



Building greening and green roof systems



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Contents



- Building greening
- What are green roofs?
- Major types of green roofs
- Key components
- Benefits of green roofs
- Design considerations





Building greening

- **Greening** in a building may be in various approaches, forms, extent and locations
 - Landscape at ground level, on roof, in sky garden, on podium, on vertical surface or on building façade
- **Building greening** can improve city liveability:
 - Urban living condition, ecology, energy saving, quality of living
 - It is closely related to sustainability of the city

Common types of building greening



Potted plants



Fixed planters



Vertical planting in modular systems



Garden Furniture



Modular planting on roofs



Planting on facade



Fish/water ponds



Landscaping on roof/podium

Collapse of green roof in Hong Kong (20 May 2016)



Too much rainwater
and poor drainage.

(Comments on CityU green roof incident by Dr. Sam C. M. Hui: 講清講楚 (On the Record - TVB iNews) 2016-05-29
<http://news.tvb.com/programmes/ontherecord/574acbb46db28c8e75000000>)

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

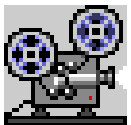
Building greening



- Skyrise greenery 天際綠化
 - Greening at the buildings or other structures beyond the ground level, such as
 - Roof greening (horizontal or inclined)
 - Vertical greening
 - Sky gardens, podium gardens
 - Terrace and balcony planting
 - Edge greenery
 - Multi-level greening
 - History
 - Hanging gardens of Babylon (600 B.C.)



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



(Video: Gift for a Queen - Hanging Gardens of Babylon (2:44) <http://youtu.be/Kfg1YE-BqTc>)

(Source: <http://weburbanist.com>; see also http://en.wikipedia.org/wiki/Hanging_Gardens_of_Babylon)

Building greening



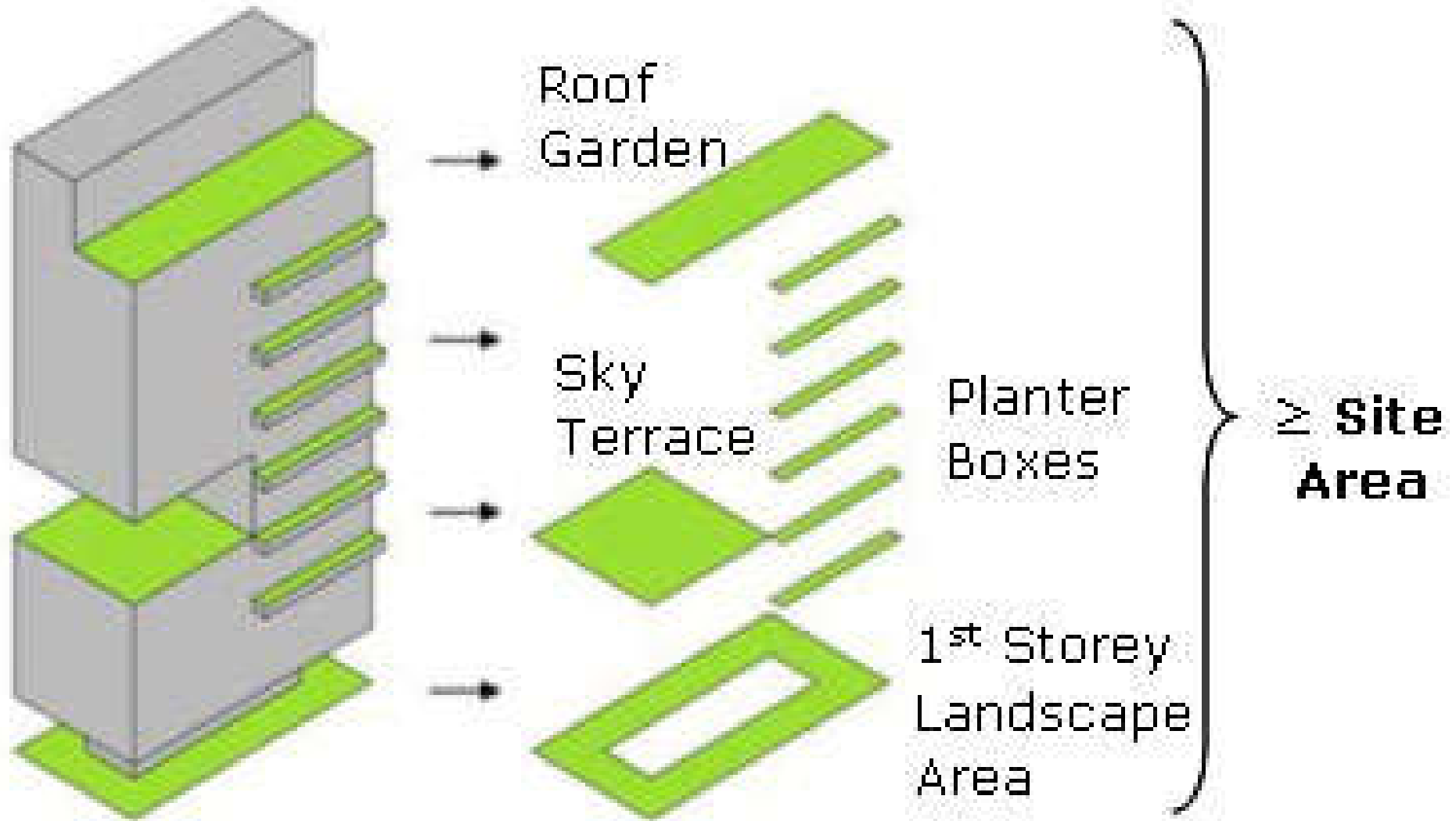
- Skyrise greenery in modern world
 - High-density urban cities
 - Highrise buildings and concrete jungle
 - Limited space for greening & relaxing



- Greenery in urban landscape
 - Make good use of existing spaces in urban areas
 - Integrate **nature** into our urban development
 - Create urbanscapes that are dynamic in more environmental and sustainable ways



Types of landscape areas from skysrise greenery



 Landscape Replacement Areas

What are green roofs?



- **Green Roofs:** roofs bearing vegetation –FLL*
 - “Living vegetation installed on the roofs”
 - “Vegetated roof” 植被屋頂
- **Green Roof System – Definition** 屋頂綠化系統
 - “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*
生態屋頂，活生屋頂
- 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)



ACROS Fukuoka Prefectural International Hall, Fukuoka, Japan (Source: 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)



Marina Barrage, Singapore (14,000 m²) (Source: www.skyrisegreenery.com)

Examples of green roofs in Hong Kong



Ocean Park Hong Kong



EMSD Headquarters



Parklane, Tsimshatsui



A school in San Po Kwong

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?!



Major types of green roofs



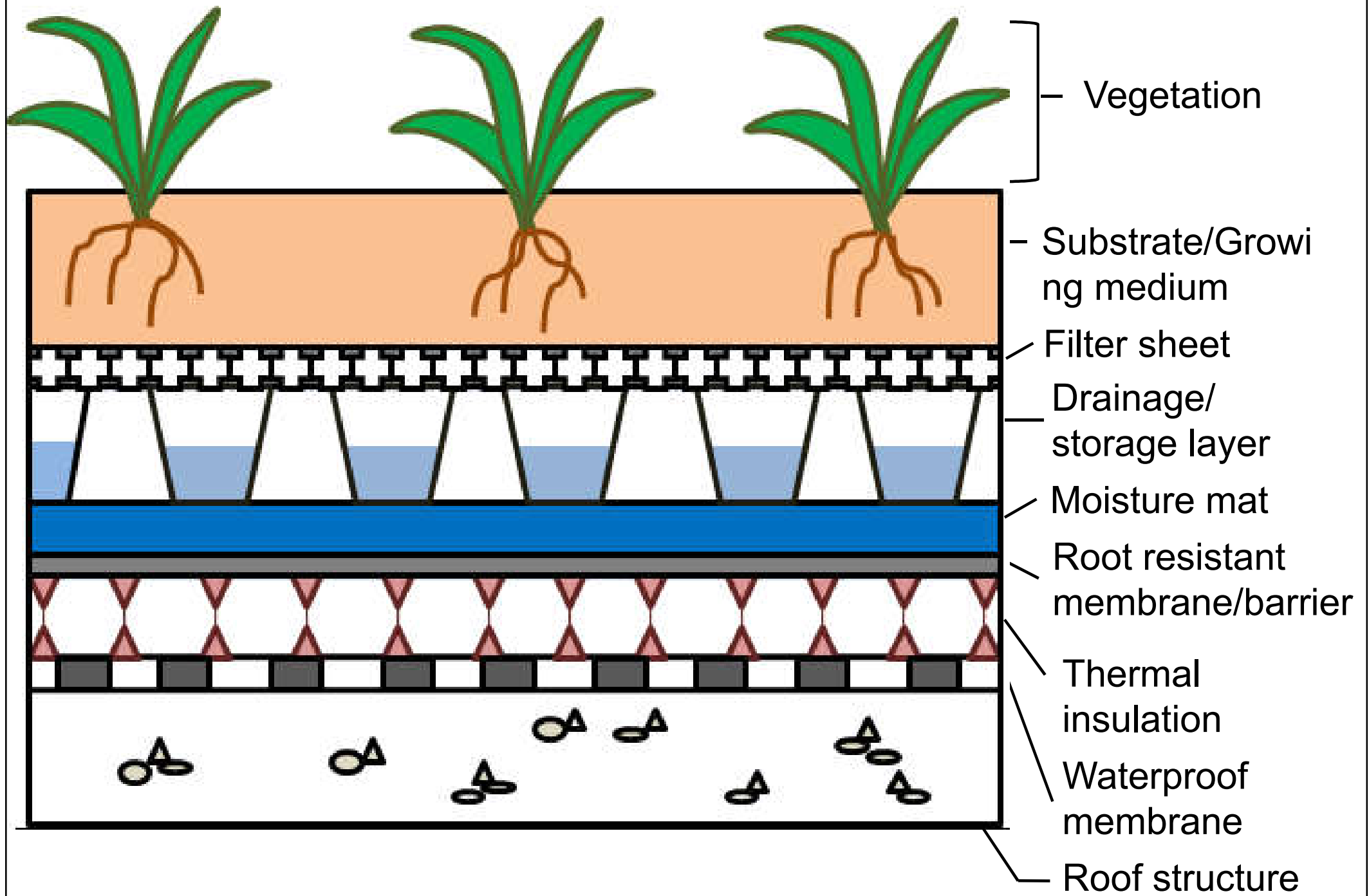
- Major types of green roofs (see Table 1)*
 - Extensive
 - Semi-intensive
 - Intensive
- Roof gardens: usually intensive greening with other features such as potted plants, pond, etc.
 - Examples in HK: podium gardens, sky gardens
- Classify green roof systems by basic design:
 - Built-in green roofs 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 ²)	Varies (170-290 kg/m ²)	High (290-970 kg/m ²)
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/m²)
- 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



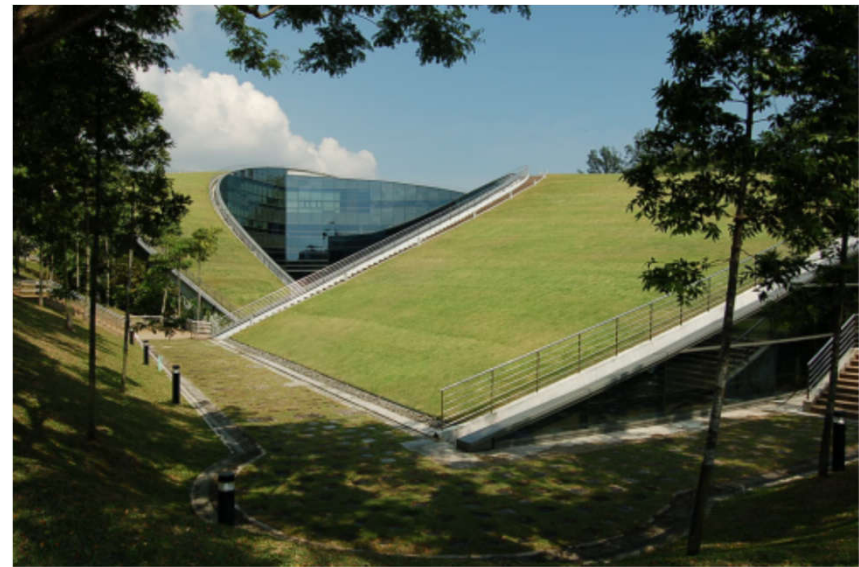
Carpark roof of public housing (modular green roof)



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)



Tray system (www.liveroof.com)



Sack system (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



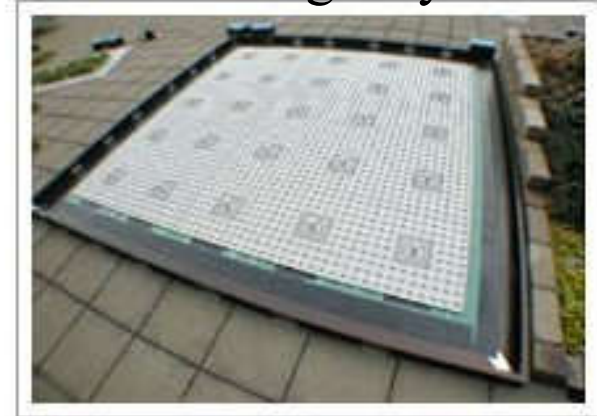
1 防水層施工直後

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

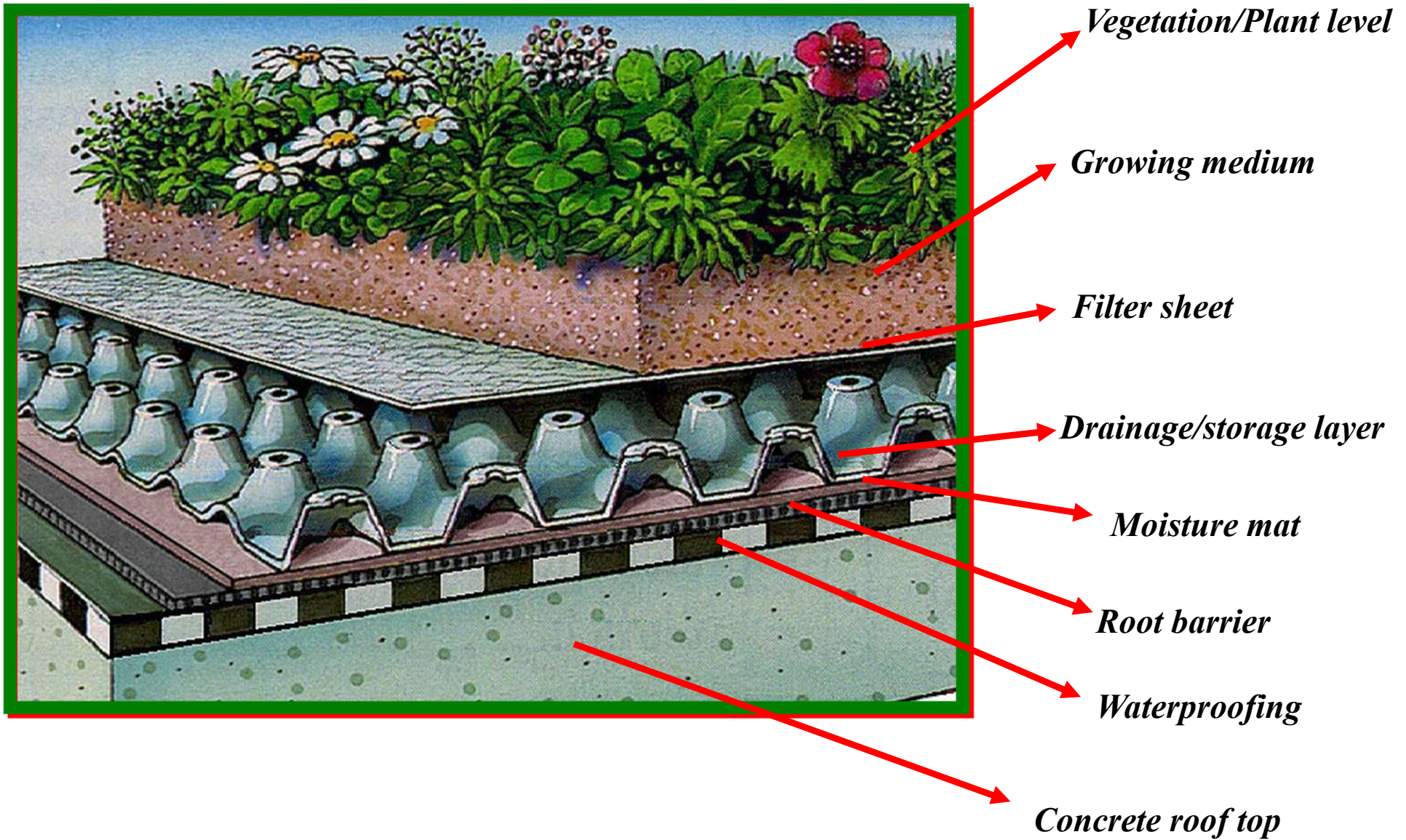


- Typically components of green roofs:
 - Vegetation (plants)
 - Growing medium or soil (substrate)
 - Filter sheet (geotextile fabric)
 - Drainage/storage layer
 - Moisture mat
 - Root repellent layer
 - Waterproof layer

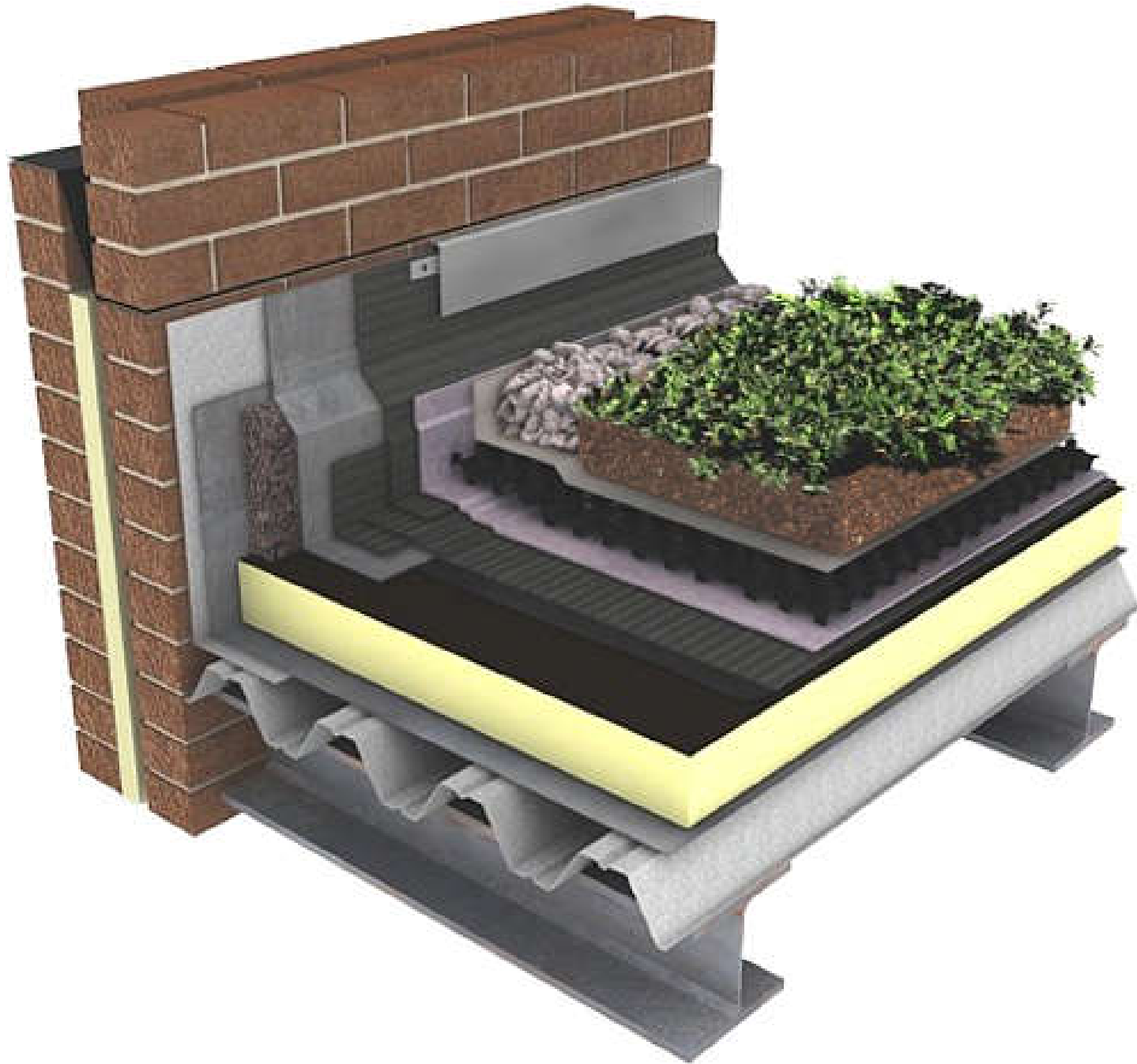
Green roof systems from Germany (left) and Japan (right)



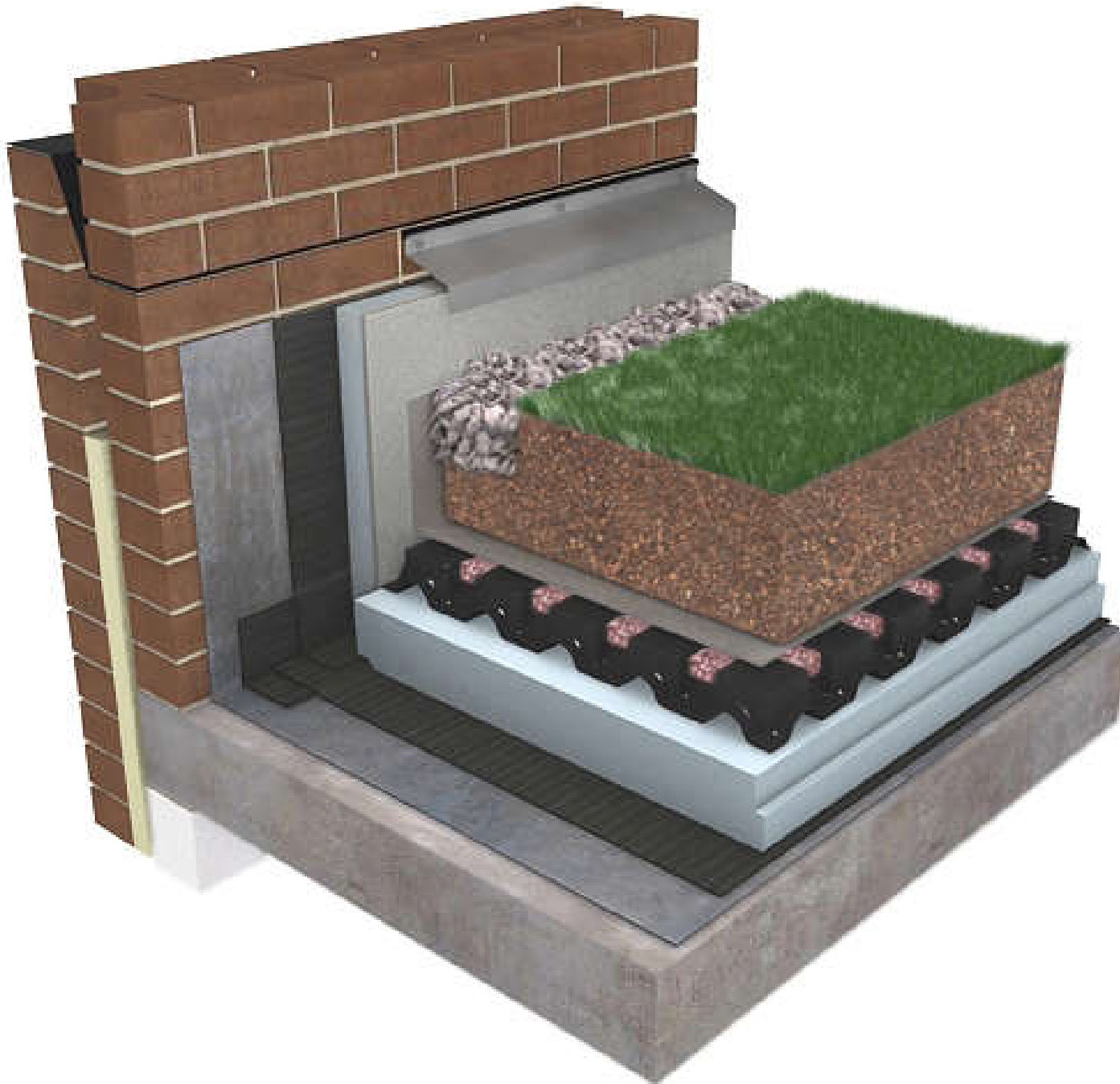
Green Roof Structure



Green roof on steel deck structure



Green roof on concrete structure



Key components



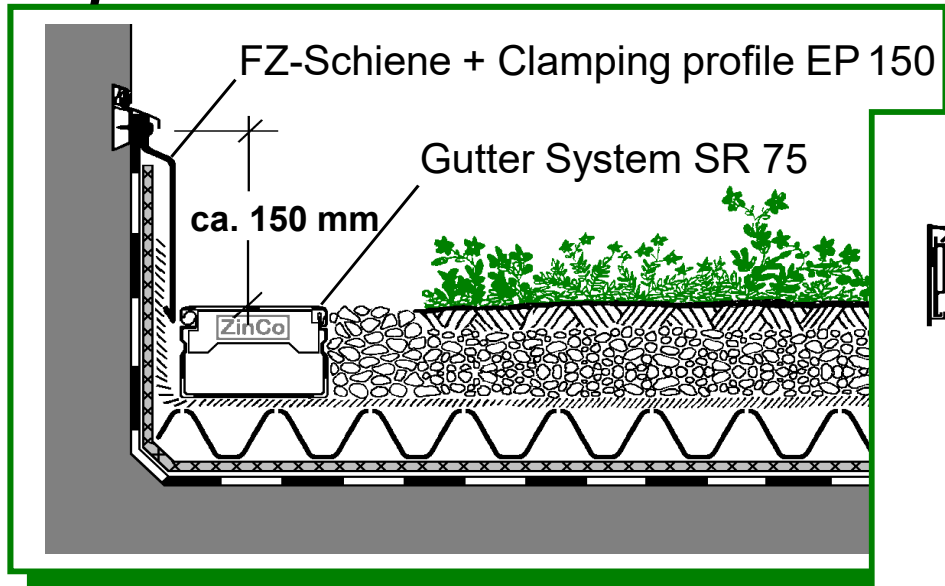
- Other components of green roofs:
 - Insulation
 - Membrane protection layer
 - Leak detection system
 - Ponds and pools
 - Irrigation system
 - Walkways
 - Curbs and borders
 - Railings
 - Lighting



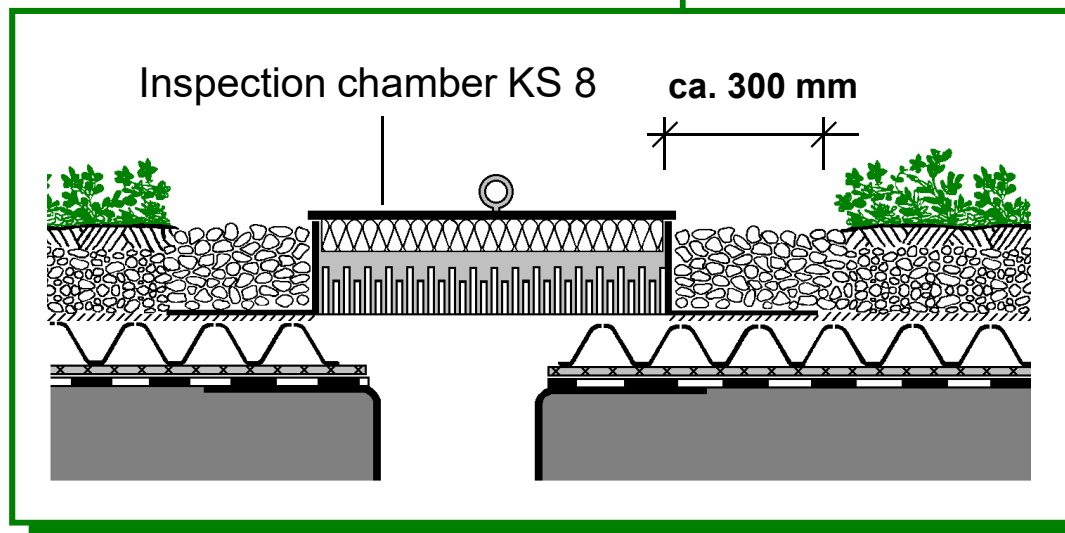
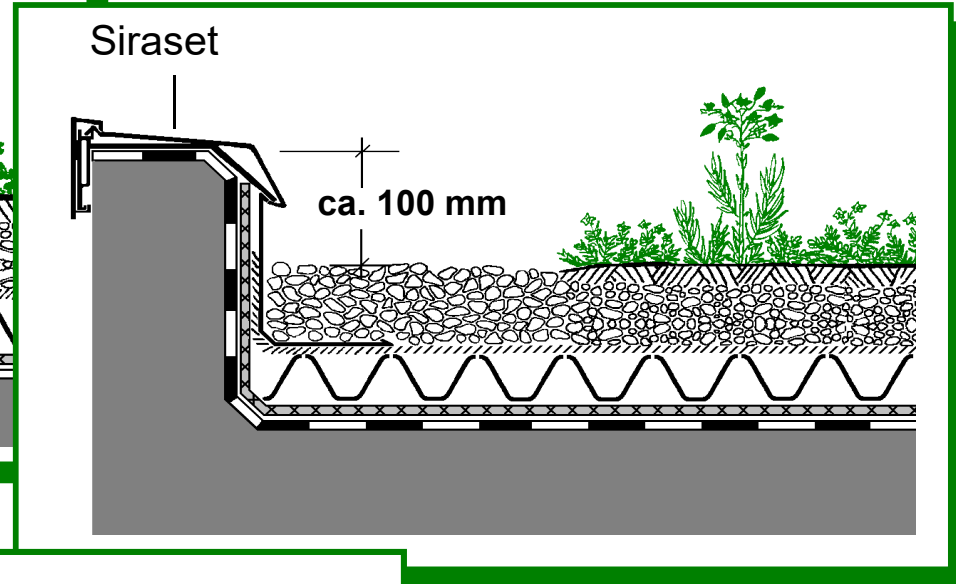
(Source: www.tajima-roof.jp)

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. Social 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

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

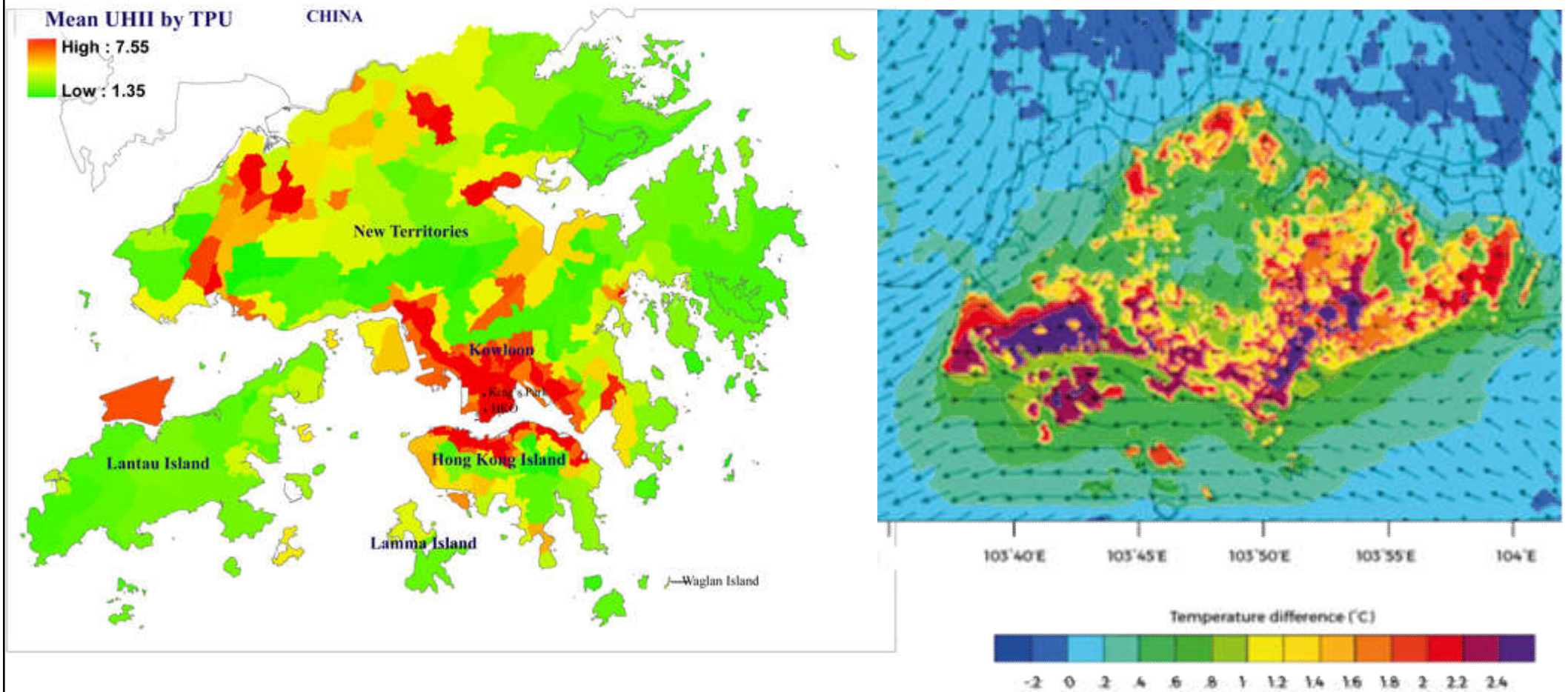
Benefits of green roofs



- 1. Environmental benefits:
 - Mitigate urban heat island
 - Improve air quality
 - Stormwater management
 - Create natural habitat
 - Increase biodiversity
 - Insulate and absorb sound
 - Possible urban farming



Urban heat island effects in Hong Kong and Singapore



(Source: Goggins WB, Chan EYY, Ng E, Ren C, Chen L (2012) Effect Modification of the Association between Short-term Meteorological Factors and Mortality by Urban Heat Islands in Hong Kong. PLOS ONE 7(6): e38551. <http://doi.org/10.1371/journal.pone.0038551SCMP> and Hong Kong Observatory and <http://www.coolingsingapore.sg/uhi-singapore/>)



GREEN ROOF



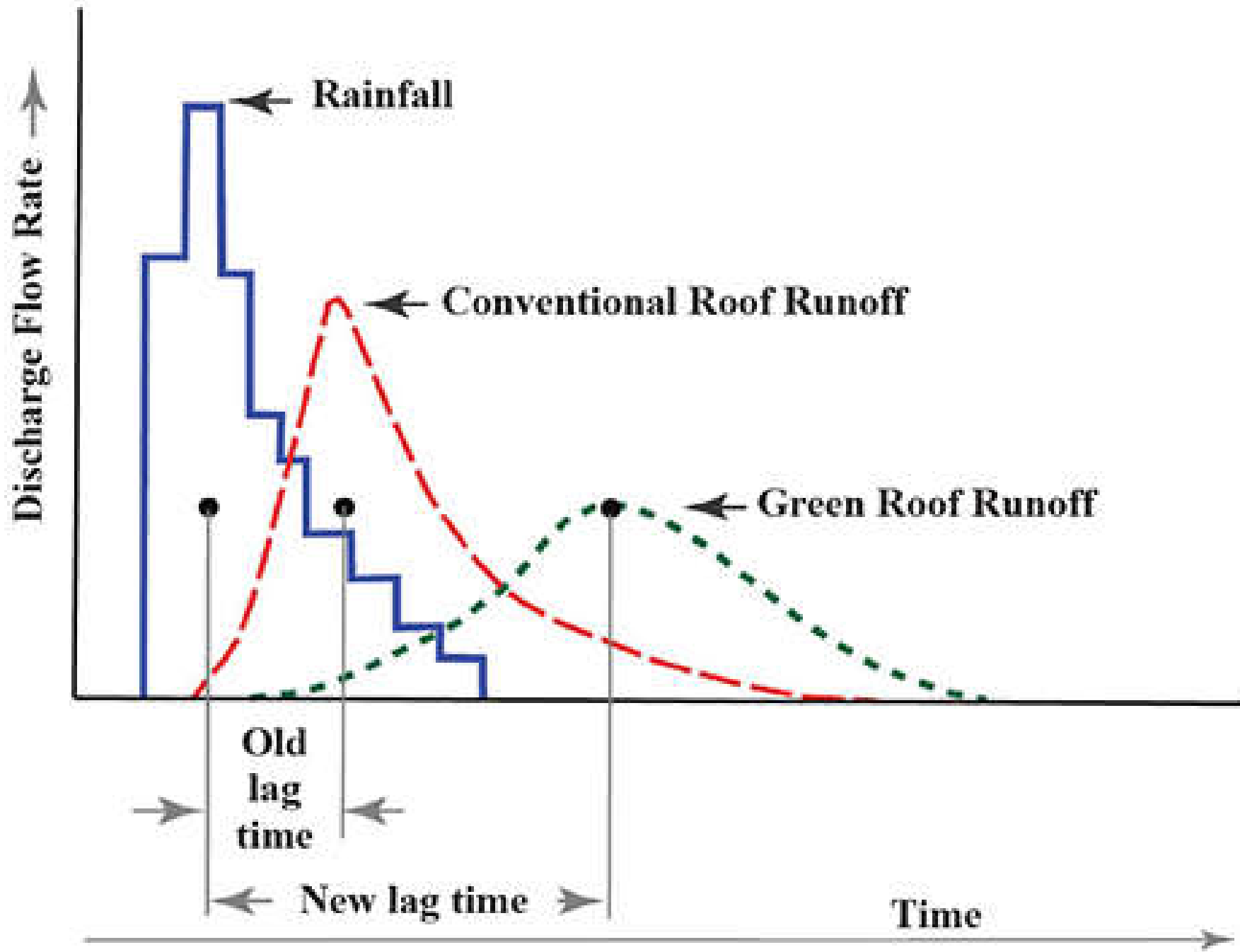
TRADITIONAL ROOF



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)

Typical rainfall and runoff hydrographs for conventional and green roofs



Benefits of green roofs



- 2. Economic benefits:

- Improve roof durability
- Increase roof material lifetime
- Reduce building cooling load and energy costs
- Provide open space & increase property value
- Attracts buyers and tenants
- Attracts and retains employees
- Green building credit points & image





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



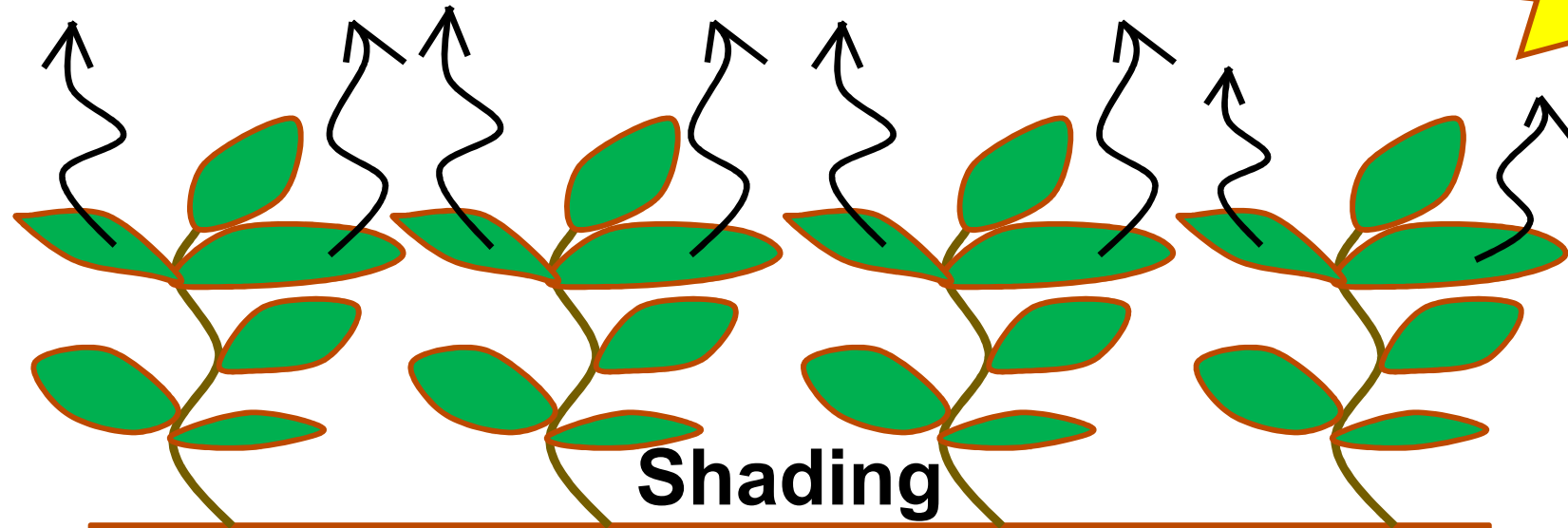
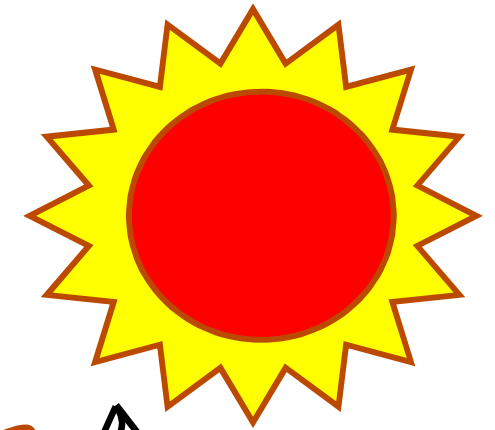
Benefits of green roofs

- 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

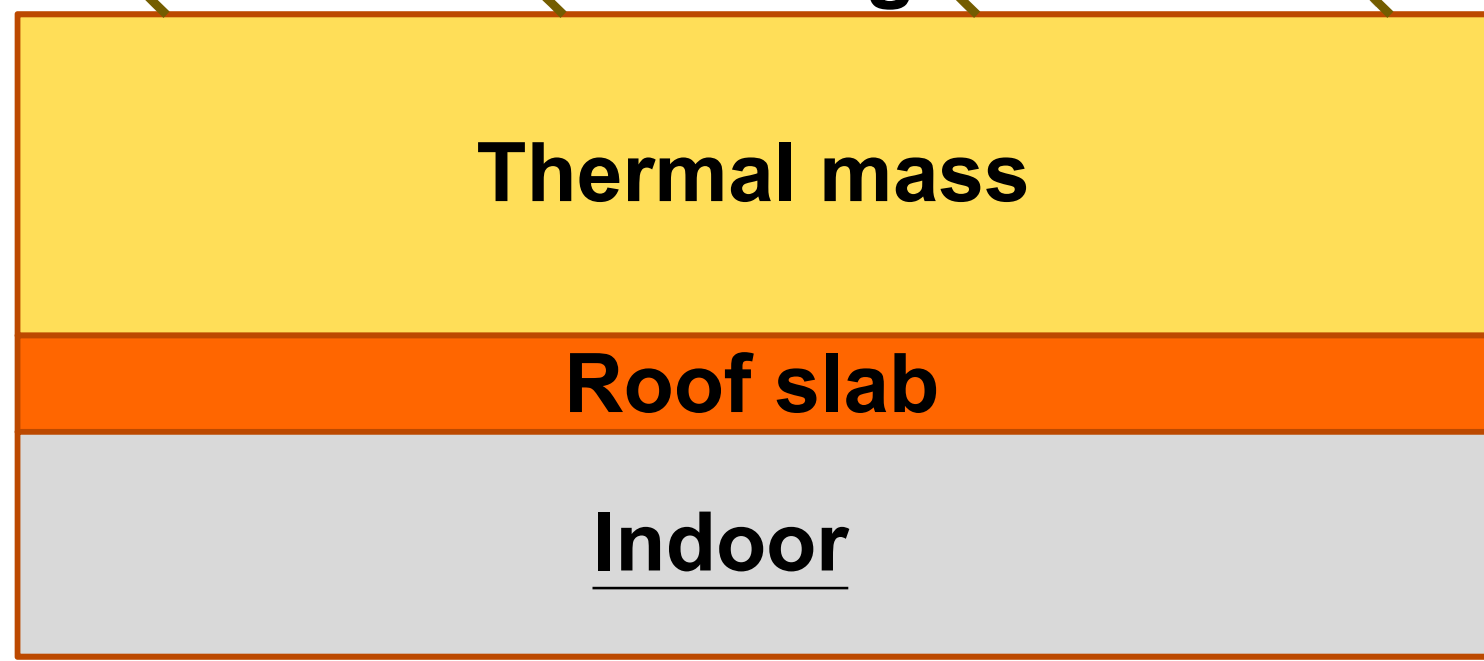
Thermal properties of green roofs

Outdoor

Evapo-transpiration



Shading



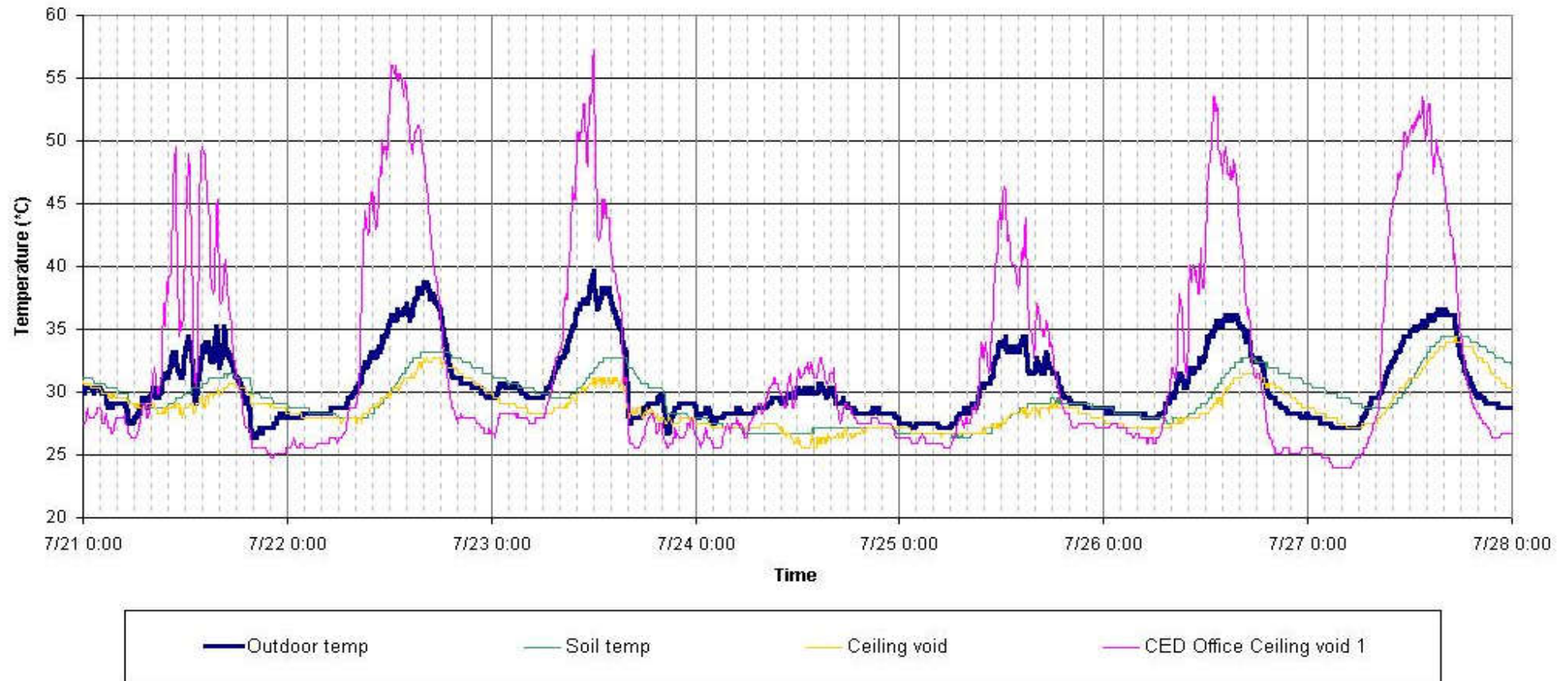
Insulating property

Thermal mass

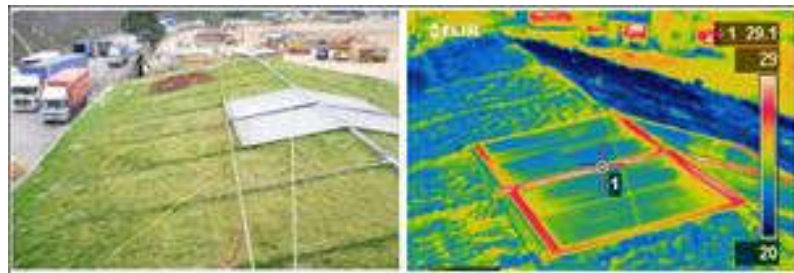
Roof slab

Indoor

Green roof research at a construction site office in Hong Kong



Infrared pictures:



Green roof



Conventional roof

Heat and mass transfer equations for green roof

Heat and mass transfer in the structural material

(a) Heat transfer:
$$\frac{dT}{dt} = a_c \frac{\partial^2 T}{\partial z^2} + \frac{\varepsilon \lambda}{c_c} \frac{\partial q_c}{\partial t}$$

(b) Mass transfer:
$$\frac{dq_c}{dt} = \alpha_m \frac{\partial^2 q_c}{\partial z^2}$$

Heat and mass transfer in the air

(a) Heat transfer:
$$\frac{dT}{dt} = \alpha_a \frac{\partial^2 T}{\partial z^2} + \frac{(h_a - h_b)}{c_{pa} \rho_a} I_1 - \left(\frac{c_1 - c_2}{c_p} \right) \left(D \frac{\partial q_a}{\partial z} \frac{\partial T}{\partial z} \right)$$

(b) Mass transfer:
$$\frac{dq_a}{dt} = D \frac{\partial^2 q_a}{\partial z^2} + \frac{1}{\rho_a} I_1$$

Heat and mass transfer in the soil

(a) Heat conduction:
$$\frac{dT}{dt} = \frac{1}{\rho_g c_G} \frac{\partial}{\partial z} \left(K_s \frac{\partial T}{\partial z} \right)$$

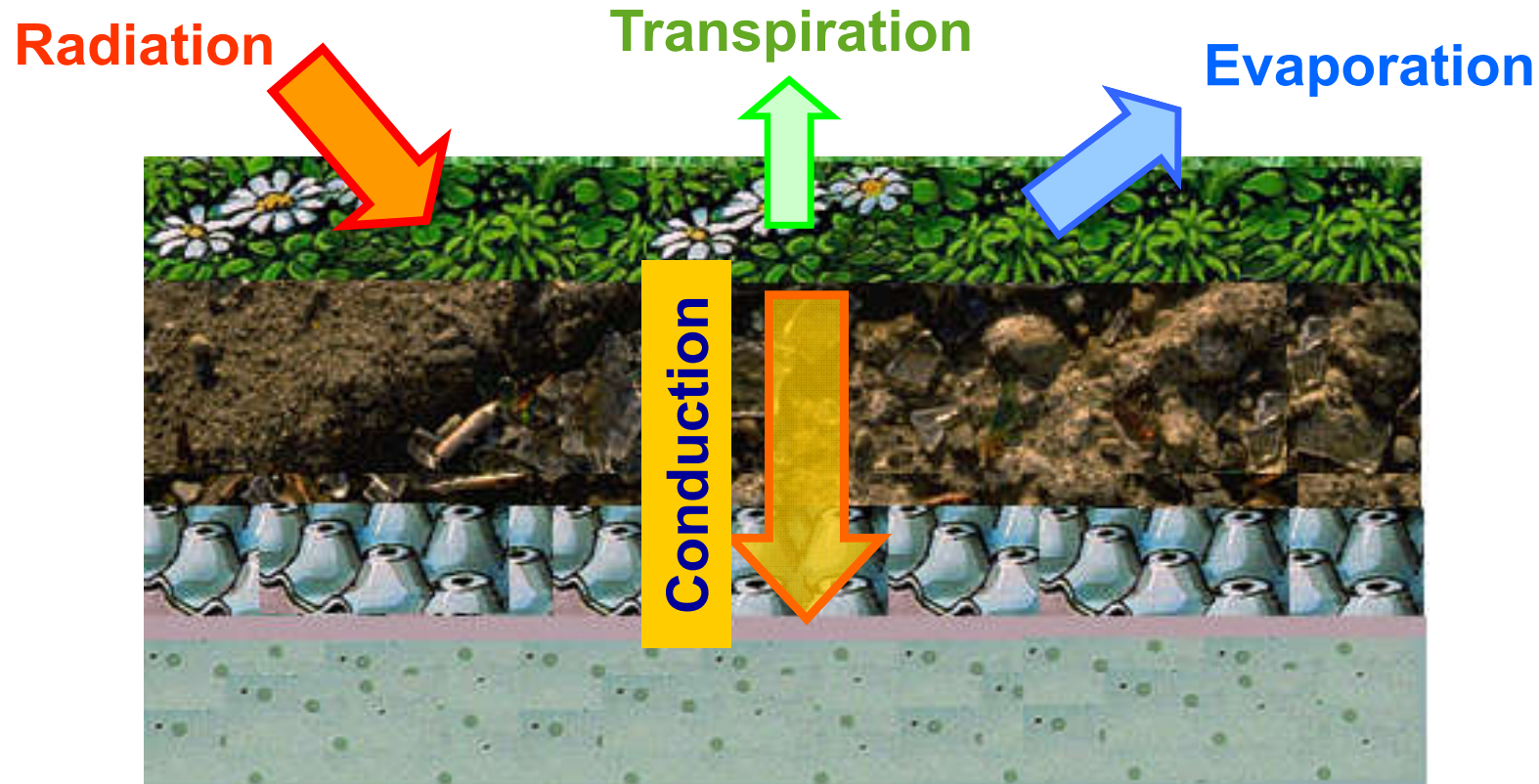
(b) Mass transfer:
$$\frac{d\omega_g}{dt} = \frac{\partial}{\partial z} \left(K_g \left(\frac{\partial \psi_p}{\partial z} + 1 \right) \right) = \frac{\partial}{\partial z} \left(D_g \frac{\partial \omega_g}{\partial z} + K_g \right)$$

Heat and mass transfer in the canopy

(a) Air temperature:
$$\frac{dT_a}{dt} = \alpha_a \frac{d^2 T_a}{dz^2} + \frac{1}{r_{aH}} \frac{\partial T}{\partial x} \Big|_1 - \frac{c_1 - c_2}{c_{pa}} D_a \frac{\partial q_a}{\partial z} \frac{\partial T_a}{\partial z} \Big|_a$$

(b) Vapour diffusion:
$$\frac{dq_a}{dt} = D_a \frac{d^2 q_a}{dz^2} + \frac{1}{r_a + r_s} (e_s(T_1) - e_a)$$

Thermal modelling of green roofs 綠化屋頂的導熱建模



Radiation: $R_n = R \exp(-k_s LAI)$

Evapo-transpiration: $q'' = -2LAI \frac{\rho C_p}{\gamma(r_e + r_i)} \left(\frac{w \mathcal{R} T}{h_m} \right)$

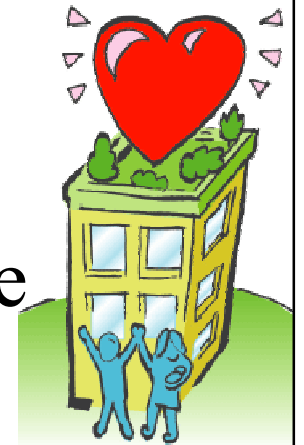
Conduction: $q'' = (T_{s1} - T_{s2}) / R_{total}$

Benefits of green roofs



• 3. Social and aesthetic benefits:

- Aesthetic for urban space (natural outlook)
 - Relief from concrete construction
- Provide usable green space for sports & leisure
 - Community gardens, recreational/relaxing space
- Community participation for greening
 - Such as urban agriculture
- Enhance local employment
 - For greenery installation & maintenance

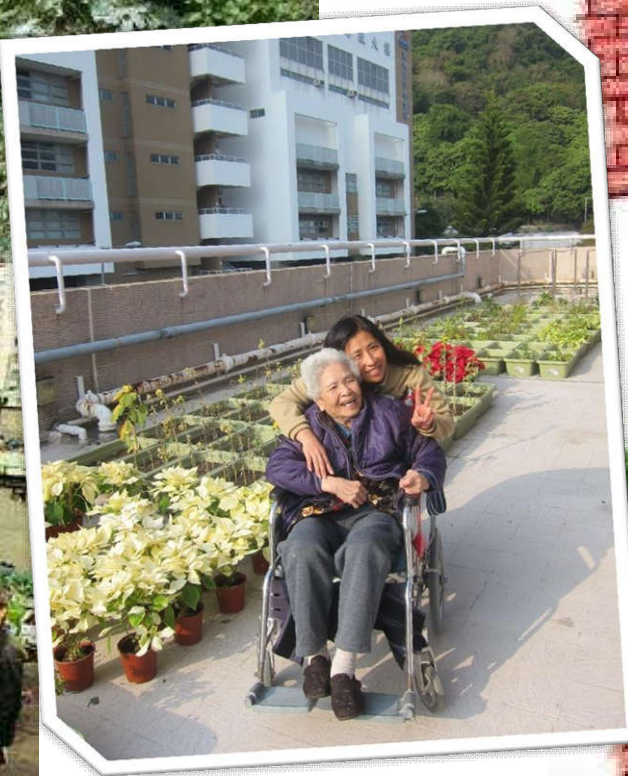


Benefits of green roofs



- 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



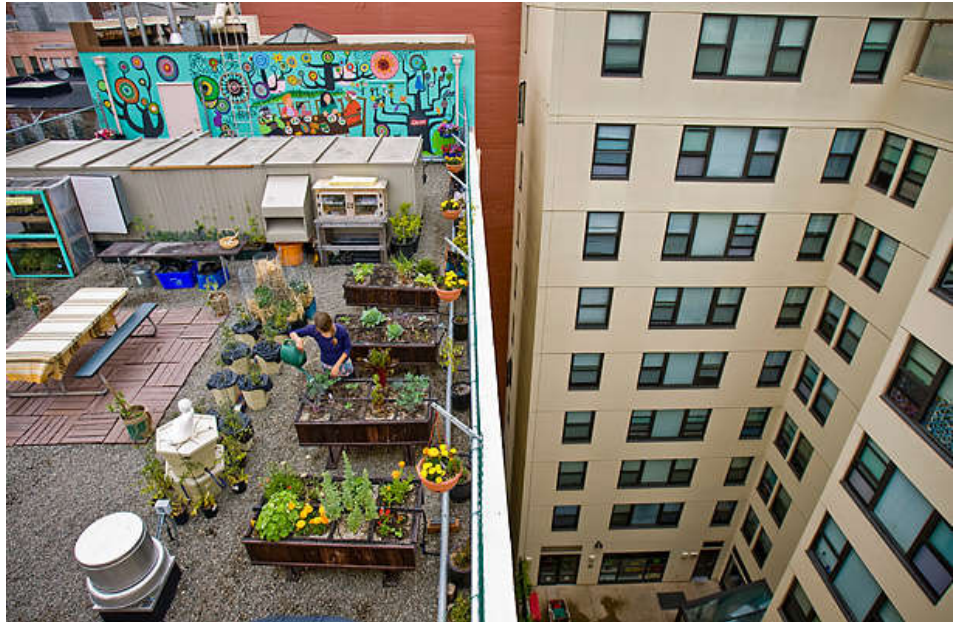
Bangkok, Thailand (with rice and fruits)



Tokyo, Japan (rooftop greenhouse)



London, UK (with bee keeping)



San Francisco, USA (for kitchen/restaurant)

Urban farming on green roofs



Farming on the roof



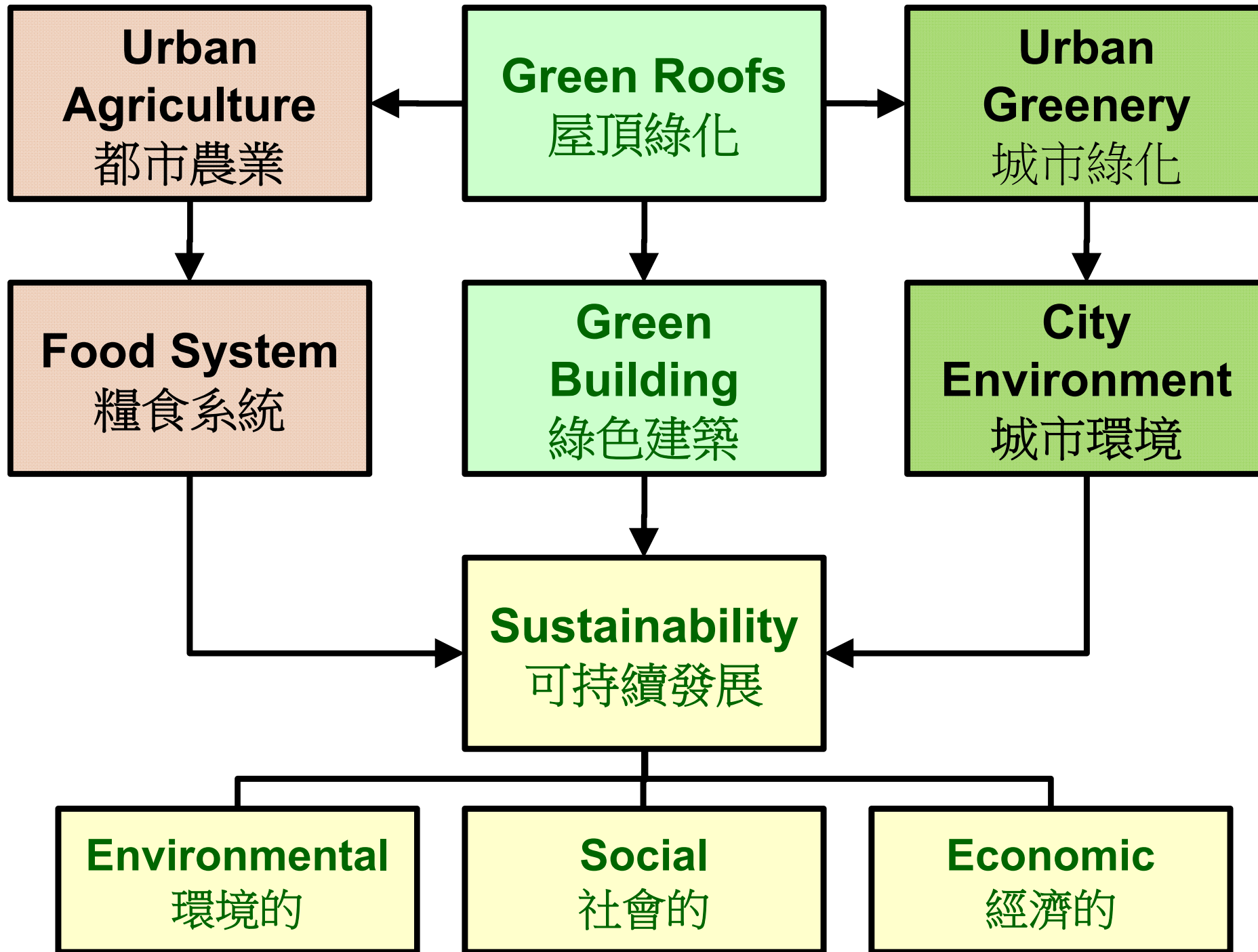
Vegetables and herbal plants



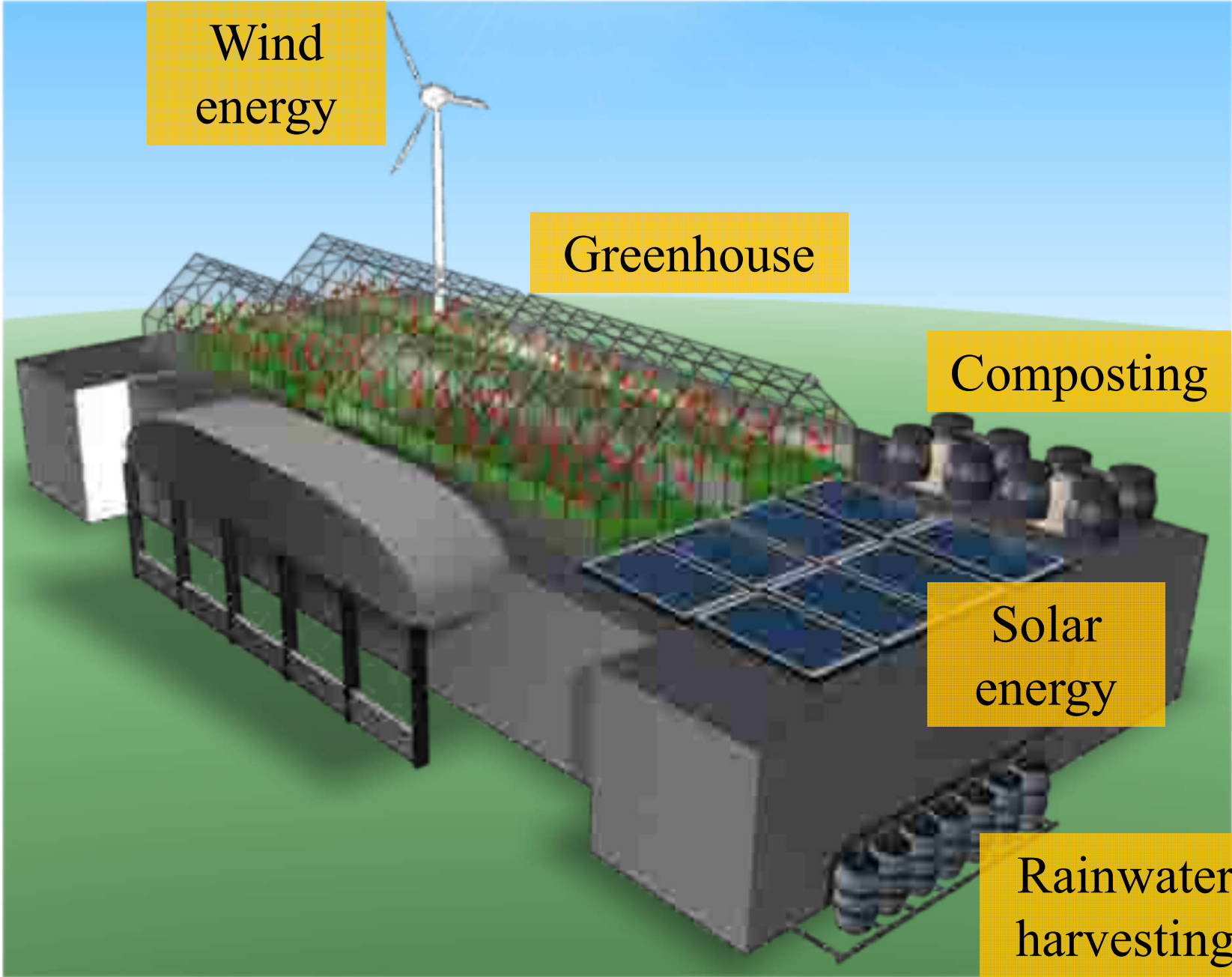
Water melon



Green beans

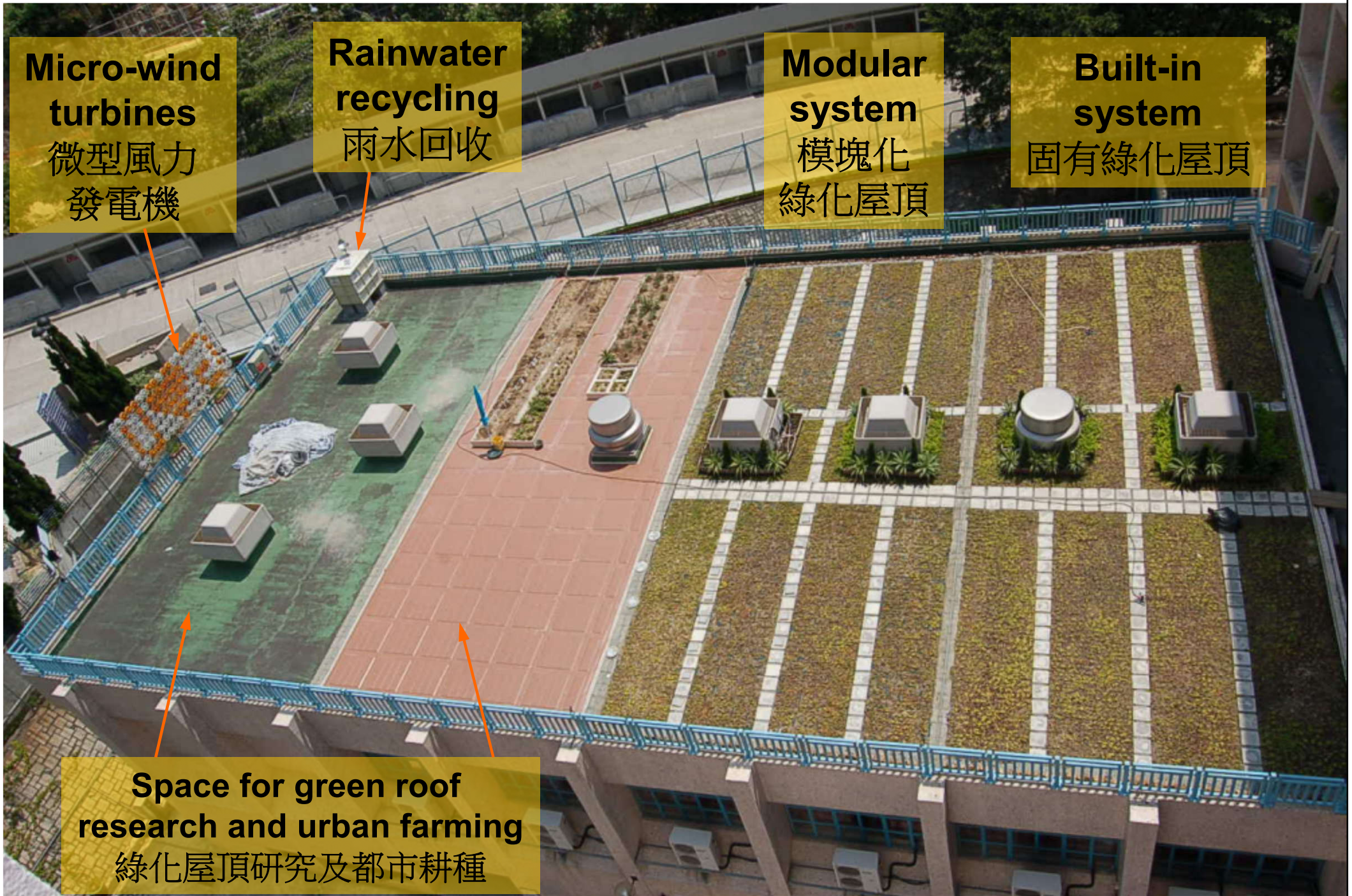


Sustainable rooftop farming



(Source: 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 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)	1-2
Credit 5: Local/Regional materials	1-2
<i>Secondary credit impacts:</i>	
<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

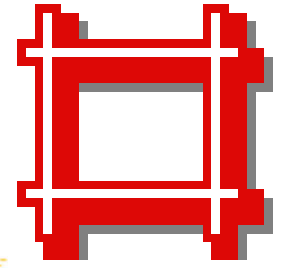
Source: extracted from USGBC (2009)

BEAM Plus credit points of green roof systems

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

Source: extracted from BEAM Society (2009)

Design considerations



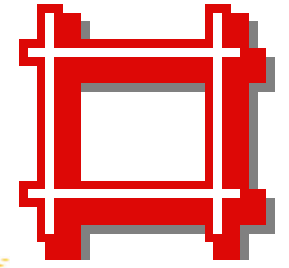
- Key factors for planning
 - Structural loading
 - Accessibility
 - Waterproofing
 - Drainage
 - Maintenance
- Other design considerations
 - Selection of plants
 - Stakeholders' involvement & support



Major factors to consider when applying green roofs

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

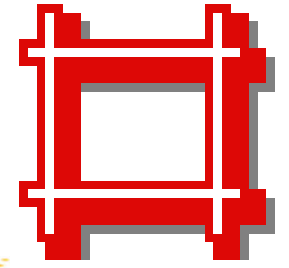
Design considerations



- 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



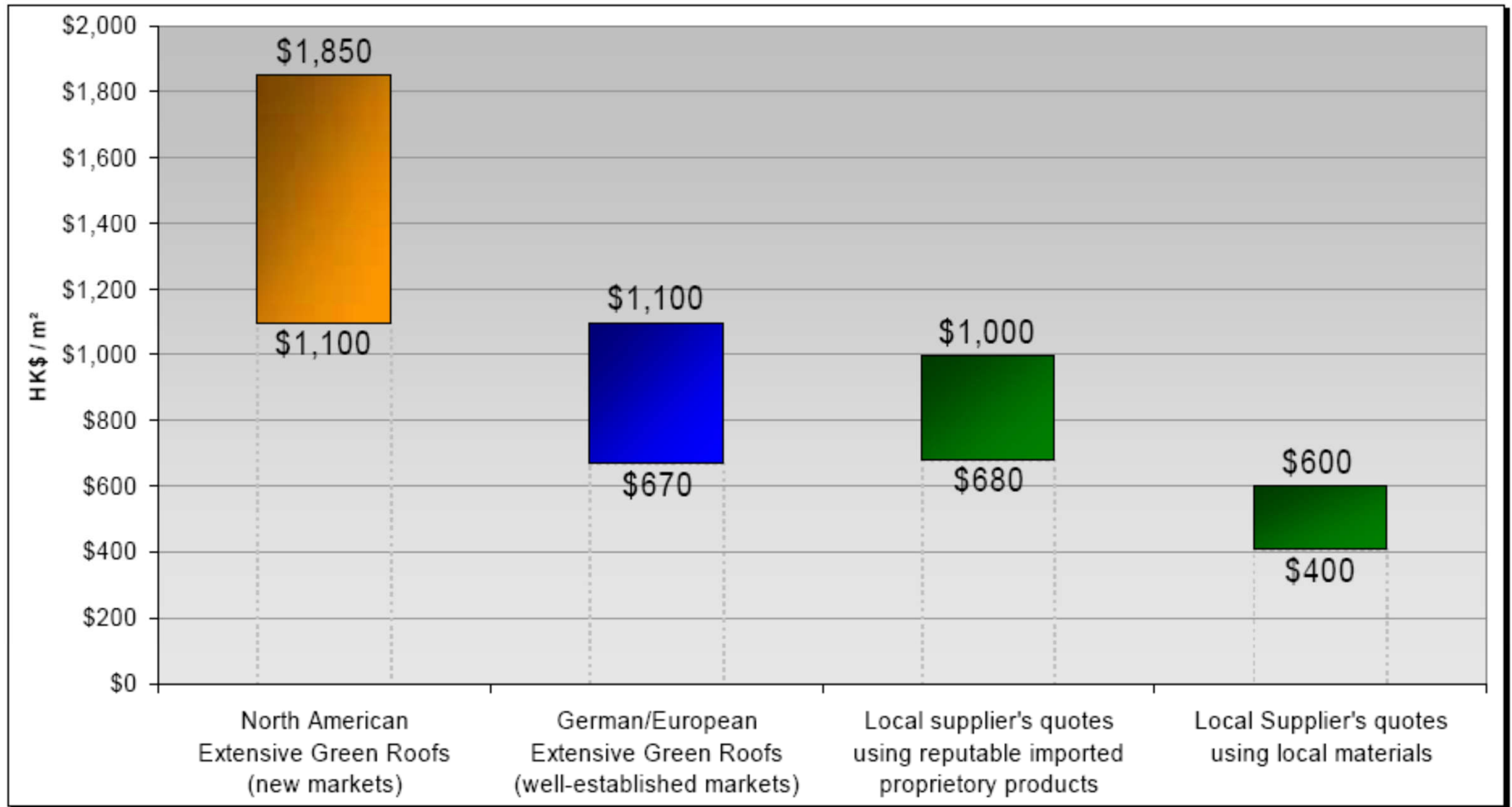
Design considerations



- Cost breakdown of typical extensive greenroof (example from www.greenrooftops.com)
 - 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

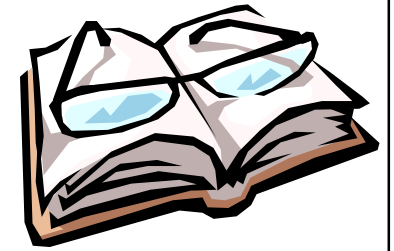


Capital cost rang comparison of extensive green roof



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)



Further reading

- Video: Do Cities Need More Green Roofs? | NPR (3:49) <https://youtu.be/FIJoBhLnqko>
- Introductory Guide on Greening in Buildings (Buildings Department)
 - http://www.bd.gov.hk/english/documents/pamphlet/IGG_e.pdf
- Skyrise Greenery
 - http://www.greening.gov.hk/en/green_technologies/skyrise.html
- Hui, S. C. M., 2016. Green roof development in Hong Kong, *Hong Kong Engineer*, 44 (7).
 - <http://www.hkengineer.org.hk/program/home/article.php?aid=8841&volid=193>