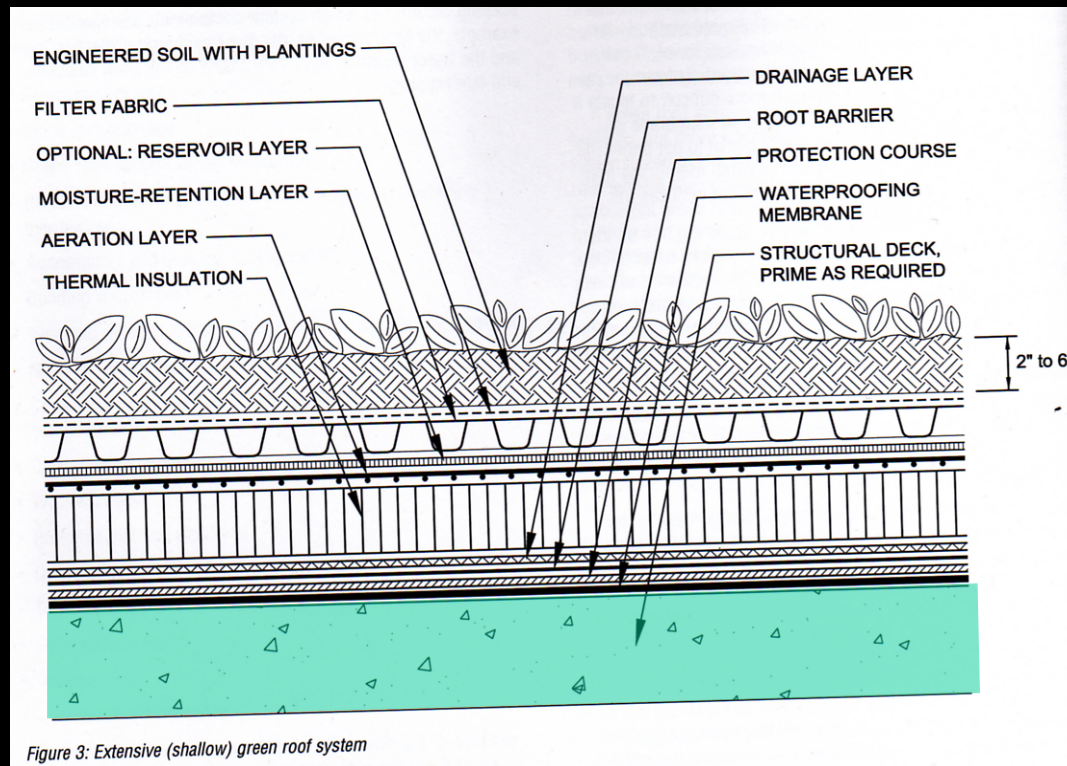
Green Roof Components



Source: NRCA Green Roof Systems Manual

Green Roof Components

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



Green Roof Components

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

Green Roof Weight

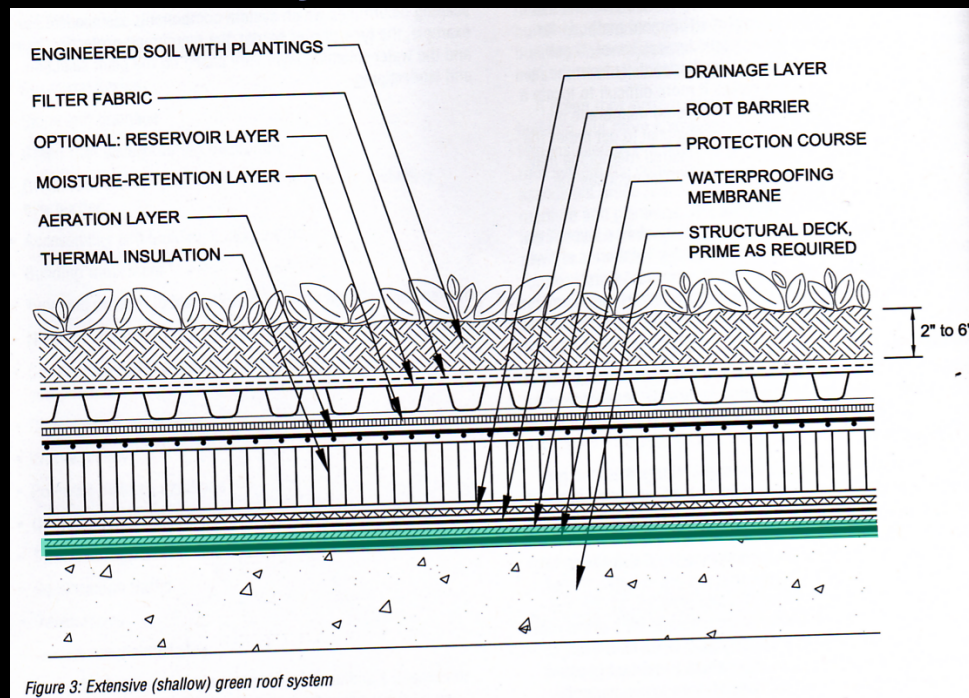
<u>Thickness</u>	<u>Weight (psf)</u>
1-in (vegetated mat)	8-15
2-in	10-22
4-in	22-34
6-in	33-51
8-in	47-65

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**

Green Roof Components

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



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

Green Roof Components

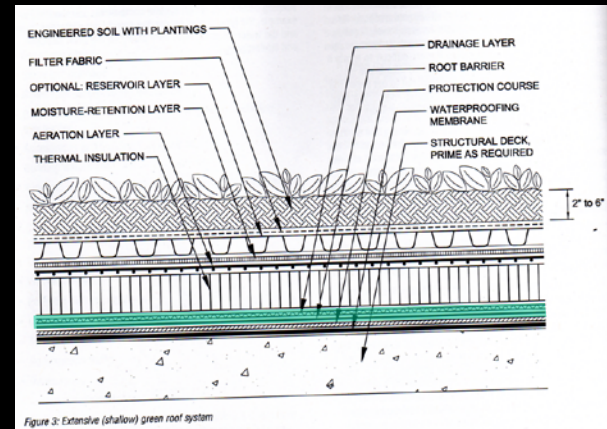
- Types of membranes
 - Built-up (layers of felt/fabric & bitumen)
 - Fluid applied
 - Elastomeric – EPDM (sheets of rubber-like material)
 - PVC/TPO
 - Others



American Hydrotech MM6125® monolithic fluid applied rubberized asphalt membrane

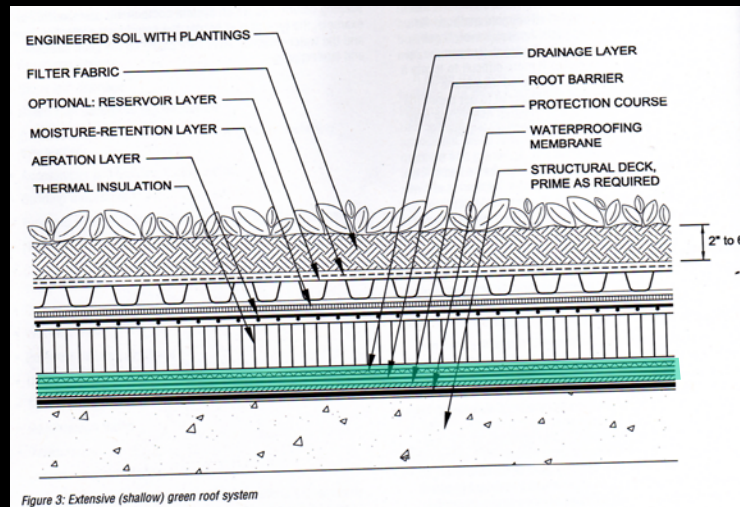
Green Roof Components

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



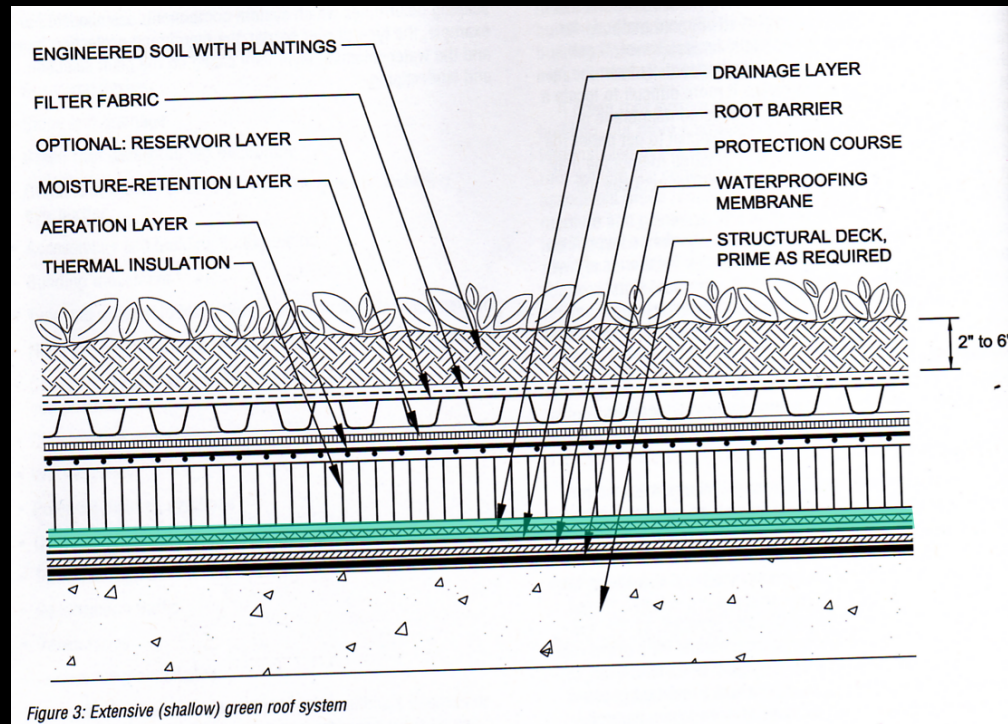
Green Roof Components

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



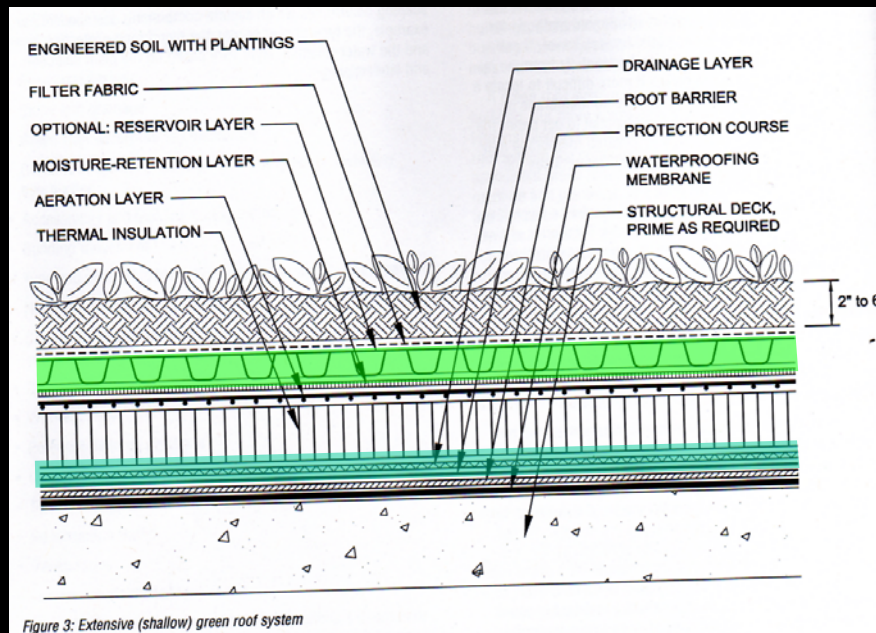
Green Roof Components

- Drainage layer (Roofing perspective)
 - Relieves hydrostatic pressure
 - Allows insulation to breathe



Green Roof Components

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



Green Roof Components – Drain Layer

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

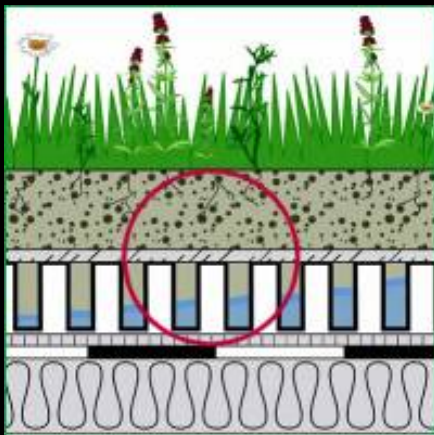
Green Roof Components – Drain Layer

- **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**

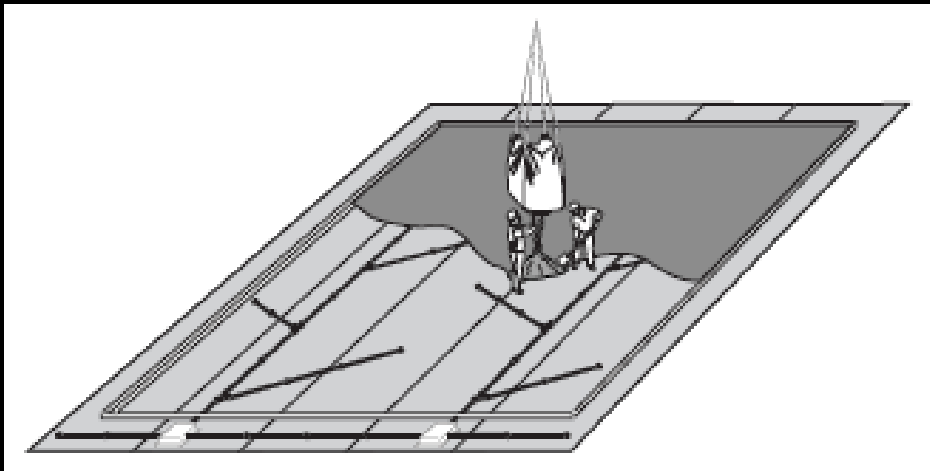
Green Roof Components – Drain Layer

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



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

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



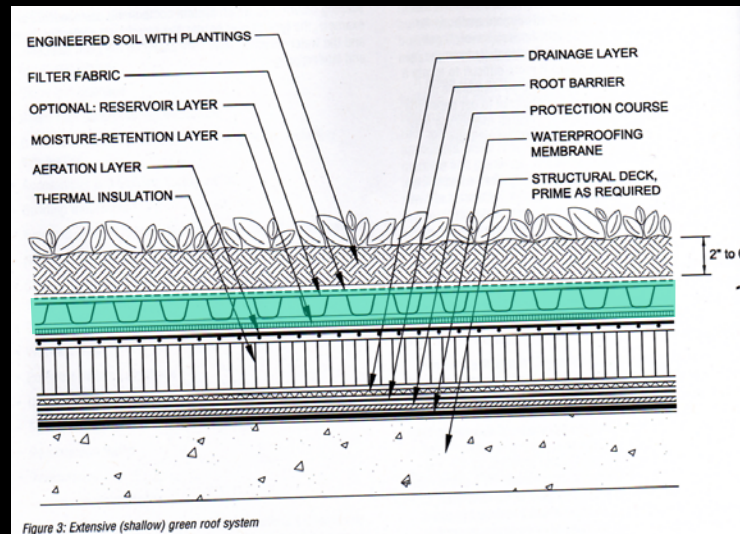
Source: Conservation Technology, Inc.



Source: www.optigreen.com

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



Green Roof Components

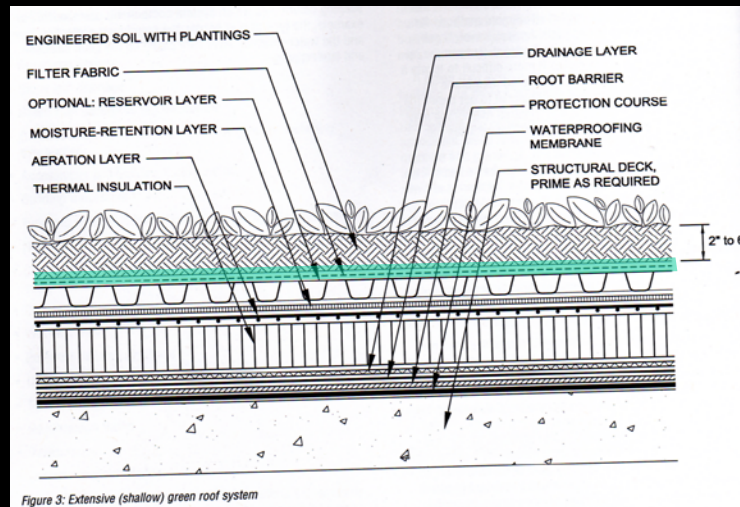
- Moisture Retention Layer



Source: American Hydrotech

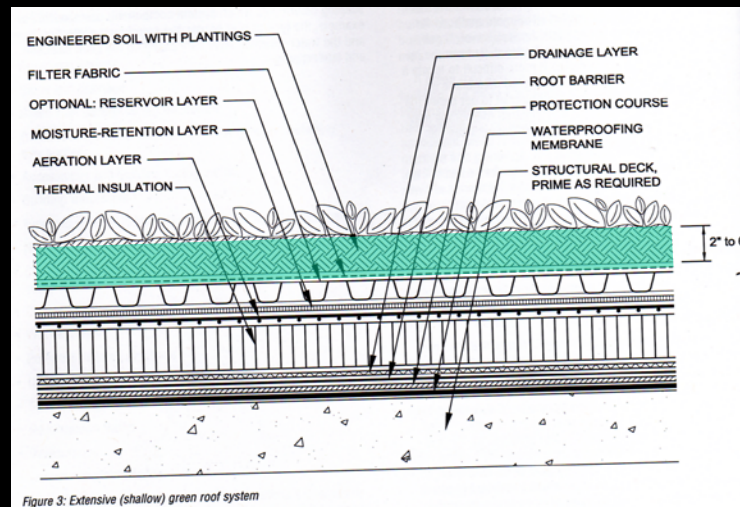
Green Roof Components

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



Green Roof Components

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

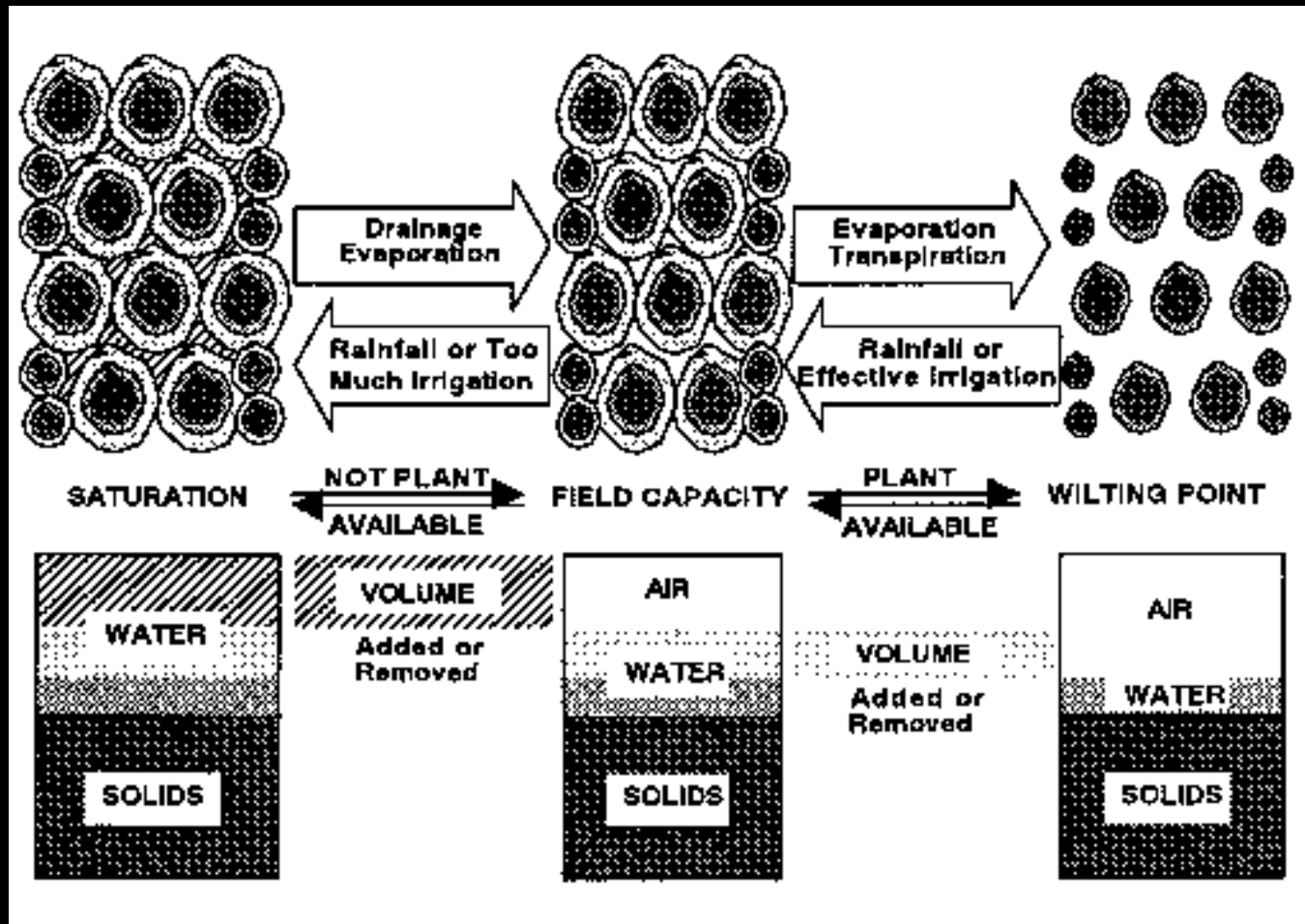


Green Roof Components - Growing Media

- 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

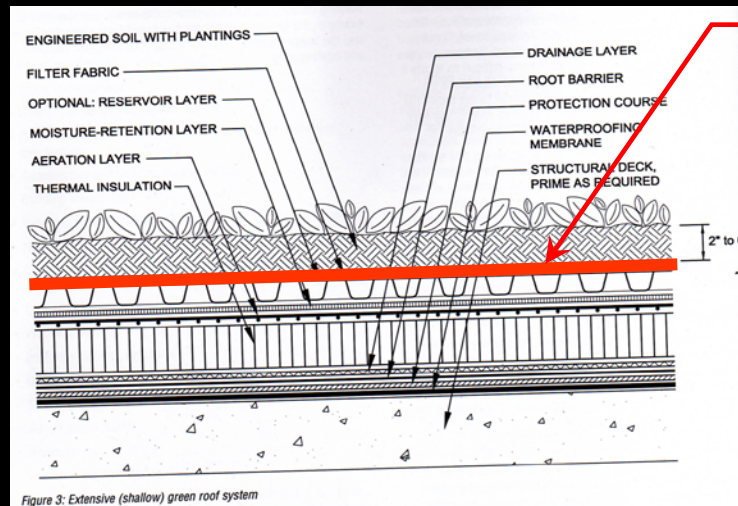
Green Roof Components - Growing Media

- Moisture retention & plant water availability



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

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%**

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

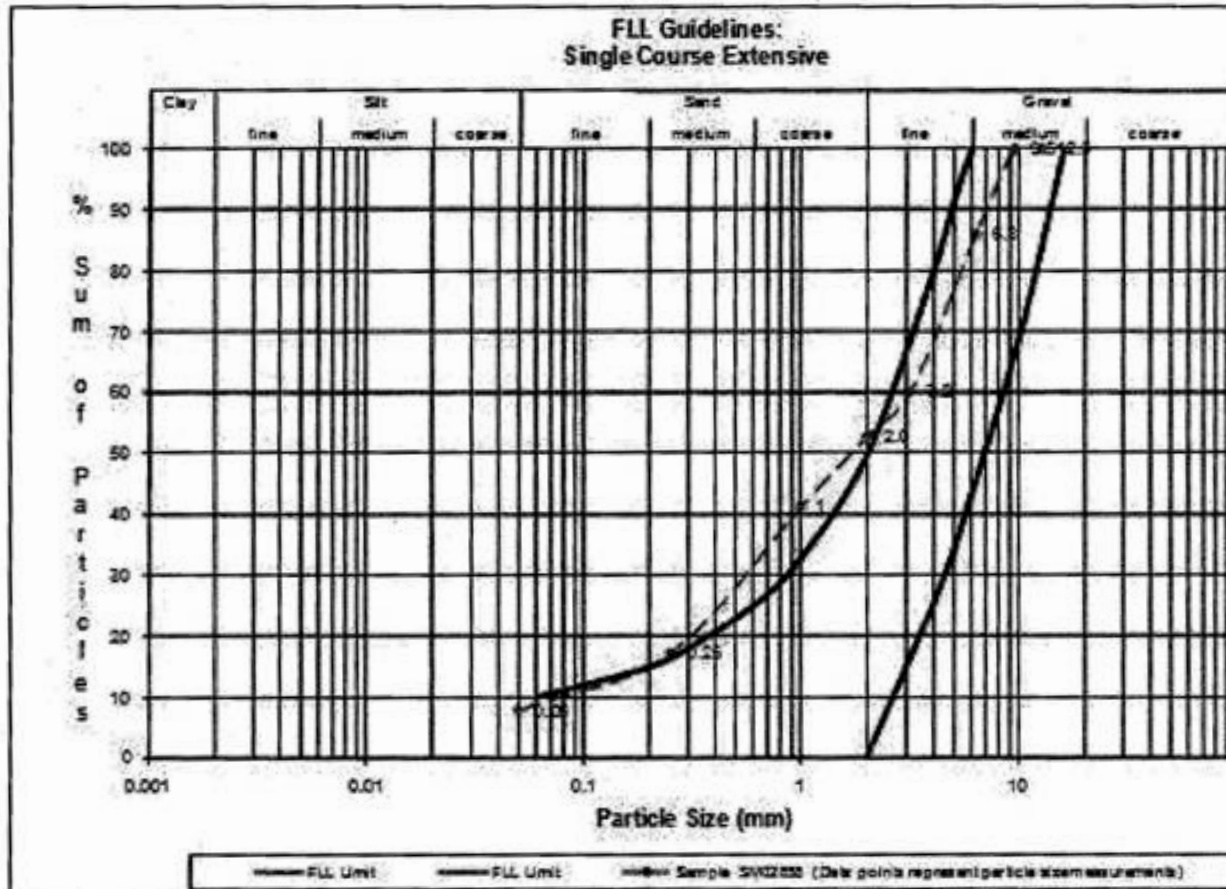
Green Roof Components - Growing Media

- **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

Specifying Growing Media

FLL¹ Particle Size Distribution Graph
for Single Course Extensive Systems



¹Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL). 2008. Guidelines for the Planning Execution and Unkeep of Green-Roof Sites

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

Key Media Parameters for Storm Control

- Media composition (% organic)
- Maximum water content (field capacity)
 - 35 – 50% typ.
- Saturated/dry weights
- Saturated Hydraulic Conductivity (permeability)
 - 0.001 to >1.0 cm/s (!)

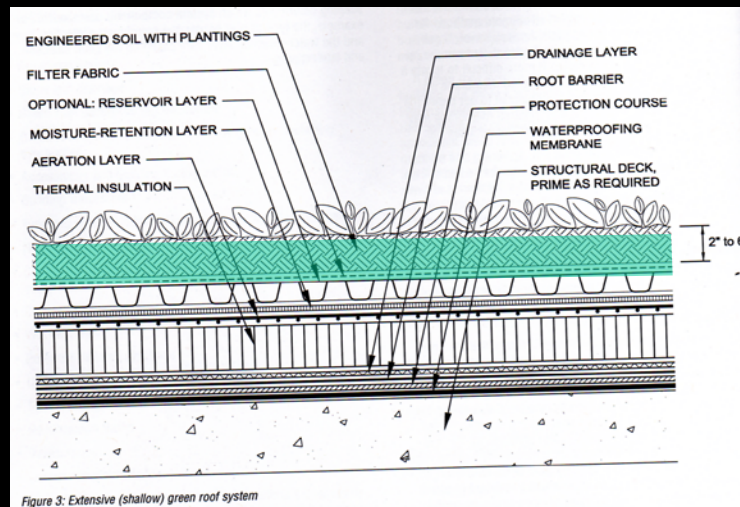
Specifying Growing Media

- **Quality Assurance**
 - **Test growing media delivered to site**
 - **Spot checks on roof for uniformity**
 - **Avoid separation of components during handling**

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



Green Roof Components

- Common Plants
 - Succulents
 - Grasses
 - Herbaceous

Green Roof Plants

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



Sedum oregonum



Sedum album



Green Roof Plants

- Succulents also have fewer stomata
 - **Sempervivum**
 - **Delosperma**

Sempervivum 'Edge of Night'



Delosperma cooperii



Green Roof Components

- Proven Pacific Northwest Plants (unirrigated)
 - Sedum
 - Sempervium
 - Delosperma
 - Coastal Strawberry



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**

Green Roof Costs

- Always use a quality waterproofing membrane (est. \$5-\$10/sf)
- Allow \$7-\$20/sf additional for the green roof
- Economy of scale
- Warranty likely to increase cost
- Leak detection system extra \$5-10K

Green Roof Factors

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

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**

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



SLOPETAME2

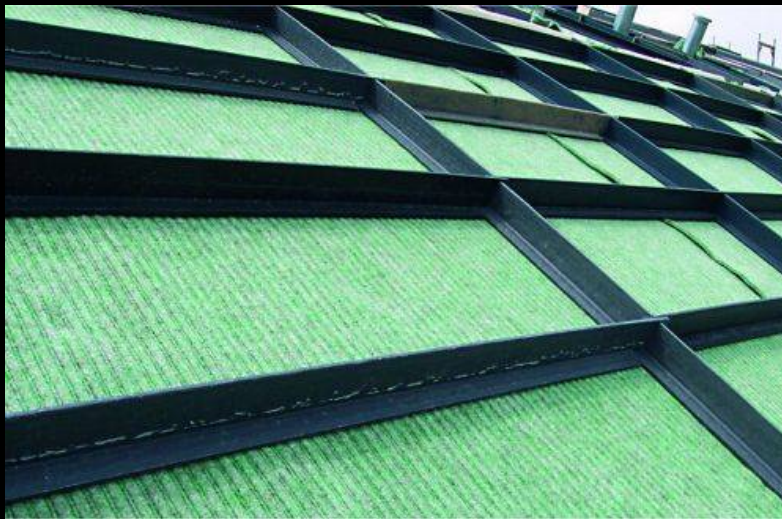


Image: www.optigreen.com



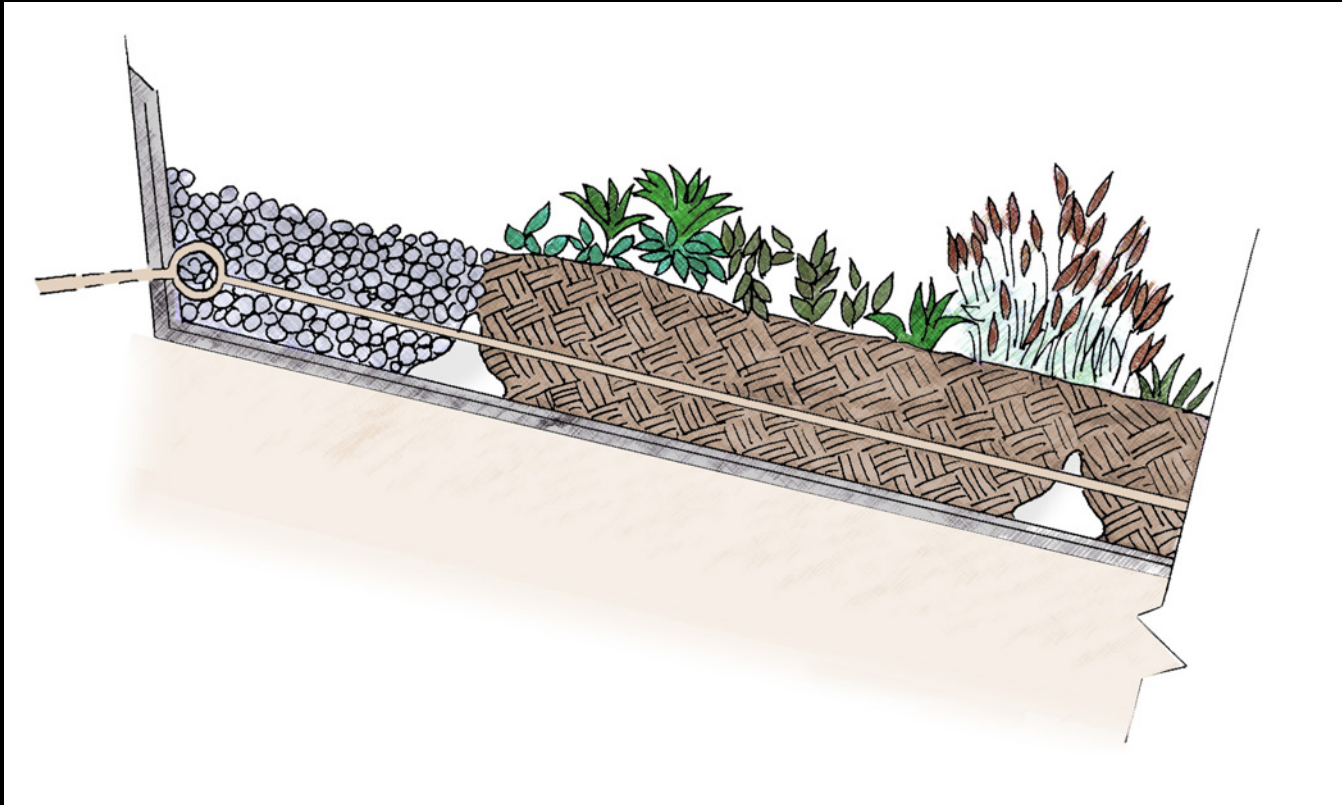
Image: www.hydrotechusa.com

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

- Sloped roofs: Cellular confinement



Green Roof Factors

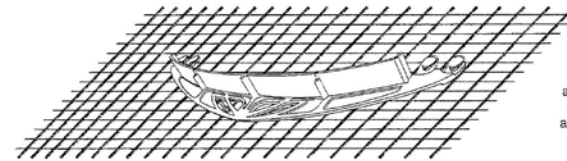
- Sloped roofs:
Cellular
confinement

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 root barriers or floating membranes are not recommended. Optigreen 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 15°, it is essential to use a mechanical slope stabilization system. We offer two basic types to accommodate different roof architecture: one system transfers soil loads up the roof and one transfers soil loads down the roof.

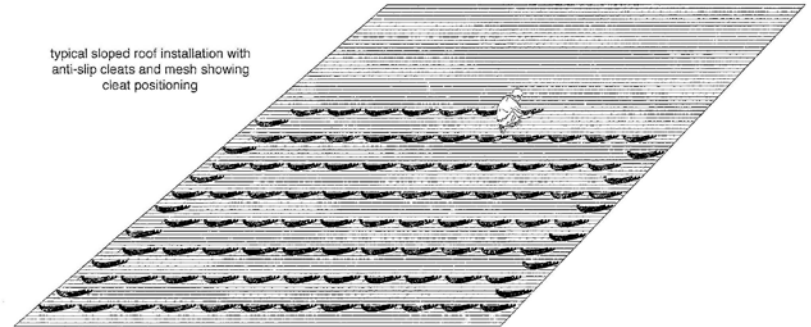
ANTI-SLIP CLEATS AND MESH: This system offers a simple and inexpensive means to prevent soil sliding by transferring soil loads up the roof. Optigreen Anti-Slip Mesh is simply laid over Optigreen Drainage Mat and Optigreen Anti-Slip Cleats are clipped onto the mesh. The high-strength structural plastic mesh is mechanically fastened at the top of the roof, or if the roof is gabled or barrel-shaped one side of the roof can be used to balance the opposite side. The row spacing of the banana-shaped plastic cleats varies from 10" to 50" depending on the roof slope. To distribute load on the mesh each row is shifted one-quarter cleat from the row above and below and extra cleats are inserted between rows at edges to fill the voids.

anti-slip cleat



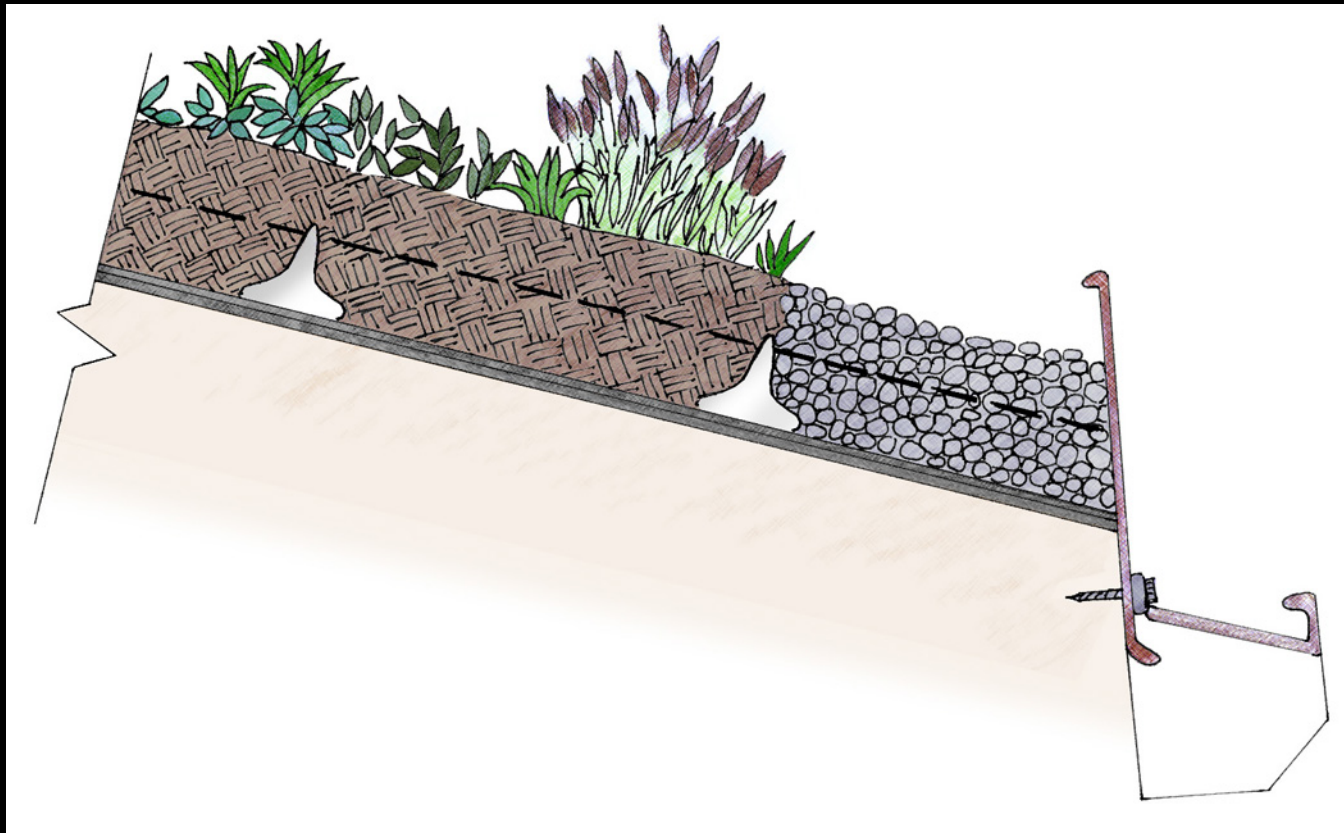
anti-slip cleat
clipped to
anti-slip mesh

typical sloped roof installation with
anti-slip cleats and mesh showing
cleat positioning



Green Roof Factors

- Sloped roofs: Cellular confinement

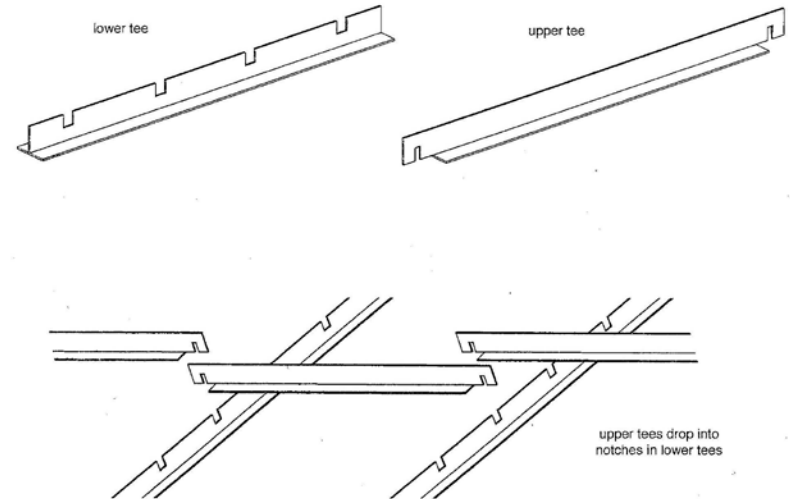


Green Roof Factors

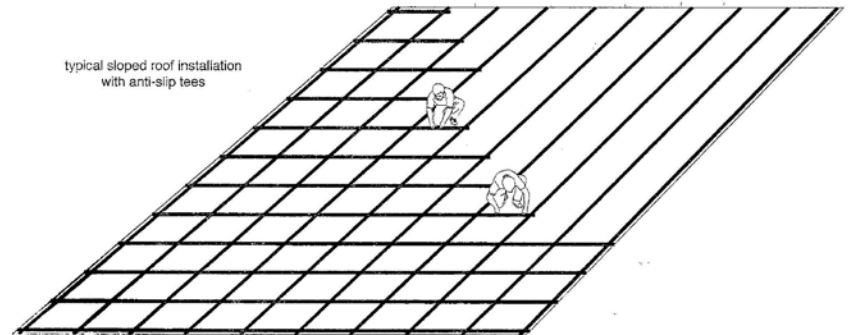
- Sloped roofs:
Cellular
confinement

19

ANTI-SLIP TEES: In contrast with the cleat/mesh system, The Optigreen Anti-Slip Tee system transfers soil load down the roof to a structural parapet or fascia at the bottom of the roof slope. The system consists of two interlocking T-shaped plastic extrusions: the lower one follows the slope of the roof and the upper one crosses the slope of the roof. The lower tees are spaced approximately one meter (40") apart and the spacing of the upper tees varies from 10" to 50" depending on the roof slope.



typical sloped roof installation
with anti-slip tees



Sloped Green Roof Case Study



Green Roof Factors

- Sloped roofs: Slippage restraint



Image: www.hydrotechusa.com

Green Roof Factors

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

Green Roof Costs

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

Installation Considerations

- **Coordination of trades is critical**
 - **Waterproofing installer**
 - **Landscape crew**
 - **Mechanical equipment**
 - **Access to cranes/elevators**

Installation Considerations

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

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

Installation Considerations

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

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**

Installation Considerations

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

Installation Considerations

- Mulch/matting
 - Prevent wind erosion
 - Discourage weed germination
 - Reduce soil moisture loss
- Bird netting

Challenges – Birds



Maintenance

- 2- to 3-yr establishment period (80-90% coverage)
 - Irrigation
 - Watch for over-/under-compacted areas
- Monitor & repair steep slope sloughing
- Weeding
- Temporary mulch/matting
- Fertilization
 - Slow-release
 - May not be needed after first 5-yr

“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

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

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

Design Load Verification

- Snow load
- Load Swapping
- Plaza/Decks

Design Load Verification (cont.)

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

Design Load Verification (cont.)

- **Load Swapping**
 - **Ballast typically 10 psf \pm**
 - **Concrete Sloping Slabs say 10 to 50 psf \pm**
 - **Tiles**



Design Load Verification (cont.)

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

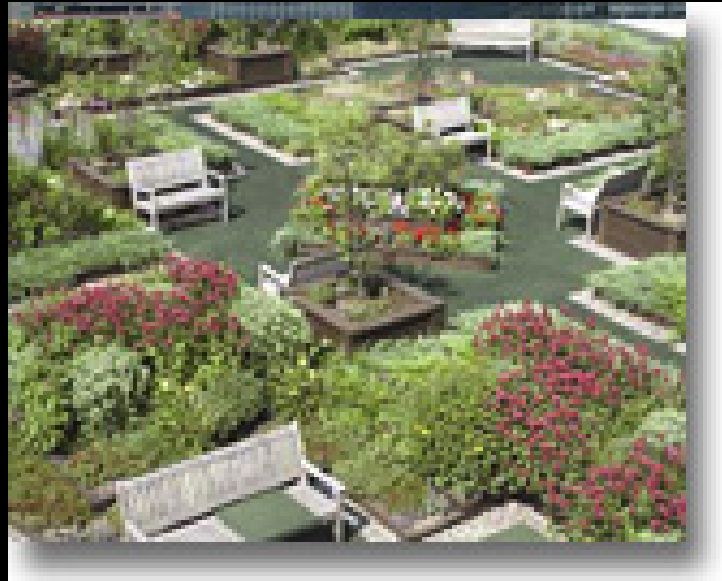


Image: www.greengridroofs.com

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

Seismic

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

Seismic (cont.)

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

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

Structural Screening Criteria (cont.)

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

Target Weight

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

Example: Park Place Building, Seattle

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



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



Questions?



Brian Taylor, P.E.
btaylor@mka.com
www.mka.com