ASHRAE Distinguished Lecturer Program
Seminar, April 2011

Green Roof Systems and Technology



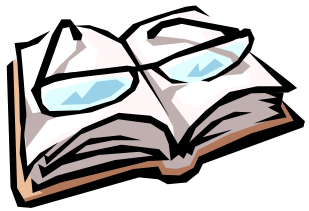
1911-2011

Dr. Sam C. M. Hui
Department of Mechanical Engineering
The University of Hong Kong
E-mail: cmhui@hku.hk

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

* FLL = Research Society for Landscape Development and Landscape Design (Forschungsgesellschaft Landschaftsentwicklung Land-schaftsbau e.V.) (www.fll.de)

Examples of green roofs in the world

Solar Campus Jülich, Germany (11 Jul 2001)

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

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

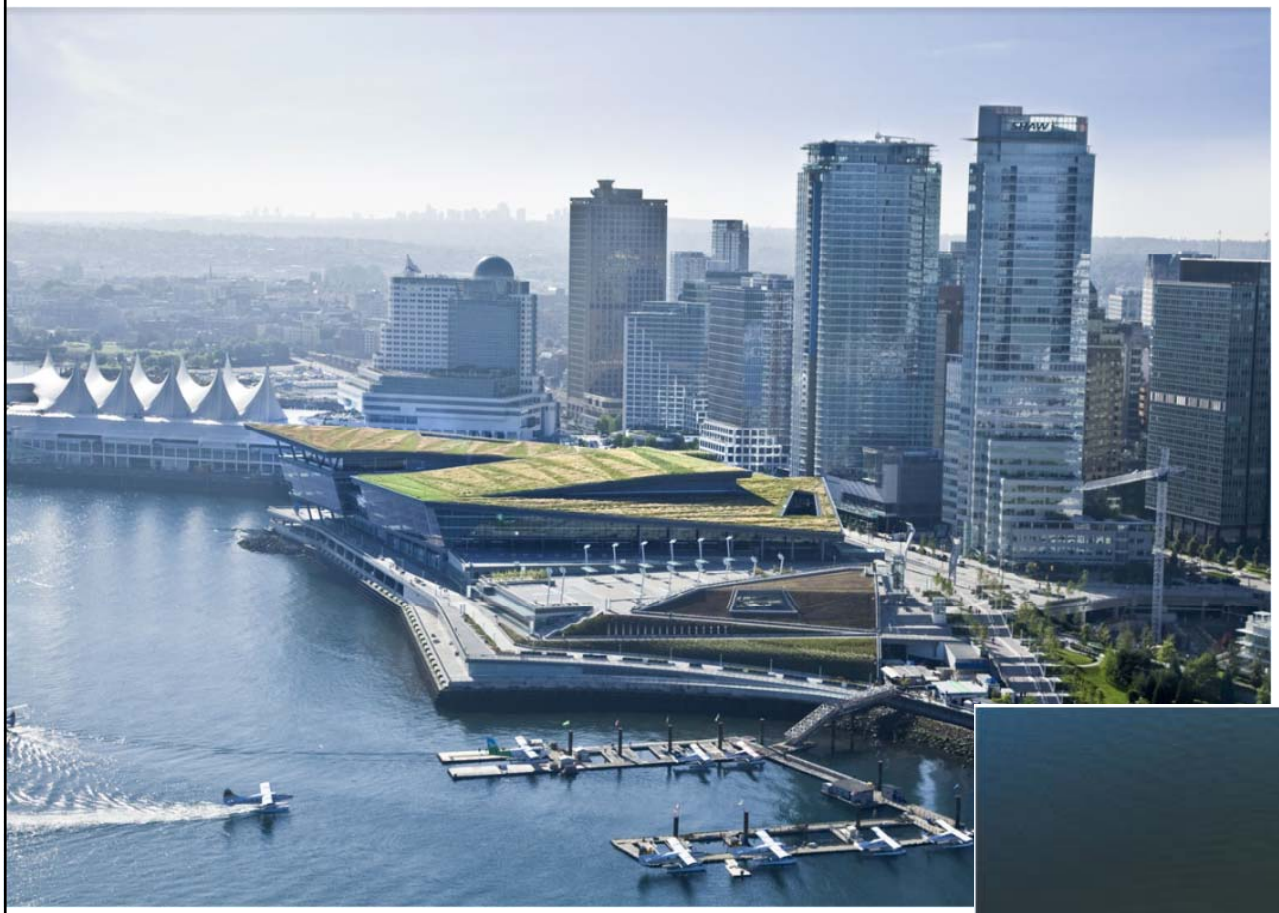
Beitou Taipei Library, Taiwan (6 Aug 2007)

(Photos taken by Dr Sam C M Hui)

Green roof at the Ford Truck Assembly Plant at Dearborn, Michigan, USA (41,000 sq.m)

(Source: www.greenroofs.com)

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



(Source: http://lmnarchitects.com)

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)

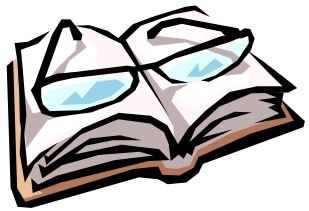
A landscape podium garden in North Point, Hong Kong

(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)

Brief history of green roofs

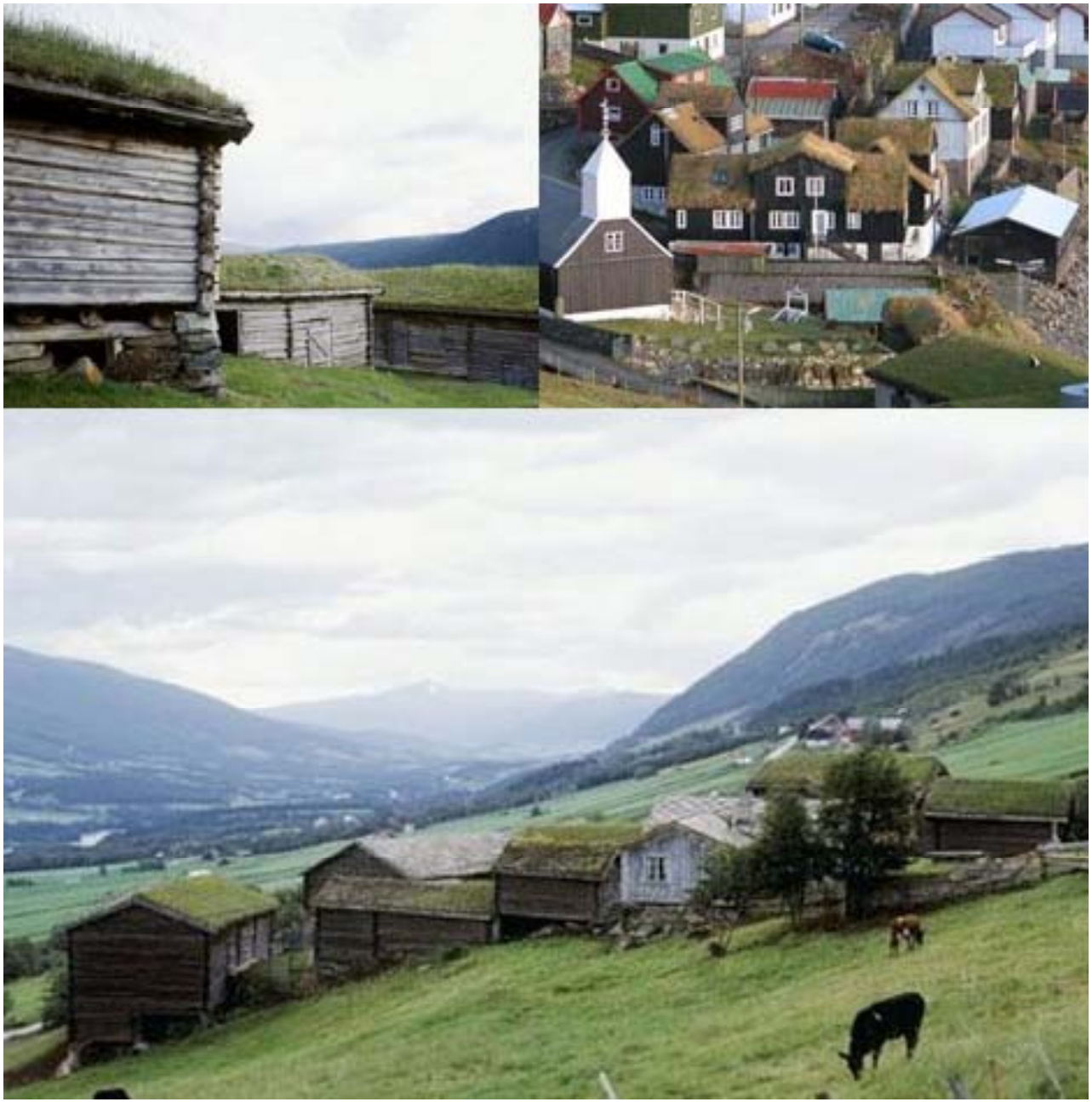


- Green roofs are not a new phenomenon
  - Hanging Gardens of Babylon (600 B.C.)
  - Traditional houses in China and Japan
  - Vikings' grass-covered green roofs on residential and farm houses in Scandinavia (1600 D.C.)
  - Terraced green roofs in Germany & Switzerland (1960's)
- Countries with mature 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)

(Source: http://weburbanist.com)

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

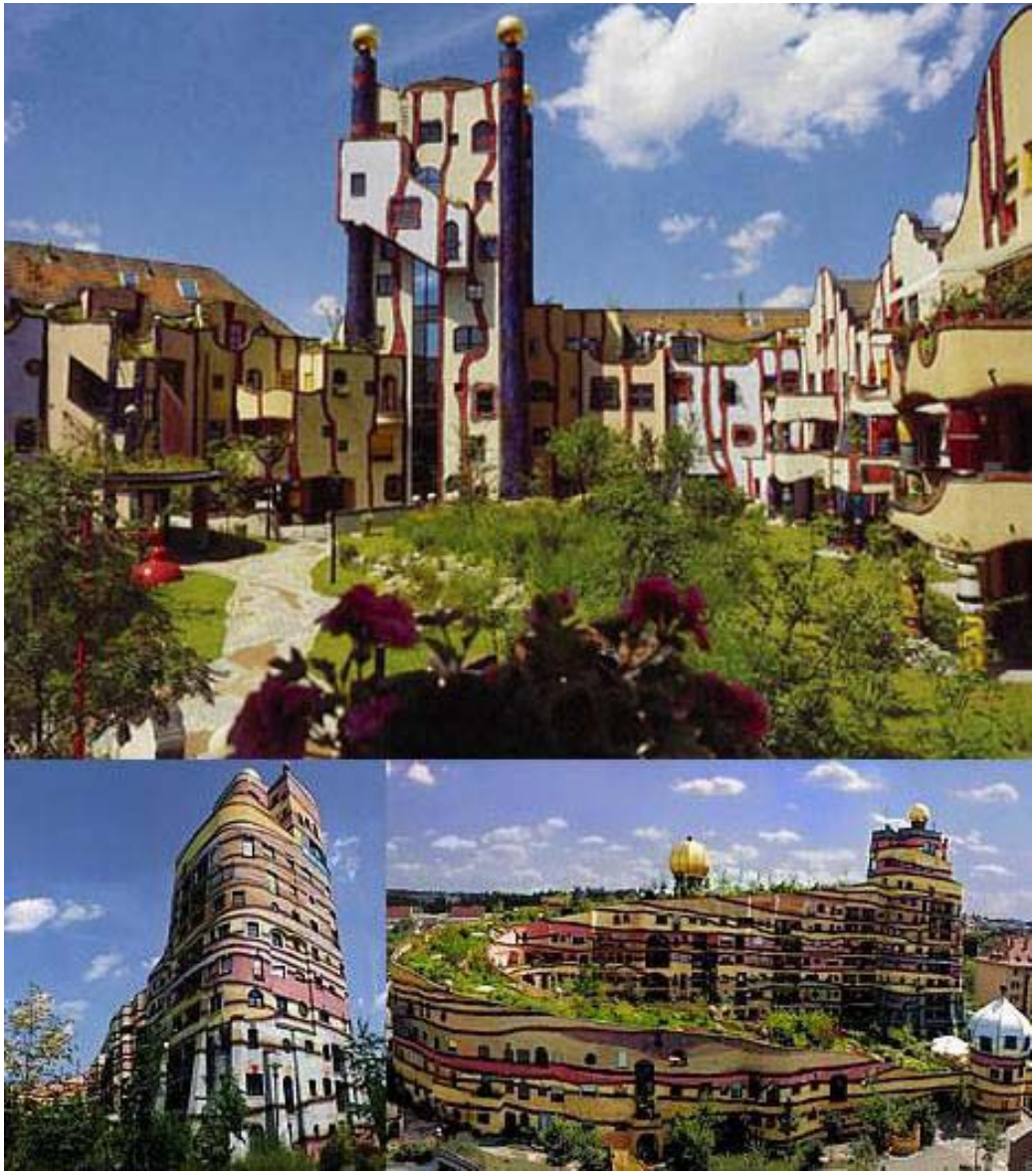


(Source: http://weburbanist.com)

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)

(Source: http://weburbanist.com)

Modern green roofs in Osaka, Japan (Namba Parks) (2003)

(Source: www.treehugger.com & www.toho-leo.co.jp)

Major types of green roofs

- Major types of green roofs (see Table 1)*
  - Extensive
  - Semi-intensive
  - Intensive

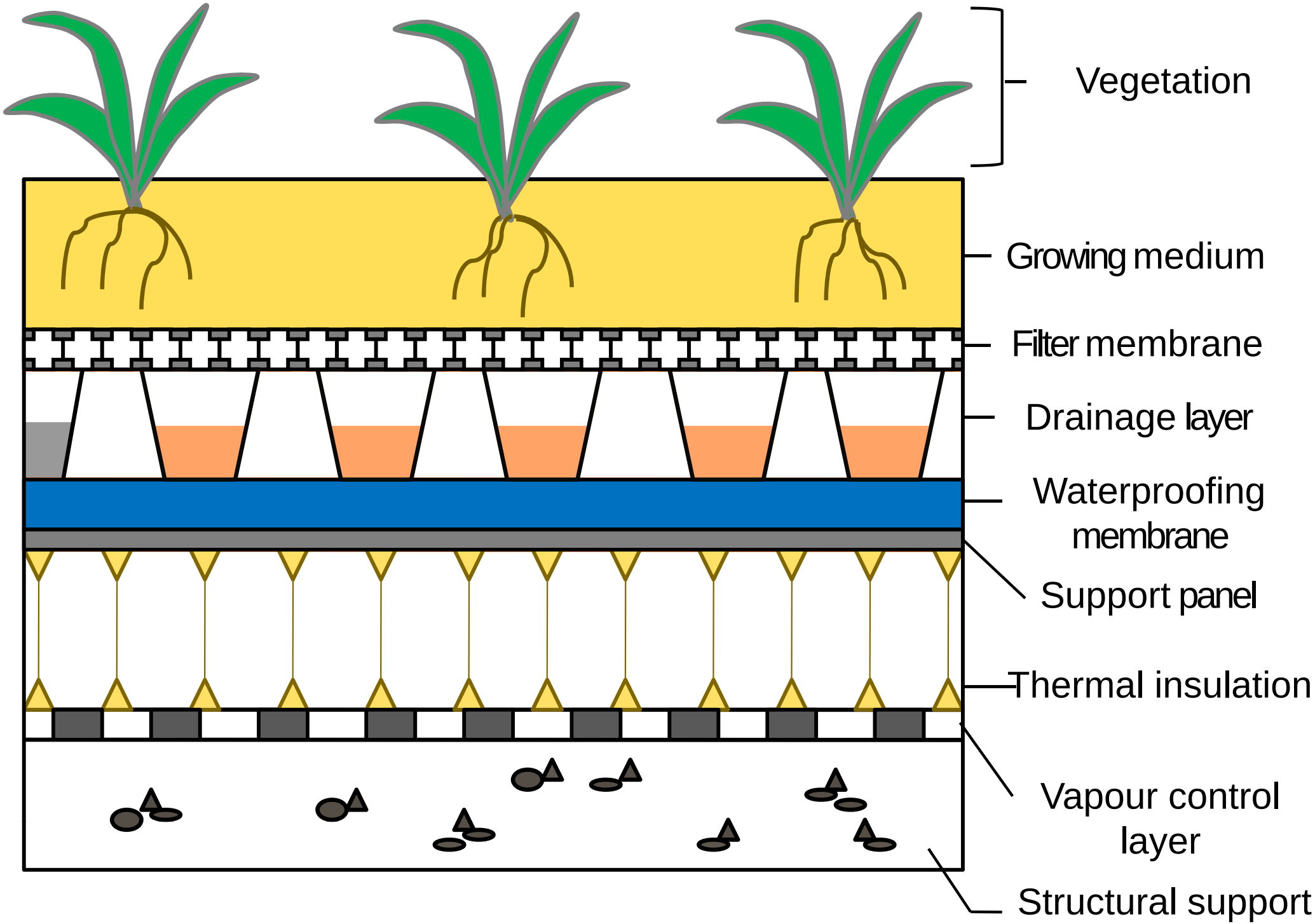
* Could also be combined as hybrid types

- 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

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/m^2)
  - 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

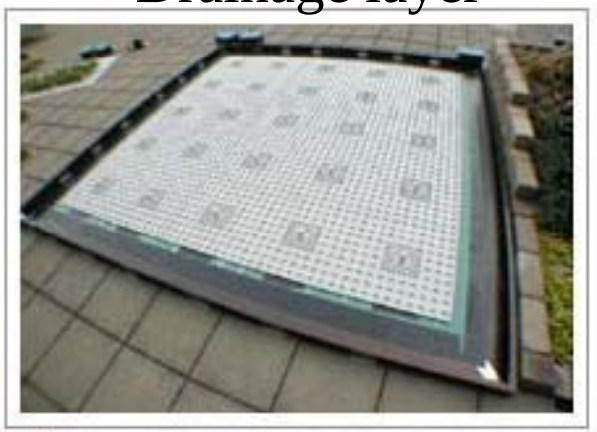
Waterproofing

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

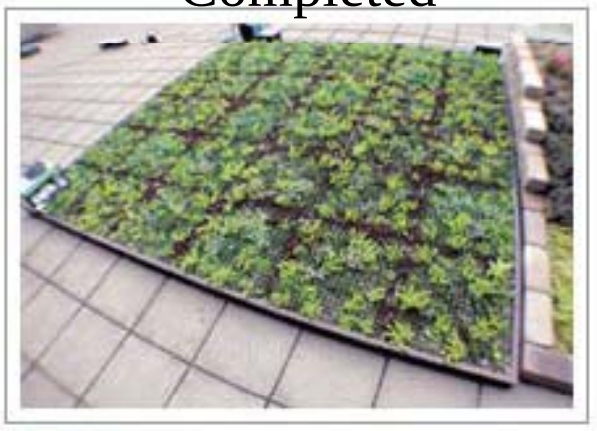
Install modules

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

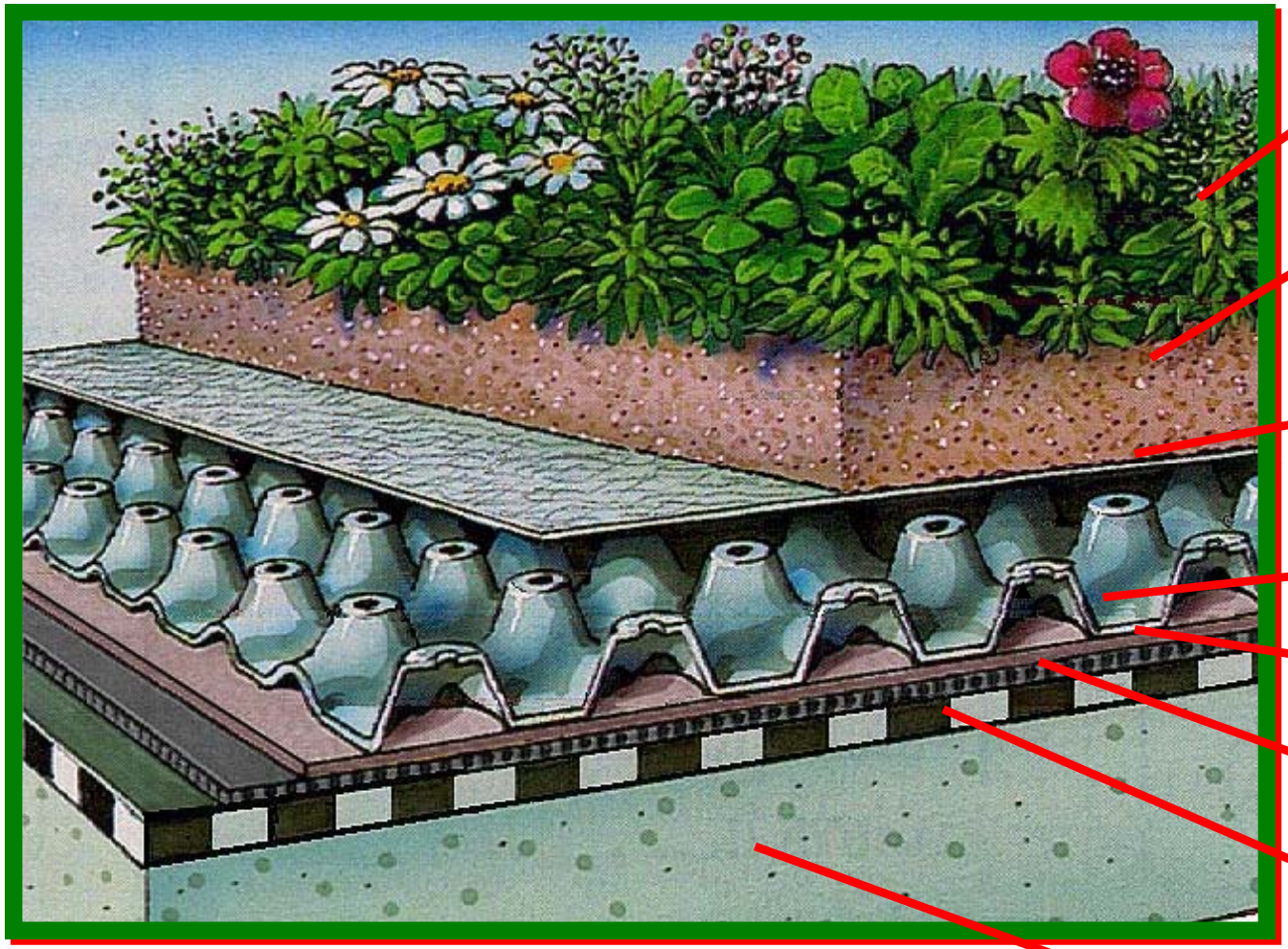
(Source: www.tajima-roof.jp)

Key components

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

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

Green Roof Structure



Vegetation/Plant level

Growing medium

Filter sheet

Drainage/storage layer

Moisture mat

Root barrier

Waterproofing

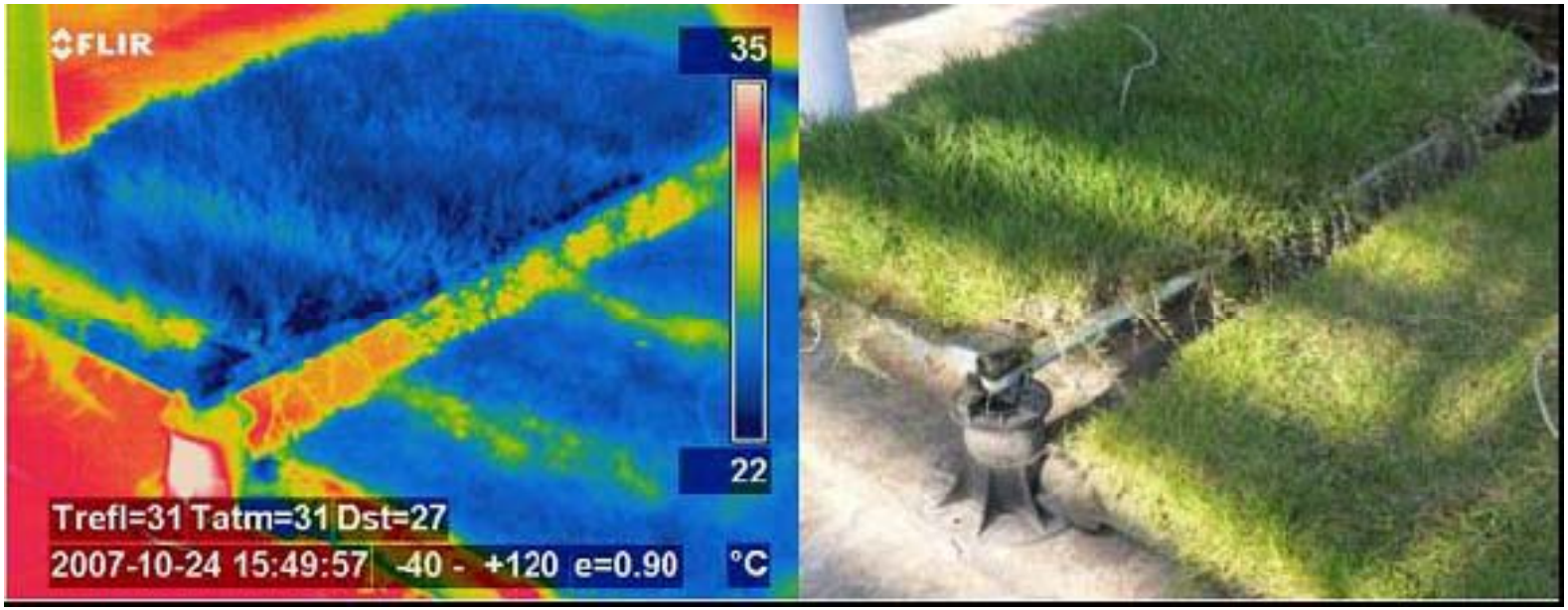
Concrete roof top

(Source: www.zinco.de)

Key components

- Vegetation (plants)
  - Vital & beautiful components of green roofs
  - Can be perennials, biennials or annuals
    - Extensive systems: mostly perennials
    - Intensive systems: use full plant palette, suitable to climate and other design features
  - Functions:

    - Aesthetic benefits, insulation, stormwater management, biodiversity protection, fire retardant potential, filtering air pollution, shading, transpiration, absorb CO_2, produce oxygen, allow horticultural therapy



Infrared photo for assessing thermal effects

Typical hardy plants (sedums) used for green roofs

Key components

- Growing medium or soil (substrate)
  - Utilize mixture of organic & inorganic matter
    - Extensive systems: usually more inorganic matter
    - Inorganic matter used includes: perlite, zeolite, vermiculite, expanded slate, clay, volcanic rock, coarse sands, pumice stone & rock wool
  - Functions:
    - Critical to plant survival, stormwater retention, thermal mass transfer, habitat for birds, mammals & insets
    - Important for weight, evaporation & drainage
    - Provide fire resistance, insulation & protect waterproofing

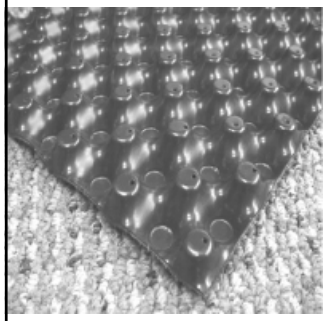
Key components

- Filter sheet/cloth
  - Non-woven & non-biodegradable geotextile fabric made of non-rotting, polypropylene fibers
  - Typical materials are white, lightweight, water resistant, chemically & biologically neutral
  - Functions:

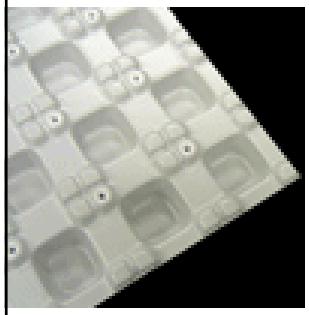
    - Prevent fine sediments from growing media from accumulating on the layer below & clogging drains
    - May help prevent roots from working their way toward the membrane

Key components

- Drainage/storage layer
  - Egg-crate plastic, porous mats or granular media
    - Some systems are designed to retain water for the plants; modular system may have built-in drainage
    - A wide variety of drains that allows water to be transported to pipes and downspouts; some also allow water to remain on the roof for irrigation



  - Functions:
    - Maintain the growing media in a drained condition; discharge stormwater; may provide root repellency, insulation & water storage benefits



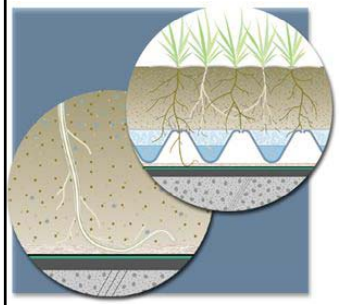
Key components

- Moisture mat
  - A geotextile fabric mat, manufactured from recycled polypropylene, and is often grey/brown in colour
  - It is non-rotting, bitumen compatible, and chemically and biologically neutral
  - Functions:

    - For use as a moisture/nutrient retention and protection layer under extensive and intensive green roof

Key components

- Root barrier/repellant layer
  - An root resistant sheet made of polyethylene, and is black in colour
    - It is non-rotting and bitumen compatible
    - Metal lining (e.g. copper) or impregnated with chemical-based root repelling agents may also be used
  - Function:
    - Prevent unwanted plants from compromising the waterproofing, especially species with aggressive root systems



Key components

- Waterproof layer
  - Modified bitumen reinforced with non-woven polyester or fiberglass matting
  - Impervious concrete
  - Membranes may be liquid applied, specially designed single-ply sheet or a built-up roof system
  - 20 year warranty recommended
  - Functions:
    - Prevent water from entering the building; facilitate runoff during storm events

Green roof on steel deck structure

(Source: www.alumasc-exteriors.co.uk)

Green roof on concrete structure

(Source: www.alumasc-exteriors.co.uk)

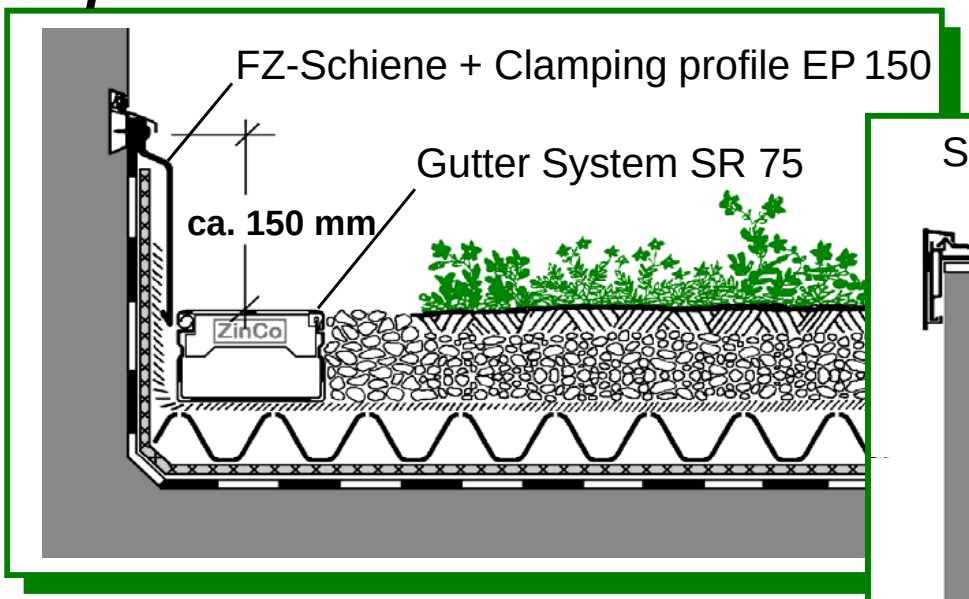
Key components

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

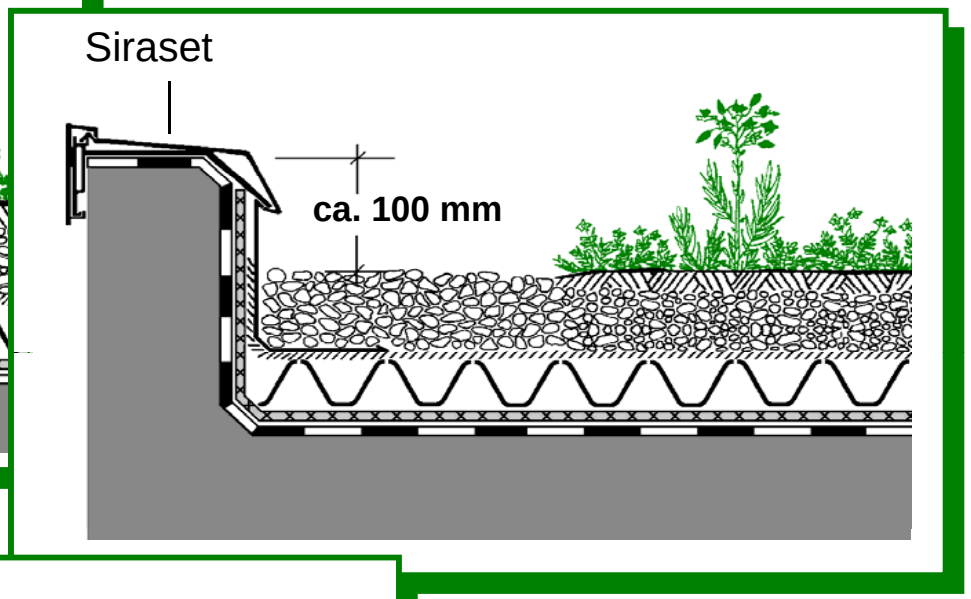
(Source: www.tajima-roof.jp)

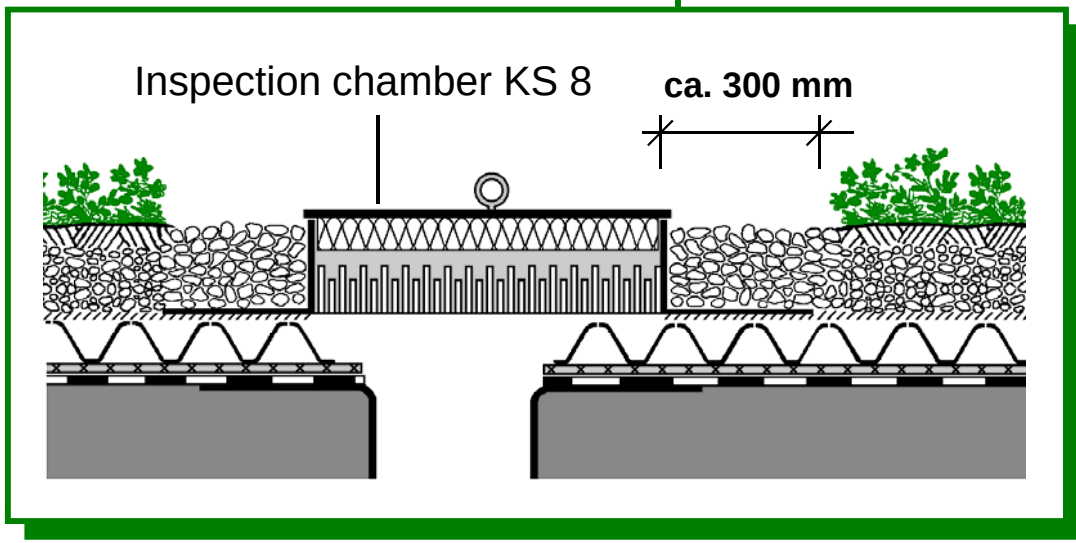
Examples of green roof details

Upstands



Roof Perimeters





Roof outlet with inspection chamber

(Source: www.zinco.de)

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

Public benefits:	**Private benefits:**
- Aesthetic value - Mitigate urban heat island - Stormwater retention - Create natural habitat - Functional open space - Agricultural space - Filter dust and pollutants - Filter rainwater	- 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

LEED 2009 credit points of green roof systems

LEED criteria impacts:	Points
Sustainable Sites (SS)	
Credit 6.1: Stormwater design – quantity control	1
Credit 6.2: Stormwater dseign – quality control	1
Credit 7.2: Heat island effect – roof	1
Water Efficiency (WE)	
Credit 1: Water efficient landscaping	2-4
Energy and Atmosphere (EA)	
Credit 1: Optimize energy performance	1
Materials and Resources (MR)	
Credit 4: Recycled content (roof components)	1-2
Credit 5: Local/Regional materials	1-2

Secondary credit impacts:	Points
Water Efficiency (WE)	
Credit 2: Innovative waste water technologies	2
Credit 3: Water use reduction	2-4
Innovation in Design (IN)	
Credit 1: Innovation in design	1-5

Source: extracted from USGBC (2009)

Benefits of green roofs

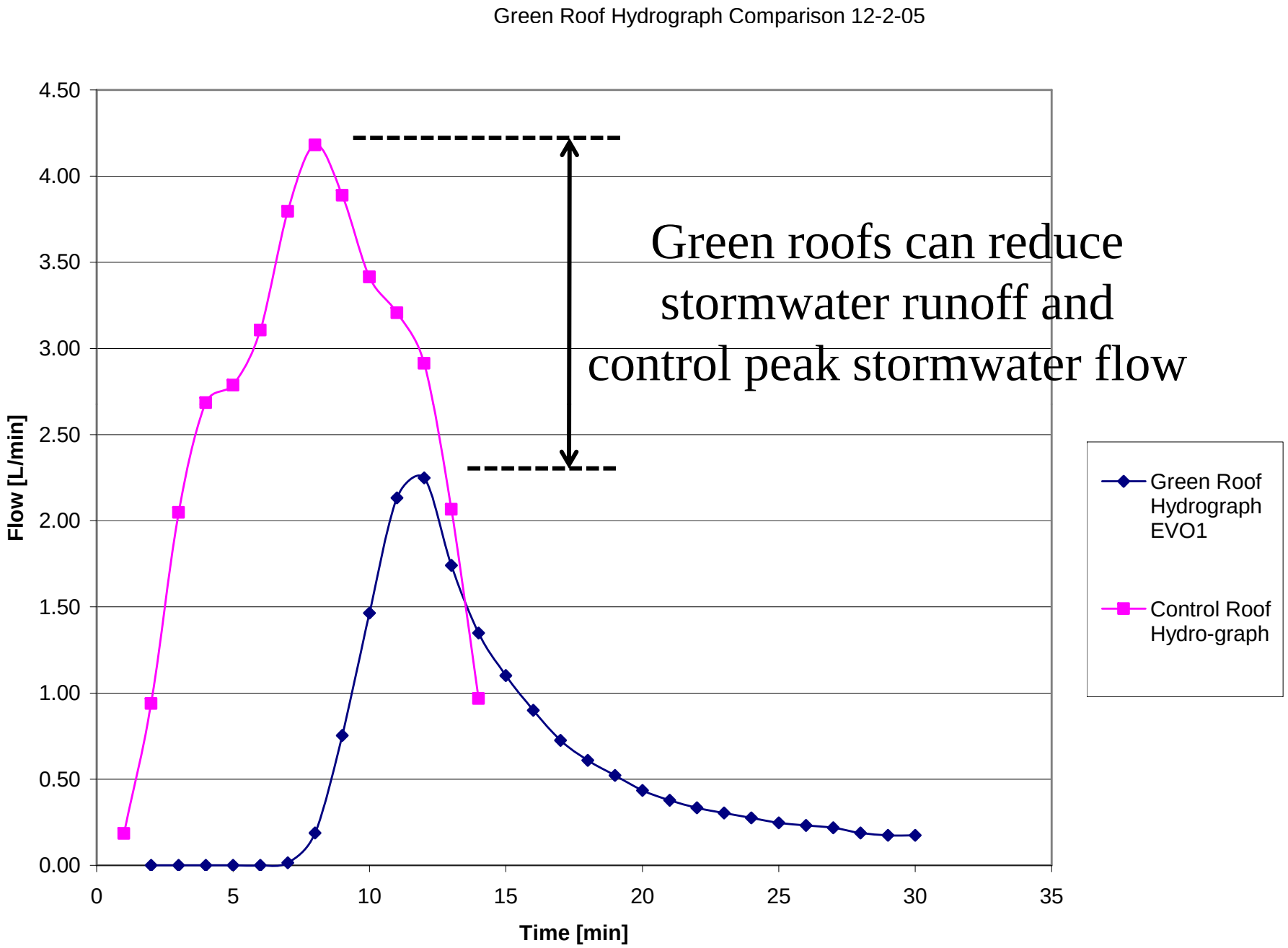
- 1. Environmental benefits:
  - Biodiversity and wildlife value
  - Stormwater management
  - Rainwater runoff quality
  - Air pollution mitigation
  - Carbon sinks (sequestration)
  - Mitigation of urban heat island
  - Control of noise pollution

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



(Source: Stormwater Academy, University of Central Florida)

Benefits of green roofs

- 2. <u>Economic benefits</u>:
  - 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

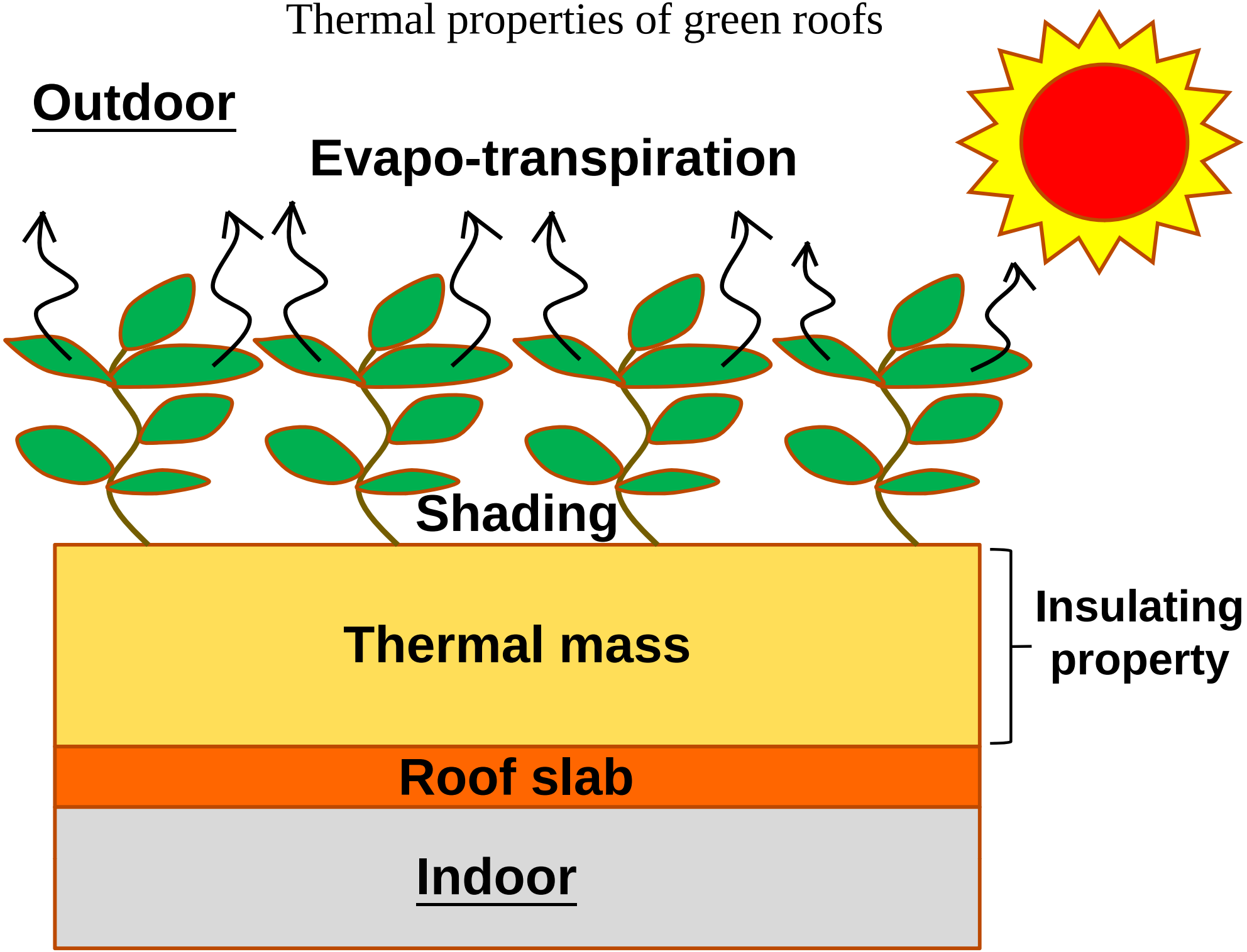
Benefits of green roofs

- 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

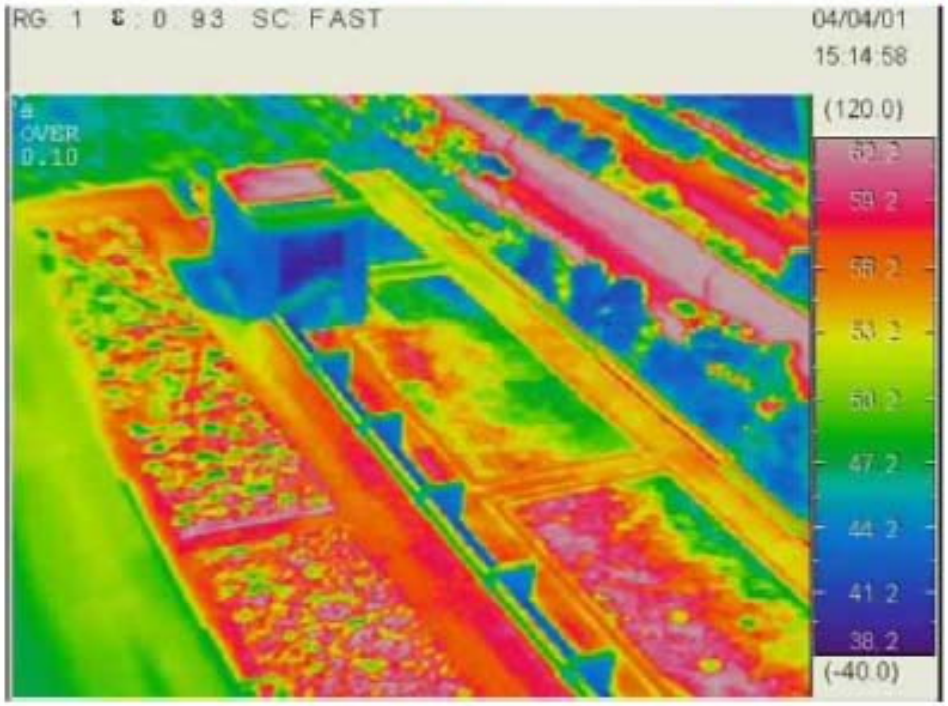
Benefits of green roofs

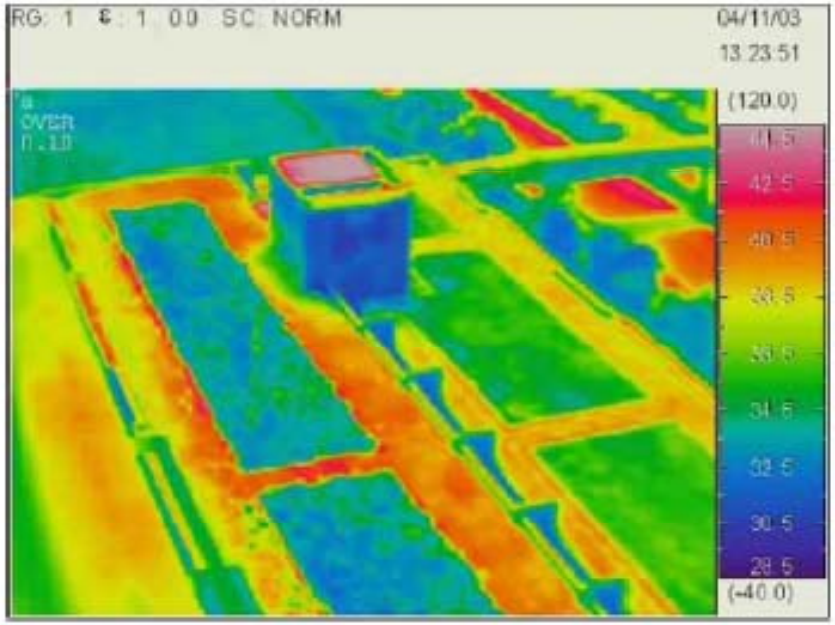
- 2.2 Cooling, insulation and energy efficiency
  - Thermal properties of green roofs
    - Direct shading of the roof
    - Evaporative cooling from the plants & substrate
    - Additional insulation from the plants & substrate
    - Thermal mass effects of the growing medium
  - Summer reduction in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

Thermal properties of green roofs



Green roof evaluation in Singapore





(Source: Wong, Tan and Chen, 2007)

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

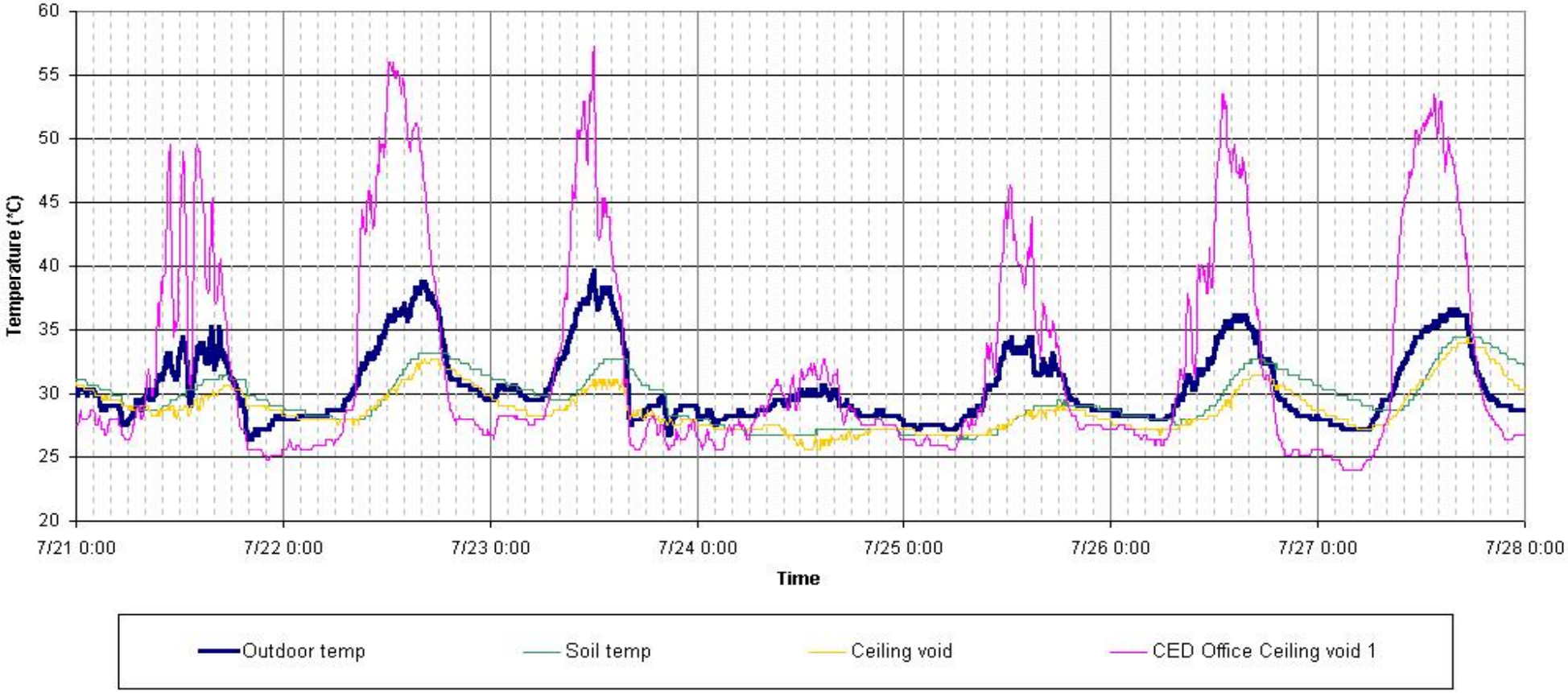
Green site office

Modular design

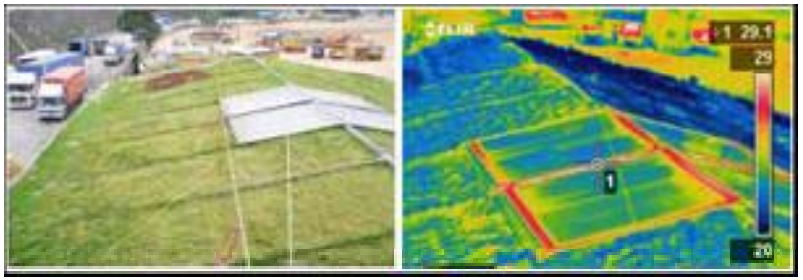
Green site office and typical site office

Water sprinkler

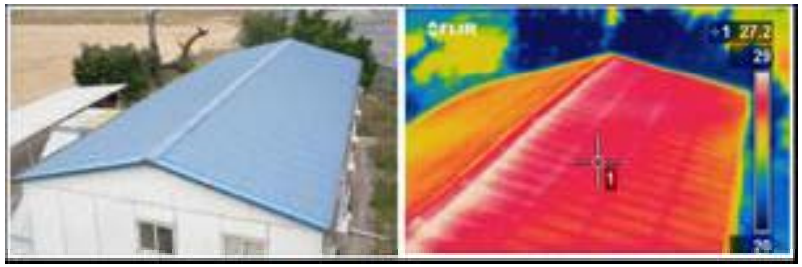
Green roof research at a construction site office in Hong Kong



Infrared pictures:



Green roof



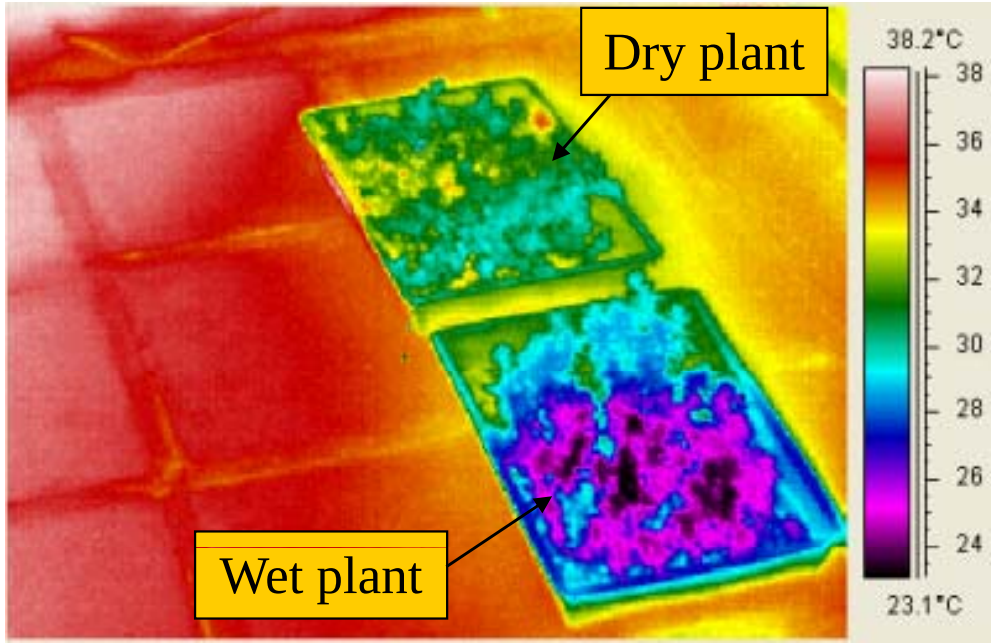
Conventional roof

Study of modular green roof systems (2007-2008)

Aluminum trays

Wooden boxes

Plastic trays



Plastic trays (infrared photo)

Benefits of green roofs

- 3. <u>Amenity and aesthetic benefits</u>:
  - 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

Urban farming & education

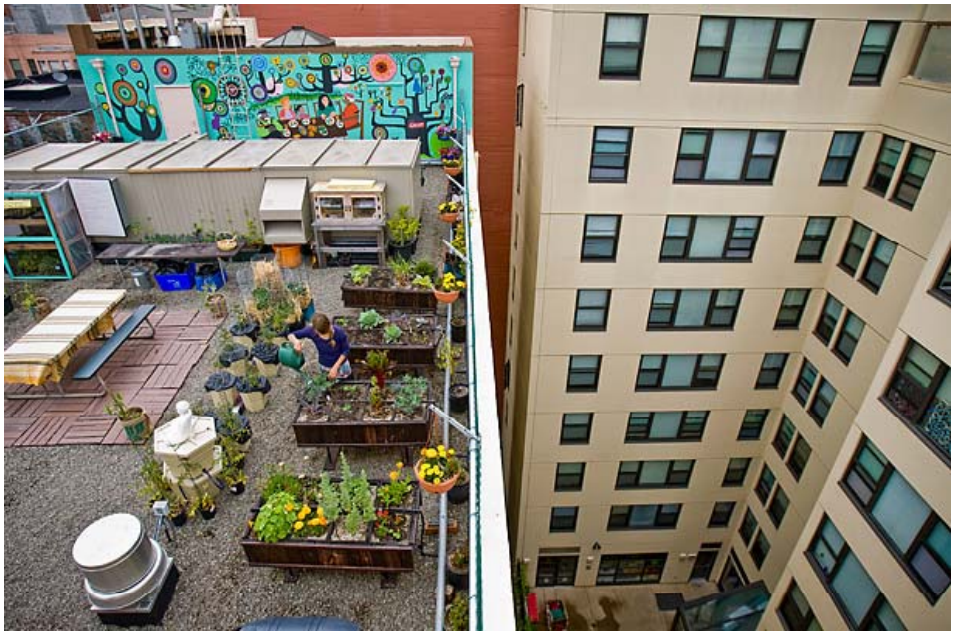
Horticultural therapy & social functions

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)

Container garden in Taiwan

(Source: http://yiu.com.tw/green.htm)

Urban farming on green roofs

Farming on the roof

Vegetables and herbal plants

Water melon

Green beans

(Photos taken by Dr Sam C M Hui; Acknowledgement: St. Bonaventure Catholic Primary School)

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	- Functions and effects - Structural loading - Accessibility - Site conditions (wind, shade) - Water proofing condition - Green building credits
Design Considerations	- 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	- Safety issues (preventing falls) - Vegetation planting method - Testing & monitoring
Maintenance	- Maintenance requirements - Warranties - External fire hazard - Safety issues
Project Management	- Green building assessment - Financial incentives - Regulatory measures - Contractual matters

Design considerations

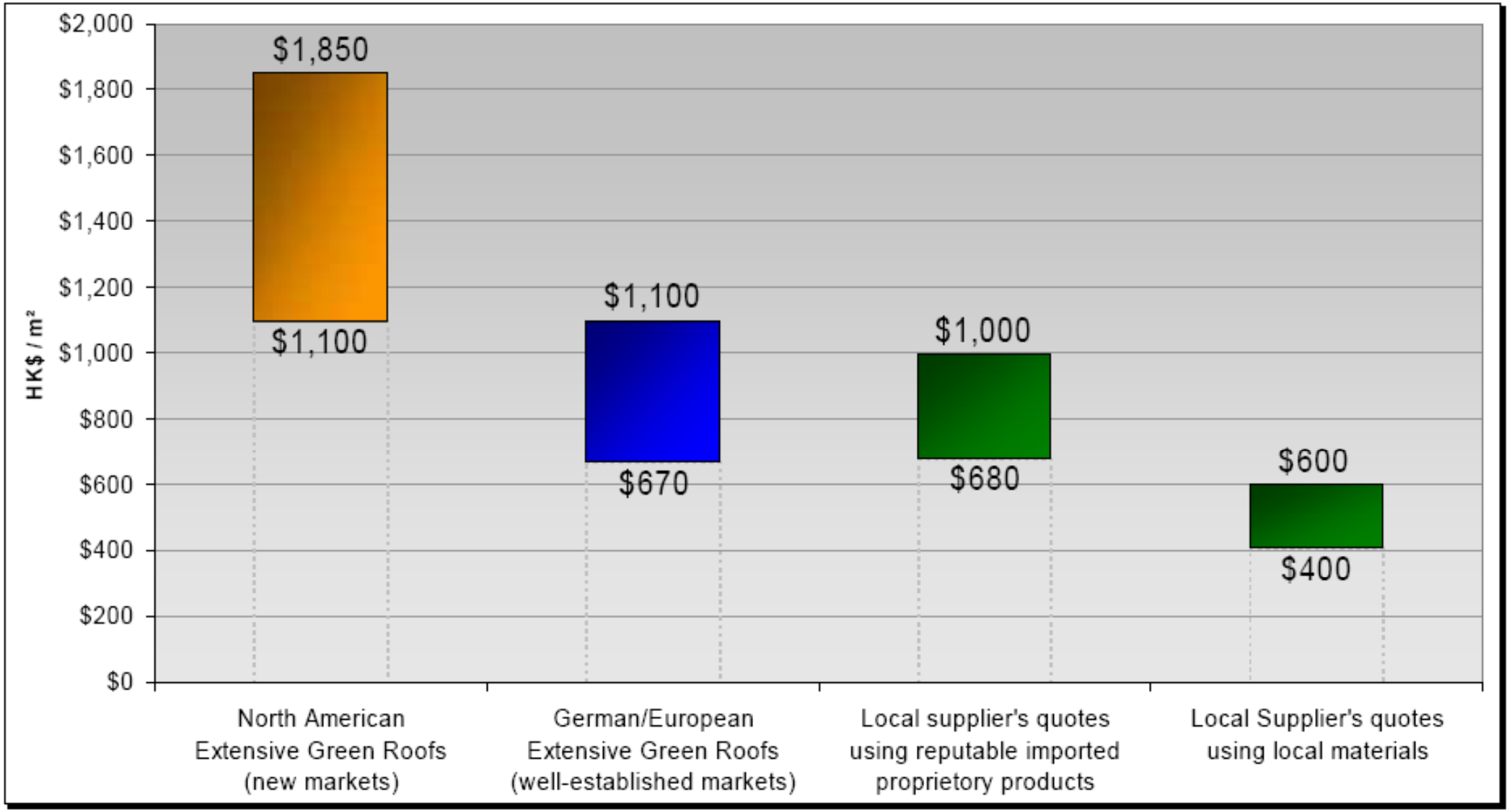
- Choosing the site (on existing buildings)
  - Loading capacity
    - Weight of green roof, equipment & people
  - Government regulations
    - e.g. on height, railing
  - Sunlight and wind exposure
  - Access and safety
    - e.g. access to water, electricity
  - Specific needs
    - e.g. elderly and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

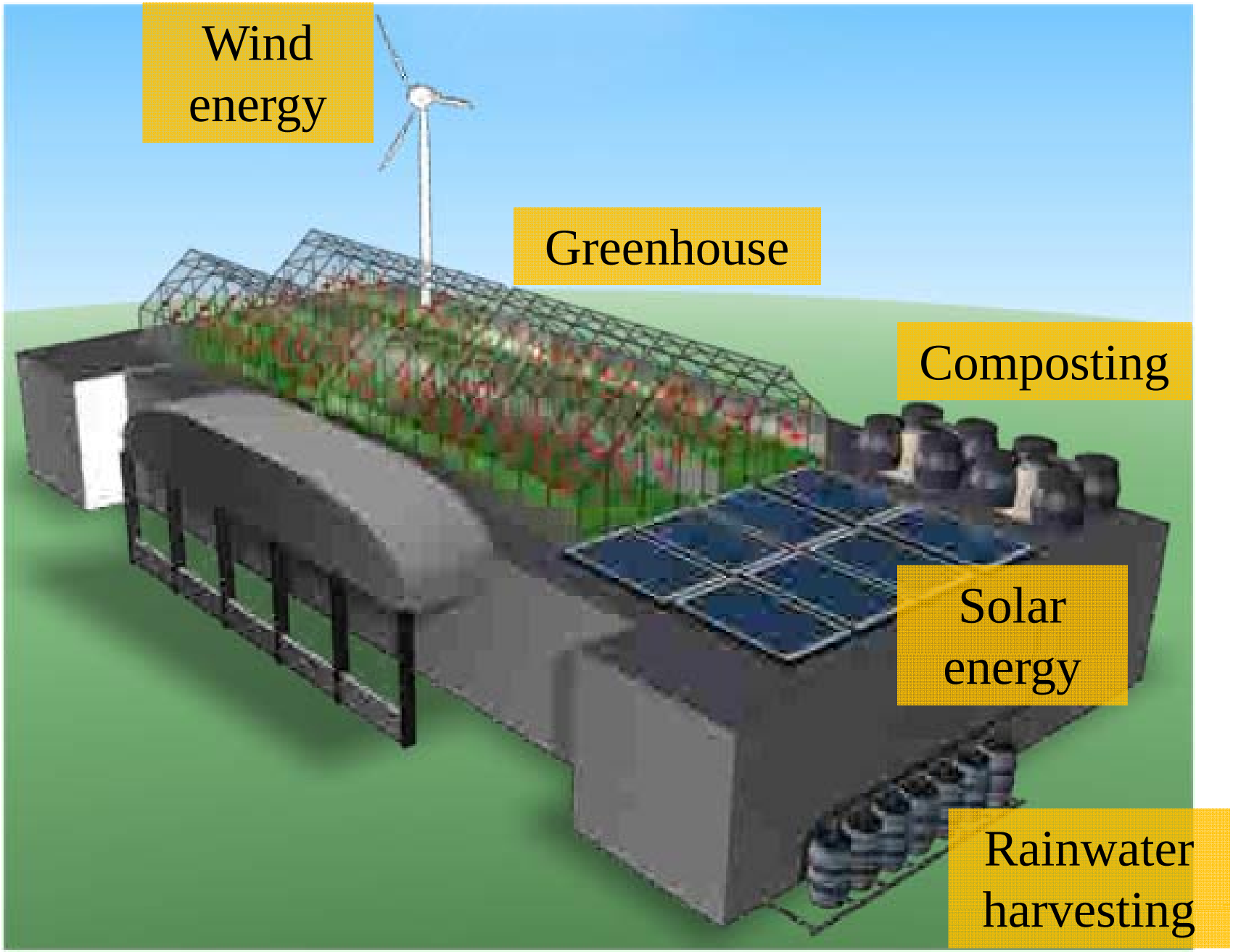
Capital cost rang comparison of extensive green roof



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

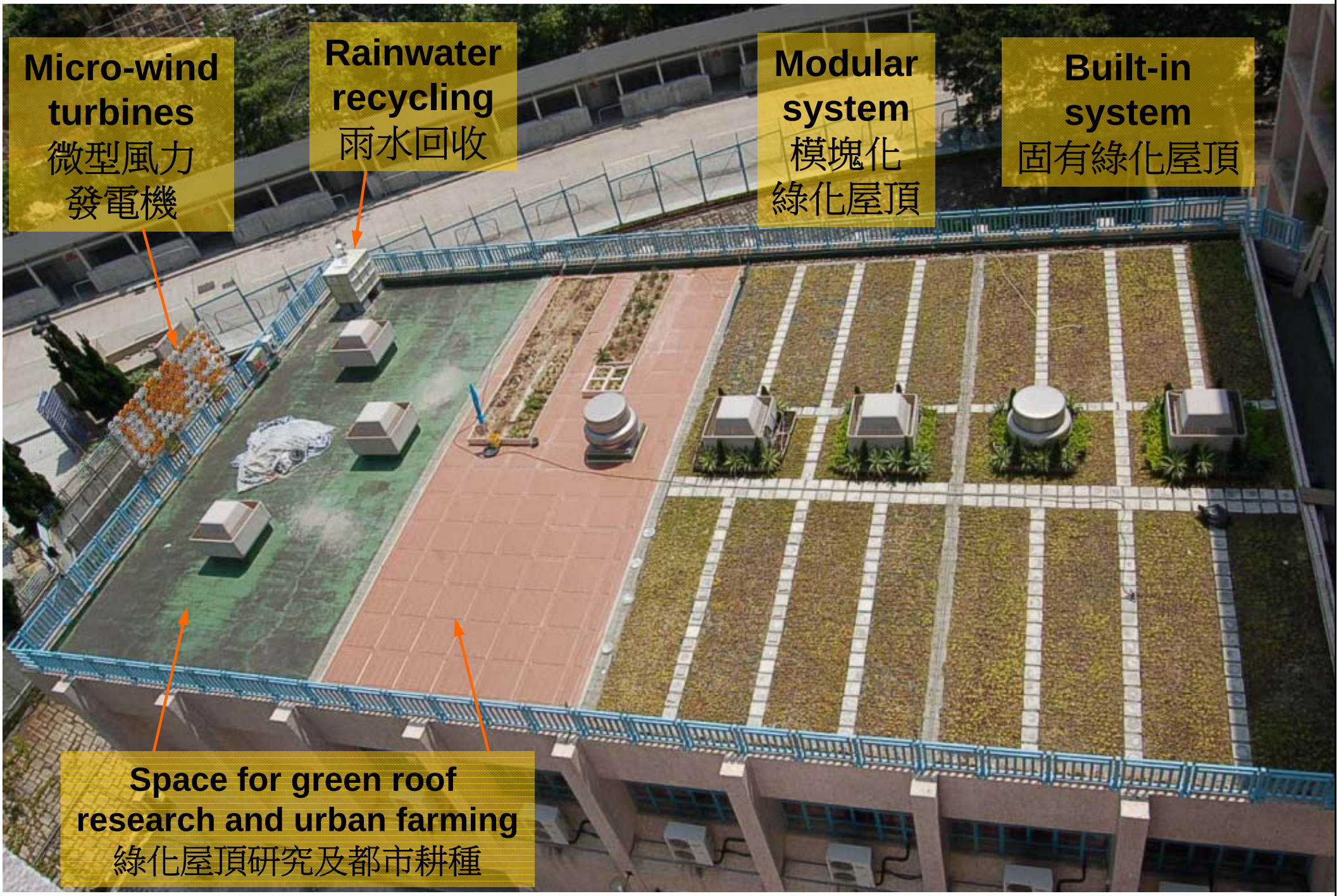
(Source: ArchSD - Study on Green Roof Application in Hong Kong Final Report)

Sustainable rooftop farming

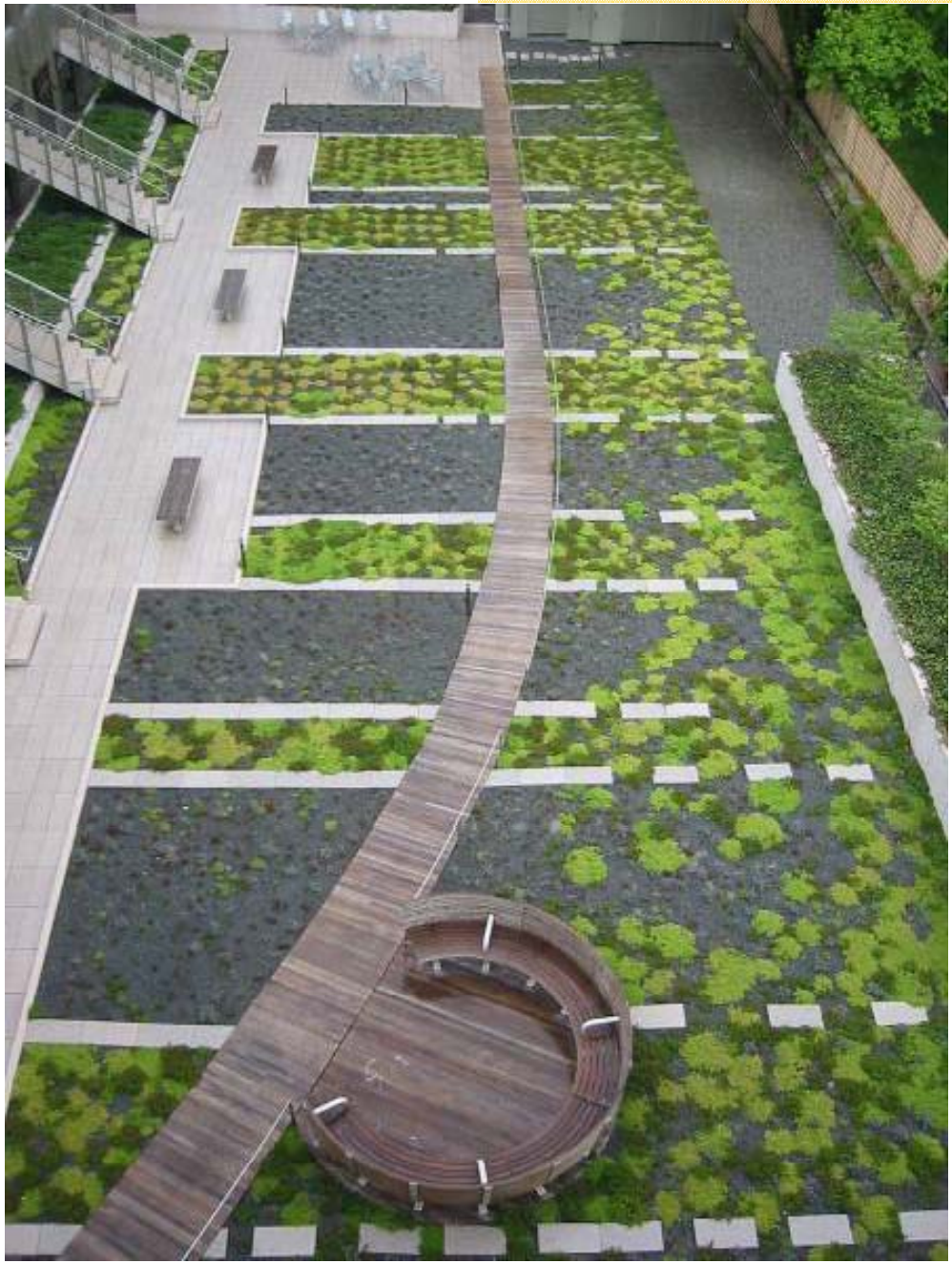


(Source: www.skyvegetables.com

A green roof project with integrated systems



THANK YOU !!



(More information: www.hku.hk/bse/greenroof/)