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Energy saving potential of green roofs in university buildings

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ABSTRACT

Green roofs are living vegetation installed on roofs and can provide many environmental, economic and social benefits to the community. In recent years, green roofs have rapidly become a key green development tool and design features in many urban cities in the world and have been widely applied in academic institutions. This research aims to assess the energy saving potential of green roofs in university buildings and investigate the practical issues for the implementation. A field study was conducted to examine the buildings at the University of Hong Kong and evaluate the major factors and issues for green roof application. Building energy models were set up on EnergyPlus simulation software to analyze the thermal performance and energy saving potential of the green roofs. Usually, integrating green roofs into new buildings has less problems to handle. However, as existing buildings constitute a major portion of the building stock in the university campus, it is essential to develop green roofs for retrofit projects to achieve a larger impact. It is found that buildings with a higher air-conditioning demand and poor thermal insulation can benefit more from green roof in energy and economic aspects. Most energy savings come from cooling demand reduction in summer. The energy saving potential is affected by the building function, green roof type, leaf area density, plant height, irrigation rate and maintenance.

Keywords: Green roofs, energy saving potential, university buildings, Hong Kong.

1. Introduction

Green roofs are living vegetation installed on roofs and can provide many environmental, economic and social benefits to the community (Dunnett and Kingsbury 2008; Hui, 2016, 2013 & 2006). They could contribute positively to more livable cities by mitigating urban heat island effect, filtering air pollution, enhancing stormwater management and biodiversity, extending the life of roof materials, reducing heat gains and cooling energy (Besbes, *et al.*, 2012; Del Barrio, 1998), providing healthier, aesthetically pleasing communal green space.

In recent years, green roofs have rapidly become a key green development tool and design feature in many urban cities in the world including Hong Kong (Chan and Chow, 2013; Hui, 2011). They have also been widely applied in academic institutions, such as university buildings (Kravitz, 2006). At present, the main attraction points for green roofs are often based on aesthetic appeal and ecological benefits. In fact, if properly designed, green roofs can offer good energy saving potential to the building owners (Castleton, *et al.*, 2010; Coma, *et al.*, 2016; Hui, 2009; Jaffal, Ouldboukhitine and Belarbi, 2012; Jim, 2014; Moody and Sailor, 2013; Raji, Tenpierik and van den Dobbelteen, 2015; Roche and Berardi, 2014; Saadatian, *et al.*, 2013).

This research aims to assess the energy saving potential of green roofs in university buildings and investigate the practical issues for the green roof implementation. A field study was conducted to examine the buildings at the University of Hong Kong (HKU) and evaluate the major factors and issues for green roof application. Building energy models were set up on EnergyPlus simulation software to analyze the thermal performance and energy saving potential of green roofs on some of the university buildings. Important factors affecting the energy saving were identified. Practical issues for planning, designing, installing and maintaining the green roofs were studied. It is hoped that a better understanding of the green roof benefits can be developed for decision making and policy formulation.

2. Green Roof Energy Saving

Modern roof greening has two main approaches: intensive and extensive. A semi-intensive or hybrid green roof system can also be found in the market. Table 1 shows three major types of green roofs and their characteristics. Depending on site specific factors such as location, structural capacity of the building, budget, client needs, and material and plant availability, a single type or a combination of intensive, semi-intensive and extensive systems may be used.

Table 1. Major types of green roofs and their characteristics

Characteristics	Extensive	Semi-intensive (hybrid)	Intensive
Depth of material	60-200 mm	120-250 mm	150-500 mm
Accessibility	Often inaccessible	May be partially accessible	Usually accessible
Fully saturated weight	Low (50-150 kg/m^2)	Varies (150-200 kg/m^2)	High (150-500 kg/m^2)
Plant diversity	Moss-sedum and grass-herbs	Grass-herbs and shrubs	Lawn or perennials, shrubs and trees
Use	Ecological protection layer	Designed green roof	Park-like garden
First cost	Low	Varies	Highest
Maintenance	Minimal	Varies	Highest

According to the basic construction method, green roof systems can be divided into two categories: built-in green roofs and modular green roofs. Built-in green roofs are installed as a series of layers set up on site and are more permanent. Modular green roofs are often prefabricated off-site and pre-grown in nursery, therefore, they are more flexible (Hui, 2011).

2.1 Principles of Energy Saving

Green roofs can reduce building energy consumption through several mechanisms related to the vegetation and soil (substrate or growing medium) layers as shown below.

(a) Absorbing and storing heat in the vegetation
(b) Shading the roof surface by vegetation
(c) Cooling by evapotranspiration from the vegetation
(d) Insulation by the soil
(e) Cooling by evaporation from the soil

The principles of energy saving of green roofs have been reviewed by Raji, Tenpierik and van den Dobbelteen (2015) and Saadatian, *et al.* (2013). As the greening system can control the heat flow and have a significant impact on the energy balance within a given building, the heat transfer through the roof is reduced and the air temperature of the building interior spaces is modulated (Roche and Berardi, 2014). As a result, the thermal properties of the roof and the energy performance of the building can be improved (Nichaou, *et al.*, 2001). Energy saving in cooling and heating the building can be obtained.

Also, green roof can affect the immediate environment and contribute to the mitigation of urban heat island (UHI) effect (Alexandri and Jones, 2008). The efficiency of the heating, ventilating and air-conditioning (HVAC) systems of the building itself and the nearby structures can be improved from the reduction of air temperature by the greenery which provides local free cooling to the air in the micro-climate.

2.2 Analysis of Heat and Mass Transfer

The thermal and energy performance of green roofs is depending on the heat and mass transfer process in the building (Hui, 2009; Tabares-Velasco, 2009). To analyse this, some researchers have developed heat and mass transfer model for the assessment and prediction of energy saving potential of green roofs and tested the model with field data (Ouldboukhitine, *et al.*, 2011; Tabares-Velasco, *et al.*, 2012). Other researchers applied computer-based building energy simulation model to evaluate the green roof performance (Sailor, 2008; Kumar and Kaushik, 2005). Both experimental measurements and numerical modeling are important for assessing the energy performance of green roofs (Lazzarin, Castelloti and Busato, 2005) because the actual heat and mass transfer process is quite complicated when the behaviour of green roof vegetation and effects of climatic conditions are considered.

In order to provide a rapid estimate of energy savings associated with a green roof for a range of generic building types, some researchers have developed a green roof energy calculator which is a simplified software tool to quantify the energy savings of specific green roof designs (Moody and Sailor, 2013; Sailor and Bass, 2014). Simple functions for analyzing green roof thermal performance have also been introduced in building energy simulation programs such as MIT Design Advisor (http://designadvisor.mit.edu/design/) (Ray, 2010). However, the current simplified estimation tools for green roofs are established based on generic data and assumptions of the characteristics of buildings and climatic information. They cannot be used effectively in different situations in the world with dissimilar characteristics.

Although the algorithms for green roof modelling have been added to some sophisticated building energy simulation programs such as EnergyPlus and ESP-r (Sailor, 2008), the efforts required to prepare the inputs, examine the assumptions and run the programs are significant and their applications are limited to academic research at present. In order to assess the energy saving potential of green roofs on a specific site and climate, investigation is needed to evaluate the impacts of climatic conditions and local site environment. Practical issues on green roof planning, design and operation should also be considered.

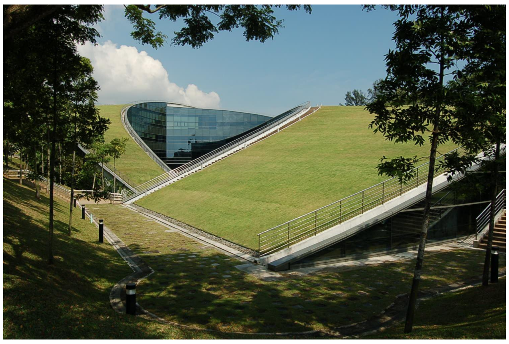
2.3 Impacts of Climatic Conditions and Local Site Environment

Extensive green roofs have been applied in many urban areas in the world because of light weight and low maintenance. Lin, *et al.* (2013) studied an extensive green roof in sub-tropical and tropical island climates in Taiwan and indicated that its thermal effectiveness is closely related to the climate and the daytime cooling effectiveness was relatively high in summer. Tsang and Jim (2011) conducted a theoretical evaluation of thermal and energy performance of tropical green roofs and found that latent heat dissipation is twice more effective than the temperature climate. The potential of air-conditioning energy saving of an extensive tropical green roof could justify the cost of green roof installation on public buildings (Jim and Peng, 2012). Even with the influence of climate change, the application of green roof could provide a reasonable economic payback under the Hong Kong climate (Chan and Chow, 2013).

The green roof type, plant height and leaf area, soil thickness, moisture content, irrigation and rainfall, building function and operation will affect the energy saving effect. Consideration of local data and construction practice is needed so as to formulate appropriate assumptions and conditions for the calculation and modelling of energy saving potential.

3. University Buildings

Academic institutions are often keen on leading the way for sustainability and green reputation by promoting green buildings and adapting green roofs to current and new buildings on their campuses. Nowadays, this has become a trend in the world that many universities and colleges would not like to miss out. Figure 1 shows two examples of green roofs in university buildings (Singapore and Canada).



(a) School of Art, Design and Media at Nanyang Technological University in Singapore (Image source: Dr. Sam C. M. Hui)

(b) Computer Sciences Building at York University in north Toronto, Canada (Image source: York University)

Figure 1. Examples of green roofs in university buildings (Singapore and Canada).

In Hong Kong, green roof development is growing fast in recent years (Hui, 2016) and many universities and schools have installed green roofs for promoting green or sustainable campus. Nevertheless, alarmed by the collapse of a green roof at the City University of Hong Kong on 20 May 2016, anxiety and questions on roof overloading and potential threat of adding rooftop vegetation have been raised and discussed. This incident reflected inadequate understanding and knowledge of green roof systems in the society.

3.1 Green Roofs in University Buildings

Besides the environmental, economic and social benefits as mentioned earlier, green roofs have other significant implications to universities including education, research and publicity. In fact, many universities are committed to sustainability initiatives and green campus. They have a responsibility to develop and implement sustainability solutions and practices through campus policies and operations, as well as research, teaching and knowledge exchange. For example, the Hong Kong Sustainable Campus Consortium (http://www.hkscc.edu.hk) was formed in 2010 with a goal to provide appropriate response to creating sustainable campuses.

As found out from the green roof projects in the universities in many countries and some pilot projects in Hong Kong, it is noted that implementing green roofs in university buildings can provide good opportunities for enhancing the awareness of green campus, enabling multidisciplinary participation in sustainability initiatives, and fostering sustainability thinking in education and research. Because of this, the economic performance and energy saving impact of the green roofs in university buildings are usually not so critical in the decision making.

Of course, it is important to recognize the energy saving potential of the green roofs and apply cost effective methods to increase the uptake of green roofs in the campuses on new developments and existing buildings. By determining and sharing the good practices of green roof application and design in university buildings, it is possible to improve the understanding and reduce the knowledge gap.

3.2 New Buildings

There are some advantages to applying green roofs to new buildings as compared to existing ones (Hui, 2013; Urbis Limited 2007). First, costs can be saved in the design stage since the systems can be part of the existing contract. Second, roof slabs can be designed to take heavier soil depth loads. Third, irrigation and water supply can be built into the roof from the start. Fourth, utilities can be arranged to maximize green roof area. Fifth, barrier-free access (such as lifts) can be incorporated into the design. Finally, extended side walls to protect green roofs from excessive wind may be incorporated at the design stage.

As green roof is already widely accepted as a common design feature for green buildings, many new building developments in academic institutions have included it in the design brief. However, the actual design details and environmental performance of the green roof are often overlooked when implementing the building project and operating the building facilities. It is important to consider and develop reliable and sustainable practices in green roof construction and performance evaluation (Hui, 2011). Indication of energy saving performance is a useful method for the economic evaluation (Castleton, *et al.*, 2010; Chan and Chow, 2013; Peng and Jim, 2015).

3.3 Existing Buildings

It should be noted that promoting green roofs on existing buildings is an important measure for improving urban cities because existing buildings constitute a major portion of the building stock. Roof greening is an effective way to maximize the greenery of built-up areas. For academic institutions, usually there are many opportunities to apply green roofs in the current buildings, but some of them may be more challenging in the design arrangement, such as historic buildings and outdated structures. The campus strategic planning and development timeline must be evaluated carefully in order to set out the greening programme effectively.

When applied to the existing 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. Thus, a suitable green roof system (usually lightweight) and proper design are needed. When considering a retrofit project in academic institutions, the age and condition of the existing building and roof will affect the feasibility of a green roof. Rooftop utilities and plant space can constrain the possible greening area. The current structural loading and building requirements may limit growing medium depth and type of vegetation. Additional rooftop water points and new drainage points may need to be installed.

Usually, site survey and inspection will be needed to collect key information and assess the current conditions of the building. The information about building operation and existing building services systems are essential to the future analysis of energy saving potential. Energy audits may be carried out to identify the information if needed.

4. Field Study

A field study was carried out in October 2015 to March 2016 to examine the buildings at HKU in order to find out which buildings have the potential for setting up green roofs and what are the practical issues affecting the green roof application. The study is focusing on the HKU Main Campus located in Pokfulam Road of Hong Kong Island. Figure 2 shows a map of the HKU Main Campus which consists of the new Centennial Campus and the old Main Campus. After the official opening of the Centennial Campus in 2012, re-organisation and rehabilitation of the old main campus are needed as some offices have moved to the new campus and some of the existing buildings in the old campus require updating and re-configuration. This could give rise to an opportunity to consider green roof application on the existing buildings of the old campus.

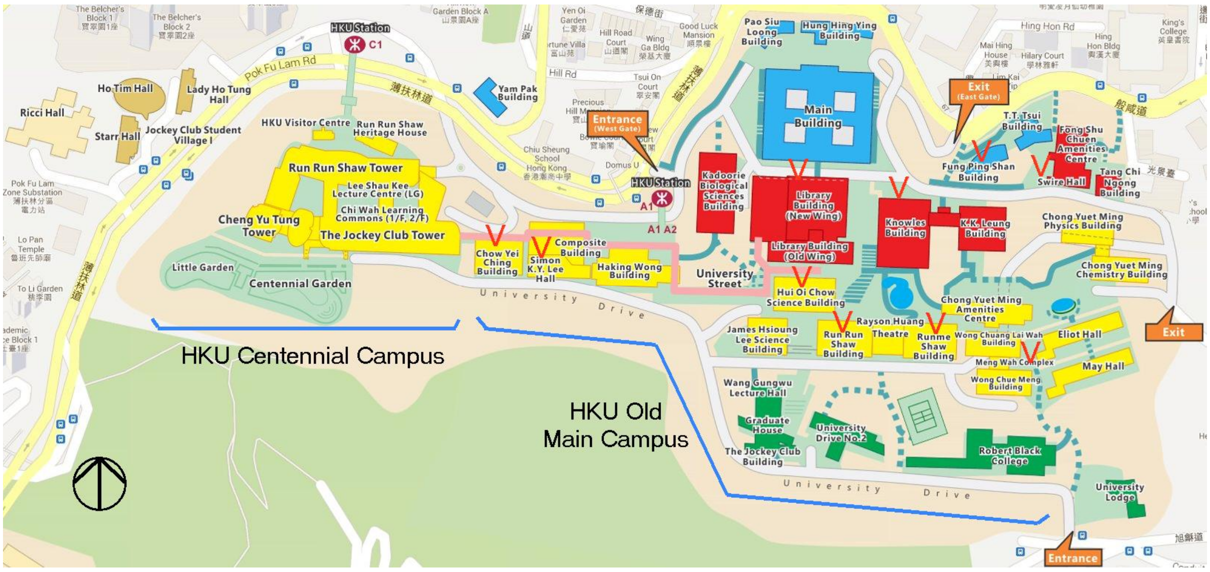


Figure 2. HKU Main Campus (including the Centennial Campus and Old Main Campus) (Image source: http://www.maps.hku.hk/)

4.1 Key Findings

Interviews and discussions have been conducted with the HKU Estates Office and the researchers from Division of Landscape Architecture of the HKU Faculty of Architecture. Information about the university buildings and pilot greening projects (for research and education) have been studied in order to understand and evaluate the major factors and considerations for green roof application. Some pilot projects including HKU rooftop farm (Pryor, 2016) and other green roof research (Hui, 2006 & 2011; Jim, 2014; Jim and Peng, 2012) have been identified. Aerial photos of the campus were collected and site visits were done to the university buildings to examine the current roof conditions. Figure 3 shows diagrammatically the outlook of the buildings and the shape of their roofs.

Figure 3. Current buildings in HKU Main Campus (Image source: HKU)

It is found that the relatively new buildings in the Centennial Campus have included green roofs and green space in the building design. Green facilities in these buildings formed part of the integrated building design. The Centennial Campus has also received the platinum certification under LEED and BEAM Plus green building rating systems. However, the actual energy saving performance of the green roofs has not been studied and reported; other sustainable practices for rooftop greening (such as farming, education and living experiment) have not been implemented.

On the other hand, there are some historic buildings in the HKU Main Campus such as the Main Building, Hung Hing Ying Building, May Hall and Eliot Hall. Roof greening on these buildings is not recommended because of the constraint of architectural design, outlook appearance, conservation and maintenance concerns. It is believed that the age of the existing building and the condition of the roof will affect the feasibility of green roof application. The technical difficulties to install green roofs in existing buildings must be carefully examined and resolved before installing the green roofs.

4.2 Practical Issues on Retrofit Green Roof

Hong Kong has a subtropical climate and the most important climatic factors affecting rooftop greening include typhoons, heavy rainfalls, high temperature and strong sunlight (Hui, 2011). Usually extensive green roofs and modular systems are more suitable for retrofit projects which have their own technical constraints. When considering a retrofit project, some practical issues must be studied carefully. Roof-top utilities and plant room space can constrain the possible area of green roofs. The current structural loading and building requirements may limit growth medium depth and type of vegetation. The structural integrity and moisture protection of the building must be verified. Also, the installation of additional rooftop water points and new drainage points may be needed. Moreover, if access to the roof may be difficult (such as only by using cat ladder), then additional transportation and safety devices may need to be installed. In some situation, barrier-free access for disabled persons may be impossible to a retrofit project.

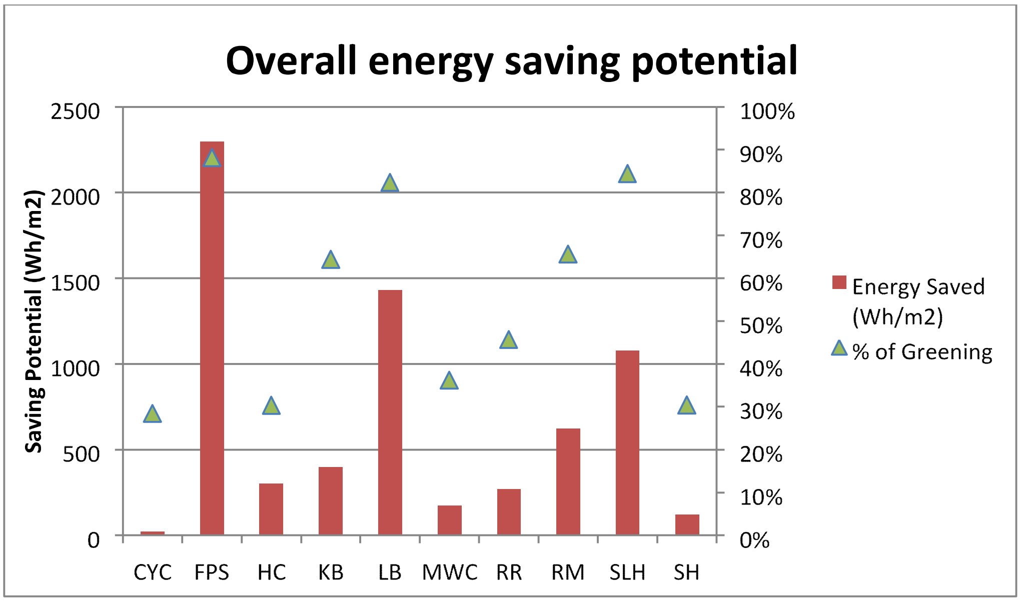
After considering the practical issues, ten potential buildings in HKU Main Campus were selected for further investigation on energy saving potential. The locations of these buildings are indicated on Figure 2 using the symbol of red "V" arrow heads. These buildings are of 3 to 15 storeys and their roof area ranges from 497 m^2 to 2312 m^2. Six of them are for academic functions (such as offices, classrooms and laboratories); two are student halls; one is a library building and one is a museum.

5. Building Energy Simulation

DesignBuilder (version 4.6), which is based on the calculation engine, EnergyPlus, is adopted for the building energy simulation to evaluate the energy saving potential of green roof. Reference models of the ten potential buildings were set up as the baseline to assess the possible energy saving. Alternative cases were designed to study the effects of building functions and green roof design parameters. The key results are identified and described below.

5.1 Overall Energy Saving Potential

Figure 4 shows the overall energy saving potential of the ten buildings selected in the field study. The assumed percentage of green roof coverage (% of greening) for each building is determined by considering the available roof space and practical issues. The energy saving potential (Wh/m^2) is calculated by dividing the difference of cooling energy between the respective reference model and the model with an extensive green roof added, by the gross floor area of the building. It is found that Fung Ping Shan Building (FPS), Library Building (New Wing) (LB) and Simon K. Y. Lee Hall (SLH) have the largest energy saving potential.



CYC = Chow Yei Ching Building, FPS = Fung Ping Shan Building, HC = Hui Oi Chow Science Building, KB = Knowles Building, LB = Library Building (New Wing), MWC = Meng Wah Complex, RR = Run Run Shaw Building, RM = Run Run Shaw Building, SLH = Simon K. Y. Lee Hall, SH = Swire Hall

Figure 4. Overall energy saving potential for the ten potential buildings

For all the ten buildings together, there is more than 40,000 kWh of cooling energy saved annually, which is equivalent to 0.56% of the total building energy consumption. It is found that 85% of the energy saving is from the summer months (May to September) and the energy saving effect is much more significant in summer than in winter. This is consistent with the findings in other research done for sub-tropical climate, such as Lin, *et al.* (2013), Jim and Peng (2012), and Chan and Chow (2013).

5.2 Effect of Building Functions

In order to study the effect of building functions on the energy saving, different operation schedules and internal loads were applied to all the ten buildings simultaneously to represent five typical usages in the university, including classroom, office, library, museum and student hall. Figure 5 shows a summary of the energy saving potential for the five different building functions. The result indicates that building functions with a higher demand in air-conditioning have a greater energy saving potential, like office, museum and library. Office has the largest energy saving potential in this comparison because it has significant internal loads and relatively long operation hours.

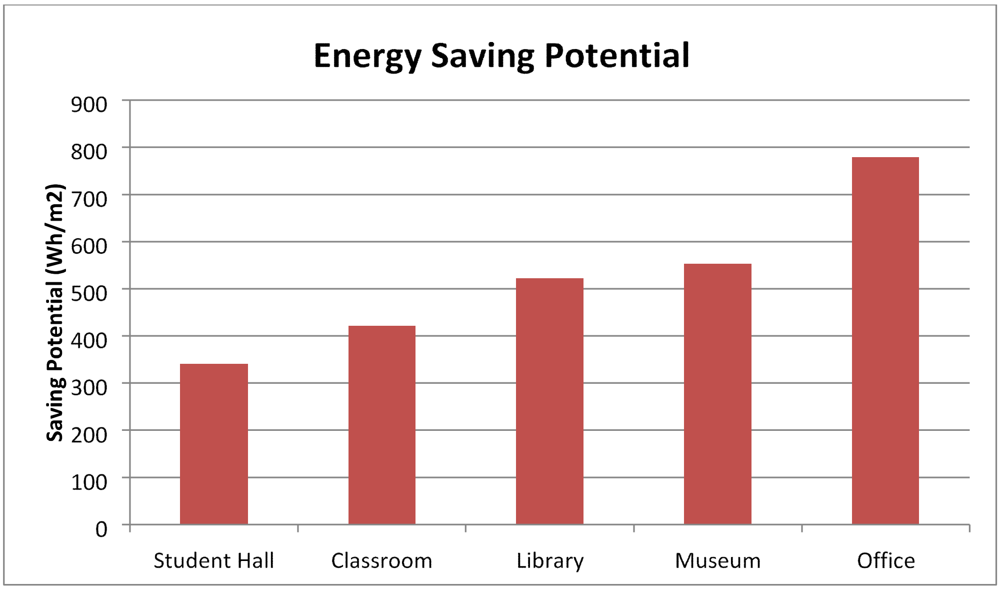


Figure 5. Energy saving potential for five building functions

5.3 Green Roof Design Parameters

To compare the energy saving effect of different types of green roof, the simulation models have been modified to different vegetation and soil layers to represent the three types of green roof systems. It is found that semi-intensive and intensive green roof have greater energy saving potential than extensive green roof. The degree of energy saving will depend on the actual green roof design and vegetation density.

As indicated by other researchers (Moon, An and Han, 2014), buildings with poor existing insulation will benefit more in energy saving from a green roof because the greening can significantly improve the thermal properties of the building with poor or moderate thermal insulation (Hui, 2009). If it is expected that some buildings in the university campus have poor thermal insulation on the roof, those buildings will be the target for maximizing the energy saving benefit of rooftop greening.

The vegetation density of green roof can be represented in the building energy simulation by changing the parameters of leaf area index (LAI) and height of plants (HOP). It is found that a higher LAI has a bigger influence on the reduction of solar heat gain, cooling load and energy because higher LAI can reduce heat gain through shading, insulation, evapotranspiration, and thermal mass. On the other hand, increasing the HOP will enhance the cooling load reduction and energy saving because the transpiration cooling effect is facilitated when the aerodynamic resistance within the canopy layer decreases.

Green roofs have the ability to cool down the surrounding air temperature and migrate the UHI effect. To assess this effect on the energy saving potential, the air temperature of the weather file of building energy simulation was adjusted by decreasing 1 ºC. It is found that about 12.6% energy saving can be obtained for the ten buildings together. However, further analysis is needed to evaluate the urban temperature and the influence on nearby buildings.

6. Discussions

The energy saving potential of green roof is affected by many factors in planning, designing and managing of the greening project. It is important to consider the purpose of the project and balance the different requirements during the implementation. For university buildings, green roof is a worldwide trend and can be applied to create a pleasant and sustainable campus environment. If the energy saving effect of the green roof can be realized and enhanced in the university buildings, it can set out good examples for other building owners and organizations.

Using the HKU campus as a pilot site, this research has identified and analyzed some typical factors affecting the energy saving potential of green roof. It is hoped that the experience learnt (good and bad) can be shared with other academic institutions and organizations for considering the true value of the greening projects. It is important to note that green roofs are living eco-systems and must be designed and maintained well to achieve the expected performance and functions. Maintenance issues such as irrigation, weeding and fertilizing can influence the energy saving effect because a poorly maintained green roof with dried plants and soil will result in higher energy consumption for the building.

The market for green roofs is still developing in Hong Kong and more information on their technical design, effectiveness and actual benefits are needed. Although green roof technology is relatively straightforward, it is possible for people who are unfamiliar with it to misunderstand its value and make mistakes in the application. To maximize the energy benefit of green roofs, systematic analysis and site evaluation are needed. Beside green roofs, vertical greening systems can also be integrated into buildings to reduce the demand for cooling and helps lower indoor temperatures and electricity consumption.

7. Conclusion

Green roofs have rapidly become a key green development tool in the urban expansion and renewal of the cities in the world. Nowadays, they have also been applied effectively in many university buildings to promote green campus and education. Usually, integrating green roofs into new buildings has less problems to handle, such as structural load, accessibility and roof drainage. However, as existing buildings constitute a major portion of the building stock in university campuses, it is essential to develop green roofs for retrofit projects to achieve a larger impact. Using the HKU campus as an example, this research has investigated the issues using field study and building energy simulation techniques.

It is found that buildings with a higher air-conditioning demand and poor thermal insulation can benefit more from green roof in energy and economic aspects. Most energy savings come from cooling demand reduction in summer. The energy saving potential is affected by the building function, green roof type, leaf area density, plant height, irrigation rate and maintenance. To justify the implementation of the greening project, it is important to demonstrate that installing a green roof is worth the investment.

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References

Alexandri, E. and Jones, P., 2008. Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates, *Building and Environment*, 43 (4) 480-493.

Besbes, K., Zoughaib, A., Bouchie, R. and Farkh, S., 2012. Green roofs impact on buildings cooling load, *International High Performance Buildings Conference*. Paper 69 (http://docs.lib.purdue.edu/ihpbc/69).

Castleton, H. F., Stovin, V., Beck, S. B. M. and Davison, J. B., 2010. Green roofs; building energy savings and the potential for retrofit, *Energy and Buildings*, 42 (2010) 1582-1591.

Chan, A. L. S. and Chow, T. T., 2013. Energy and economic performance of green roof system under future climatic conditions in Hong Kong, *Energy and Buildings*, 64 (2013) 182-198.

Coma, J., Pérez, G., Solé, C., Castell, A. and Cabeza, L. F., 2016. Thermal assessment of extensive green roofs as passive tool for energy savings in buildings, *Renewable Energy*, 85 (2016) 1106-1115.

Del Barrio, E. P., 1998. Analysis of the green roofs cooling potential in buildings, *Energy and Buildings*, 27, 179-193.

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

Hui, S. C. M., 2016. Green roof development in Hong Kong, *Hong Kong Engineer*, 44 (7), (http://www.hkengineer.org.hk/program/home/article.php?aid=8841&volid=193).

Hui, S. C. M., 2013. *Guidelines for the Design and Application of Green Roof Systems*, Chartered Institution of Building Services Engineers, London.

Hui, S. C. M., 2011. *Technical Guidelines for Green Roofs Systems in Hong Kong*, Chartered Institution of Building Services Engineers Hong Kong Branch, Hong Kong.

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 *Proceedings of the 2nd Megacities International Conference 2006*, 1-2 December 2006, Guangzhou, China, pp 351-360.

Jaffal, I., Ouldboukhitine, S.E. and Belarbi, R., 2012. A comprehensive study of the impact of green roofs on building energy performance, *Renewable Energy*, 43 (2012) 157–164.

Jim, C.Y., 2014. Air -conditioning energy consumption due to green roofs with different building thermal insulation, *Applied Energy*, 128 (2014) 49-59.

Jim, C. Y. and Peng, L. L. H., 2012. Weather effect on thermal and energy performance of an extensive tropical green roof, *Urban Forestry and Urban Greening*, 11 (2012) 73-85.

Kravitz, R, 2006. Greening a university's roof: University of Wisconsin educates itself on the benefits of a green roof, *Environmental Design and Construction*, 9(3) S16-S17.

Kumar, R. and Kaushik, S. C., 2005. Performance evaluation of green roof and shading for thermal protection of buildings, *Building and Environment*, 40 (11): 1505-1511.

Lazzarin, R. M, Castelloti, F. and Busato, F., 2005. Experimental measurements and numerical modeling of a green roof, *Energy and Buildings*, 37, 1260-1267.

Lin, B., Yu, C., Su, A. and Lin, Y., 2013. Impact of climatic conditions on the thermal effectiveness of an extensive green roof, *Building and Environment*, 67 (2013) 26-33.

Moody, S. S. and Sailor, D. J., 2013. Development and application of a building energy performance metric for green roof systems, *Energy and Buildings*, 60 (2013) 262-269.

Moon, H. J., An, K. A. and Han, S. W., 2014. Energy saving effects of green roof in existing buildings with low insulation levels, In *Proceedings of IBPSA Asia Conference*, Nagoya, Japan, 28-29 Nov 2014, p. 443-450.

Niachou, A., Papakonstantinou, K., Santamouris, M., Tsangrassoulis, A., Mihalakakou, G., 2001. Analysis of the green roof thermal properties and investigation of its energy performance, *Energy and Buildings*, 33 (7) 719-729.

Ouldboukhitine, S., Belarbi, R., Jaffal, I. and Trabelsi, A., 2011. Assessment of green roof thermal behaviour: A coupled heat and mass transfer model, *Building and Environment*, 46 (2011) 2624-2631.

Peng, L. L. H. and Jim, C. Y., 2015. Economic evaluation of green-roof environmental benefits in the context of climate change: The case of Hong Kong, *Urban Forestry and Urban Greening*, 14(3) 554-561.

Pryor, M., 2016. *The Edible Roof: A Guide to Productive Rooftop Gardening*, MCCM Creations, Hong Kong.

Raji, B., Tenpierik, M. J. and van den Dobbelteen, A., 2015. The impact of greening systems on building energy performance: a literature review, *Renewable and Sustainable Energy Reviews*, 45 (2015) 610-623.

Ray, S. D., 2010. *Energy Saving Potential of Various Roof Technologies*, MSc Thesis, Massachusetts Institute of Technology, Dept. of Mechanical Engineering, Massachusetts.

Roche, P. L. and Berardi, U., 2014. Comfort energy savings with active green roofs, *Energy and Buildings*, 82 (2014) 492-504.

Saadatian, O., Sopian, K., Salleh, E., Lim, C. H., Riffat, S., Saadatian, E., Toudeshki, A. and Sulaiman, M. Y., 2013. A review of energy aspects of green roofs, *Renewable and Sustainable Energy Reviews*, 23 (2013) 155-168.

Sailor, D. J., 2008. A green roof model for building energy simulation programs, *Energy and Buildings*, 40(8) 1466-1478.

Sailor, D. J. and Bass, B., 2014. Green roof energy calculator, *Journal of Living Architecture*, 3, 1-24.

Tabares-Velasco, P. C., 2009. *Predictive Heat and Mass Transfer Model of Plant-based Roofing Materials for Assessment of Energy Savings*, PhD Thesis, Department of Architectural Engineering, Pennsylvania State University, State College, PA.

Tabares-Velasco, P. C., Zhao, M., Peterson, N., Srebric, J. and Berghage, R., 2012. Validation of predictive heat and mass transfer green roof model with extensive green roof field data, *Ecological Engineering*, 47 (2012) 165-173.

Tsang, S. W. and Jim, C. Y., 2011. Theoretical evaluation of thermal and energy performance of tropical green roofs, *Energy*, 36 (5) 3590-3598.

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