香港都市綠化研討會
Seminar on Urban Greening in Hong Kong

School of Life Sciences
The Chinese University of Hong Kong
生命科學學院

Vertical Greening 垂直綠化

Opportunities and Challenges 機遇與挑戰

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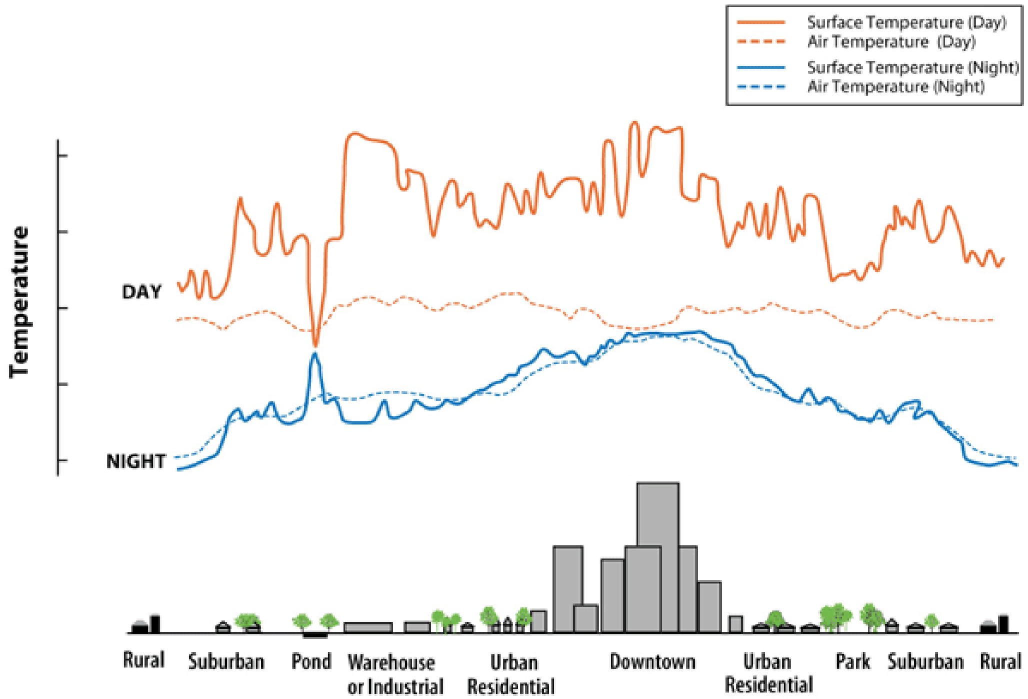
1. INTRODUCTION 引言

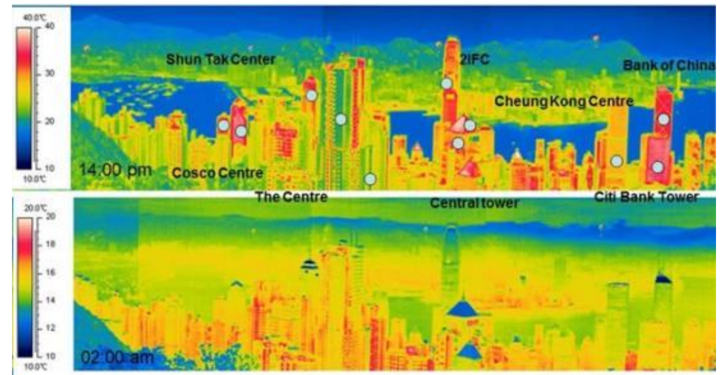
1.1 Adverse impacts of urbanization 城市化的負面影響

- population growth 人口增長
- habitat loss 棲息地破壞
- pollution 污染
- climate change 氣候變化

1.2 Concrete jungles 石屎森林

- urban heat island effect 城市熱島效應
- higher night temperature 提升夜間溫度
- elevated air particulate contents
  增加空氣微粒含量
- urban canyon 城市峽谷
- lack of greening space 綠化空間短缺





1.3 Urban landscaping 都市绿化

(This illustration is inspired by: Scientific American, September 2011)

Green / Liveable City 绿色/宜居城市


COURTESY STUDIO INVISIBLE



COURTESY STUDIO INVISIBLE


Bosco Verticale, Milan (2013)

AgoraGarden, Taipei (2016)

Clearpoint Residencies, Sri Lanka (2015)

Vegitecture

Urban Greening for the Future?

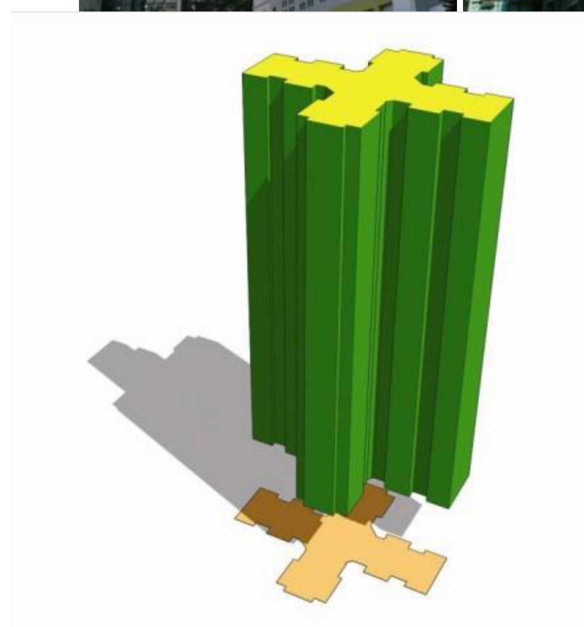
未來城市綠化？

Architecture for the Future?

未來建築？

1.4 Vertical greenery as alternative 垂直綠化？

- tall building blocks 高樓大廈
  - high wall:roof 高牆：屋頂
  - large SA 更大表面面積
- free up precious ground space for other uses 騰出珍貴的地面空間作其他用途
- alleviate increased solar heat interception by urban canyon 減輕城市峽谷的太陽熱能截取
- alleviate visual barrier in concrete jungles 緩解石屎森林的視覺障礙







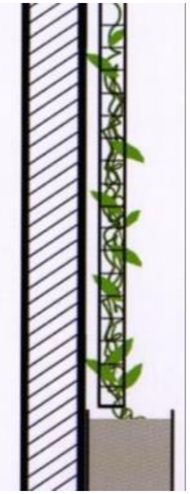


2. VERTICAL GREENING 垂直綠化

- vertical garden/living curtain/green wall/green facade
  垂直綠化、壁面綠化、立體綠化、綠牆、植生牆
- horticultural practices that expand and extend vertically in space
  垂直延伸的園藝種植方法
- free-standing or part of a building
  獨立式或成為建築物的一部分
- partial or complete vegetation coverage
  部分或完全被植被覆蓋
- outdoor or indoor 室外或室內

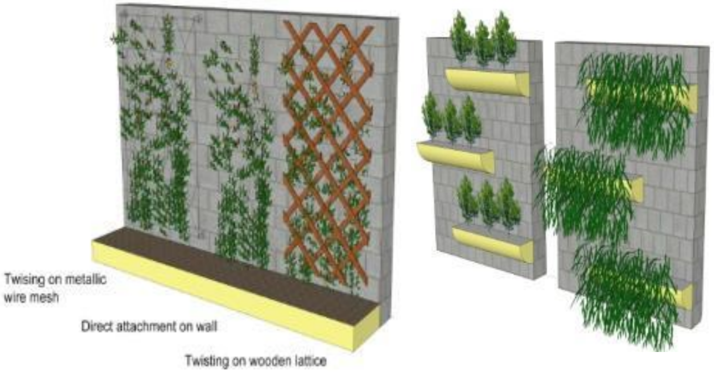



2.1 Types of vertical greening method
垂直綠化方法及種類



Facade greening / Green wall

- support system 支架式系統
  – vines 藤本植物
  1. on soils at ground/elevated level 地面上/高架位置的花槽
  2. grow on support 支架上生長



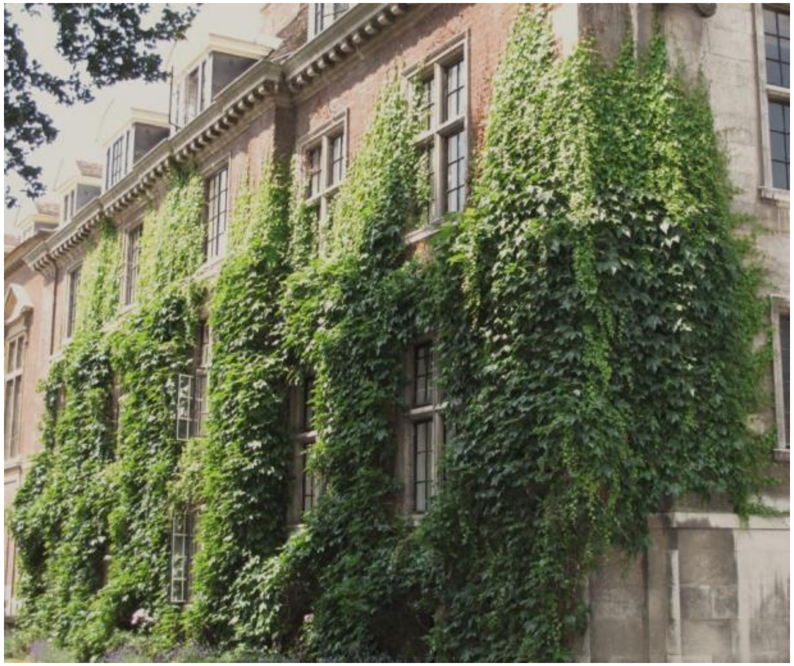
On-the-ground type using vines
在地面種植藤本植物

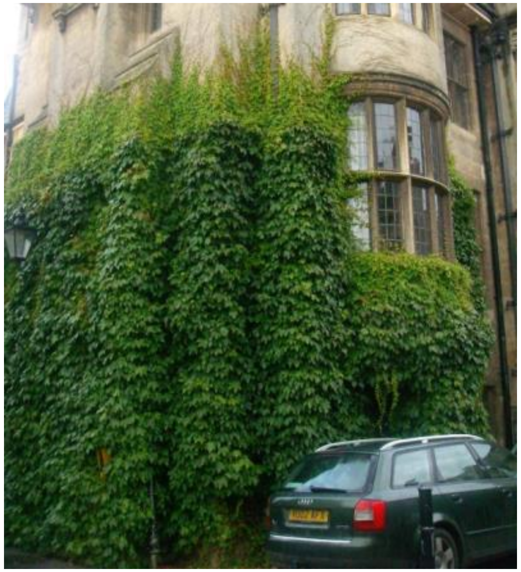
Elevated planter
高架種植

Exterior of a railway station in Hong Kong. *Parthenocissus himalayana* can directly attach to brick or concrete surface.
香港一火車站的外觀 - 爬山虎直接生長在磚或混凝土表面。

Vines can grow on wires and pergolas to form a green cover on building.
藤蔓可在金屬線和棚架上生長，形成一個綠色覆蓋的建築物。

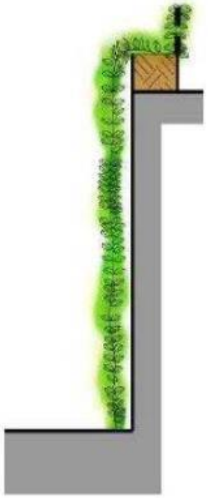


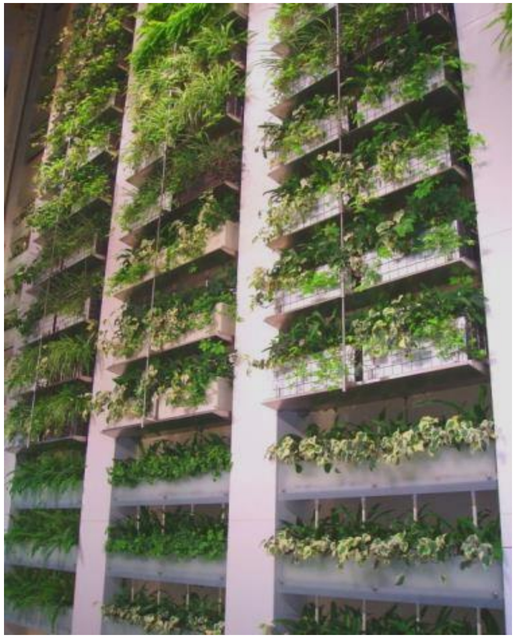




Elevated planters 高架種植

- raised planters/elevated boxes at certain height
  使用高架花槽
- climbing and hanging plants, other herbaceous plants
  攀爬和懸掛植物、其他草本植物
- weight loads – light soil mixes 負載重量 – 輕混合土壤

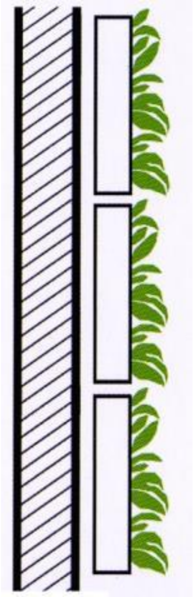




Elevated planters on a commercial building in Ginza, Japan.
日本銀座一商業樓宇的高架花盆。

Shower of gold climber on the Library at the Singapore National Management University. 新加坡國立管理大學三星果藤。

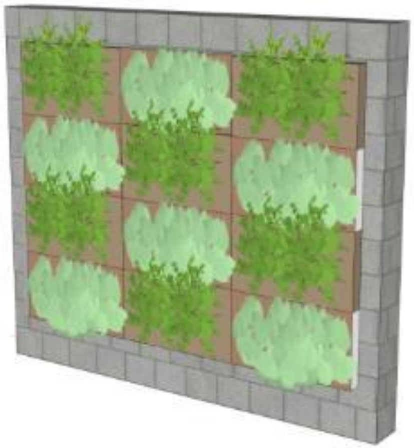
2.1 Types of vertical greening method
垂直綠化方法及種類



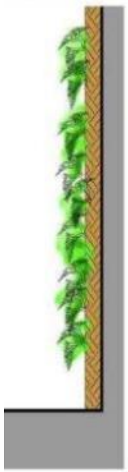
Wall planting / Living wall

- carrier system 承載式系統
  - groundcovers, grasses, sedges, ferns and even shrubs
    地被植物、禾本科、莎草科、蕨類甚至灌木

1. on soils contained within modular planters mounted on wall 模塊花盆安裝在牆上
2. irrigation system on top 頂部裝灌溉系統



Modular planter 模塊式花盆



Mur vegetal

Quai Branly Museum, Paris, France 法國巴黎

Les Halles, Avignon, France 法國阿維尼翁

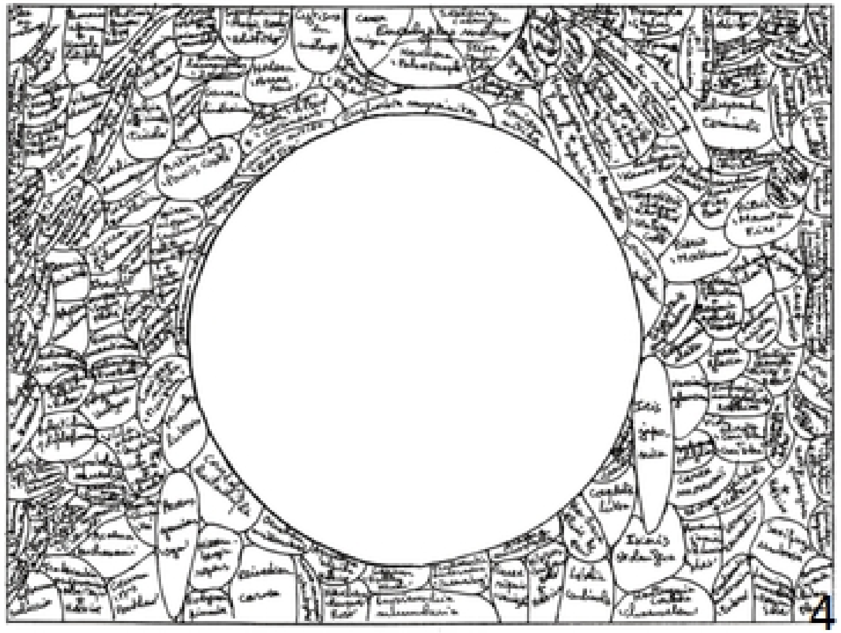
BHV, Paris, France 法國巴黎

Vinet Square, Bordeaux, France 法國波爾多

Hotel Icon, Hong Kong 香港

Mr Patrick Blanc

Le Forum Culturel du Blanc-Mesnil 勒布朗 - 梅尼爾



Green Gate, Muharraq, Bahrain 巴林穆哈拉格

Vertical gardens by Patrick Blanc

Patrick Blanc 的垂直花園

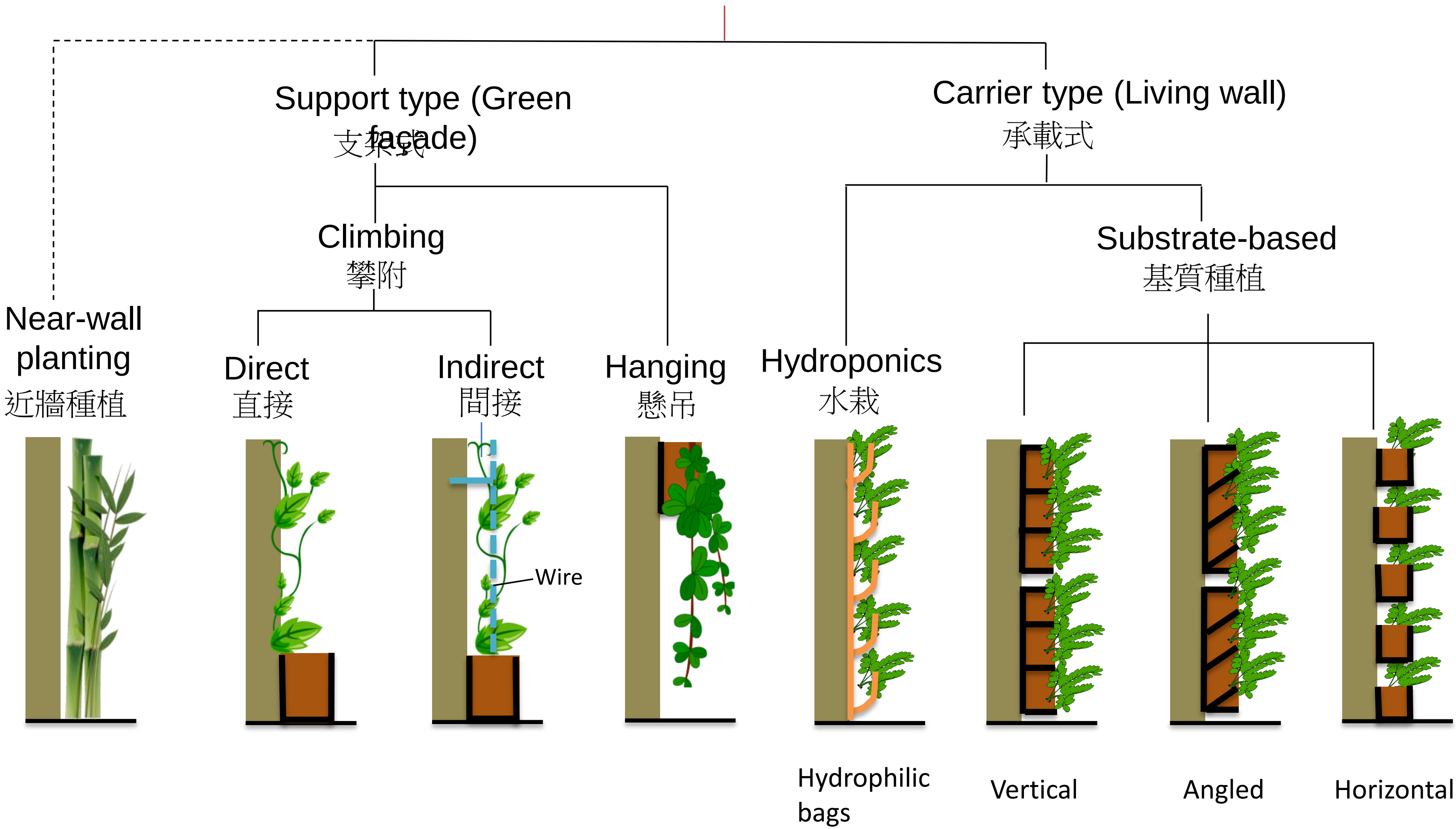

Francfranc


Panasonic
Panasonic


VAIO
GIORGIO ARMANI

Vertical Greenery Systems

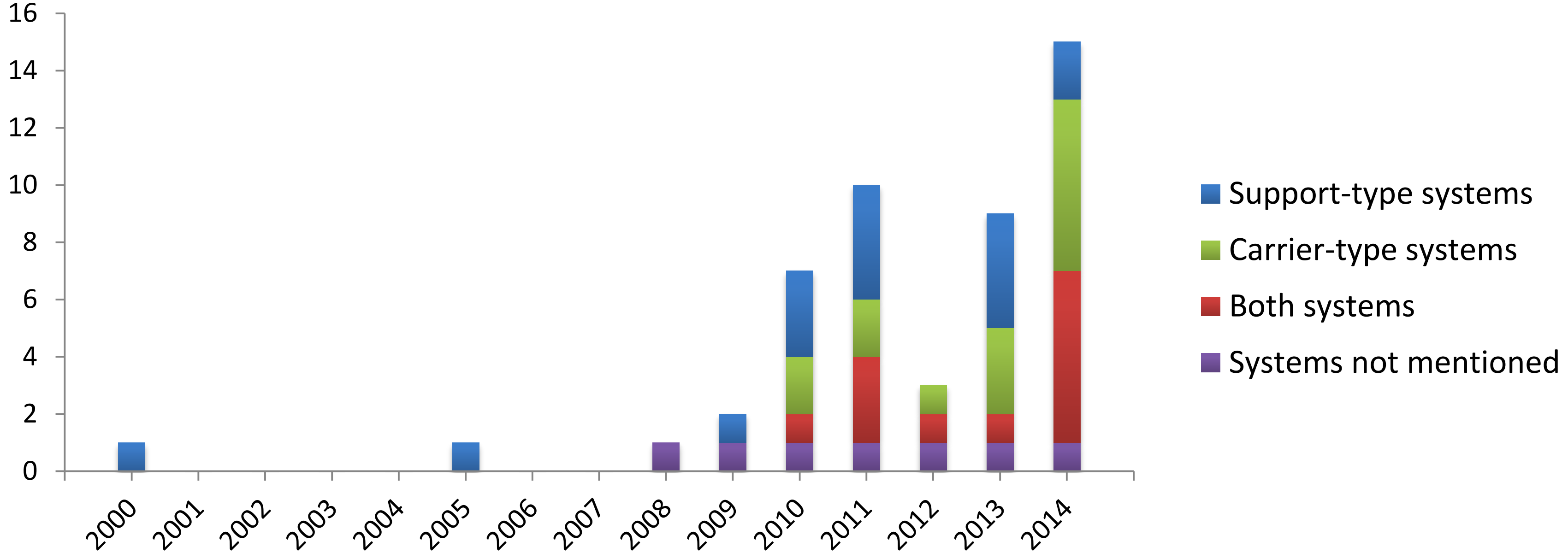
垂直綠化系統



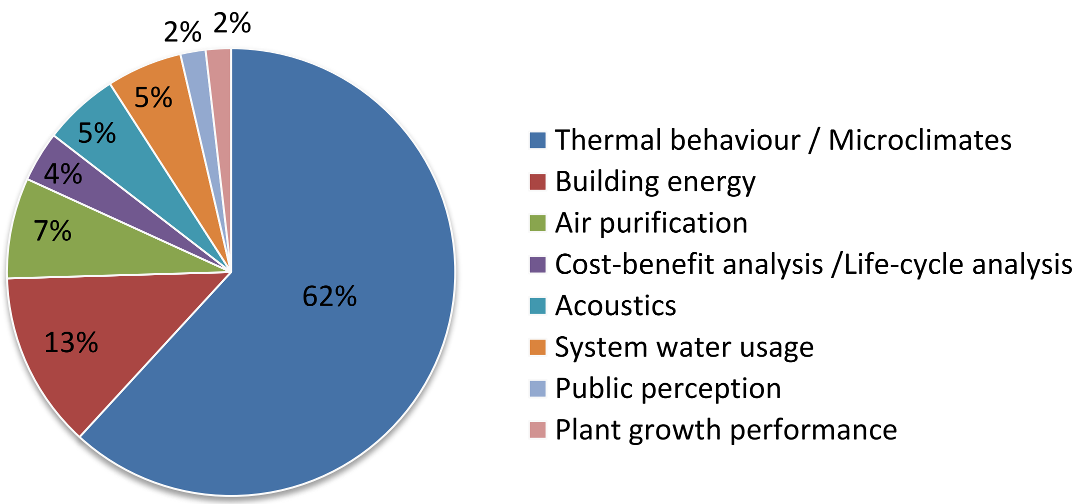
Major types of VGS according to planter position and orientation

根據花盆位置和方向分辨主要垂直綠化的類型

3. RESEARCH IN VERTICAL GREENING
垂直绿化研究



Number of SCI publications (N=49) on vertical greening from 2000 to 2014 (June) classified by greenery systems and research topics.



3.1 Our research on vertical greening

3.1.1 Assessment of the temperature reduction ability of support-type vertical greening system

- support system
- outdoor
- east-facing wall
- 13 species (climbers)
- on planters and metallic mesh


Bauhinia glauca
羊蹄甲藤


Bougainvillea spectabilis
簕杜鵑


Clerodendrum thomsonae
龍吐珠


Clitoria ternatea
藍花豆


Lonicera japonica
忍冬


Mandevilla × amabilis
飄香藤


Mansoa alliacea
蒜香藤


Pandorea jasminoides
紅心藤


Passiflora edulis
百香果


Pyrostegia venusta
爆仗花

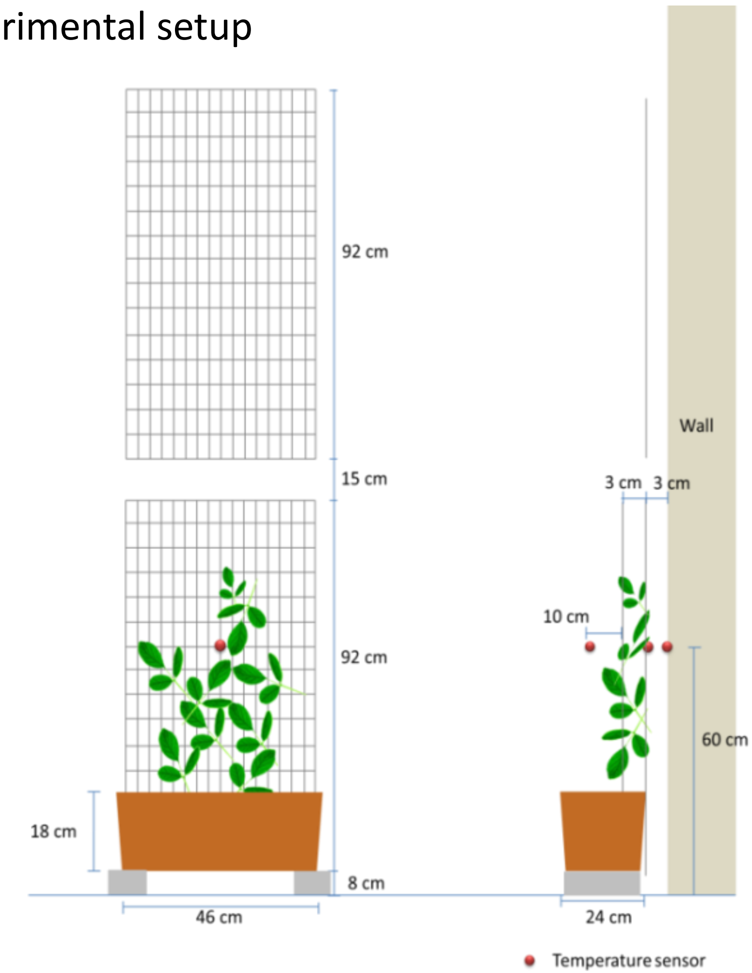

Quisqualis indica
使君子


Thunbergia grandiflora
大鄧伯花

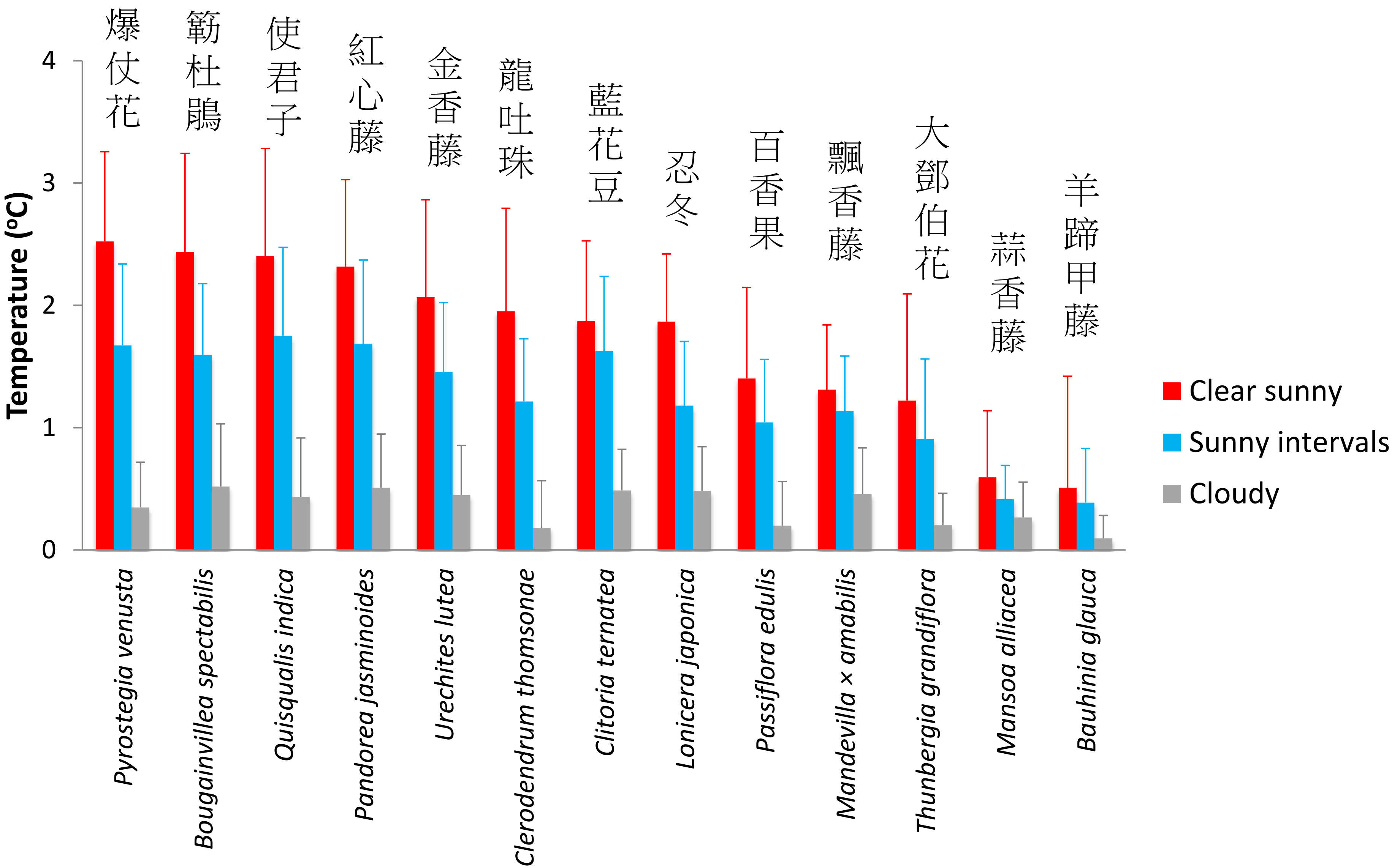

Urechites lutea
金香藤

13 climbing species

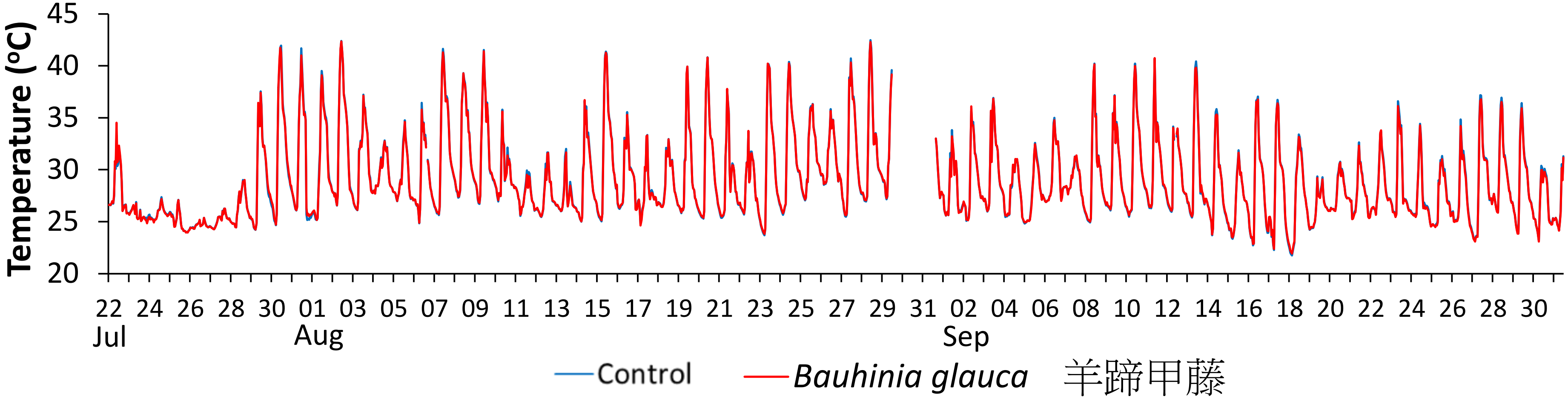

Experimental setup

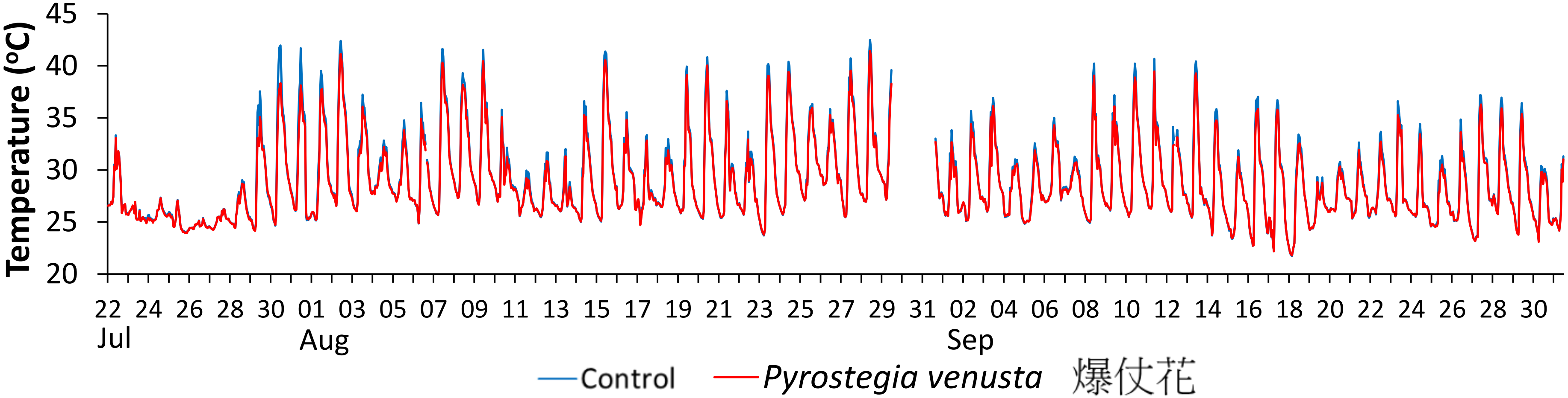


Design and installation of modular planter

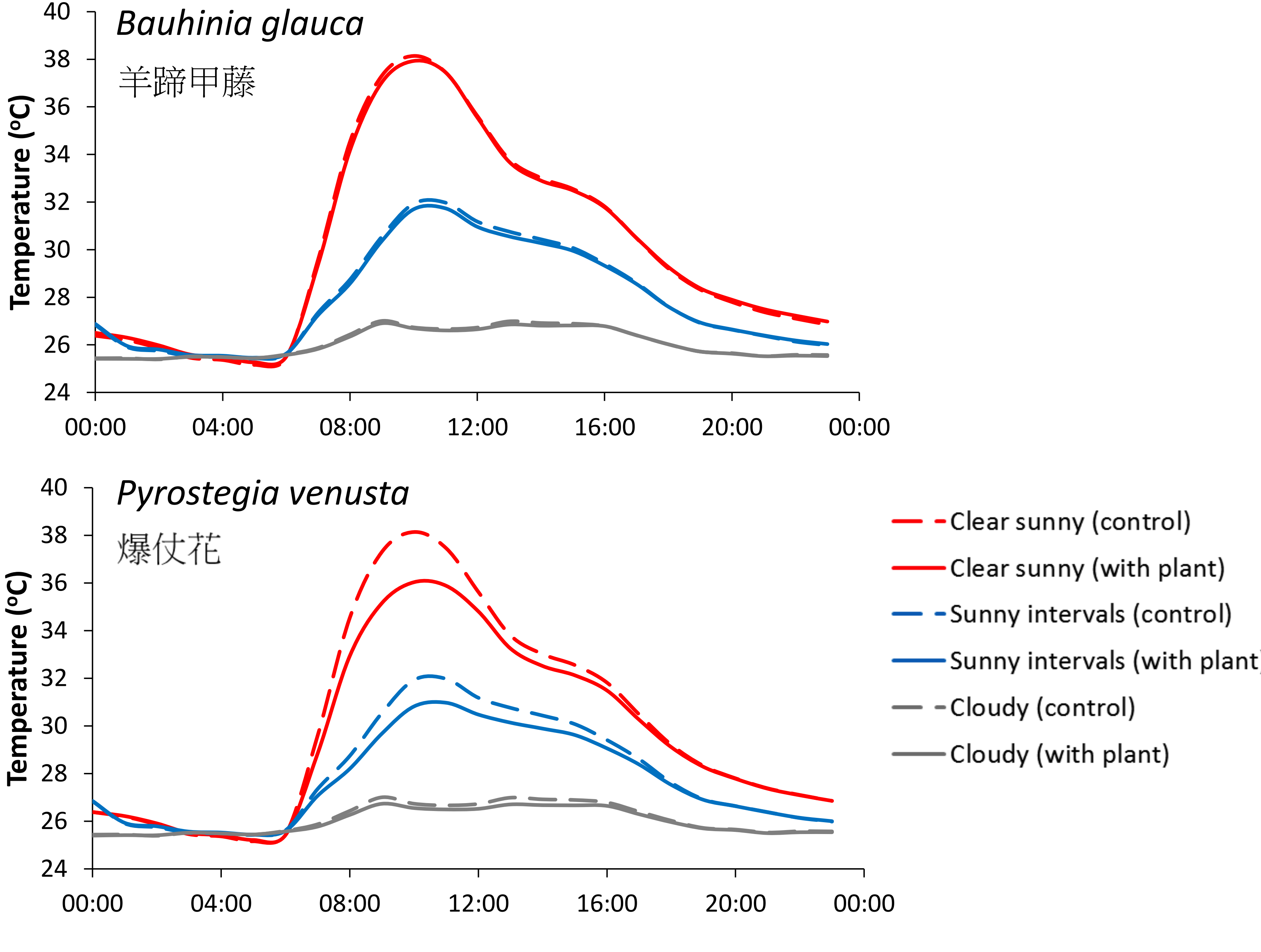


Average maximum temperature reduction ability of each species under different weather conditions





Mean hourly temperature behind canopy of *Bauhinia glauca* and *Pyrostegia venusta*



Diurnal temperature changes behind canopy

Pearson correlation between temperature reduction behind canopy and canopy characteristics on clear sunny days

	Correlation coefficient
Leaf number	0.26
Leaf density (no./cm^3)	0.04
Leaf angle (º)	0.04
Effective LAI	0.42
Leaf area (cm^2)	-0.10
Canopy thickness (cm)	**0.62****
Canopy coverage (%)	**0.84****
LAI	**0.73****
Leaf thickness (cm)	0.21
Leaf color (hue)	0.11
Leaf length to width ratio	0.10
PC 1	0.16
PC 2	**0.79****
PC 3	-0.07
PC 4	-0.23
PC 5	0.38

* p < 0.05; ** p < 0.01

Major PCs 主元 and their attributes 屬性 of canopy characteristics of the 13 climbing species

Canopy characteristics	PC1	PC2	PC3	PC4	PC5
Leaf number	**-0.79**	0.54	0.27	0.02	-0.10
Leaf density (no./cm^3)	**-0.82**	0.34	0.37	0.18	-0.13
Leaf angle (º)	**-0.73**	0.04	-0.44	0.01	0.43
Effective LAI	**0.80**	0.45	0.31	0.07	-0.19
Leaf area (cm^2)	**0.77**	-0.41	-0.16	-0.33	0.11
Canopy thickness (cm)	-0.06	**0.82**	-0.46	-0.07	0.11
Canopy coverage (%)	0.18	**0.84**	-0.35	-0.04	-0.14
LAI	0.56	**0.73**	0.10	-0.04	0.26
Leaf thickness (cm)	0.31	-0.14	**0.55**	-0.27	0.35
Leaf color (hue)	-0.44	0.17	0.34	**-0.67**	-0.13
Leaf length:Leaf width	0.29	0.16	-0.18	-0.56	**-0.53**
Variance explained (%)	35	29	11	8	**6**

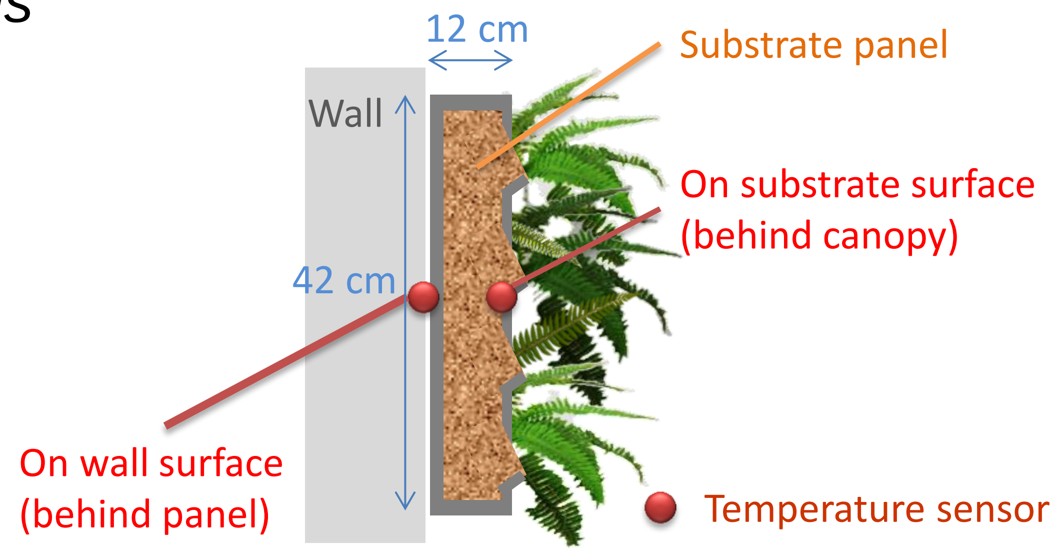
Summary

- There were difference in thermal reduction performance between the various species studied.
- *Pyrostegia venusta* was significantly higher than *Bauhinia glauca* in their temperature reduction ability in the support-type vertical greening system.
- Thermal performance was significantly related to canopy attributes such as canopy thickness, canopy coverage and LAI.
- Denser, thicker and better-covered vegetation was better in terms of microclimate modification.

3.1.2 Assessment of the temperature reduction ability of carrier-type vertical greening system

- carrier system
- outdoor
- east-facing wall
- 2 species
  - *Ophiopogon japonicus* cv. Nanus 日本蒲草
  - *Nephrolepis exaltata* 波士頓蕨
- on modular panels

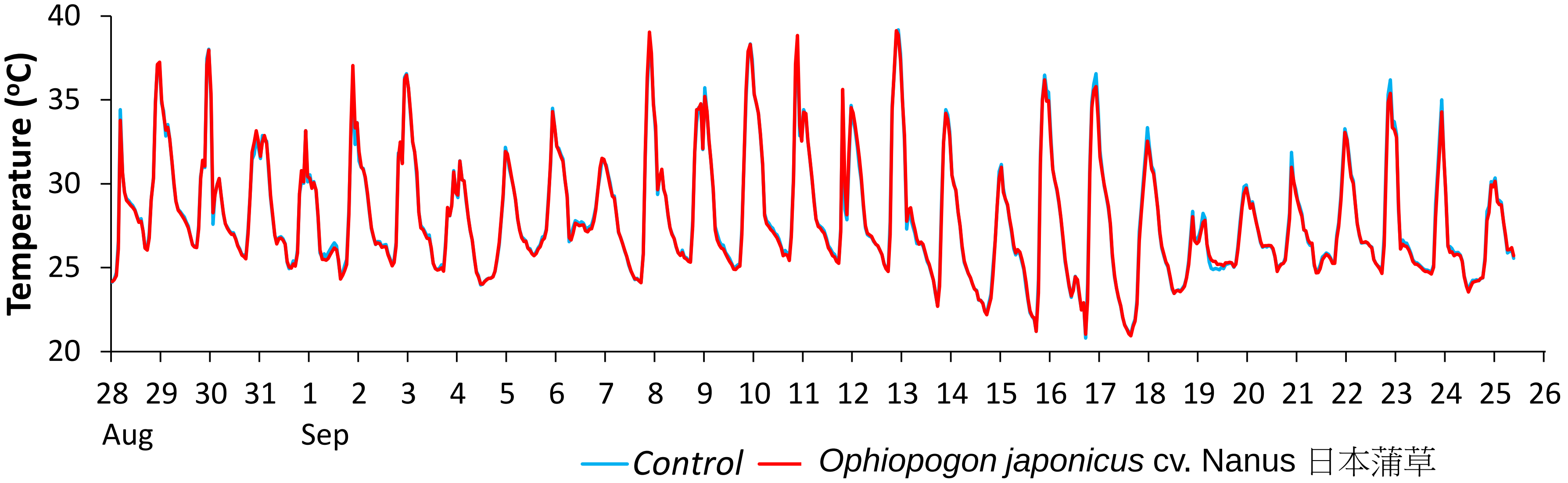
Experimental setup

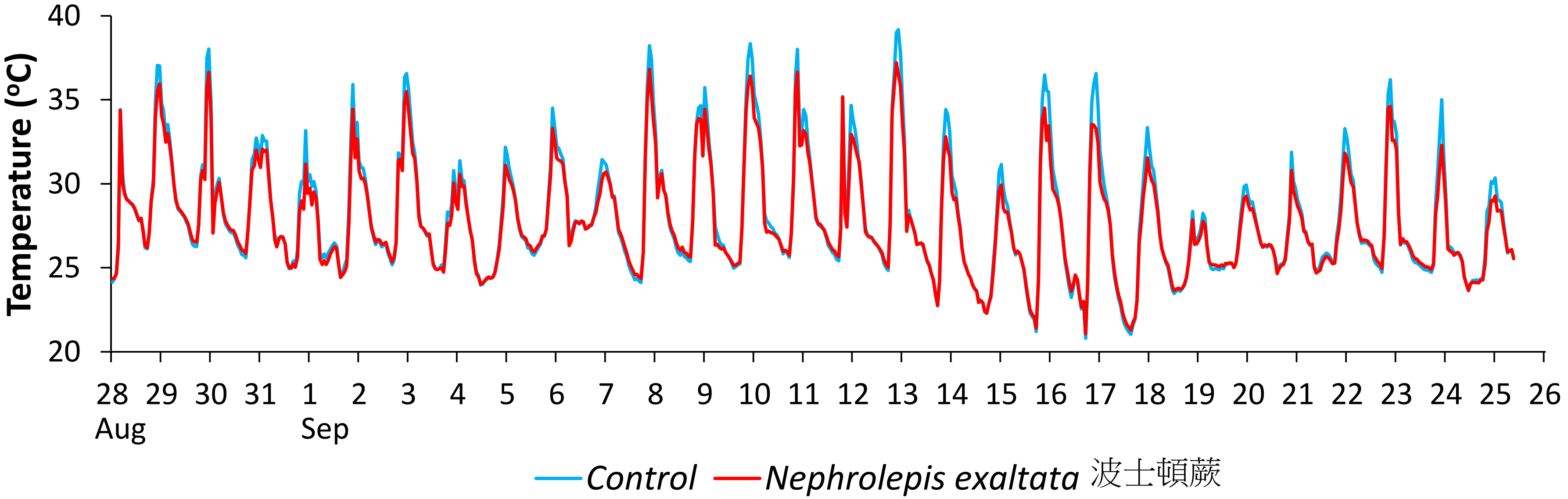


Modular panel

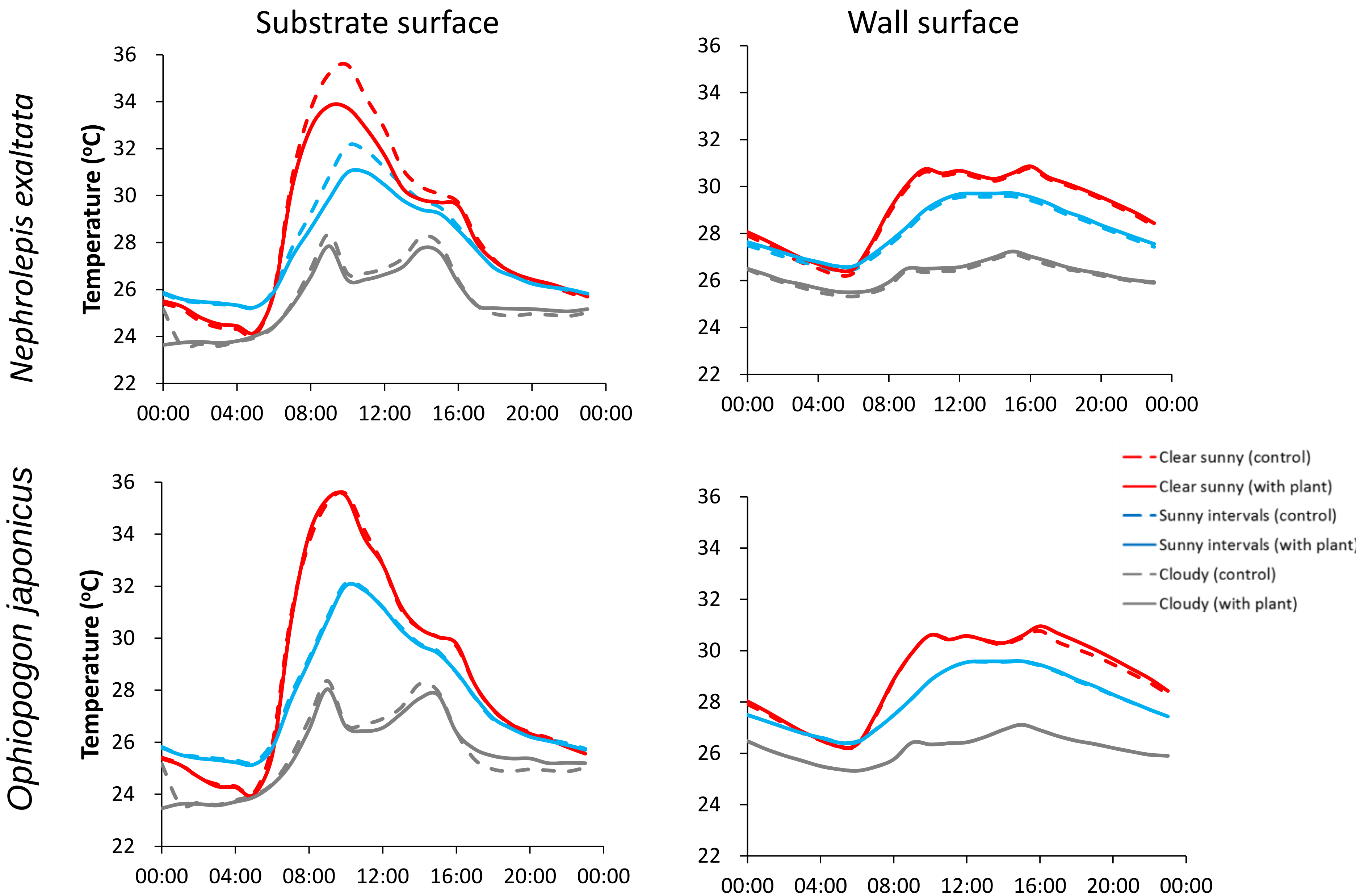
Canopy characteristics of *Ophiopogon japonicus* cv. Nanus and *Nephrolepis exaltata* on the vertical greenery system

	Ophiopogon japonicus		*Nephrolepis exaltata*	
	Mean	SD	Mean	SD
Plant height (cm)	6.0	0.3	16.8	1.2
Canopy thickness (cm)	4.9	0.3	14.5	1.0
Canopy coverage (%)	55	1	71	5
LAI	0.63	0.06	1.10	0.11





Temperature trends of *Ophiopogon japonicus* cv. Nanus (upper) and *Nephrolepis exaltata* (lower) on the substrate surface.



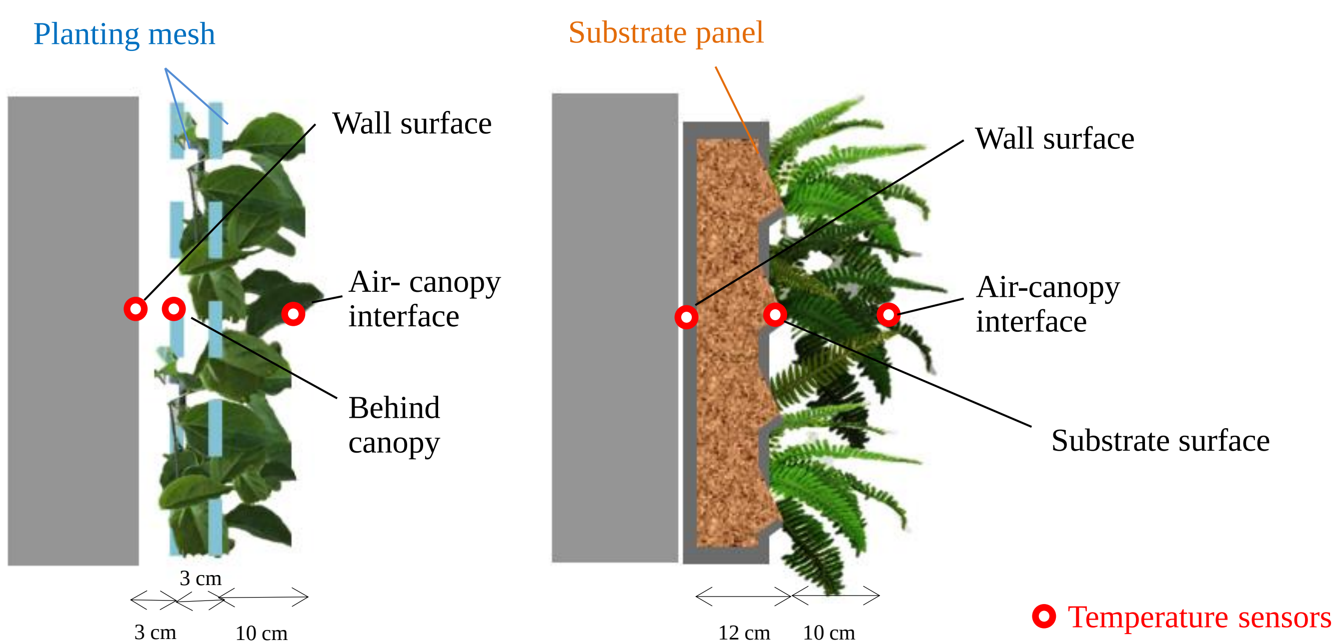
Diurnal temperature changes behind canopy and panel

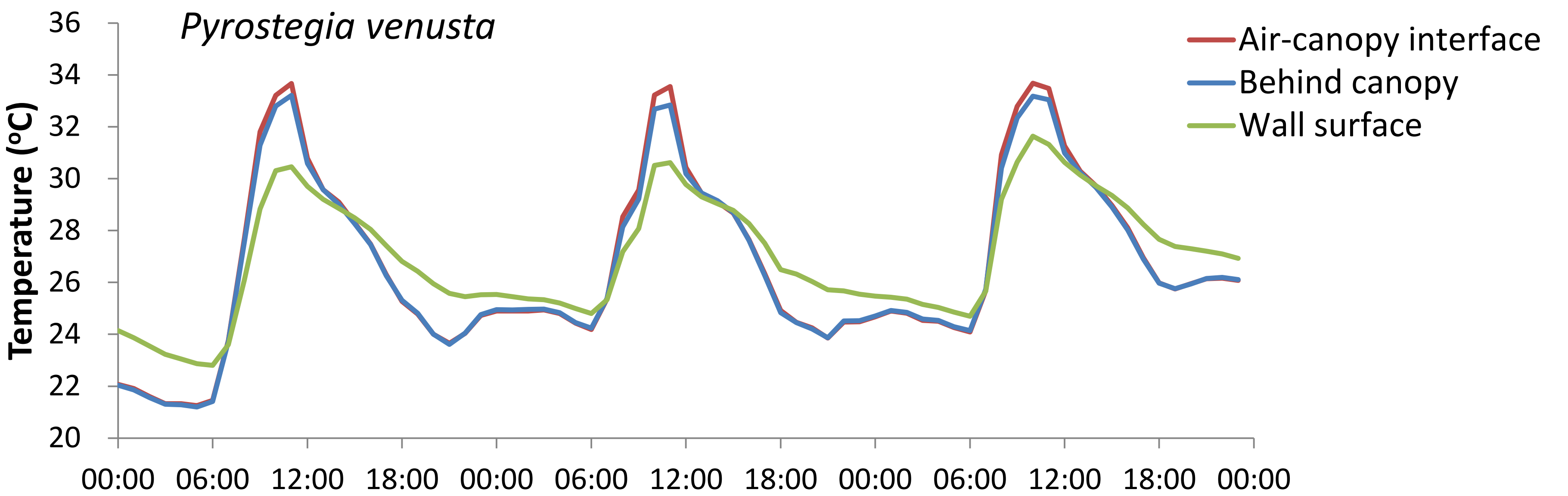
Summary

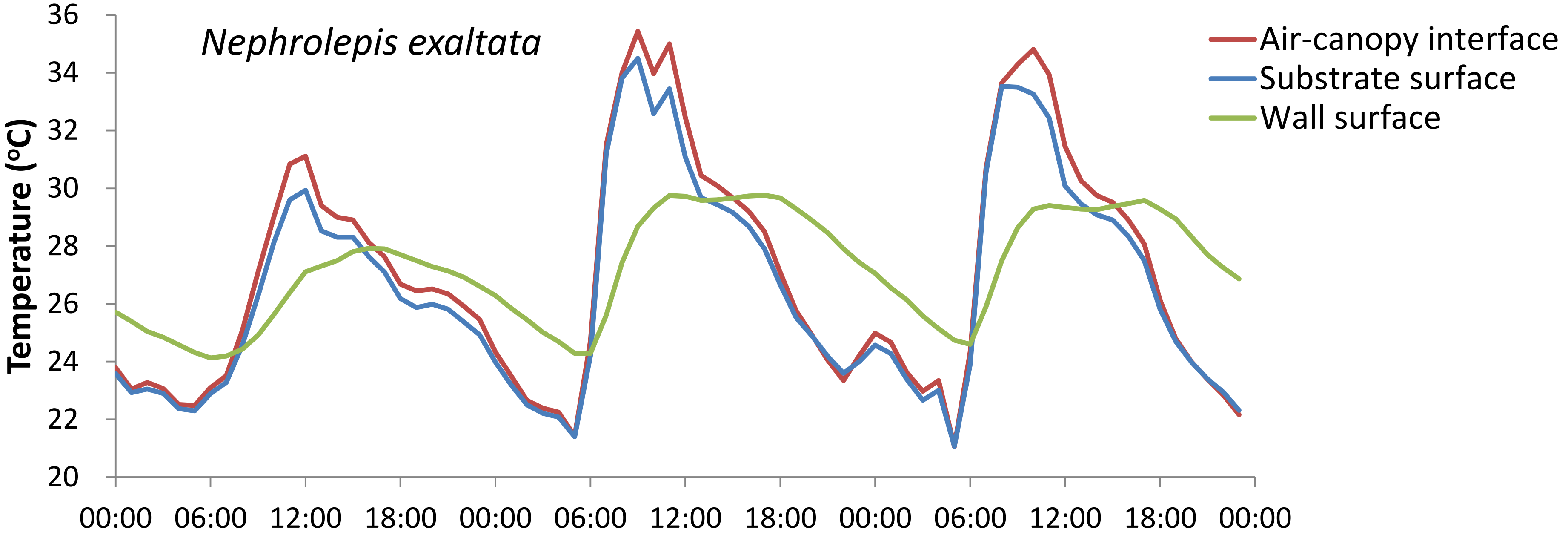
- *Nephrolepis exaltata* was significantly higher than *Ophiopogon japonicus* cv. Nanus in their temperature reduction ability in carrier-type vertical greening system.
- This was attributed to its denser coverage & taller individuals.
- *Nephrolepis exaltata* reduced 1.5^{o}C behind canopy while *Ophiopogon japonicus* cv. Nanus was ineffective.
- Temperature reduction on the wall surface was negligible with or without vegetation.
- Species selection for carrier type vertical greening in maximizing temperature reduction efficiency would not be significant when there was thick substrate (thermal mass) with high *in situ* water content (thermal buffer).

3.1.3 Performance comparison between support-type and carrier-type vertical greenery systems

- Species with best temperature reduction ability
  - *Pyrostegia venusta* and *Nephrolepis exaltata*
- Focused on wall surface temperature reduction which affects cooling energy loads and indoor living comfort





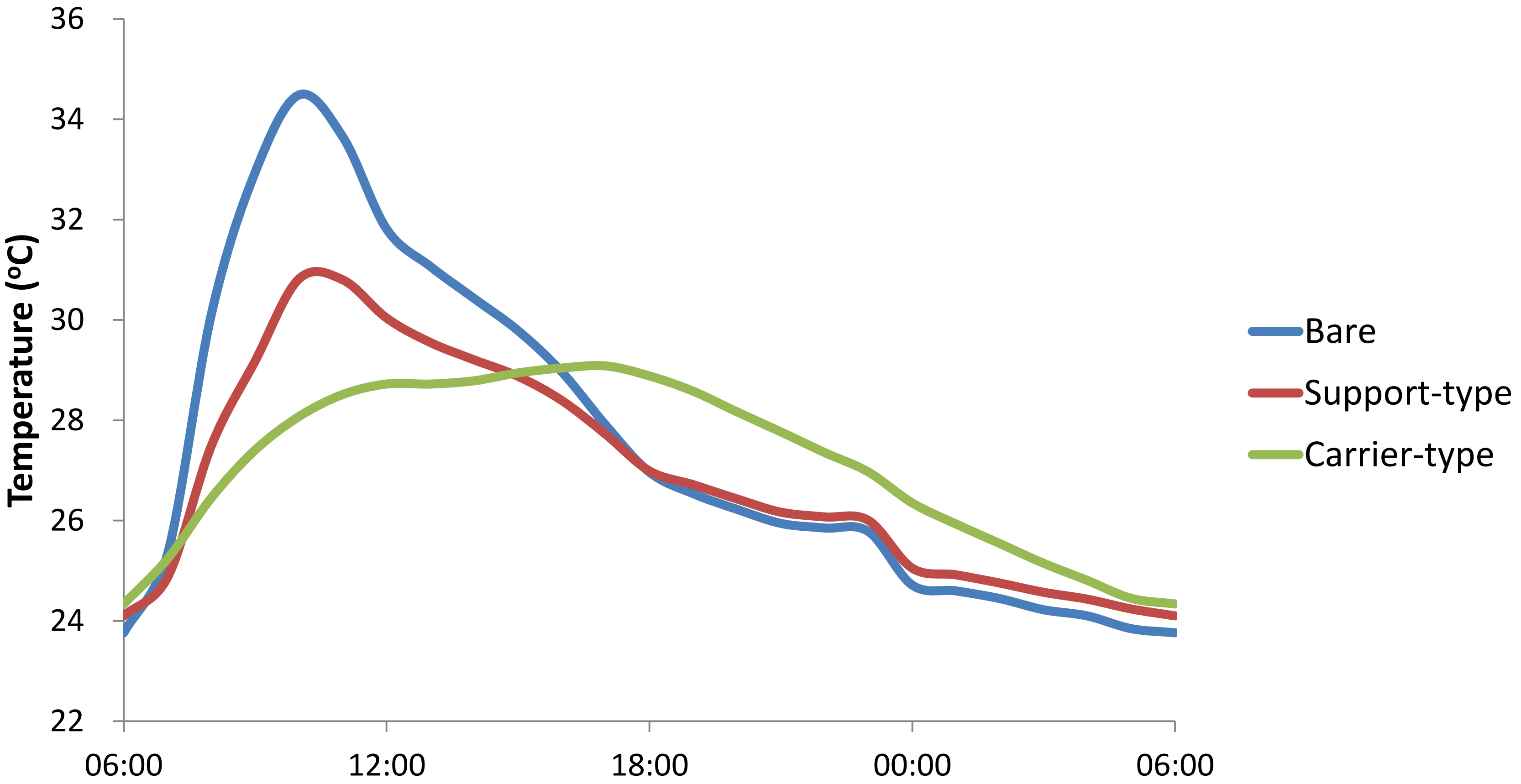


Diurnal temperature changes at various locations

Average daily maximum temperature of bare wall surface, ambient air and different locations of the support-type system and carrier-type system

	Daily maximum temperature (°C) [a]		Wall surface temperature reduction (°C)
Bare wall surface	35.2	a	
Ambient air	31.9		
Support system			
Air-canopy interface	34.9		
Air cavity	33.9		
Wall surface	31.3	b	3.8
Carrier system			
Air-canopy interface	34.0		
Substrate surface	32.4		
Wall surface	28.8	c	6.4

[a] One-way ANOVA followed by Tukey HSD post-hoc test to determine any significant difference between mean daily maximum wall surface temperature



Wall surface temperature under two types of vertical greenery systems and a bare wall

Summary

- Support-type VG system was less effective than carrier-type in heat reduction at the wall surface.
- Despite this thermal advantage, there was a lag in heat transfer in the wall of carrier system, which resulted in slower cooling in late afternoon and higher temperature than bare wall after sunset.
- A higher continuous inflow of heat at nighttime would likely to cause excessive air-conditioning or discomfort to residents in hot summer nights.
- Although carrier-type vertical greenery system did better in heat reduction, it should be carefully selected for its installation in residential buildings.

4. FUNCTIONAL STRUCTURE AND BEHAVIOR
系統結構及性能分析

- System type - design features and mechanism
  系統種類;設計特色與結構

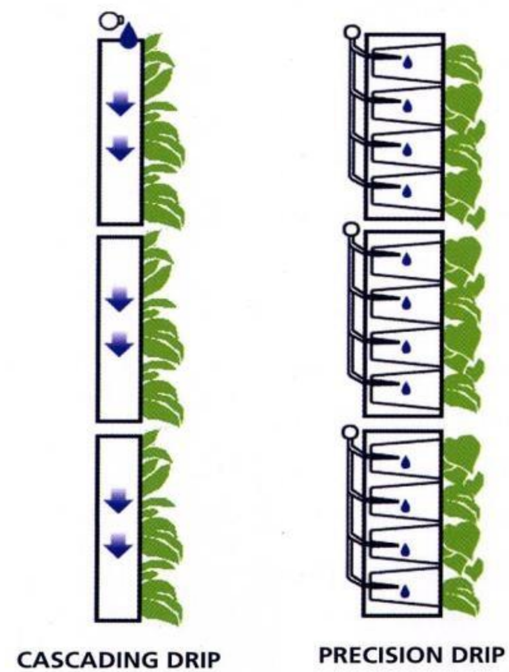
- Plant selection and in cooperation with VGS
  植物應用與系統配合

- Irrigation application and characteristics
  灌溉系統應用與設計特色

- Substrate characteristics
  基質特性

4.1 Irrigation application and characteristics 灌溉系統應用與設計特色

Automation by timer switch
(cheaper but prone to dry spell)
or by moisture sensor.
自動化定時開關或濕度傳感器。



Chiang & Tan, 2009

Proper selection of irrigation system:

- Reduce water wastage
- Improve water distribution evenness
- Increase plant survival

Related to irrigation program and substrate properties

4.2 Substrate characteristics
基質特性

Substrate characteristics:

- sandy; rocky; organic

Physical properties:

- porosity; water holding capacity; permeability; water retention

Chemical properties:

- pH; nutrient contents

4.4 VGS maintenance requirement 管理技術與要求

- Maintenance = time + labor + sustainability = 
- Maintenance issues:
  - system/irrigation/vegetation (repair)
  - pest/weed control
  - fertilization/fungicide
  - sanitization (especially important for indoor VG)

5. PROSPECTS & POTENTIALS 發展前景和潛力

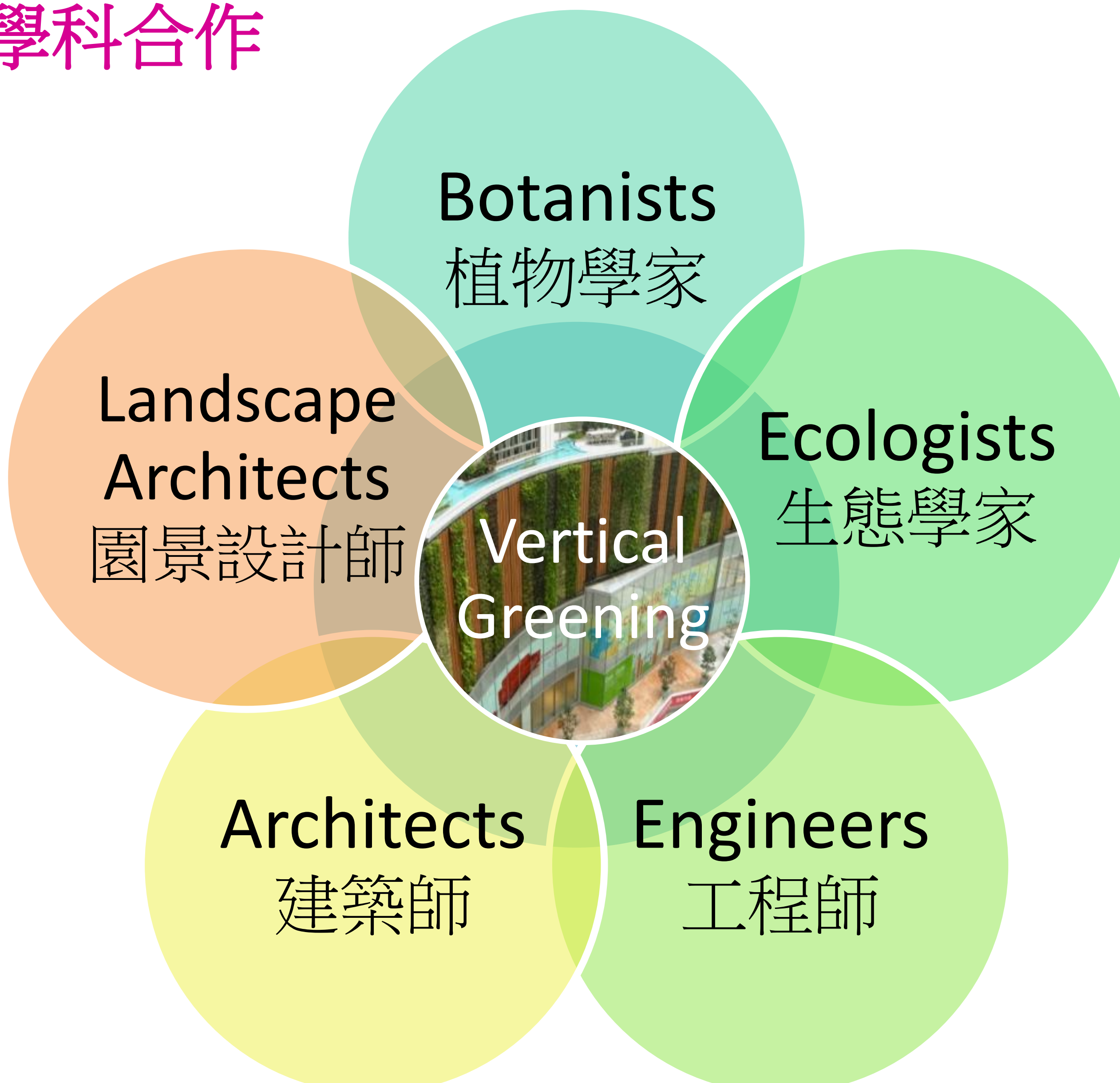
- New dimension in urban landscaping & green building development?
  城市園林綠化與綠色建築的新發展方向?
- System optimization in terms of functional performance, operational cost, maintenance, sustainability by matching the plant needs and system design
  通過植物篩選和系統設計，優化系統的性能、運營成本、維護和可持續性



6. OTHER CONSIDERATIONS 其他考慮因素

- Carbon/Water footprint 碳/水足印
- Cost 成本
- Technology 技術
- Sustainability 可持續性
- Weight loading 負重
- Public perception 社會需要
- Policy 政策

7. INTERDISCIPLINARY COLLABORATION
跨學科合作



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- Strongly International Ltd
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- LAI Po Ying 賴寶凝
- PAN Lan 潘瀾