ASHRAE-HKC / CIBSE-HKB / HKIE-BSD
Joint Function Technical Talk

Green Roof Systems and Technology

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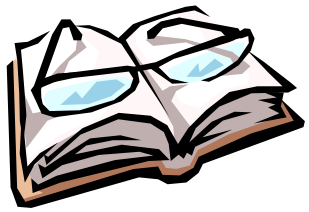
Dr. Sam C M Hui
Department of Mechanical Engineering
The University of Hong Kong
E-mail: cmhui@hku.hk

Contents

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

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 Hong Kong

HK Wetland Park

EMSD Headquarters, Kowloon Bay

Parklane, Tsimshatsui

A school in San Po Kwong

(Photos taken by Dr Sam C M Hui)

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)

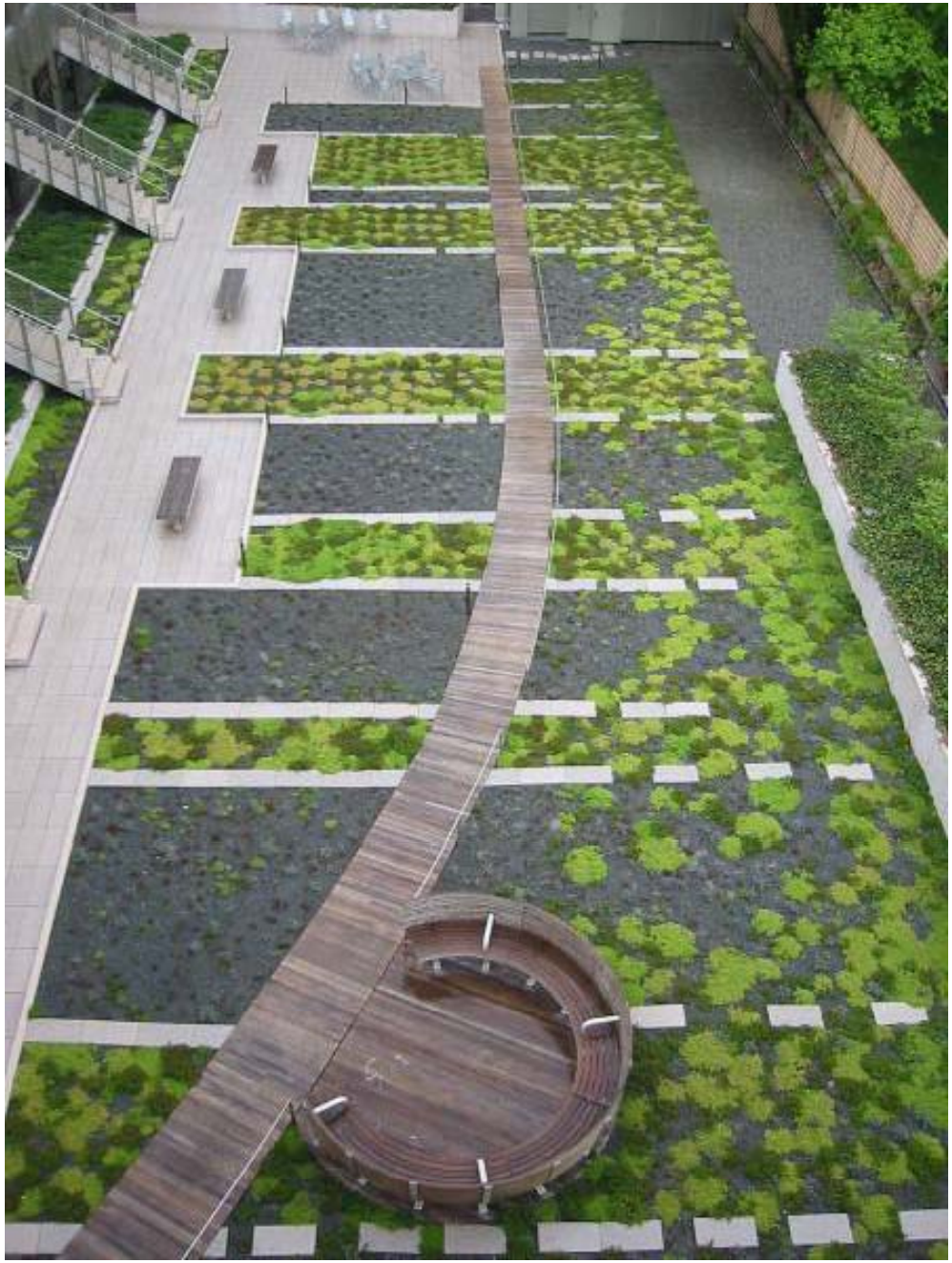
Beitou Taipei Library, Taiwan (6 Aug 2007)

(Photos taken by Dr Sam C M Hui)

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

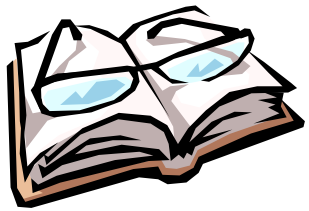
World's largest intensive green roof project
Millennium Park, Chicago, USA (100,000 sq.m)

Innovative and interesting green roof designs



(Source: Havard University)

Brief history of green roofs

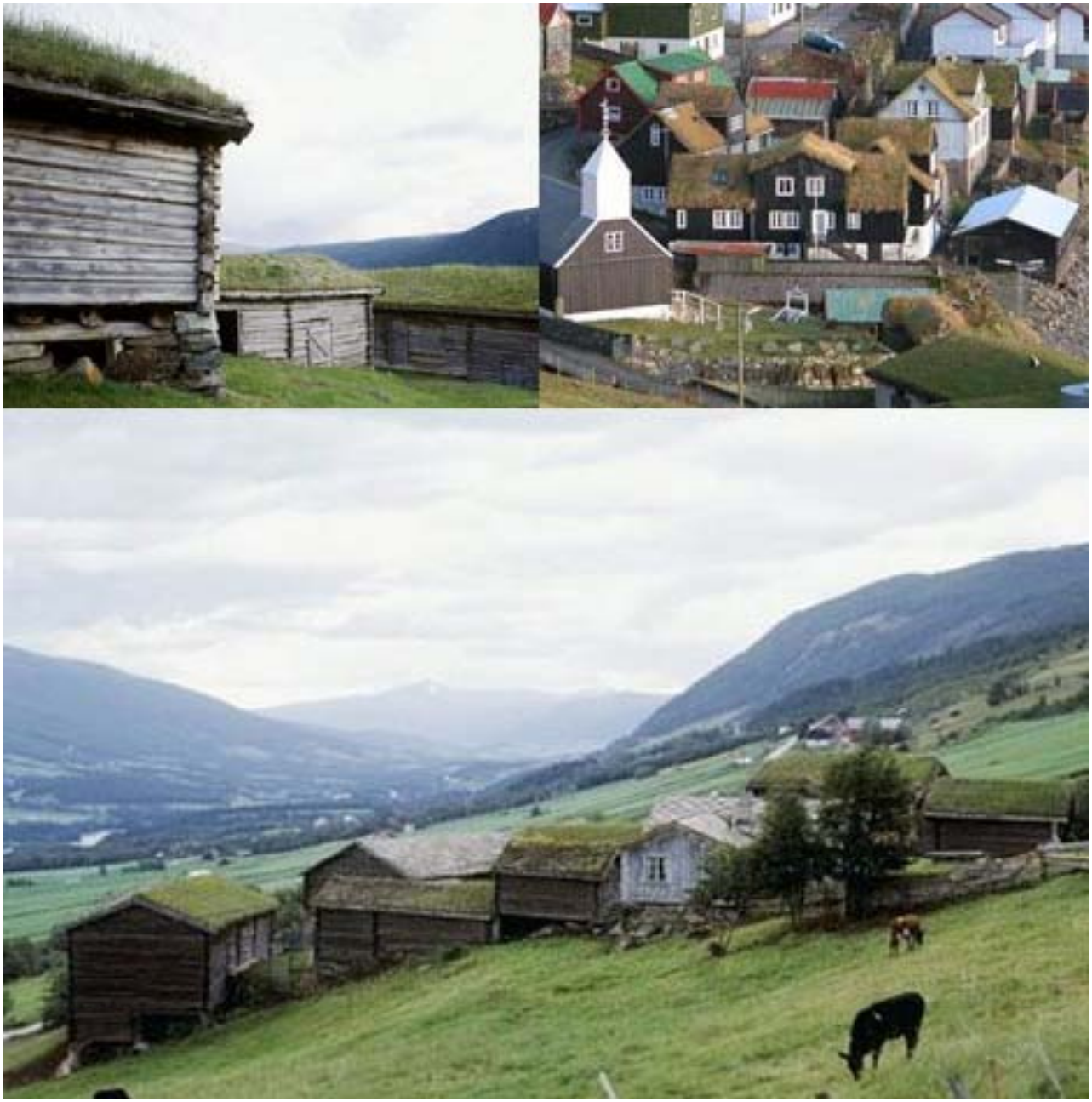


- Green roofs are not a new phenomenon
  - Hanging Gardens of Babylon (600 B.C.)
  - Traditional houses in China and Japan
  - Vikings' grass-covered green roofs on residential and farm houses in Scandinavia (1600 D.C.)
  - Terraced green roofs in Germany & Switzerland (1960's)
- Countries with mature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

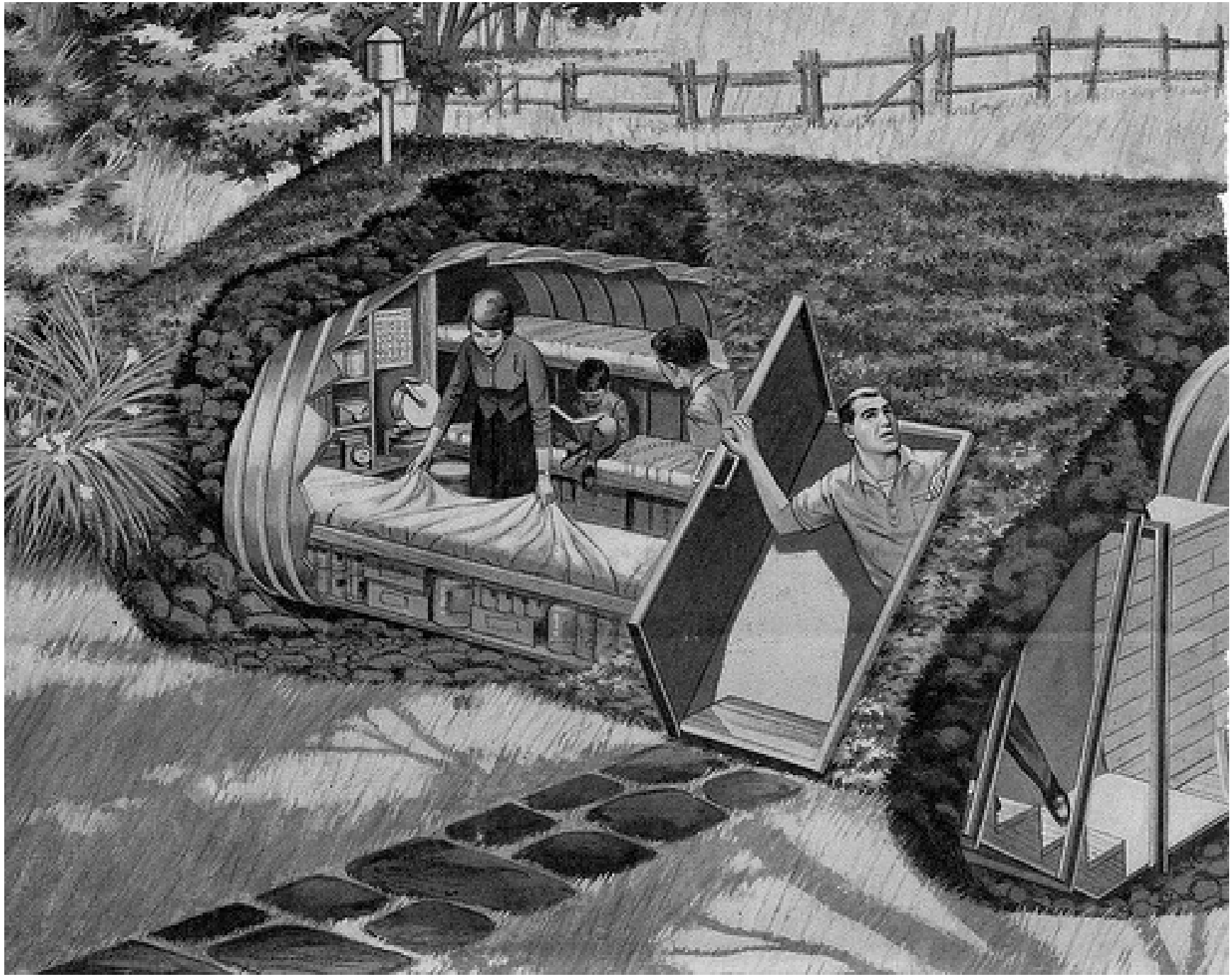
(Source: http://weburbanist.com)

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



(Source: http://weburbanist.com)

1963 pre-fab fallout bomb shelter incorporates a green roof

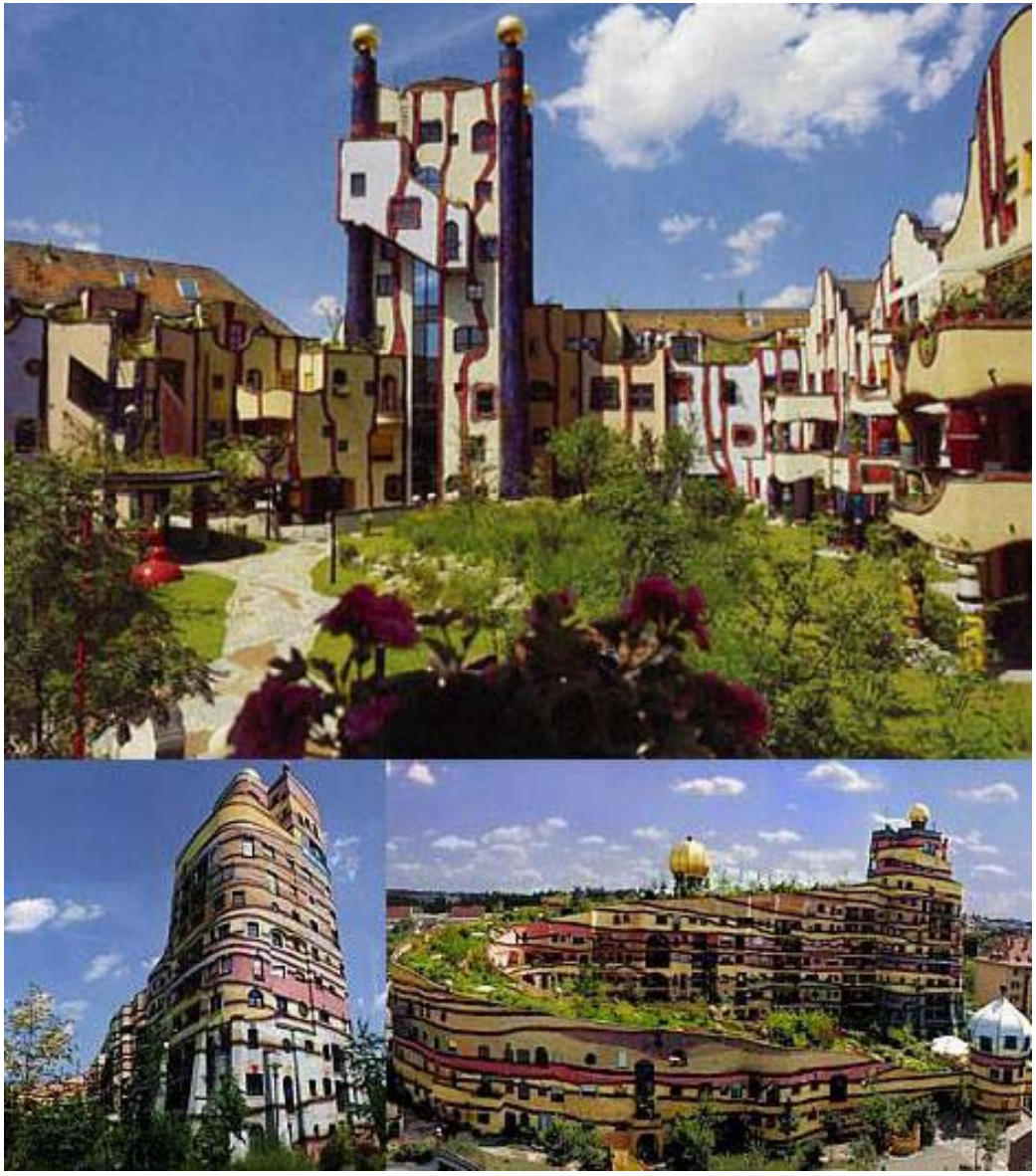


(Source: http://weburbanist.com)

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

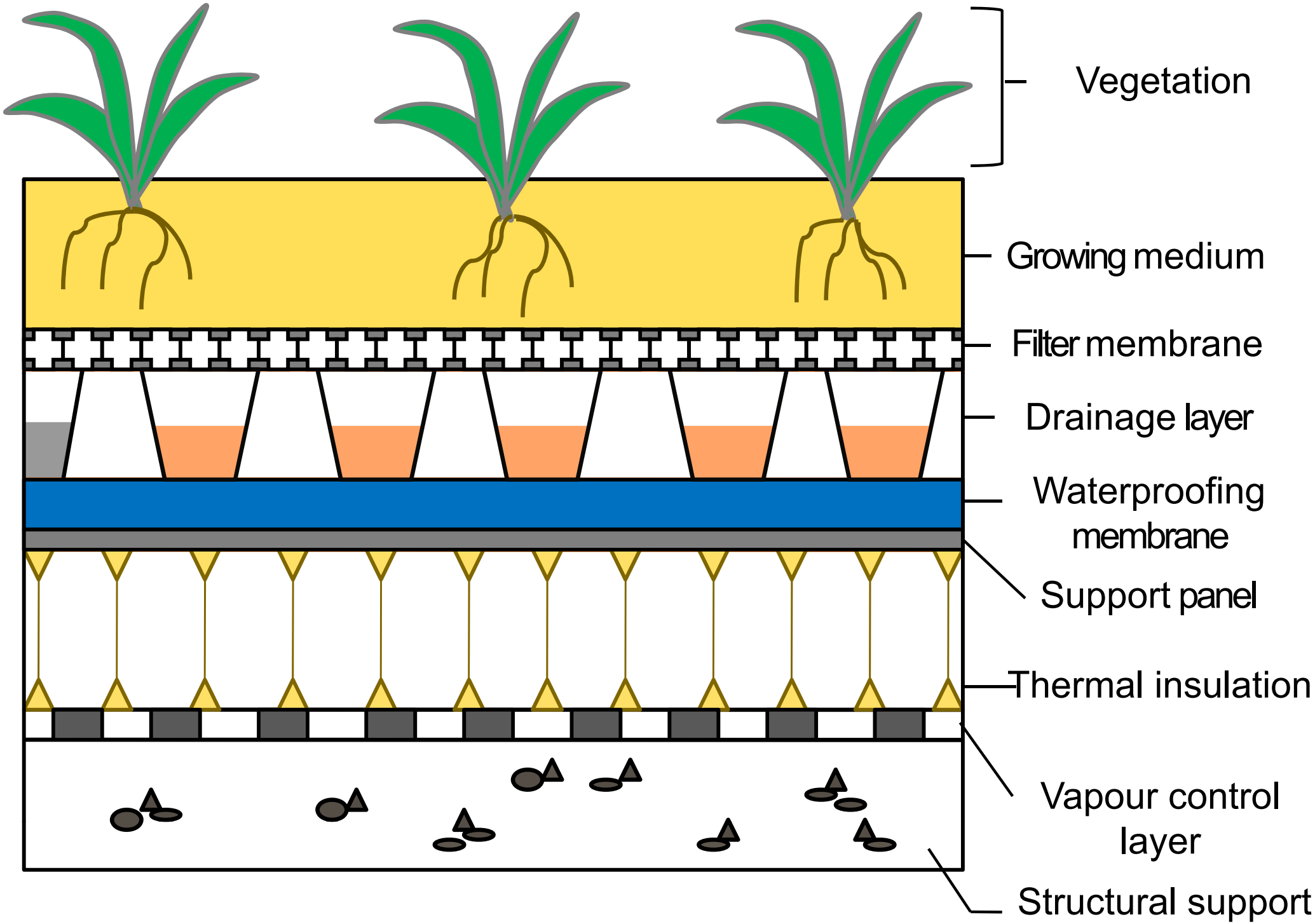
* Could also be combined as hybrid types

- 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

- Green roofs for biodiversity
  - **Brown roofs**, or biodiverse roofs
  - Originated in Switzerland
  - Concentrates primarily on habitat creation
    - Replicate the brownfield habitat, e.g. ground-nesting birds and rare invertebrates
  - Local soils & substrate materials are used
  - The roofs may be seeded like the intensive or extensive roofs or self-colonised (naturally)

Major types of green roofs

- Classify green roof systems:
  - Built-in green roofs
    - Whole area
    - Layer by layer
    - Built on site
  - Modular green roofs
    - By modules
    - Interchangeable
    - Pre-grown

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)

Examples of green walls (Singapore)

D.I.Y. vertical garden (Albert Quek)

Vertical greening (panel type)

Vertical greening (net & pack type)

Various types of vertical greening

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

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

Major types of green roofs

- Types of modular green roofs
  - Mat system
    - Vegetated mat, pre-grown, rolled up and transported
    - Very light weight and thin (45 mm)
  - Tray system
    - Most commonly found nowadays
    - Tray containers (e.g. plastic) filled with all elements
  - Sack system
    - Sack paks easily conformed to irregular areas
    - Growing medium in fabric module ready for planting

Vegetated mat system (www.elteasygreen.com)

Tray system (www.liveroof.com)

Sack system (www.greenpaks.com)

Major characteristics of the 3 modular green roof systems

Mat System (Source: Elevated Landscape Technologies, www.elteasygreen.com)	
Size :	1 m^2/module (vegetated area)
Saturated weight :	39 - 73 kg/m^2 (soil depth ≤ 40 mm)
Materials :	High density polyethylene (50% post-industrial recycled materials)
Handling :	Modules must be installed within two days after being palletized
Installation :	Interlocking panels are placed on top of root barrier. Overlap two pockets on the panel and fasten by polyethylene rivets.
Tray System (Source: LiveRoof, www.liveroof.com)	
Size :	0.18 m^2/ module (0.3 m x 0.6 m)
Saturated weight :	73 - 130 kg/m^2 (soil depth = 75-100 mm)
Materials :	100% post-industrial recycled polypropylene
Handling :	18 modules/pallet, 54 pallets/truck
Installation :	Ergonomically designed modules can be installed by just one person. They are placed on root barrier and needs to be watered immediately after installation.
Sack System (Source: Green Paks, www.greenpaks.com)	
Size :	0.48 m^2/module
Saturated weight :	83.2 kg/m^2 (soil depth = 100 mm)
Materials :	Woven fabric knitted of high density polyethylene
Handling :	42 modules/pallet, 20 pallets/truck
Installation :	Modules can be stored prior to installation. They are placed on root barrier and cut slits in the fabric module to insert plant plugs or seeds.

Construction process of modular green roofs

G-WAVE Ecom construction distance

Gウェイブ エコム 施工の流れ 作業工程

作業工程

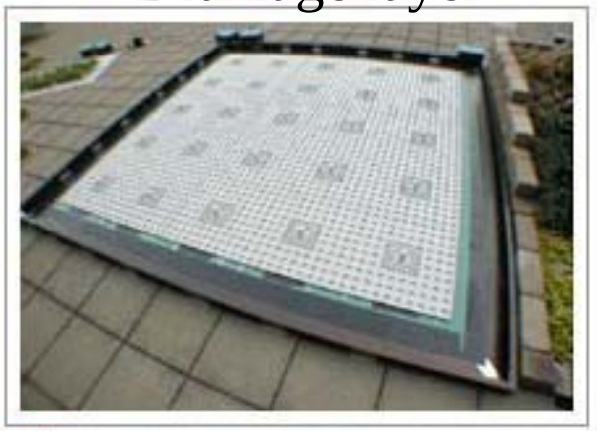
Waterproofing

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

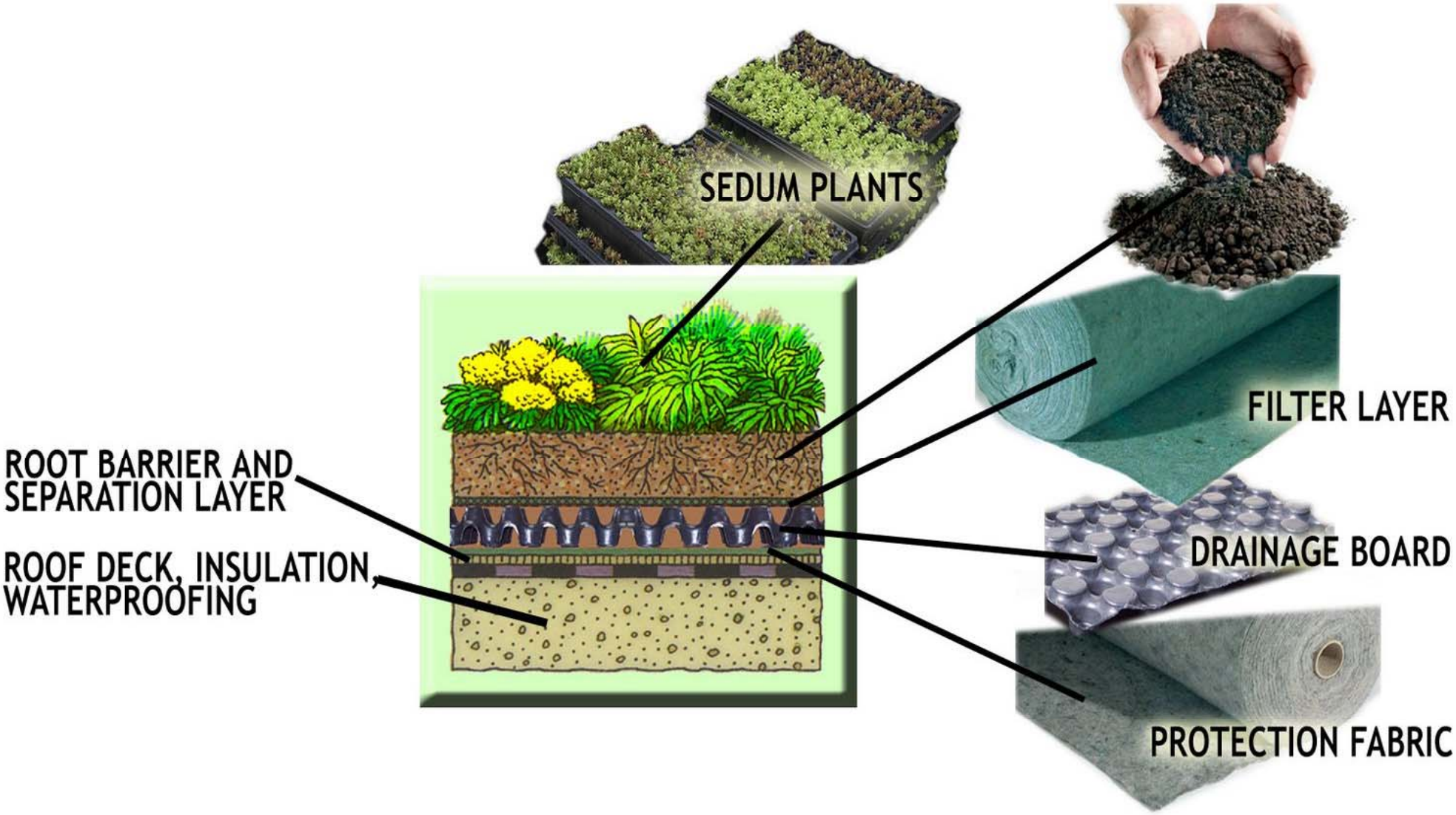
(Source: www.tajima-roof.jp)

Key components

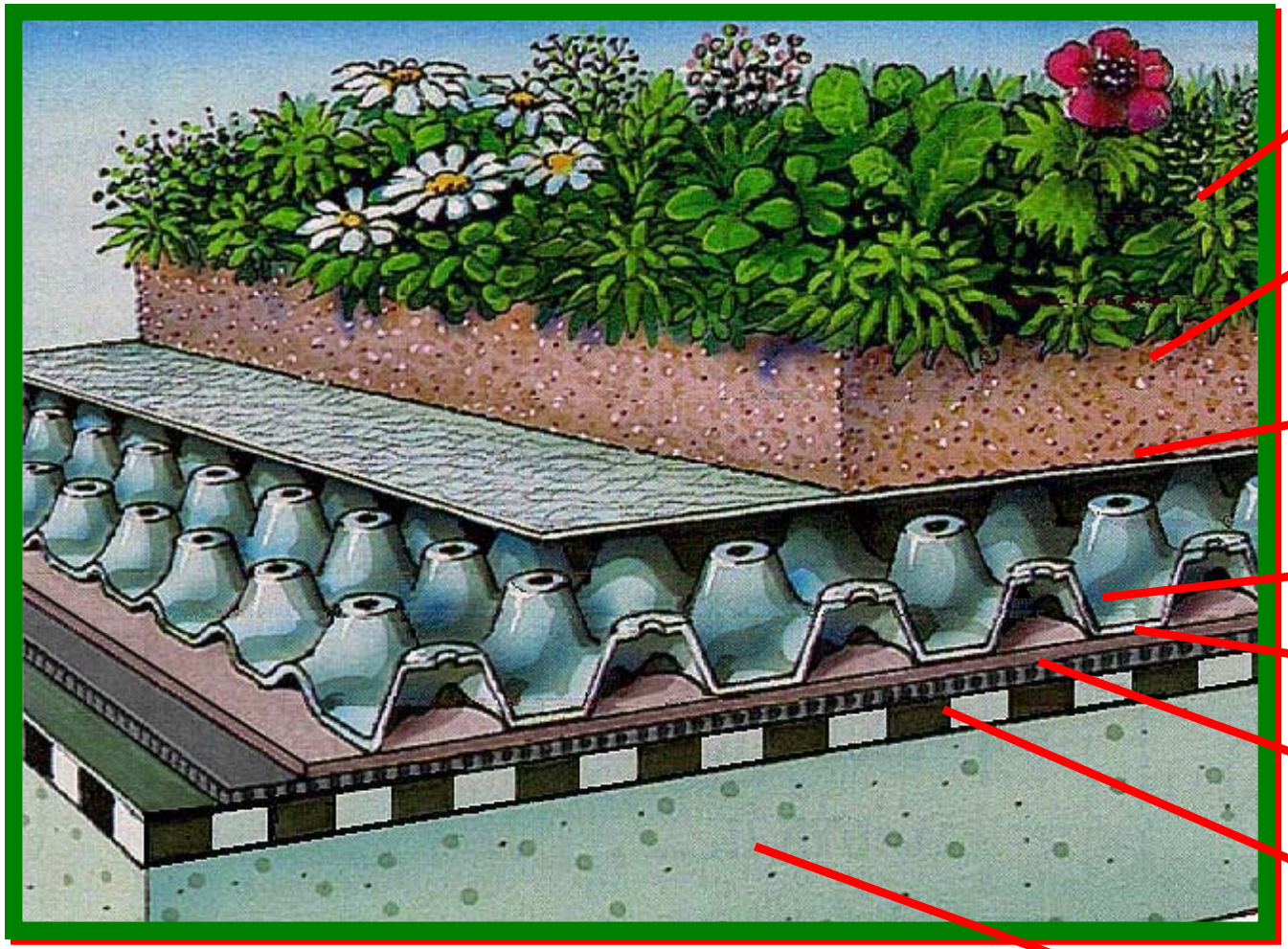
- Typically components of green roofs:
  - Vegetation (plants)
  - Growing medium or soil (substrate)
  - Filter sheet (geotextile fabric)
  - Drainage/storage layer
  - Moisture mat
  - Root repellant layer
  - Waterproof layer

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

Typical set up of green roof systems (extensive)



Green Roof Structure



Vegetation/Plant level

Growing medium

Filter sheet

Drainage/storage layer

Moisture mat

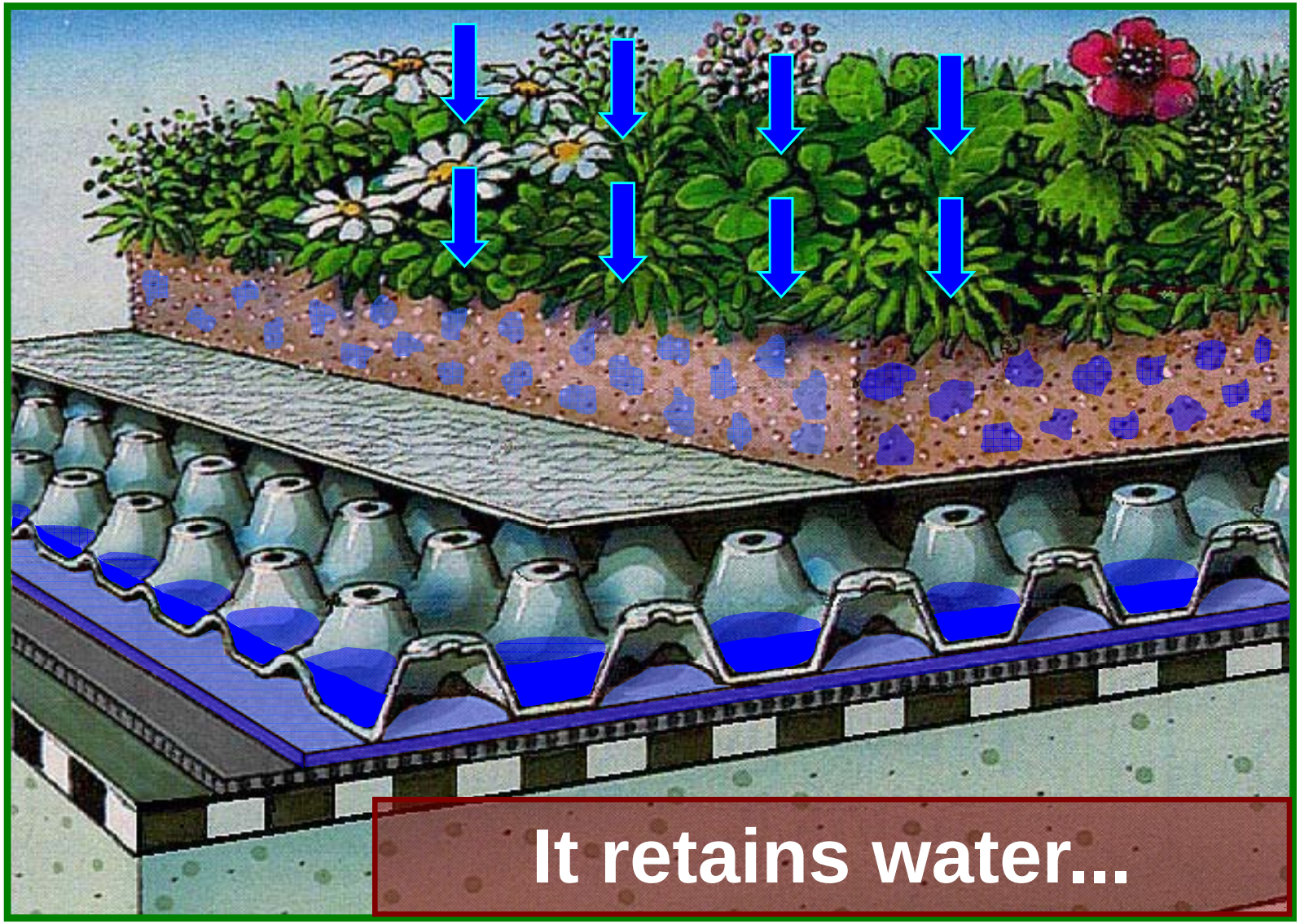
Root barrier

Waterproofing

Concrete roof top

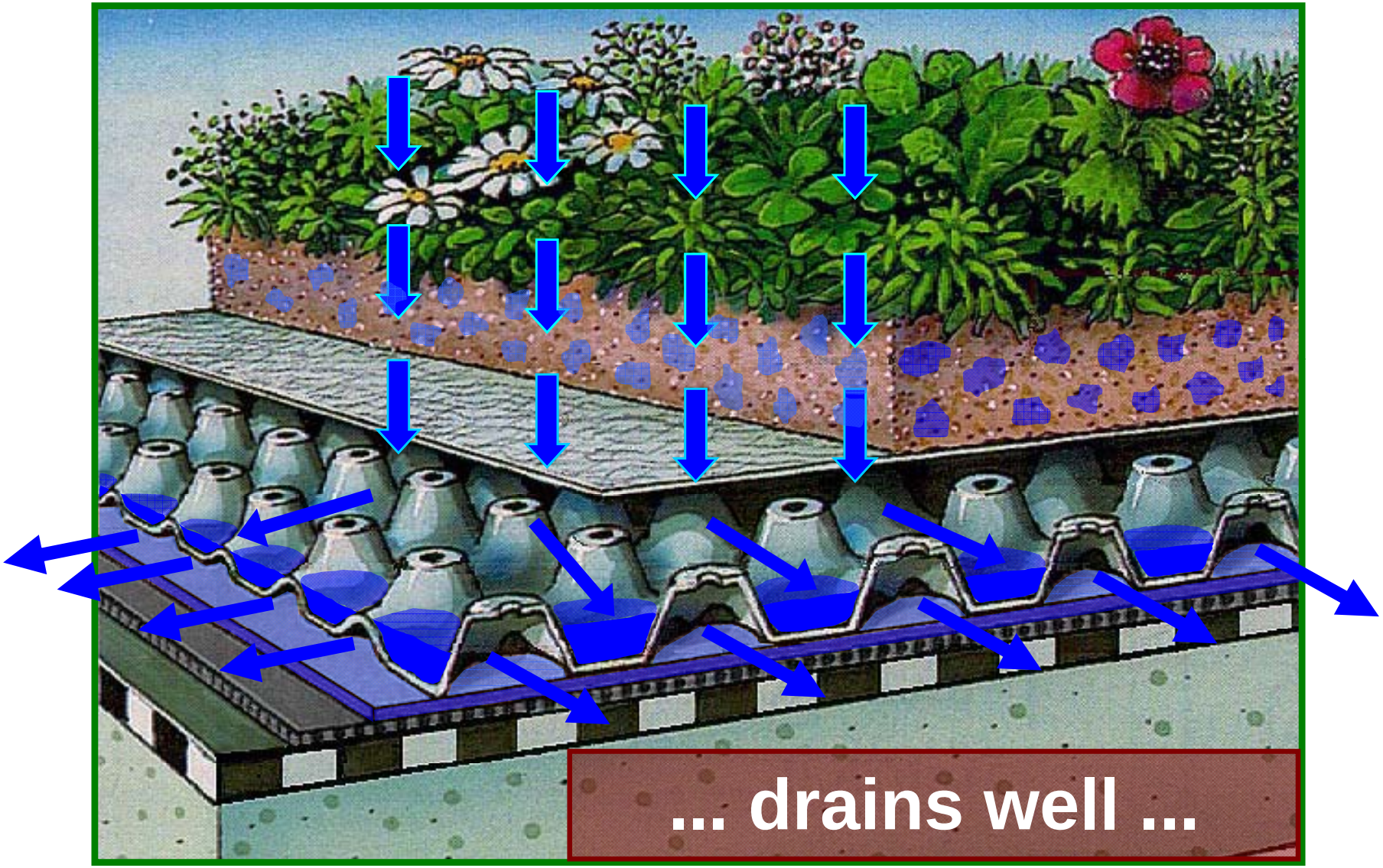
(Source: www.zinco.de)

How Does The System Work – (1) ?



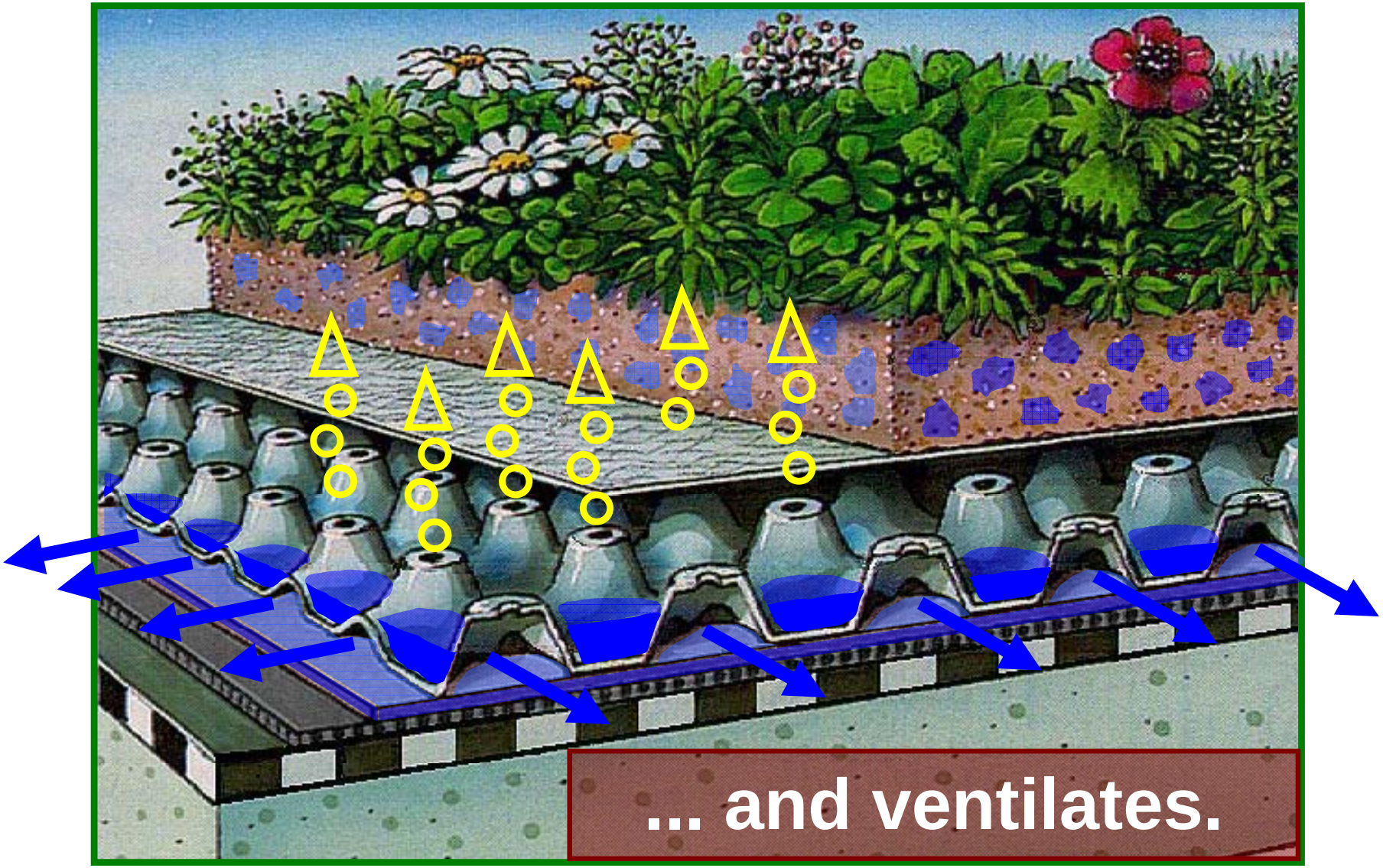
(Source: www.zinco.de)

How Does The System Work (2) ?



(Source: www.zinco.de)

How Does The System Work (3) ?

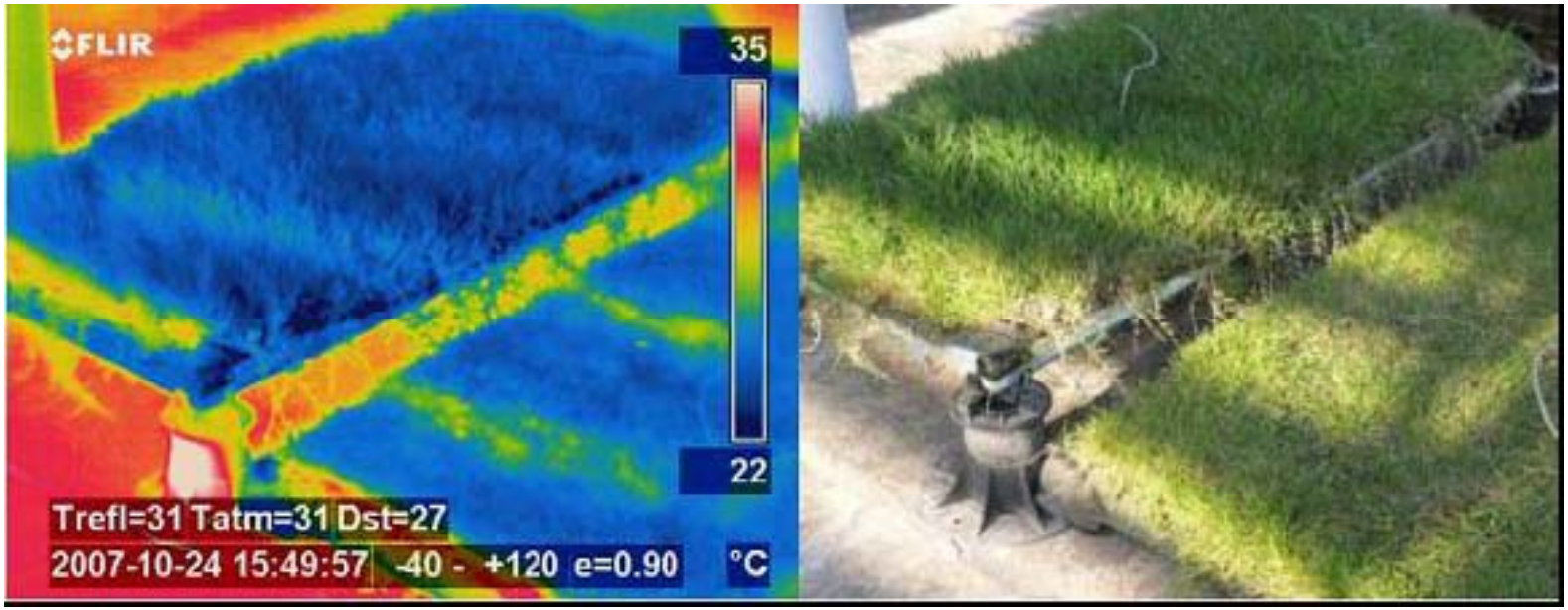


(Source: www.zinco.de)

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

用於屋頂綠化的典型耐寒植物（景天科佛甲草）

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

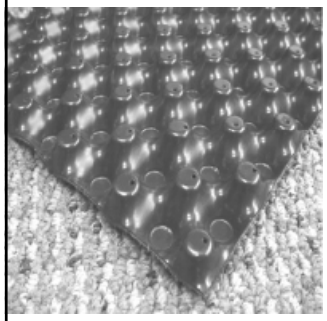
Key components

- 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:

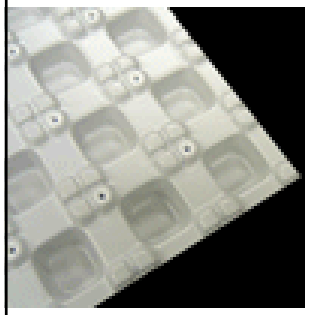
    - Prevent fine sediments from growing media from accumulating on the layer below & clogging drains
    - May help prevent roots from working their way toward the membrane

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



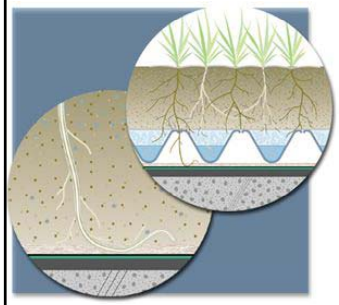
Key components

- 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)

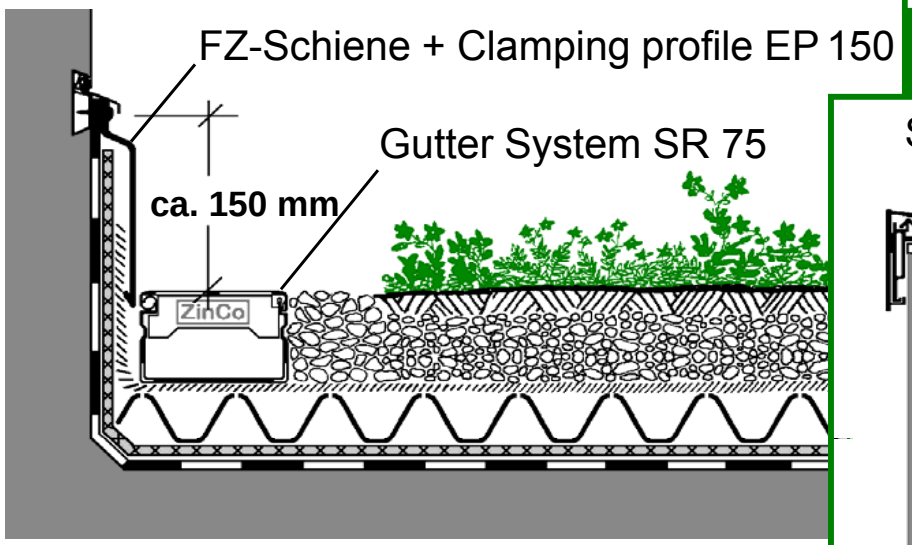
Key components

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

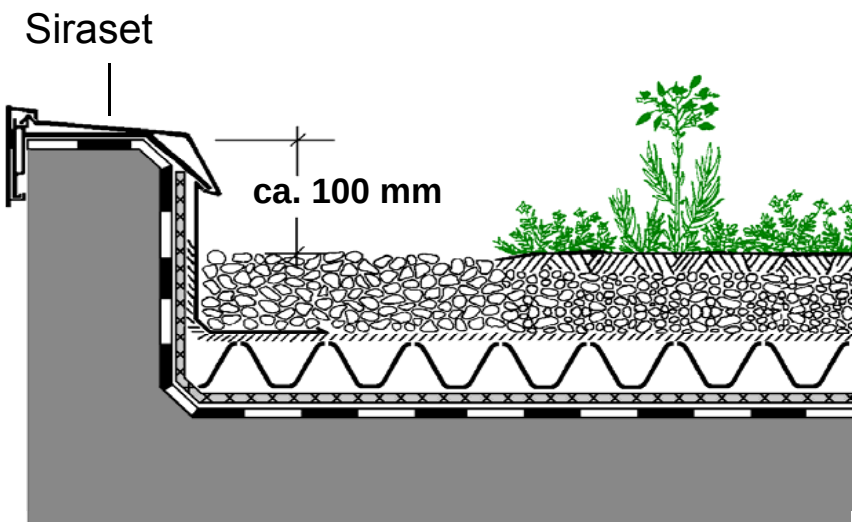
(Source: www.tajima-roof.jp)

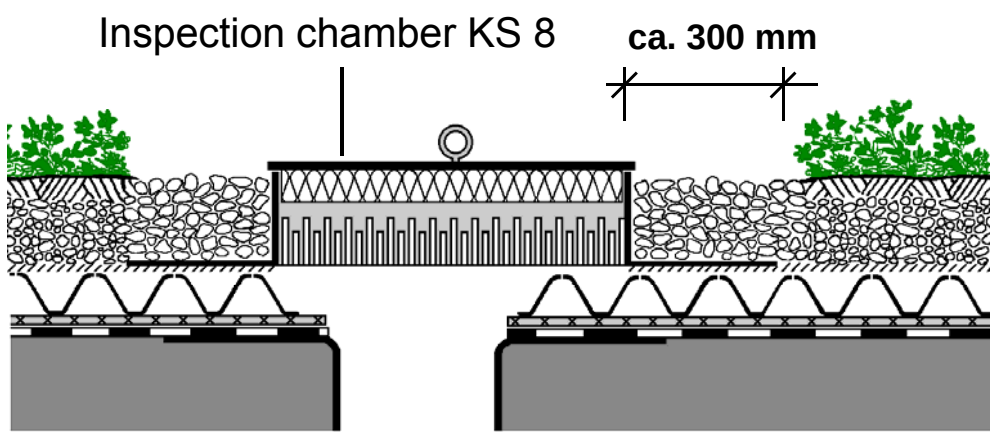
Examples of green roof details

Upstands



Roof Perimeters





Roof outlet with inspection chamber

(Source: www.zinco.de)

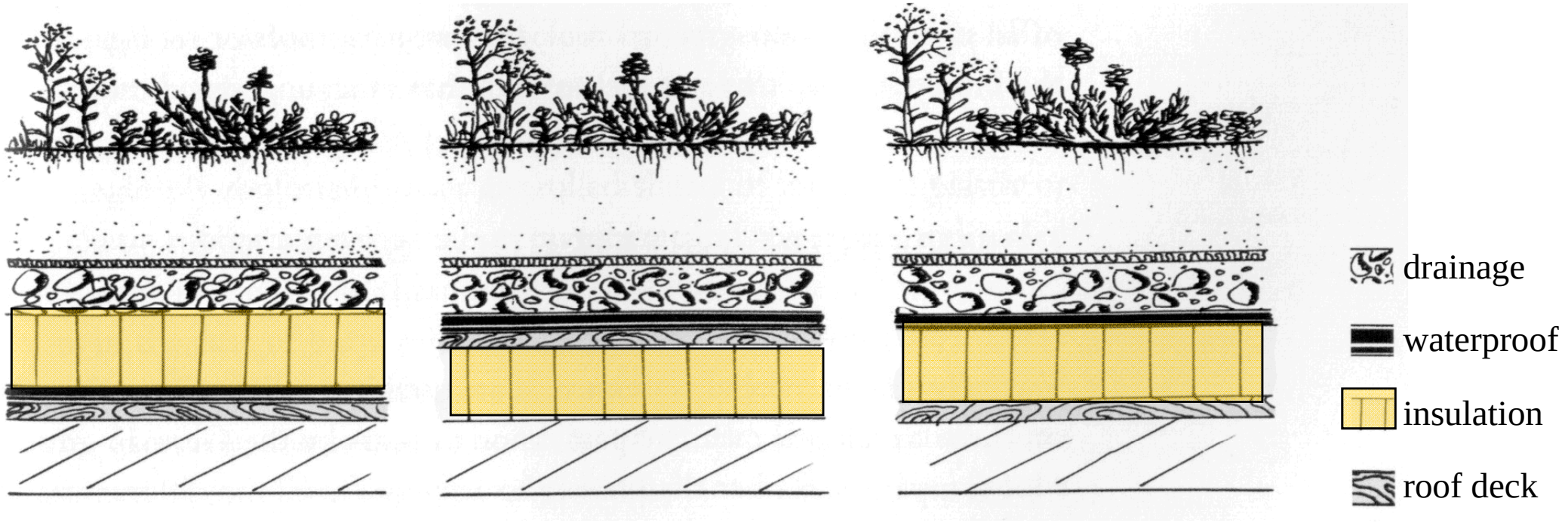
Key components

- Insulation
  - May be made of foams or fibres
    - Foams: expanded or extruded polystyrene, polyurethane foam, phenolic foam; Fibres: vegetable or glass
  - Functions:
    - Reduce heat transfer to and from the building
    - In the winter, prevent moisture trapped in the substrate from removing heat from the building
    - Protect plant roots from freeze thaw cycle
    - May protect waterproofing in inverted system (insulation above the waterproofing)

Key components

- Position of the insulation layer
  - ‘Cold roof’: insulation layer beneath the roof deck (i.e. on top of the ceiling)
  - ‘Warm roof’: insulation layer above the roof deck
    - Roof structure temperature is close to the interior
    - Reduce thermal bridging & risk of condensation
    - Weight/Load resistance required for the insulation
  - ‘Inverted warm roof’: insulation above the waterproof layer rather than below

Three types of roof construction, related to the position of the insulation layer



Inverted

Cold

Warm

(Source: *Planting Green Roofs and Living Walls*)

Key components

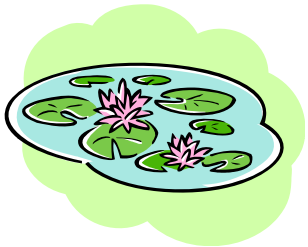
- Membrane protection layer
  - Protective non-woven fabrics, boards and sheeting that are lightweight and water resistant
  - Relatively inexpensive, non-woven and non-biogradable landscape fabric
  - Function:
    - Protect waterproof membrane from construction stress and installation of the drainage layer, if required

Key components

- Leak detection system
  - Electronic field vector mapping (EFVM) uses electrical flow to pinpoint the location of leaks as small as a pin hole
  - 48 hours or longer flood test prior to installation
  - Functions:
    - Ensure quality of waterproofing, e.g. on sloped roofs where water tests are impractical
    - Used to locate leaks

Key components

- Ponds and pools
  - Water features e.g. waterfalls, fountains & ponds can be incorporated into green roof design
  - Separate waterproofing membranes may be used
  - Precast fiberglass shells may be used for ponds
  - Functions:
    - Aesthetic use primarily and psychological benefits
    - May include stormwater management feature



Key components

- Irrigation system
  - Overhead or spray, surface or near surface drip irrigation, capillary irrigation, and base drip or trickle irrigation
    - Extensive systems may function without this
  - Function:
    - Ensure plant survival initially & ongoing health
    - Temporary irrigation required to help plant establish
    - Ongoing irrigation for intensive systems fairly standard

Key components

- Walkways
  - Precast concrete pavers, natural stone, gravel, wood, fiberglass rocks, & recycled plastic decking
  - May be set on pedestals to allow unimpeded drain
  - Functions:

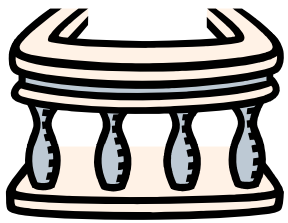
    - Aesthetic benefit; access to mechanical equipment & other roofing features requiring maintenance
    - Control movement of people (keep them from walking on plants)
    - Separate or isolate sections to prevent spread of fires

Key components

- Curbs and borders
  - Precast concrete curbs, aluminum edging, timber borders, planter boxes, recycled curb products
  - May be set on pedestals to allow unimpeded drain
  - Function
    - Aesthetic benefits
    - Separates vegetation areas from structural roof components e.g. parapet walls, drains & skylights
    - May be used to separate vegetation components and provide a fire break or protection from wind uplift

Key components

- Railings
  - Wide range of railing technologies
  - Worker safety anchor systems should be considered during green roof installation
  - Functions:
    - Protect people from falling off the roof
    - May also perform an aesthetic function
    - Limit the access of people to the entire roof, areas of which may be support an intensive system or live loads



Key components

- Lighting
  - Wide range landscape lighting
  - Functions:
    - Aesthetic benefits
    - Night time use and possible security functions

Benefits of green roofs

- Green roofs provide many benefits for building owners and the society
  - Some benefits of green roofs will only be apparent if roof greening is on a large scale; others can operate on a much smaller scale
  - Some benefits are common to almost all green roofs, but many are project design specific

Table 1. Public and private benefits of green roof systems

Public benefits:	**Private benefits:**
- Mitigate urban heat island	- Increase roof life expectancy
- Reduce dust and pollutant levels	- Reduce noise levels
- Stormwater retention	- Enhanced thermal insulation
- Natural habitat for animals/plants	- Heat shield
- Cities and landscapes	- Better use of space
- Nature look (aesthetic)	- Reduced risk of glare for surrounding buildings

Green Roof & Wall **Benefits**

- Overview
- Building Protection
- Heat Island Mitigation
- Energy Savings
- Stormwater Control
- Health and Wellness
- Clean Air
- Sound Insulation
- Habitat Restoration
- Educational Benefits
- Marketable Feature
- Property Value ++

(Source: www.g-sky.com)

Benefits of green roofs

- 1. Environmental benefits
  - 1.1 Biodiversity and wildlife value
  - 1.2 Stormwater management
  - 1.3 Rainwater runoff quality
  - 1.4 Air pollution mitigation
  - 1.5 Carbon sinks (sequestration)
  - 1.6 Mitigation of urban heat island
  - 1.7 Control of noise pollution

Benefits of green roofs

- 1.1 Biodiversity and wildlife value
  - As a habitat to support life (plants, birds, insects)
  - Create links & continuity for green space
- 1.2 Stormwater management
  - Rainwater retention
  - Peak flow mitigation
- 1.3 Rainwater runoff quality
  - Improve water quality; reduce nutrient loading; neutralize acid rain

Benefits of green roofs

- Stormwater problems
  - Stormwater runoffs causes flooding & other problems; resultant costs are borne by the community as a whole
  - Increased frequency of severe rainstorms
  - Measures to reduce/control stormwater, e.g. detention pools, green roofs
  - A key point to translate green roof benefits into improvements in immediate cash flow $$

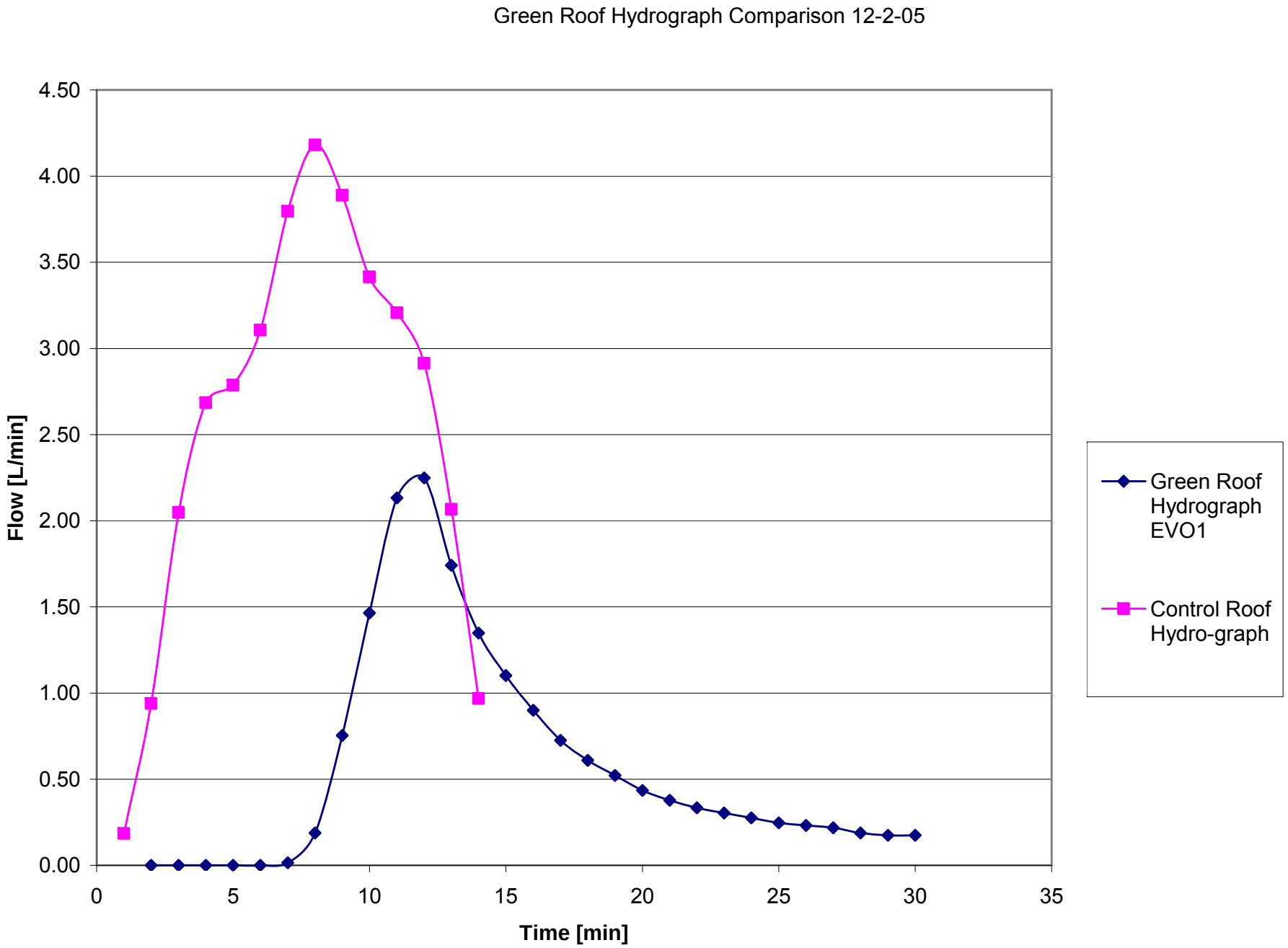
Rainstorm flooding problems in Hong Kong (2008)

(Source: www.accuweather.com)

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

- Stormwater benefits of green roofs
  - Greatest contribution is in low-intensity to moderate storms
  - Once the roofs are saturated, their effect lessens
  - When combined with other sustainable drainage measures, green roofs can be really effective
- Possibility of integrating rainwater or greywater recycling systems

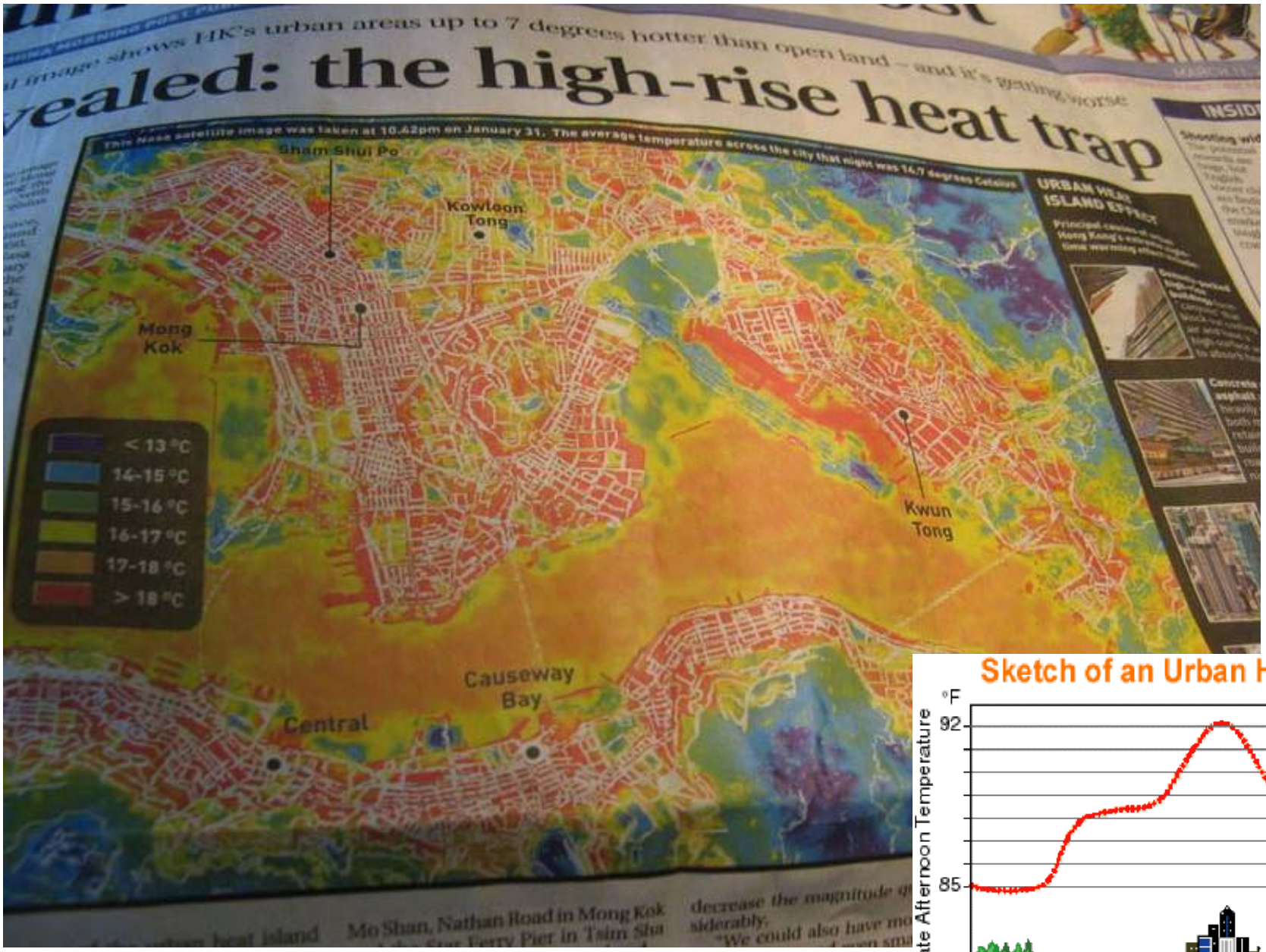
Benefits of green roofs

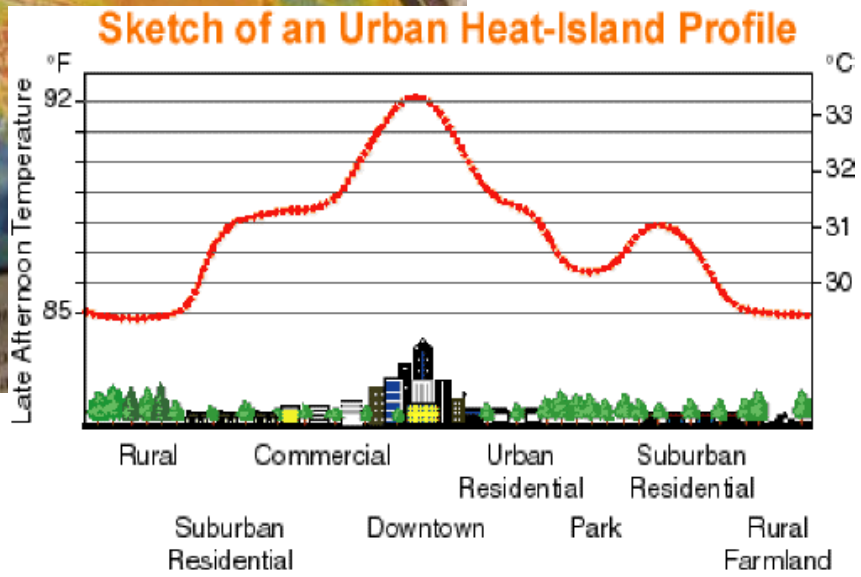
- 1.4 Air pollution mitigation
  - Filter out fine airborne particles
  - Foliage can absorb gaseous pollutants
  - Most effective if in large scale roof greening
- 1.5 Carbon sinks (sequestration)
  - Little evidence now to quantify the benefits
  - More research is needed

Benefits of green roofs

- 1.6 Mitigation of urban heat island
  - '***Urban heat island (UHI)***': elevated urban temperatures & associated atmospheric pollution
    - Large number of built structures absorb/release heat
    - Reduction in evaporating surfaces
    - Lack of vegetation cover, shading and evaporation
    - Waste heat from buildings & vehicles
    - Less cooling from wind because of shelter of buildings
  - Urban air temperatures significantly higher than in the surrounding countryside

Urban heat island in Hong Kong





(Source: SCMP and Lawrence Berkeley National Lab)

Benefits of green roofs

- 1.7 Control of noise pollution
  - Hard surfaces of urban areas tend to reflect sound rather than absorb
  - Green roofs can absorb sound and reduce noise
    - Reduce sound transmission into buildings
    - Sound damping and absorption
  - Usually very effective for metal roofs

Benefits of green roofs

- Economic benefits of green roofs
  - 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

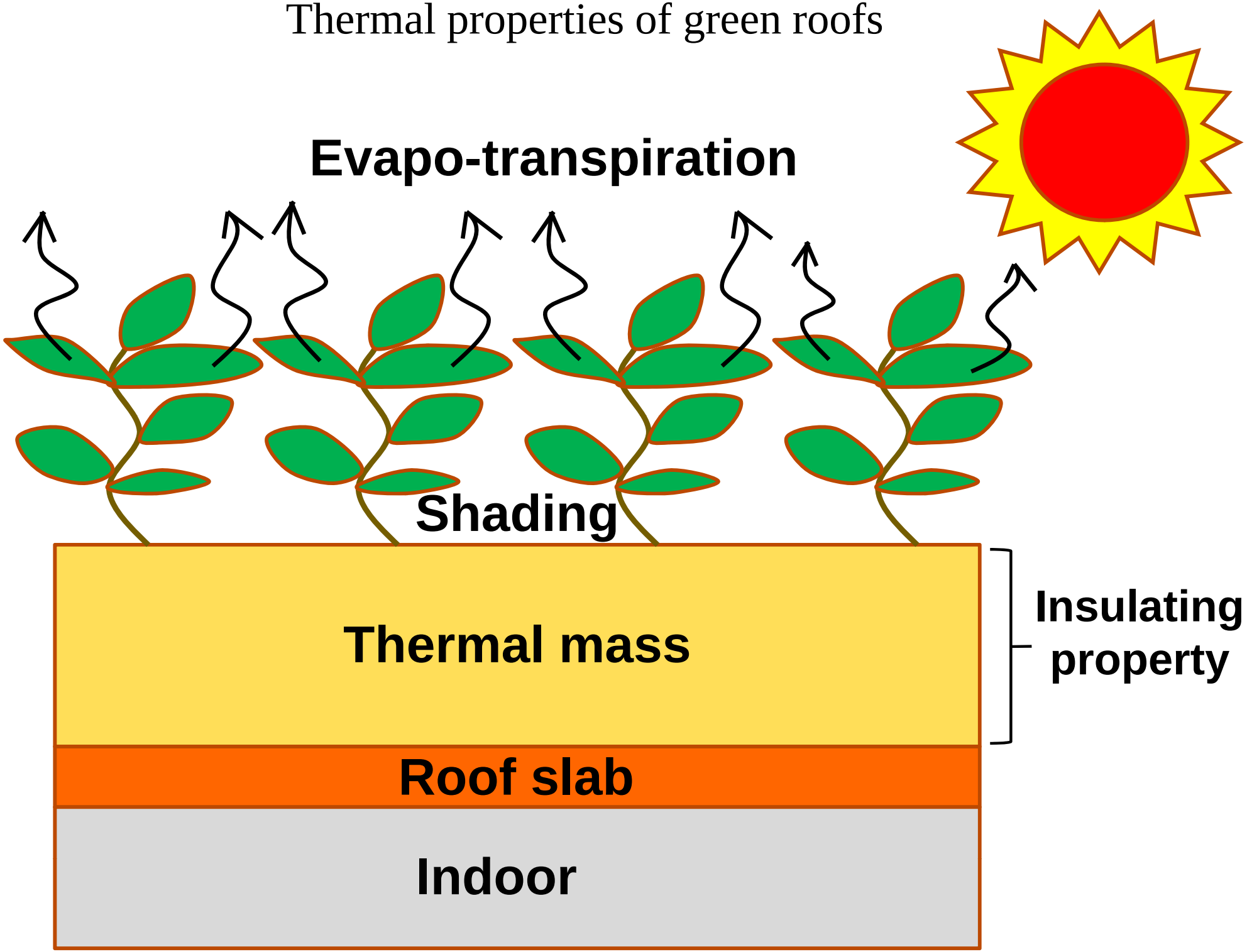
Benefits of green roofs

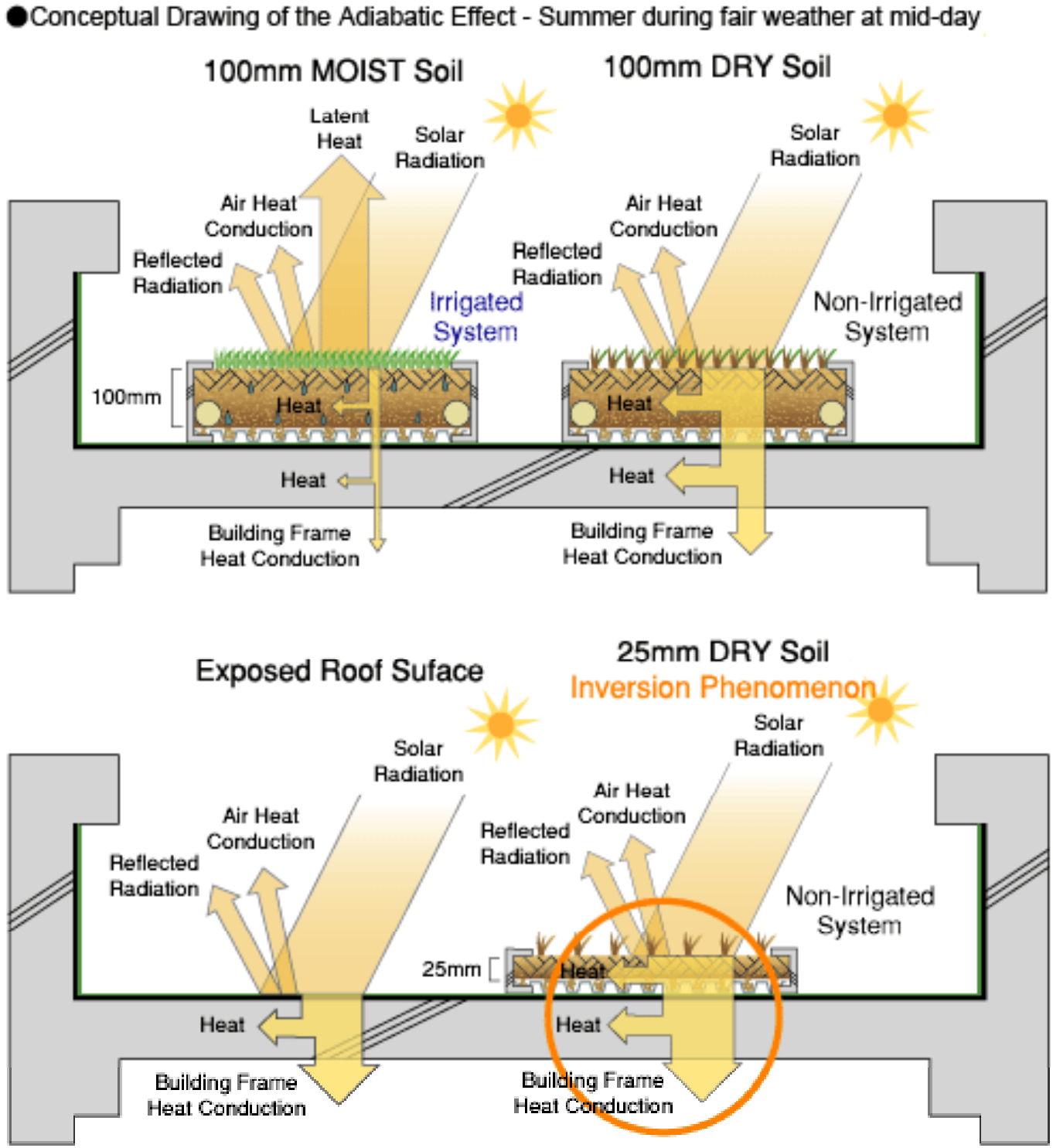
- 2.1 Increased roof life
  - Exposed roofs
    - Experience higher temperature than that of green roofs
    - Daily temperature fluctuations create thermal stresses
    - Roofing materials & membranes are degraded
  - Green roofs
    - Moderate the daily temperature fluctuations
    - Protect the roof 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

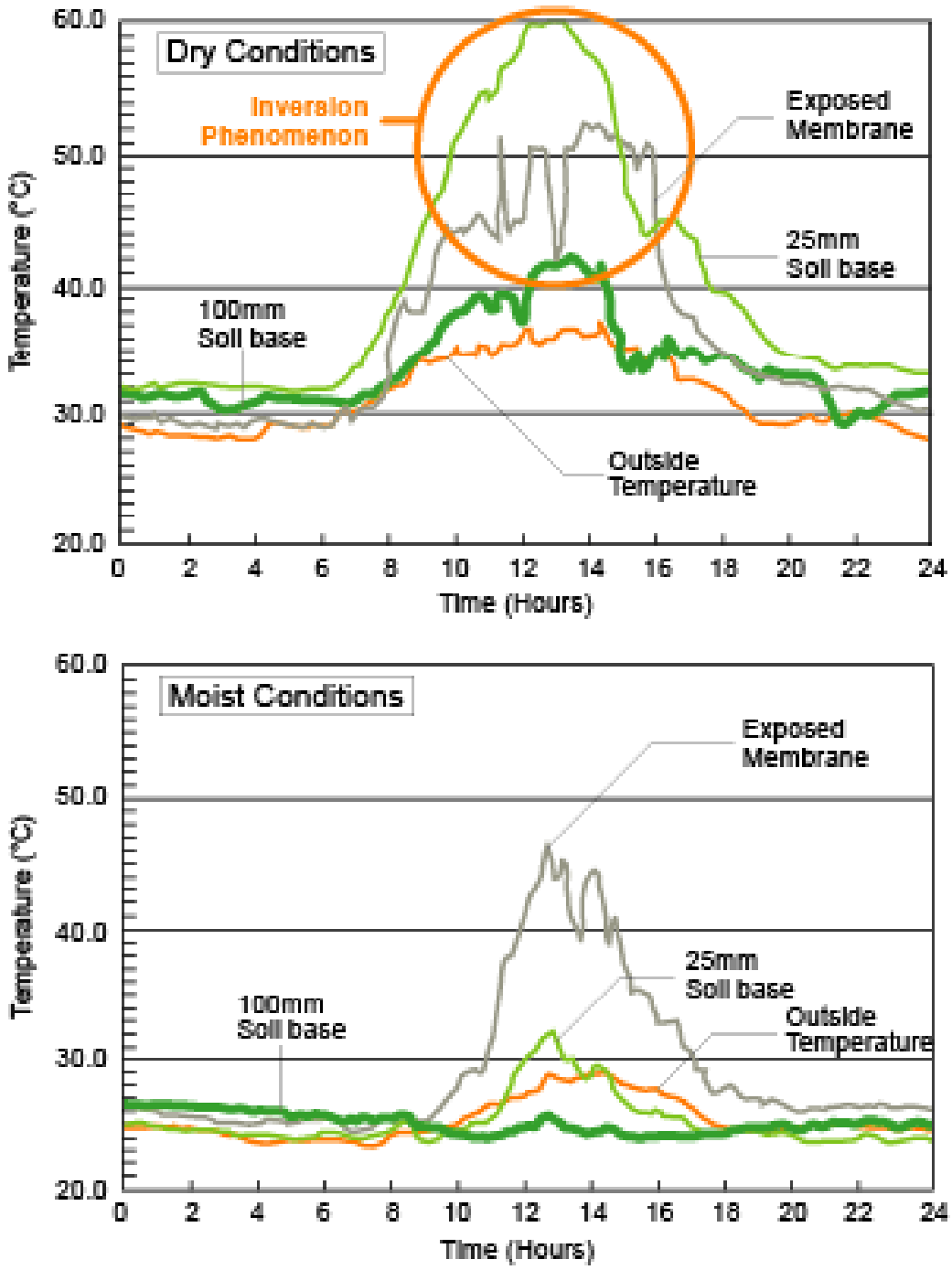
Thermal properties of green roofs





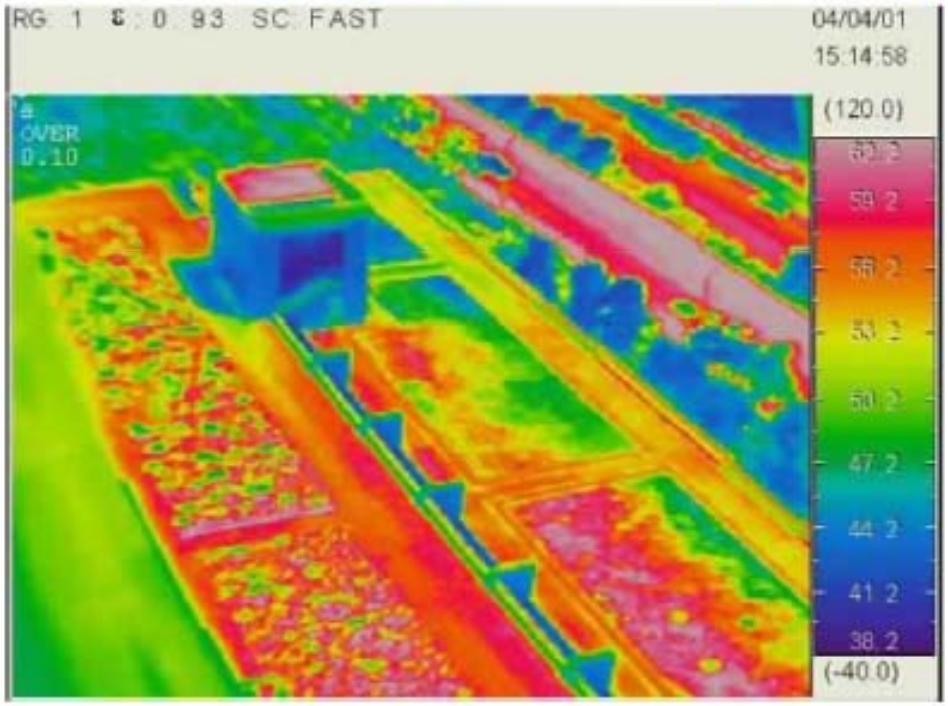
(Source: www.g-sky.com)

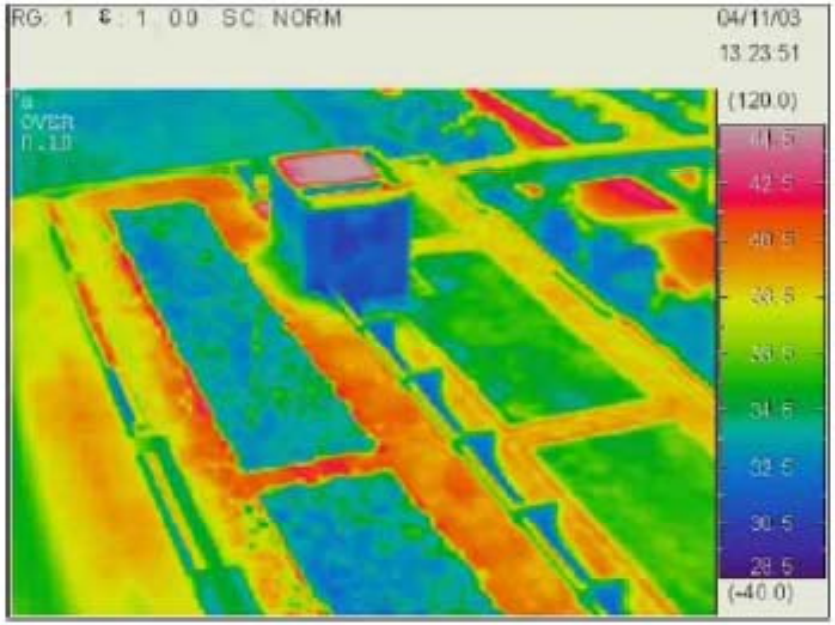
●Temperature variation of thin Green Roof Systems



(Source: www.g-sky.com)

Green roof evaluation in Singapore



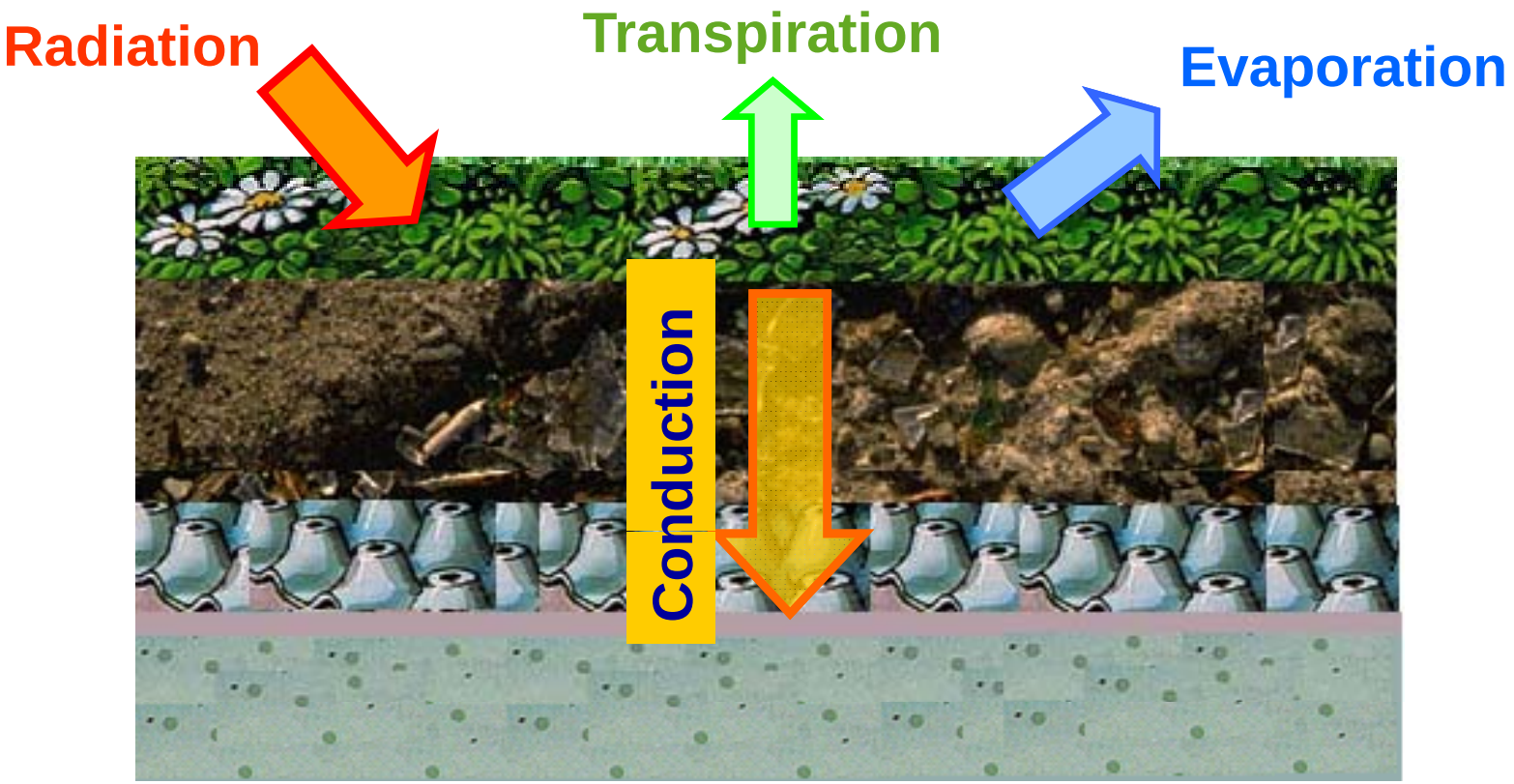


(Source: Wong, Tan and Chen, 2007)

Benefits of green roofs

- Cooling effect of a green roof
  - Affect mainly upper floors of a building
  - Saving in annual and peak energy consumption
  - Can be enhanced by active irrigation to ensure continuous evapotranspiration and by circulating water through wetland vegetation on the roof

Thermal modelling of green roofs

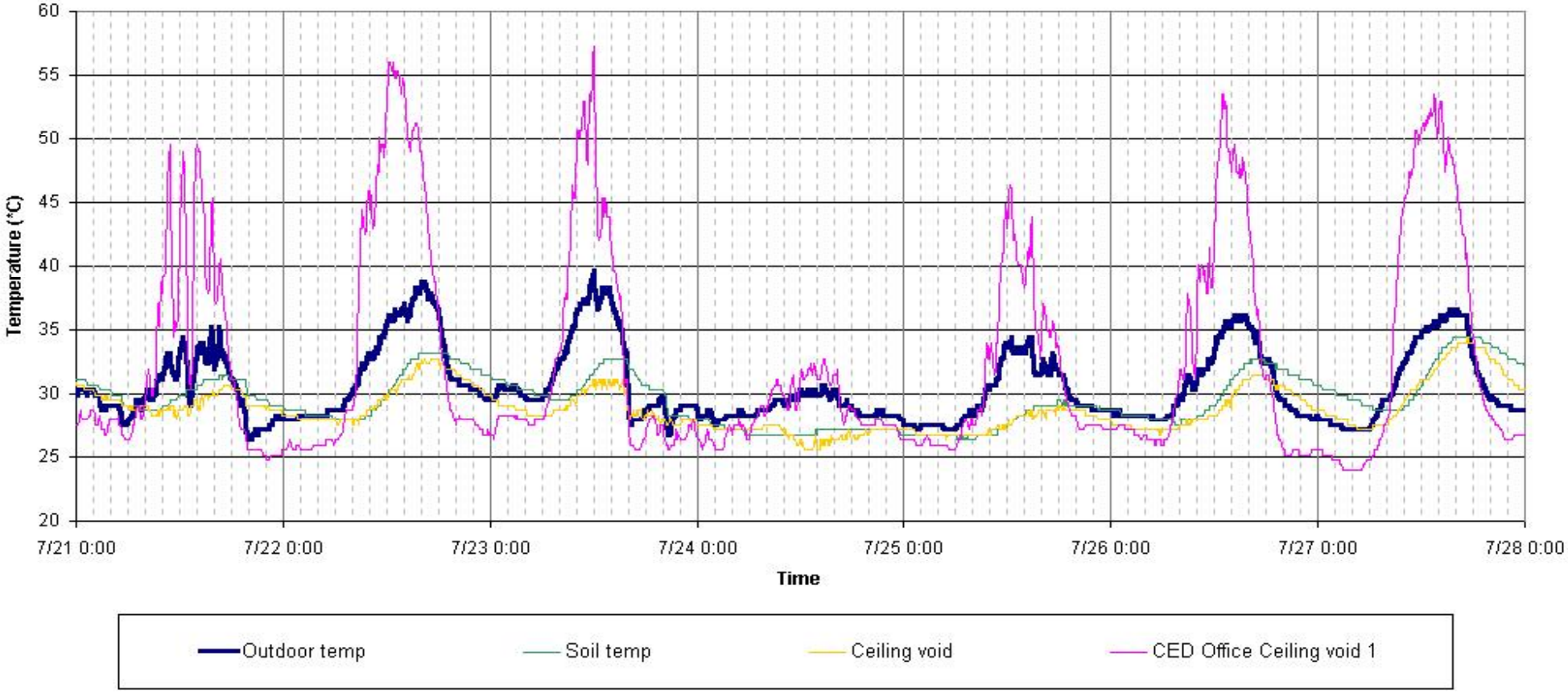


Radiation: $R_n = R \exp(-k_s LAI)$

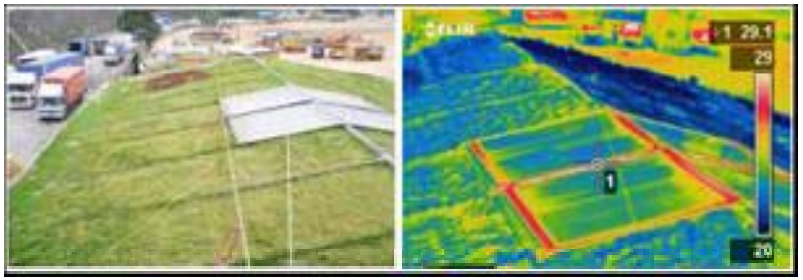
Evapo-transpiration: $q'' = -2LAI \dfrac{\rho C_p}{\gamma(r_e + r_i)} \left(\dfrac{w\Re T}{h_m}\right)$

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

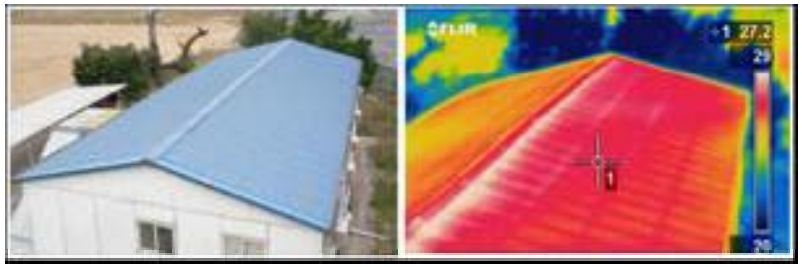
Green roof research at a construction site office (cont'd)



Infrared pictures:



Green roof



Conventional roof

Benefits of green roofs

- 2.3 Green building assessment
  - Green roofs can gain points in some green building rating schemes, e.g. LEED in USA
    - 1) Reduced site disturbance, protect/restore open space
    - 2) Water efficiency
    - 3) Energy and climate
    - 4) Materials and resources
    - 5) Indoor environmental quality
    - 6) Innovation in design
  - Up to 15 LEED credit points may be available

Benefits of green roofs

- 2.4 Public relations and image
  - Promote ‘green’ image of a building/organisation
  - Public relations (PR) and marketing value
  - May attract environmentally-conscious tenants
  - May increase rental income & uptake rate
  - Can have direct financial benefit

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
    - 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.

Benefits of green roofs

- Other possible social benefits of green roofs
  - Urban farming (e.g. growing vegetables, herbs)
    - Make best use of roof space; may be organic
  - Education (environmental, scientific, liberal study)
    - Integrated with school curriculum
  - Community and social functions
    - Exercises & hobbies for children, adults & elderly
  - Healing landscape (e.g. horticultural therapy)
    - Sensory, meditation effects; manage emotion/stress

Urban farming & education

Horticultural therapy & social functions

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

Nanyang Technological University, Singapore
School of Art, Design and Media

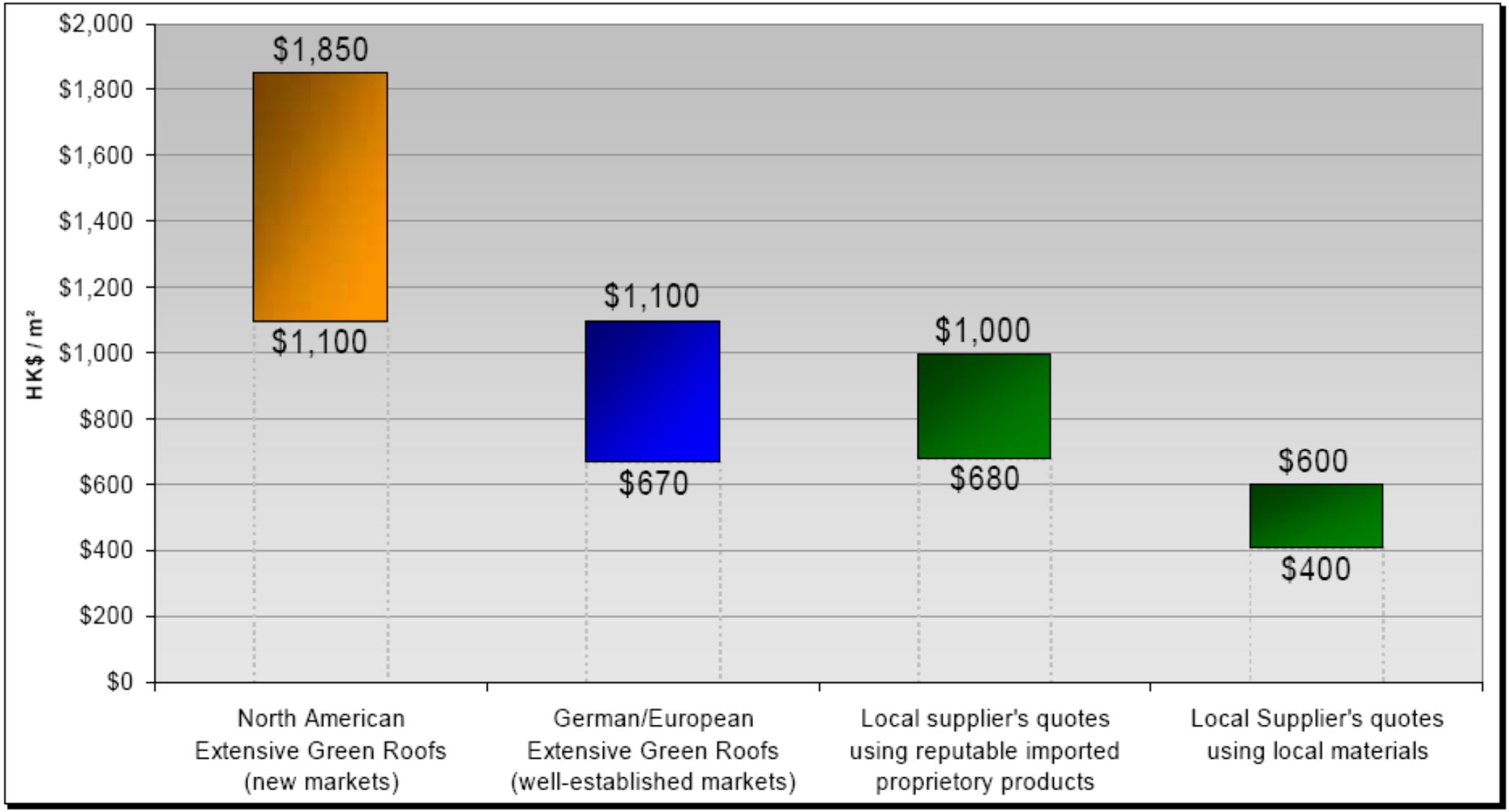
(Source: www.inhabitat.com)

Costs of green roofs

- Typical green roof prices (capital cost) in HK:
  - Extensive green roofs: HK$400 to 1,000 per sq.m (average HK$500 per sq.m)
  - Intensive green roofs: HK$1,000 to 5,000 per sq.m, (average HK$2,000 per sq.m)
- Typical recurrent (maintenance) costs
  - Extensive green roofs: HK$0.8 to $2.2/sq.m/year
  - Intensive green roofs: HK$6.5 to $44/sq.m/year (average $20/sq.m/year)

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

Capital cost rang comparison of extensive green roof



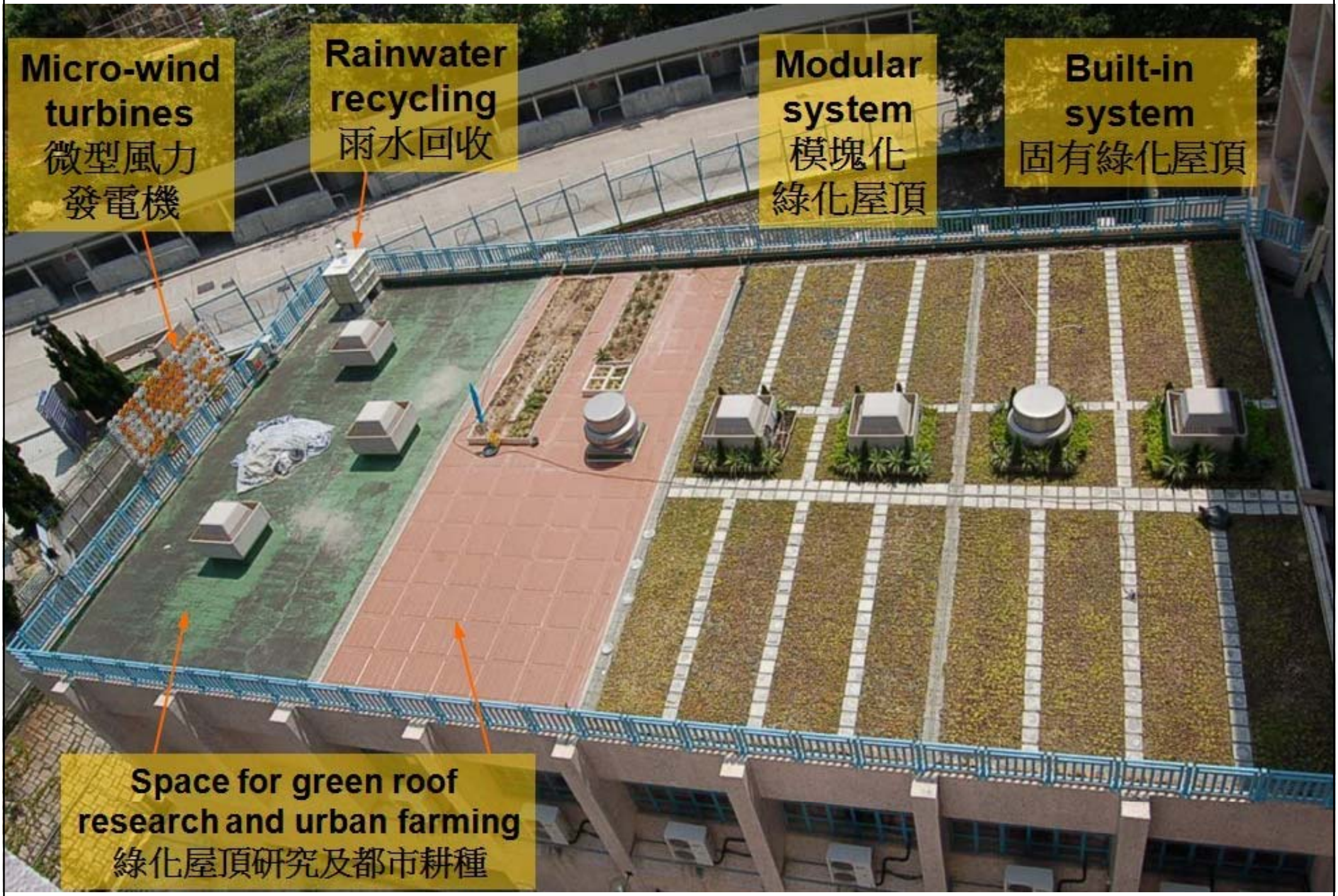
Note: All costs quoted in Hong Kong Dollars

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

Costs of green roofs

- 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

Green roof research and urban farming



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)

THANK YOU 謝謝 !!

The green roof volunteers in Hong Kong
香港綠色屋頂的志願者

(Our green roof research information can be found at: www.hku.hk/bse/greenroof/)