

# GEE5303 Green and Intelligent Building

<http://ibse.hk/GEE5303/>



## Green roof systems and technology

**Thei**

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# Building + **Green**, but done in a wrong way.



(Image source: <http://hk.apple.nextmedia.com/>)

# Contents



- What are green roofs?
- Brief history of green roofs
- Major types of green roofs
- Key components
- Benefits of green roofs
- Design considerations



# What are green roofs?



- **Green Roofs:** roofs bearing vegetation –FLL\*
  - “Living vegetation installed on the roofs”
  - “Vegetated roof”
- **Green Roof System** – Definition
  - “A roof area of plantings/landscape installed above a waterproofed substrate at any building level that is separated from the ground beneath it by a man-made structure.” – *NRCA Green Roof System Manual 2007*
- Other green roof terms: **Eco-roof, Living roof**

# Examples of green roofs in the world



Solar Campus Jülich, Germany (11 Jul 2001)



IBN-DLO Wageningen, the Netherlands (2 Jul 2001)



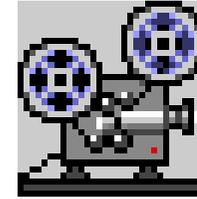
Putrajaya Int. Conven. Centre, Malaysia (30 Jun 2006)



Beitou Taipei Library, Taiwan (6 Aug 2007)

(Photos taken by Dr Sam C M Hui)

# Green roof at the Vancouver Convention Centre (24,290 sq.m)



Design concepts: Vancouver's 6 Acre Living Green Roof (4:31)  
<http://youtu.be/OX0JHdVd27o>

Living Green Roof: Vancouver Convention Centre - BC, Canada  
(2:43)

[http://youtu.be/5R\\_zgAsTf0c](http://youtu.be/5R_zgAsTf0c)



# Examples of green roofs in Hong Kong



Ocean Park Hong Kong



EMSD Headquarters



Parklane, Tsimshatsui



A school in San Po Kwong

(Photos taken by Dr Sam C M Hui)

# A landscape podium garden in North Point, Hong Kong



(Photos taken by Dr Sam C M Hui)

# Hong Kong Wetland Park Phases II (the largest green roof in Hong Kong)



(Source: Architectural Services Department)

Another type of “green roof” in Hong Kong?!



# Brief history of green roofs



- Green roofs are not a new phenomenon
  - Hanging Gardens of Babylon (600 B.C.)
  - Traditional houses in China and Japan
  - Vikings' grass-covered green roofs on residential and farm houses in Scandinavia (1600 D.C.)
  - Terraced green roofs in Germany & Switzerland (1960's)
- Countries with mature green roof markets & policies
  - Germany: > 15% of all flat roofs had been greened
  - Japan: in Tokyo, building > 1,000 sq.m must include a minimum of 20% of the roof covered in vegetation



# The Hanging Gardens of Babylon (an ancient wonder of the world)



Hanging Gardens of Babylon (3:16), <http://youtu.be/-m4wJxWB2w4>

(Source: <http://weburbanist.com>)

Simple grass-covered green roofs on residential and farm houses in Northern Europe (absorb rainfall & provide thermal protection)



(Source: <http://weburbanist.com>)

# Goats on a green roof in Wisconsin (USA)

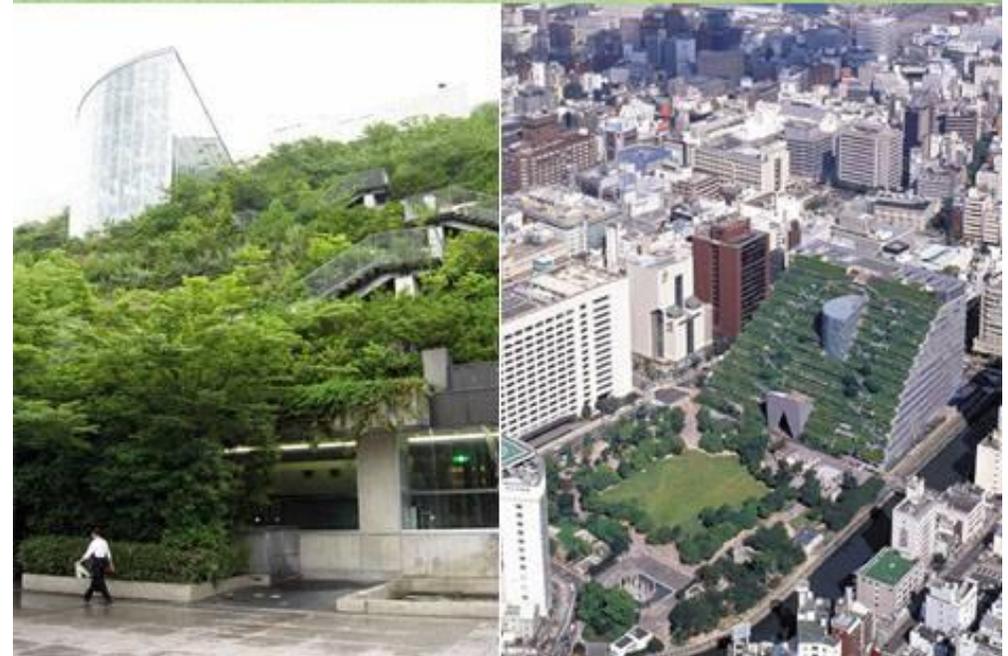


(Source: <http://weburbanist.com>)

Green roofs in Germany (2000)  
(Hundertwasser Building, Darmstadt)



Green roofs in Japan (1995)  
(ACROS Fukuoka building)





ACROS Fukuoka Prefectural International Hall, Fukuoka, Japan (Source: [www.greenroofs.com](http://www.greenroofs.com))



Library Square Building in downtown Vancouver, BC, Canada (Source: <http://urbangreens.tumblr.com>)



Bukit Panjang Sports Hall, Singapore (Source: [www.skyrisegreenery.com](http://www.skyrisegreenery.com))



Marina Barrage, Singapore (14,000 m<sup>2</sup>) (Source: [www.skyrisegreenery.com](http://www.skyrisegreenery.com))

# Major types of green roofs



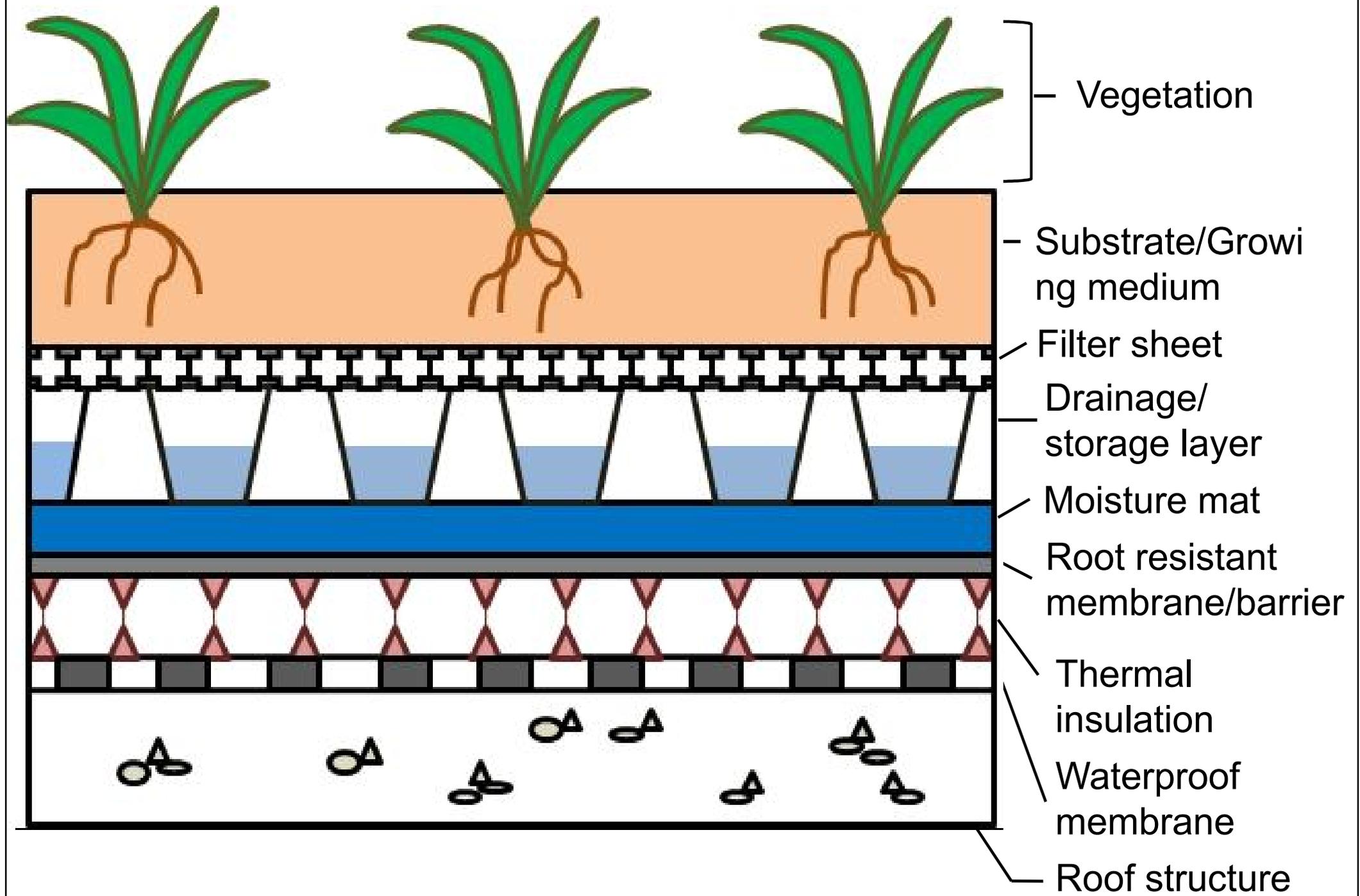
- Major types of green roofs (see Table 1)\*
  - Extensive
  - Semi-intensive
  - Intensive
- Roof gardens: usually intensive greening with other features such as potted plants, pond, etc.
  - Examples in HK: podium gardens, sky gardens
- Classify green roof systems by basic design:
  - Built-in green roofs vs Modular green roofs

\* Could also be combined as hybrid types

Table 1. Major types of green roofs and their characteristics

Characteristics	Extensive	Semi-intensive	Intensive
Depth of material	150 mm or less	Above and below 150 mm	More than 150 mm
Accessibility	Often inaccessible	May be partially accessible	Usually accessible
Fully saturated weight	Low (70-170 kg/m <sup>2</sup> )	Varies (170-290 kg/m <sup>2</sup> )	High (290-970 kg/m <sup>2</sup> )
Plant diversity	Low	Greater	Greatest
Plant communities	Moss-sedum-herbs and grasses	Grass-herbs and shrubs	Lawn or perennials, shrubs and trees
Use	Ecological protection layer	Designed green roof	Park like garden
Cost	Low	Varies	Highest
Maintenance	Minimal	Varies	Highest

# Typical structure of extensive green roof



# Major types of green roofs



- Built-in green roofs

- Installed in layers for the roof surface
- More complex and permanent
- Time needed for on-site installation & growing
- Excess weight (180 to 450 kg/m<sup>2</sup>)
- Complexity of maintenance



- Modular green roofs

- Prefabricated off-site, pre-grown, with modular design
- Sub-divided into standard interchangeable parts

# Examples of green roofs in Singapore



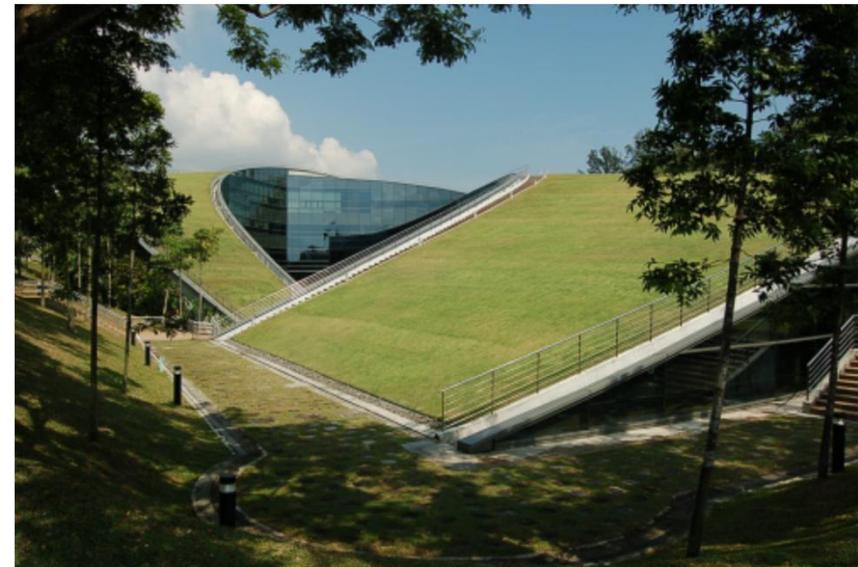
Carpark roof of public housing (modular green roof)



Carpark roof of housing estate (built-in green roof)



Carpark roof of public housing (intensive green roof)



Lawn green roof (Nanyang Techn. Univ.)

(Photos taken by Dr Sam C M Hui, 29 May & 1 Jun 2009)



Vegetated mat system ([www.elteasygreen.com](http://www.elteasygreen.com))



Tray system ([www.liveroof.com](http://www.liveroof.com))



Sack system ([www.greenpaks.com](http://www.greenpaks.com))

# Construction process of modular green roofs

Gウェイブ エコム 施工の流れ

作業工程

## 作業工程

Waterproofing



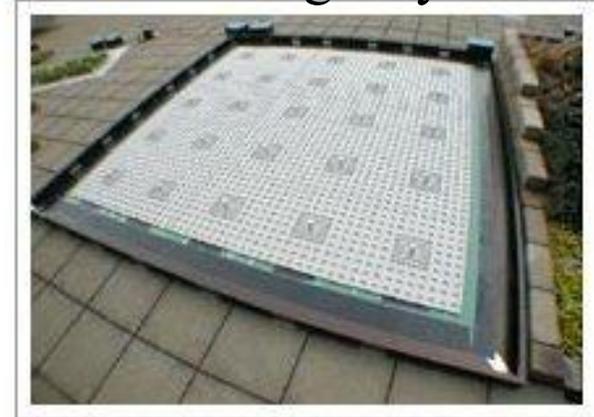
1 防水層施工直後

Roof barrier layer



2 エコムテープ

Drainage layer



3 FDドレインEN FDウォール80E

Install modules



4 エコムユニット

Fix modules (if needed)



5 FDワッシャー

Completed



6 仕上がり

# Key components

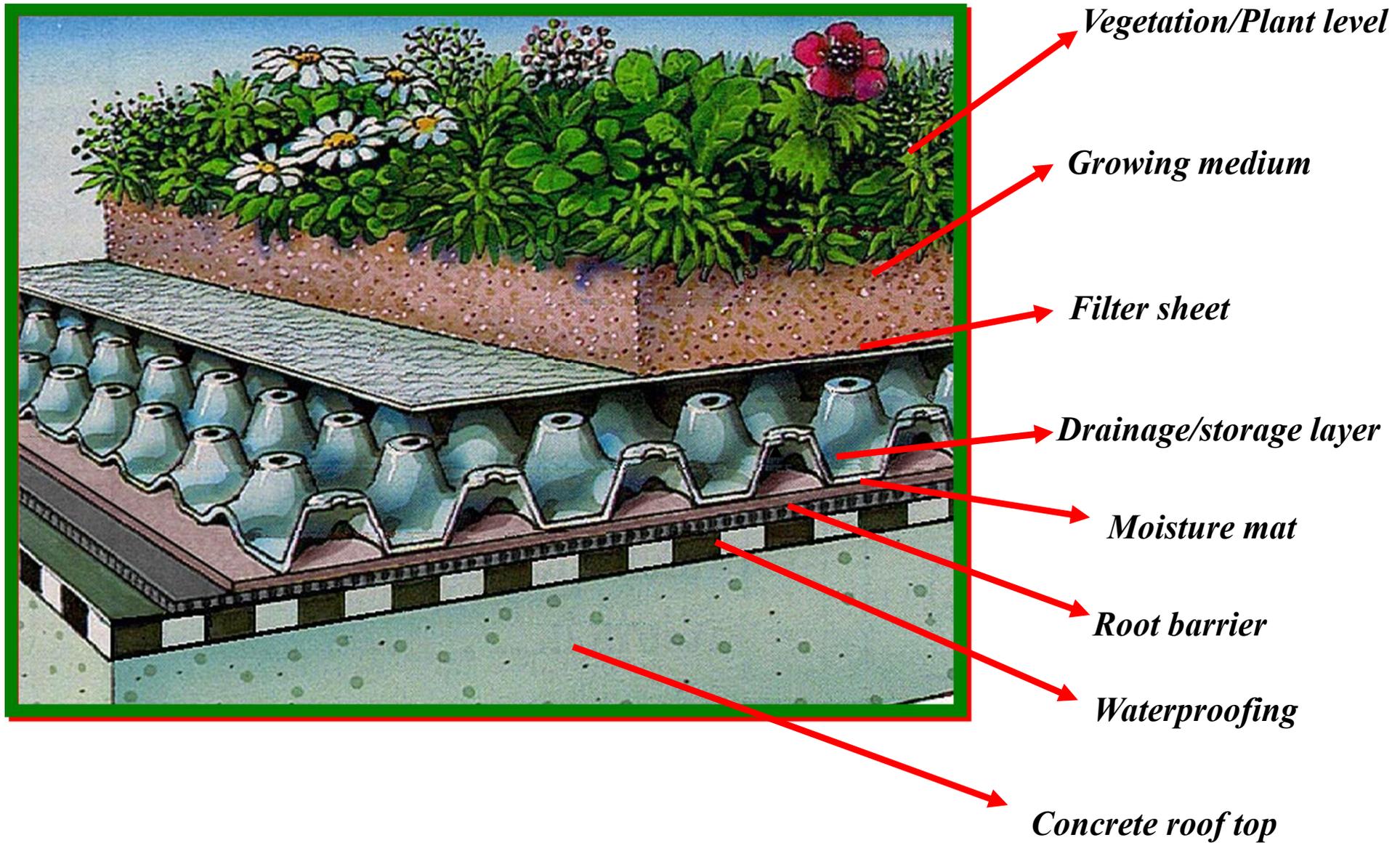


- Typically components of green roofs:
  - Vegetation (plants)
  - Growing medium or soil (substrate)
  - Filter sheet (geotextile fabric)
  - Drainage/storage layer
  - Moisture mat
  - Root repellent layer
  - Waterproof layer

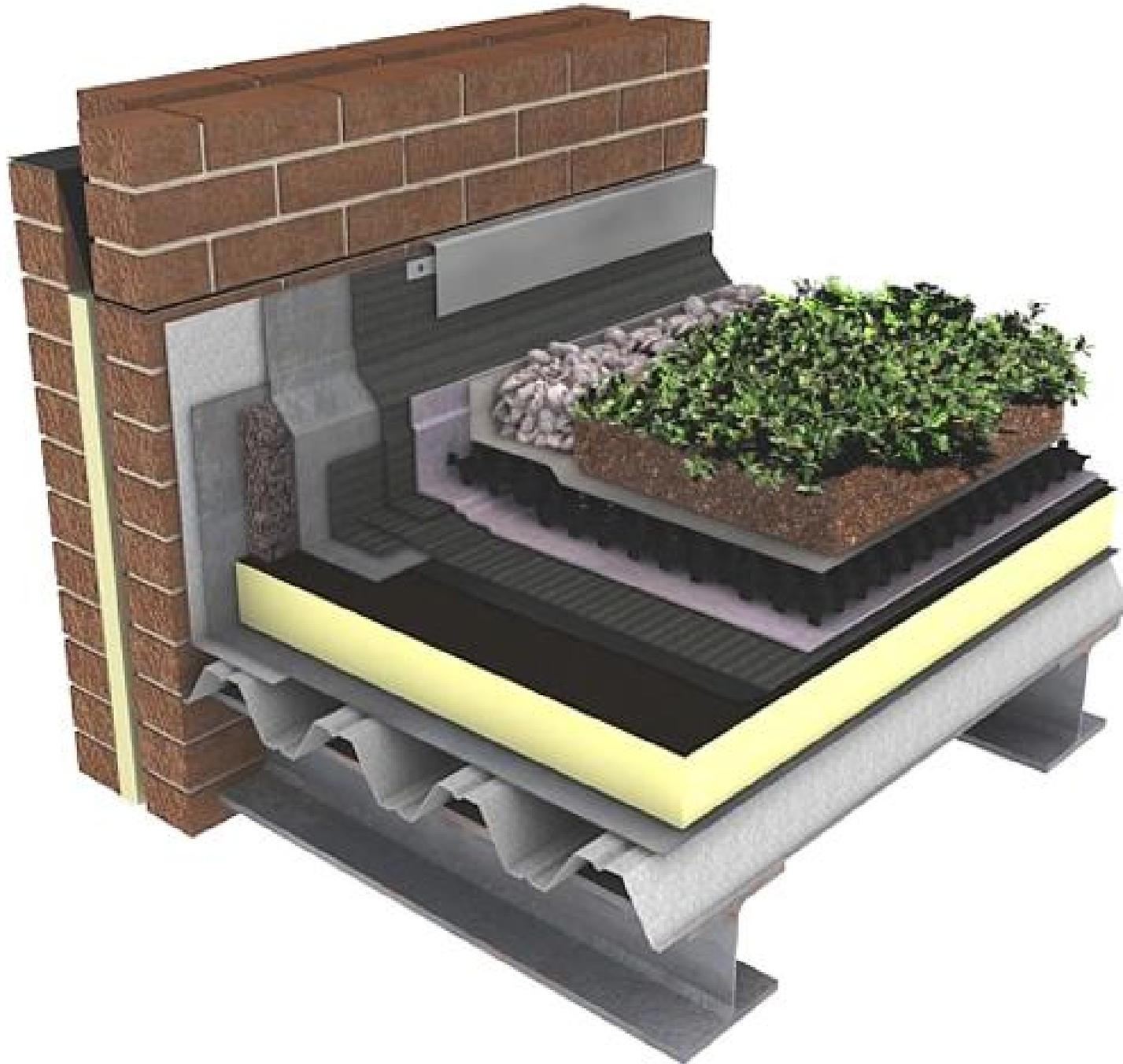
# Green roof systems from Germany (left) and Japan (right)



# Green Roof Structure



# Green roof on steel deck structure



# Green roof on concrete structure



# Key components



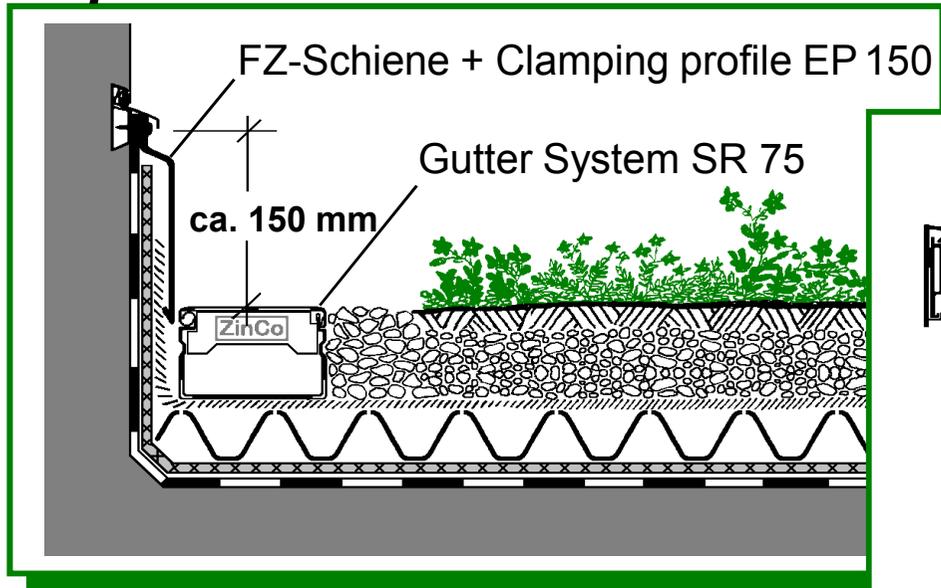
- Other components of green roofs:
  - Insulation
  - Membrane protection layer
  - Leak detection system
  - Ponds and pools
  - Irrigation system
  - Walkways
  - Curbs and borders
  - Railings
  - Lighting



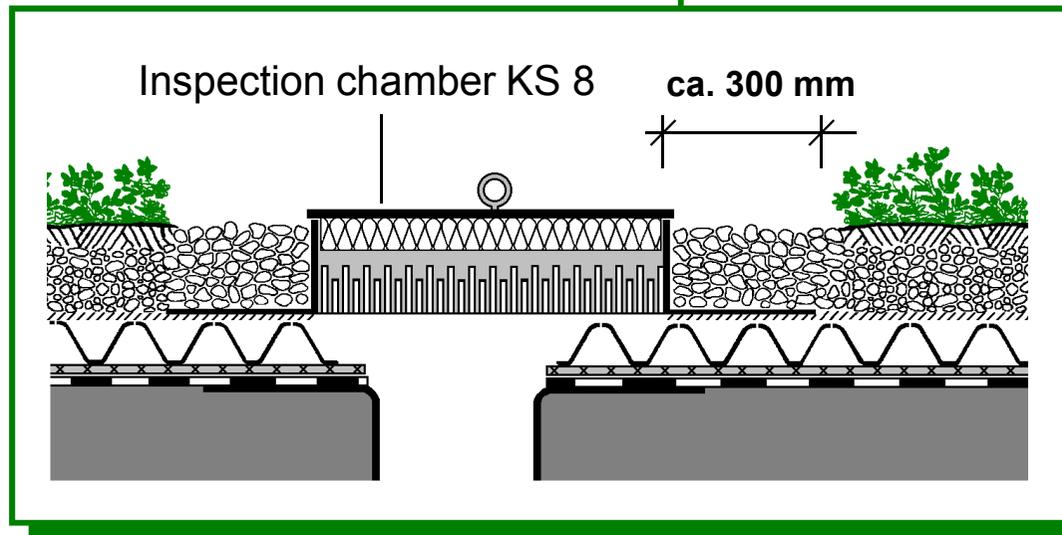
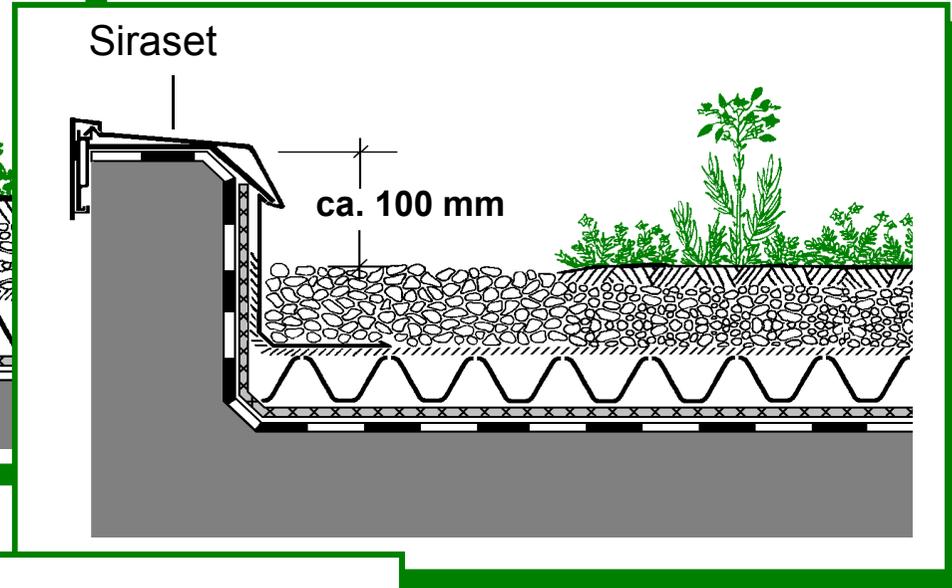
(Source: [www.tajima-roof.jp](http://www.tajima-roof.jp))

# Examples of green roof details

## Upstands



## Roof Perimeters



## Roof outlet with inspection chamber



# Benefits of green roofs

- Green roofs provide many benefits to the society (public) and building owners (private)
  - 1. Environmental benefits
  - 2. Economic benefits
  - 3. Amenity and aesthetic benefits
- Important considerations:
  - Some benefits are common to all green roofs, but many are project design specific; some benefits will be apparent if roof greening is on a large scale

Table 2. Public and private benefits of green roof systems

<b>Public benefits:</b>	<b>Private benefits:</b>
<ul style="list-style-type: none"><li>- Aesthetic value</li><li>- Mitigate urban heat island</li><li>- Stormwater retention</li><li>- Create natural habitat</li><li>- Functional open space</li><li>- Agricultural space</li><li>- Filter dust and pollutants</li><li>- Filter rainwater</li></ul>	<ul style="list-style-type: none"><li>- Increase roof life span</li><li>- Reduce cooling loads</li><li>- Contribute to green building rating credit points</li><li>- Better use of space</li><li>- Reduce noise levels</li><li>- Reduce risk of glare for surrounding buildings</li></ul>

# Green roof benefits for developers, owners and community

	<b>Benefit</b>	<b>Developer</b>	<b>Owner</b>	<b>Community</b>
1.	Aesthetics and property values	√√	√√	√
2.	Mitigate urban heat island			√
3.	Stormwater retention	√	√	√√
4.	Create natural habitat			√
5.	Provide functional open space	√√	√√	√√
6.	Provide agricultural space	√	√	√
7.	Filter dust and pollutants		√	√
8.	Filter rainwater			√
9.	Carbon sequestration			√√
10.	Increase roof life span	√√	√√	
11.	Reduce cooling loads		√√	
12.	Green building rating credit points	√√	√	
13.	Reduce noise levels		√	√
14.	Reduce risk of glare		√	√
15.	Possible food production		√	√√
16.	Increase property value	√√	√√	
17.	Improve efficiency of solar PV panels	√√	√√	



# Benefits of green roofs

- 1. Environmental benefits:
  - Biodiversity and wildlife value
  - Stormwater management
  - Rainwater runoff quality
  - Air pollution mitigation
  - Carbon sinks (sequestration)
  - Mitigation of urban heat island
  - Control of noise pollution





**GREEN ROOF**



**TRADITIONAL ROOF**

# Benefits of green roofs

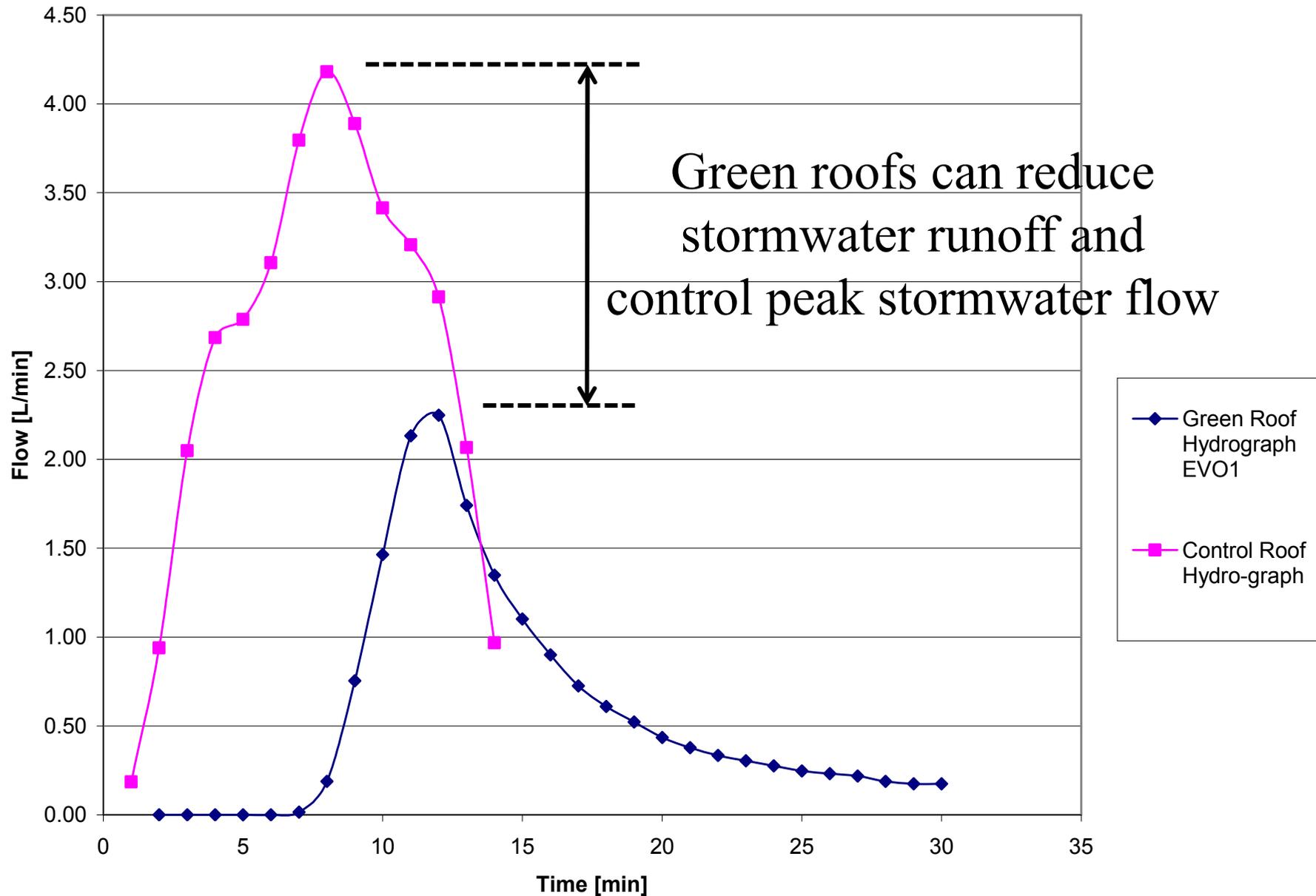


- Effects of green roofs on water runoff
  - Water can be absorbed into pore spaces in the substrate or taken up by the absorbent materials
  - Water taken up by the plants (stored in plant tissues or transpired back to the atmosphere); lodged on plant surfaces & evaporate away (*'evapo-transpiration'*)
  - Water stored and retained by drainage system
- Reduce actual runoff and act as a buffer (mitigate peak flow, during summer storms)



# Green roof hydrograph comparison

Green Roof Hydrograph Comparison 12-2-05

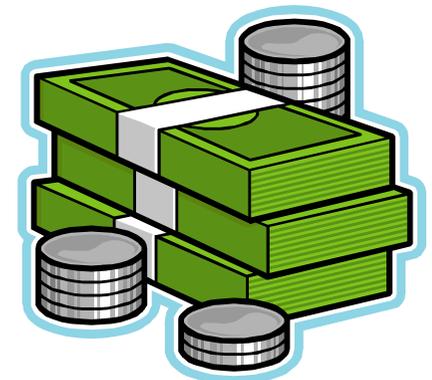


(Source: Stormwater Academy, University of Central Florida)



# Benefits of green roofs

- 2. Economic benefits:
  - Extends roof life
  - Reduces air conditioning & heating costs (energy and maintenance)
  - Reduces capital costs for equipment and installation (air conditioner, drainage and pipes)
  - Reduces water and sewerage charges
  - Attracts buyers and tenants
  - Attracts and retains employees





# Benefits of green roofs

- 2.1 Increased roof life
  - Exposed roofs
    - Experience higher temperature than that of green roofs
    - Daily temperature fluctuations create thermal stresses
    - Roofing materials & membranes are degraded
  - Green roofs
    - Moderate the daily temperature fluctuations
    - Protect the roof system from heat, UV radiation & other mechanical damages: the roof will last longer



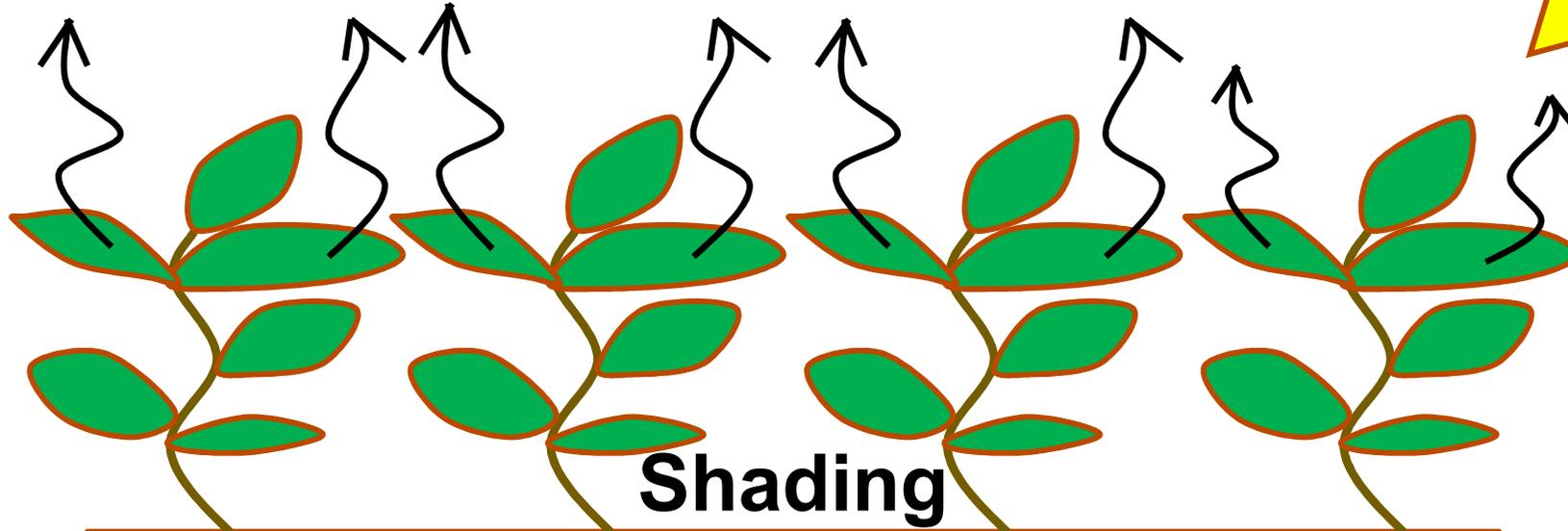
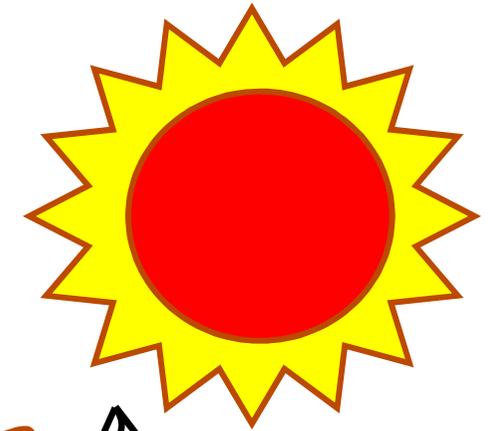
# Benefits of green roofs

- 2.2 Cooling, insulation and energy efficiency
  - Thermal properties of green roofs
    - Direct shading of the roof
    - Evaporative cooling from the plants & substrate
    - Additional insulation from the plants & substrate
    - Thermal mass effects of the growing medium
  - Summer reduction in cooling energy requirements
    - Possible winter insulation effect
  - To maximize the cooling potential, a healthy & complete plant cover is important

# Thermal properties of green roofs

Outdoor

**Evapo-transpiration**



**Shading**



**Thermal mass**

**Roof slab**

Indoor

**Insulating property**

# Green roof research at a construction site office in Hong Kong (2002-2006)



Green site office



Modular design

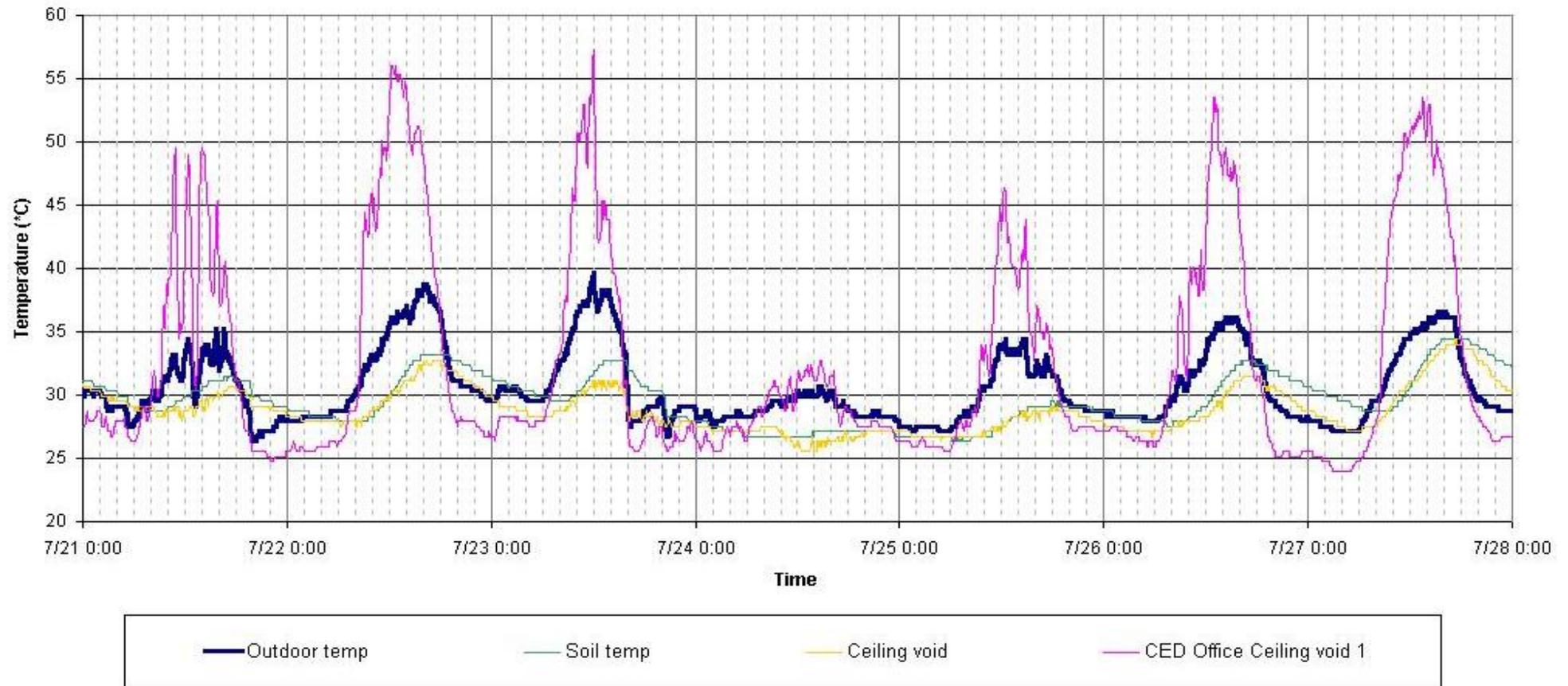


Green site office and typical site office

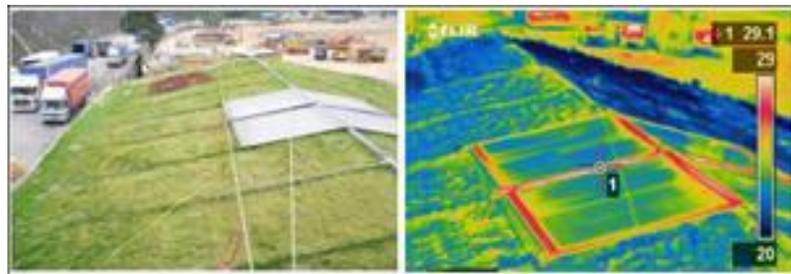


Water sprinkler

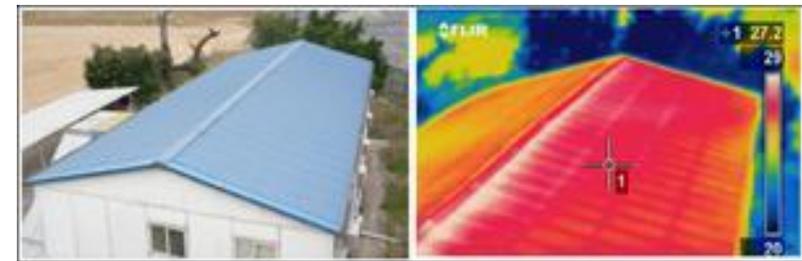
# Green roof research at a construction site office in Hong Kong



## Infrared pictures:



Green roof



Conventional roof



# Benefits of green roofs

## • 3. Amenity and aesthetic benefits:

### • Aesthetically pleasing, useful space

- If roof loading is sufficient, green roofs can be planned for amenity and recreational use

### • Food production (e.g. community gardens)

- Opportunity for growing healthy food in urban areas
- A range of marketable products (vegetable, fruit)

### • Local job creation (direct and indirect)

- On green roof maintenance, urban agriculture, etc.
- Useful for low-income group



# Benefits of green roofs



- Aesthetic value of green roofs
  - Unattractive view of bare roofs (dark asphalt)
  - Green roofs are more pleasant to be looked at
    - Improve employee productivity
- Therapeutic effects
  - Stress reduction
  - Lower blood pressure
  - Relieve muscle tension
  - Increase positive feeling





Urban farming & education



Horticultural therapy & social functions

# Rooftop urban farming in the world



Bangkok, Thailand (with rice and fruits)



Tokyo, Japan (rooftop greenhouse)



London, UK (with bee keeping)



San Francisco, USA (for kitchen/restaurant)

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

# Urban farming on green roofs



Farming on the roof



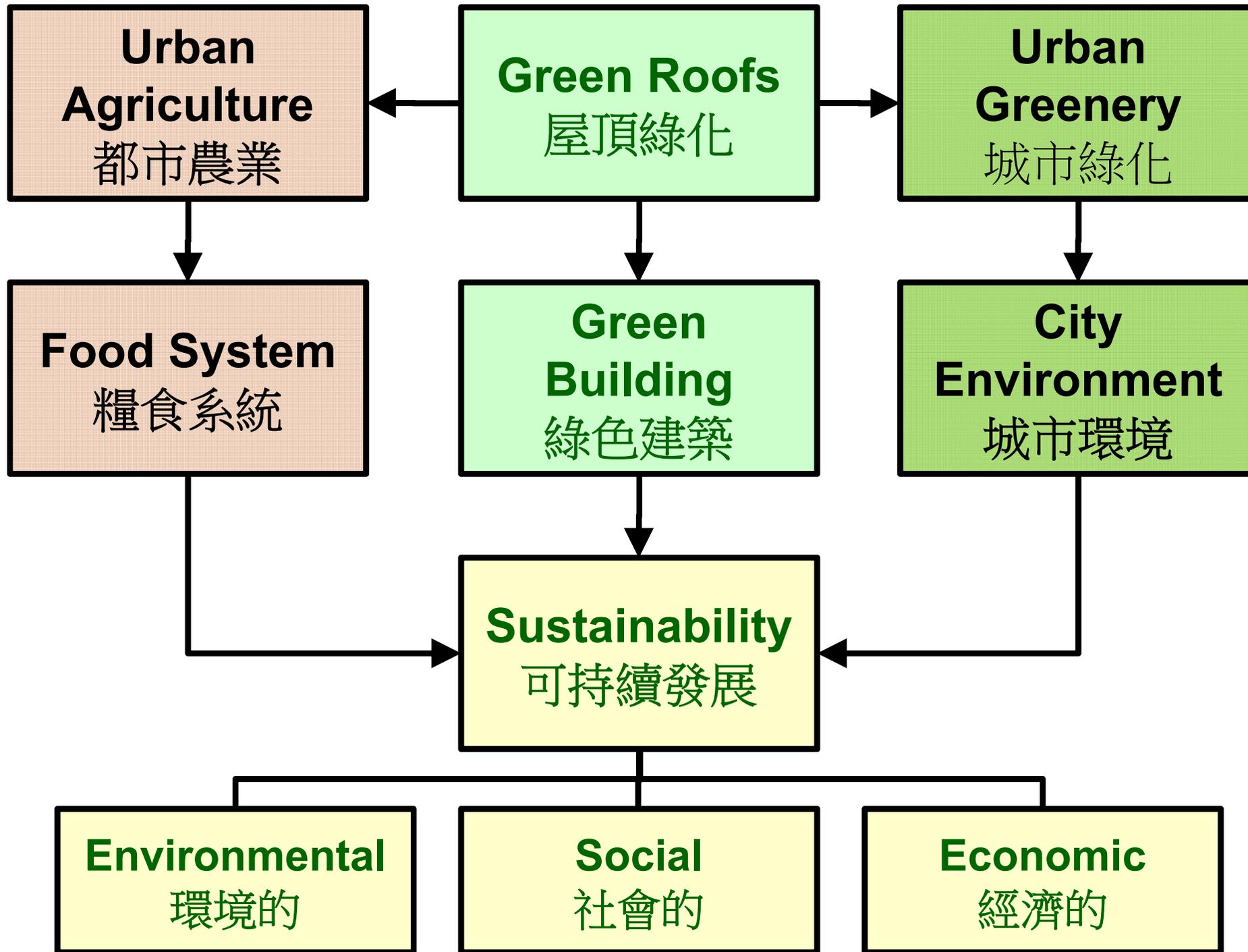
Vegetables and herbal plants



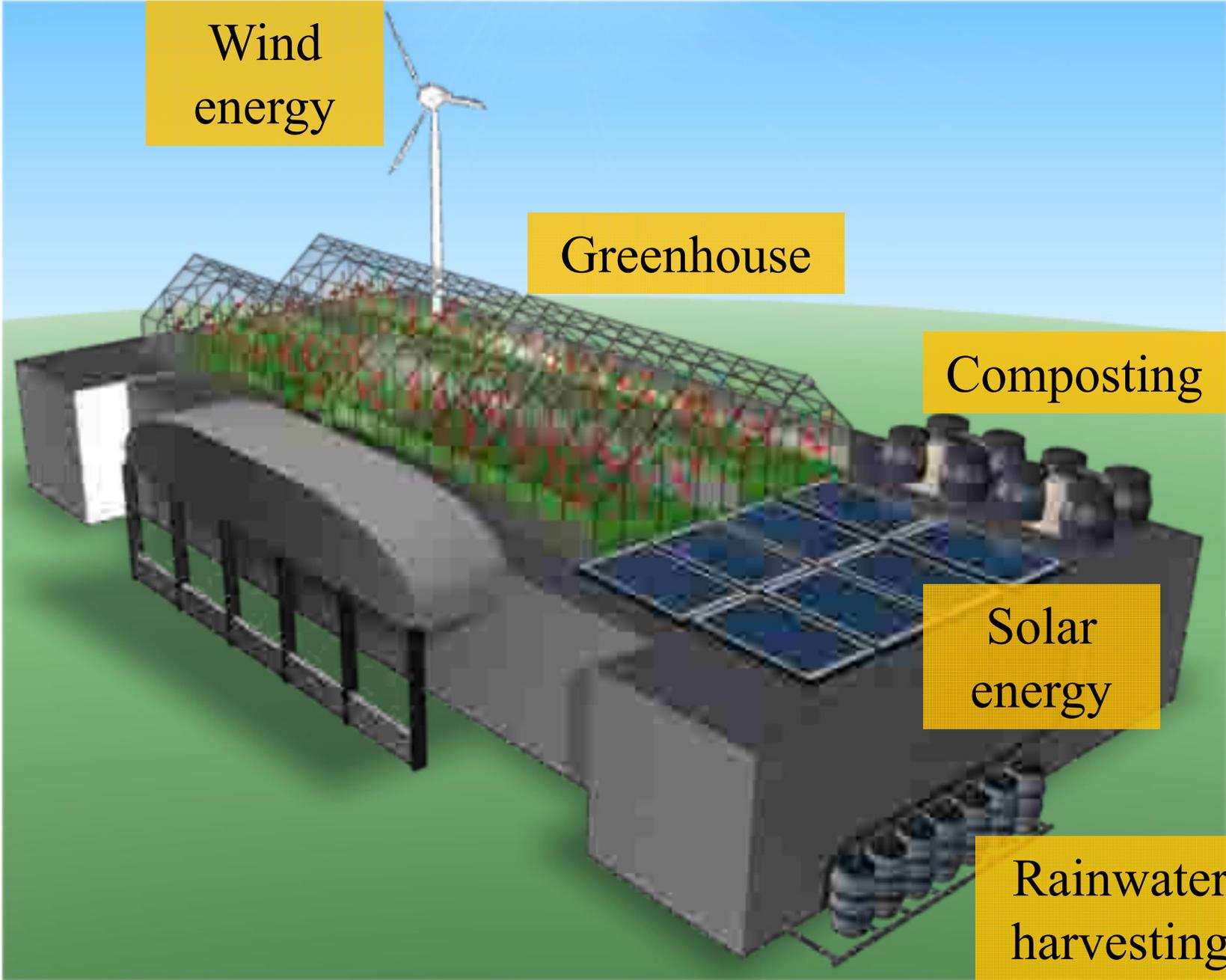
Water melon



Green beans

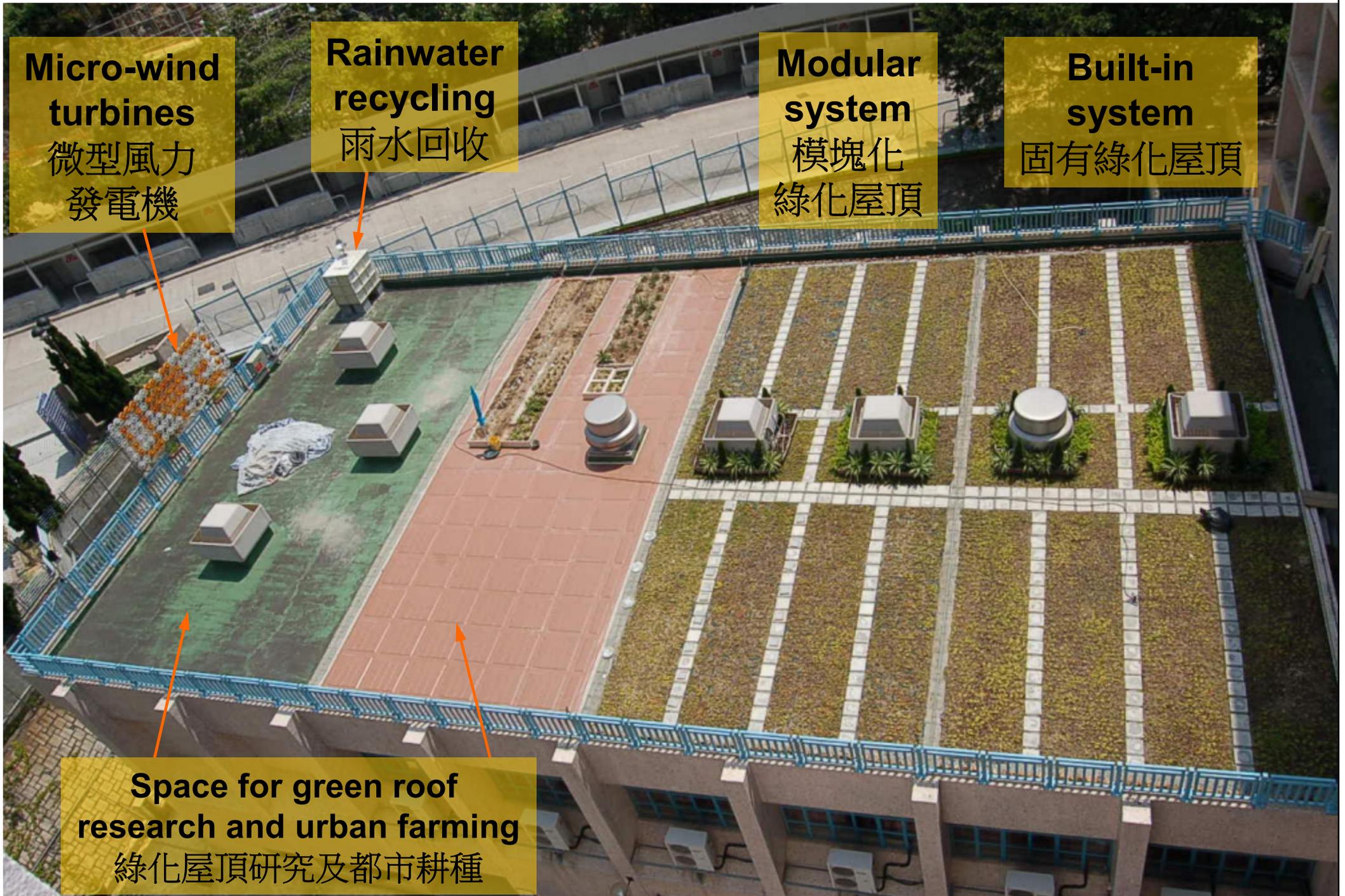


# Sustainable rooftop farming



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

# A green roof project with integrated systems



**Micro-wind turbines**  
微型風力發電機

**Rainwater recycling**  
雨水回收

**Modular system**  
模塊化綠化屋頂

**Built-in system**  
固有綠化屋頂

**Space for green roof research and urban farming**  
綠化屋頂研究及都市耕種



# Benefits of green roofs

- Green Building Assessment Methods
  - Such as LEED and BEAM Plus
  - They are becoming more and more popular and important
  - In fact, greening technology has significant implications to the assessment results
  - Green roofs can gain credit points in the green building assessment or rating schemes

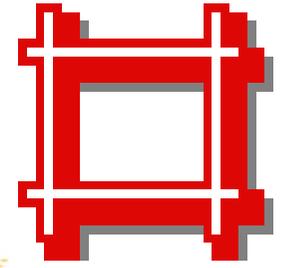
# LEED 2009 credit points of green roof systems

LEED criteria impacts:	Points
<i>Sustainable Sites (SS)</i>	
Credit 5.1 Site development – protect or restore habitat	1
Credit 5.2 Site development – maximize open space	1
Credit 6.1: Stormwater design – quantity control	1
Credit 6.2: Stormwater design – quality control	1
Credit 7.2: Heat island effect – roof	1
<i>Water Efficiency (WE)</i>	
Credit 1: Water efficient landscaping	2-4
<i>Energy and Atmosphere (EA)</i>	
Credit 1: Optimize energy performance	1
<i>Materials and Resources (MR)</i>	
Credit 4: Recycled content (roof components)	1
Credit 5: Local/Regional materials	1
Secondary credit impacts:	Points
<i>Water Efficiency (WE)</i>	
Credit 2: Innovative waste water technologies	2
Credit 3: Water use reduction	2-4
<i>Innovation in Design (IN)</i>	
Credit 1: Innovation in design	1-5

# BEAM Plus credit points of green roof systems

BEAM Plus criteria impacts:	Points
<p><i>Sites Aspects (SA)</i></p> <p>Perequisite: Minimum landscape area</p> <p>SA 5: Ecological impact</p> <p>SA 7: Landscaping and planters</p> <p>SA 8: Microclimate around buildings (roof)</p>	<p>Required</p> <p>1</p> <p>1-3</p> <p>1</p>
<p><i>Materials Aspects (MA)</i></p> <p>MA 7: Recycled materials (roof components)</p> <p>Credit 5: Local/Regional materials</p>	<p>1</p> <p>1-2</p>
<p><i>Energy Use (EU)</i></p> <p>EU 1: Reduction of CO<sub>2</sub> emission</p> <p>EU 2: Peak electricity demand reduction</p>	<p>1-15</p> <p>1-3</p>
<p><i>Water Use (WU)</i></p> <p>WU 1: Water efficient irrigation</p> <p>WU 6: Effluent discharge to foul sewers</p>	<p>1</p> <p>1</p>
<p>Secondary credit impacts:</p>	<p>Points</p>
<p><i>Water Use (WU)</i></p> <p>WU 4: Water recycling (rainwater)</p>	<p>1-2</p>
<p><i>Innovations and Additions (IA)</i></p> <p>IA 1: Innovative techniques</p>	<p>1-5</p>

# Design considerations



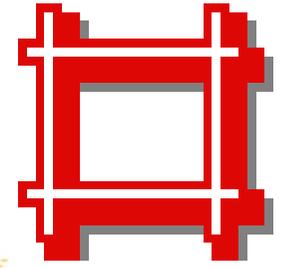
- Key factors for planning
  - Structural loading
  - Accessibility
  - Waterproofing
  - Drainage
  - Maintenance
- Other design considerations
  - Selection of plants
  - Stakeholders' involvement & support



# Major factors to consider when applying green roofs

Planning Requirements	<ul style="list-style-type: none"><li>- Functions and effects</li><li>- Structural loading</li><li>- Accessibility</li><li>- Site conditions (wind, shade)</li><li>- Water proofing condition</li><li>- Green building credits</li></ul>
Design Considerations	<ul style="list-style-type: none"><li>- Landscape design</li><li>- Irrigation &amp; water supply</li><li>- Stormwater drainage</li><li>- Plant species</li><li>- Wind design (e.g. typhoons)</li><li>- Sustainable technologies (e.g. solar)</li><li>- Food production (farming)</li><li>- Rainwater recycling</li><li>- Roof slope</li></ul>
Construction	<ul style="list-style-type: none"><li>- Safety issues (preventing falls)</li><li>- Vegetation planting method</li><li>- Testing &amp; monitoring</li></ul>
Maintenance	<ul style="list-style-type: none"><li>- Maintenance requirements</li><li>- Warranties</li><li>- External fire hazard</li><li>- Safety issues</li></ul>
Project Management	<ul style="list-style-type: none"><li>- Green building assessment</li><li>- Financial incentives</li><li>- Regulatory measures</li><li>- Contractual matters</li></ul>

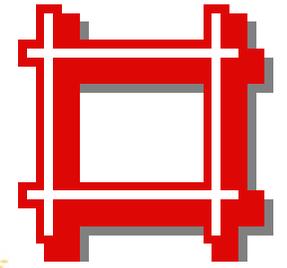
# Design considerations



- Choosing the site (on existing buildings)
  - Loading capacity
    - Weight of green roof, equipment & people
  - Government regulations
    - e.g. on height, railing
  - Sunlight and wind exposure
  - Access and safety
    - e.g. access to water, electricity
  - Specific needs
    - e.g. elderly and handicaps



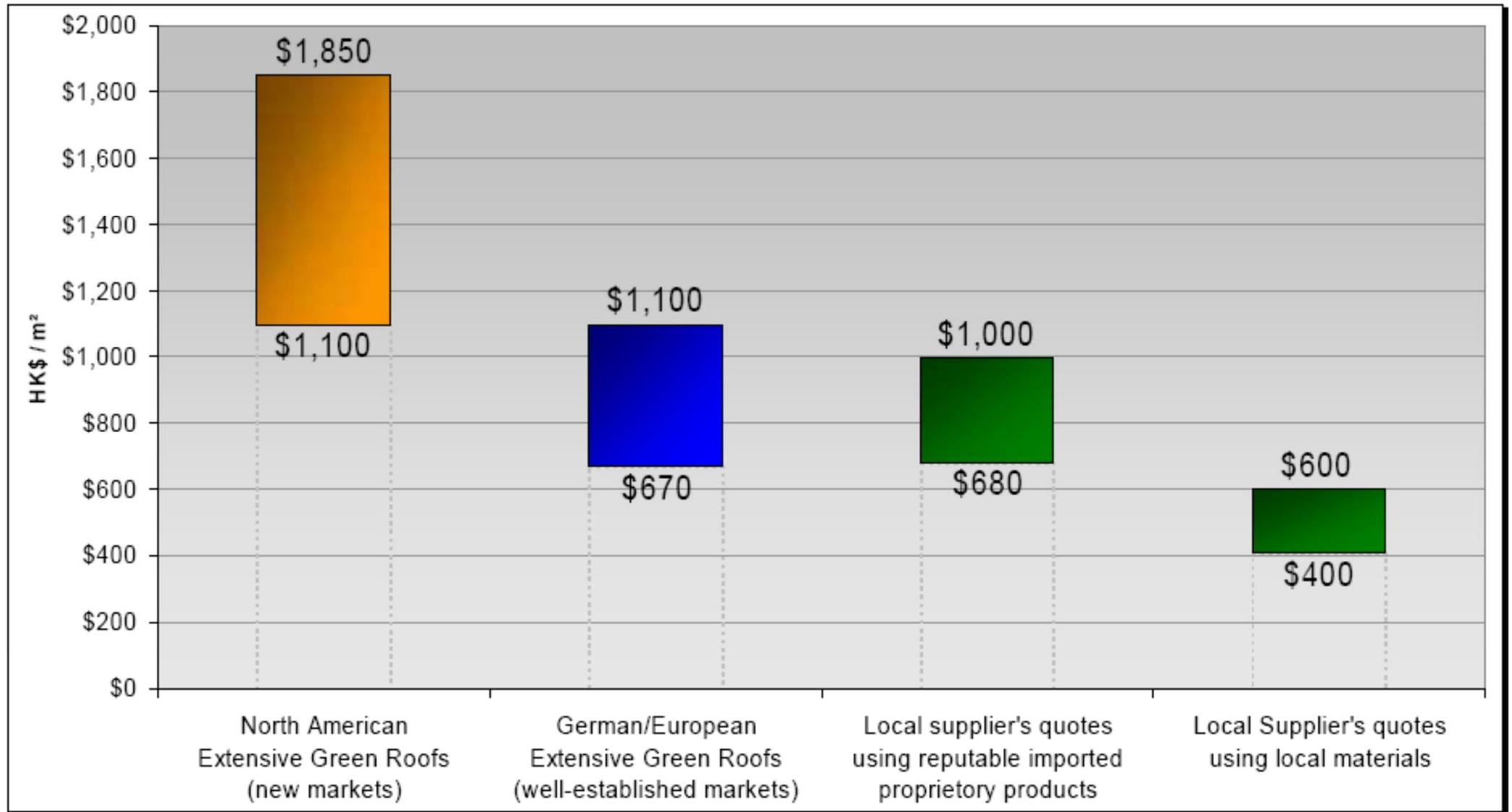
# Design considerations



- Cost breakdown of typical extensive greenroof (example from [www.greenrooftops.com](http://www.greenrooftops.com))
  - Soil substrate + drainage + mulch (48%)
  - Plant materials (31%)
  - Root barrier & waterproofing (16%)
  - Drip irrigation (5%)
- Planning and funding of green roofs requires an understanding of life-cycle costs
  - From cradle to grave; environmental benefits



# Capital cost rang comparison of extensive green roof



Note: All costs quoted in Hong Kong Dollars (US\$1 = HK\$7.8; CAN\$1 = HK\$8.1)

(Source: ArchSD - Study on Green Roof Application in Hong Kong Final Report)

# THANK YOU !!

