Green roof performance under malaysia tropical climates: a review

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ABSTRACT

Green roof system is one of sustainable approach for energy consumption reduction and improving the aesthetic value of the built environment. The system has been adopted by most of developed countries; and in Malaysia, research on green roof studies are quite evolving however the implementation of the system is slow due to some perceptions and obstacles. Green roof has potential on providing benefits such as reduction on the urban heat island effect, reduces temperatures, pollution and improves the attenuation of stormwater. This paper will highlights on a preliminary review of the implementation green roof system in Malaysia and explores the performances of Malaysian green roof in order to highlight the performance of green roof under tropical climatic conditions using local configurations.

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1. INTRODUCTION

Globally, urbanization has becoming a threat to the environmental issues. Urbanisation has led to the acceleration of numerous environmental problems in most developed countries especially in developing countries such as Malaysia. The environmental problems are mainly due to the production of pollution, modification the physical and chemical properties of soil, air and water [1], and transform the natural landscape to anthropogenic urban land and changes surface physical characteristics [2].

Most of urban facilities use energy resouces for industrial, transport sector for burning fuels such as natural gases, oil, and coal; and has led these usage to the increment of gaseous concentration and particle pollutants in the atmosphere [3]. Hence, acid rain has become the most serious problems and gives serious impact on soil parameters, on aquatic ecosystem, on forest trees, on crop plants, on lower plants, on materials and buildings, on animals, on human health [4-8]. Buildings, streets, and driveways are replacing grasslands and forests, which also causes the increment in the rainwater runoffs volume that generates flood [9, 10], river erosion [11] and reduction of of groundwater discharges [12, 13].

In their handbook for Sustainable Urban Drainage System (SuDS), [14] highlighted that all these urbanisation processes are same in all countries including tropical countries, however each countries have variety ways of approaches on their mitigation strategies that suit to their specific conditions. Malaysia had adopted the use of SuDS to manage runoff by installing various SuDS devices and management trains throughout the country based on the Malaysian drainage manual [14, 15]. Green roof is one of the SuDS devices that gradually adapted in Malaysian construction culture that mainly due to landscape aesthetic [16-18], green building [19, 20], thermal comfort [21-23] but SuDS itself represents the urban drainage system for water management [24, 25]. Therefore, this paper will explores on some of the green roof performances by Malaysian studies.

2. MALAYSIA AND THE GREEN ROOF IMPLEMENTATION

The region of Kuala Lumpur experienced a declining in its green areas from its original 24,222 hectare of city area to only about 59.4% of the total area that equivalent to 14,386 hectares [26, 27]. Following this reduction, Kuala Lumpur exemplifies the negative effect of urbanization in the country and the urgent need to develop sustainable strategies that can maintain the green coverage in parallel with modern urbanization. Green roof has the potential to increase green areas within wasted roof in urban areas. The depletion and degradation of the environmental resources such as soil, water and air in Malaysia has also generated interest in the green roof system from most of Malaysian professionals, scholars and practical perspective [17, 28]. From the green roof projects information compiled by [28], green roof concept may not new where it have been implemented since 1992 to 2005 for the landscape purpose [17]. However, it have been recently discovered in more technical ways by professionals scholars since 2006 to 2008 and its gradually evolving since then [17, 28].

In [17, 29], once reported in their studies that the Ministry of the Federal Territories and Urban Wellbeing, Malaysia had the initiative to allocate an area of 150,000 m2 of traditional roofs that are to be converted to green roofs by the end of 2020. However, although green roofs gaves many benefits on environments, it is noticed that very few buildings have been adopted green roofs system [19]. This may be due to perception, challenges in development, obstacles or barriers in green roof implementation [17, 28-30].

The study also identifies the obstacles to the implementation of the green roof concept within Malaysia. One of the challenges is the absence of clear design rules and guidelines for the implementation of the concept in the country [19]. Without such guidelines, the implementation of the roof for the owners of buildings becomes a challenge. There are additional obstacles in the form of the absence of experts or green roof professionals for installation. The rest feature past failures of these roofs, complexities and costs of maintenance, high costs of installation, and the susceptibility to fire. The challenges also feature the fear for a previously unimplemented concept within the country [25].

Malaysian society is not sufficiently aware of green roof technology, hence there is a need for publicity to ensure that the technique is known by a significant population [19]. The green roof systems have been adopted in Malaysia but are not monitored scientifically, hence their performance is not sufficiently proved [31, 32].

2.1. Green Roof Benefits

The core aspect that should guide the decision to implement the green roof within any surrounding is the degree of benefits that the concept provides. This paper explores on the summary of the findings on the potential of environmental benefits from the use of the green roof system in Malaysia. Based on the reviews from 4 researchers findings, [17] also identified 10 beneficial factorgreen roof similar to [28] findings as listed:

i)Increase the roof life span by protecting it against the sun's direct heat.	vi)Reduce water surface runoff and urban flood.
ii)Increase the aesthetics and economic values of properties.	vii)Reduce a building cooling load and CO2 emissions.
iii)Reduce the Urban Heat Island Effect.	viii)Create urban green spaces for social activities and agriculture.
iv)Restore the ecosystem of flora and fauna into the urban.	ix)As a buffer zone from noise and air pollution.
v)Gain recognition and certification through Green Building Index (GBI).	x)Reducing the Roof Thermal Transfer Value (RTTV).

Furthermore, [33] in their study has reported that in any building construction, green roof has the opportunity to gain between 7% and 10% point from the building assessment tools such as Building Research Establishment Environment Assessment Method (BREEAM), Leadership in Energy and Environmetal Design (LEED), CASBEE, Green Mark and Green Building Index (GBI). Green roofs is well known to have direct contribution on greenery provision, greenery and roof and storm water design, noise attenuation, air pollution reduction, insulation and biodiversity of animals.

2.2 Green Roof Configurations

Typical green roof system consists of vegetation, growth medium and drainage layers that are placed on roof structure but the layers can be extended depending on the requirements for roof protection [34]. Typically, green roof can be classified as extensive or intensive depending on the depth of growing media.

The extensive green roof is lightweight and has shallow layer of growth depth which normally less than 150 mm and planted with small plant types. While intensive green roof has deeper layer of growing media more than 150 mm to support larger types of vegetation such as shrubs and trees. Due to limitation on plant selection, study by [28] reported that intensive green roofs are the most common green roof implemented in Malaysia, with a dominance survey at 77.5% from total of 120 respondent, while extensive green roofs are less dominant at 22.5%.However, even though the green roof layer configurations may be differ in their details, its usually features vegetation, a growth medium, a drainage and water proofing layer, as well as the final protection layer. The design of the roof must also be such that the slope achieves proper capacities of retention and porosity [26].

2.2.1 Type of Vegetation

Plant selection in green roof is more relying on the type of green roof itself. Shallow substrate depth of extensive green roof lead to restricted of plant species like drought tolerance succulents such as Sedum, annuals grasses, herbaceous perennials and mosses. Succulents like Sedum, mostly well suitable to extensive green roof [35-38]. In Malaysia, several research based on types of vegetation had been conducted by [35, 39-43] mainly focusing on the performance of the plants in reducing the stormwater runoff. Table 1 shows the summary of all the findings.

Table 1. Summary of Green Roof Vegetations used by Malaysian Studies

Researchers	Types of Vegetation used and Findings
D.Kamarun et al.,(2017) [40]	- Pearl grass (*Axonopus compressus (dwarf))*, Philippine grass (*Zoysia matrella)* and Cow grass (*Axonopuscompressus)*. - Philippine grass (*Zoysia matrella)* exhibited the highest potential in the reduction of water runoff
J. Johari et al., (2011) [39]	-family *Portulacea, Crassulaceace*, and *Neoregelia*
R. Krishnan and H. Ahmad, (2014) [43]	Malaysian species except Sedum: *Nephrolepis bisserrata* (fern), *Cynadon dactylon* (grass), *Kaempferia galangal* (herb), and *Sedum mexicanum* (succulent).
K.A. Shahid et al., (2014) [41]	The Creeping Ox-Eye (*Wedelia Trilobata*) - its a dense cover; and beach morning glory (*Ipomoea pes-caprae*) - has ability to tolerate with high ambient temperature
A. Ismail et al., (2011) [44]	-Five types of potted plant: *syngonium podophyllum* (arrowhead plants), *ipomoea batatas* (sweet potato), *jasminum sambac*, *ipomoea horsfalliae* (cardinal creeper) and *ipomoea pes-caprae* (beachmorning glory)). -*Ipomoea pes capraehas* ability to uptake higher amount of CO_2 and resilience to higher outdoor temperatures.
K.R. Ayub et al., (2015) [42, 45]	-*Kalanchoe pinnata* (cathedral bell*)*, *Arachis* Pintoi (pinto peanut), *Axonopus compressus* (cow grass). -*Kalanchoe pinnata* is the best in removing pollutant. - *Axonopus compressus* has good performance in flow attenuation.

2.2.2 Green Roof Layers Materials

In term of environment sustainability, it is important to utilize waste material into the research of green roof materials. In a research conducted by [41], it can be concluded that the palm oil clinker is suitable to replace pumice as drainage layer in green roof system. Another research had utilised rubber crumbs, palm oil shell, and polyfoam as drainage layer. Based on capabilities in peak flow attenuation and lighter green roofs, rubber crumbs are the best [31]. This is supported by [46] and [47]. Additionally, it was suggested that the impacts of a green roof are investigated under different soil conditions [24]. Summary of green roof layer materials used by Malaysian studies as shown in Table 2.

3. GREEN ROOF RESEARCH PERFORMANCE

This study focuses particularly on runoff and indoor temperature as the potential advantages of the implementation of the concept.

3.1. Stormwater Performance

In terms of stormwater retention, most studies shown that the green roof or eco-roof method could reduce peak flow and its magnitude as well as improving the water quality through soil infiltration and seepage process. The methodology and the findings for stormwater water quantity and water quality performance are shown in Table 3 and Table 4.

Table 2. Summary of Green Roof Layer Materials used by Malaysian Studies

Researchers	Findings
R.Rashid and M.H. Ahmed, (2009) [23]	The extensive type of full scale rooftop garden is organized by 50 nos. of greenary pot plants to cover the rooftop surface. Plants are arranged densely.
A. Ismail et al., (2011) [44]	Field measurement on full scale concrete flat roof of a single storey detached house. The the test room is 3.05 m x 2.73 m x 3.05 of the brick wall. The flat roof surface was insulated with bituminous felt which was black in colour.
R. Krishnan and H. Ahmad, (2014) [43]	Extensive green roof modules in black PVC trays 350 x 270 x 100 mm deep of substrate and 10 mm of gravel at the base
K.A. Shahid et al., (2014) [41]	The experimental trays with soil depth layer of 5 cm and 4 cm of drainage layer and the materials used for substrate is the same and drainage layer are pumice and palm oil clinker in three different sizes 2 mm, 5 mm and 10 mm.
K.R. Ayub et al., 2015 [42]	Small scale test beds with dimension of 1 m x 1 m. Every beds consist of 25 mm of drainage cell, cover with filter fabric (geotextile), 50 mm clean river sand (diameter 2 mm) are put on top and follow with 150 mm top soils with coefficient of permeability, k, value is 9.05×10^{-5}cm/s follow by vegetation seeds
M. Mimezhad, et al., 2017 [22]	The extensive full scale roof on the rooftop of Heriot-Watt University building
N.S.A. Asman, et al., 2017 [31]	9 small scale test beds with different drainage layer different recycled waste (polyfoam, rubber crump, palm oil shells), natural fibres (coconut fibre, palm oil fibre and sugarcanes fibres) and one test bed as a control bed.

Table 3. Summary of Stormwater Performance-Water Quantity

Researchers	Methodology	Findings
S. Musa et al., (2007) [48]	Two models of extensive flat type roof were built (1m x 0.75m); one with vegetated roof (test) and one non-vegetated roof (control) to evaluate flow rate and retention capacity.	Vegetated roof model retained 17 % to 48 % storm water runoff.
A. Shaharuddin, et al., (2011) [24]	Two different surfaces; concrete roof and eco-roof (645 m^2 green roof).The total rainfall volume is calculated using Rongfu formula.	Green roof helps to store 52,632m^3 volume of rainfall by using 9.8 mm of total rainfall as a threshold value.
K. H. Kok et al., (2011) [49]	Float method was applied to measure the surface velocity of the flow. The performance of green roof in peak runoff reduction was monitored by comparing the peak discharge obtained from on-site experiment with the standard peak discharge for district of Kuala Lumpur (impervious roof) calculated from simple rational method with referring to MASMA chapter 13 (DID, 2000).	The standard peak discharge calculated from simple rational method for the impervious roof was 0.0034 m^3/s, by comparing it with peak discharge estimated for green roof, the green roof showed peak discharge reduction up to 44%.
R. Krishnan and H. Ahmad, (2014) [43]	Rainfall from weather station, water runoff = rainfall (infiltrated water runoff + surface runoff)	Effectiveness in reducing water runoff fern followed by herbs, sedum and grass. Nephrolepis biserrata had highest runoff reduction at 133.4 mm and highest rate of water loss at 0.87 g followed by Kaempferia galangal with reduction at 100.5 mm
K.A. Shahid et al., (2014) [41]	The saturated hydraulic conductivity is calculated using Darcy's law with following expression: $Ks\left[\frac{cm}{h}\right]=\frac{V[cm^3]*L[cm]}{A[cm^2]*\Delta t[h]*h[cm]}$ Infiltration rate: $v_i\left[\frac{cm}{min}\right]=\frac{V_1\left[\frac{cm^3}{cm^2}\right]}{t[min]}$	Two parameters: saturated hydraulic conductivity and infiltration rate. Palm oil clinker has the ability to drain the water fast. The bigger size of clinker the higher value of hydraulic conductivity between 1550 cm/h and 1800 cm/h compared to pumice at 1650 cm/h.
K.R. Ayub et al.,(2015) [42]	With dry days of 96 hours (4 days), 4 rainfall simulation starts at 2.0L/min (intensity = 159 mm/hr) for 1 hour continuously. Outflow from the green roof is obtained after 1 hour the rainfall simulation stopped.	Due to grass density, the highest percentage peak flow attenuation between 51% and 67%.
K. H. Kok et al., (2016)[25]	The simulation was done based on the local rainfall temporal patterns derived for HTC which were 10, 30, and 60 min in 2 years average recurrence interval. Time–Area run-off generation model was used to transform the effective rainfall to run-off hydrograph.	The peak discharge of stormwater run-off was reduced up to 26% in relation to concrete tile roof.

Table 4. Summary of stormwater performance-water quality

Researchers	Methodology	Findings
K.R. Ayub et al., (2015) [42]	Runoffs generated from the simulated rainfall were collected for water quality parameter analysis: Total Phosphorus (TP), Total Nitrogen (TN), Ammoniacal Nitrogen (AN) and Potassium (K)	All vegetation used have the ability to remove TP: 20.11% - 89.10%, & AN: 59.92% - 95.34%Base on capabilities in flow reduction and pollutants removal, K.pinnata is suitable, its manage to survive in long period of dry season and less maintenance
K. H. Kok et al., (2016) [23]	Three water samples were collected at the early, middle, and late stage of the storm event to calculate Water Quality Index (WQI).	An average WQI of 92(Class I) was obtained out of 15 samples for the run-off generated from the green roof, which indicated that the run-off produced was clean.
N.S.A. Asman, et al., (2017) [31]	The inflow from rainfall simulator are for 15 minutes continuously. The outflow was taken for one hour continuously after the simulator started with five minutes interval.	Parameters: pH value, total suspended solid (TSS), turbidity and chemical oxygen demand. pH values: all below control under 6.64, but for layer polyfoam + sugarcane fibre 5.42 and rubber crumb+sugarcane fiber 5.1 TSS: 5 layers type has larger than 10 mg/L (Rubber Crump + coconut fibre -10, Polyfoam + Palm oil fibre - 12, Polyfoam + sugarcane fibre – 17, and 22 for Palm Oil Shells & Rubber Crumb + sugarcane fibre Higher turbidity at 10.4 ahd higher COD at 63 NTU was Rubber Crumb + sugarcane fibre

3.2. Thermal Performance

Green roofs have been recognised as a great means of limiting the Urban Heat Island (UHI) effect by removing heat from the air through evapotranspiration of the plants, which leads to a reduction of the temperatures of the roof surface and the surrounding air [21]. The methodology and findings obtained from thermal performance research in Malaysia are summarized in Table 5.

Table 5. Summary of Thermal Performance

Researchers	Methodology	Findings
A.Ismail et al., (2011) [44]	Field measurement on full scale flat roof of a single storey detached houseof indoor and outdoor microclimates of test room with different types of roof treatments	The maximum solar radiation for the measurement of black bare roof, green roof and white roof are 1009, 1126 and 1048 W/m^2 respectively. The average temperature difference between two roofs was 6.85˚C observed from 1 pm to 8 pm. Average indoor surface temperature difference between whiteroof and black bare roof was 5.30˚C at 4.15pm. Green roof have the ability to lower the indoor air temperature better than white roof by providing shades and evapotranspiration to the roof.
R.Rashid and M.H. Ahmed, (2009) [23]	Field measurement on pot plants for every 15 minutes for internal and external data using Dickson data logger, infra red ray gun data logger and air temperature & humidity sensor logger	Rooftop surface maximum temperature was decreased around 11.2°C to 19.8°C in field experiment.Green roof reduces the ceiling surface temperature by a maximum of 3.0°C and on average 1.7°C, in comparison to bare roof. The maximum temperature difference between indoors and outdoors is 4.4°C with green roof during day time
M. Mirnezhad, et al., (2017) [22]	Field measurement on two different depths of soil (12 cm & 28 cm) using thermocouples for every 10 minutes	Highest temperatures are ranging between 24.9 to 60.7 °C and are captured from hard roof. Green roof with deeper soil thickness varies from 27.4 to 34.5 °C, lower soil depth green roof from 29.1 to 35.2°C with similar fluctuation. wet soil helps to boost soil capacity in CO_2 sequestration.

4. VIABILITY OF RESULTS AND CONCLUSIONS

The study concludes that the use of the green roof is a viable concept for application in Malaysia. This conclusion bases on the data showing the roof having reduced the runoff and lowered the indoor temperature for the buildings on which it was tested. However, the conclusion of viability may be limited for this particular study due to the choice data applied in the process. The study reports inaccuracies in the results collected regarding the runoff recorded following implementation of the roof. This shortcoming is attributed to the lack of scientific equipment suitable for the collection of data in such a context [43]. There are also shortcomings on the data on the rainfall patterns for the area. The data limitation diminishes the accuracy of the terms of the experiment, as the assumptions applied about the rain were unsuitable to the context. Therefore, the elements of this study cannot conclusively be used to generalize the assumptions about the green roof concept to the entire country or any typical tropical climate.

5. CONCLUSIONS ON THE GREEN ROOF CONCEPT IN TROPICAL CLIMATES

The research establishes that the concept of a green roof has been adopted in Malaysia since the early 1990's, but has not been fully embraced. The review also establishes that both intensive and extensive green roof technologies are applied. Other than the efforts of researchers and scholars, the government has also set aside a given percentage of the urban area for the establishment of the green roof technology. However, sufficient research work has not been done to establish optimal conditions for the use of green roofs in Malaysia, therefore it is necessary for the more scholarly effort to be put into establishing the most suitable way in which the technology should be applied for the maximum environmental and economic benefit.

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