Study of Green Roofs: Green Roof Guidelines, Water Quality and Peak Runoff

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Motivations

Global Issues

--Greenhouse Gases

--Climate Change

Local Issues

--Air pollution

--Intensive sporadic rainstorms (HKO: annual total rainfall is on a rising trend at a rate of 56mm/decade)

Motivations

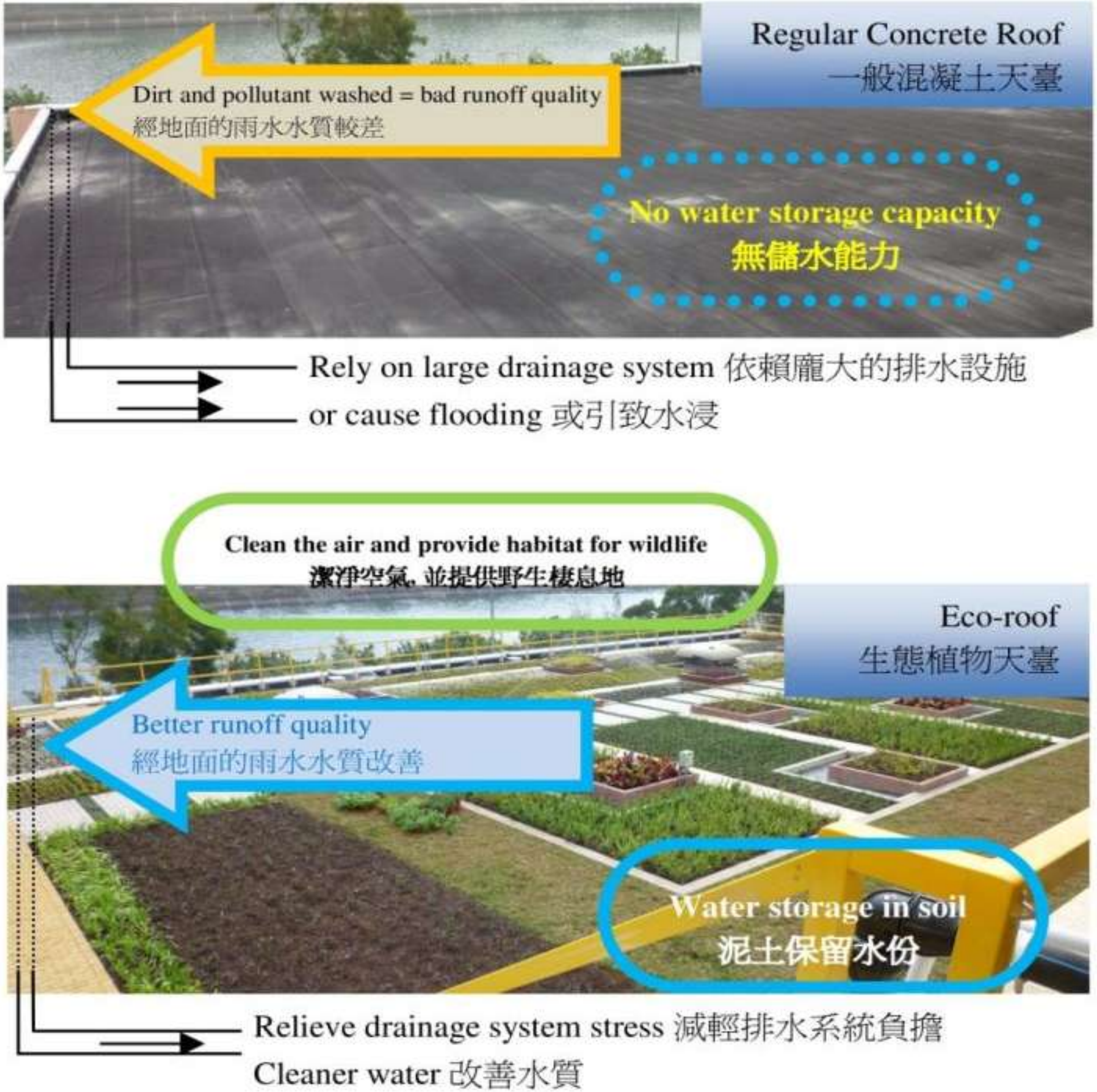
藍天行動 Action Blue Sky

It is not a slogan. It is an action.

Advocate Greening

Urbanized Wan Chai

Greening Wan Chai


Regular Concrete Roof
一般混凝土天臺
Dirt and pollutant washed = bad runoff quality
經地面的雨水水質較差
No water storage capacity
無儲水能力
Rely on large drainage system 依賴龐大的排水設施
or cause flooding 或引致水浸
Clean the air and provide habitat for wildlife
潔淨空氣, 並提供野生棲息地
Eco-roof
生態植物天臺
Better runoff quality
經地面的雨水水質改善
Water storage in soil
泥土保留水份
Relieve drainage system stress 減輕排水系統負擔
Cleaner water 改善水質

Stormwater Benefits (the Canadian Study)

Annual average stormwater flow reduction of 12 million cubic meter

Capital cost from infrastructure reduction of $504 million

Capital cost from erosion control measures of $25 million

CSO Benefits (the Canadian Study)

- One overflow reduction per year
- Three additional beach open days per year
- Capital cost from infrastructure reduction of $45 million
- Dollar value of beach openings is $752,000 per year

▪ Introduction – Green Roof and Structure

- Intensive and extensive green roof due to different thickness of substrate layer

- Green roof consists of
  - Vegetation layer
  - Substrate layer
  - Filter layer
  - Drainage layer
  - Root barrier
  - Water proofing

The thickness of green roof defined by authors[1~7]

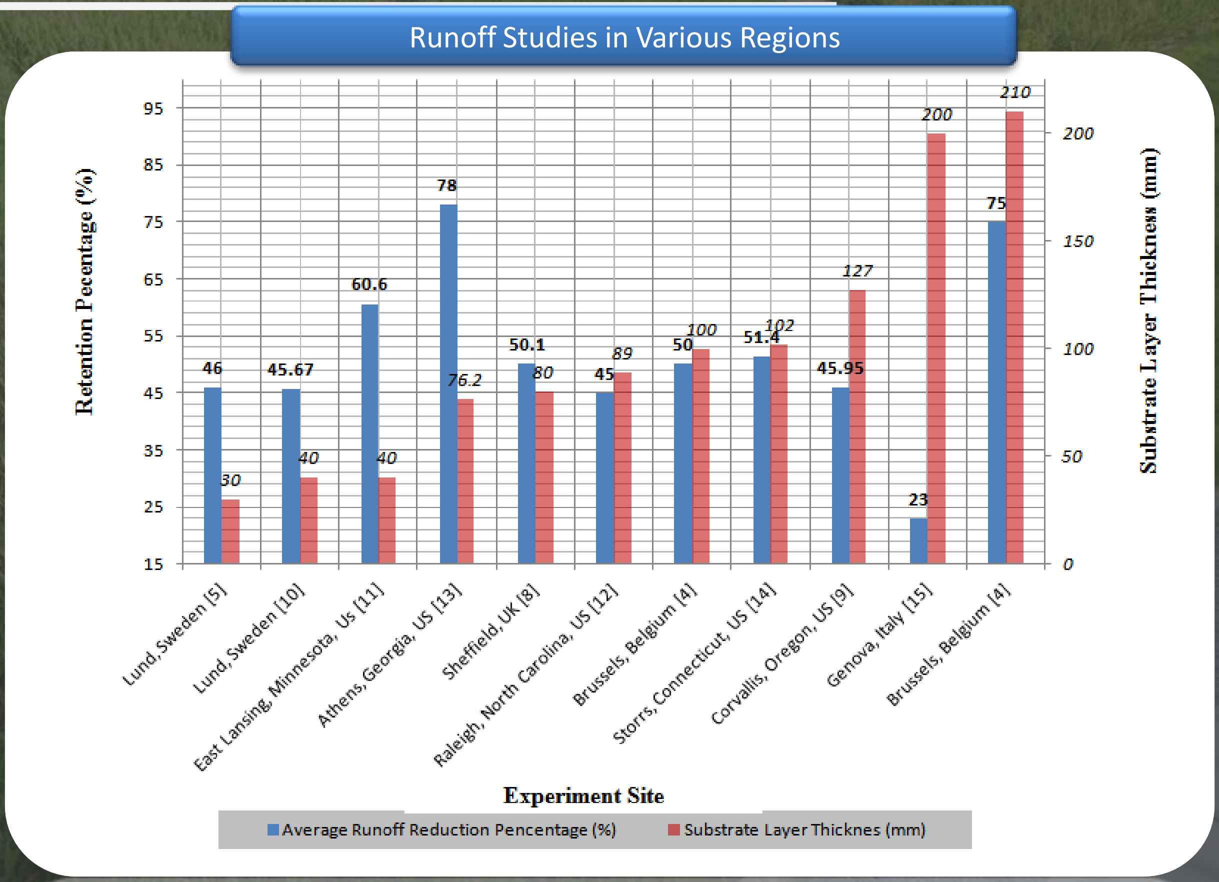
Intensive (mm)	Extensive (mm)	Reference
150-1200	50-150	Kosareo and Ries (2007)
>500	-	Köhler *et al.* (2002)
150-350	30-140	Mentens *et al.* (2006)
>100	<100	Wong *et al.* (2007)
>300	-	Bengtsson *et al.* (2005)
>100	20-100	Graham and Kim (2005)
300-1500	80-150	Townshend (2007)

- Benefits: stormwater management, air pollution abatement, heat island effect mitigation, noise reduction. etc.

▪ Introduction – Runoff Studies in Various Regions

- ○ Different regions achieve different result of storm water retention percentage due to **climate and green roof configuration differences,** ranging from 23~78%.

- ○ Thicker substrate layer, more storm water retention.



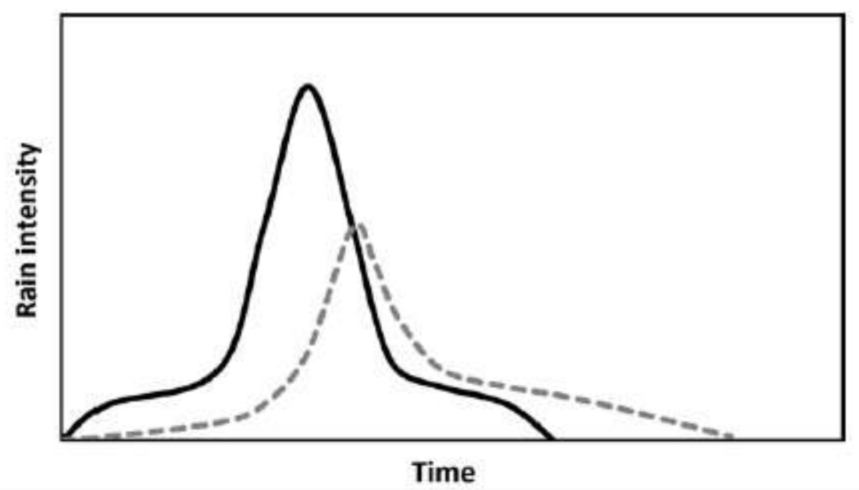
Introduction – Factors Affecting Runoff Results

○ Substrate Layer Thickness

Intensive green roof reduced annual runoff as **85-86%** of normal precipitation while the **extensive achieved 27-81%** [4].

○ Rainfall Intensity

For small storms (<25.4mm) 88% retained, for medium storms (25.4–76.2mm) more than 54% retained and for large storms (>76.2mm) 48% retained [13] .



Example runoff from a green roof (dashed line) generated by a given rain event (black line) [16]

Introduction – Factors Affecting Runoff Results

○ Slope

2° slope **double** the retention capacity as compared to 14° slope [10].

○ Season

For the substrate thickness between 50 and 150 mm, season-wise runoff reductions were: 70% for the warm season, 49% for the in-between seasons, and 33% for the cold season [4].

Rainfall retention by *Sedum* extensive green roof under different slopes [10]

Rain (mm/min)	Duration (min)	Total precipitation, *P* (mm)	Rain to start runoff (mm)	Total runoff	Retention (mm)
Slope 2°					
0.4	60	24	12	9.2 (38%)	14.8 (62%)
0.8	30	24	10	11.0 (46%)	13.0 (54%)
1.3	30	39	9	31.0 (79%)	8.0 (21%)
Slope 8°					
0.4	50	20	8	11.4 (57%)	8.6 (43%)
0.8	30	24	7	16.7 (70%)	7.3 (30%)
Slope 14°					
0.4	60	24	8	14.6 (61%)	9.4 (39%)
0.8	60	48	7	38.0 (79%)	10.0 (21%)
1.3	60	78	6	70.0 (90%)	8.0 (10%)

▪ Introduction – Factors Affecting Runoff Results

○ Vegetation

Vegetated roofs retained 60.6% rainfall; the media-only roofs retained 50.4% rainfall and the gravel ballast roof retained 27.2% rainfall [11] .

Vegetation is likely to have the greatest impact on stormwater management (about 40% better than medium-only roofs) under conditions characterized by frequent relatively small rain events [17] .

The incredible green roof at the School of Art, Design and Media at Nanyang Technical University in Singapore [18]

- Objectives

(i) To carry out a review based on overseas design guidelines and published literature on the benefits of green roofs in runoff water quality improvement and peak runoff mitigation;

(ii) To design green roof trials at Sludge Thickening House and its Extension at STSTW;

(iii) To supply data collection equipment for the green roof trials;

(iv) To collect wind tunnel test data and develop wind suction numerical models for evaluating the wind damage to green roofs and the danger of lifting a green roof system;

(v) To establish a guideline for planning requirements and design and maintenance criteria of Hong Kong green roof systems

▪Key Issues in Design and Planning

- Structural loading capacity
- Wind suction forces
- Setback distance
- Legal considerations
- Growing medium and substrate
- Vegetation replacement and weeding frequency/maintenance

▪Major Tasks

1. To carry out a review based on oversea design guidelines and published literature on the benefits of green roofs in runoff water quality improvement and peak runoff mitigation
2. To provide design inputs for 2 trial green roofs at the Sludge Thickening House and its Extension of Sha Tin Sewage Treatment Works for the purposes of demonstration, testing and monitoring
3. To carry out field measurements to obtain the data of soil moisture and rainfall-runoff and making use of their relationship to calibrate and verify stormwater numerical models
4. To carry out laboratory experiments to investigate the stormwater retention performance of different green roof systems under different growing medium depths, roof slopes, antecedent moisture conditions and number of layers by using hydrology apparatus

▪Major Tasks (continued)

5. To use a soil moisture transport model to estimate the soil hydraulic properties and stormwater runoff based on the data obtained from the field measurements and laboratory experiments

6. To conduct field measurements and laboratory experiments to investigate the benefit of green roofs in insulation properties and runoff water quality improvement , and evaluate the performance of green roofs in relation to some key water quality parameters such as pH, colour, turbidity, hardness, metals and additional nutrients

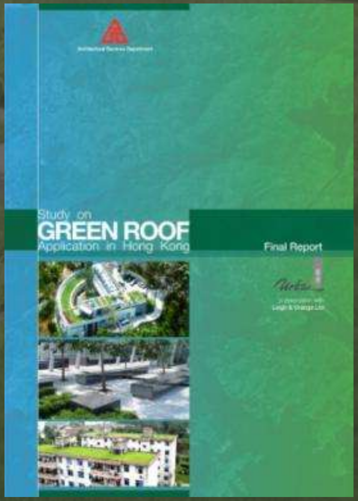
▪Major Tasks (continued)

7. To develop a wind suction numerical model to address the wind damages to the green roofs as well as the danger of lifting green roofs
8. To establish a design guideline for Hong Kong green roof systems to address some key issues including but limited to structural loading capacity, wind suction forces, set back distance, legal consideration, selection of growing medium and substrate as well as vegetation replacement and substrate as well as vegetation replacement and weeding frequency/maintenance

▪ Task 1 – Literature Review

Related Publications in Hong Kong

- (ASD, Urbis) Study on Green Roof Application in Hong Kong



- (DSD) Application of Green Roof in Wan Chai East and West Preliminary Treatment Works

- (CEDD) Objective of Greening Master Plan (GMP)

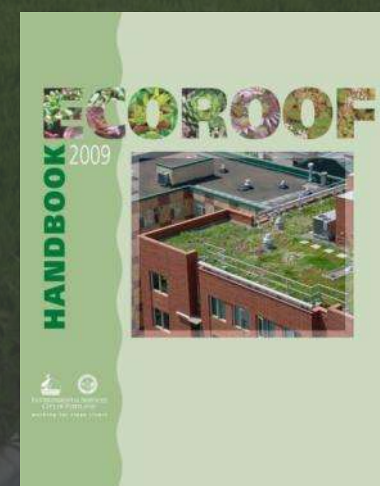
Task 1 – Literature Review

Overseas Green Roof Guidelines

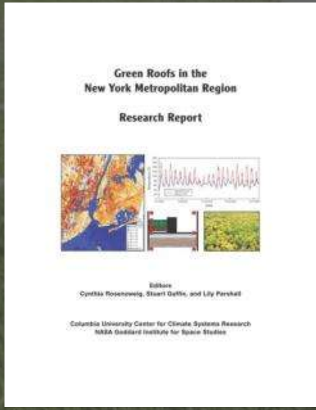
No.	Name	Organization (Country)	Year Published
1	*Guidelines for the Planning, Construction and Maintenance of Green Roofing*	FLL (Germany)	1982 (first published); 2008 (newest edition)
2	*A Guide to Rooftop Gardening*	Chicago Department of Environment (US)	2008
3	*Design Guidelines for Green Roofs*	Ontario Asso. Of Architects and etc. (Canada)	2009
4	*Handbook on Skyrise Greening in Singapore*	Nparks and NUS (Singapore)	2002
5	*Extensive Green (Living) Roofs for Stormwater Mitigation*	Auckland Regional Council (New Zealand)	2010
6	*The GRO Green Roof Code*	The Green Roof Organisation (UK)	2011
7	*Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West*	EPA and etc. (US)	2010
8	*Ecoroof Hand Book 2009*	City of Portland, Environmental Services (US)	2009

Technical Type:
-Experiment data and methods
-Codes and legal references
-Target: Government, Research, Construction

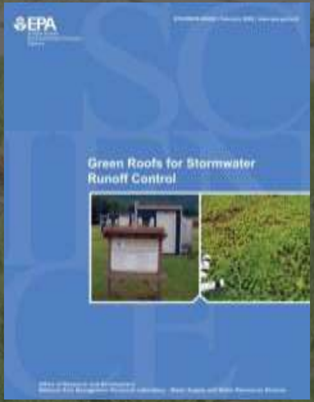
General Public Type:
-Definitions, concepts and benefits
-Case examples, costs estimates
-Target: General Public, Construction and Design



Some other Green Roof Guidelines/Reports on specific aspects

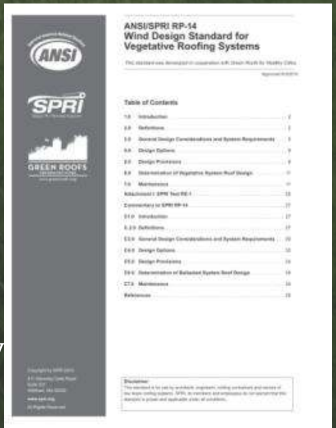


Green Roofs in the New York Metropolitan Region
(NASA, US)



Green Roofs for Stormwater Runoff Control
(EPA, US)

Guidelines for Monitoring The Hydrologic and Water Quality Performance of Green Roofs in the Greater Seattle, Washington Region
(Seattle Office of Sustainability and Environment and Seattle Public Utilities, US)



Wind Design Standard for Vegetative Roofing Systems
(ANSI/SPRI, US)

And of course,
many other green roof and eco-roof related studies and journal papers...

Quick Introduction of Germany FLL Guideline

- Longest development history (since 1980s)

- Strong interaction with **Deutsche Industry Norm** "**DIN**" and **DIN EN** (German edition of European standards)

- In Germany, 180 km^2 built, additional 11 km^2 every year (2008 data)

- Widely accepted in many other countries

Some of the basic consensus on green roof design:

Key issues	Basic consensus among the guidelines
Structural loading capacity	- Consider dead load, live load and, static liquid pressure (e.g. rainwater ponding) - Roof slope - Wind suction pressure
Legal considerations	- Fire safety - (For people access) exits, lighting, guardrails, and barrier free access
Growing medium	- Lightweight aggregates (LWA) - Low organic content to reduce shrinking
Maintenance	- Irrigation, even for extensive green roofs - Fertilization using slow-release fertilizers - Inspection of waterproofing and blocking in drains

Task 2 – STH, STHE Green Roof Design

Sludge Thickening House (STH)


1. Original roof


3. Paving green roof layers


2. Staircase construction to STHE


4. Adding soil substrate


5. Completed green roof

Roof Area: 840m^2
Plants: 12 species
Soil Thickness: 150mm

Sludge Thickening House Extension (STHE)


1. Original roof


1. Wall tiles and stairs construction


3. Paving green roof layers

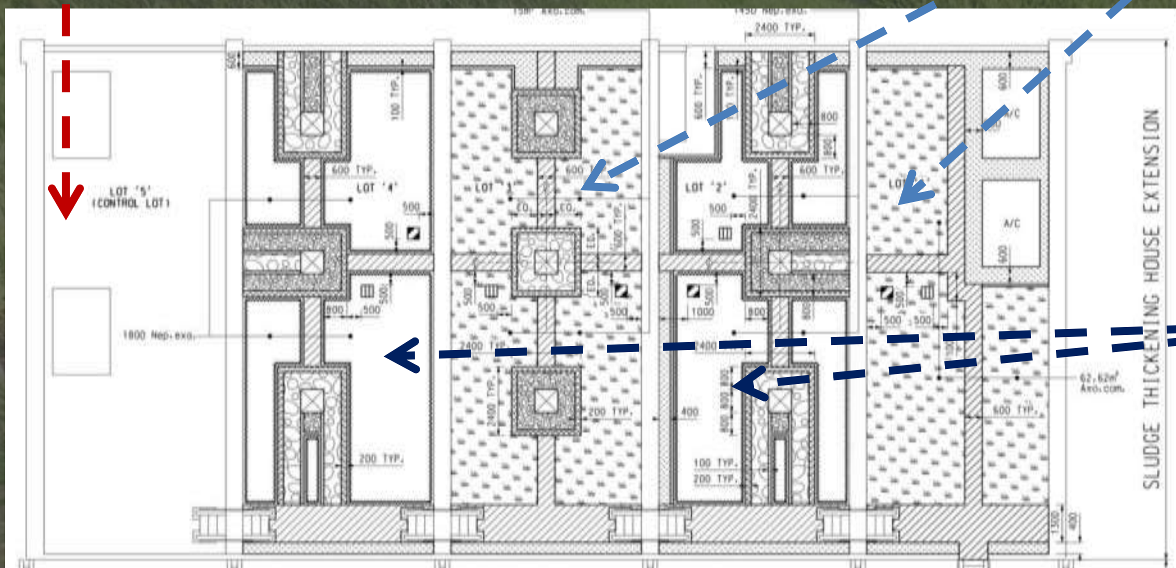

4. Adding soil and plants


5. Completed green roof

Roof Area: 602m^2
Area of each lot: 108 to 113m^2
Plants: 2 species
Soil Thickness: 100mm, 150mm and 0mm (control)

Sludge Thickening House Extension (STHE) (cont.)

Lot 5: Control Lot
(original roof unchanged)



Lot 3, 4: Soil Thickness 150mm

Lot 1, 2: Soil Thickness 100mm

Lot 1, 3:
Axonopus comperssus
(Carpet Grass)

Lot 2, 4:
Nephrolepis exaltata
(Boston Fern)

Sludge Thickening House Extension (STHE) (cont.)
Photos of the sensors and equipments

Weather station sensor suite

V-notch weir chamber (runoff measurement)

Runoff experiment setup (left) and ultrasonic flow meter (right)

3D anemometer

Thermocouple and data logger

Soil temperature and moisture sensor (right) and data logger (left)

▪ Task 3 – Field Measurement

Diagram 1: Temp Comparison between Substrates and Control Roof Surface

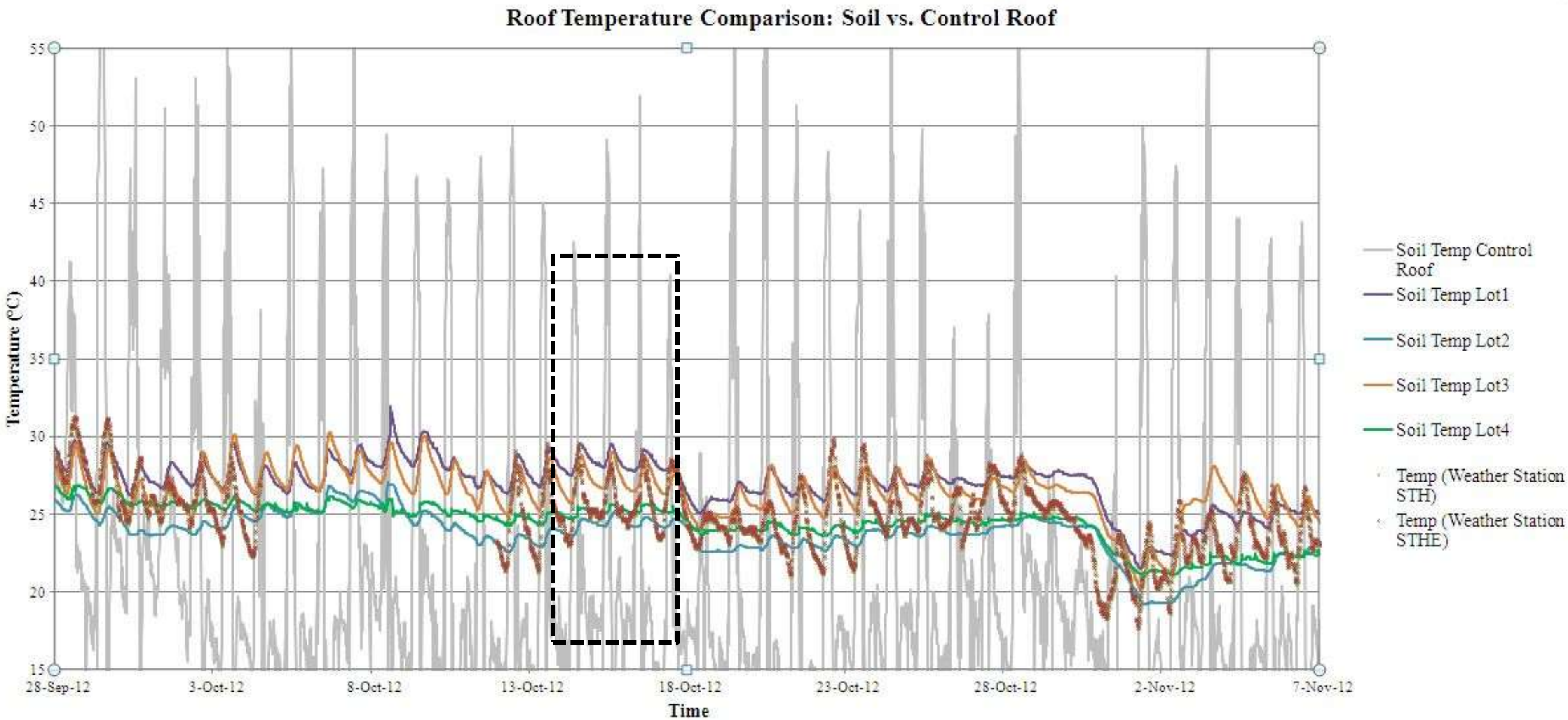


Diagram 1: Temp Comparison between Substrates and Control Roof Surface (cont.) Highlight - Heating of the roofs during sunny days

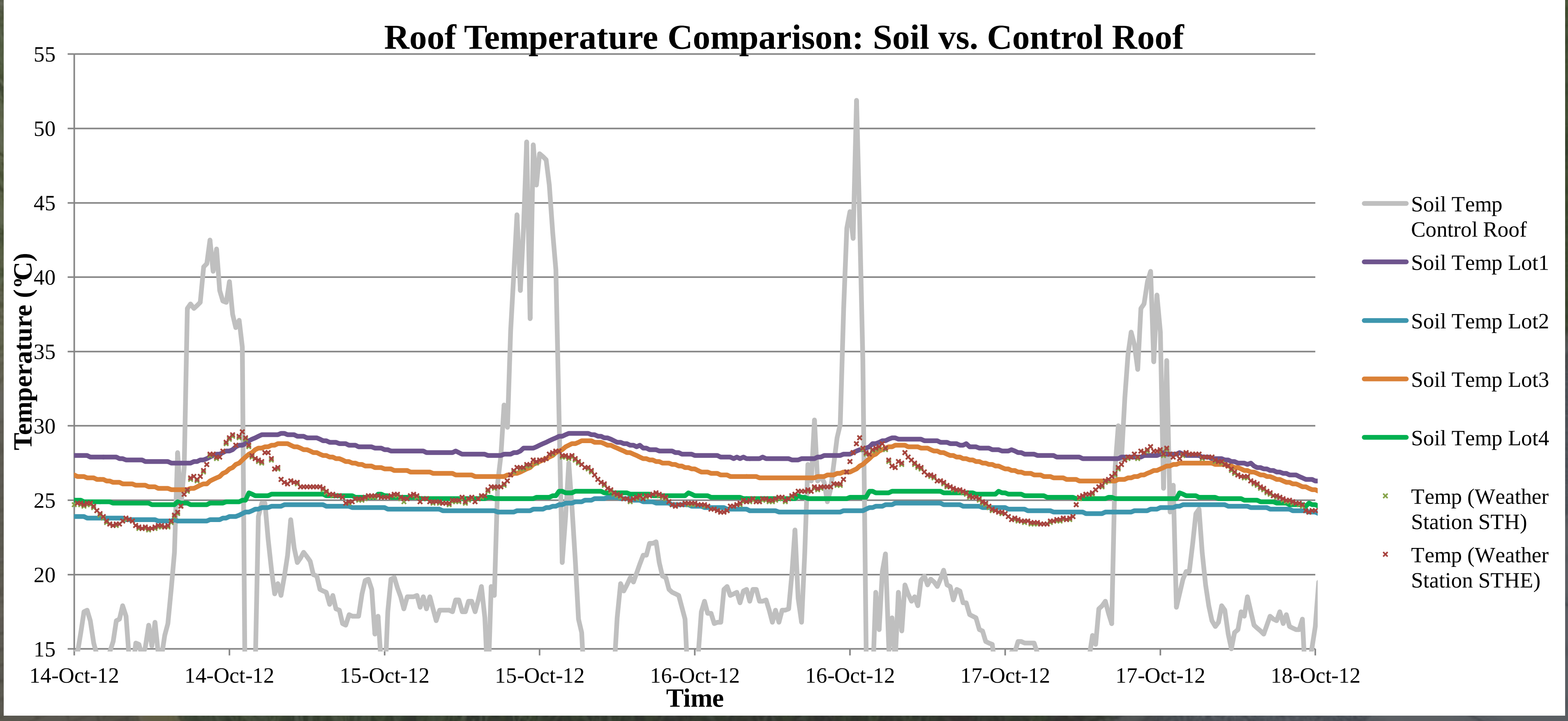
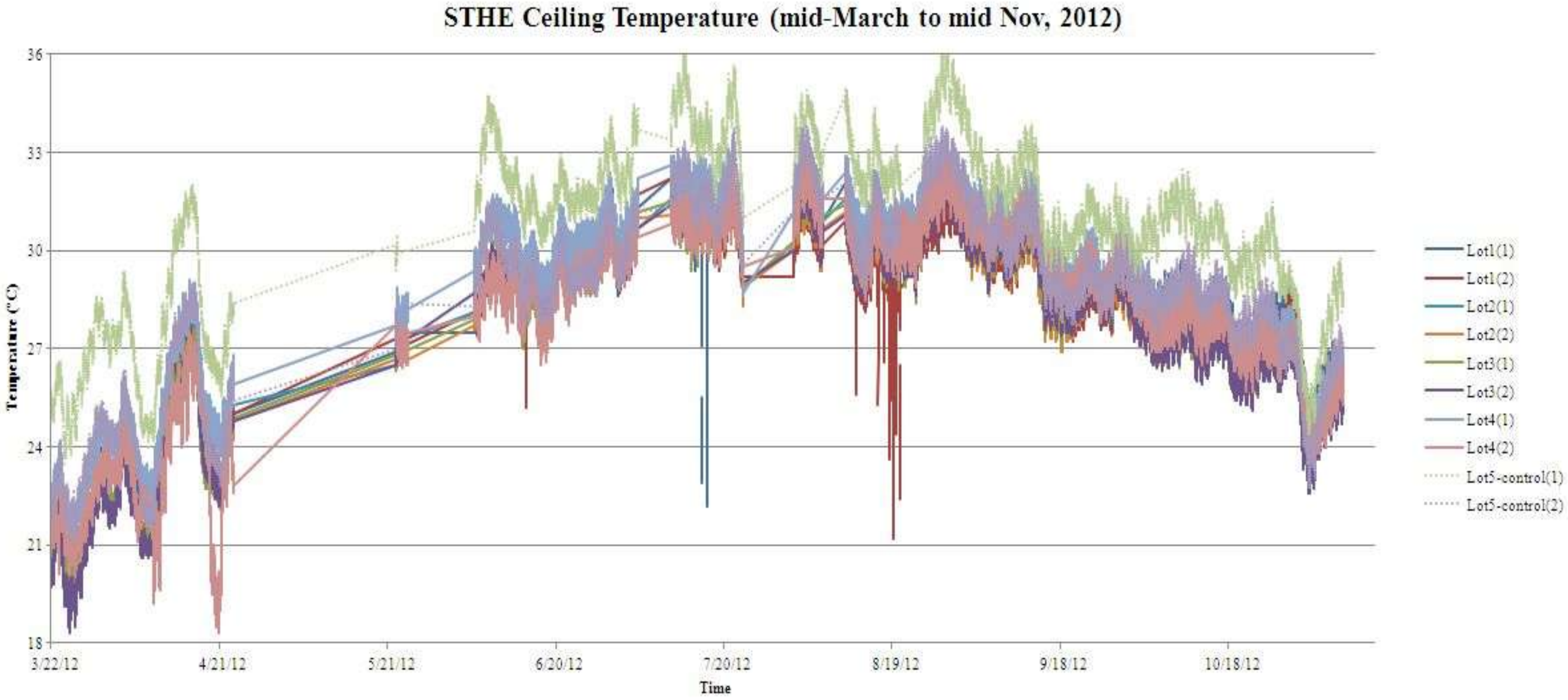


Diagram 2: STHE Ceiling Thermocouple Readings



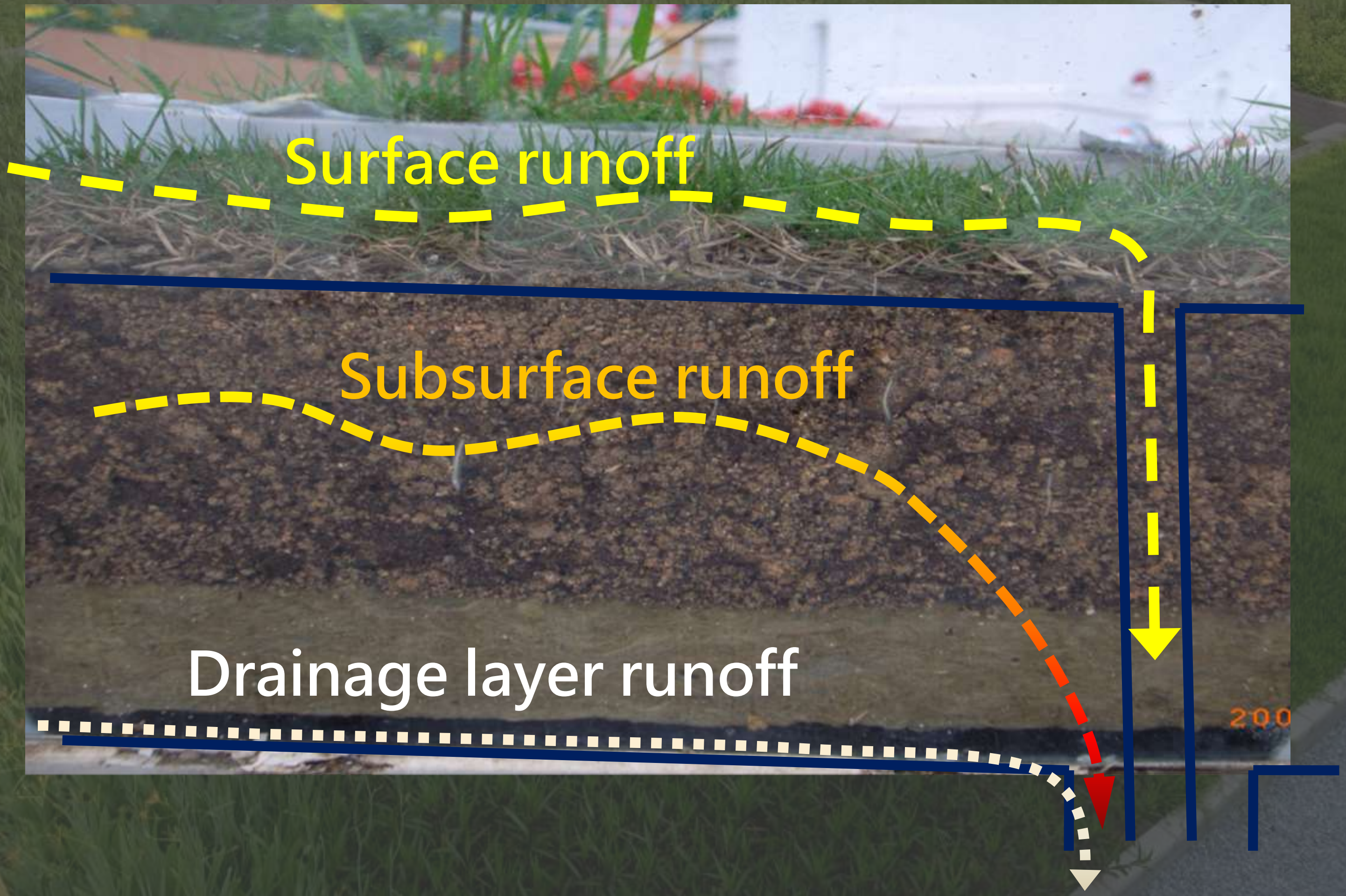
Field Measurement - Runoff Measurement

Drainage Inspection Chamber

Each green roof lot is connected to the corresponding V-notch chamber through an individual downpipe

V-notch weir chamber

Field Measurement - Runoff Measurement



V-notch calibration: Lot 1

Discharge expression of a V-notch weir:

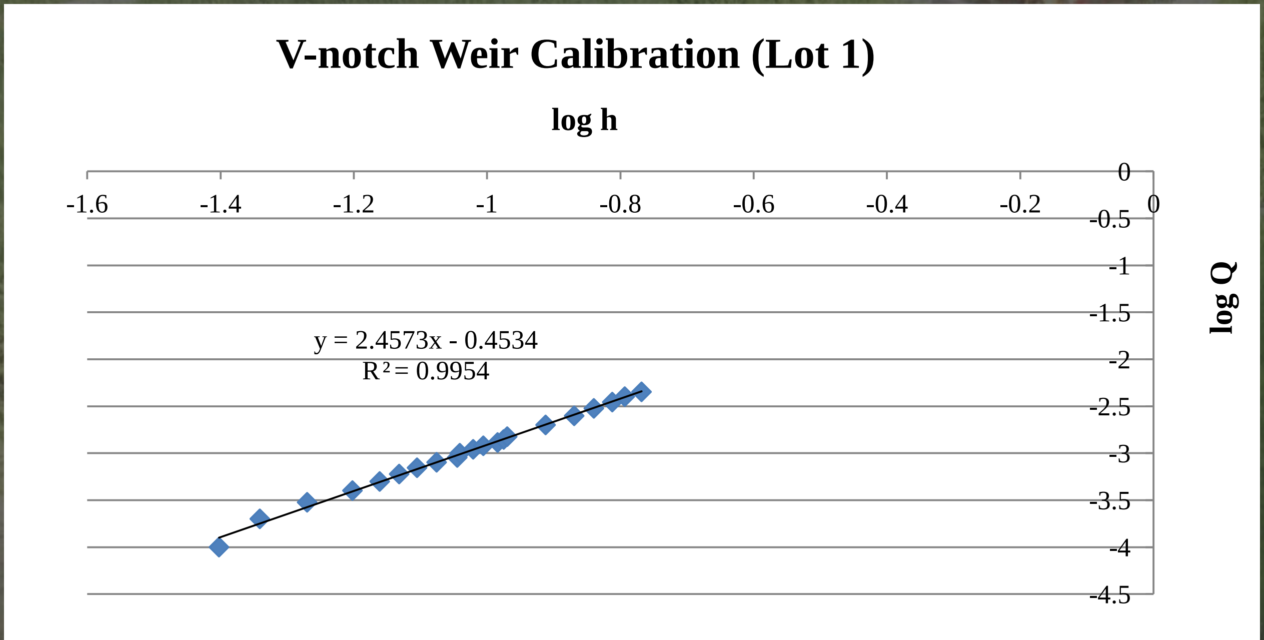
$$Q = \left(\frac{8}{15}\sqrt{2g}C_d \tan\frac{\theta}{2}\right)h^{\frac{5}{2}}$$

Q = discharge
C_d = coefficient of discharge of the V-notch
θ = angle of the V-notch (30 in this case)
h = water level from vertex of the V-notch
g = standard gravity (9.8m/s^2)

By measuring Q and h,
C_d can be calculated through a calibration plot of log Q against log h

$$\log Q = \log\left(\frac{8}{15}\sqrt{2g}C_d \tan\frac{\theta}{2}\right) + \frac{5}{2}\log h$$

V-notch calibration : Lot 1



V-notch calibration setup in Hydraulics Laboratory

(Lot 1) $C_d = 0.556$

Diagram 3: Runoff Measurement 23 July 2012 (Typhoon Vicente)

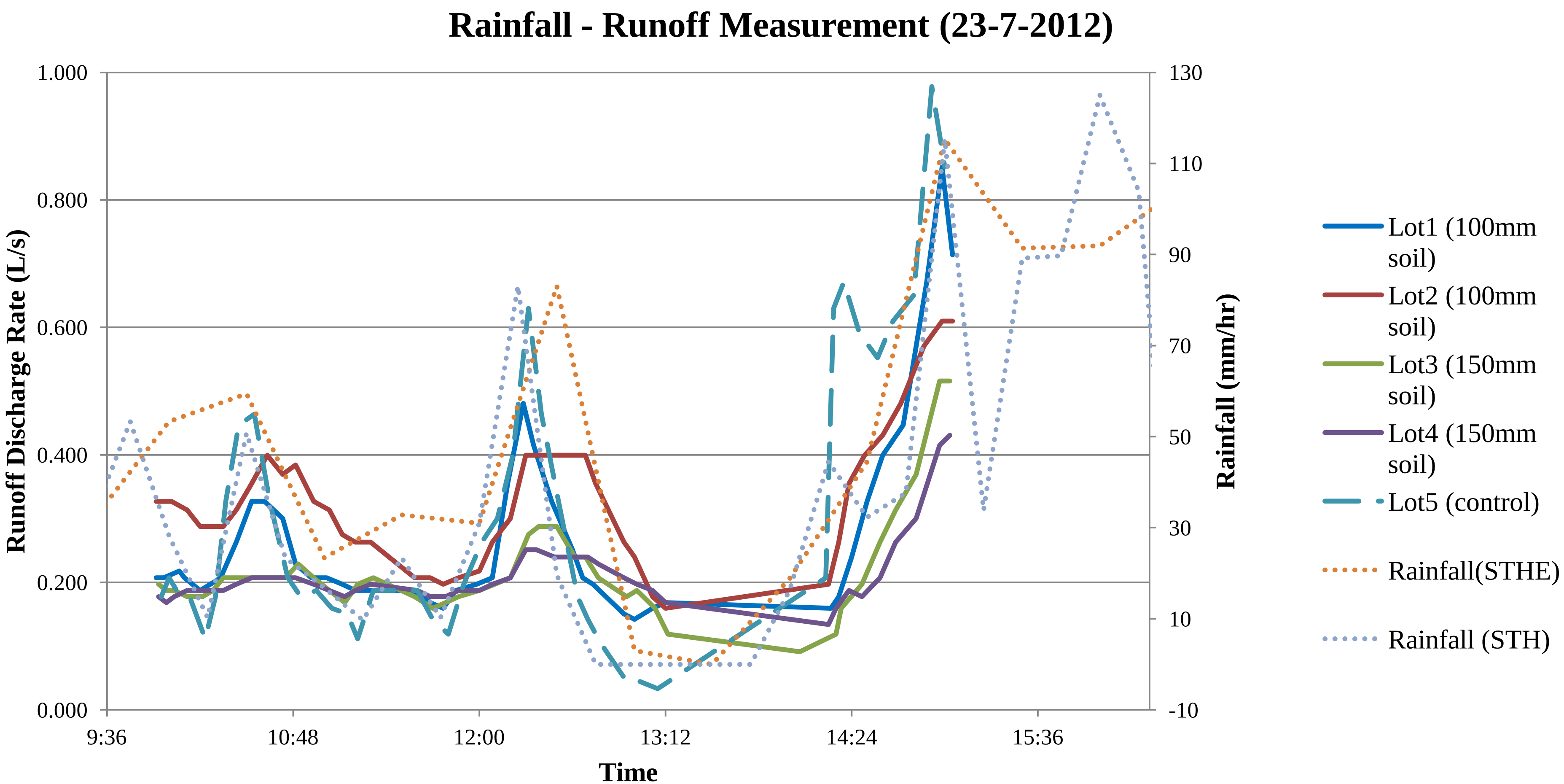


Diagram 4: Runoff Measurement 27 July 2012

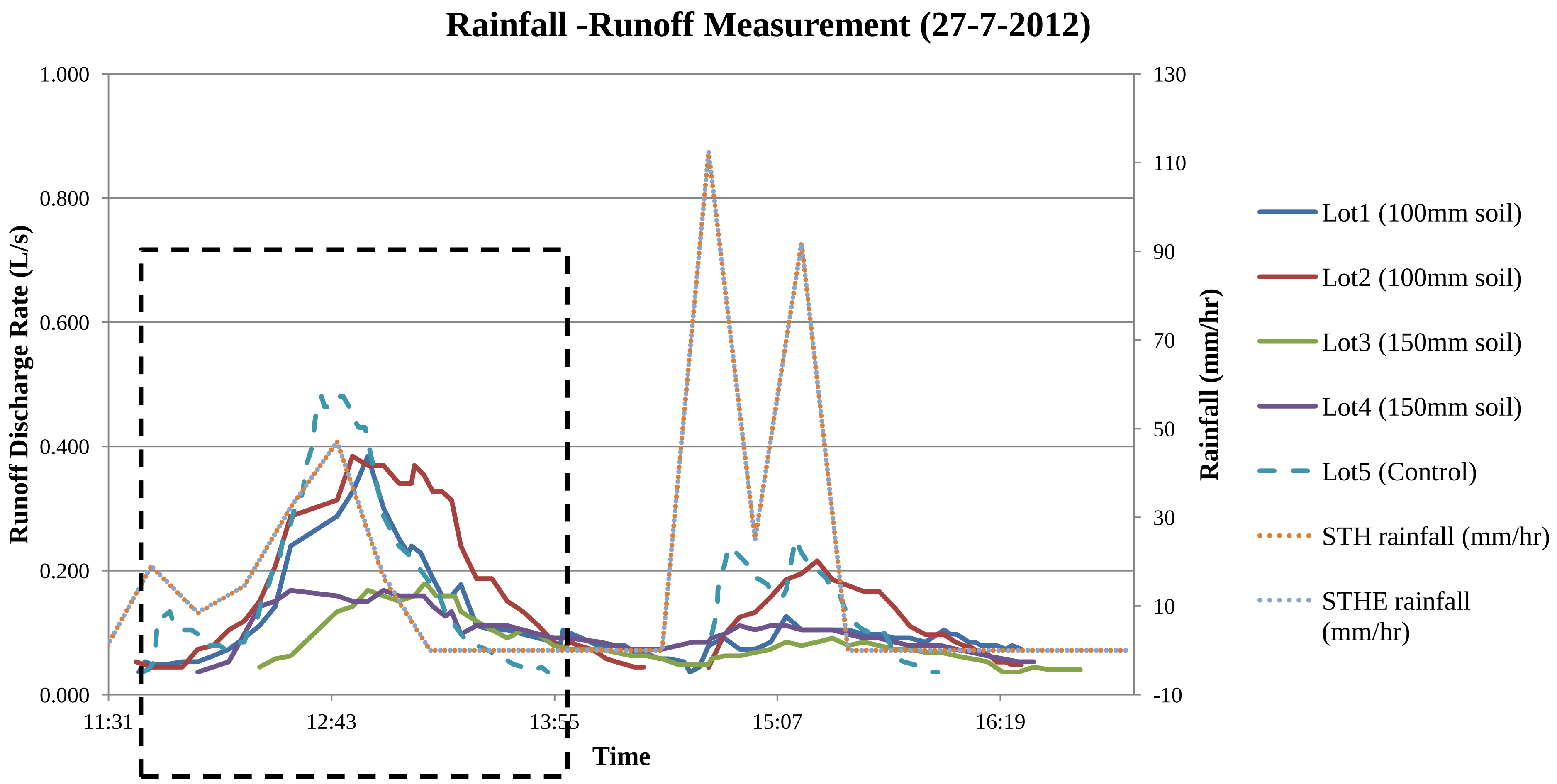
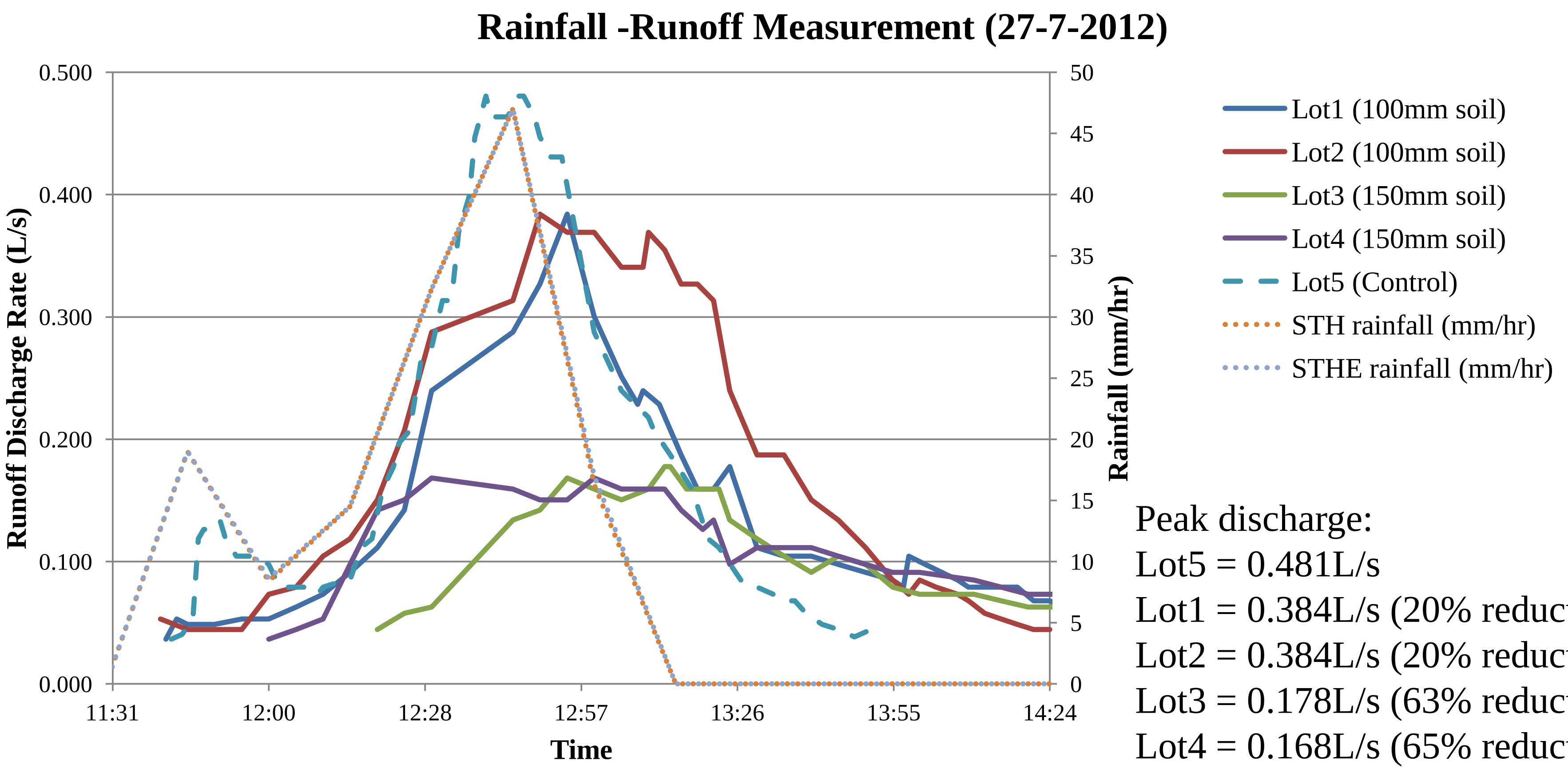


Diagram 4: Runoff Measurement 27 July 2012
Highlight – Runoff reduction of green roofs



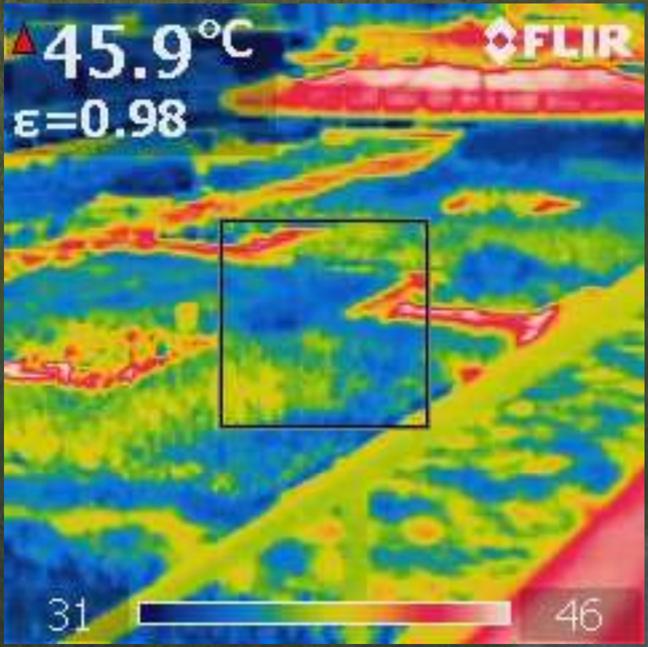
Peak discharge:
Lot5 = 0.481L/s
Lot1 = 0.384L/s (20% reduction)
Lot2 = 0.384L/s (20% reduction)
Lot3 = 0.178L/s (63% reduction)
Lot4 = 0.168L/s (65% reduction)

Runoff Measurement - Preliminary Observations:

1. Noticeable difference between green roofs and control roof on peak runoff reduction
2. Noticeable difference between 150mm soil and 100mm soil on peak runoff reduction and retention
3. The effect of the two plant types (carpet grass and Boston fern) on runoff do not show significant differences even under heavy rains

Diagram 5: Thermo-camera Images
(9 May 2012, 12:39pm, Ambient temp 32.3°C)

Sludge Thickening House Green Roof



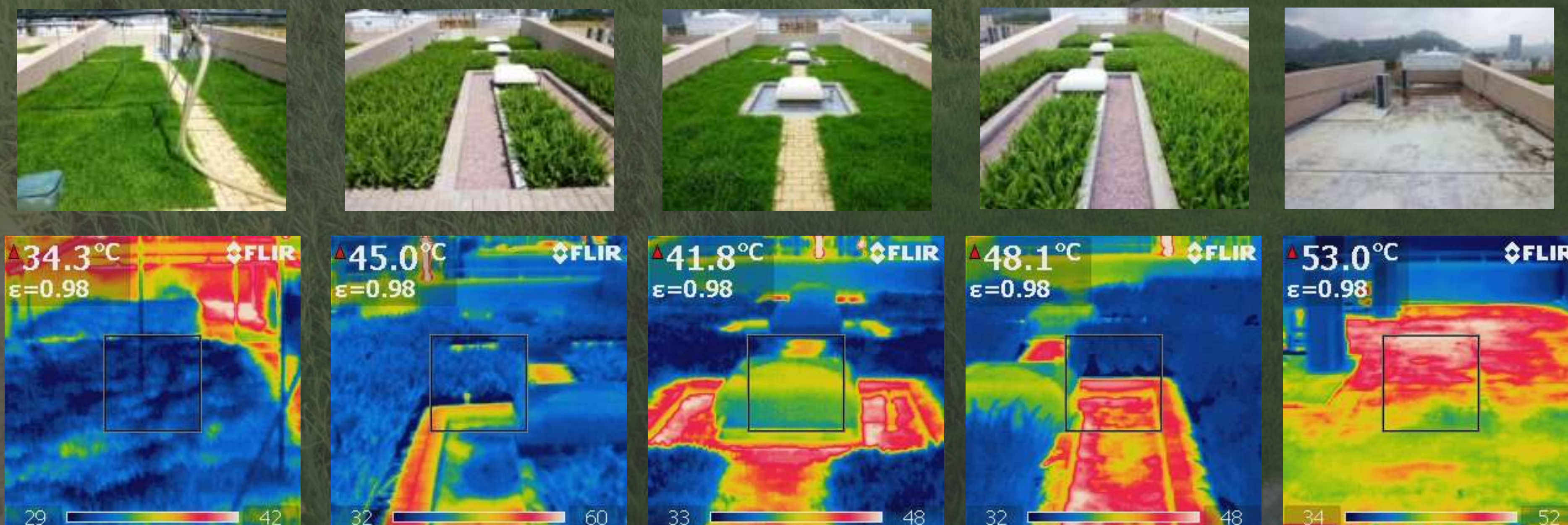
emissivity (ε): a value between
0 (reflect) and 1 (absorb / black body)

Diagram 5: Thermo-camera Images

(9 May 2012, 12:39pm, Ambient temp 32.3°C)

Sludge Thickening House Extension Green Roof

Lot 1 (100mm soil)	Lot 2 (100mm soil)	Lot 3 (150mm soil)	Lot 4 (150mm soil)	Lot 5 (control)



(Lot1 during irrigation)

Task 4 – Laboratory Experiments

I. Laboratory runoff experiments

- 36 test plots (0.6m x 0.45m x 0.4m plastic container)
- Test parameters:
    - 2 types of soil substrate
    - 3 types of vegetations
    - Rainfall rate (10, 30, 50, 70, 100 mm/hr)
    - Gradient (1^{o}, 3^{o}, 6^{o})
    - Antecedent soil moisture content (1, 3, 7days after watering)

I. Laboratory runoff experiments (cont.)

Soil A:
50% sand
50% peat moss

Soil B:
Commercial potting soil (Taiwan brand)

Test Plot 1-12:
Zoysia matrella
(manila grass, 台北草)

Test Plot 13-24:
Sedum lineare
(needle stonecrop, 佛甲草)

Test Plot 25-36:
Veronica serpyllifolia
(Thyme-leaf speedwell, 水藍星)

I. Laboratory runoff experiment (cont.)

	Soil A	Soil B	Soil A	Soil B	Soil A	Soil B
2nd month	1	7	13	19	25	31
4th month	2	8	14	20	26	32
6th month	3	9	15	21	27	33
8th month	4	10	16	22	28	34
10th month	5	11	17	23	29	35
12th month	6	12	18	24	30	36

Configuration of the soil/plant combinations

Actual setup on the roof of PolyU, building-P
8 October 2012

II. Physical and chemical analysis of soil and runoff samples

- Physical Characteristics of Soil

- Dry bulk density
- Saturated weight
- Water holding capacity
- Water permeability
- Particle size distribution

- Chemical Characteristics of Soil

- Organic content
- pH (in $CaCl_2$)
- Nutrient content (nitrogen, phosphorus, potassium, magnesium)
- C:N ratio (nitrogen availability to plants)

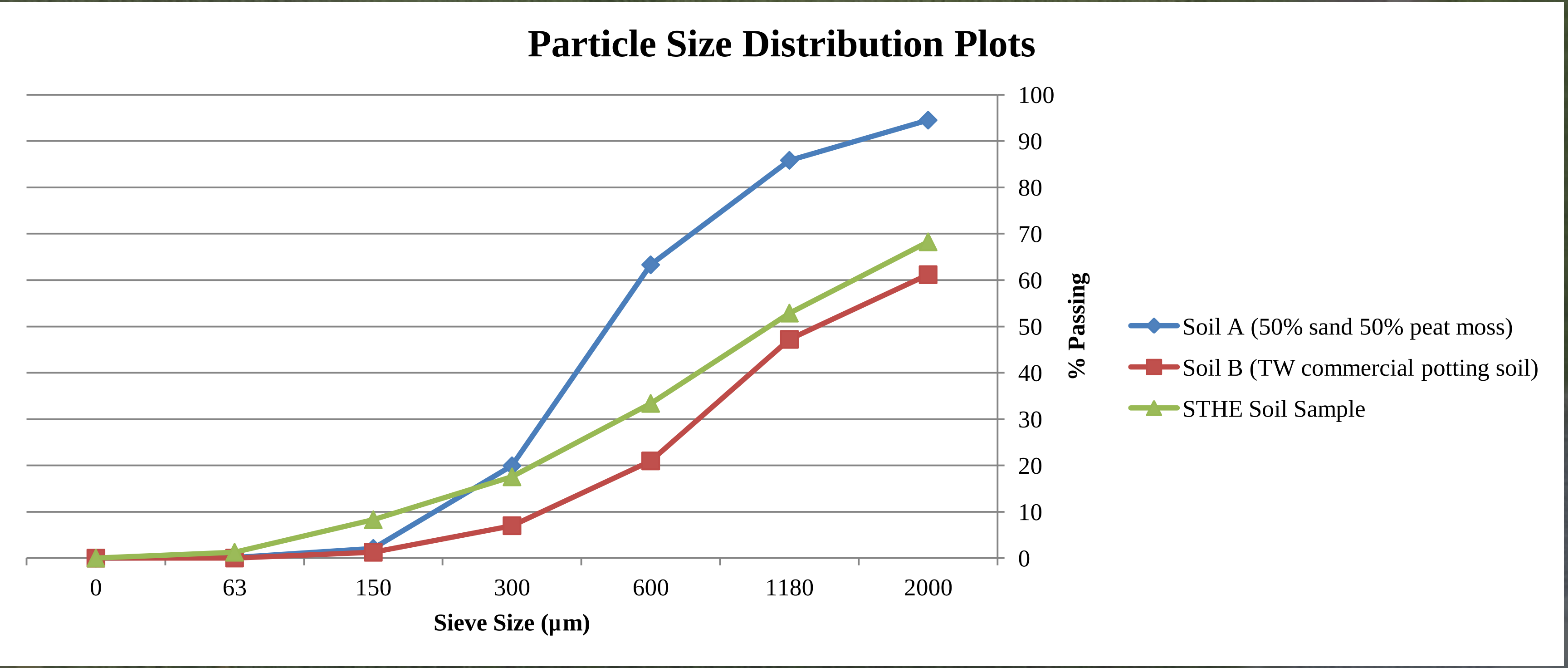
Sample compaction:
soil sample core and metal cover (left); 4.5kg standard hammer (right)

A soil sample undergoing permeability test (FLL guideline method)

II. Physical and chemical analysis of soil and runoff samples (cont.)
Physical Analysis of Soil – Preliminary Results

	Soil A: **50% sand + 50% peat moss**	**Soil B:** **commercial potting soil**	**Soil C:** **sample from STHE roof**
Dry Bulk Density (kg/m^3)	1045.97	173.1	1012.2
Particle Size Distribution	(>2000um) 5.49% (1180um range) 8.66% (600um range) 22.55% (300um range) 43.37% (150um range) 17.83% (63um range) 1.97% (<63um) 0.13%	(>2000um) 38.83% (1180um range) 13.96% (600um range) 26.23% (300um range) 13.99% (150um range) 5.72% (63um range) 1.25% (<63um) 0.02%	(>2000um range) 31.75% (1180um range) 15.37% (600um range) 19.49% (300um range) 15.85% (150um range) 9.25% (63um range) 7.02% (<63um range) 1.27%
Volume Remained after Compaction	68.7%	62.1%	(in progress)
Organic Content Wt.% (% mass loss due to ignition)	9.1%	58.5%	(in progress)
Water Permeability (cm/s)	0.009 (FLL method)	0.028 (FLL method)	(in progress)
Max Water Retention	54.9%	54.3%??	(in progress)

Physical Analysis of Soil – Preliminary Results
Soil Sample – Particle Size Distribution (PSD) Plots



▪ Task 5 – Soil Moisture Transport Model (HYDRUS-1D)

-To simulate STHE green roofs performance under rainstorm up to 200mm/hr (to simulate infiltration process and water content profile)

Important parameters:

Step	Selection/Parameter(s)
Main Process	Water flow, root water uptake
Soil hydraulic model	Van Genuchten-Mualem model
Soil hydraulic parameters	Measured values
Water flow boundary conditions	Upper boundary: atmospheric BC with surface runoff Lower boundary: horizontal drainage
Root water uptake model	Water uptake reduction model: Feddes Root water uptake parameters: Grass type
Time variable boundary conditions	Precipitation (10, 30, 50, 70, 100, 150, 200mm/hr) for 1hr

Model Governing Equations

- The HYDRUS models numerically solve the Richards' equation:

$$C_w(h)\frac{\partial(h)}{\partial t}=\frac{\partial}{\partial z}\left(K(h)\frac{\partial h}{\partial z}\right)+\frac{\partial K(h)}{\partial z}-S(h)$$

$C_w(h)$ = soil water retention
K = hydraulic conductivity
h = pressure head
z = elevation above datum
t = time

which means water flux into this volume during time interval, ∂t, equals
changes of water capillarity movement (first term on right hand side)
plus changes of water gravity movement (second term)
minus a sink function of root water uptake (last term)

- Soil water retention function, $C_w(h)$, is solved using the van Genuchten equation:

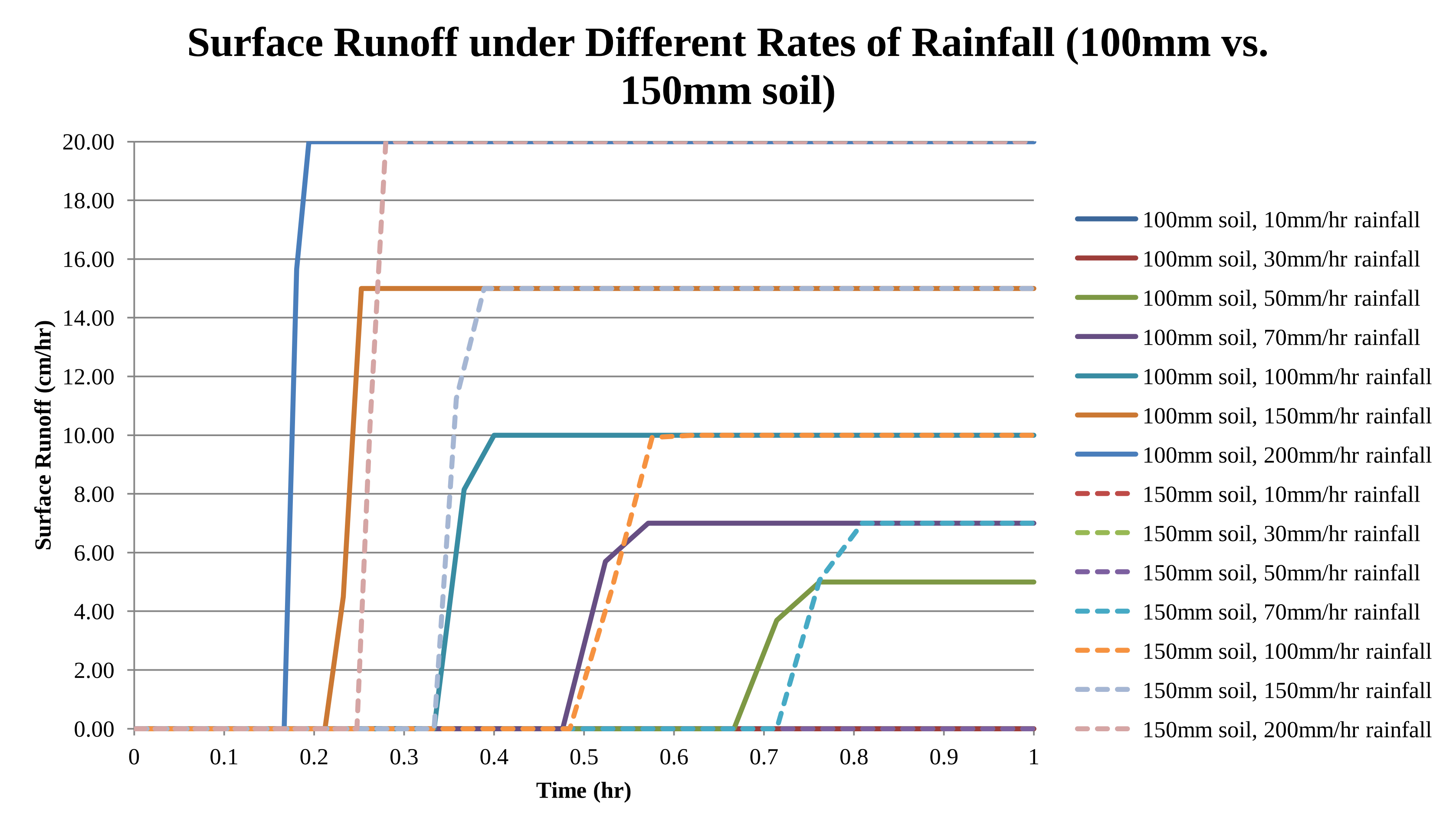
$$C_w(h)=\frac{\alpha^n(\theta_s-\theta_r)mn(-h)^{n-1}}{\left[1+(-\alpha h)^n\right]^{m+1}}$$

α = inverse of air entry suction
θ_s = saturated water content
θ_r = residual water content
n = pore-size distribution
$m = 1-n^{-1}$

- Soil hydraulic parameters (e.g. α, θ_s θ_r) can be predicted in HYDRUS-1D given the soil textural characteristics, such as the sand/silt/clay fractions, and bulk density

Hydrus-1D Preliminary Results

Appearance of Surface Runoff under 1-hour Constant Rainfall (runoff experiment scenario)



Task 6 – Runoff Water Quality Analysis

- To compare the difference between the runoffs from the green roofs and the conventional roof
- Also, to examine the chemical characteristics of the runoff as effluent (purifying or polluting)

Summary of Parameters

Groups	Items
Hydrocarbons	Poly-nuclear aromatic hydrocarbons Total petroleum hydrocarbon
Metals	Total and dissolved copper Total and dissolved lead Total and dissolved zinc
Others	Total suspended solid Total dissolved carbon Biochemical oxygen demand E-coli Total phosphorous Dissolved phosphorous Total nitrogen Nitrate Nitrite pH Residual chlorine

Runoff Analysis – Preliminary Results

Parameter	Inflow (Irrigation water)	Effluent (Runoff)
Total Suspended Solid (mg/L)	0.65	4.10
BOD (mg/L)	0.41	0.42
pH	7.47	7.19
Total Chlorine Residual (mg/L)	1.36	0.02
Ammonia Nitrogen (mg/L)	0.11	0.90
Nitrite Nitrogen (mg/L)	0.006	0.006
Nitrate Nitrogen (mg/L)	1.6	0.90

V-notch chamber receiving runoff from a green roof

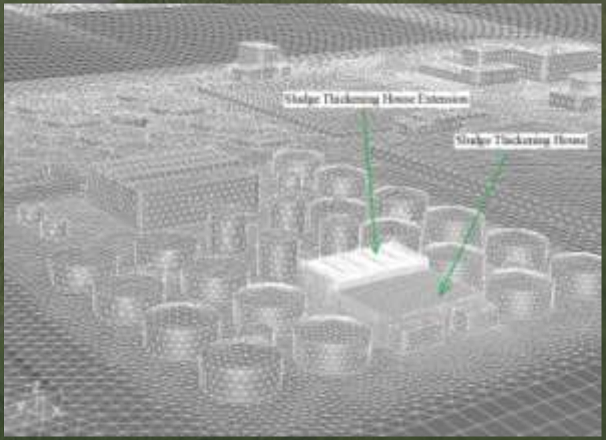
V-notch chamber receiving runoff from the control roof

▪ Task 7 – Wind Field Study of STSTW

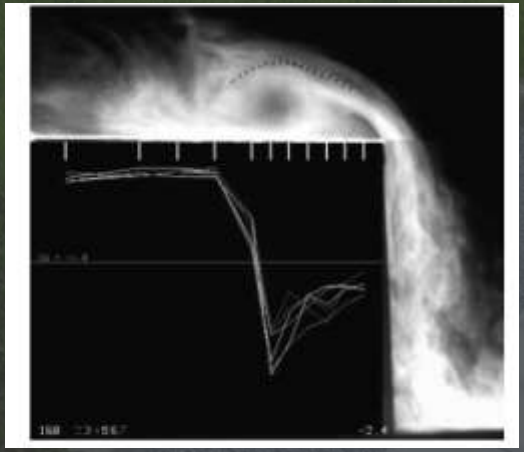
- A numerical model (FLUENT) is constructed to simulate the wind field of the STH and STHE green roofs from 8 wind directions
- Wind flow at height up to 40m above ground level is simulated
- Designed hourly-mean wind velocity (m/s) at different height is assumed to follow:

  $$38.7 \times (z/10)^{0.11},$$

  where z is the elevation above ground

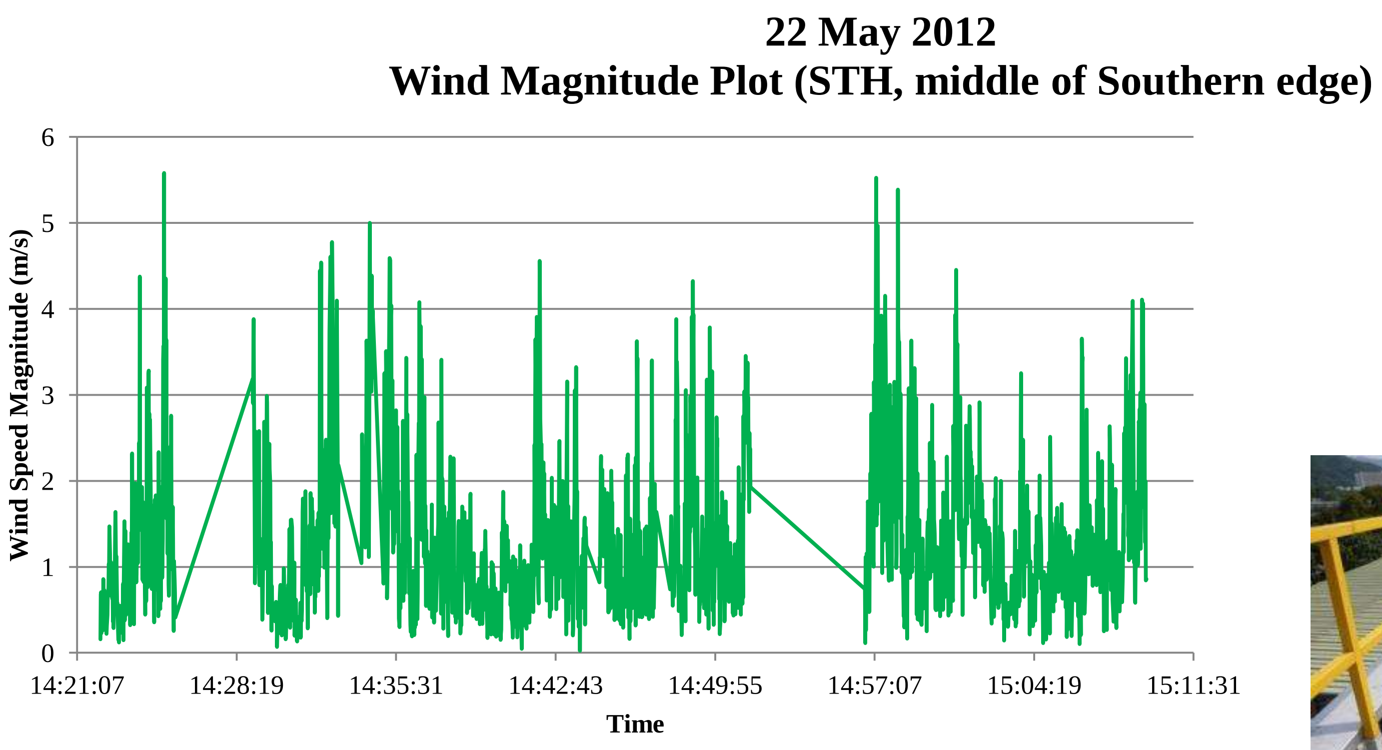


Model mesh of STSTW and its surrounding



Suction pressure acting on a green roof

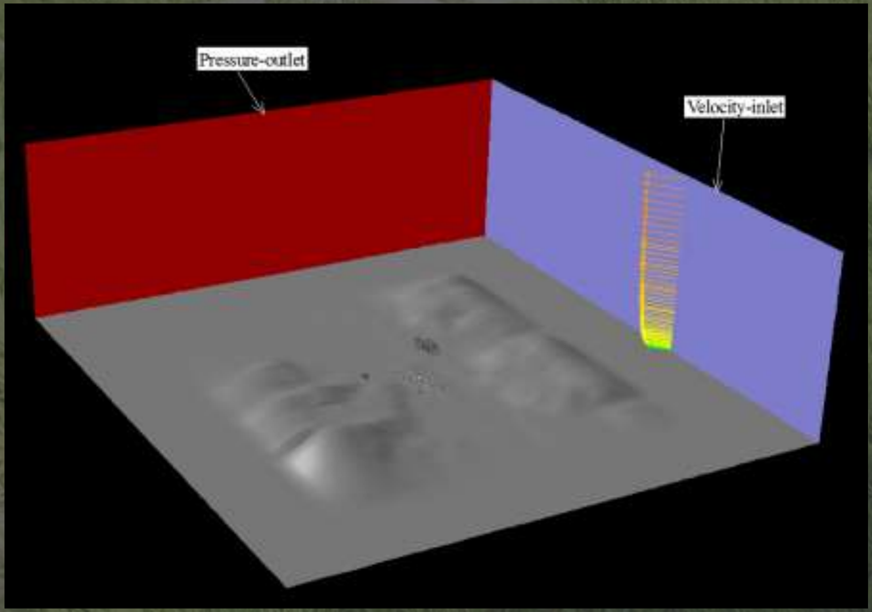
Wind Speed Field Measurements (22 May 2012)



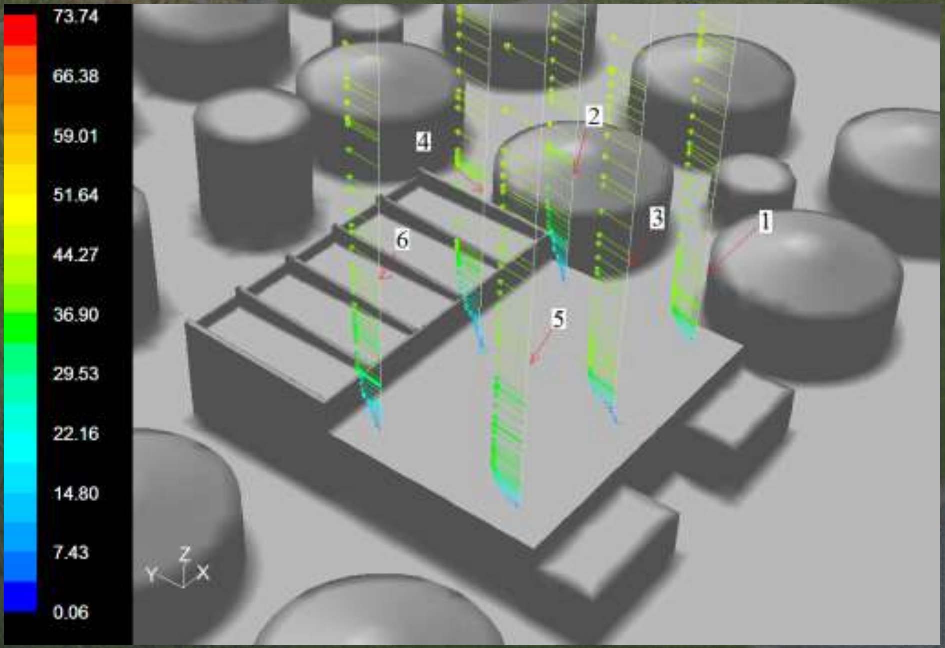
Wind (HKO): force 5 to 6 (E)
No. of sample: 2156
Mean speed: 1.31 m/s
Max speed: 5.58 m/s

Middle of Southern edge of the STH roof, 0.5m above soil level

▪ Task 7 – Wind Field Study of STSTW



Boundary condition of the model



Velocity vectors on Line 1 to Line 6, at various locations of STH roof

Wind loading calculation

Pressure Equation

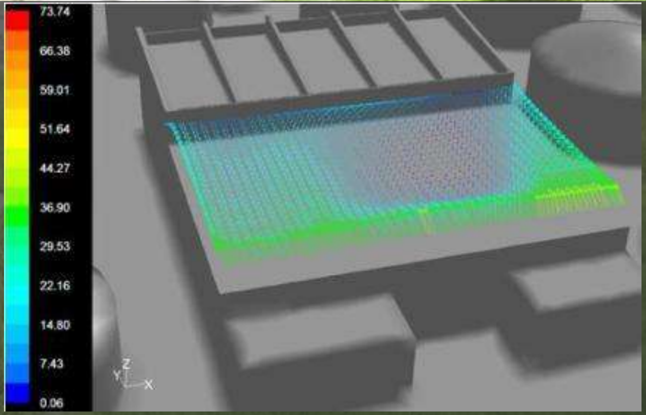
$$P = P_o + \frac{1}{2} C_P \rho U^2$$

P – suction pressure (Pa)
P_o – ambient pressure = atmospheric pressure = 0 gage pressure.
C_p – pressure coefficient = -1.2 (based on Table E1, Flat roof away from edge zones.)
ρ – air density = 1.2 kg/m^3.
U – wind velocity = 35.8 m/s (based on Table F3, maximum design wind velocity if building under 5 m high without sheltering effect.)
$P = 0 + 0.5 \times -1.2 \times 1.2 \times (35.8)^2 = -922.78$ N/m^2.
Thus, maximum suction pressure calculated is -922.78 N/m^2 (or -0.9228 kPa). This suction pressure is larger than the green roof loading of 0.75 kPa (non-accessible roofs). The wind reduction due to sheltering effect will be investigated in this project.

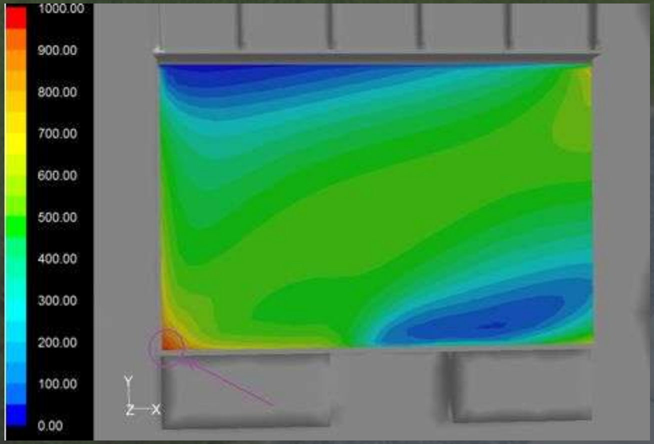
STH Green Roof

- Vegetation experiences the strongest wind speed and suction pressure under Southerly Wind

- At 0.5m above roof level, within a small region maximum suction pressure can reach 930Pa, above the design standard for green roof with 150mm soil thickness (i.e. 750Pa)



Velocity vectors at Z=17m (2m above the roof)

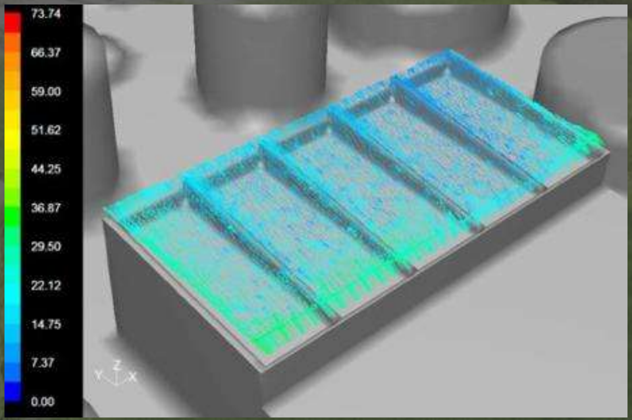


Visualization of max. suction pressure showing region over design limit (in red)

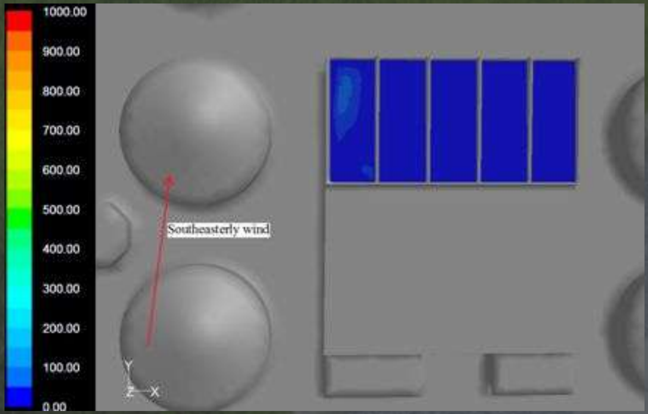
STHE Green Roof

- Vegetation experiences the strongest wind speed and suction pressure under Northerly Wind

- At 0.5m above roof level, the average suction pressure is 16.94Pa and the maximum is 133.16Pa. This pressure is even lower than the one in STH roof because there is concrete structure surrounding the STHE roof

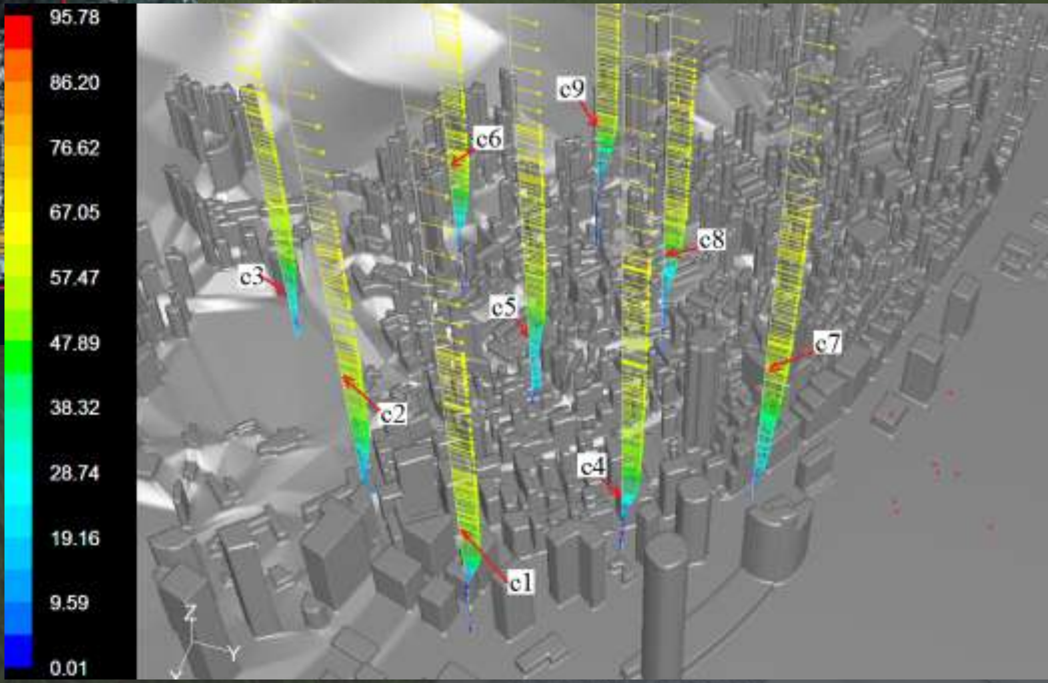


Velocity vectors at Z=17m (2m above the roof)



Visualization of max. suction pressure (in blue)

Wind field in Central region



Wind field in Central region

Model grid of IFC-one

Safe region

▪ Task 8 – Green Roof Design Guideline

Hong Kong Green Roof Survey

- Gain insights into the technology, trends, advantages and challenges
- Existing green roofs in places including universities and schools, government buildings, private residential and public recreational areas
- Inventory items include:

Aspect	Items
General	Name, Location, Type of Green Roof
Structural Concerns	Building Age, Roof Height, Weight of Green Roof, Slope%, Contractor Info
Vegetation	Species, Quantity, Soil, Irrigation, Fertilization, Pest & Weed Control
Surrounding Environment	Land Use, Animals and Plants, Air Quality
Achievements and Challenges	Safety and Maintenance, Studies Involved, Design Process, Experiences

(Visits and interviews are in progress)

Hong Kong Green Roof Survey

Part 1: General Information 基本資料

Facility Name: 設施名稱:		
Address: 地址:		
Contact Info 聯絡方法	Website: 網頁:	
	Tel.: 電話:	
	Email: 電郵:	
Contact Person: 聯絡人:		
Type of Facility: 設施類別:		Commercial 商業 / Industrial 工業 / Residential 住宅 / Recreational 休閒 / Other 其他
Type of Green Roof: 綠化天台類型:		Extensive 粗放 / Intensive 集約 / Other 其他
Survey Conducted: 問卷形式:		Site visit 上門採訪 / By email 電郵採訪

Part 2: Structural Concerns 結構相關

Part 2a - Construction Phase 興建期

Construction Contractor Info (if applicable): 承建商資料(如適用):	
Structural Consultant Info (if applicable): 結構顧問(如適用):	
Roof Height: 天台高度:	
Age of the Building: 設施樓齡:	
Designed Structural Loading: 設計負重:	
Expected Weight of the Green Roof: 預計綠化天台重量:	
Slope of the Green Roof (% or degree): 綠化天台傾斜度:	
Wind Safety Measures: 防風措施:	(e.g. walls, set-back distance, etc. 例:矮牆, 設安全距離等)
Fire Safety: 防火措施:	(e.g. fire-proof material choices, fire alarms, fire extinguisher, etc. 例:防火物料, 警鐘, 滅火器等)
Sign of Degradation (e.g. cracks, peeling): 老化痕跡(如裂痕,剝落等):	
Legal Considerations (e.g. handrail, lighting, exits, etc.): 法律相關 (如圍欄, 照明, 出入口等):	

Hong Kong Green Roof Survey

Part 2b - Maintenance Phase 保養期

Maintenance Contractor Info (if applicable): 承辦商資料(如適用):	
Annual Cost: 每年費用:	< $5,000 / $5,000 - $10,000 / $10,000 - $50,000 / > $50,000
Irrigation: 灌溉相關:	Auto 自動 / Manual 手動 Recycling rain water?循環雨水再用? Yes 是 / No 否 Method 方式 (e.g. spray, subsurface, etc. 例: 噴灑, 內置水管等): Frequency and Quantity 次數及用量 (Summer 夏季: _____ time(s) per day 每天次數, ____ L per time 每次用量) (Winter 冬季: _____ time(s) per day 每天次數, ____ L per time 每次用量)
Storm Runoff: 下雨時去水:	Performance on drainage 去水表現: Surface runoff 表面徑流: Yes 是 / No 否
Fertilizing: 施肥相關:	Type 種類: organic 有機肥 / inorganic 化肥 / both 混合 Frequency 次數: ________time(s) a year 每年次數 Quantity: ________ per time 每次用量
Pest Control: 除蟲:	Type of Pest(s) 類型: Type of Pest Control 除蟲方式: Chemical 藥物/ Physical 捕蟲器/ Other 其他 Freq.次數: __________time(s) a year 每年次數 Quantity 用量:________ per time 每次
Weed Control: 除草:	Type of Weed(s) 類型: Damage 對種植之影響 (Scale 1-5 級): ____ (1=no harm 無影響, 5=seriously affecting plants 影響嚴重) Type of Weed Control 除草方式: Freq. 次數: __________time(s) a year 每年次數
Pruning Frequency: 修剪相關:	Freq. 次數: _________time(s) a year 每年次數 Purpose 目的: appearance 外觀 / reduce wind drag 防止風吹/ enhance growth 幫助生長/ other 其他:
Frequency of Replanting/Repairing vegetation: 重種/修補植被:	Freq. 次數: __________time(s) a year 每年次數

Part 3: Basic Components of the Green Roof 綠化天台

Part 3a - Vegetation Related 植物相關

Types of Vegetation (scientific names if possible): 植物品種(學名, 如有):	(e.g. mosses 苔蘚, sedums 多肉, grasses 草, shrubs 灌木, trees 樹, etc.)
Total Quantity of Plants: 植物總數:	no. of shoot per area (herbs) 每單位面積內株數 (草類): total number (trees) 總棵數 (樹類): others 其他:
Vegetation Height (each type): 植被高度 (每種):	
Spacing: 植物之間的空隔:	

Part 3b - Substrate Related 土地相關

Area of the Soil Cover: 綠化面積:	
Total Area of the Roof: 天台總面積:	
Substrate Depth: 植料深度:	
Substrate Type and the Components: 植料種類及成份:	e.g. soil mix (%clay, %sand, etc.), artificial, etc. or brand name 例: 泥土(%泥, %砂, 等), 人工植料, 其他, (牌子名)

Hong Kong Green Roof Survey

Part 3c - Accessories and Hardware Related 工具雜項相關

Type of Root Barrier: 防根層類型:	
Type of Waterproof Layer: 防水層類型:	
Type of Boundaries/Fences: 圍欄種類:	
Other Hardware / Additional Elements (e.g.: decoration, furniture, sensors & data acquisition devices, maintenance tools, pets, etc.): 其他硬件或元素(如裝飾/傢俬/儀器/工具/寵物等)	

Part 4: Macro Environment and Ecology 附近環境

Type of Land Use: 該地區的土地利用:	Commercial 商業/ Industrial 工業 / Residential 住宅 /Recreational 休閒/ Other 其他:
Building Density: 樓宇密度:	
Ambient Temperature: 附近溫度:	
Humidity: 附近濕度:	
Air Quality: 附近空氣質素:	(Scale: 1 – 5 級) ______ (1=very bad 代表最差: smog 煙霧, dust 塵埃; 5=natural environment 自然)
Influences from Nearby Buildings (e.g. shading, wind shield): 附近樓宇影響 (如陰影, 風屏等):	
Faunal (animal) Attraction: 附近動物:	
Floral Density: 附近植物:	

Hong Kong Green Roof Survey

Part 5: Micro Ecology of the Green Roof 綠化天台生態

Animal Attraction: 天台外來動物:	
Plant Attraction: 天台外來植物:	
Relationship with Adjacent Green Roof/Vegetations: 與附近植物的互動:	
Air Quality: 天台空氣質素:	(Scale 1 – 5 級) _______ (1=very bad 代表最差: smog 煙霧, dust 塵埃; 5=natural environment 自然)
Ambient Temperature: 天台溫度:	
Humidity: 天台濕度:	

Part 6: History, Health and Innovation of the Green Roof 歷史及近況相關

Starting Date of Construction: 動工日期:	
Completion Date of Construction: 完工日期:	
Name of the Project: 工程名稱:	
Theme of the Project: 工程主題:	
Design of the Green Roof (inspiration & processes): 設計(靈感及設計過程):	
Expected Duration of the Program, and Reason: 項目為期(及原因):	
Prior Experiences on Gardening and Greening: 項目之前的綠化/園藝經驗:	
Health of Green Roof (e.g.: growth rate, diversity): 天台目前狀況 (如生長速度, 物種數增減):	
Studies Conducted and Key Findings: 過往研究及主要發現:	

Hong Kong Green Roof Survey

Part 7: Problems Encountered 各種挑戰

Water (drought & flood, leakage): 水相關 (乾旱, 水浸, 滲漏等):	
Pest: 蟲害:	
Weed: 雜草:	
Safety Issues: 安全問題:	
Maintenance Problems: 維修相養問題:	
Resources Problems (e.g.: man power, technical support, financial, management): 資源問題 (如人手, 技術, 財政, 管理):	
Environmental Aspects (climate, neighborhood): 環境問題 (如氣候, 相鄰設施):	

Part 8: Goal and Achievements 成就

Primary Goal of this Project: 項目之目標:	Education 教學 / Research 科研 / Exhibition 展覽 / Energy saving 節省能源/ Other 其他:
Major Achievements: 主要成就:	
Satisfaction to the Green Roof: 對天台的滿意程度:	(Scale 1 – 5 級) ______ (1= very disappointed 非常失望, 5=very satisfied 非常滿意)
Received Funding: 獲得資助:	
Main Users of the Green Roof: 綠化天台的使用者:	
Energy Saved: 節省能源:	
Competitions/Contests/Events and the Results: 參與的比賽或活動及成績:	

Hong Kong Green Roof Survey

List of Interviewees for the survey:

設施名稱	Name of facility	Type	Location
東華三院伍若瑜夫人紀念中學	T.W.G.Hs. Mrs. Wu York Yu Memorial College	School	Kwai Chung
保良局羅氏基金中學	Po Leung Kuk Laws Foundation College	School	Tseung Kwan O
香港中國婦女會馮堯敬紀念中學	HKCWC Fung Yiu King Memorial Secondary School	School	Ma on Shan
仁濟醫院第二中學	Yan Chai Hospital No.2 Secondary School	School	Tuen Mun
李求恩紀念中學	Lee Kau Yan Memorial School	School	San Po Kong
香港道教聯合會青松中學	The Hong Kong Taoist Association Ching Chung Secondary School	School	Sau Mau Ping
保良局顏寶鈴書院	Po Leung Kuk Ngan Po Ling College	School	Kowloon City
聖文德天主教小學	St. Bonaventure Catholic Primany School	School	Diamond Hill
聖言中學	Sing Yin Secondary School	School	Kwun Tong
樂善堂梁銶琚書院	Lok Sin Tong Leung Kau Kui College	School	Sai Ying Pun
可道中學(嗇色園主辦)	Ho Dao College (Sponsored by Sik Sik Yuen)	School	Yuen Long
賽馬會毅智書院	The Jockey Club Eduyoung College	School	Tin Shui Wai
香港道教聯合會鄧顯紀念中學	HKTA Tang Hin Memorial Secondary School	School	Sheung Shui
金巴崙長老會耀道小學	Cumberland Presbyterian Church Yao Dao Primary School	School	Tin Shui Wai
嘉諾撒聖家學校(九龍塘)	Holy Family Canossian School (Kowloon Tong)	School	Kowloon Tong
沙田循道衛理小學	Sha Tin Methodist Primary School	School	Sha Tin
光明英來學校	Kwong Ming Ying Loi School	School	Yuen Long
德信學校	Tak Sun School	School	Tsim Sha Tsui
聖士提反女子中學	St. Stephen's Girls' College	School	Central
新會商會學校	San Wui Commercial Socity School	School	Sheung Wan
嗇色園主辦可信學校	Ho Shun Primary School (Sponsored By Sik Sik Yuen)	School	Kwai Chung
浸信會沙田圍呂明才小學	Baptist (Sha Tin Wai) Lui Ming Choi Primary School	School	Sha Tin
天水圍天主教小學	Tin Shui Wai Catholic Primary School	School	Tin Shui Wai
漢華中學	Hon Wah College	School	Chai Wan
香港大學 圖書館(新翼)天台	Library Extension of HKU	School	Pok Fu Lam
尖沙咀東公共運輸交匯處	Transport Link in Tim Sha Tsui East	Gov	Tsim Sha Tsui
鑽石山火葬場	Diamond Hill Crematorium	Gov	Diamond Hill
銅鑼灣社區中心	Causeway Bay Community Centre	Gov	Causeway Bay
香港仔網球及壁球中心	Aberdeen Tennis & Squash Centre	Gov	Aberdeen
渠務署灣仔東灣仔西污水隔篩廠	DSD Wanchai East & Wanchai West Sewage Screening Plants	Gov	Wan Chai
沙田污水處理廠風機房	DSD STSTW Air Blower House	Gov	Sha Tin
牛頭角上邨	Upper Ngau Tau Kok Estate	Gov	Ngau Tau Kok
清河邨垃圾收集處	Ching Ho Estate (trash collection center)	Gov	Sheung Shui
上環污水泵房	Sheung Wan Sewage Pumping Station	Gov	Sheung Wan
水務署上水泵房	WSD, pumping station shuen shui	Gov	Sheung Shui
水務署大埔泵房	WSD, pumping station Tai Po	Gov	Tai Po
水務署馬料水泵房	WSD, pumping station Ma Liu Shui	Gov	Ma Liu Shui
水務署石門泵房	WSD, pumping station, Shek Mun	Gov	Ma On Shan
濕地公園遊客中心	HK Wetland Park Tourist Center	Gov	Tin Shui Wai
香港房屋協會 真善美村	Hong Kong Housing Society - Chun Seen Mei Chuen	Private	Kowloon City
浸會愛群社會服務處	Baptist Oi Kwan Social Service	Private	Wan Chai
仁愛堂賽馬會社區及體育中心	Yan Oi Tong Jockey Club Community and Sport Centre	Private	Tuen Mun
香港基督教服務處賽馬會日出山莊	Hong Kong Christan Service Jockey Club Lodge of Rising Sun	Private	Tuen Mun
明愛陳震夏郊野學園	Cartias Chan Chun Ha Field Studies Centre	Private	Cheung Chau
賽馬會總部大樓天台"綠之源"	Jockey club headquarter "our green place"	Private	Happy Valley
宏天廣場	Skyline Tower (Sino Estates Management) - 9/f roof "Mission Green Top	Private	Kowloon Bay
大埔墟火車站上蓋	Tai Po Market Railway Station roof	Private	Tai Po
理工大學 P 棟 6/f 天台	HKPU P core 6/f roof	POLYU	Hung Hom
理工大學 VA 天台	HKPU VA roof	POLYU	Hung Hom
理工大學文康大樓天台	HKPU Communal building roof	POLYU	Hung Hom

Green roof layer (dead load)

- Growing medium
- Filter layer
- 20mm Drainage layer
- 40mm concrete cover
- 10mm protected screed
- Waterproofing layer
- 20mm screed-coat
- 30mm Sloping layer
- Insulation layer
- Vapor barrier layer (not in figure)
- 20mm screed-coat (not in figure)
- Concrete substrate

中国建筑标准设计研究院 （2005） “05J909-工程做法”

General -- Minimum imposed load (MIL)

- Buildings constructed in different periods may have been designed with different design imposed load.
- Relevant statutory requirements have changed over time.
- Waterproofing system adopted at different periods may have been changed.
- The advances in material technology may render the use of less heavy waterproofing material.
- The use of different systems for thermal insulation, for green roof, cladding the roof envelop, etc., may lead to different dead load.

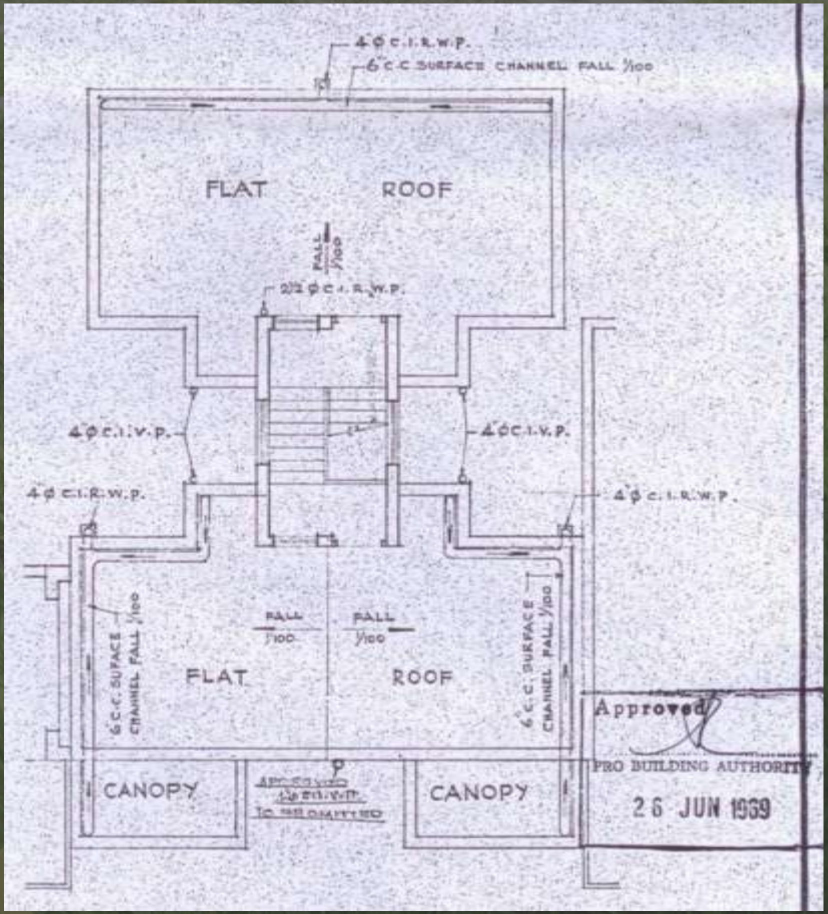
Minimum imposed load (MIL)

- In general, MIL of a flat roof can be divided into
  - Accessible
  - Inaccessible = No access other than maintenance work
- Building (Construction) Reg (before Aug 2011):
  - MIL for accessible flat roof is 1.50 kPa
  - MIL for inaccessible flat roof is 0.75 kPa
- Current Building (Construction) Reg:
  - MIL for accessible flat roof is 2.00 kPa
  - MIL for inaccessible flat roof is 2.00 kPa
- Wind load acting on the roof could be > MIL

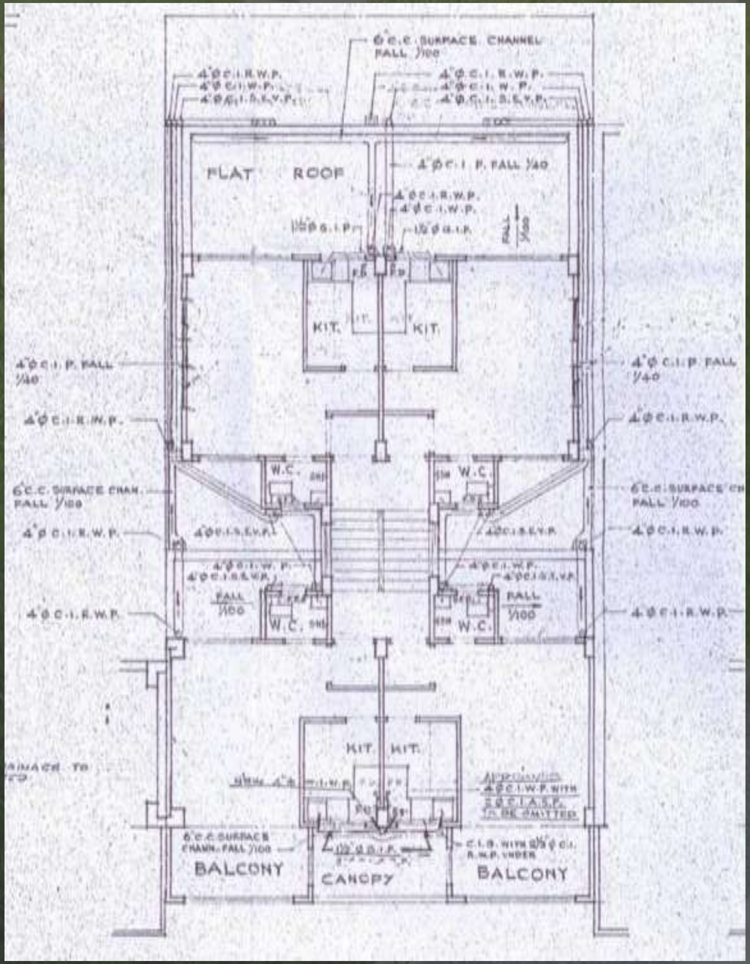
Old Buildings -- (MIL)

- Building (Construction) Reg 1975
  - MIL for accessible flat roof is 15 lb/ft^2 or 0.79 kPa
  - MIL for accessible flat roof is 30 lb/ft^2 or 1.58 kPa
- Building (Construction) Reg 1956
  - Refers to the Code of Practice in force by then
- For buildings constructed before the mid-50s, MIL (by then as superimposed load) can be referred to London Country Council (General Power) Act, 1909:
  - MIL > 56 lb/ft^2 or 2.95 kPa

Nos. 236-238 Yu Chau Street on N.K.I.L



Roof Plan



1st Floor Plan

Design Stage
設計階段

↓

Installation Stage
施工階段

↓

Maintenance Stage
保養階段

Flow Chart for Green Roof Application

Design Stage:

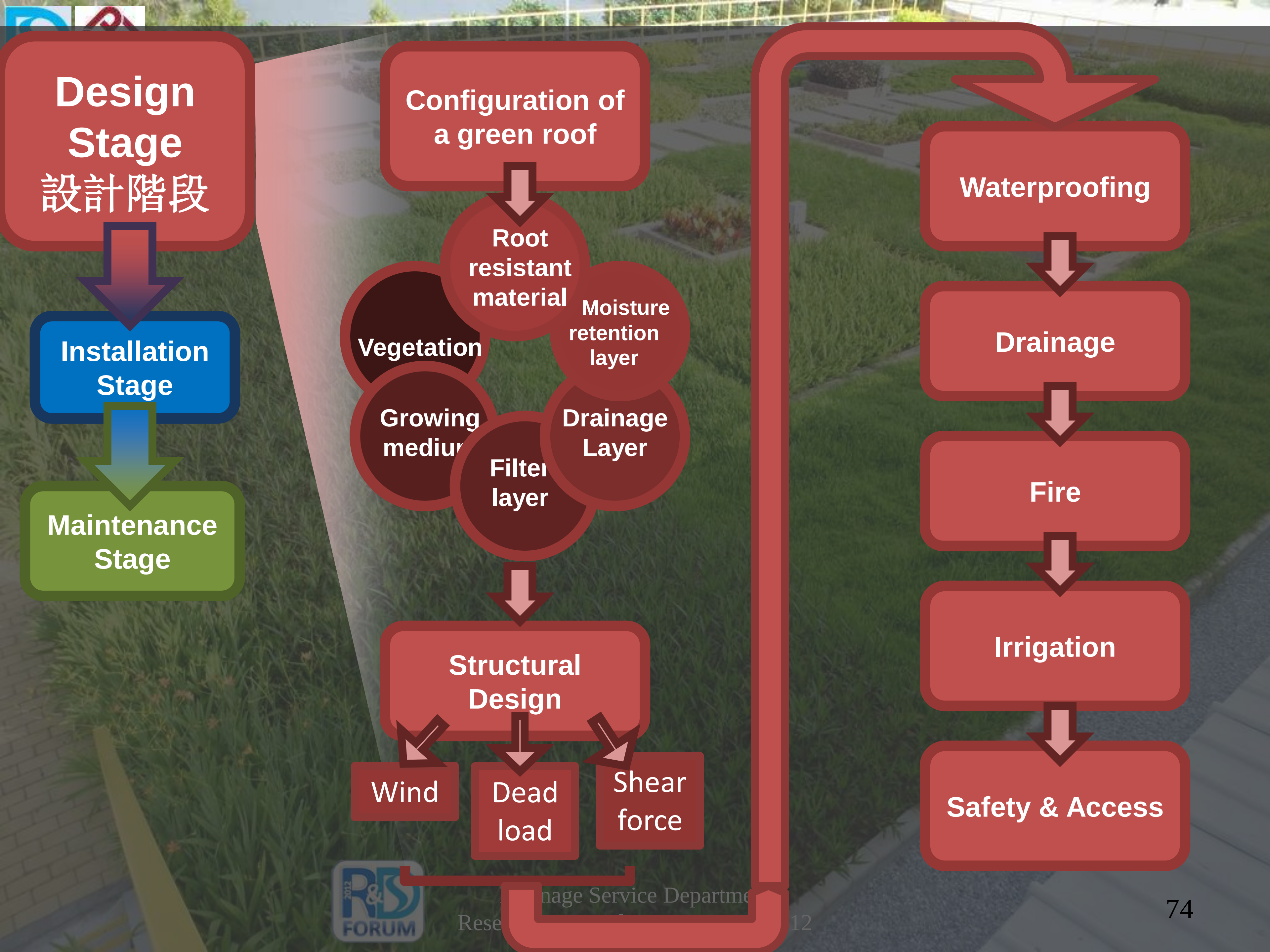
Consideration for designated green roof configurations and functions based on the objectives.

Installation Stage:

Implementation the installation according to the practical conditions.

Maintenance Stage:

Ensuring the initial establishment and continued health of the green roof system.


Design Stage
設計階段
Installation Stage
Maintenance Stage
Configuration of a green roof
Root resistant material
Vegetation
Moisture retention layer
Growing mediu
Filter layer
Drainage Layer
Structural Design
Wind
Dead load
Shear force
Waterproofing
Drainage
Fire
Irrigation
Safety & Access

Design Stage

Installation Stage
施工階段

Maintenance Stage

Site Preparation & Planning

Installation of System Components

- Protection sheets, drainage layers & filter layers
- Substrate installation
- Plant layer installation
  - Sedum mat
  - Plug planting
  - Hydroplanting & seeding

Installation of Perimeter & Penetration Details

Design Stage

Installation Stage
施工階段

Maintenance Stage

Site Preparation & Planning

Installation of System Components

Installation of Perimeter & Penetration Details

場地準備及布置

Contractors trained in the areas:

-Site preparation prior to installation;

-Preparation~Logistics;

-Essential system components;

-Growing medium;

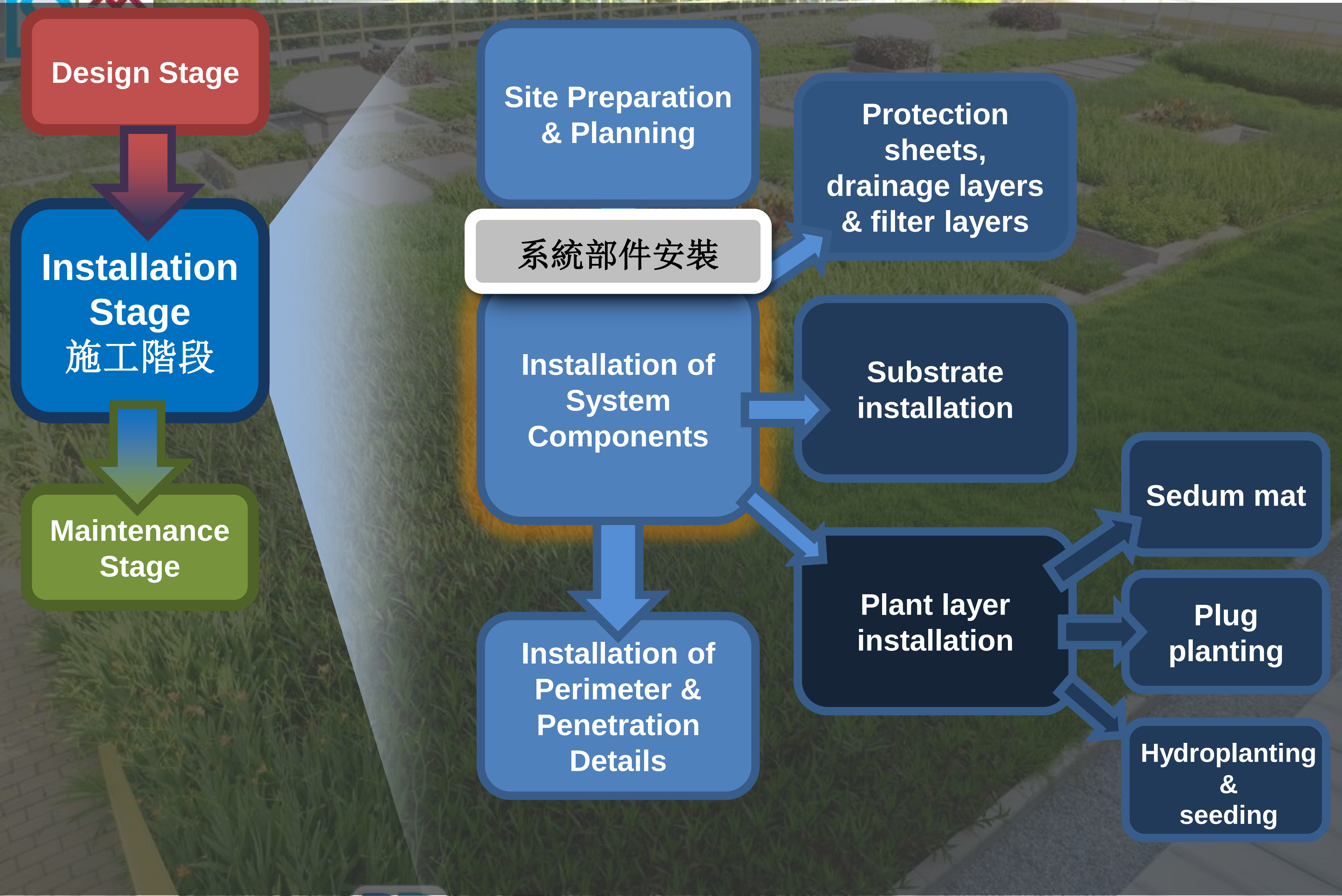
-Planting program;

-Installation of support system to the plants;

-Installation of plants;

-Post installation maintenance.

Hydroplanting & seeding


Design Stage
Installation Stage 施工階段
Maintenance Stage
Site Preparation & Planning
系統部件安裝
Installation of System Components
Installation of Perimeter & Penetration Details
Protection sheets, drainage layers & filter layers
Substrate installation
Plant layer installation
Sedum mat
Plug planting
Hydroplanting & seeding

Design Stage

保護層、排水層及
過濾層安裝

eparation

Installatio
Stage
施工階段

It is recommended that specific installation advice is sought from the specified system provider to **ensure compliance** with manufacturer's recommendations.

Components

Protection sheets, drainage layers & filter layers

Substrate installation

Plant layer installation

Sedum mat

Plug planting

Hydroplanting & seeding

Installation of Perimeter & Penetration Details

Maintenance Stage

Design Stage

Installation Stage
施工階段

Maintenance Stage

Site Preparation & Planning

Protection sheets, drainage layers & filter layers

種植物料施工

-Bags
Conductive to smaller projects or large projects with multiple roof spaces;

-Bulk deliveries
Offer economies of scale on large projects.

Substrate installation

Perimeter & Penetration Details

Plant layer installation

Sedum mat

Plug planting

Hydroplanting & seeding

Design Stage

Installation Stage
施工階段

Maintenance Stage

Site Preparation & Planning

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植物層種植

Optimal periods to install green roof are late **September/early October** or **late March/early April** (cooler and wetter conditions)

Design Stage

Installation Stage 施工階段

Maintenance Stage

Site Preparation & Planning

Protection sheets, drainage layers & filter layers

Installation of System Components

景天屬植被

Should be **thoroughly watered** in and kept moist thereafter for **4~5 week**.

installation

Sedum mat

Plug planting

Hydroplanting & seeding

Installation of Perimeter & Penetration Details

Design Stage

Installation Stage
施工階段

Maintenance Stage

Site Preparation & Planning

Protection sheets, drainage layers & filter layers

Installation of System Compone

Substrate ion

In

插秧式種植

-Substrate layer should be saturated;

-Pre-water the plants before removing from their trays;

-Apply slow release fertiliser;

-Insert plants and gently water them in

-Keep moist for 4~5 week.

Sedum mat

Plug planting

Hydroplanting & seeding

Design Stage

Installation Stage
施工階段

Maintenance Stage

Site Preparation & Planning

Installation of System Components

Protection sheets, drainage layers & filter layers

Substrate installation

yer

Sedum mat

Plug planting

Hydroplanting & seeding

噴播及播種

-A minimum of six sedum species;

-At a rate of about 150 g/m^2;

-Appropriate organic nutrient source.

Design Stage

Installation Stage
施工階段

Maintenance Stage

Site Preparation & Planning

Protection sheets, drainage layers & filter layers

Installation of System Components

安裝邊沿及滲透細節

Details for perimeters, drainage outlets, fire breaks, fall arrest system incorporation and penetrations should be installed according to manufacturer’s system.

Installation of Perimeter & Penetration Details

Hydroplanting & seeding

Design Stage

Installation Stage

Maintenance Stage 保養階段

General Maintenance Actions

- Irrigation
- Fertilizing
- Plant management
- General clearance or removal

Maintenance Actions by Roof Types

- Extensive
- Biodiverse
- Semi intensive
- Intensive

Ancient Hong Kong greenroof

An early practice of greenroof in Hong Kong (near Fan Kam Road in Yuen Long). Greenroofs need little maintenance but cannot be none.

Summary

1. Literature survey of various green roof guidelines has been carried out.
2. Large-scale green roof in Shatin WWTP has been constructed for in-situ experiments.
3. Reduction of roof top temperature fluctuation has been observed using thermal sensors.
4. Preliminary runoff experiments show considerable storm water retention and detention.
5. Thermal imagery reveals heat reduction on the roof surface.
6. Preliminary runoff analysis indicates water runoff quality improvement.
7. Numerical modeling approach has been applied to wind suction force and stormwater runoff on green roofs.

Upcoming Study

1. To continue the runoff investigations insituly, experimentally and numerically.
2. To conduct public survey on the existing green roofs in Hong Kong (the survey results can be used to verify the applicability of the overseas recommendations).
3. To continue the runoff water quality analysis.
4. To write guidelines for extensive green roofs based on the present study results.
5. To improve the prediction accuracy of the CFD model with field measurements and wind tunnel test data.

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THANK YOU!