Development of technical guidelines for green roof systems in Hong Kong

Dr. Sam C. M. Hui

Department of Mechanical Engineering, The University of Hong Kong. E-mail: cmhui@hku.hk Web: http://web.hku.hk/~cmhui

ABSTRACT

Green roof systems are living vegetation installed on the roofs and can provide many environmental and social benefits for achieving low carbon high performance building. This paper describes the major findings of a research to develop technical guidelines for green roof systems in Hong Kong. The current knowledge and latest trends of green roof technology in the world have been studied. Useful information and experience were examined for assessing the potential benefits and key design factors. By investigating the system components and practical considerations of typical green roof projects in Hong Kong and other countries, key information is established for preparing the technical guidelines. It is hoped that the research findings will not only fill in the information gap, but also enable the making of policy and strategy to promote better urban greenery and assess their performance systematically.

1. INTRODUCTION

Nowadays many cities in the world are facing problems of urban heat island (UHI) and lack of greenery space (Wong and Chen, 2009). In Hong Kong, with the growing concerns about environmental issues and the need to promote sustainable urban environment, green roofs have attracted growing attention (Hui, 2009; Jim, 2010; Urbis Limited, 2007). However, the market for green roofs in Hong Kong is still developing and immature. There is a lack of good information and understanding on their technical design, effectiveness and actual benefits.

It is believed that green roofs can help mitigate the adverse effects of UHI and bring the nature back to the urban area (Bass and Baskaran, 2003; Chiang and Tan, 2009; Dunnett and Kingsbury, 2008; Hassell and Coombes, 2007). They not only can help lower urban temperatures, but also can improve aesthetics and urban psychology, as well as reduce pollutant concentrations and noise (Hui, 2006; Peck, *et al.*, 1999; Wong and Chen, 2009).

Traditional roof gardens have largely been restricted to growing plants in containers and planters or spreading top soil across the roof (Forbes, 2006). In recent years the development of multi-layered systems which re-create growing conditions across the roof has opened up a variety of planting options (Luckett, 2009; Weiler and Scholz-Barth, 2009).

This paper describes the major findings of a research to develop technical guidelines for green roof systems in Hong Kong. The current knowledge and latest trends of green roof technology in the world have been studied. Useful information and experience were examined for assessing the potential benefits and key design factors. By investigating the system components and practical considerations of typical green roof projects in Hong Kong and other countries, key information is established for preparing the technical guidelines. It is hoped that the research findings will not only fill in the information gap, but also enable the making of policy and strategy to promote better urban greenery and assess their performance systematically.

2. GREEN ROOF SYSTEMS

Green roof systems are living vegetation installed on the roofs and can provide many environmental and social benefits for achieving low carbon high performance building (Hassell and Coombes, 2007; Hui, 2009). They could contribute positively to make cities more liveable by providing green spaces, mitigating UHI, reducing air quality problem, enhancing stormwater management and biodiversity. Figures 1 and 2 show two examples of green roofs in Hong Kong.

(Source: Architectural Services Department)

Figure 1. Intensive green roof at Hong Kong Wetland Park

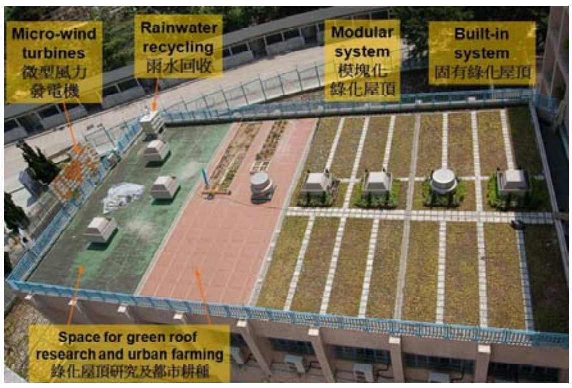
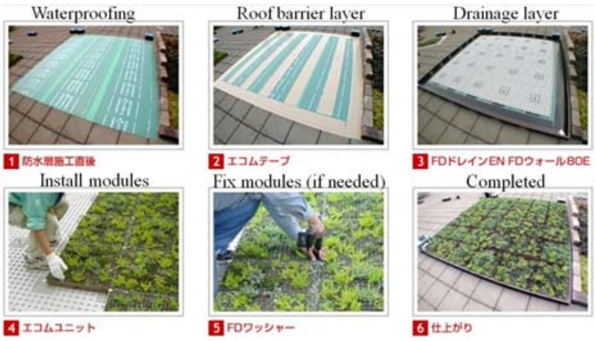


Figure 2. Extensive green roof at a school building

2.1 Green Roof Types

Modern roof greening has two main approaches: intensive (depth 150 to 1000 mm) and extensive (depth 50 to 150 mm). Intensive green roofs (including roof gardens) have a greater depth of growing medium to support a wider range of planting (Figure 1), and often include shrubs and trees. Extensive green roofs are systems with low growing plants, such as sedums, with no access other than for occasional maintenance (Figure 2); this type of roof is intended to be self sustaining and more economical.

Some of the green roof systems are installed as pre-cultivated vegetation blankets rolled out on site or constructed and planted by hand when insitu on roofs. Interlocking modular systems are also developed to suit particular site conditions (Hui and Chan, 2008). Figure 3 shows an example of modular green roof system from Japan.



(Source: www.tajima-roof.jp)

Figure 3. Modular green roof system from Japan

2.2 Structure of Extensive Green Roof

Figure 4 shows the typical structure of extensive green roof (Hui, 2009). It is usually composed of a waterproof membrane, followed by a root barrier, a layer of insulation, a drainage layer, the growing medium or soil substrate, and the plant material. A shallow layer of gravel or pebbles are placed from 0.5 m to 1 m within the outside perimeter of the roof, providing additional drainage, fire control, and access to the roof for maintenance.

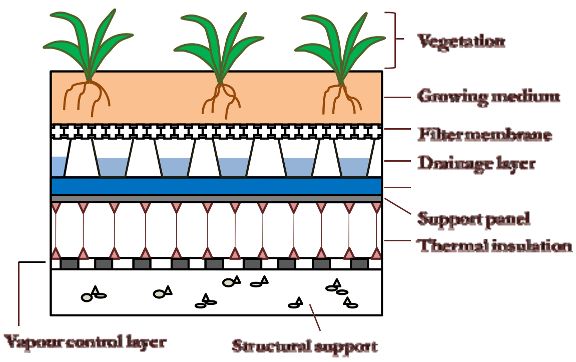


Figure 4. Structure of extensive green roof

Roofs utilised by pedestrians and traffic require a minimum incline of 2°. For pitched roofs with an incline of 15° or more, anti-slip measures are necessary on roofs to prevent the green roof substrate from slipping through shear forces.

2.3 Costs and Benefits

In all types of roofs the main issues to consider are waterproofing and adequate drainage; in a green roof structural loading and maintenance requirement are also important. Some existing buildings cannot be retrofitted with certain kinds of green roof because of the weight load of the substrate and vegetation exceeds permitted static loading. Vegetation selection is often crucial to the viability and long term success of the green roof system.

The cost of green roof systems depends on what kind of roof it is, the structure of the building, and what plants can grow on the material that is on top of the roof. Table 1 shows a summary of the estimated costs for Hong Kong (Urbis Limited, 2007). A holistic evaluation of green roofs should consider not only the initial cost but also the life cycle costs of the system (Saiz, *et al.*, 2006; Wong, *et al.*, 2003).

Table 1. Initial and maintenance costs of green roof systems

	Intensive	Extensive
Initial cost (HK\$/m^2)	1,000 to 5,000 (average: 2,000)	400 to 1,000 (average: 500)
Maintenance cost (HK\$/m^2/yr)	6.5 to 44 (average: 20)	0.8 to 2.25

Source: (Urbis Limited, 2007)

In fact, green roofs provide a wide range of benefits from amenity to ecological, technical advantages to financial aspects (Hui, 2006). Table 2 gives a summary of the public and private benefits of green roof systems. It is believed that cities could benefit from green roofs both in visual, aesthetic and local human climatic amelioration. However, it is not easy to quantify all of them for economic comparison.

Table 2. Public and private benefits of green roof systems

Public benefits:	Private benefits:
- Aesthetic value	- Increase roof life span
- Mitigate urban heat island	- Reduce cooling loads
- Stormwater retention	- Contribute to green building rating credit points
- Create natural habitat	- Better use of space
- Functional open space	- Reduce noise levels
- Agricultural space	- Reduce risk of glare for surrounding buildings
- Filter dust and pollutants	
- Filter rainwater	

3. WORLDWIDE EXPERIENCE

Comprehensive literature search and review have been conducted to study the current knowledge and latest trends of green roof guidelines and standards in the world. The research findings indicate that Germany and Japan are technically more advanced and have done a lot of pioneering work in supporting roof greening with various innovations. Today, it is estimated that more than 10% of all German roofs have been "greened". The Germany's guidelines and standards for planning and designing green roof systems are widely adopted and referred in many other countries.

3.1 Germany

Currently the most comprehensive document for green roof planning and design is the Germany's FLL guidelines (FLL, 2008). The FLL, established in 1975 as a not-for-profit organization, is the Research Society for Landscape Development and Landscape Design (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V.) (www.fll.de).

The FLL is a key player in the development of the green roof movement in Germany (Lawlor, *et al.*, 2006). When the green roof market boom first took off in Germany, many unqualified green roof companies surfaced, leaving behind a legacy of poorly constructed green roofs. The FLL guidelines have been highly successful in setting quality standards for green roof systems throughout Germany. Home and building owners are guaranteed a sound product when purchasing green roof systems and products designed according to the FLL guidelines.

The FLL guidelines is the standard regulatory work for intensive greening, simple (semi-) intensive greening and extensive greening of already sealed roofs and building covers. They contain details of care and maintenance work to the greened areas and service information for the technical installations. The FLL guidelines are also valid for other greening works on roofs and building covers (e.g. special tree plantations and useable grassed areas). Due to the special requirements of these works, deviations from parts of this regulatory work and the examination of other object specific regulatory works may be necessary.

The FLL guidelines complement the appropriate standards of the Construction Tendering and Contract Regulations in Germany and the German Standards Institute (Deutsches Institut für Normung, DIN) for landscape contractors. This applies to the execution of soil, planting and lawn works (soft landscaping) and the associated maintenance.

Great detail is paid in the FLL guidelines to the fundamentals of planning, the requirements of the construction to be greened, the demands on building materials and plants, regulatory statutes, required testing and contractual obligations. Furthermore, the possible types of greening and their functions and effects are demonstrated. The appendix contains orientation figures for bearing loads and water storage, testing methods, and the FLL method for examining the root resistance of root protection membranes and coatings.

Also, the planning guides (some are written in German) from a green roof supplier (www.zinco.de) are often used in the industry. They can provide practical information and guidance for green roof projects (Zinco, 2010).

3.2 Japan

In Japan, the Organization for Landscape and Urban Green Technology Development (known as "Urban Green Tech"), set up in November 1990 (www.greentech.or.jp), is responsible for promoting urban greenery and green spaces. It has developed and published a few important guidelines on rooftop and wall greening (written in Japanese):

- Neo Green Space Design, Volumes 1 to 4 (1996)
- Guide to Roof and Wall Green Technologies (1999)
- Green Roof Q&A (2000)
- Green Wall Q&A (2006)

With the support of the Ministry of Land, Infrastructure and Transport and the Ministry of the Environment in Japan, Urban Green Tech organised annual competition on specialized greening technology for rooftops, wall facings and new green spaces since 2002. It also coordinates research and development (R&D) work, conferences and incentive schemes on urban greening. These financial incentives are important, as they offset the higher costs of green roof technology. However, as green roofs are more widely implemented, technology costs fell.

Similar to Germany, because Japan has a mature green roof market, some green roof suppliers and companies prepare and provide planning guides and information for the practitioners. The local provincial governments also developed their requirements and standards, together with incentive schemes. This help to ensure quality of work for the green roof systems and promote the market development.

3.3 Other Countries

In recent years, some other countries have developed guidelines, manuals and codes for green roof systems to suit their own needs. A summary of them is given in Table 3.

Table 3. Technical guidelines and codes for roof greening

Country	References
Australia	Sydney City Council (2009)
Canada	Peck and Kuhn (2004); Lawlor, *et al.* (2006)
China	Beijing: BBQTS (2005), Guangzhou: GBQTS (2007), Shenzhen: SBQTS (2009)
Singapore	Tan and Sia (2008); Chiang and Tan (2009)
UAE	Dubai Municipality (2009)
UK	Newton, *et al.* (2007); Forbes (2006)
USA	NRCA (2009)

Besides green roof guidelines and codes, some countries have also developed technical standards in order to specify the quality and requirements of green roof systems and components. Below are some examples of these standards:

- ASTM standards: ASTM (2006); ASTM (2005a); ASTM (2005b); ASTM (2005c); ASTM (2005d)
- SPRI standards (on wind design and external fire design): SPRI (2010a); SPRI (2010b)
- Singapore standards (on design loads and safety): CUGE (2010a); CUGE (2010b)

The experience in most countries in the world indicates that the technical guidelines and standards are very important for ensuring the quality and performance of green roof systems, as well as promoting the development of urban greening technology and local market. There is an urgent need in Hong Kong to develop such information.

4. HONG KONG SITUATION

In Hong Kong, green roofs can be found on podium decks, in the form of roof gardens. They are often acting as landscape podiums in residential buildings (Figure 5).

Figure 5. A landscape podium garden in Hong Kong

Some new commercial and residential buildings also have "sky gardens" or greenery on the upper floors or at the top of the building. Many public open spaces are also built either wholly or partially on structure. It is therefore not surprising that Hong Kong has some degree of intensive green roof coverage already.

However, the application of extensive green roofs and other urban greening technologies is still limited in Hong Kong because there is no direct government requirement or industry incentive for private developers to build them. In the past decade, Hong Kong Government has devoted more concerted efforts to promote greening, particularly in the urban area. The target is to bring noticeable improvements in urban greenery, improve the quality of existing greened areas, and maximise the greening opportunity of public and private projects.

4.1 Greening Policy

Under the greening policy (www.devb.gov.hk/greening), greenery and landscaping have been widely incorporated in the planning of new towns and new development areas in Hong Kong where landscape master plans are usually prepared at the early planning stage. The difficult part is in the urban areas where competition of land uses is keen and land cost is high thus limiting the scope for greening, except where there is opportunity for comprehensive redevelopment.

Usually greening activities face a difficult situation because of disordered urbanisation and the escalation in land prices. With increasing population and limited land, the Government had to adopt a high-density and high-rise strategy. Space constraints have reduced the applicability of green surfaces in various areas surrounding the building envelope. Consequently, green roofs become the only promising choice for densely populated urban areas. However, up to now, a clear policy framework for green roofs is not available.

4.2 Government Pilot Projects

Since 2001, the Architectural Services Department (ArchSD) has incorporated rooftop or podium landscape designs in new government building projects wherever practicable (source: www.devb.gov.hk/greening). About 70 projects with such green features have been completed, including schools, office buildings, hospitals, community facilities and government quarters. ArchSD has also completed more than 20 retrofitting green roof projects for existing government buildings since 2006.

Other Government Departments have applied and installed green roofs on their buildings, such as the pumping stations and sewage treatment works of the Drainage Services Department (DSD, 2009). The Housing Authority (HA) has put in green roofs on low-rise structures and podiums, in its new housing developments designed since 2004 (source: www.housingauthority.gov.hk). Green roof retrofitting is also implemented in existing public rental housing estates. The species chosen for the HA's green roofs include turf, sedum, and a combination of small shrubs and groundcovers.

Although the pilot projects can help to promote urban greenery, the design technology, technical requirements and actual performance of the green roof systems are often not well defined and understood. Effective planning, design, implementation and acceptance quality of green roofs could be affected.

It was pointed out by some practitioners in Hong Kong that without a local code or technical guideline, the design specification and actual performance of green roof projects cannot be determined clearly and effectively. This will hinder the development of the local green roof or greenery market and technology. It is necessary to establish the key information from research studies for preparing the technical guidelines.

4.3 Green Roof Research

In 2006-07, the Government commissioned a consultancy study on "Green Roof Application in Hong Kong", focusing on the technical aspects of rooftop landscaping (Urbis Limited, 2007). The primary objective is to conduct a quick review of the latest concepts and design technology of green roofs and recommend technical guidelines to suit applications in Hong Kong to promote public understanding and awareness. This study forms a reference for further research and development.

In the past few years the number of research projects in Hong Kong related to green roof is increasing, but the research information and impacts are still limited (Hui, 2009). Most of the research focuses on field experiments and measurements with the aim to evaluate the benefits and impacts of green roofs, for example Jim and He (2010) and Luk *et al.* (2006). There is a lack of research on practical design issues to develop technical codes for the green roof systems. The experience from other countries could be helpful. For instance, in Germany FLL coordinates the R&D work and in Singapore the Centre for Urban Greenery and Ecology (CUGE) is the body driving the greening technology development.

5. DEVELOPING TECHNICAL GUIDELINES

At present, efforts are being made to study critically the information from other countries and to investigate the system components and practical considerations of typical green roof systems. It is hoped that useful information can be developed for preparing the technical guidelines in Hong Kong and promoting urban greening technology and market.

The guidelines and standards of Germany and Japan are useful references; the experience from mainland China and Singapore is also constructive to Hong Kong since they have similar climate and society structure. Neverthless, they should not be copied directly without considering and adapting the local conditions of Hong Kong.

5.1 Proposed Contents

Table 4 shows the proposed contents of the green roof guidelines. It is divided into three parts and will provide a systematic guidance to the readers on planning, design, construction, maintenance and management of green roof systems. It is expected that local data and information will be developed and used, wherever appropriate.

Table 4. Proposed contents of the guidelines

Part 1	1. Introduction 2. Scope 3. Definitions
Part 2	4. Planning Requirements 5. Design Considerations 6. Construction 7. Maintenance 8.Project Management
Part 3	References Appendices

When creating and planning a green roof, the first consideration is to establish its objectives and functions. For example, is the green roof to be used for environmental and green building benefits; or is it also accessible by, and to provide recreational amenities to, the people. The crucial factors are the load-bearing capacity of the roof construction and the choice of appropriate green roof build-up. Table 5 shows the major factors to consider in the design process.

Table 5. Major factors to consider

Planning Requirements	- Functions and effects - Structural loading - Accessibility - Site conditions (wind, shade) - Water proofing condition - Green building credits
Design Considerations	- Landscape design - Irrigation & water supply - Stormwater drainage - Plant species - Wind design (e.g. typhoons) - Sustainable technologies (e.g. solar) - Food production (farming) - Rainwater recycling - Roof slope
Construction	- Safety issues (preventing falls) - Vegetation planting method - Testing & monitoring
Maintenance	- Maintenance requirements - Warranties - External fire hazard - Safety issues
Project Management	- Green building assessment - Financial incentives - Regulatory measures - Contractual matters

5.2 Considerations for Hong Kong

Some important technical issues have been identified and considered for Hong Kong. They are briefly described below. Further investigation will be carried out to examine them so as to establish the guidance.

(a) High-density urban areas

Hong Kong has a high building density and the high-rise buildings usually have very limited roof area (Hui and Chan, 2008). It is usually more effective to apply green roofs to the top of medium- or low-rise buildings/structures or the intermediate podium roofs. By doing this, the occupants from surrounding tall buildings can enjoy the green roof and appreciate the application. Guidelines will be developed to assess the potential and constraints of green roof applications in high-density urban areas in Hong Kong.

(b) Green roof on existing buildings

Existing buildings constitute a major portion of the building stocks. When applied to these buildings, the green roof design will be limited to the loading capacity of the existing roof unless a higher initial cost is paid to upgrade the structure. Guidance will be provided to help people select a suitable green roof system (usually light-weight) and implement it effectively in existing buildings.

(c) Typhoon and stormwater

Hong Kong often faces typhoon and stormwater problems during the rainy season (Hui and Chu, 2009). The strong wind and heavy rainstorm could cause flooding and serious damages to the society. The typhoon might blow away the vegetation and soil, therefore, green roof modules and plants must be well secured and protected. Also, the green roof should be able to hold and drain the rain water without creating pools of stagnant standing water.

5.3 Green Building Assessment Methods

Green building assessment methods, such as LEED (USGBC, 2009) and BEAM-Plus (BEAM Society, 2009), are becoming more and more popular and important in Hong Kong and other countries. It is proposed that the technical guidelines will include information to help people optimise the credit points for the assessment from their green roofs.

Tables 6 and 7 gives examples of credit points related to green roof systems in LEED 2009 version and BEAM Plus, respectively. The main criteria impacts and secondary credit impacts are shown. It can be seen that the greening technology has significant implications to the results of the assessment schemes. It is hoped that this can help to promote greenery to developers and building professionals.

Table 6. LEED 2009 credit points of green roof systems

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

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

Source: extracted from USGBC (2009)

Table 7. BEAM Plus credit points of green roof systems

BEAM Plus criteria impacts:	Points
Sites Aspects (SA)	
Perequiste: Minimum landscape area	Req'd
SA 5: Ecological impact	1
SA 7: Landscaping and planters	1-3
SA 8: Microclimate around buildings (roof)	1
Materials Aspects (MA)	
MA 7: Recycled materials (roof components)	1
Credit 5: Local/Regional materials	1-2
Energy Use (EU)	
EU 1: Reduction of CO_2 emission	1-15
EU 2: Peak electricity demand reduction	1-3
Water Use (WU)	
WU 1: Water efficient irrigation	1
WU 6: Effluent discharge to foul sewers	1

Secondary credit impacts:	Points
Water Use (WU)	
WU 4: Water recycling (rainwater)	1-2
Innovations and Additions (IA)	
IA 1: Innovative techniques	1-5

Source: extracted from BEAM Society (2009)

5.4 Green Roof Performance and Quality

Hong Kong has good potential to promote green roofs (Hui and Chan, 2008). However, the current knowledge and understanding of the green roof performance are still not sufficient for the decision makers and stakeholders to consider the true value of green roof systems and their impacts to the urban environment or to their own business.

The actual performance of green roof systems depends on a number of factors. Nowadays, some research studies have been done on thermal and energy performance (Bass and Baskaran, 2003; Hui, 2009; Niachou, *et al.*, 2001), hydrologic or stormwater management performance (Carter and Jackson, 2007; Hui and Chu, 2009; Köhler, *et al.*, 2001; Luk, *et al.*, 2006; Simmons, *et al.*, 2008), as well as air quality/ pollution control (Currie and Bass, 2008; Yang, Yu and Gong, 2008). The research information is helpful for understanding and evaluating the potential and limitation of green roof systems.

However, in order to ensure that a green roof achieves its performance goals or performs its ecological function, it is necessary to examine the various performance aspects in a holistic manner. The experience in Germany would be a good reference (Lawlor, *et al.*, 2006).

In Germany, the FLL developed a performance rating system for green roofs to aid with regulatory measures to ensure compliance. The points-based system assesses the components and functions of the green roof. To obtain the base value, it takes the depth of the green roof system that can be penetrated by the plant roots and assigns 10 points for each centimetre of penetration. For example, if the depth is 10 cm, the system's base value is 100 points. From here, the system sets performance criteria for four further categories as shown below. People can use this tool to ensure that a green roof meets the desired ecological functions.

- Water retention capacity of the growing medium
- Water retention capacity of the drainage layer
- Number of plant species for extensive green roofs
- Plant biomass or volume for intensive green roofs

Also, the FLL rating system identifies qualitative characteristics to judge whether a project is suitable for ecological compensation. The FLL's qualitative parameters for assessing green roof performance are sumarised in Table 8.

Table 8. FLL's qualitative parameters for assessing green roof performance

Category:	Description:
Soil	Quality of soil
Water	Improvement in surface water quality Reduction in load of the sewer system Improvement in groundwater recharge Purification of stormwater
Air & tempera-ture	Filtering of air Contribution to oxygen production Contribution to urban temperature levelling
Habitat	Contribution to establishment of flora and fauna habitat
Landscape	Contribution to landscape and urban scenery
Amenity	Contribution to amenity for people / leisure / healing

Note: * Each parameter is deemed "possible to fulfill completely", "possible to fulfill partially", or "slightly or not possible to fulfill."

Karlsruhe, a city in the south weat of Germany, has set up the "Karlsruhe Performance Rating System" for green roofs to rate green roofs according to five natural functions (the percentage represents the relative weighting):

- Type and depth of soil used (Soil) – 15%
- Impact on climate due to evapotranspiration (Climate) – 15%
- Type and variety of vegetation (Flora) – 30%
- Impact on zoological biodiversity (Fauna) – 30%
- Average annual stormwater retention (Water Balance) – 10%

Inspecting green roofs after installation is an important way to ensure that green roofs meet FLL guidelines and their ecological requirements. Therefore, a quality control system for completed green roofs and a green roof "seal of approval" have been implemented in Germany.

It is believed that a simple scheme for assessing the performance of green roof systems can be added to the proposed technical guidelines in Hong Kong so as to enhance quality control and project management.

5.5 Green Roof Professional and Training

The knowledge level of the green roof practitioners and stakeholders play a significant role in determining the success of the technical guidelines. It is essential to provide training and education for people to enhance their understanding and skills in green roof design and project management. The experience in Canada is constructive.

A non-profit organisation called "Green Roofs for Healthy Cities" (www.greenroofs.org) located in Toronto, Canada has developed an accreditation scheme and examination for Green Roof Professional (GRP) since 2003. They also introduced the first training course (Green Roof Design 101) in the spring of 2004. Since the first course was completed, three subsequent courses, Green Roof Design and Implementation 201, Green Roof Waterproofing and Drainage 301, and Green Roof Plants and Growing Media 401 have been developed and they are currently being offered in cities across North America. Usually people taking the GRP training come from fields such as architecture, building services engineering, civil and structural engineering, horticulture, roofing and waterproofing, and landscape architecture.

This type of training and accreditation is useful to the long-term health and growth of the green roof industry. It is believed that successful green roofs require a combination of knowledge and expertise in the so-called 'black arts' and 'green arts'. The 'black arts' focus on the critical, non-living elements of a green roof assembly such as water proofing, structural engineering and project management, while the 'green arts' deal with the living architectural components such as water management, growing media, plants and maintenance.

Properly trained Green Roof Professionals will be well versed in both the 'black' and the 'green' arts in order to gain this professional distinction of green building expertise. In order to ensure successful implementation of the green roof guidelines in Hong Kong, it is advisable to consider setting up better training on green roof knowledge and technology.

6. CONCLUSIONS

Greening plays an important role in building an environmentally friendly society. It brings about many benefits to our environment, and engages various sectors of the society. It is believed that urban cities in the world like Hong Kong can benefit from green surfaces, especially when both walls and roofs are covered with vegetation.

In recent years, green roofs are becoming more and more popular in the world and have also attracted much attention in Hong Kong. However, when people consider applying green roof systems, they often find it difficult to understand the technical requirements, design an effective system and evaluate their performance. There is an urgent need to develop local technical guidelines for planning, designing and commissioning green roof systems in Hong Kong.

Like any innovation, lingering doubts about green roofs still persist, worries ranging from costs, leakage to mosquito prevent the widespread adoption of green roofs. Financial incentives, public awareness and building codes can help encourage the adoption of green roofs and other greening measures. It is important to help property owners and developers to look beyond the immediate financial burden to realise the long-term benefits and the pressing need to achieve a sustainable urban environment.

For Hong Kong, with the dominance of hard-paved surfaces including roofs, vertical faces and street level, it is important to review administrative/legislative measures to promote roof and multi-level greening. In the urban area, the greening can enhance the quality of our living environment and provide opportunities for other community functions, such as community gardens, urban farming and healing landscape. Green roofs can also be a mitigation measure for climate change, as they allow developers to meet their green space requirements.

It is believed that green roofs can help reduce three of the four top problems facing the society in the next 50 years: energy, water, and environment. In this way, the green roof technology has a potential to improve quality of population health and welfare in the urban areas with dramatically reduced vegetation. Hopefully this will lead to a holistic green building – better ventilation, shade, micro-climate, less energy reliance for the city.

Green roof movement in Hong Kong has just begun.

ACKNOWLEDGMENTS

The author would like to thank the CIBSE Hong Kong Branch for providing funding to this research project. Sincere thanks are also expressed to the Energy Efficiency Office of the Electrical and Mechanical Services Department for allowing some information of a consultancy study to be used here.

REFERENCES

ASTM, 2006. *ASTM Standard E 2400 – 06, Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems*, ASTM International, West Conshohocken, PA.

ASTM, 2005a. *ASTM Standard E 2396 – 05, Standard Test Method for Saturated Water Permeability of Granular Drainage Media [Falling-Head Method] for Green Roof Systems*, ASTM International, West Conshohocken, PA.

ASTM, 2005b. *ASTM Standard E 2397 – 05, Standard Practice for Determination of Dead Loads and Live Loads associated with Green Roof Systems*, ASTM International, West Conshohocken, PA.

ASTM, 2005c. *ASTM Standard E 2398 – 05, Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Green Roof Systems*, ASTM International, West Conshohocken, PA.

ASTM, 2005d. *ASTM Standard E 2399 – 05, Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roof Systems*, ASTM International, West Conshohocken, PA.

Bass, B. and Baskaran, B., 2003. *Evaluating Rooftop and Vertical Gardens as an Adaptation Strategy for Urban Areas*, NRCC-46737, Institute for Research in Construction, National Research Council Canada, Ontario, Canada.

BBQTS, 2005. *DB11/T 281-2005, Code for Roof Greening*, Bejing Bureau of Quality and Technical Supervision (BBQTS), Beijing, China. (in Chinese)

BEAM Society, 2009. *Building Environmental Assessment Method: BEAM Plus for New Buildings*, BEAM Society, Hong Kong.

Carter, T. and Jackson, C. R., 2007. Vegetated roofs for stormwater management at multiple spatial scales, *Landscape and Urban Planning*, 80 (2007): 84-94.

Chiang, K. and Tan, A., 2009. *Vertical Greenery for the Tropics*, National Parks Board, Singapore.

CUGE, 2010a. *CS E 01: 2010, Guidelines on Design Loads for Rooftop Greenery*, Centre for Urban Greenery and Ecology (CUGE), Singapore.

CUGE, 2010b. *CS E 02: 2010, Design for Safety for Rooftop Greenery*, Centre for Urban Greenery and Ecology (CUGE), Singapore.

Currie, B. A. and Bass, B., 2008. Estimates of air pollution mitigation with green plants and green roofs using the UFORE model, *Urban Ecosystems*, 11 (2008): 409-422.

DSD, 2009. *Application of Green Roof in Wan Chai East and West Preliminary Treatment Works*, Research & Development Item No. RD 1059, Project Management Division, Drainage Services Department (DSD), Hong Kong.

Dubai Municipality, 2009. *Green Roof Manual: Guidelines for Planning, Execution & Maintenance of Green Roof Various Applications*, Dubai Municipality, Government of Dubai, UAE.

Dunnett, N. and Kingsbury, N., 2008. *Planting Green Roofs and Living Walls*, Revised and Updated Edition, Timber Press, Oregon.

FLL, 2008. *Guidelines for the Planning, Construction and Maintenance of Green Roofing*, 2008 edition, Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. (FLL), Bonn.

Forbes, R., 2006. *The Green Roof Pocket Guide*, The Green Roof Forum, Sheffield, UK.

GBQTS, 2007. *DB440100/T 111-2007, The Technical Code for Roof Greening*, Guangzhou Bureau of Quality and Technical Supervision (GBQTS), Guangzhou, China. (in Chinese)

Hassell, C. and Coombes, B., 2007. *Green Roofs*, CIBSE Knowledge Series KS11, Chartered Institution of Building Services Engineers, London.

Hui, S. C. M., 2009. *Study of Thermal and Energy Performance of Green Roof Systems: Final Report*, Department of Mechanical Engineering, The University of Hong Kong, Hong Kong.

Hui, S. C. M., 2006. Benefits and potential applications of green roof systems in Hong Kong, In *Proc. of the 2nd Megacities International Conference 2006*, 1-2 December 2006, Guangzhou, China, pp. 351-360.

Hui, S. C. M. and Chan, H. M., 2008. Development of modular green roofs for high-density urban cities, paper presented at *the World Green Roof Congress 2008*, 17-18 September 2008, London, 12 pages.

Hui, S. C. M. and Chu, C. H. T., 2009. Green roofs for stormwater mitigation in Hong Kong, In *Proc. of the Joint Symposium 2009: Design for Sustainable Performance*, 25 November 2009, Kowloon Shangri-La Hotel, Hong Kong, p. 10.1-10.11.

Jim, C. Y., 2010. *School Green Roof: City Cooler and Cleaner*, Friends of the Country Parks and Cosmos Book, Hong Kong.

Jim, C. Y. and He, H.-M., 2010. Coupling heat flux dynamics with meteorological conditions in the green roof ecosystem, *Ecological Engineering*, 36 (8): 1052-1063.

Köhler, M., *et al.*, 2001. Urban water retention by greened roofs in temperate and tropical climate, In *Proc. of the 38th IFLA World Congress*, Singapore, International Federation of Landscape Architects, pp. 151-162.

Lawlor, G., *et al.*, 2006. *Green Roofs: A Resource Manual for Municipal Policy Makers*, Canada Mortgage and Housing Corporation (CMHC), Ottawa, Canada.

Luckett, K., 2009. *Green Roof Construction and Maintenance*, McGraw-Hill, New York.

Luk, H. K., *et al.*, 2006. Quantitative analysis of green rooftop (GRT) technology effects on air quality and energy usage in Hong Kong, presentation at *the HKSTAM 2005/2006 Annual Meeting*, 11 March 2006, Hong Kong Society of Theoretical and Applied Mechanics (HKSTAM), Hong Kong.

Newton, J., *et al.*, 2007. *Building Greener: Guidance on the Use of Green Roofs, Green Walls and Complementary Features on Buildings*, Construction Industry Research Information Association (CIRIA), London.

Niachou, A., *et al.*, 2001. Analysis of the green roof thermal properties and investigation of its energy performance, *Energy and Buildings*, 33 (2001); 719–729.

NRCA, 2009. *The NRCA Vegetative Roof Systems Manual*, Second Edition, National Roofing Contractors Association (NRCA), Rosemont, IL.

Mentens, J., Raes, D. and Hermy, M., 2006. Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st Century?, *Landscape and Urban Planning*, 77 (2006): 217-226.

Peck, S. and Kuhn, M., 2004. *Design Guidelines for Green Roofs*, Ontario Association of Architects (OAA) and Canada Mortgage and Housing Corporation (CMHC), Ontario, Canada.

Peck, S. W., *et al.*, 1999. *Greenbacks from Green Roofs: Forging a New Industry in Canada, Status Report on Benefits, Barriers and Opportunities for Green Roof and Vertical Garden Technology Diffusion*, Canadian Mortgage and Housing Corporation (CMHC), Ottawa, Ontario, Canada.

Saiz, S., *et al.*, 2006. Comparative life cycle assessment of standard and green roofs, *Environmental Science and Technology*, 40 (2006): 4312-4316.

SBQTS, 2009. *DB440300/T 37-2009, Code for the Design of Roof Greening*, Shenzhen Bureau of Quality and Technical Supervision (SBQTS), Shenzhen, China. (in Chinese)

Simmons, M. T.. *et al.*, 2008. Green roofs are not created equal: the hydrologic and thermal performance of six different extensive green roofs and reflective and nonreflective roofs in a sub-tropical climate, *Urban Ecosystems*, 11 (2008): 339-348.

SPRI, 2010a. *ANSI/SPRI RP-14, Wind Design Standard for Vegetative Roofing Systems*, Single Ply Roofting Industry (SPRI), Waltham, MA.

SPRI, 2010b. *ANSI/SPRI VF-1, External Fire Design Standard for Vegetative Roofs*, Single Ply Roofting Industry (SPRI), Waltham, MA.

Sydney City Council, 2009. *Green Roof Design Resource Manual*, Sydney City Council, Sydney, Australia.

Tan, P. Y. and Sia, A., 2008. *A Selection of Plants for Green Roofs in Singapore*, Second Edition, National Parks Board, Singapore.

Urbis Limited, 2007. *Study on Green Roof Application in Hong Kong, Final Report*, Architectural Services Department, Hong Kong.

USGBC, 2009. *LEED 2009 for New Construction and Major Renovations*, U.S. Green Building Council (USGBC), Washington, DC.

Weiler, S. and Scholz-Barth, K., 2009. *Green Roof Systems: A Guide to the Planning, Design and Construction of Building Over Structure*, John Wiley, Hoboken, N.J. and Chichester.

Wong, N. H. and Chen, Y., 2009. *Tropical Urban Heat Islands: Climate, Buildings and Greenery*, Taylor & Francis, London and New York.

Wong, N. H., *et al.*, 2003. Life cycle cost analysis of rooftop gardens in Singapore, *Building and Environment*, 38 (3): 499-509.

Yang, J., Yu, Q. and Gong, P., 2008. Quantifying air pollution removal by green roofs in Chicago, *Atmospheric Environment*, 42 (2008): 7266-7273.

Zinco, 2010. *System Solutions for Thriving Green Roofs*, Zinco GmbH, Unterensingen, Germany.