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LIFE CYCLE COST OF AIR PLANT GREEN ROOFS IN HOT AND HUMID CLIMATE

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Abstract: *The benefitsof green roofshave beenrecognizedby many researchers worldwide.Green roofs have been wildly implemented in many countries due to the trend of green architecture, sustainable architecture and environmental friendly concept. The computational life cycle cost of air plant green roofs is classified into two parts. One is the initial investment, which composes of the cost of materials and installation process. Another is the cost of operation and maintenance. This paper has investigated in the economics of green roofs by reviewing secondary data of extensive green roof and intensive green roofs and collecting experimental data of air plant green roofs. The investigation of life cycle cost of "Cotton Candy" air plant green roofs is around 140.21\$/m^2 and "Spanish moss" air plant green roofs is around 125.78 \$/m^2. Although the digit is lower than other types of green roofs, the benefit is almost the same. It was found from the research that life cycle cost of air plant green roof is less than other types of green roof. However, the benefits are not different from other type of the roof. Another strengthof air plant green roofs is shading to the roof of the building. These will extend the life cycle of the roof. The consideration of life cycle cost of air plant green roofs will be another tool using in making final decision. The owner can be confident for the result using the air plant green roofs that it is suitable for buildings in hot and humid climate. According to the detail above, green roofs can be considered as a good choice and can be widely applied in buildings located in hot and humid climate.*

Keyword: *Air plant green roofs, Life cycle cost, Spanish mossand Tillandsia Cotton Candy*

1. INTRODUCTION

1.1 Background of Air plant green roofs in hot and humid climate

The concept of air plant green roofs was adopted from the sustainable development and the design of environmental friendly.The construction and maintenance cost of air plant green roofs are quite low. Types of plants are particularly important to green roofs(Bates, Sadler and Mackay 2013, Bianchini and Hewage 2012). Plants can reflect the solar radiation and be an effective shading device (Zuo and Zhao 2014). The selection of plants also relates to the economic feasibility (Zhang

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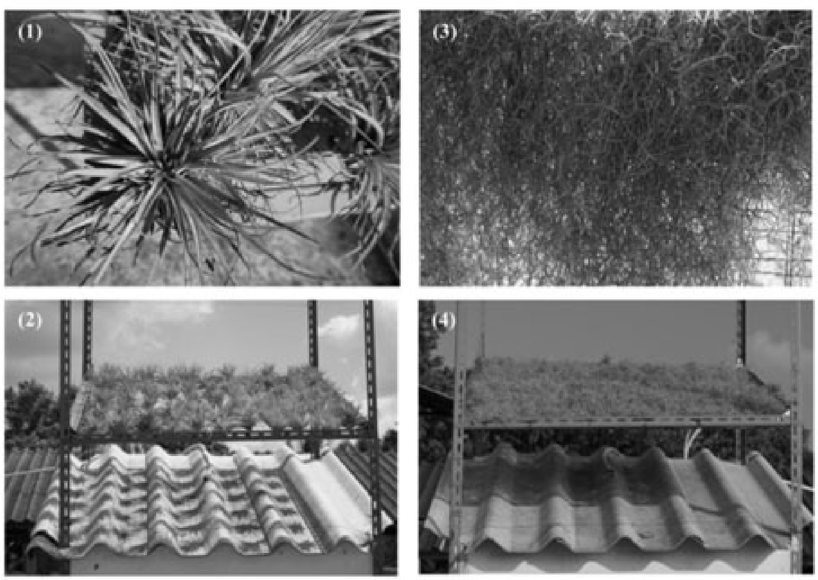
et al. 2012) and the lifecycle cost analysis, which are the most importantfactor before making up any decisions(Carter and Keeler 2008). The criterion for plant selection for green roof has been determined by considering various benefits of green roof (Bianchini and Hewage 2012). The selected plant must be able to resist the climate(Laar and Grimmer 2006) which is hot and humid climate in this paper. The others selection criteria are weight of plant, climate resistance, maintenance ease, growth direction, evergreen plants, convenience of buying and affordable price (Berardiand GhaffarianHoseini 2014). *Tillandsia usneoides L. "Spanish moss"*and*Tillandsia recurvifolia Hooker "Cotton Candy",* which are Crassulacean Acid Metabolism (*CAM*) plants have been used for air plant green roof in this paper. (see in Figure 1)

The weathercondition of hot and humid climatic is high temperature, high humidity, highvolume of rain in rainy season and intensive solar radiations(Hooi, Toe and Kubota 2015). The direct sun light should workbefore shining on the building by shading devices (Ghaffarianhoseini and Berardi 2015). The provided shading for building can reduce heating on building. Air plant green roofs create shadows on the roof, which can reduce thetransferred heat to buildings (Yang, Qian and Lau 2013). Moreover, the air plant green roof can be installed easily in both old and new buildings because of its light weight. These arenew alternative aiming at reducing heat that enters the building and buildenvironment regard to the environmental sustainability.

Figure 1. Plants for air plant green roof: ***Tillandsia recurvifolia Hooker "Cotton Candy"*****(1, 2) and** ***Tillandsia usneoides L."Spanish moss"*** **(3, 4).**



1.2 Classifications of green roofs in hot and humid climate

The different types of green roofs affect to the profitabilityin buildings and environment benefits (Berardiand GhaffarianHoseini 2014). Intensive green roofs and extensive green roofs have been generally classified as major categories (Berardiand GhaffarianHoseini 2014, Chen 2013, Czemiel and Berndtsson 2010). Furthermore, many researchers of green roof have developed many classifications such as semi-intensive green roofs, which are integrated between intensive and extensive green roofs (Fernandez-Cañero et al. 2013). The characteristic of green roofs by types is shown in Table 1.

Table 1.
Characteristics of green roof by type

Characteristics	*Intensive Green roofs*	*Extensive Green*	*Air plant Green roofs**
Thickness of growing media	Above 20 cm	Media below 20 cm	Media below 10 cm
Accessibility	Accessible	Inaccessible (fragile roots)	Inaccessible (slope roof)
Weight	Above 300 kg/m^2 (re-inforced structure)	60–150 kg/m^2	5–10 kg/m^2
Diversity of plants	High (lawn or perenni-als, shrub and tree)	Low (moss, herb and grass)	Low (Cotton Candy, Spanish moss)
Construction method	Technically complex	Moderately easy	Fairy easy
Irrigation	Drainage and irriga-tion systems	Often not necessary	not necessary
Maintenance	Complicated	Simple	Low maintenance (once a year)
Cost of construction	High	Low	Very low
Building	New building	New and old building	New and old building

Source: *Air plant green roofs data from experiment and secondary data from (Berardi, GhaffarianHoseini and GhaffarianHoseini 2014, Ascione et al. 2013)

Intensive green roofs have been accepted that it is useful for human's activities and accessibilities in aesthetics and conveniences. The distinctly appearance characteristic of intensive green roofs is the biodiversity of plants, for instance perennials or trees, shrubs and ground covering plants (Berardi and GhaffarianHoseini 2014, Bianchini and Hewage 2012). The thickness of the growing media is higher than 20 cm. Heavy weight of green roofs' structure result from increasing construction, irrigation and maintenance cost. On the contrary, extensive green roofs have been fabricated as a lightweight which have weight around 60-150 kg/m^2 and uncomplicated. The thickness of growing media is lower than 20 cm. It has low biodiversity of plants; moos, herb, grass and vegetable (Berardi and GhaffarianHoseini 2014, Van Mechelen, Dutoit and Hermy 2015).

The air plant green roof has the lightest weight at 5–10 kg/m^2 (combined with additional structure). The weight of growing media is about 1.5-3 kg/m^2 and the thickness is lower than 5-10 cm. Air plant green roofs require low maintenance or can be called zero maintenance. It has low cost on the construction of irrigation because it can combineand install with traditional roof without new drainage system. The construction method of air plant green roofs is very simple.

2. REVIEW OF ECONOMIC BENEFITS OF GREEN ROOF

The study on the economics perspective of green roofs had been analyzed by many researchers, for example Bianchini and Hewage, Porsche and Köhler and Wong et al. They had discussed and focused on the economics benefit analyzing of green roofs by life cycle costs and Peri et al had studied by focusing on the cost of disposal in the life cycle perspective covering the gap of high initial investment.

Table 2.
Economic benefits and barriers of green roofs

	Economic benefits and barriers of green roofs	*Intensive*	*Extensive*	*Air plant*
Economic benefits	Reduce energy consumption of the building	High	High	High
	Increase thermal insulation in retrofitting	High	Medium	High (air gab)
	Reduce maintenance costs of roof due to lengthening life	Medium	High	High
	Reduce costs of water rain off and urban infrastructure	High	Medium	Low
	Improve market and price of the buildings	High	High	High
	Increase usable surface of the building	High	Medium (visible)	Medium (visible)
	Increase shading for the building	Medium (plant)	No	High
	Improvement building appearance	High	High	High
Economic barriers	Construction cost	High	Medium	Low
	Maintenance cost	High	Medium	Low
	Complexity of construction	High	Medium	Low
	Risks of failure	Medium	Medium	Medium
	Expensive integration in existing buildings	High	Medium	Low

Source: *Air plant green roofs data from experiment and secondary data from (Berardi, GhaffarianHoseini and GhaffarianHoseini 2014, Ascione et al. 2013)

The analysis of the economics helps and supports the decision making in the utilization of green roof in private and public sectorbuildings for both short and long term. The profitability of air plant green roofs depends on some factors such as type of plant, construction of building, location of buildings and climate condition of location. The appropriately favorable type selection ofair plant green roof will particularly result in the value of profitability as above Table 2.

3. LIFE CYCLE COSTS OF GREEN ROOF

The decision making in choosing green roofs for building bases on several factors. The life cycle costs during lifespan of green roofs cover both internal and external costs (Bianchini and Hewage 2012, Peri et al. 2012). The internal costs are also named as private costs, which determined and managed just by private organization such as: owner, architect, engineer and developer. The external costs are also named as social costs because these are extremely related to the result in economic, environment or social system. This paper targets to analyze the life cycle costs of intensive green roofs, extensive green roofs and air plant green roofs.

3.1 Internal costs of green roofs

This research considered internal costs of green roofs by including the initial construction costs, repairing and maintenance costs and disposal or recycling costs.

Initial construction costs

The initial construction costs are extremely important because the initial project cost is nearly as great as the present value of repair, maintenance, replacement, operations, disposal or recycling and utility costs through over 30 years of a building's life (Carter and Keeler 2008, Kim et al. 2015, Han, Srebric and Enache-Pommer 2013). This paper targets to compare the initial investment costs and other costs of air plant green roofs by comparing with another green roof as in Table 3.

This paper has particularly calculated the price from experiment and mocked up construction in the south of Thailand, 2014. Air plant green roofs have the initial construction costs from the covering structure, hanging structure of plant and labor. The covering structure of green roofs consists of lightweight steels such as steel box, slotted angle steel and welded wire mesh. The approximation costs of *"Cotton Candy"* are \$ 2.38/plant[3](20g) or \$ 221.53/m^2.The estimation price of

3. The price of Tillandsia recurvifolia Hooker "Cotton Candy" and Tillandsia usneoides L."Spanish moss" from: http://ssairplants.com/pricelist.html

*"Spanish moss"*is 78 plants /m^2 is around \$ 53.65/m^2(1,500 g/m^{2}or 78 plants /m^2). The estimation of covering structure cost of air plant green roofs is at \$ 18.54/m^2. The different plant of air plant green roofs results in the different cost such as plant cost, hanging structure cost and labor cost. The evaluation of hanging structure of *"Cotton Candy"* is at \$ 11.63/m^2 and the estimation cost of hanging structure of *"Spanish moss"* is at \$ 2.98/m^2. The evaluationlabor cost of *"Cotton Candy"*air plant green roof is at \$ 5.37/m^2 and the labor cost of *"Spanish moss"* air plant green roof is appraised as \$1.49/m^2 because of its simple installation. The amount of initial construction cost of *"Cotton Candy"* green roof is estimated around \$ 257.07/ m^2. In addition,the total of initial construction cost of *"Spanish moss"* green roof can beestimated at \$ 76.67/m^2.Table 3 isthe summarization of initial construction costs of air plant green roofs.

The initial construction cost of intensive green roof in British Columbia, Canada started around \$ 540/m$^{2.}$ Moreover, the originallyconstruction value of extensive green roof in British Columbia varied from \$ 130/m^2-\$ 165/m^2 (Bianchini and Hewage 2012). This research considered the amount of initial construction cost of *"Cotton Candy"* green roof around \$ 257.07/ m^2. The total initial construction cost of *"Spanish moss"* green roof could be estimated at \$ 76.67/ m^2.

Table 3.
Initial construction costs of air plant green roofs. Costs were calculated per m^2 and the prices were collected from the experiment.

Initial construction costs of air plant green roofs	*"Cotton Candy" green roof (\$/m^2)*	*"Spanish moss" green roof (\$/m^2)*
Plant cost	221.53	53.65
Covering structure cost (welded wire mesh)	18.54	18.54
Hanging structure cost	11.63	2.98
Labor cost	5.37	1.49
Total cost	257.07	76.66

* Source: Bank of Thailand and The exchange rate on 6 May, 2015 is ฿33.548 per \$1.

Operation and maintenance costs

According to the review of the operation and maintenance costs of intensive and extensive green roofs, it is found that the cost is rather high (Peri et al. 2012, Wong et al. 2003, Williams, Rayner and Raynor 2010, Kosareo and Ries 2007). The cost includes watering, weeding, cuttings and all lifespan operation. Especially, the costs of surveying for loss of growing media and eliminating of risk (Bianchini and Hewage 2012). These are extremely accepted as the second important cost besides initial costs.

Intensive green roofs and extensive green roofs had the operation and maintenance costs between $ 0.7/m^2 and $ 13.5/m^2(Bianchini and Hewage 2012). Porscheand Köhler had illustrated the lifespan costs of 90 years which had resulted to the operation and maintenance costs of roof types $ 720/m^2 for green roof (8 times/year and about $ 100/supply). The maintenance cost for the extensive green roofs can be improved to be $ 90/m^2(Porsche and Köhler 2003).

The characteristic of air plant green roofs(CAM)is that they have very low operation and zero maintenance(Lüttge 2004, Vovides et al. 2002, Martin, Hsu and Lin 2010) because these plants are *CAM* plant, which does not require watering, weeding and trimming (Rowe et al. 2014, Starry et al. 2014, Liu et al. 2012). Regular check the covering structure of air plant green roofs is the general operation and maintenance of air plant green roofs. The analysis of operation and maintenance costs of air plant green roofs were estimated at $ 3.58/m^{2}and need to be cheeked twice a year in summer and rainy season.

Table 4.
Operation and maintenance costs of air plant green roofs.

Operation and maintenance costs	*"Cotton Candy" green roof ($/m^2)*	*"Spanish moss" green roof ($/m^2)*
Total cost	3.58	3.58

Disposal or recycling costs

Generally, the materials of green roofs are environmental friendly and sustainability (Bianchini and Hewage 2012, Yang, Qian and Lau 2013). The main costs of disposal or recycling of green roof includes disposal growing mediums, transportation materials, plant demolition (Peri et al. 2012, Kosareo and Ries 2007). After the end of lifespan of green roofs, the supporting structures can be recycled, reused and landfilled (Getter and Rowe 2006, Rincón et al. 2014, Murillo 2010,Lough 2015).

According to Peri et al., he described about the disposal cost in a life cycle perspective of green roof in Italy. The disposal cost analysis is estimated about $ 9.56/ m^2 (Peri et al. 2012). Bianchini and Hewage explained the landfilling cost of intensive green roofs as $ 2.7E-4/m^2 and $ 0.13/m^2, while the landfilling cost for extensive green roofs varied between $ 8.9E-3/m^2 and $ 0.20/m^2 (Bianchini and Hewage 2012). The materials of air plant green roofs have very little quantities at the end lifespan because the air plant does not require soil or substrate (Lüttge 2004, Vovides et al. 2002). In addition, the lightweight structure characteristic of air plant green roofs causes low transportation costs, low labor costs and low plant demolition (Carter and Keeler 2008, Wong et al. 2003, Madre et al. 2013, Lamond, Wilkinson and Rose 2014, Blank et al. 2013). The covering structures, which consist of steel box, slotted angle steel and welded wire mesh, can be recycled and reused. Furthermore at the end of green roof lifespan, the plants, which are *"Cotton Candy"* and *"Spanish moss"*, can be sold as well.Consequently, the disposal and recycling costs of air plant green roof was evaluated at $ 5.37/m^2.

Table 5.
Disposal or recycling costs of air plant green roofs.

Disposal or recycling costs	*"Cotton Candy" green roof ($/m^2)*	*"Spanish moss" green roof ($/m^2)*
Total cost	5.37	5.37

3.2 External costs of green roofs

Obviously, it is widely known that green roofs havesustainable design and high social advantages (Pinheiro and Heitor 2014, Asdrubali et al. 2015, Evans 2008, Kokogiannakis and Darkwa 2014). Green roofs also have the benefits to environment (Carter and Keeler 2008, Clark, Adriaens and Talbot 2008, Murillo 2010, Rowe, Getter and Durhman 2012, Volder and Dvorak 2014, Tsang and Jim 2013).Bianchini and Hewage had explained that the materials of green roofs can be used in a long term (13–32 years). It can balance the polymer's production process and the released air pollution such as the emissions of NO_2, SO_2, O_3 and PM_{10}(Bianchini and Hewage 2012). Rowe had demonstrated green roofs as a mean of pollution abatement, which improved urban air quality, human health and human wellbeing (Rowe 2011). Similarly, air plant green roofs are made of the sustainable materials resulting in less pollution.

3.3 Internal benefits of green roofs

Distinctly, the benefits of green roofs are the value-added of heating or cooling energy demand reduction, thermal solution effectiveness, building value, saving operation cost for infrastructure and maintenance (Clark, Adriaens and Talbot 2008, Getter and Rowe 2006, Pérez et al. 2012, Castleton et al. 2010, Garrison, Horowitz and Lunghino 2012).

Energy saving

The significant characteristic of green roofs is energy saving for building (Williams, Rayner and Raynor 2010, Kosareo and Ries 2007, Evans 2008, Clark, Adriaens and Talbot 2008, Castleton et al. 2010, Sproul et al. 2014, Fang et al. 2011, Zinzi and Agnoli 2012, Wallbaum et al. 2012, Rumble and Gange 2013, Pisello, Piselli and Cotana 2015). The plants and the layer of growing media of green roofs are insulation to decrease the indoortemperatures (Clark, Adriaens and Talbot 2008, Murillo 2010, Sailor, Hutchinson and Bokovoy 2008). Bianchini and Hewage calculated that the annual economic will benefit from green roofs in heating at $

0.22/m^2 for cooling, each type of green roof has benefit between \$ 0.18/m^2 to \$ 0.68/m^2 (Bianchini and Hewage 2012).

Benefit from increasing surface function, recreational space and aesthetic of the building

The main objective of green roofs is to create natural space, surface function and aesthetic and recreational space into the building (Fernandez-Cañero et al. 2013, Rowe et al. 2014, Blank et al. 2013, Van Mechelen, Dutoit and Hermy 2014). These will add values to the property (Fernandez-Cañero et al. 2013). The visual comfort and human's sensationare the benefits from plants (Peng and Jim 2013). The reflection of green roofs will reduce the direct glare (Feng et al. 2015) and providethe recreational space (Fernandez-Cañero et al. 2013, Bianchini and Hewage 2012, Williams, Rayner and Raynor 2010). According to Bianchini and Hewage, it was estimated that the aesthetical benefit of intensive green roof is about 5% to 8% of property value and extensive green roofs is about 2% to 8% of property value. The considered property values of the intensive green roofs are between \$ 8.3/m^2 and \$ 43.2/m^2 and between \$ 2.6/m^2 to \$ 8.3/m^2 for the extensive green roofs (Bianchini and Hewage 2012).

For air plant green roofs, it was calculated that the benefit of aesthetically building is about 5% to 8% of property value. Accordingly, the estimation of the aesthetical benefit of *"Cotton Candy"* green roof is from \$ 12.85/ m^2 to \$ 20.57/ m^2 andthe consideration of aesthetical benefit of *"Spanish moss"* green roof is around \$ 3.83/ m^2 to \$ 6.13/ m^2.

Benefit of property value

At the present time, it was showed that various studies have discussed about the increasing value and opportunities of the property (Berardi and GhaffarianHoseini 2014, Bianchini and Hewage 2012, Peri et al. 2012, Williams, Rayner and Raynor 2010, Tsang and Jim 2013).Moreover, the utilizations of green roofs are the strengths and opportunities in the property market. The project and company can identify the social responsibility by using green roofs (Zuo and Zhao 2014). The Wharton School at the University of Pennsylvania has illustrated the tree planting along a street close to building. The property's value had leveled up to 9% (Wachter 2005, Commission 2008). Significantly, the sales prices of residential building in Greenville, South Carolina had been increased from the provided neighborhood parks (small park increases 11% on the sales prices of residential building)(Been and Loan 2008). Commercially, Bianchini and Hewage also considered the increasing property values from the sales prices at 10% and 20%. For extensive green roofs, the increased value is between 2% and 5%or about

\$181.5/m^2 and \$648/m^2. The extensive green roofs is varied about \$132/m^2 and \$174/m^2(Bianchini and Hewage 2012b).

According to this research, the increasing value of the propertywhen applying air plant green roofs are calculated from *"Cotton Candy"*and *"Spanish moss"* green roofs.The results are varied around 3% and 6% of initial construction costs or approximately\$ 264.78/ m^2 to \$ 272.49/ m^2 for*"Spanish moss"* green roof and varied from \$78.96/ m^2 to \$81.26/ m^{2}for *"Cotton Candy"*green roofs.

Benefit of tax reduction

Many countries utilize the tax and law incentive policy and the financial support, which can encourage the building owners in the utilization of green roofs (Clark, Adriaens and Talbot 2008, Tomalty, Komorowski and Doiron 2010).The green roof promoting policies in Taiwan supports 30% tax credit to the commercial owners (Chen 2013).The City of Chicago supports the maximum value up to \$100,000 for the cost for the building envelope development of green roofs and 50% of total roof space (Berardiand GhaffarianHoseini 2014). Bianchini and Hewage considered that the benefit of tax reduction in the green roof and extensive green roof law intensive varies from \$ 0/m^2 to \$ 48/m^2 (Bianchini and Hewage 2012).

At present, the consideration and values of tax reduction in many cities are quite different. In Thailand, the tax reduction considerations of the city in the world have the different values. Currently, there are not any direct tax reduction policyfor green roof in Thailand. Therefore, the benefit of tax reduction of air plant green roofs is \$ 0/m^2.

Benefit of green roof longevity

The green roof covering increases the conventional roof's lifespan. Green roofs also reduced the time period of maintenance and replacement (Bianchini and Hewage 2012, Evans 2008, Ouldboukhitine, Belarbi and Sailor 2014). American society of landscape architects showed that a lifespan of green roofs in Germany could last for 40 to 50 years. On the other hand, the typical lifespan of conventional roofs was 15-20 years (Evans 2008). Bianchini and Hewage explained that the replacement cost of conventional roofs is about \$ 160/m^2 in two times of the lifespan of conventional roofs. Hence, the longevity benefit of intensive green roofs and extensive green roof valued as \$ 320/m^2(Bianchini and Hewage 2012).

The average lifespan of conventional roofs in Thailand is about 10 – 15 years. The replacement cost of Thai conventional roof is about \$ 56.64/m^{2}to \$ 92.40/ m^2. The cost of roof material and structure, labor for installing and demolition[4]

4. The standard price of building material from Department of public works and town planning Songkla office, 2015: www.dpt.go.th/songkhla/

are already included. The profitability time frame of *"Cotton Candy"* and *"Spanish moss"* green roof is 30 years. Therefore, the owner of those properties can save the replacement cost approximately 2 times, which can save the money up to $ 113.27/m^2 to $ 184.81/m^2.

Benefit of avoided storm water in drainage system

One of the potential benefits of green roofs is the water drainage retention before flowing into the public aqueduct (Zhang et al. 2012, Laar and Grimmer 2006, Murillo 2010, Speak et al. 2014). Moreover, the water retention of green roofs can reduce heating from solar radiation to building (Blank et al. 2013, Kokogiannakis and Darkwa 2014, Volder and Dvorak 2014, Pisello, Piselli and Cotana 2015, Lin et al. 2013, Coutts et al. 2013). The United States General Services Administration reported that the runoff rate from conventional roof was up to 65% (General Services Administration 2011).The benefit of from slowing the amount of rainfall down before flowing to the irrigation system or water-distribution system showed that there were $ 100/m^2 and $ 324/m^2 and extensive green roof about $ 39/m^2 and $ 100/m^2.

Air plant green roofs have well – design that it can avoid the combined flooding rate from sewer roofs and the delay of drainage problem. These air plants also help to slow down the storm water. In this research, the consideration of infrastructure saving analysis is about 20% to 40% of the green roof's initial cost, which is less than other types of green roofs because of the thinness of growing media. Therefore, the profitability of avoided storm water can be calculated for "cotton candy" green roof about $ 15.33/m^2 to $ 30.67/m^2 and *"Spanish moss"* green roof between $ 15.33/m^2 to $ 30.67/m^2.

Benefit of plant sales in market

The growth and buddingof air plan green roof can be another source of income. Those plants can make the profit and added value to the building's owner. In this research, the advantages of air plant green roofs gains from the growth and distribution. Distinctly, the research of plant growth is observed and found that the propagation characteristics of *"cotton candy"*are germination growing rapidly.

4. CONCLUSION

The study of life cycle cost of air plant green roofs is one of the important tools helping the building ownertomake up final decision about applying green roofs on the buildings. These elements were considered from internal costs, external costs and internal benefits of green roofs. The consideration of external costs of green roofs showed the social costs through the life cycle of the green roofs. The result presented that it costs less or zero pollution when comparing with other materials, which have some effects to environment, economic and social.The level of economic barriers of air plant green roofs is significantly low when comparing with other type of green roofs such as construction cost, maintenance cost, complexity of construction, expensive integration in existing buildings. (See Table 2 Economic benefits and barriers of green roofs)The characteristic of green roofs is an important variable in evaluating initial construction costs. It can be observed from the structure and pattern of air plant green roofsthat stays without growing media layer. (Thickness of growing media is below 10 cm, very lightweight of 5–10 kg/m^2 and does not effect to dead load of the old and new building structure. Moreover, it can integrate the roof irrigation system together with previous roof structure without further cost. This outstanding characteristic will decrease the cost of initial construction costs of air plant green roofs.)

However when comparing with the cost of initial construction of air plant green roofs, it appeared that the costs of plants, covering structure, hanging structure and labor are higher especially in "Cotton Candy" green roof, which costs $221.53/m^2. Hence after comparing with other costs, this weak spot needs to be identified. Sustainable design and environmental friendly are the outstanding characteristics of the green roofs. By reducing the restriction of economic barrier, it will motivate user to apply air plant green roofs sustainably.

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References

Ascione, F., Bianco, N., de' Rossi, F., Turni, G. and Vanoli, G.P. (2013)"Green Roofs in European Climates. Are Effective Solutions for the Energy Savings in Air-Conditioning?".*Applied Energy*, 104,pp. 845–59.

Asdrubali, F., Baldinelli, G., Bianch, F. and Sambuco, S. (2015)"A Comparison between Environmental Sustainability Rating Systems LEED and ITACA for Residential Buildings". *Building and Environment*, 86, pp. 98–108.

Bates, A.J., Sadler, J.P. and Mackay, R. (2013)"Vegetation Development over Four Years on Two Green Roofs in the UK".*Urban Forestry and Urban Greening*, 12(1), pp. 98–108.

Been, V. and Voicu, L. (2008)"The Effect of Community Gardens on Neighboring Property Values The Effect of Community Gardens on Neighboring Property Values".*Real Estate Economic*, 36(2),pp. 241–83.

Berardi, U., AmirHosein, G. and Ali, G. (2014)"State-of-the-Art Analysis of the Environmental Benefits of Green Roofs".*Applied Energy*, 115, pp. 411–28.

Bianchini, F., and Kasun, H. (2012)"How 'Green' Are the Green Roofs? Lifecycle Analysis of Green Roof Materials".*Building and Environment*, 48(1), pp. 57–65.

Bianchini, F., Hewage, K.(2012)"Probabilistic Social Cost-Benefit Analysis for Green Roofs: A Lifecycle Approach".*Building and Environment*, 58, pp. 152–62.

Blank, L., Vasl, A., Levy, S., Grant, G., Kadas, G., Dafni, A., Blaustein, L. (2013)"Directions in Green Roof Research: A Bibliometric Study". *Building and Environment*, 66, pp. 23–28.

Carter, T., and Andrew, K. (2008)"Life-Cycle Cost-Benefit Analysis of Extensive Vegetated Roof Systems".*Journal of Environmental Management"*, 87(3), pp. 350–63.

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 (10), pp. 1582–91.

Chen, C.(2013)"Performance Evaluation and Development Strategies for Green Roofs in Taiwan: A Review".*Ecological Engineering*, 52, pp. 51–58.

Clark, C., Peter, A. and F Brian, T. (2008)"Green Roof Valuation: A Probabilistic Economic Analysis of Environmental Benefits".*Environmental Science & Technology*, 42(6), pp. 2155–61.

Coutts, A.M., Daly, E., Beringer, J. and Tapper, N.J. (2013)"Assessing Practical Measures to Reduce Urban Heat: Green and Cool Roofs". *Building and Environment*, 70, pp. 266–76.

Berndtsson, J.C.(2010)"Green Roof Performance towards Management of Runoff Water Quantity and Quality: A Review".*Ecological Engineering*, 36(4), pp. 351–60.

Evans, D. (2008)"Cost Benefit Evaluation of Ecoroofs".*Bureau of Environmental Services*, pp. 1-25.

Fang, W., Xiaosong, Z., Junjie, T. and Xiuwei, L. (2011)"The Thermal Performance of Double Skin Facade with Tillandsia Usneoides Plant Curtain".*Energy and Buildings*, 43(9), pp. 2127–33.

Feng, C., Zheng, H., Wang, R., Yu, X. and Su, Y. (2015)"A Novel Solar Multifunctional PV/T/D System for Green Building Roofs".*Energy Conversion and Management,* 93, pp. 63–71.

Fernandez-Cañero, R., Emilsson, T., Fernandez-Barba, C. and Herrera Machuca, M. Á. (2013)"Green Roof Systems: A Study of Public Attitudes and Preferences in Southern Spain".*Journal of Environmental Management*, 128, pp. 106–15.

Garrison, N. and Horowitz, C. (2012)"Looking Up: How Green Roofs and Cool Roofs Can Reduce Energy Use, Address Climate Change and Protect Water Resources in Southern California".*Nrdc Report*.

Getter, K.L. and Rowe, B. (2006)"The Role of Extensive Green Roofs in Sustainable Development". *HortScience*, 41(5),pp. 1276–85.

Ghaffarianhoseini, A. and Berardi, U. (2015)"Thermal Performance Characteristics of Unshaded Courtyards in Hot and Humid Climates".*Building and Environment*, 87,pp. 154–68.

Han, G., Srebric, J. and Enache-Pommer, E. (2013)"Variability of Optimal Solutions for Building Components Based on Comprehensive Life Cycle Cost Analysis". *Energy and Buildings,* 79, pp. 223–31.

Hooi, D., Toe, C. and Kubota, T. (2015)"ScienceDirect Comparative Assessment of Vernacular Passive Cooling Techniques for Improving Indoor Thermal Comfort of Modern Terraced Houses in Hot – Humid Climate of Malaysia".*Solar Energy*, 114, pp. 229–58.

Kim, C.J., Kim, J., Hong, T., Koo, C., Jeong, K. and Park, H.S.(2015)"A Program-Level Management System for the Life Cycle Environmental and Economic Assessment of Complex Building Projects".*Environmental Impact Assessment Review*, 54, pp. 9–21.

Kokogiannakis, G. and Darkwa, J., (2014)"Support for the Integration of Green Roof Constructions within Chinese Building Energy Performance Policies".*Energy*, 65, pp. 71–79.

Kosareo, L. and Ries, R. (2007)"Comparative Environmental Life Cycle Assessment of Green Roofs". *Building and Environment*, 42(7), pp. 2606–13.

Laar, M. and Grimmer, F.M. (2006)"Thermal Comfort and Reduced Flood Risk through Green Roofs in the Tropics".*The 23rd Conference on Passive and Low Energy Architecture*, pp. 575–80.

Lamond, J., Wilkinson, S. and Rose, C. (2014)"Conceptualising the Benefits of Green Roof Technology for Commercial Real Estate Owners and Occupiers".*20th Annual PRRES Conference, Christchurch, New Zealand,* pp. 19–22.

Lin, B. S., Yu, C. C., Su, A. T. and Lin, Y. J. (2013)"Impact of Climatic Conditions on the Thermal Effectiveness of an Extensive Green Roof".*Building and Environment*, 67, pp. 26–33.

Liu, T. C., Shyu, G. S., Fang, W. T., Liu, S. Y. and Cheng, B. Y. (2012)"Drought Tolerance and Thermal Effect Measurements for Plants Suitable for Extensive Green Roof Planting in Humid Subtropical Climates".*Energy and Buildings*, 47,pp. 180–88.

Lough, C. K. (2015)"The Cost of Design: A Life-Cycle Assessment of Green Infarstructure Technology. The Master of Landscape Architecture".*The School of Landscape*.

Lüttge, U., (2004)"Ecophysiology of Crassulacean Acid Metabolism (CAM)".*Annals of Botany*, 93(6),pp. 629–52.

Madre, F., Vergnes, A., Machon, N. and Clergeau, P. (2013)"A Comparison of 3 Types of Green Roof as Habitats for Arthropods".*Ecological Engineering*, 57,pp. 109–17.

Martin, C. E., Hsu, R. C. C. and Lin, T.C. (2010)"Sun/shade Adaptations of the Photosynthetic Apparatus of HOYA Carnosa, an Epiphytic CAM Vine, in a Subtropical Rain Forest in Northeastern Taiwan".*Acta Physiologiae Plantarum*, 32(3),pp. 575–81.

Murillo, E. (2010)"Influence of Construction and Demolition (C&D) Waste on Green Roof Performance".*The University of British Columbia*.

Ouldboukhitine, S. E., Belarbi, R. and Sailor, D. J.(2014)"Experimental and Numerical Investigation of Urban Street Canyons to Evaluate the Impact of Green Roof inside and Outside Buildings".*Applied Energy*, 114,pp. 273–82.

Peng, L. L. H. and Jim, C. Y.(2013)"Green-Roof Effects on Neighborhood Microclimate and Human Thermal Sensation".*Energies,* 6(2), pp. 598–618.

Pérez, G., Coma, J., Solé, C., Castell, A. and Cabeza, L. F.(2012)"Green Roofs as Passive System for Energy Savings When Using Rubber Crumbs as Drainage Layer".*Energy Procedia*, 30,pp. 452–60.

Peri, G., Traverso, M., Finkbeiner, M. and Rizzo, G. (2012)"The Cost of Green Roofs Disposal in a Life Cycle Perspective: Covering the Gap".*Energy*, 48(1), pp. 406–14.

Pinheiro, M. D. and Heitor, T.(2014)"From Indicators to Strategies: Key Performance Strategies for Sustainable Energy Use in Portuguese School Buildings".*Energy and Buildings,* 85,pp. 212–24.

Pisello, A. L., Piselli, C. and Cotana, F. (2015)"Thermal-Physics and Energy Performance of an Innovative Green Roof System: The Cool-Green Roof".*Solar Energy*, 116. pp. 337–56.

Porsche, U. and Köhler, M. (2003)"LIFE CYCLE COSTS OF GREEN ROOFS - A Comparison of Germany, USA, and Brazil - Ulrich." *RIO 3 - World Climate & Energy Event*, pp. 1–5.

Rincón, L., Coma, J., Pérez, G., Castell, A., Boer, D. and Cabeza, L. F. (2014)"Environmental Performance of Recycled Rubber as Drainage Layer in Extensive Green Roofs. A Comparative Life Cycle Assessment". *Building and Environment*, 74, pp. 22–30.

Rowe, D. B. (2011)"Green Roofs as a Means of Pollution Abatement".*Environmental Pollution*, 159(8-9), pp. 2100–2110.

Rowe, D. B., Getter, K. L. and Durhman, A. K.(2012)"Effect of Green Roof Media Depth on Crassulacean Plant Succession over Seven Years".*Landscape and Urban Planning*, 104(3-4), pp. 310–19.

Rowe, D. B., Kolp, M. R., Greer, S. E. and Getter, K. L. (2014)"Comparison of Irrigation Efficiency and Plant Health of Overhead, Drip, and Sub-Irrigation for Extensive Green Roofs". *Ecological Engineering*, 64, pp. 306–13.

Rumble, H. and Gange, A. C.(2013)"Soil Microarthropod Community Dynamics in Extensive Green Roofs".*Ecological Engineering*, 57,pp. 197–204.

Sailor, D. J., Hutchinson, D. and Bokovoy, L. (2008)"Thermal Property Measurements for Ecoroof Soils Common in the Western U.S."*Energy and Buildings*, 40(7), pp. 1246–51.

Speak, a. F., Rothwell, J. J., Lindley, S. J. and Smith, C. L. (2014)"Metal and Nutrient Dynamics on an Aged Intensive Green Roof". *Environmental Pollution*, 184(3), pp. 33–43.

Sproul, J., Wan, M. P., Mandel, B. H. and Rosenfeld, A. H. (2014) "Economic Comparison of White, Green, and Black Flat Roofs in the United States".*Energy and Buildings*, 71, pp. 20–27.

Starry, O., Lea-Cox, J. D., Kim, J. and van Iersel, M. W. (2014)Photosynthesis and Water Use by Two Sedum Species in Green Roof Substrate.*Environmental and Experimental Botany* 107, pp. 105–12.

Tomalty, R. and Komorowski, B. (2010)"The Monetary Value of the Soft Benefits of Green Roofs".*Smart Cities Research Services*.

Tsang, S. W. and Jim, C. Y.(2013)"A Stochastic Model to Optimize Forecast and Fulfillment of Green Roof Demand".*Urban Forestry and Urban Greening*, 12(1), pp. 53–60.

Van Mechelen, C., Dutoit, T. and Hermy, M. (2014)"Mediterranean Open Habitat Vegetation Offers Great Potential for Extensive Green Roof Design".*Landscape and Urban Planning*, 121, pp. 81–91.

Van Mechelen, C., Dutoit, T. and Hermy, M. (2015)"Vegetation Development on Different Extensive Green Roof Types in a Mediterranean and Temperate Maritime Climate". *Ecological Engineering*, 82,pp. 571–82.

Volder, A. and Dvorak, B. (2014)"Event Size, Substrate Water Content and Vegetation Affect Storm Water Retention Efficiency of an Un-Irrigated Extensive Green Roof System in Central Texas".*Sustainable Cities and Society*, 10,pp. 59–64.

Vovides, A.P., Etherington, J.R., Dresser, P.Q., Groenhof, A., Iglesias, C. and Ramirez, J.F. (2002)"CAM-Cycling in the Cycad *Dioon Edule* Lindl . in Its Natural Tropical Deciduous Forest Habitat in Central Veracruz , Mexico".*Botanical Journal of Linnean Society*, 138(2), pp. 155–62.

Wachter, S. (2005)"The Determinants of Neighborhood Transformations in Philadelphia Identification and Analysis: The New Kensington Pilot Study". *University of Pennsylvania.*

Wallbaum, H., Ostermeyer, Y., Salzer, C. and Zea Escamilla, E. (2012)"Indicator Based Sustainability Assessment Tool for Affordable Housing Construction Technologies". *Ecological Indicators*, 18,pp. 353–64.

Williams, N.S.G., John, P. R. and Kirsten, J.R. (2010)"Green Roofs for a Wide Brown Land: Opportunities and Barriers for Rooftop Greening in Australia".*Urban Forestry and Urban Greening*, 9(3), pp. 245–51.

Wong, N.H., Tay, S.F., Wong, R., Ong, C.L. and Sia, A. (2003)Life Cycle Cost Analysis of Rooftop Gardens in Singapore.*Building and Environment*, 38(3),pp. 499–509.

Yang, F., Qian, F. and Lau, S.S.Y. (2013)"Urban Form and Density as Indicators for Summertime Outdoor Ventilation Potential: A Case Study on High-Rise Housing in Shanghai".*Building and Environment*, 70,pp. 122–37.

Zhang, B., Xie, G., Zhang, C. and Zhang, J. (2012)"The Economic Benefits of Rainwater-Runoff Reduction by Urban Green Spaces: A Case Study in Beijing, China".*Journal of Environmental Management*, 100,pp. 65–71.

Zinzi, M. and Agnoli, S. (2012)"Cool and Green Roofs. An Energy and Comfort Comparison between Passive Cooling and Mitigation Urban Heat Island Techniques for Residential Buildings in the Mediterranean Region".*Energy and Buildings*, 55,pp. 66–76.

Zuo, J. and Zhao, Z.Y. (2014)"Green Building Research-Current Status and Future Agenda: A Review".*Renewable and Sustainable Energy Reviews*, 30,pp. 271–81.