Green Roof Research in Hong Kong: Key Findings and their Applications to Policy and Practice

Seminar Series on New Horizon in Greening: Skyrise Greenery
Hong Kong Central Library
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Green Roof Research in Hong Kong

1. Introduction and Exemplaries
2. HKU Runme Shaw Building
3. CLP Sky Woodland
4. KCR (MTR) Taipo Railway Station
5. HKU Library Building
6. School Green Roof Project
7. DSD Vertical Greening Experiment
8. Other Green Roof and Green Wall Sites
9. Policy and Practice Implications
The idea: Origin in antiquity

Ziggurat of Nanna in Ur, Mesopotamia, c. 2000 BC

Hanging Gardens of Babylon, c. 500 BC

The idea: Modern revival

50 great ideas for the 21st century
(The Independent, 06 August 2006)

“21. Green roofs

A hi-tech 21st-century version of the traditional turf roofs still found in parts of Scandinavia, a green roof is one covered with a thin layer of growing material which, in turn, supports a range of low-maintenance plants such as stonecrop and moss - all ready-grown on a kind of net matting which can be cut to fit. The results may be pretty, but it’s not so much the aesthetics as the ecological and, to a lesser extent, economic benefits that really count. They’re good for insects and birds, they soak up between 50 and 80 per cent of the rainwater that falls on them, and they provide natural insulation. Provided your roof is strong enough and not too steep (you can plant on slopes of up to 30 degrees), a green roof is now the perfect eco-friendly architectural accessory. (Christopher Stocks)”
Green roof research in Hong Kong

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8. Other Green Roof and Green Wall Sites

9. Policy and Practice Implications

Green roof and green wall sites:

1. Runme Shaw Building, rooftop, HKU (c. 400 m²)*
   The first research green roof in Hong Kong

2. Library Building, 3/F podium, HKU (c. 400 m²)
   The first library in Hong Kong with a green roof accessible to users

3. Library Building, rooftop, HKU (c. 2000 m²)*
   The second research green roof in Hong Kong

4. Electricity substation, rooftop, CLP (c. 200 m²)*
   The first sky woodland in Hong Kong, composed of native tree species

5. Railway Station, Taipo, MTRC (c. 3000 m²)*
   The first railway station with green roof and vertical greening

6. Sewage Works, Shatin, vertical greening of sewage treatment tank surfaces, DSD (c. 3500 m²)*
   The first research green wall in Hong Kong

7. Lowu Prison, rooftop of the three inmate blocks, ArchSD and CSD (c. 1200 m²)*
   Believed to be the first prison in the world with green roofs

8. Green Roof for Schools (involving thus far 10 schools with 13 sites) (total c. 4000 m²):
   The first school green roof initiative in Hong Kong, successfully triggered over 50 similar projects
   (a) King Ling College (Tseung Kwan O)
   (b) Hong Kong and Kowloon Kaifong Women’s Association Sun Fong Chung College (Taipo) (2 sites)
   (c) Kau Yan College (Taipo)
   (d) Caritas Tuen Mun Marden Foundation Secondary School (Tuen Mun)
   (e) Tsang Mui Millennium School (Sheung Shui)
   (f) Baptist Lui Ming Choi Primary School (Shatin)
   (g) Tin Shui Wai Catholic Primary School (Fanling) (2 sites)
   (h) Christian Alliance SW Chan Memorial College (Fanling)
   (i) SKH Kei Fook Primary School (Cheung Sha Wan)
   (j) Marymount Primary School (Happy Valley) (2 sites)

Total 20 sites; Total area = 14,700 m²

* Six sites are equipped with environmental monitoring equipment
HKU: First research green roof in 2006

Green roof benefits: Suppress urban heat island effect
HKU: research on hydrological benefit

HKU: plant species trial

Oct 2007

Jan 2008

May 2008
**Scientific journal research paper**

**Coupling heat flux dynamics with meteorological conditions in the green roof ecosystem**

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**Abstract**

Green roofs can notably enhance the thermal properties of the building envelope and adjacent air to bring environmental benefits. This study investigated the heat flux dynamics of the typical green roof components to provide a scientific basis for design and management. Case study experiment plots were set up at the University of Hong Kong to monitor daily heat flux under different meteorological conditions. Data were collected in a 10-month period from March 2013 to December 2013. The green roof was found to have a significant impact on the heat flux characteristics. The measured heat flux rates were compared with the background heat fluxes for a clear sky day. The results demonstrated that the green roof was highly effective in reducing the heat flux. The temperature of the roof surface was significantly lower than that of the bare roof. The overall energy balance was calculated to be 78% lower than that of the bare roof.

**Environmental monitoring equipment**

- **Monitoring Equipment Description**
  - **Vegetation bed**
  - **Roof waterproofing**
  - **Thermal insulation**
  - **Concrete deck**
  - **Rainwater harvesting**
  - **Soil temperature**
  - **Infiltration temperature**
  - **Condensation collector**
  - **Monitoring equipment**

*CY Jim: Green Roof Research in Hong Kong* 13

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Summer cooling effect

Seasonal heat flux
## Major research findings

1. The study assessed the ecological dynamics of heat flux transmission and energy balance of the green roof ecosystem so as to develop a scientific basis for its design and management.

2. The heat flux components of the green roof ecosystem express peculiar life cycle characteristics. The dynamic changes of fluxes in sensible heat, latent heat and soil heat demonstrate single-peak quadratic curves.


4. Seasonal heat fluxes vary with the fluctuation of meteorological driving forces. Extreme values of sensible heat and latent heat fluxes correlate well with rainfall and temperature.

5. The dynamics of heat flux magnitude and partitioning demonstrate notable differences amongst daily time periods and seasons which are dependent on group characteristics.

6. Temporal heat-flux fluctuations are strongly correlated with meteorological variables. Latent heat and sensible heat fluxes show major differences in response to precipitation. Temperature is one of the key contributors to heat flux. Latent heat flux is inversely related to atmospheric pressure.

7. Evaporation is the principal determinant of latent heat flux and soil moisture. There is a considerable range in flux partitioning characteristics (Rn, λE, H, and β).

8. Fluctuation trends of Bowen ratio are strongly influenced by weather condition and vegetation type.

9. The cooling effect of the green roof ecosystem is due to the imbalance of energy closure. The characteristics of plant canopy and soil properties contribute to heat loss of green roof ecosystem which leads to an unbalanced energy closure. Meteorological conditions, such as the amount, duration and density of clouds and precipitation incur variations in heat flux components in relation to the energy closure analysis.
Simulation of thermodynamic transmission in green roof ecosystem

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Soil temperature

ABSTRACT

Green roofs entail the creation of vegetated space on the top of artificial structures. They can modify the thermal properties of buildings by lowering cooling energy consumption and improve human comfort. This study evaluates the thermodynamic transmission in the green roof ecosystem under different vertical vegetation layers and horizontal climatic factors. Modelling of four scenarios for the rooftop was performed using the Radiative Transfer for BRAMS (RTR) and a proposed solar radiation shield effectiveness model (SREM). The RTR model simulates the absorption of different components of radiation, and the SREM calculates the radiation shield effectiveness. The proposed model was tested and validated to be effective in simulating solar radiation transmission in green roofs and also in urban buildings. The study shows that the solar radiation transmission parameters require for the considered urban situation simulation. Defining the properties of the green roof is important for thermal design. Nighttime or allowance of negative values requires a careful assessment model to reduce solar radiation transmission in green roofs. The study's results are in agreement with other previous studies. Nighttime solar radiation is highly correlated with peak temperature. The energy balance and climate response are strongly connected. The urban layer heat treatment has the highest shield effectiveness (SRE), followed by two-layer ginseng and single-layer ginseng. Green and vegetative effects and layers large amounts of heat to form an effective and thermal buffer against daily temperature fluctuations. Neglecting effects drastically decreases air temperature as compared with green ground control treatment. Finally, the thermodynamic model is relatively simple and efficient for investigating thermodynamic transmission in green roof ecosystem, and it could be applied into thermal solar radiation load green model.

Parameters in radiation shield effectiveness of vegetation

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Observed heat flux daily cycles

Fig. 3. Observed heat flux daily cycles of the experimental green roof plots in 2008.

Shield effective model for three vegetation types

Fig. 7. Vegetation shield effectiveness for three vegetation types in the green roof ecosystem for 2008.
Major research findings

1. We adopted an ecological approach by evaluating both the abiotic and biotic components of the green roof as a living system. We devised a field experiment to monitor the total solar radiation and net radiation, and to obtain detailed microclimatic data to calculate the sensible and latent heat fluxes of the green roof ecosystem with the traditional Bowen ratio energy balance method. We also evaluated green roof insulation effects on basis of the proposed solar radiation shield effectiveness model.

2. The dynamics of heat flux magnitude and partitioning demonstrate notable differences amongst daily time periods which are dependent on treatment characteristics. Ambient temperature is one of the key contributors to heat flux. Evaporation is the principal determinant of latent heat flux and soil moisture. The characteristics of plant canopy and soil properties contribute to the differential heat loss of the green roof ecosystem which leads to an unbalanced energy closure.

3. Radiation transmission and shield effects strongly correlate with vegetation structure and canopy transmittance and reflectance. A key function of the vegetation layer is to create a quiescent layer of air immediately above the roof surface.

4. Green roof vegetation has the capacity to absorb and store large amounts of heat to buffer against daily temperature fluctuations. The more complex vegetation structures have higher values of reflectance and transmittance, and absorb more radiant energy.

5. Predictions of thermal energy management benefits are possible only with the assistance of building envelope analysis techniques that can integrate all of these effects. As a result, the potential benefits of green roofs in managing energy can be approximated in different areas under different circumstances.

Scientific journal research paper

Effect of vegetation biomass structure on thermal performance of tropical green roof

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Landscape and Ecological Engineering (in press)
Diurnal cooling benefit of two vegetation types

Material temperatures in three layers

Fig. 10. Material temperature in the soil, rockwool and tile layers at the grass green roof site.
Material temperatures in three layers

![Graph showing temperature changes over time for different layers: Shrub, Rockwool, Soil, and Tile.]

Fig. 12. Material temperature in the soil, rockwool and tile layers at the shrub green roof sites.

Major research findings

1. Differential effects of three vegetation types of different biomass structure on green roof cooling impacts
2. Suppression of daily maximum and minimum temperature, but not of diurnal temperature range
3. Nighttime cooling effect of vegetated roof not better than control (bare) roof
4. Grass roof cools air temperature better than groundcover and shrub roofs
5. In daytime, grass develops a miniature suspended temperature inversion (STI) and shrub develops a canopy temperature inversion (CTI)
6. Shrub has the densest and most complex biomass structure but creates the most extreme diurnal air temperature regime
7. Grass has the simplest biomass structure, but it is more able to bring passive air cooling
Major research findings

8. Groundcover and shrub with a concentration of transpirational foliage elevated above the soil, create passive cooling respectively by perched thermal discontinuity (PTD)

9. The air gap of the plastic drainage layer arrested downward heat transmission in all vegetated plots to form a subsurface thermal discontinuity (STD)

10. Little heat moves from soil and rockwool layers to the tile, indicating the effective insulation provided by the drainage layer

11. The natural passive cooling effect of green roofs could play a useful role in ameliorating the urban heat stresses, and providing the collateral ecological and amenity benefits

12. Both daytime and nocturnal urban heat island effect could be ameliorated by irrigated green roofs

13. The findings provide an alternative dimension to the choice of vegetation and system design for roof greening in tropical cities, as a part of the bioclimatic building design making use of natural and sustainable cooling features

Scientific journal research paper

Modeling the heat diffusion process in the abiotic layers of green roofs

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Energy and Buildings (in press)
Experimental design

Modelled and measured temperature: rainy day
Modelled and measured temperature: after rainy day

![Graph showing temperature variations at plot bottom]

Fig. 9. Comparison of daily modelled and measured temperatures at nodes 2-4 of Plot 3 on a sunny day after a rainy day (31 March 2006).

Temperature variations at plot bottom

Fig. 10. Graph illustrating the temperature variations at the plot bottom.
Major research findings

1. A theoretical model has been developed successfully to evaluate the heat diffusion process of the soil, rockwool and plastic drainage materials used in green roof installation.

2. The lowest temperatures and the narrowest temperature ranges occur in the complex Plot 3, because the rockwool can retain an appreciable amount of rainwater for evaporative cooling through the soil surface on the sunny day after a rainy day, and to raise the specific heat capacity of the water-rockwool-air mixture.

3. The plastic drainage sheet with ample internal air spaces has been found to be a highly effective thermal insulation layer.

4. The seasonal and weather effects do not significantly affect the accuracy of the theoretical model.

5. The findings contradict with researches in the temperate region that the thermal dissipation in the vegetated roof with dense vegetation is lower than the thermal insulated bare roof.

6. Overall, the abiotic components of the modern green roof contribute significantly to the thermal performance and cooling effect of the elevated green spaces.

Scientific journal research paper

Game-theory approach for resident coalitions to allocate green-roof benefits

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Abstract. Roof greening in cities provides a range of environmental, economic, and social benefits. However, the lack of motivation among property owners in high-rise buildings poses an insurmountable obstacle to its wide implementation in compact cities. Cooperation amongst stakeholders, from individual-building to city-block scales, could facilitate adoption of green roofing, with implications for urban sustainability. This study is an attempt to evaluate the net gain from roof greening in terms of apportioned collective costs and benefits to a group of property owners. With government tax incentives to encourage green-roof installation, a fair-allocation scheme, based on the Shapley value, is adopted to distribute the net gain in a partnership structure. A case study in Hong Kong serves to illustrate the application of the method to allocate theoretically the shapley gains of roof greening translated into monetary terms. The results verify the importance of individual owners in different coalition configurations in modeling the benefit profile. The rise of the financial incentive scheme is the enhanced rewards to optimized cooperation, and the pump-priming triggering of cooperation and action. The benefits of green roofs could be maximized by their widespread and contiguous, rather than piecemeal, installation. Green roofs could reduce both capital and recurrent public expenditures in stormwater management, healthcare, and greenhouse-gas emissions, the savings from which would be more than enough to fund the tax-exemption scheme. The findings yield essential justifications for government financial incentives to promote public–private partnerships and cooperative coalitions of risk-holders in roof greening in compact urban areas.
1. Stormwater management
2. Health care service
3. Green space provision
4. Costs of constructing and maintaining green roofs
5. Reduction in energy consumption
6. Urban sustainable development

Cost-benefits of green roof in HK context

Computed costs and benefits

Table 1: Building information, and costs and benefits before and after green roof installation

<table>
<thead>
<tr>
<th>Building Information</th>
<th>Cost</th>
<th>Small coalition 1 (HK)</th>
<th>Scheme 1 (HK)</th>
<th>Scheme 2 (HK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building No.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof area (m²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total roof area (m²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before installation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After installation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof area (m²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CY Jim: Green Roof Research in Hong Kong
Net gains of roof greening

<table>
<thead>
<tr>
<th>Members</th>
<th>Total floor area (m²)</th>
<th>Tax exemption rate (%)</th>
<th>Cost before installation (HK$)</th>
<th>Cost after installation (HK$)</th>
<th>Characteristic value (HK$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(14)</td>
<td>309.08</td>
<td>0.1</td>
<td>1701302.73</td>
<td>96836.70</td>
<td>1761302.73×0.1-96836.70= 73493.57</td>
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<tr>
<td>(20)</td>
<td>177.11</td>
<td>0.1</td>
<td>1798307.22</td>
<td>55214.29</td>
<td>1763307.22×0.1-55214.29= 121622.45</td>
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<tr>
<td>(23)</td>
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<td>2100105.93</td>
<td>111866.23</td>
<td>2100105.93×0.1-111866.23= 98344.36</td>
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</table>

Major research findings

1. Applicability of Shapley value (game theory) approach in forming coalitions and allocating benefits
2. Tax exemption can mobilize interest and promote roof greening
3. Stakeholders, including building owners and the government, can benefit from coalition formation
4. Importance of every owner in the cooperation regime
5. Benefits can be maximized by widespread rather than piecemeal installation
6. Ample justifications for government to encourage installation by offering attractive financial incentives
7. More benefits in high-density neighbourhoods
8. Both the administration and residents can share the benefits of roof greening in a long-term, community-wide and public-private-partnership win-win scenario
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Scientific book chapter
Ecological design of rooftop native woodland for sustainable cities

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Abstract

The green roof idea is rooted in antiquity, with a modern revival about 50 years ago. Most green roofs are extensive, with a simple herbaceous cover. The intensive type with trees and shrubs is often dominated by horticultural design requiring significant maintenance inputs. Green roofs could adopt an innovative ecological or naturalistic design to establish native woodlands to bestow high-level ecological benefits and environmental amelioration such as cooling and suppression of urban heat island effect. Hong Kong’s excessively compact urban development mode leaves scarce ground-level green spaces. Green roofs offer alternative greening sites to reduce the environmental stresses associated with urbanization. A low-rise electricity substation has been earmarked for roof greening, and the rooftop urban woodland idea was implemented. Ecodesign principles were applied to establish a humid-subtropical native woodland that can attract local wildlife and other valuable ecosystem services in a densely developed residential area.

Keywords: ecological design, intensive green roof, urban woodland, urban biodiversity, ecosystem services.

International EcoBalance 2010 Conference
Tokyo, 9-12 November 2010

Sky woodland: The vision
Emulation of subtropical native woodland

- Emulates the natural woodland in terms of high vegetation coverage, high biomass volume, high leaf area index, high species-area index, and complex biomass structure.

Camellia hongkongensis  Hong Kong Camellia

Soil depth and rooting room

- Provides sufficient soil depth of 1 m to permit the healthy spread of tree roots, based on tree root research.
Major implications and applications

- Successful application of ecological concepts and ecological engineering to establish the most complex green roof in HK
- Feasible to use native trees to create a sky woodland on rooftop
- Diversified species composition and biomass structure
- Enhance urban wildlife (birds, butterflies, etc.)
- Cost-effective green roof installation
- Significant cooling effect by evaporation and transpiration
- Significant insulation effect by vegetation and soil layers
- Lower indoor temperature and reduce electricity consumption
- Reduce of stormwater drainage
- Improve quality of stormwater and reduce water pollution
- Notable landscape and amenity values for neighbourhood
- Exemplary demonstration project for HK and the region
- Findings for technology sharing and transfer

Scientific journal research paper

Biophysical properties and thermal performance of an intensive green roof

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Abstract

Green roofs have been increasingly recognized in alleviating urban environmental problems associated with urban heat island effect and stormwater management. This study focuses on evaluating the potential of an intensive green roof, with a vegetative cover of the species Iris pseudacorus, to control temperature and energy consumption. The results indicate that the green roof can reduce the surface temperature by up to 10°C and the energy consumption by up to 35% compared to a bare roof. This finding is consistent with previous studies, which suggest that green roofs can effectively mitigate the urban heat island effect and improve the energy efficiency of buildings.
Environmental monitoring

- Equipped with environmental monitoring equipment to glean data for scientific assessment of the benefits under humid-subtropical and densely-urbanized conditions

Air temperature in summer and winter
Canopy and ground temperature in summer and winter

Fig. 2. Diurnal woodland canopy and ground surface temperature in summer and winter on sample days of sunny and rainy weather conditions in 2008 and 2009.

Soil temperature in summer and winter
Soil moisture on sunny summer day

Heat flux in the sky woodland under different weather conditions
### Major research findings

1. The seasonal effect is significant for air temperature at different heights, soil surface temperature, soil moisture, tree canopy and ground surface temperature; it is not significant for soil temperature at different depths, tile and concrete slab temperature.

2. The weather effect is significant for diurnal air temperature at different heights, canopy, ground surface, and soil surface temperature; it is not significant for diurnal soil temperature and moisture at different depths (except on the soil surface), tile and concrete slab temperature.

3. The cooling effect due to transpiration rate (latent heat absorption) varies widely depending on seasonal and weather conditions, and it peaks in early autumn due to rather warm but dry weather condition.

4. The tree canopy layer could reduce solar radiation reaching the soil surface by reflecting some incident solar radiation back to the atmosphere; the air trapped in the canopy could reduce the convective heat loss and increase the air temperature near the soil surface.

5. The soil substrate layer operates as a large heat sink to reduce temperature fluctuation. The soil absorbs solar radiation on sunny daytime and retains it as storage heat. In nighttime, the storage heat is dissipated as sensible and convective heat.

6. On rainy days, soil absorbs rain water to increase the soil heat capacity to store a considerable amount of energy without increasing the soil temperature to achieve good thermal insulation performance.

7. The experiment demonstrates that soil thermal insulation performance does not require a thick soil. A thin soil layer of about 10 cm is sufficient to reduce substantially heat penetration into the building.

8. In winter, heat flows notably upwards from the substrate to the ambient air. The warmer indoor air below the roof slab creates a temperature gradient to draw heat upwards into the substrate and hence to dissipate in the air as sensible and latent heat. The resulting cooling of the building interior creates demands for more energy consumption to warm the indoor air. This finding contradicts the temperate latitude studies that point to reduction in heat loss through the roof in winter to lower heating energy consumption.
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Railway station: Green roof
Railway station: Green wall

Temperature on typical summer sunny day
Major research findings

1. The monthly analyses show great variations in diurnal thermal performance of the green roof. On average, the extensive green roof could reduce daily maximum temperature at the concrete roof surface at Tr by 1.5-4.6°C and at U10 by 0.8-1.4°C. The effect of green roof on air temperature at 160 cm is marginal. The surface temperature on the green roof surface at Ts is even higher than Tr on bare roof by 4.2-7°C due to limited solar protection by plants.

2. Solar radiation and relative humidity are the key meteorological factors with a bearing on the green roof thermal effect. High solar radiation combined with low relative humidity could optimize the thermal performance of the green roof.

3. Soil moisture enhances the green roof cooling effect by storing heat, dampening diurnal temperature fluctuations, and sustaining evapotranspiration and associated cooling.

4. Rainfall can offset the relative temperature reduction of the green roof due to rapid cooling of the bare roof.

5. Wind can reduce surface and air temperature of the green roof by enhanced evapotranspiration, but it has no significant correlation with temperature reduction because it could effectively and simultaneously dissipate the stored heat of the bare roof.
Major research findings

6. The thermal effect of the green roof displays considerable variations under different weather conditions. It is optimal on the sunny summer day, declines on the cloudy day, and tends to be negligible on the rainy day.

7. The reduction in maximum temperature by the green roof at Tra, Ts, U10 and U160 can reach respectively 11°C, 3.2°C, 4.5°C and 3.4°C on the sunny summer day. The values decline to 7.2°C and 2.3°C at Tra and U10 on cloudy days, which are associated with no significant reduction at U160 and even an increase at Ts. The green roof serves the role of thermal conservation on the rainy day with minor temperature reduction except for a slight nocturnal cooling.

8. The green roof could reduce cooling load by 0.9 kWh m⁻² on the sunny day and 0.57 kWh m⁻² on the cloudy day, but it can add a slight cooling load to the building on the rainy day. Overall, the 484 m² green roof has a potential for energy saving for indoor summer air-conditioning that is equivalent to 6.3×10⁴ kWh.

9. Especially on fine sunny days and to a lesser extent on cloudy days, the solar energy heats up the bare roof considerably to contribute to heat flux into the building indoor space, which in turn demands fossil fuel energy to cool down the indoor air by air-conditioners. The same solar energy works in the opposite direction on the green roof to propel evapotranspiration and to cool down the roof mainly during daytime. The green roof has transformed the consumptive and unwelcomed use of solar energy into productive and beneficial use.
HKU: Second research green roof

Ipomoea cairica

Thunbergia grandiflora
Green roof research in Hong Kong

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6. School Green Roof Project
7. DSD Vertical Greening Experiment
8. Other Green Roof and Green Wall Sites
9. Policy and Practice Implications
Proposal submitted to Hongkong Bank Foundation in July 2007
- Funding approval in October 2007
- Donate green roofs to 10 schools
- Each school to receive about 400 m² of lawn plus irrigation system
- Maintenance shouldered by school

Completed school green roof

Sun Fong Chung College
Recreational activities

Innovation dissemination: School

<table>
<thead>
<tr>
<th>No.</th>
<th>School Name</th>
<th>Project Name</th>
<th>Amount ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>San Wa Commercial Society Secondary School</td>
<td>Extensive Green Roof</td>
<td>486,500</td>
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<tr>
<td>17</td>
<td>Buddhist Wong Wan Tin College</td>
<td>空中花園計劃</td>
<td>185,600</td>
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<td>16</td>
<td>Cognitio College (Hong Kong)</td>
<td>Stop Global Warming: Green Roof</td>
<td>403,800</td>
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<td>Gagarini English Primary School</td>
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<td>H.K.T.A. Tang Hin Memorial Secondary School</td>
<td>Eco-Greenroof System</td>
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<td>13</td>
<td>TWG He Yau Tsz Tin Memorial College</td>
<td>Butterfly Garden on the Roof</td>
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<td>12</td>
<td>Hong Chi Pinehill No.2 School</td>
<td>Eco Green Roof</td>
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<td>Maryknoll Fathers’ School (Primary Section)</td>
<td>Green Roof Green School</td>
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<td>10</td>
<td>Chuk Lam Ming Tong Care &amp; Attention Home For The Aged</td>
<td>Vitality of Greenroof in Chuk Lam</td>
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<td>9</td>
<td>Ping Shuk Estate Catholic Primary School</td>
<td>Children under the Green Roof</td>
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<td>8</td>
<td>Lee Kau Yee Memorial School</td>
<td>Green Roof</td>
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<td>7</td>
<td>Holy Family Carassian School (Kwailoon Tong)</td>
<td>Green Roof System</td>
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<td>6</td>
<td>Shatin Methodist Primary School</td>
<td>Organic Sky Garden with Renewable Energy</td>
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<td>5</td>
<td>HKCW Fung Yiu King Memorial Secondary School</td>
<td>Green Roof Action</td>
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<td>4</td>
<td>Christian Alliance SY Yeh Memorial Primary School</td>
<td>Yeh’s Rooftop Garden Cum Environment Learning</td>
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<td>3</td>
<td>Caritas Lok Ken School</td>
<td>Project E.R. II (Environmental Roof)</td>
<td>810,370</td>
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</table>

Subtotal $12,498,303

Grand total $16,488,973
Educational use of school green roof

Green roof research in Hong Kong

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DSD sewage treatment works: Vertical greening

Wisteria sinensis

Lonicera japonica
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Lo Wu new prison: Green roof
Lo Wu new prison: Green roof

HKU: Vertical greening project
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High built-up density and heat absorption

Hong Kong: Warming trend 1885-2009
Urban heat island effect

Very hot days in Hong Kong: 1885-2009
Heat-related health problems

Disposition to heat-related health problems

Environmental factor
- Temperature of EHE
- Duration of EHE
- Humid and muggy weather
- High atmospheric pressure
- Prolonged drought

Human factor
- Intrinsic issue
  - Age >65
  - Age <4
  - Obesity
  - Frailty
- Compromised health state
  - Fever
  - Sunburn
  - Dehydration
  - Over-exertion
  - Alcohol consumption
  - Medication side-effect
- Chronic illness
  - Heart disease
  - Poor circulation
  - High blood pressure
  - Mental illness

Green roof benefits and functions
Air pollutant: Plant removal

Green roof: Air pollutant removal
Ground-level ozone formation

- Atmospheric precursors
  - Nitrogen oxides (NOx)
  - Volatile organic compounds (VOC)

Anthropogenic sources
- Vehicle exhaust
- Non-road equipment
- Electricity generation
- Fossil fuel combustion
- Industrial processes
- Waste disposal

Natural sources
- Vegetation fire
- Lightning (for NOx)

Sunlight and heat

Ozone (O3)

Green roof: Water movement
Outdoor recreation & visual amenity

Wildlife habitat & noise abatement
### Green roof promotion and policies

#### Policies and incentives

1. Demonstration green roof sites
2. Technical information centre
3. Technical assistance
4. Green roof as an integral part of urban greening programme and sustainable development
5. Financial subsidies to home owners (rate rebate)
6. Stormwater charge (impermeable surface fee)
7. Gray water collection and use
8. Green roof award of excellence

#### Regulatory framework

1. Removal of institutional barriers
2. Adjustment of land, planning, building and related development and safety regulations
3. Contractor and worker certification programme
4. Green roof standards and sample specifications
5. Planning approval condition
6. Green building guidelines
7. Green roof exemption from GFA calculation
8. Statutory requirement
Green roof promotion and policies

**Publicity and public education**

1. Green Roof Research and Application Centre
2. Platform for sharing of information and experience
3. Seminars and workshops
4. Training programmes
5. Posters, leaflets, booklets, API, website
6. Supply correct and modern green roof knowledge and technology
7. Overcome misconceptions and psychological barriers
8. Emphasis on environmental and energy conservation benefits

The End
Questions and Comments are Welcome