Evaluation of green roof as green technology for urban stormwater quantity and quality controls

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Abstract. Promoting green design, construction, reconstruction and operation of buildings has never been more critical than now due to the ever increasing greenhouse gas emissions and rapid urbanizations that are fuelling climate change more quickly. Driven by environmental needs, Green Building Index (GBI) was founded in Malaysia to drive initiative to lead the property industry towards becoming more environment-friendly. Green roof system is one of the assessment criteria of this rating system which is under category of sustainable site planning and management. An extensive green roof was constructed in Humid Tropics Center (HTC) Kuala Lumpur as one of the components for Stormwater Management Ecohydrology (SME) in order to obtain scientific data of the system. This paper evaluates the performance of extensive green roof at Humid Tropics Center with respect to urban heat island mitigation and stormwater quantity and quality controls. Findings indicate that there was a reduction of around 1.5°C for indoor temperature of the building after installation of green roof. Simulations showed that the peak discharge was reduced up to 24% relative to impervious brown roof. The results show an increment of pH and high concentration of phosphate for the runoff generated from the green roof and the runoff water quality ranged between class I and II under INWQS.

1. Introduction

Depleting natural resources has appealed to sustainable developments. “Green” technology or “green” innovation is the common term for a particular method which can improve quality of natural resources such as water and air by inducing no or minimal pollutants to the nature. Malaysia is a developing country and it is inevitable that more natural resources are sacrificed for purpose of development and commercial activities. One of the prominent depleting natural resource in densely built urban areas is green spaces. It is a norm that green spaces in urban areas are replaced with impervious surfaces like concrete and roadways and phenomenon like Urban Heat Island (UHI) and flash flood are pertinent to excessive impervious surfaces.

Green Building Index (GBI) aims to evaluate the design and performance of local buildings with responses to degree of damages to environment and energy consumption. Green roof is suggested as one of the environmental friendly innovation under category of sustainable site planning and management. In fact, Urban Stormwater Management Manual for Malaysia (MSMA) was firstly introduced in 2001 as a guideline to adopt and design Best Management Practices (BMPs) in controlling stormwater in term of quantity and quality to achieve least impacts of post-development hydrologically [7]. Recently, MSMA second edition was released in 2012 whereby additional BMPs like bioretention was compiled and revised into the manual.

However, green roof was not compiled under MSMA yet though it is one of the BMPs as well. As other stormwater manuals applied at overseas like SUDs (UK), LID (USA), and WSUD (Australia) have been suggesting that green roofs can be used as a practice for stormwater quantity and quality controls, thus there is a urge to study the performances of green roof under local tropical climate. The scientific data obtained can be applied to develop design guideline of green roof system for Malaysia in future.
2. Green Roof Concept
Green roofs are made of a system of manufactured layers deliberately placed over roofing structures which support growing medium and vegetation. Green roof systems can be generally divided into extensive green roof (Eco-roofs) and intensive green roof (Podium Garden & Sky Gardens) [1][6]. Extensive green roof is low-weighted and requires only minimal maintenance. On contrary, intensive green roof is much heavier and requires higher construction cost and constant maintenance. Its substrate layer over 150mm is a common. The basic components of a green roof system regardless of extensive or intensive are vegetation, growth media, drainage layer, filter layer, water proofing layer and protection layer. The type of vegetation selected for the green roof system in HTC is *Zoysia Japonica* (Japan Grass). Figure 1 shows the configuration of green roof components in HTC, while Figure 2 shows the retrofitted green roof system for surau located in HTC.

3. Literature Review on Green Roof Performances
Numerous studies and researches conducted overseas have proven that extensive green roof gives positive effects on peak discharge reduction and thermal reduction. Green roofs reduce runoff by delaying the initial time of runoff due to absorption of water in the green roof, reducing the total runoff by retaining part of the rainfall, and spreading the residual runoff over a long time period through a relatively slow release of the excess water that is stored in the substrate layer [2]. Two extensive green roofs installed at North Carolina of America indicated that both of these roofs retained 64% of the total precipitation recorded and each green roof showed reduction in average peak flow by more than 75% [3]. Water storage capacity or stormwater retention ability has close relationship with rainfall intensity [4][5], the ability decreases during heavy storm events.

Green roof contributes to building insulation and energy efficiency by trapping air layer within the plant mass so that the building surface is cooled in summer and warmed in winter [5]. Vegetation of green roof act as a cooling agent by dissipating portion of city heat via evapotranspiration, thus green roof is applied as a way to combat urban heat island effect and to conserve more energy which is initially used to cool the buildings. Green roofs were able to reduce solar energy gained up to 90% when compared with non greened-top buildings, indoor temperature for green roof’s buildings was reported to have reduction of 3-4°C as outdoor temperature ranges between 25 °C to 30 °C [4]. Performance of green roof in enhancing water quality is debatable since it sometimes can be a source of nutrients/pollutants to the outflow. Green roofs did remove phosphorus concentration during moderate storms but not the efficient filter for pH, BOD$_7$, and COD [5]. However, higher concentration of TN and TP were observed in the green roof outflow during the first two years of green roof’s life and its media was the origin of the nutrients [3].

4. Methodology
The hydrological performance of green roof in HTC was studied by monitoring the runoff hydrographs that the green roof produced in certain storm events. These runoff hydrographs were named as observed green roof hydrographs. The runoff produced by the green roof was gauged by ultrasonic flow module and a runoff collection tank with V-notch weir. Simulated green roof hydrographs were then plotted using stormwater modeling software (XP-SWMM). Simulation was done both for actual storm events and design storms. For design storm events, the simulation was done based on the rainfall temporal patterns derived for HTC. The specific design storms durations were 10, 30, and 60 minutes with 2 years ARI. Runoff water samples from the green roof were collected as grab samples for randomly selected storm events. They were sampled into a plastic bottle with capacity of 2 litre and sent to certified laboratory for chemical testing. Besides that, an in-situ water quality probe also installed at the runoff collection tank for
measuring the physical properties of the runoff such as pH, temperature, and conductivity. Indoor temperature of the green roof building was measured by a digital thermometer which was attached to the inner wall of the building. Differences in maximum temperature recorded before and after installation of the green roof were evaluated.

5. Results and Discussions

Time-Area runoff generation model was used to transform the effective rainfall to runoff hydrograph. The calibrated and verified hydrologic parameters were applied to simulate runoff hydrograph for green roof and brown roof. The peak discharges obtained for green roof were then compared to brown roof in order to determine the ability of the green roof in HTC in reducing the peak discharge. The simulations were conducted for design storms of 2 years ARI with duration of 10 minutes, 30 minutes, and 60 minutes. Local rainfall temporal pattern in HTC was applied to generate the simulation. Figure 3 below indicates the comparison of simulated green roof and brown roof hydrographs for 60 minutes design storm and results for other duration of design storms were summarized in Table 1.

Results show that the simulated green roof hydrographs yielded lower peak discharge than the brown roof in each specified duration of design storm and the reduction ability increased for storms with lower rainfall intensities. Simulation also carried out for actual storm events and the results were compiled in Table 2. Average peak discharge reduction of 23.6% was estimated from the specified storms. Figure 4 shows the comparison of simulated hydrographs for actual storm on 16/8/2012.

![Figure 3. Comparison of simulated green roof and brown roof hydrographs.](image-url)

![Figure 4. Comparison of simulated hydrographs for actual storm on 16/8/2012.](image-url)

Table 1. Relationship between intensity with reduction of peak discharge

| Duration of Design Storm (minutes) | Rainfall Intensity (mm/hr) | Reduction of Q<sub>peak</sub> (%) |
|-----------------------------------|---------------------------|----------------------------------|
| 10                                | 146.6                     | 24.4                             |
| 30                                | 86.0                      | 40.7                             |
| 60                                | 59.9                      | 47.3                             |

Table 2. Comparison for simulated hydrographs based on actual storm events

| Events       | Q<sub>peak</sub> (l/s) (Green Roof) | Q<sub>peak</sub> (l/s) (Brown Roof) | Reduction (%) |
|--------------|------------------------------------|------------------------------------|---------------|
| 6/7/2012     | 0.881                              | 1.156                              | 23.7          |
| 8/7/2012     | 0.466                              | 0.629                              | 25.9          |
| 20/7/2012    | 0.639                              | 0.840                              | 19.1          |
| 16/8/2012    | 1.720                              | 2.315                              | 25.7          |

There were total 15 runoff water samples collected from April 2012 to September 2012. The samples were sent to certified laboratory for water quality analysis. Water Quality Index (WQI) of each sample was then calculated based on the results obtained from laboratory and in-situ probe. Table 3 portrays extract of WQI of the samples in several storm events. An average WQI of 92 was estimated out of 15 samples for the runoff generated from the green roof in HTC which indicated that the runoff produced was clean (not polluted).

Although the runoff samples achieved high WQI and considered not polluted, but results told that the green roof in HTC was a source of phosphate (PO<sub>4</sub>-P). Average concentration of 2.40 mg/l was founded from the samples collected. The substrates (fertilized planting soil) were thought as the origin of this nutrient contained in the runoff. However, the concentration of PO<sub>4</sub> presented in the runoff samples were noticed to be reducing as time lapsed due to uptake by the vegetation. Unestablished vegetation during early stage caused the nutrient leached into the runoff.

Thermal performance of the green roof was monitored by comparing the maximum mean temperature recorded prior and after installation of green roof. Indoor temperature of the green roof building was
measured in every interval of 15 minutes daily. In order to succeed the comparison, an assumption was made that the local climate in HTC before installation and after installation of green roof was about the same and fluctuation of surrounding temperature was negligible. Reductions of mean temperature were noticed in both months of January and February after installation of green roof. The amount of the comparison of temperature before and after installation of green roof was illustrated in Figure 5.

### Table 3. WQI and SI for runoff samples

| Event | TSS | BOD | COD | DO  | pH | NH₃-N | WQI | Class |
|-------|-----|-----|-----|-----|----|-------|-----|-------|
| 2/5   | 94  | 93  | 70  | 95  | 93 | 89    | 89  | II    |
| 7/5   | 95  | 93  | 80  | 96  | 95 | 95    | 93  | I     |
| 10/5  | 96  | 95  | 80  | 94  | 94 | 91    | 92  | I     |
| 11/5  | 95  | 94  | 75  | 94  | 94 | 90    | 90  | II    |
| 26/6  | 93  | 94  | 75  | 100 | 93 | 84    | 90  | II    |
| Average| 94  | 95  | 80  | 95  | 94 | 90    | 92  | I     |

Figure 5. Reduction of room temperature after installation of green roof

6. Conclusion

Findings show that the performances of extensive green roof system in HTC are promising under local tropical climate. Simulations in design storms and actual storm events indicated that it could reduce the peak discharge relative to impervious brown roof. However, its ability reduced for storms with intense rainfall. The water quality of the outflow produced by the green roof was generally good and achieved high WQI. However, it was a source of PO₄ and basic outflow were noticed producing from the green roof during storms. Substrates of the green roof could be the essential factor in affecting the quality of the outflow. Cooler environment was created inside the green roof building since reduction of indoor temperature was noticed after installation of the green roof system.

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