GREENROOFS IN SINGAPORE: HOW GREEN ARE THEY?

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ABSTRACT

Green roofs are more common in the tropical climate of Singapore compared with the other eco-roof types partly due to the government incentives. With limited natural resources and land, Singapore is unique, as most system components for green roofs are imported while waste is incinerated. However, the focus of green roof studies in Singapore setting so far has been the in-use performance benefits in terms of cost, energy and water savings without considering the lifetime performance. The decision to promote any strategy nevertheless needs to consider resource costs as well as benefits.

This paper discusses results from a life cycle study of common green roof types used in Singapore. The results suggest that environmental performance, evaluated using energy and carbon footprint, depends on the construction details and system components employed. The end-of-life waste disposal significantly affects the overall performance, and even with system expansion to include avoided electricity generation because of waste incineration, green roofs lead to an increased carbon footprint.

Keywords: green roofs, life cycle assessment, carbon footprint, tropical climate, Singapore, energy, cost

INTRODUCTION

Three types of eco-roofs; green (living), blue (water managing) and white (heat reflecting), are commonly used in urban locations to moderate the effects of climate change, such as extreme rainfall and temperature. A green roof is a conventional roof covered with a layer of vegetation, while a blue roof stores water using flow controls, such as downpipe valves, gutter storage systems and cisterns. A white or a cool roof maintains a lower roof temperature, compared to a traditional roof, by reflecting heat away using white paint or reflective coatings. The benefit of white roof is limited to temperature modifications while both green and blue roofs can in addition provide storm water management. In addition to these, green roofs provide biodiversity through habitat creation, improve air quality, and sequester carbon (Getter et al. 2009).

Singapore is a thriving world-class urban centre facing land and resource constraints. However, Singapore boasts a high level of greenery due mainly to meticulous planning over decades. Government goals under the Singapore Sustainable Development Blueprint (Ministry of the Environment and Water Resources and Ministry of National Development 2009) includes, making optimum use of land while ensuring green space is maintained at 8m^2/person, and increasing greenery in high-rise buildings to 50ha by 2030. Currently, green roofs are more common in the tropical climate of Singapore compared with the other eco-roof types due partly to the government incentives introduced under the Skyrise Greenery Incentive Scheme. Since its inception in 2009, this scheme, which provides up to 50% of the installation cost of green roofs (and green walls), has funded over 200 developments.

Local and international research has already established performance benefits of green roofs in different climate zones (Alexandri and Jones 2008; Fioretti et al. 2010; Parizotto and Lamberts 2011; Voyde et al. 2010; Wong 2002) and building types (Castleton et al. 2010; Santamouris et al. 2007; Whatley 2011; Wong et al. 2003a). The focus of local research seems to be on the in-use performance benefits without considering the resource costs involved in establishing, maintaining and end-of-life disposal of these systems. The limited international studies that do consider lifetime performance have highlighted the need to find alternatives with lesser environmental impact to those green roof materials in current use (Bianchini and Hewage 2012). This may be especially applicable in Singapore where all materials/components used in green roof projects are imported while waste is incinerated. Therefore, prior to promoting wider uptake of green roofs through incentives a holistic evaluation that considers resource costs as well as benefits accrued over the lifetime is needed.

Khoo and Mithraratne (2012) in a study comparing the relative performance of blue and green roofs in Singapore concluded that green roofs are better in terms of environmental and financial performance even with a long-term perspective. However, the current blue roof projects in Singapore tend to be limited to retention type incorporating large water bodies for their architectural merit, and the relative environmental performance of detention type blue roofs could be somewhat different to these. Furthermore, the above study considered only limited green roof types, while excluding the maintenance

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requirements. The thermal simulation software used for that study (*EnergyPlus*) could not simulate true properties of water bodies, and therefore the effect of both green roof and water body was limited to a mass layer neglecting the effect of soil moisture on the thermal benefit of green roofs. While, soil moisture could increase thermal conductance, plant shading could reduce the solar gain and the roof surface temperature.

This paper presents the results of a life cycle assessment study of alternative green roof systems commonly used in Singapore with concrete roof slabs. The benefits from green roofs cover a broad range; both qualitative (improvements in habitat and urban air quality, reduction in noise and urban heat island effect) and quantitative (reduction in storm water runoff and energy use in buildings, and carbon sequestration). Stovin et al. (2012) have highlighted difficulties in quantifying the stormwater benefit, while carbon sequestration has been estimated to be negligible (Getter et al. 2009). Therefore, this paper is limited to implications on the building energy use. The indicators selected to denote lifetime environmental and financial performance are, energy and carbon footprint, and payback period. The paper structure is as follows. First, the life cycle assessment undertaken is outlined, along with the green roof systems considered and assumptions used. Results, on relative performance, are then presented, and conclusions are drawn.

ALTERNATIVE GREEN ROOF OPTIONS IN SINGAPORE

Green roofs can be classified using maintenance requirements (extensive, semi-intensive and intensive) and construction methods (continuous build-up or modular). Accessible, intensive green roofs, also known as roof gardens, are more common in Singapore compared with extensive roof gardens, which are inaccessible. While roof gardens are built on-site layer by layer and therefore continuous in construction, extensive green roofs can be either build-up or use modular systems that generate an instant effect. The modular construction system provides easy access to the roof structure in case of water damage or alternative roof use at a later stage compared with the build-up system and therefore could be more attractive in certain situations. However, the resources out lay of the two systems, modular and continuous, vary widely.

To assess the lifetime performance of green roof options used in Singapore, three green roof systems are considered; continuous extensive, modular extensive and continuous intensive. The construction, maintenance and end-of-life disposal scenarios of these systems are discussed next.

<u>Construction</u>

- *Continuous extensive green roof system*, with 100mm thick substrate layer and ground cover plants covering 100% roof area
- *Modular extensive green roof system*, with light weight polypropylene tray system, 70mm thick substrate layer and ground cover plants covering 100% roof area
- *Continuous intensive green roof (roof garden) system*, with 700mm thick substrate layer, 80% of the roof area covered with shrubs (roughly 0.5m high) while the rest is covered with ground cover plants

<u>Maintenance</u>

Extensive green roofs require weeding, pruning and fertilising three times a year, while around 10% of the plants need to be replaced annually. Regular maintenance, the frequency of which could vary from daily to fortnightly depending on the building, is necessary for intensive green roofs while plant replacement is also higher at about 20% per annum. Due to higher fertiliser demand and frequent stability and pest attack tests of shrubs, a part-time gardener would also be necessary.

<u>End-of-life</u>

The end-of-life waste disposal practices for green roofs are not established in Singapore. The waste handling scenarios suggested by industry sources varied from one supplier to the other. While it is likely to reclaim the drainage layer and substrate materials, the low value products of the remaining layers mixed with dirt are likely to be sent to landfill. The plants and plant media removed are likely to be taken back to the nursery for composting and re-use, respectively. Although the plant tray (with a 5–6 year useful life) can be re-used, currently trays are sent to landfill once removed.

LIFE CYCLE ASSESSMENT STUDY METHOD

The study involved two main steps. First, a streamlined life cycle assessment (LCA) was conducted of the three systems identified using industry data on material sourcing. The indicators selected for this LCA are, energy, greenhouse gas emissions and cost. The system boundary extended from acquiring the raw materials, producing the green roof materials, transporting the materials to the construction site, constructing the green roof, maintaining the green roof to disposing the waste materials at the end of the life span for the three strategies. It was assumed that the green roofs are established on a 5-storey hypothetical office building with a 1000m^2 roof area. The LCA is limited only to the parts of the building and roof that are affected by the change in materials across the roof types.

Then, the annual energy requirement of this office building located in Singapore, to maintain 24°C internal temperature between 7am and 9pm during the weekdays, was simulated using *EnergyPlus* 7.2 (Crawley et al. 2001) thermal software. An exposed roof with a PVC water proofing membrane was used as the base case, and the relative overall benefit of green roof systems in reducing the cooling energy requirement was estimated. The benefit of cooling is considered to be limited to the floor space directly beneath the green roof.

ASSUMPTIONS

The assumptions used to facilitate the assessment with respect to resource use and energy benefit are as follows.

Useful life

Green roofs are a recent development in Singapore and therefore the useful life in local conditions is not established yet. Useful life depends not only on the technical aspects but also on the economic considerations such as the demand on limited land. In previous studies, Kosario and Ries (2007) used 45years as useful life in the USA while Wong et al. (2003b) used 40years in Singapore. Considering that the buildings in Singapore are demolished long before the end of their useful life, to accommodate changing building demands, a shorter useful life of 20years is used in this study.

Modular tray

Trays used in the modular construction system are produced in Singapore using recycled polypropylene. Although the use of recycled plastics eliminate the resource use associated with oil extraction and polymer manufacture, the resource cost associated with recycling and recovery process needs to be included. Data on recycled polypropylene tray manufacturing process in Singapore, are not available. Therefore, for production of recycled polypropelene pellets, inventory data from literature (Vidal et al. 2009) are used with current Singapore specific waste management practices (National Environment Agency 2002) and electricity data (Tan et al. 2010). Resource requirements for plastic moulding have been added to this based on ecoinvent data modified to represent Singapore grid electricity. It is assumed that the trays are replaced at 5-year intervals.

Origin of materials and components

Most materials used in green roof systems such as drainage layers, filter layers, substrate and plants are sourced from overseas. Although the substrate composition can vary from one green roof supplier to the other, main ingredients are, recycled construction waste (bricks/clay tiles), pumice, minerals and organics. Substrate materials are predominantly sourced from Malaysia and Indonesia. Seedlings grown in polyethelene bags generally come from Malaysia. Green roof drainage components, filtering and roof protection layers used in Singapore are mainly sourced from Germany.

Transport

For imported products and materials, land transport within the source country, shipping to Singapore, and lorry transport within Singapore are included. It is assumed that the return trip for land transport is empty while ships carry other goods on their return journey. A 25km distance by lorry from green roof site to supplier's yard and from yard to waste management facility at the end of useful life is also included (Tan and Khoo 2006).

Waste management

The following scenario was used based on suppliers' data. All materials and components removed are transported to the supplier's yard. The drainage layer and substrate material are reclaimed for re-use, while the rest of the under layer products and modular trays (except drainage system) are transported to waste management facility. It is assumed that 10% of drainage layer (due to odd-sizes) and substrate material are also sent to waste management facility. At the supplier's yard, plants are composted and plant media is reused.

DATA SOURCES

Embodied energy and CO_2 emissions of drainage materials, filtering and roof protection layers are based on *ecoinvent* 2.1 data. The gaps in LCA data were filled with literature sources (Ledgard et al. 2011; Vidal et al. 2009). These are limited to recycled polypropelene and fertilisers. The overseas data were modified to reflect the respective local practices and conditions.

All diesel vehicles used in Singapore are assumed to conform to EURO 4 emissions standards (Silitonga et al. 2012) and modelled using ecoinvent data. Data on production of fertilisers are based on European practices from literature (Ledgard et al. 2011). Transport (shipping) of fertilisers from Europe to Singapore has been included.

The main ingredient in substrate is recycled construction waste. The substrate resource use is therefore considered to be limited to transport (shipping and road transport). Resource uses for plants are considered to be limited to polyethelene bags and road transport.

Installed cost of green roof systems and components were sourced from industry sources. Any savings in cooling energy requirement is considered to be a saving of average grid electricity in Singapore with a unit cost of 28.57cents (SP Services 2013). Since its impossible to forecast the likely inflation rate over the next 20years, which is the evaluation period, the life cycle cost is calculated using real costs (inflation excluded), using current prices for green roof components and electricity, at a discount rate of 5% and constant prices. The life cycle cost thus established represent the present value of the total amount that needs to be set aside today to maintain the green roofs over the 20-year evaluation period.

RESULTS

Energy and carbon footprint of green roof systems

The energy and emissions associated with the three green roof systems considered are shown in Figure 1 and 2, respectively.

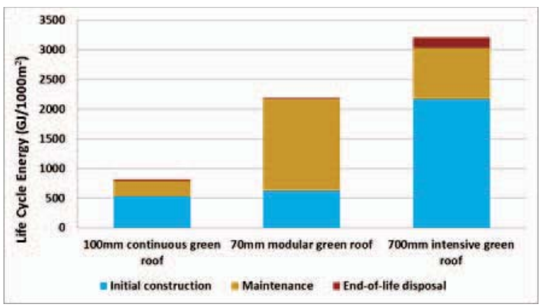

Figure 1 – Lifetime energy of common green roofs in Singapore

In terms of relative performance, lifetime energy of modular extensive green roof system is about three times that of continuous extensive green roof while the intensive green roof system is four times that of continuous extensive green roof. The total emissions associated with different green roofs systems follow a pattern similar to life time energy, with emissions of modular extensive and intensive green roofs being three and five times, respectively compared with those of continuous extensive green roof.

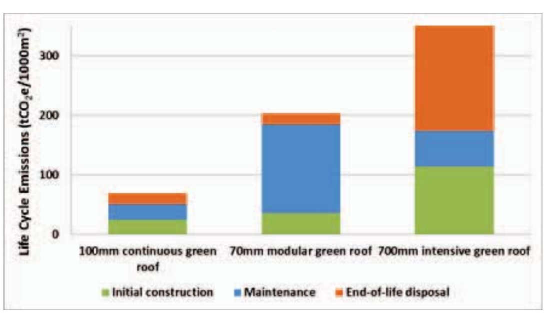

Figure 2 – Lifetime carbon emissions of common green roofs in Singapore

The results indicate that the life stage responsible for the majority of energy use or carbon emissions depends on the green roof construction system; continuous or modular. For continuous construction, the majority of energy (over 65% of the total) and emissions (over 70% of the total) are a result of initial construction, irrespective of whether it is an accessible or inaccessible green roof. For modular construction system however, the maintenance is responsible for 71% of total energy use while also releasing 73% of the total emissions. This could be expected due to the short useful life of the tray, even though the trays are produced of recycled polypropylene in Singapore.

However, whether green roofs are environmentally prefereable would depend on the energy savings that may be accrued over the lifetime, and whether the energy and emissions saved over the 20year life out weigh the energy and emissions embodied in the systems. The total lifetime energy of the three green roof systems including the reduction in cooling energy requirement as a result of green roof (relative to a bare concrete slab roof) is shown in Figure 3.

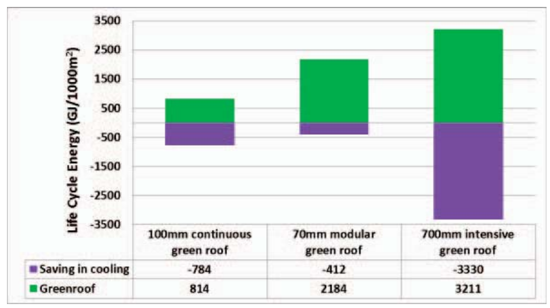

Figure 3 – Lifetime energy of common green roofs in Singapore including cooling energy savings

During the 20-year useful life considered in this study, only intensive green roof system pay off the energy invested in the green roof as electricity savings. While the cooling energy savings represent 96% of energy used by continuos extensive green roof, it is only 19% of the energy used by extensive modular tray green roof.

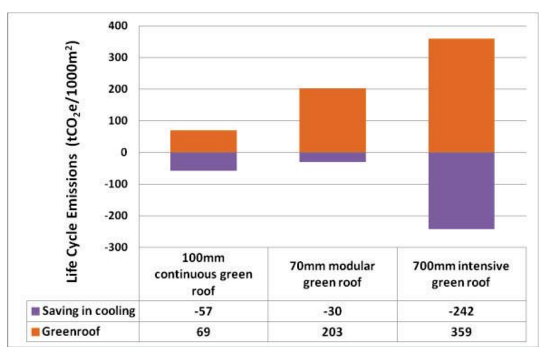

Figure 4 – Lifetime emissions of common green roofs in Singapore including cooling energy savings

If the emissions are considered, none of the green roofs avoid sufficient emissions as electricity savings to pay back the emissions associated with the green roof system. The emissions savings due to cooling energy reduction are only 82%, 15% and 67% respectively for continuous extensive, modular tray and intensive green roof systems (see Figure 4).

However, as main waste management method in Singapore is incineration, any waste generated as a result of establishment, maintenance and end-of-life disposal of green roof system components can avoid electricity generation using other fossil fuel sources. Therefore for a true evaluation of the performance of green roof systems, the system boundary should be expanded to include the avoided electricity generation.

Once the system boundary considered for green roof systems is expanded to include the waste-to-electricity generation, both continuous extensive and intensive green roof systems, save more energy than invested in the system over the 20-year lifetime (see Figure 5). However, the modular tray system performance improves only marginally, with 20% of the lifetime energy recovered during the 20-year period as energy savings.

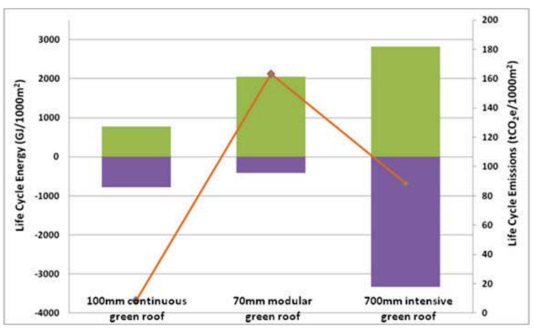

Figure 5 – Lifetime energy and emissions of common green roofs in Singapore including avoided electricity generation

However, none of the green roofs avoid sufficient emissions as electricity savings to pay back the embodied emissions. Both modular and intensive green roofs generate significant emissions burdens at 163kgCO_2/m^2 and 89kgCO_2/m^2, respectively. This is to be expected as, waste-to-electricity generation, is over 3.6 times emissions intensive compared with the curent gird electricity (Tan et al 2010), although lower in energy intensity.

<u>Financial performance of green roof systems</u>

The life cycle cost of the three green roof options, which includes initial cost, maintenance and energy savings, is shown in Figure 6. While the continuous extensive roof is 8% higher in initial cost compared with modular roof, it is lower in maintenance expenditure while achieving higher energy savings. If the 20-year cost is considered both continuous and modular extensive green roofs are similar. With the government incentive of 50% of the total cost of the construction included, the absolute costs of the systems are lower but the pattern remains the same. However, the cost of electrcity could increase over time and this has not been considered in this evaluation.

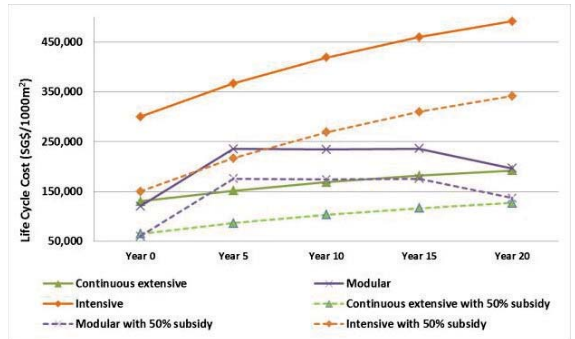

Figure 6 – Additional cost of common green roofs in Singapore with and without incentives

CONCLUSIONS

The results reported here, based on quantifiable benefits of green roofs, suggest that environmental performance of green roof systems depend on the typology and components used. However, as an emissions reduction measure none of the current typologies used in Singapore are effective. In terms of life cycle cost, the green roof systems do not seem to pay back the initial investment, although it could provide a safeguard against future price increases in electricity. In any case, overall benefits of green roofs extend well beyond the energy benefit considered in this paper.

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