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Green Roof Retrofit: A Case Study

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Abstract: Retrofitting green roofs on existing buildings efficiently reduces building energy consumption, and variation of indoor temperature. Despite such clear benefits, green roof is not widely practiced, probably due to a number of reasons. Different types of green roofs vary from as simple and thin as 5-cm thick grass covering to as complex as a fully designed park with trees, with weight varying from 15 kg/m^2 to over 350 kg/m^2, and significantly different installation cost. Moreover, the load capacity may be the predominant constraint, and a structural survey may be required to allow the retrofit. In other words, a thorough investigation is needed to examine roof load capacity, identify green roof type, and determine the cost involvement. Therefore, this paper demonstrates a step-wise decision-making process for a green roof retrofit/construction project, through a case study, in terms of accessibility to roof, structural capacity, type of green roof, ease of construction and maintenance and cost involvement, to suit the prevailing conditions of existing building. Within the allowable load capacity and availability in the local market, the study revealed that semi-intensive type of green roof is the cheapest, with installation cost of Brunei \$208/m^2 and monthly maintenance cost of Brunei \$1/m^2, compared to 'modular extensive' and 'intensive' types. The outcomes ae expected to allow policy makers to devise suitable program in Brunei for undertaking green roof retrofit projects to improve energy performances of existing buildings. Although the outcomes cannot be generalized elsewhere, the methodology developed can be applied for investigating specific cases under certain condition and targeting suitable solutions.

Keywords: Brunei Darussalam, case study, green roof, existing building, retrofit, structural capacity

1. Introduction

Many studies suggest that buildings are liable for almost half of global energy consumption and CO_2/GHG emissions [1-2]. Existing buildings are responsible for this to a great extent, since about their 95% consume high amount of energy [3]. It is also argued that operation/occupancy stage consume over 80% of building life-cycle energy [4]. Therefore, achieving energy efficiency in existing buildings is very important. This is argued to be achieved by equipping the old/existing buildings with sustainable, modern and energy-saving/efficient features, which can considerably improve environmental performance and energy profile of old/existing buildings [5-6]. According to USGBC [7], it can reduce about 35% of GHG emission compared to conventional old buildings.

Retrofitting/constructing green roofs on existing buildings is one such sustainable and environment friendly practice. Roofs are the largest building areas exposed to the sun, and they account for about 20–25% of urban surface

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areas [8]. Green roof can be adapted to existing buildings with no extra construction, except for the green roof itself [9]. Green roof absorbs heat, reduces heat island effect and keeps building interior cooler [10-11]. Green roof reduces variation of indoor air temperature and building energy consumption [12-13], as well as energy cost/bill up to 48% [14]. Green roof reduces heat fluxes [15], acts as fire protection [11, 16], retains storm water [8], increases sound insulation [17], and improves air quality [16] and ecosystem [18].

Due to such wider benefits, green roof retrofitting seems to be gaining popularity globally. However, a recent study showed that such greening of old/existing buildings in general, and retrofitting green roofs in particular, is not being widely adopted in Brunei, despite high awareness of construction professionals to the approach, and government initiatives [19]. It was therefore felt the need to demonstrate the process of green roof retrofitting and disseminate the outcomes to motivate public to adopt greening existing buildings in general, and retrofitting green roofs in particular, especially on buildings with flat roof, e.g. multi-story residential and office buildings. As such, this paper attempts to demonstrate the process of assessing an old building and selecting the cost-effective green roof type through a case study. The next section introduces green roof, before presenting the case study.

2. Green Roof

The basic idea of green roof is to vegetate building roof tops with various plants or vegetation. The concept is used to get many environmental, economic and social benefits. Green roofs are also known as vegetated roofs, cool roofs, roof garden, eco roofs and living roofs [8-9, 20]. The idea emerged since ancient times, dating back to as early as 500 BC, around when the Hanging Gardens of Babylon were constructed. In order to mitigate the adverse effects of urbanization, people in those days used rooftop gardens to improve insulating capability of roof. However, it was re-invented in modern times in 1960s, when Germany introduced green roofs for reducing building energy consumption to fight their energy crisis [9]. Modern green roofs are much more effective and efficient than those in ancient times, as they are now designed following certain specifications [25]. Green roofs can be constructed/retrofitted on various types of buildings, including residential, commercial and industrial buildings [8], as well as roof types, such as timber frame structure and block work structure [9, 26]. Green roofs can be constructed on new buildings, as well as on existing buildings. Green roofs on new buildings can be properly designed for relevant dead-loads. On the other hand, additional dead-load is the main concern for retrofitting green roof on existing buildings, as it can potentially lead to structure failure [26]. Green roof retrofitting is argued to be more cost-effective than constructing in newly buildings, since most of the existing buildings are not properly insulated, as they were constructed before enforcement of energy consumption regulations and the 'greening' concept had emerged [9, 26-27].

Green roofs can be constructed/retrofitted on flat roofs, vertical walls, as well as pitched or sloped roofs [27]. Vertically vegetated walls are known as living walls or green walls. For sloped green roof, the pitch should be more than 10^0 [28], and usually not exceeding 30^0, but can be even up to 45^0 for small individual houses [9, 29]. Sloped green roofs allow easier, faster and effective drainage, so less likely to suffer water penetration, but they can slip or erode due to over irrigation or heavy rain, as they are usually not supported by parapet walls or similar structures. So, relevant confinement or anchoring system plays a very critical role, especially when the slope is too steep [29]. Green roof on flat roofs are usually supported by parapet walls, and are designed with a minimum of 1-2% slope, along with more complex drainage system [28-29].

Green roof is typically made up of a number of layers. and they include: (1) vegetation/plant layer or the outer layer that is seen from the top, (2) substrate layer or growth medium like soil but may be a combination of organic and inorganic materials, (3) filter layer or membrane that separates the growth medium from other lower layers, (4) drainage layer/material that helps to remove excess water from substrate, (5) protection layer and anti-root barrier that prevents plant/vegetation roots from coming out of the green roof structure, (6) insulation is the penultimate layer that extracts temperature from cool air in summer and heat in winter to allow increased thermal comfort, and (7) water proofing layer/membrane that allows avoidance of water leakage on roof slabs [8-9, 20-21, 30]. Each component/layer plays an important role and their proper selection is critical to obtain the best results [22]. However, design of green roof depends on various criteria, such as underlying climate (e.g. arid, semi-arid, dry and semi-arid, hot and rainy and so on), location (e.g. north hemisphere, south hemisphere or on tropic), ambient environment (desert area, village area, urban area, and so on), building condition (old/existing, new, high rise, low-rise, and so on), and roof structure (e.g. flat or pitched), among others. As such, not each and every layer is used in all green roofs, and not different layers with equal or similar depth, instead green roof can be as thin as 5cm grass/ground covering or as thick as several meters and complex like a fully designed park complete with trees [9]. Although literature suggests various kinds of classification, green roofs are broadly classified into intensive, extensive and semi-intensive category, based on their overall thickness that depends on the thickness of substrate layer, and again they can be continuous and modular type [20].

Intensive green roofs are the thickest with their thicker substrate layer that varies from 20cm to 200cm but usually more than 30cm, whereas extensive green roofs are much thinner and vary from 5cm to 20cm [8-9, 31]. Increased thickness of this category allows planting various shrubs and small trees/plants with relatively deeper roots, which come with greater weight/load and high capital cost, and involves high maintenance cost [8-9, 31]. They are usually of continuous type and require in-situ construction. New buildings are therefore suitable to construct intensive green roofs, where extra load from increased thickness can be considered while designing the building structures [32] Due to the increased load and the need for frequent maintenance, intensive green roofs are not considered suitable for old/existing buildings.

Much thinner extensive green roofs of 5cm-20cm thickness, on the contrary, are considered suitable for retrofitting old/existing buildings that are featured with thinner substrate layer of up to 15cm, much lower weight, minimal maintenance, low capital cost and usually within the limit of structural ability, so requires no extra structural support [20, 33]. Extensive green roofs can be single- or multi-course extensive type. Single-course extensive green roofs allow small vegetation only, like sedum or grass, with substrate thickness of 7.5cm–10cm [9]. They usually do not need irrigation, and involve very small construction and maintenance costs, in comparison to other types [9, 33-34]. Multi-course extensive roofs, on the other hand, consist of 10-15 cm substrate thickness. These are usually light weight and are able to accommodate only a few types of vegetation, like grasses, moss and succulents [9, 34].

Substrate thickness of semi-intensive type of green roof is in between intensive and extensive types [9]. They allow grasses, groundcovers, small shrubs and small herbaceous plants, but need frequent maintenance and high capital/initial costs for better performance [8-9]. Among all these types, 'lightweight green roofs', i.e. extensive green roofs, are commonly used for retrofitting old/existing buildings around the globe, with a lesser degree of semi-intensive green roofs, for their relatively less weight, considering load bearing restrictions of buildings/roofs, costs and maintenance, as well as for not requiring irrigation [9, 20]. Green roofs are more effective when designed and 'build up' (/construct) to suit specific requirements. Nevertheless, various modified types of green roofs are commercially available in many countries, or as offered by many commercial organizations, with slightly different names, especially for semi-intensive and extensive category, which can be used readily on roofs [9, 20, 26, 29-34].

However, cost of green roof to be installed may vary significantly, since it depends on the type of the green roof selected. Cost of construction, maintenance and irrigation requirements are different for different types. It therefore requires examining the suitability of the type of green roofs from the perspectives of cost. Moreover, load bearing capacity of existing building/roof is the key issue for green roof retrofitting [9, 23]. Many relatively older buildings with reinforced concrete roofs may have some more reserve capacity than newer buildings, since newer buildings are outcomes of modern design, sophisticated analysis, and more effective construction methods, and they display improved structural efficiency [24]. Nevertheless, the 'reserve capacity' may not be sufficient for the selected green roof. Moreover, many existing buildings of even 10-15 years old may not have as-built drawings. A structural survey is therefore necessary for determining load capacity of existing roof/building, before designing the green roof retrofit. Furthermore, the dead load of the green roof itself should be counted when deciding the potential for retrofit [23-24]. The following section presents the case study demonstrating the analysis of the bearing capacity requirements, and eventual cost-effective selection of the green roof for a building in Brunei Darussalam.

3. The Case Study

A specialized school building of two-story with flat reinforced concrete roof at two levels was considered suitable for the case study. The building is a relatively new one, which was built in 2014, and relevant specifications/drawings and the original structural designer were available and accessible. Moreover, it had reasonably large roof top area of 290m^2 for the lower roof slab and 314m^2 for the upper roof slab. Information was collected through multiple means, e.g. for the building, (i) by paying a number of visits to the site, (ii) by consulting the drawings/ specifications, and (iii) by discussing the designer. A specialist supplier, who has constructed almost all the green roofs in Brunei up to the time of collecting data, was consulted for information on (i) availability of different green roof types in local market, and their (ii) construction and (iii) maintenance costs. Calculation was done by one of the authors, which was checked and confirmed by the designer.

According to the structural designer of the building, the roof slab can carry about 20KN/m^2. It was initially designed for chillers, but the area was unused during construction due to variations of the air-conditioning system. Since consultant confirmed about the strength, the roof was initially considered suitable and strong enough to carry additional loads of green roofs. For the purposes of demonstration, however, it was decided to examine the suitability of retrofitting/constructing green roof on this structure, in terms of the followings:

a) Examining the accessability to roof, for construction and post-construction maintencance, including the availability of suffucient roof sapce.
b) Evaluating the structural capacity of the building for loading due to extra weight for different types of green roof on the roof top, with the target of identifying the most workable solution.
c) Analysis of different types of green roofs to know which type is suitable to install. This step has direct relevance to the previous one. Installing extensive green roof can only allow ecological benefit, but intensive green roof can provide more substantial benefits like public spaces and allow more plants species. Cost of green roof also plays significant role for choosing the best option.

3.1 Roof Access and Available Roof Space

Access to roof is necessary not only for construction of green roofs, but also for post-construction maintenance purposes. Existing buildings usually use extensive green roofs [9, 20, 33], which also require maintenance, although minimal, for clearing gutters and removing 'weeds' [9, 33-34]. Therefore, ease of access to all types of green roofs is expected. It was found that roof access to first floor level was designed for the maintenance of the originally planned chillers. Two staircases allow quite convenient access to the first-floor level of the building, which can be used both by the construction and maintenance purposes. The roof is located above the lecture theatre and classroom. During leisure or breaks between different sessions, students can also easily access to green roof for relaxation using either staircase. For the upper roof slab, however, there is no existing or permanent access to roof. For the purposes of construction and maintenance, access to the upper roof slab needed to be provided by using a temporary ladder or constructing a permanent staircase. For safety reasons, it was decided that access to upper roof slab should be restricted only to construction and maintenance workers. Therefore, a temporary ladder type stair, built with frame of steel pipes, was used for access.

The area identified for green roof is quite spacious, with about 290m^2 on the lower roof slab and about 314m^2 for the upper roof slab. As mentioned above, the space was initially designed for chillers, but eventually was left as redundant. The roof area was clear from any mechanical and electrical plants, water tanks and any other equipment. The area looked safe for green roof, with walls on one side and 1.2m wide concrete gutter on other side, which surrounds the roof of the building. The concrete gutter could also allow adequate space for green roof but it looked unsafe, as green roof will attract people like a normal garden, where the height of the parapet wall with 230mm was not designed for students to relax and walk around. A fence could be constructed for safety, but underneath of the gutter is an open space, so green roof on top of the concrete gutter would not benefit that much to the building. It was therefore decided not to include the space of the gutters.

There are eleven and eight numbers of 100mm rainwater PVC downpipes for the lower roof slab and upper roof slab, respectively. This was more than the design standard followed (i.e. UK design standard). Rain water is allowed to flow down a gentle slope on the roof surface into the 250mm scupper drain, which discharges into the adequately spaced PVC downpipes.

3.2 Structural Capacity

As presented in Table 1, summarized results from structural analysis show that the existing reinforcement is adequate to carry the trial loads of green roof. An examination of documents revealed 200mm thickness of roof slab, of grade 30 reinforced concrete, and with T10 steel reinforcement both at top and bottom spaced 100mm apart. A worst-case slab span of 5.3m square was considered. Amount of steel (As) in the slab was found to be 524mm^2. In addition to slab weight and an imposed load of 4.5KN/m^2, two trial loads from green roof (saturated) were considered for the purposes of analysis, on the basis of locally used types of green roofs:

- Trial 1 (modular or built up extensive green roof) = 120kg/m^2 = 1.2KN/m^2, and
- Trial 2 (intensive green roof) = 500kg/m^2 = 5KN/m^2

Table 1 - Results from structural capacity analysis

Load consideration	Trial 1	Trial 2
Reinforcement required: top bar (continuous edge)	$309.61mm^2$	$415.13mm^2$
Reinforcement required: bottom bar (mid span)	$237.02mm^2$	$318mm^2$
Existing reinforcement	$524mm^2$	$524mm^2$
Comment	OK	OK

3.3 Green Roof Options

Three types of green roofs were available in local market/industry during the retrofit case, and all three types were considered for the proposed retrofit: Option 1: built-up intensive, Option2: built-up extensive and Option 3: modular extensive green roofs. Built-up Intensive Green Roof (Figure 1) or simply 'intensive' green roof of continuous type, as suggested by literature, which typically consists of a number of layers of materials for protecting the existing structure and providing proper drainage system [8-9, 20, 31]. These include a thick water proofing layer, sub-soil drainage module, a filter fabric to separate fine materials from coarse sand bed to avoid blockage, and requires thicker planting bed for trees, which uses, typically, a 300mm minimum thick growing medium.

Built-up Extensive Green Roof (Figure 2) typically uses multiple layers of materials, which are similar to that of 'built-up intensive' (or simply, 'intensive') green roof', for protecting the existing structure and providing proper drainage system. However, unlike the intensive green roof, this type requires thinner planting bed sufficient for grass, shrubs and herbs. Therefore, typically, a 75mm minimum thick planting bed of lightweight growing medium is used. In effect, it is 'semi-intensive' continuous green roof, as suggested by literature [9, 20, 33-34].

Modular Extensive Green Roofs (i.e. Planter Cell 130, Figure 3) are basically plants in a planter box, which are easily placed and removed. Typically, it consists of the modular tray itself, which is rested on water proofing or root membrane to protect the existing structure. The modular tray is filled with geotextile, growth medium and grass. Layers of materials are for protecting the existing structure and providing proper drainage system. These are therefore, what literature suggests, multi-course modular 'extensive' green roofs [20, 33-34].

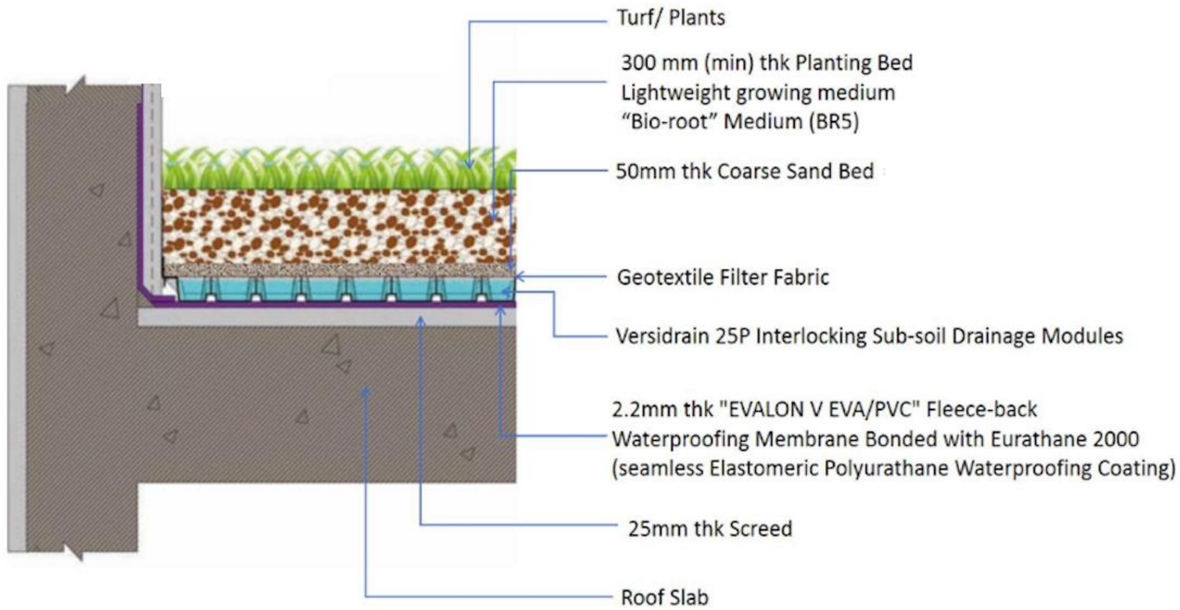

Fig. 1 - Example of built-up intensive green roof

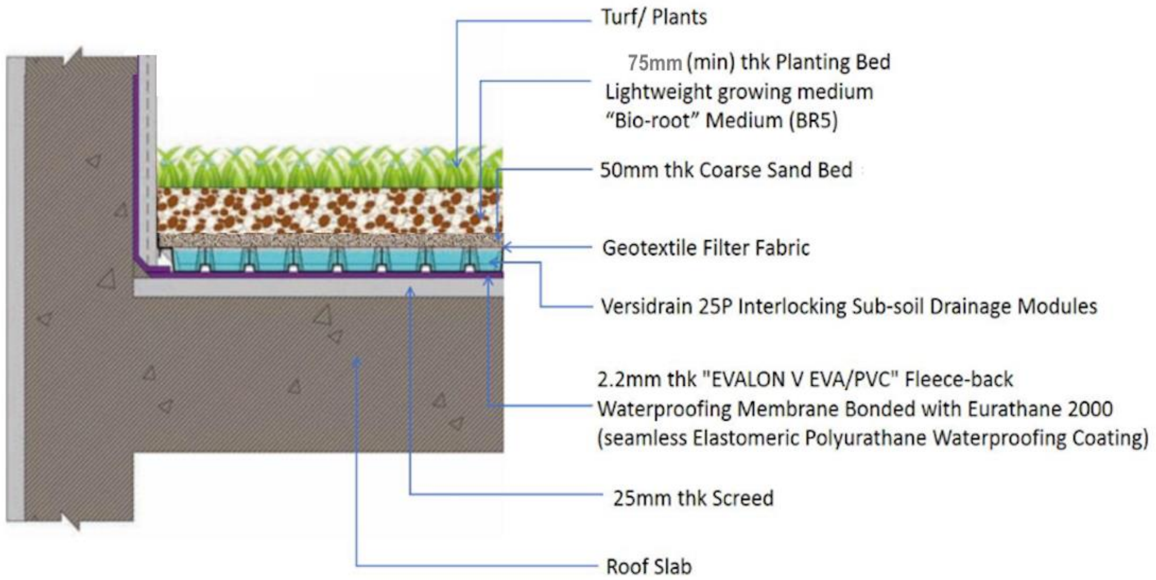

Fig. 2 - Example of built-up extensive green roof

3.4 Construction and Maintenance Cost

For the purposes of demonstration, detailed cost estimates for the lower level roof slab area of 290m^2 was carried out. For each of the three locally available green roofs, total cost was calculated using bills of quantities and the unit rate detailed estimating method. Unit rates of individual elements and/or layers were collected from the local market. On the other hand, the research team relied on the local supplier for the cost of maintenance.

Individual items for constructing/retrofitting with Option 1 (i.e. intensive category) were: (i) waterproofing membrane; (ii) subsoil drainage module; (iii) filter fabric; (iv) coarse sand bed; (v) planting bed or growth medium; (vi) carpet grass; and (vii) additional trees. Detailed specifications and quantities of individual items of works, along with their relevant unit costs, are carefully withheld for confidentiality purposes. Similarly, all the items of Option 1 were used for Option 2 (i.e. semi-intensive category), except the item number (vii), i.e. additional trees. Five items were used for Option 3 (i.e. modular extensive category): the tray, growth medium, carpet grass, water proofing with root resistant membrane, and geotextile. All options had a separate item for labor cost/charges, which varied between the options, as nature and volume of works of different options were different. All these costs were then summed up to get total construction cost for each option.

Fig. 3 - Examples of modular extensive green roof

Maintenance costs were decided using information from two sources. The first source was through consulting the specialist green roof contractor/supplier mentioned above. Secondly, collating the information supplied by the supplier with that of public works departments (PWD) standard rate for similar works. Maintenance works for intensive category was considered comparable to landscaping/maintenance for ground parks under PWD, except for the difficulties associated with height and access of maintenance workers/staffs, which may increase the maintenance cost by 20-60%. However, maintenance costs of green roofs usually reduce with the increase of area to be served. Also, the first 3-4 months involve more caring/maintenance works of green roofs and then the volume of works substantially reduces, as the cover layer or grass is more established. As such, maintenance cost of Option 1 (i.e. intensive category) was considered at the highest end of PWD rates, which lead to roughly \$362/month for the entire 290m^2 area. In case of other two options, no significantly extra/more maintenance works were involved in initial stage, so average rate was considered suitable for the entire period, which lead roughly \$300/month for 290m^2 of green roof.

Table 2 summarizes costs of each of the options. It is seen that Option 1 (i.e. intensive green roof) is the most expensive option, in terms of both construction and maintenance costs. Option 2 (i.e. semi intensive green roof) is the cheapest in terms of construction cost, which is \$60,270.00 for 290m^2 or \$208.00/m^2. It has similar maintenance cost with Option 3 (i.e. modular extensive green roof), of \$300/month for 290m^2 or monthly \$1/m^2, which is also less than the intensive green roof (i.e. Option1). Therefore, Option 2 (i.e. semi-intensive green roof) appears to be the preferred option, with the lowest cost both for construction and maintenance, if cost is the only criterion.

Table 2 - Comparison of construction and maintenance costs

Type of green roof	Construction cost (total)	Maintenance cost (monthly)
Option 1: Intensive Green Roof	\$92,424.00	\$362.00
Option 2: Semi-Intensive Green Roof	\$60,270.00	\$300.00
Option 3: Modular Extensive Green Roof	\$70,089.00	\$300.00

3.5 The Recommendation

The roof has got the adequate access, both for construction and maintenance works. However, the semi-intensive type, or the Option 2, would be easier to construct for its relatively lesser depth and lighter weight. It also involved less maintenance cost than the intensive green roof (i.e. Option 1). Structural analysis showed that the roof can withstand with the load from all the three options. On the whole, the semi-intensive green roof (i.e. Option 2) was seen to be the least expensive to construct and maintain. Therefore, Option 2, or semi intensive type of green roof, was recommended for the retrofit.

This paper is not focused on quantifying reduction of energy consumption and/or CO_2/GHG emission, instead considers significant positive impact on those aspects from green roof retrofit as suggested by literature, and attempt to demonstrate decision making process through a case study. However, it is expected that the green roof retrofit presented here would have contributed to reduced energy consumption and CO_2 emission. Such expectation, or may be acceptance, is driving Europe to increase green roof by 8 km^2 per year [9]. Berardi [35] reported reduction of energy consumption in Toronto from green roof retrofit with annual savings of 10 kWh/m^2. Literature suggests many similar claims by others as well [36-37].

4. Concluding Observations

Although very briefly, this paper has demonstrated a step-by-step procedure of systematically examining and deciding on the type of green roof to be constructed/retrofitted for existing buildings. This included examining the accessibility to the roof for constructing and maintaining the green roof, sufficiency of the available space, availability of rainwater down pipe for drainage of roof top water, structural capacity of the existing roof to see if existing reinforcement is adequate or any strengthening is needed, and the cost of construction and maintenance. Based on the three locally available types, the study identified that commercially known 'built-up extensive' green roof, or 'semi-intensive' green roof as literature suggests, was the preferred one, as cost became the eventual deciding criteria.

The results and recommendation, however, could be different in different settings, e.g. with relatively small or larger roof area, the need to construct access to roof top, the need to strengthen the roof to host green roof retrofit, and the similar. Nevertheless, a procedure has been demonstrated, which can be followed in other cases, both in Brunei and elsewhere, albeit with necessary adjustments, e.g. with the availability of specific types of green roofs in any 'local' market. The study presented, however, did not consider the impact on the thermal condition inside the building and effect on energy bills or carbon emissions resulting from the different types of green roof considered. Such consideration might have led to decide a different option, which is the next item in the agenda of this research.

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