ENGINEERING JOURNAL

Article

Green Roof Retrofitting: Assessment of the Potential for Academic Campus

Yin M. Naing[1,a], **Vilas Nitivattananon**[1,b,*], **and Oleg V. Shipin**[2,c]

1 Asian Institute of Technology, School of Environment, Resources and Development, Urban Environmental Management Program, P.O. Box 4, Klong Luang, Pathumthani 12120, Thailand
2 Asian Institute of Technology, School of Environment, Resources and Development, Environmental Engineering and Management Program, P.O. Box 4, Klong Luang, Pathumthani 12120, Thailand
E-mail: [a]yinmonnaing91@gmail.com, [b]vilasn@ait.asia (Corresponding author), and [c]oshipin@ait.asia

Abstract. Retrofitting becomes the priority action for existing buildings under uncertain economic times and increasing environmental awareness. Before retrofitting, it is necessary to evaluate the potential and feasibility of the buildings to minimize the risks. The challenge is the evaluation with relevant criteria and assessment framework from sustainable perspective. Using Asian Institute of Technology (AIT) campus as study area, this paper aims to assess the potential of existing buildings for green roof retrofitting. Multi-criteria analysis was applied in the potential assessment, where inputs were generated from questionnaires survey, visual inspection and literature records. The potential benefits were identified and estimated through systematic literature reviews and savings calculation. The results revealed that physical factors have the highest influence on the assessment where 47% of buildings in study area were found to be viable for retrofitting while 6% were not viable, and 47% as possibly viable. Free standing, concrete-framed with flat roof and oriented to south buildings appeared to be more preferable for retrofitting. Approximately 2% of annual energy use could be saved from campus-wide retrofitting however mitigation of impacts related to urban heat island and air quality need a micro scale implementation to provide more effective results. The study contributes to the building industry by providing a way to conduct the potential assessment for green roof retrofits in terms of criteria and assessment framework not only at micro scale but also at a wider scale in the regional context.

Keywords: Asian Institute of Technology, existing buildings, green roof retrofitting, multi-criteria analysis, potential assessment.

ENGINEERING JOURNAL Volume 21 Issue 7
Received 26 January 2017
Accepted 9 May 2017
Published 29 December 2017
Online at http://www.engj.org/
DOI:10.4186/ej.2017.21.7.57

DOI:10.4186/ej.2017.21.7.57

1. Introduction

Urbanization draws up development of many construction sites resulting in booming the cities with the modernized buildings. However, more than half of these buildings are constructed in line with conventional designs, usually with resource- intensive life cycles accounting for 40% of energy consumption and 30% of global greenhouse gas (GHG) emissions [1]. Together with long life span, their impacts on humans and environment happen to be long term making building sector a particularly problematic issue in terms of sustainability [2]. It is estimated that GHG emissions from buildings will be increasing to more than double in the next 20 years along with the growth of new construction areas and inefficiency of existing buildings lacking mitigation strategies [1]. On the other hand, buildings have the largest potential among all other sectors with regard to reducing potential emissions, which were estimated to be 30% of the total by 2030 if green technologies can be adapted to the construction of buildings [3].

Until recently, much of the focus of green buildings agenda in the Asia Pacific have been made on new buildings, in compliance with green building codes and certification schemes. However, even with a large quantum of new structures constructed in the region every year, the green portion is only slowly increasing among new buildings and at a much less than the existing ones. In some cities, new buildings represent 1-2% of total stock [4]. Under this context, existing buildings can present a great opportunity to increase the growth rate of green buildings in the region through retrofitting as they represent the largest portion of built environment. Moreover, the majority of the buildings envisaged to be in the market for 30 years are already in existence. Therefore, retrofitting of existing buildings is to be seen as a key priority for both owners and tenants for with regard to efficiency, amenity and resource use especially in the uncertain economic times accompanied by increasing environmental awareness and tightening standards [5].

With its significant benefits, the green roof retrofitting has a certain potential to make a valuable contribution to sustainable development, however the question remains as to how much of the potential existing buildings can offer. The potential may depend on existing conditions, surrounding environment and rules and regulations, etc. Not all existing buildings have the same viability to be retrofitted in order to be environmentally and financially sound. To avoid and/or minimize the risks from retrofitting and have maximum return on investment, a systematic assessment of the potential guided by relevant criteria is required.

In the study done by Wilkinson and Reed (2009), the buildings were assessed only from the physical aspect namely position of building, location, orientation, building height, pitch and weight limitation of building. The selected commercial buildings in the study area were evaluated by the authors themselves and bi-variate analysis was used to identify the buildings which were deemed most likely to support green roofs. In another report (Savyas et al., 2013), the building data were analyzed considering both physical attributes, accessibility and user-friendliness however the authors have not applied an analysis tool to evaluate both criteria and buildings, thereby running into a difficulty of identifying relevance of criteria and viability of buildings for retrofitting. There were only few studies of potential assessment of green roof necessitating a need of systematic framework for assessing the potential (viability) of buildings including relevant assessment criteria.

Thus, the paper aims to assess the potential (viability) of existing buildings for green roof retrofitting through integrated approach in an academic campus, AIT, which is composed of various types of buildings with different functions and ages, with a view to applying it in similar future cases. It aims to address the following research questions by applying multi-criteria analysis approach with three types of criteria: (physical, economic and social): (Q.1) What is the potential of existing buildings with regard to green roofs retrofitting?, and (Q.2) What are the potential impacts of green roof retrofitting to the campus at environmental, economic and social dimensions?

2. Literature Review

2.1. Green Roof

A green roof which is also known as an eco-roof, nature- roof or roof garden is defined as a roof which has significant vegetation on a special light-weight foundation positioned on its surface. It is one of the green building technologies, used as an alternative for typical roof in order to save energy consumption and other resources while bringing numerous other benefits [6]. Green roof system usually comes in three types: (i) complete system where all the components are integrated as a whole system; (ii) modular system where vegetation and other components are placed in the module in advance and can directly be placed on the existing roof; and (iii) pre-cultivated vegetation blanket which has only growing medium and plants [7]. A typical green roof is composed of roof structure, waterproof membrane or vapor control layer, insulation, root barrier to protect the membrane, drainage system, filter cloth, growing medium consisted of inorganic matter, organic material and air and plants [6]. Depending on the type of growing medium and plant materials, green roofs can be categorized into two types: intensive green roof and extensive green roof as shown in Table 1 [8].

Table 1. Characteristic of intensive and extensive green roofs.

Characteristics	Intensive green roof	Extensive green roof
Growing medium	Thick growing medium with minimum thickness of 150 mm	Thin layer of low nutrient substrates of 20 mm to 200 mm
Vegetation	From shrubs to small trees	Drought-tolerant plants (mosses, succulents, wild flowers, grasses)
Maintenance	Greater maintenance is required with regular irrigation and application of fertilizers	Less maintenance is required since there is little or no irrigation and fertilization
Function	Have advantage of opportunity to provide amenity and recreation for public	Disadvantage in providing amenity and recreation for public and more appropriate to biodiversity conservation

Source: [6], [8] and [9].

2.2. Benefits of Green Roof

Green retrofitting, as per United States Green Building Council (USGBC), is defined as any activities involved in upgrading of an existing building, wholly or partially in order to improve its energy efficiency and environmental performance. Most retrofitting processes include improving heating, cooling and lighting system through replacing with new system or structures. Retrofitting a conventional roof with the green roof brings higher economical and functional efficiency to the building itself and less negative effects to the surrounding landscape. Since the rooftop has very same area as the footprint of the building and also similar profile of precipitation and solar radiation, it serves as a useful space that can be turned into a substitute of lost original environmental amenity [10].

A number of studies have shown that the green roof can bring benefits not only with regard to the environmental aspect but also social and economic benefits in long run [9], [11], and [12]. From the environmental aspect, the green roof can contribute to climate change mitigation by reducing energy use [13-16], carbon dioxide and other air pollutants emission [17] and [18] by addressing urban heat island effects issue [9], [18] and [19] and also adaptation by retaining stormwater while reducing the intensity of stormwater flow discharged to ground surface [20] and [21]. Green roof is also recognized for its contribution to conservation and restoration of urban ecology as it provides habitat for insects, birds, etc., while conserving plant species at the same time [22].

In addition to these benefits, green roof has the potential to bring out economic benefits for both users and the public. The users can have expense saving by increasing the durability of building materials, tax reduction, energy saving and increasing property values from green roof installation [9] and [10]. In terms of the public, they can also gain economic benefits by turning environmental benefits such as reducing carbon dioxide emission, air pollutants, and stormwater retention into monetary values [9], [10] and [12]. As for the social benefits, vegetation on the green roof can reduce the stress for humans and outside noise level, resulting in the improvement of human health conditions. Moreover, the green roof has a certain potential to resist fire if it is maintained properly and most importantly, it also provides ample opportunities for food production on recycled in-house wastewater nutrients, while providing dramatically enhanced aesthetic value by softening, greening and improving the cityscape [9].

3. Methodology

The research was conducted with a mix of methods, using literatures for researches of green roof assessment, in-depth interview surveys, experts' opinions and analysis of the survey data. The methodological framework of the study was as follows: (i) study of existing characteristics of the buildings; (ii) analysis of assessment criteria; (iii) potential assessment of existing buildings; and (iv) identification of potential benefits of green roof retrofitting.

3.1. Study Area

The study was conducted in Asian Institute of Technology (AIT) campus, which is established in 1959 as the Southeast Asia Treaty Organization Graduate School of Engineering with a mission to enhance human resources through advanced education to promote sustainable development in the region [23]. After the Great Flood impact on the campus in 2011, AIT endeavoured to envision its strategy to move towards a sustainable campus. The campus is implementing the concept of "3S" which are (i) Safe: to protect both the campus and community from risk and danger, (ii) Secure: to minimize the dangers with the help of local authorities and, (iii) Sustainable: to create a sustainable campus with eco-friendly and resilient buildings [24].

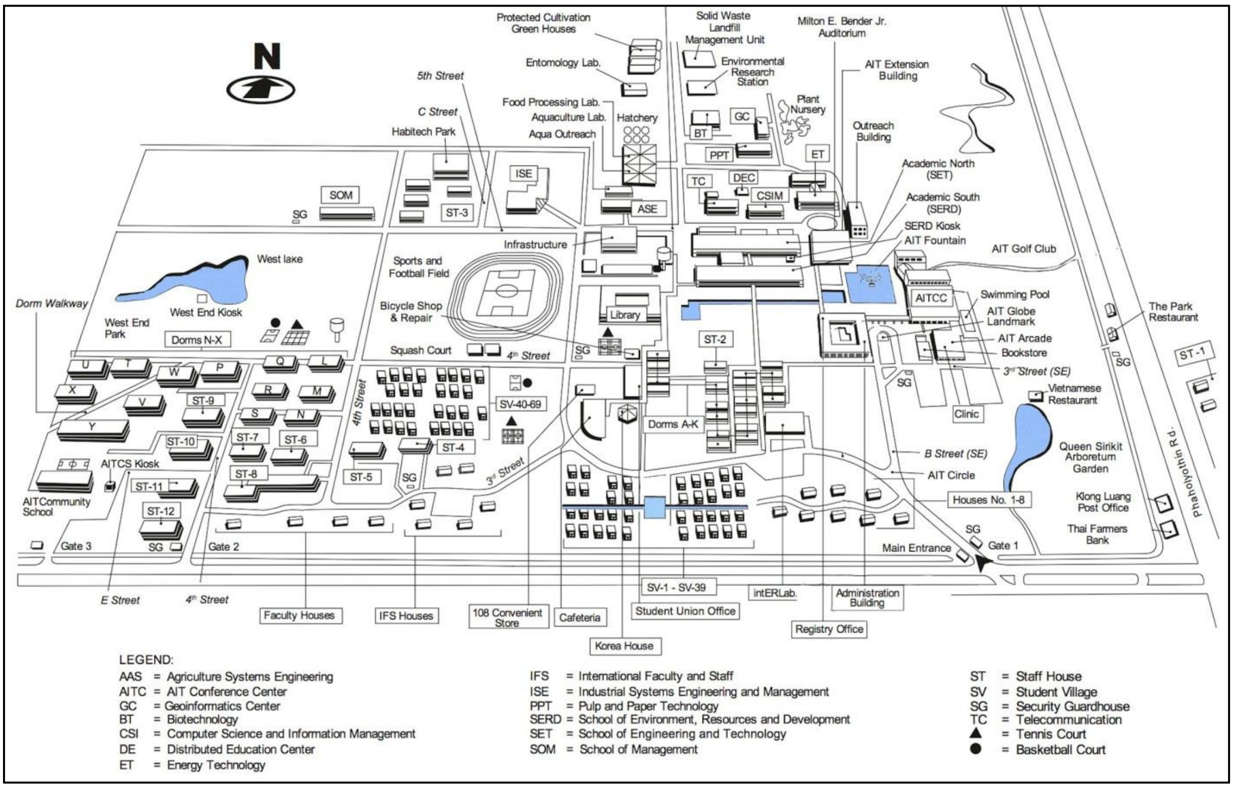
As the campus is located in central part of Thailand, it experiences long warm and hot periods with high rainfall. According to data from Pathumthani Agro-meteorological station, the average temperature ranged from 27 to 31˚C while monthly amount of rainfall varies according to seasons from 17 to 253 mm, with average annual number of rainy days of 113. The study area experiences wind coming from south and east directions with wind speed of less than 5.4 km/hour most of the time. The highest wind speeds during the three study years were within 16.09 and 24.95 km/hour, and these were registered only twice in a year [25].

Fig. 1 shows map of the current campus; besides academic buildings and laboratories, the campus has dormitories, sport and medical facilities and administrative buildings, (118 buildings in total). These buildings consume high portion of energy and water, costing THB 3 to 4 million per month for electrical energy use only, mostly for cooling (air-conditioning), as shown in Fig. 2 [27]. This high energy consumption pattern contradicts to the institute's goal to become a sustainable campus in the region. In this context, retrofitting the conventional roofs with green roofs could reduce high consumption rate. In addition, the average age of the structures was found to be 40 years with the oldest buildings built in 1972 and the most recent few in 2002 [26, 27]. Importantly, the campus houses a mix of different functional types of buildings, so the reported case could be applied in many other locations under a similar scenario. Lastly, conducting this research in campus brings awareness of the students with regard to conducting further creative research and applied efforts on the green roof retrofitting that would be relevant not only to an academic campus but also to a much wider range of urban environment.

3.2. Data Collection and Analysis

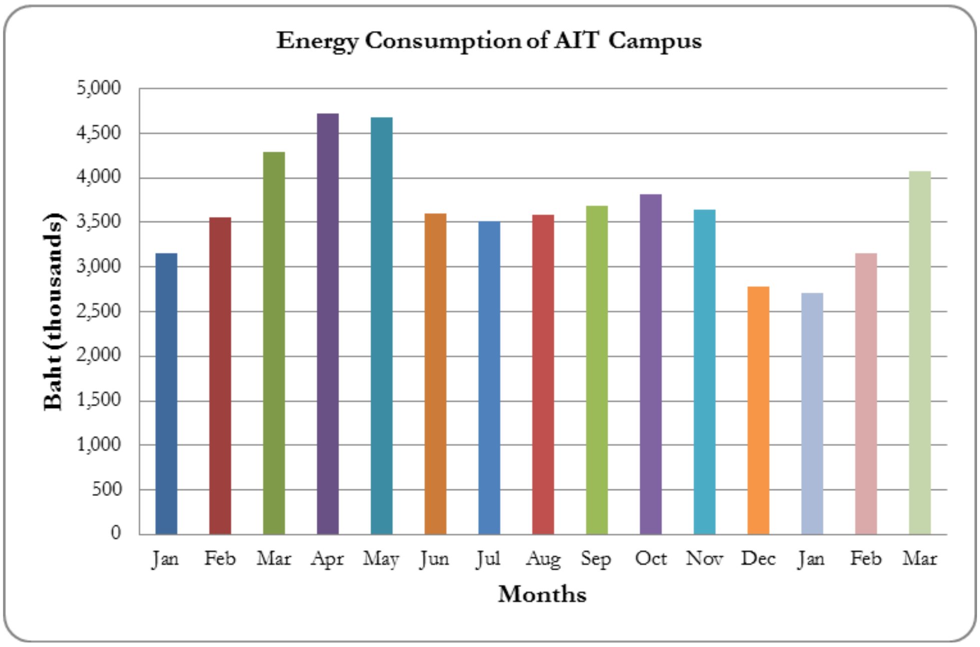
The data collection involved three methods: secondary data collection, in-depth interviews and field observations. Secondary data related to assessment criteria, green roofs' benefits, design details of existing buildings and climatic data of study area were first obtained and reviewed. The criteria were deduced from multiple sources such as relevant published/ unpublished reports, Department of Physical Planning (AIT), The Google Map and Thailand Meteorological Department.

In-depth key-informant interviews were conducted to gather data regarding (i) identification of assessment criteria, (ii) priority setting of the criteria and (iii) evaluation of existing buildings with identified criteria. A total of 30 respondents were included in identification and priority setting of criteria, in which interviewees were from Thai Green Building Institute (TGBI), academicians and experts such as research consultants, architects, surveyors, ecologists who work on green building technologies. Interviews for evaluation of buildings in case study area were mainly focused on those who were familiar with the conditions of existing buildings and there were 30 interviewees included; officers from AIT's Department of Physical Planning and Office of Facilities and Assets Management, research consultants, architects and surveyors who were working on the buildings in AIT. The respondents were selected as per Delphi analysis in line with following steps: (i) identify relevant disciplines and organizations; (ii) identify individuals in relevant disciplines and organizations; (iii) categorize experts and (iv) rank them within each list based on their qualifications [29]. Along with expert interviews, field observation was undertaken to visually inspect the currently existing conditions in study area buildings.



Source: [26].

Fig. 1. Map of study area.



Source: [26].

Fig. 2. Energy consumption of AIT campus between January 2013 and March 2014 (Thai baht to US dollar ratio was 1 USD = 32.91 THB at the time of study).

In this study, Delphi analysis was used to identify the experts and assessment criteria. The criteria collected from literatures were first categorized into three groups: physical, economic and social then expert interviews were conducted to analyze their relevance on the assessment. The questionnaire was in the form of statement where the respondents were asked to reply in two forms "Agree or Disagree" and an open questions were used to add new criteria if necessary. The analysis was done until all the respondents agreed on the criteria.

The potential evaluation of existing buildings for retrofitting was done by using multi-criteria analysis (MCA) and in this study, MCA followed the approach of Analytic Hierarchy Process (AHP) which generally consisted of three steps. The steps were as follows: (i) priority setting of the criteria (weight), (ii) evaluating the buildings with each criterion (score) and (iii) obtaining an overall relative score for each building [30]. Priority setting of the criteria was done by the respondents assigning a weight between 1 (equal importance) and 9 (extreme importance) to the more important criterion, whereas the reciprocal of this value was assigned to the other criterion in the pair. The same applied to the evaluation (scoring) of the buildings where the sample questions in survey were as follows. For each pair of criteria, the respondents were required to respond to the question: "How important is criterion A relative to criterion B?"

P1	9	7	5	3	1	3	5	7	9	P2
P1	9	7	5	3	1	3	5	7	9	P3

For evaluation of each building within each criterion, the buildings were compared pair wisely and were given a value on the scale of 1 (equally good) to 9 (absolutely better) based on their conditions as to the criteria. Each score recorded, "How well does each building meet each criterion?"

I. Physical criterion, P1

B1	9	7	5	3	1	3	5	7	9	B2
B1	9	7	5	3	1	3	5	7	9	B3

The overall relative score for each building was produced by multiplying the score of each building on criteria with the respective weight of criterion. Based on the relative scores, the potential of the buildings were determined in terms of three options: a viable option; not viable option and possibly viable option.

In order to identify the potential benefits from retrofitting existing roofs as the green, conceptual design was first developed. Due to the limited data on structural system of existing buildings, extensive green roof was proposed and designed to be simple to build and easy to replicate with low maintenance cost. In this study, the conceptual design was based on that of the American Hydrotech's extensive garden roof due to its simple construction techniques. The materials were selected based on the existing conditions of potential buildings in study area with the reference to design guidelines of green roof. It included 75 mm thick growing media where the soil was a mix of blended 55% Stalite expanded slate, 30% USGA sand and 15% of organic matter composed of worm castings. Below growing media were WSF40 roof protection sheet, SSM 45 moisture retention mat, synthetic drainage panel, geotextile filter sheet and 1.5 mm thick waterproofing membrane which were laid out respectively. For plant materials, creeping sedums were selected as they are drought tolerant thus required low maintenance and shallow growing media. However, it should be noted that the quantities of specific benefits were estimated based on cases that were similar to developed conceptual design as there was no test plot to get the actual data.

Data from questionnaire survey of pairwise comparison of criteria and buildings were computed by applying AHP priority calculator of BPMS. The criterion which had the consistency ratio (CR) of less than 1.00 was considered as valid criterion and could be applied for the potential assessment of existing building for green roof retrofit. AHP priority calculator is the part of BPMSG's free web-based AHP online software, AHP-OS. Based on the concept of Saaty, it can be used for translating individual opinions into numbers and calculate weight and score for a set of criteria and options based on pairwise comparison using AHP with Eigen vector method [31]. The annual energy performance of the existing building with green roof was estimated by using the Energy Saving Calculator (version 2) formulated by Portland State University. Inputs included typical weather data of the study site, total roof area, percentage of green roof cover, growing media depth, leaf area index of plants and utility rates in the case for estimating energy cost savings [32]. Runoff calculator, developed by Hydrotech was used in estimating the amount of stormwater runoff from green roof. Data such as total green roof area, rainfall, depth and weight of growing media, moisture retention fabric and numbers and size of drainage pipe were required to process the calculation.

4. Results and Findings

4.1. Study of Existing Buildings

Site composition: The total area of the campus was 155,398.76 m^2 wide where accommodation took most of the campus land area of 70,007.04 m^2, followed by academic buildings of 12,145.45 m^2. The buildings were categorized into three groups based on their functions namely (i) Academic and research buildings where SERD, SET, SOM, ASE, ISE, CSIM, TC, Energy, LC, and Library; (ii) Administration and facility buildings which were AIT Conference Center (CC), Administraton building, Assets Management office, Arcade, Facility building, and (iii) Residential buildings which consisted of multi-storied dorms, single unit dorms, staff dorms, faculty houses. The buildings were appeared to be clustered based on their function types in free standing position where the distance between each other ranged from 3-4 m. This led to an easier adoption of green roofs to the existing structures with low disturbance to neighbouring buildings. Large machinery and vehicles were not allowed to enter the path within dormitories and accommodation structures, making the accessibility of machineries and materials to rooftop limited in the case of Multi-storied dormitory Types 1, 2 and 5.

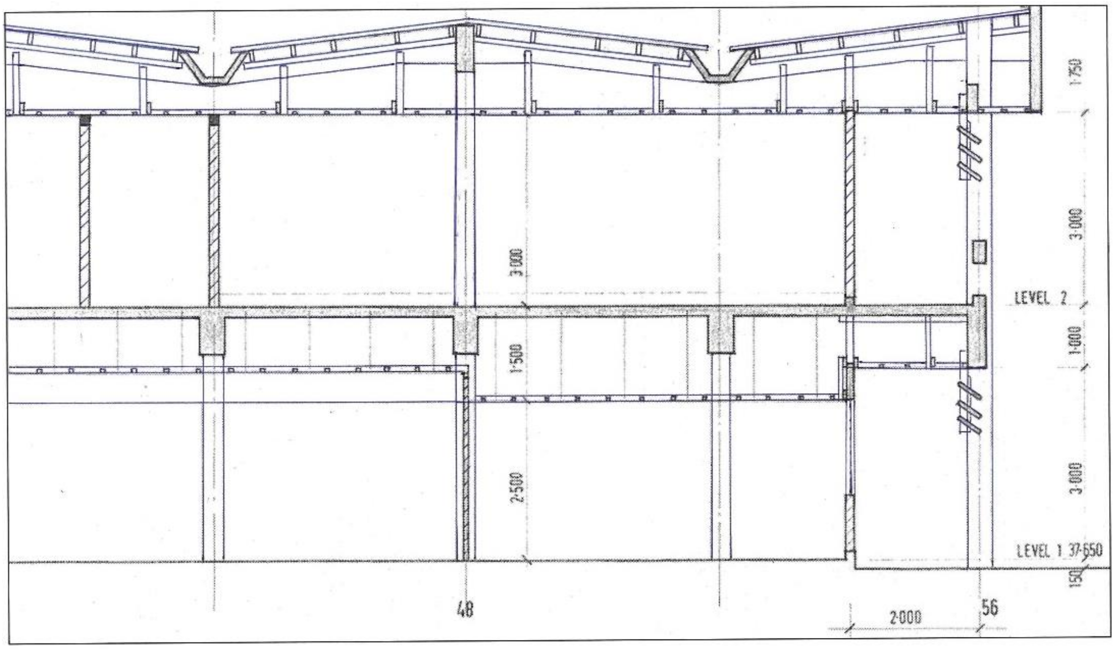
Orientation: It determines the aspect of solar and wind access. All the buildings were constructed along east-west axis allowing the structures to have the best solar access and wind access. The single unit dormitories and faculty houses were found to be North-oriented while the other buildings such as multi-storied dormitories, staff houses, administration building and academic buildings (SERD and SET) were North-South oriented. The ISE and Assets management office were facing towards South-East and the rest of the academic and research buildings were oriented to South. In Northern Hemisphere, the buildings facing south have the best solar access during daytime. Sunlight availability also varied depending on the height and distance between neighbouring structures as they could cause over shadowing on the roofs and elevations.

Building height: It influences the availability of sunlight to the roof, the ease of accessibility and public accessibility. The higher the building, the better the accessibility to sunlight but the more challenging is accessibility to services. The structures in the study area appeared to be low rise buildings in which had a maximum of four storeys with the height of 16.5 m, belonged to the Type 5 multi-storied dormitories. All academic and research buildings, administrative building and single unit dormitories were two-storied where the height ranged from 6.5 to 8.75 m, taken 64% of total. 28% were the three-storied buildings which could be found in dormitories and staff house and the rest were single-storied. All the multi-storied buildings had two stair-flights which were 1.5 m wide with no additional service stair-flight bringing disturbance to the tenants during installation.

Structural system: All the structures were reinforced concrete framing (Figs. 3 and 4) which was considered to be the most suitable system for retrofitting. Most of the buildings were 45-54 years old and they were academic buildings, administration buildings, facilities buildings and multi-storied dormitories of Types 1 and 2, and single unit dormitories. Types 3 and 4 dormitories have been built for 15-24 years while those of Type 5 were constructed for 5-14 years before. According to [27] and [28], buildings which had life span of 5-7 years needed minor adaptations while those of 20-25 years old or more required major replacement services. With a higher numbers of buildings with life span of more than 25 years, there would be a larger number of stocks due for updating and adaptation and consideration for the green roof retrofitting.

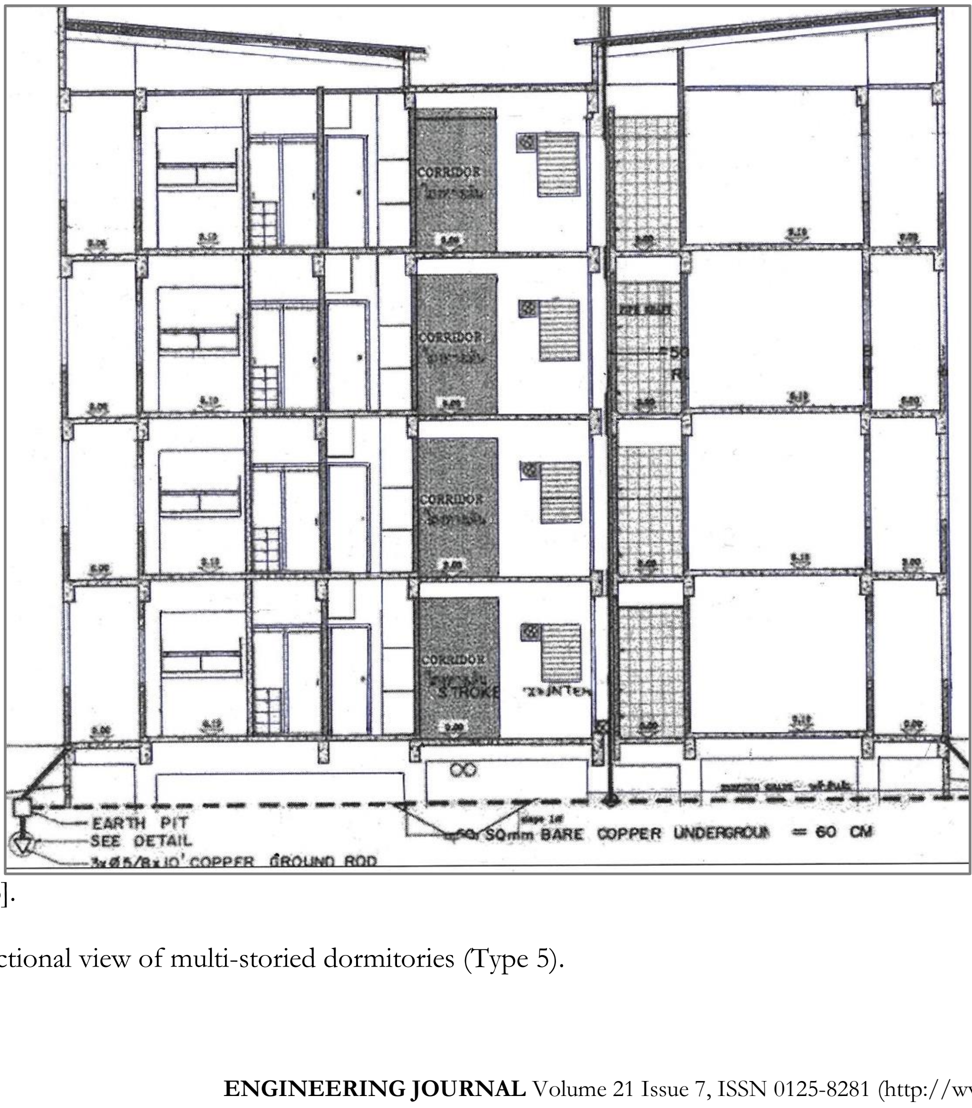
Roofing system: Three types of roofing system were found in the study area: (i) whole reinforced concrete (R.C) slab on AIT CC and the arcade building, (ii) partial RC slab with shed corrugated asbestos tile roofing and (iii) hip roof with corrugated asbestos tiles in single unit dormitories and faculty houses (Fig. 5). All rooftops had parapet of 1.5 m high and 10-15 degree pitch which was lower than allowable value for green roof, 30 degrees. However, pitch roof required more works than flat roof as it needed to deal with sheer forces, water retention for plants and run-off and additional installations to prevent sloping such as plant anchors. Outlet drain system was built into the roof and it appeared that there was no structural problem in the roofing system of all ages. However, the first group - Residential units had low water proofing in ceilings which had occasional water leakage during rainy season.

DOI:10.4186/ej.2017.21.7.57



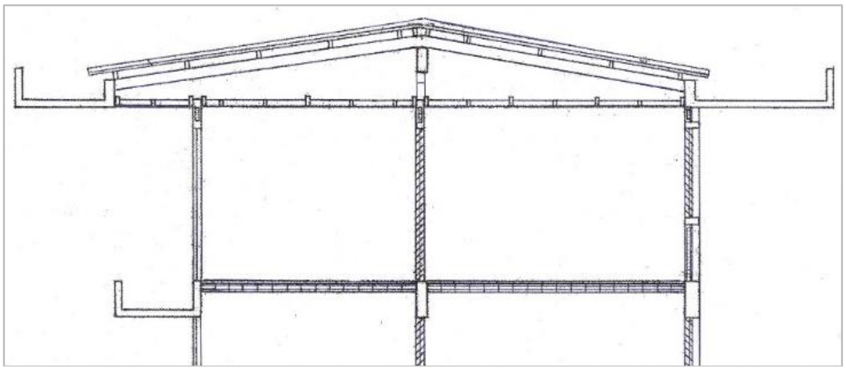
Source: [26].

Fig. 3. Sectional view of academic buildings (SERD and SET).



Source: [26].

Fig. 4. Sectional view of multi-storied dormitories (Type 5).



Source: [26].

Fig. 5. Sectional view of single unit dormitories.

As the buildings in the study area had similar characteristics and design features namely building elevations, orientations, roofing type, and structural system, those which had similar traits were combined into 15 samples as shown in Table 2; the list of buildings that were involved in the potential assessment for green roof retrofitting after compiling.

Table 2. Buildings involved in the assessment.

Categories of Building	Buildings	Code
Academic	SERD and SET	B1
	SOM	B2
	CSIM, TC and ASE buildings	B3
	Energy building	B4
	ISE building	B5
	Library and Language centre	B6
	Extension building	B7
Administration and Facility	Administrative building	B8
	AIT conference centre	B9
	Arcade	B10
	Facilities building	B11
Residential	Multi-storied dorms (T1 and T2)	B12
	Multi-storied dorms (T3, T4 and staff)	B13
	Multi-storied dorms (T5)	B14
	Single unit dorms and faculty houses	B15

4.2. Analysis of Assessment Criteria

The criteria for assessing the existing buildings were identified based on both strategic as well as technical understanding of the drivers and benefits of green roofs. Three categories of criteria were considered such as physical criteria (design specifications and properties of buildings, seasonal impacts to the buildings and safety consideration), economic criteria (ease of accessibility and opportunities to minimize the costs) and social criteria (opportunities on user friendliness of the system). The criteria derived from analysis are shown in Table 3. These were taken into account when determining whether a roof was suitable for retrofitting. Applying Delphi analysis, the criteria collected from literature reviews was analysed by two rounds of iteration, resulting three criteria be excluded from the list and two criteria be added. In this study, criterion which had 60% or more disagreements were taken as unsuitable for the assessment.

Criteria, namely 'existing energy uses of buildings' and 'noise concerns' were found to be irrelevant by more than 80% of the respondents as the former criterion served as baseline information and was used for determining the after impact of installing green roof on energy usage while noise could be occurred more or less regularly during construction period. Moreover, the criterion 'consideration of integration of green roof with PV arrays' had less than 30% on agreement since it aimed to assess an additional opportunity that came along with the green roof and it did not focus directly on the potential for the green roof. At the same time, two criteria were added as follows:

- Wind consideration as it was necessary to understand the likely wind load that a green roof would be subjected to so that it could be built to withstand the forces since even average wind speed would greater at height than at ground level. Wind shear at high elevation would also influence temperature and therefore species selection.
- Rainfall and irrigation consideration as it was essential to know the patterns and amounts of rainfall in the area to estimate stormwater discharge, irrigation and material washed away by rainwater. It was important to establish whether rainwater or another water source can be harvested from other areas on site and stored to supply an irrigation system. This would avoid or minimize the need to use potable water for irrigation.

Table 3. Assessment criteria for green roof retrofitting.

Main Criteria	Sub-criteria
Physical criteria	P1: Type of structure and load bearing capacity P2: Water proofing of roofing system P3: Roof slope (max: allowable = 58% slope, min: allowable = 2% slope) P4: Sunlight availability aspect P5: Wind consideration P6: Rainfall and irrigation consideration P7: Height of building P8: Stormwater discharge point of building P9: Safety considerations – presence of parapet and railing on roof P10: Fire risk
Economic criteria	E1: Access to site for cranes and other machinery E2: Access for maintenance E3: Size of usable roof area E4: Access to utilities such as water, electricity, storage spaces, etc. E5: Existing uses of buildings (e.g. commercial, residential, etc.)
Social criteria	S1: Likelihoods that a site would face hurdles in terms of planning and building permit requirements/ restrictions, heritage issues S2: Public accessibility potential S3: Opportunities for food production

4.3. Assessment of the Potential of Existing Buildings by Multi-Criteria Analysis

4.3.1. Prioritization of criteria

In order to identify the importance of criteria (weight), they were compared pair-wise and the questionnaire survey was carried out where the respondents gave their opinions on the scale ranged from 1-9. Based on the survey data of the pair-wise comparison of criteria, AHP priority calculator was used to rank the criteria and test the validity. The consistency ratios for all the criteria were found to be less than 1.00 i.e. the criteria were considered as valid and could be used for evaluating the potential of existing buildings for the green roof retrofitting. Table 4 shows the priority results of assessment criteria in terms of the rank according to their relative weight overall and in each group of respondents.

Among three aspects of criteria, physical category was ranked as the highest priority by all respondents. Overall, economic group of criteria stood at second position, followed by social criteria with priority value of 0.184. This showed that physical aspect was still more important than the other two categories in evaluating the potential of existing buildings for green roof retrofitting. It was also found that both green roof experts and designers provided more priority on economic aspect while academicians paid more attention to social dimension.

Among physical criteria, those which focused on design specifications and properties came first, and followed by seasonal factors and safety factors respectively. Structural system and loading capacity was ranked as the most important criteria as it could affect to both design and structural strength of existing buildings. Following closely were such factors as water proofing, roof slope and building height. Compared to other seasonal considerations, 'availability of sunlight' had a higher priority since it could affect the growth of vegetation especially for tropical climate region. In the context of the safety consideration, fire risk was found to be more important than the presence of parapets or rails on the roofs, since additional support could be added during construction to prevent fall of materials. The ranking of some physical criteria were found to vary in the groups of respondents, however, as could be seen their positions were not very much different, and 'roof slope' was the one with most the variance.

'Access to utilities' and 'access to maintenance' were ranked as the first priority in the economic category with the value of 0.343. It is not surprising from economic perspective that these criteria were easier accessibility that can minimize the running cost in long term leading to economic sustainability. 'Access to machinery and materials to site' was also found to be as a medium level criterion which was the ease of construction, closely associated with time, cost and quality of performance. The 'existing use of building' stood as a low level criterion in economic category which could alter future energy usage, followed by the 'size of usable area'. It appeared that all the respondents had same priority on E1, E2 and E3 and the only differences lied in E3 and E5. Under social category, 'Likelihoods that … heritage issues' and 'public potential accessibility', were paid more attention as they were major social issues for architects and building designers in retrofitting cases.

Table 4. Priority ranking of green roof assessment criteria.

Criteria	Priority value	Priority rank	Priority rank by		
			Expert	Academician	Designer
Physical criteria	0.584	1	1	1	1
P1: Types of structure and loading capacity	0.221	1	1	1	1
P2: Water proofing	0.207	2	2	3	3
P3: Roof slope	0.115	3	3	4	2
P4: Availability of sunlight	0.085	5	5	5	6
P5: Wind considerations	0.055	8	8	8	8
P6: Rainfall and irrigation consideration	0.056	7	7	7	7
P7: Height of building	0.100	4	4	2	4
P8: Stormwater discharge point of building	0.065	6	6	6	5
P9: Safety consideration	0.054	10	9	10	10
P10: Fire risk	0.050	9	10	9	9
Economic criteria	0.232	2	2	3	2
E1: Access to machinery and materials to sites	0.153	3	3	3	3
E2: Access to maintenance	0.343	1	2	1	1
E3: Size of usable roof area	0.075	5	5	4	4
E4: Access to utilities (water, electricity)	0.343	1	1	1	1
E5: Existing use of buildings	0.086	4	4	4	5
Social criteria	0.184	3	3	2	3
S1: Likelihoods	0.405	1	1	2	1
S2: Public potential accessibility	0.405	1	1	1	2
S3: Opportunities for food production	0.191	3	3	3	3

4.3.2. Evaluation of existing buildings

Evaluation of existing buildings was done through pairwise comparisons which meant that all the alternatives (buildings) were evaluated with each other on each criterion. Table 5 presents the value for each building from the assessment, later used in calculating the scores of existing buildings.

As from physical aspect, the buildings were first analysed by their structural system as load bearing capacity could not be considered due to the data availability. It was noted that concrete and steel framings were more likely to be suitable for retrofitting than any other systems to bear the additional load from green roof. In study area, majority of the buildings were constructed in RC system except single unit dormitories and faculty houses which were built with load-bearing brickwork construction. This analysis showed that there was a good potential in terms of structural systems, and only minimum structural changes needed to be undertaken. As for waterproofing, only concrete slab roofs applied liquid waterproof coating while the pitch roofs were constructed conventionally. The respondents provided low values for waterproofing of roofing systems, especially for multi-storeyed dorms T1 and T2 due to occasional water leakage during rainy season. For roof slope, that with 5 to 15 degrees stands the best for green roof and that greater than 30 degrees requires additional support for resistance to slip. In this case, the highest pitch found in the buildings was 15 degree, allowing for the fact that all the structures would be suitable for retrofitting while flat roofs were found to be more preferable. Building height was related to seasonal consideration and accessibility, thus leading to conclusion that three and four storeyed buildings namely B12, B13 and B14 to be less disadvantage than one and two storeyed ones.

Availability of sunlight to roof was determined by orientation (where facing south would expose to most sunlight) and building height. Except buildings with flat roofs (AIT CC and Arcade building), those with pitch roofs which were constructed along east-west axis had only partial exposure to sunlight due to shadowing of the moving sun. At the same time, its adjacent buildings' height could result in shadows over nearest lower buildings due to the sun movements. In the study area, majority of the structures with same height were aligned together except in the case of Type 5 multi- storeyed dormitories. Considering both factors, dormitories had low points on sunlight availability and above them were academic buildings, and administrative buildings respectively. However, this was opposite in the case of fire risk since too much direct sunlight exposure could increase the risk due to drying of plants. This led the respondents to provide high value for buildings with partial solar access such as dormitories and some academic buildings: B2 and B3. As for respondents and previous studies, even lightest green roof (only 27 kg/ m^2) could withstand up to 170 km per hour with wind pressure of 9.6 kPa [33] where the highest wind speed in study area was 16.1 to 24.9 km per hour. In addition, as none of the buildings were high rise, wind (shear) impacts did not need to be considered. Safety factor considered the presence of parapet to reduce the chance of materials falling down from the roof while all the roofing system structures had parapet with the height of 1 to 1.5 m. However, the respondents recommended installing additional barriers for green roof that would be installed on pitch roof.

Table 5. Values of buildings for each assessment criterion.

Criteria	Value of Buildings														
	B1	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**	**B11**	**B12**	**B13**	**B14**	**B15**
P1	0.077	0.077	0.071	0.107	0.085	0.085	0.085	0.086	0.101	0.094	0.049	0.050	0.068	0.095	0.032
P2	0.089	0.089	0.090	0.104	0.106	0.090	0.056	0.100	0.100	0.096	0.032	0.032	0.037	0.048	0.037
P3	0.055	0.055	0.055	0.108	0.055	0.052	0.055	0.074	0.100	0.100	0.055	0.055	0.055	0.055	0.034
P4	0.120	0.112	0.112	0.112	0.116	0.118	0.095	0.112	0.147	0.147	0.034	0.035	0.058	0.036	0.060
P5	0.079	0.042	0.039	0.039	0.039	0.077	0.039	0.039	0.039	0.039	0.075	0.133	0.077	0.077	0.077
P6	0.041	0.080	0.076	0.080	0.080	0.048	0.080	0.080	0.080	0.080	0.041	0.024	0.041	0.041	0.041
P7	0.049	0.049	0.049	0.046	0.049	0.049	0.049	0.049	0.049	0.095	0.095	0.049	0.049	0.030	0.049
P8	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062
P9	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
P10	0.057	0.057	0.057	0.057	0.057	0.057	0.091	0.057	0.125	0.125	0.040	0.029	0.029	0.018	0.040
E1	0.088	0.088	0.088	0.088	0.088	0.048	0.088	0.088	0.069	0.088	0.048	0.033	0.031	0.031	0.031
E2	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.038	0.038	0.024	0.075
E3	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.034
E4	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.087	0.114	0.114	0.064	0.034	0.036	0.036	0.063
E5	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067
S1	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067
S2	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067
S3	0.034	0.043	0.058	0.118	0.064	0.064	0.073	0.032	0.117	0.119	0.041	0.036	0.037	0.097	0.067

Economic criteria evaluated the level of accessibility to utilities and materials during operation and maintenance. The accessibility depends on the height of building, the presence of additional stair flights or service stairs, and the availability of storage spaces and utilities near the site and the proximity of the neighbouring buildings. As all the properties were free- standing, the buildings with presence of service stairs or low rise in case without service stairs and the closer to those utilities were given more potential/ values for retrofitting. Thus, it resulted in the high value for academic, administration and facility buildings. From social aspect, all buildings have same value for the criteria of likelihoods and public potential accessibility and the variance related to the opportunities for urban food production. Opportunities for food production were seen as related to structural capacity of the buildings where RC and steel structures provided more opportunities than in other cases.

Without considering the weight of criteria, it was estimated that administration and facility building group has higher values for each criterion as compared to academic and residential buildings. Among academic buildings, the Energy building, the ISE buildings and CSIM, TC and ASE buildings had higher values than other academic buildings. Moreover, it was found that multi-storied dormitories had lowest value with regard to water proofing and accessibility to operation and maintenance.

4.3.3. Potential of existing buildings

The scores of the existing buildings determined the potential for green roof retrofitting and the higher the scores, the more potential the buildings had. The result was obtained from multiplication of the value for each criterion by the respective weight of that criterion. Considering the weight of criteria, the assessment scores of buildings with regard to economic and social criteria were not much different while the potential was mostly influenced by physical attributes, as shown in Figs 6, 7 and 8. Table 6 presents the scores of the buildings. It was determined that the buildings which had the score of above 20% were "viable" enough to be retrofitted, those between 16-20% were "possibly viable" which may need additional construction for retrofitting while those under 16% were "not viable" to retrofit. It appeared that administration and facility building category had more potential than the academic buildings while residential buildings had the lowest potential. Among 15 types of buildings, Arcade building, AIT CC, the Energy building, ISE and the Administration building had the high potential for retrofitting with green roofs while Types 1 and 2 of multi-storied residential buildings were found not to be suitable for retrofitting due to their existing physical conditions.

Table 6. Ranking of buildings with regards to their potential for the retrofitting.

Rank	Buildings	Scores	Viable or not
1	B10:Arcade	26%	Viable
2	B9: AIT conference centre	25%	Viable
3	B4: Energy	24%	Viable
4	B5: ISE	23%	Viable
5	B8: Administrative building	23%	Viable
6	B3: TC, CSIM and ASE	21%	Viable
6	B6: Library and Language centre	21%	Viable
8	B1: SERD and SET	20%	Possibly Viable
8	B2: SOM	20%	Possibly Viable
8	B7: Extension building	20%	Possibly Viable
11	B11: Facility building	18%	Possibly Viable
12	B14: Multi-storied dorms (T5)	17%	Possibly Viable
12	B15: Single unit dormitory	17%	Possibly Viable
14	B13: Multi-storied dorms (T3 and T4)	16%	Possibly Viable
15	B12: Multi-storied dorms (T1 and T2)	15%	Not Viable

DOI:10.4186/ej.2017.21.7.57

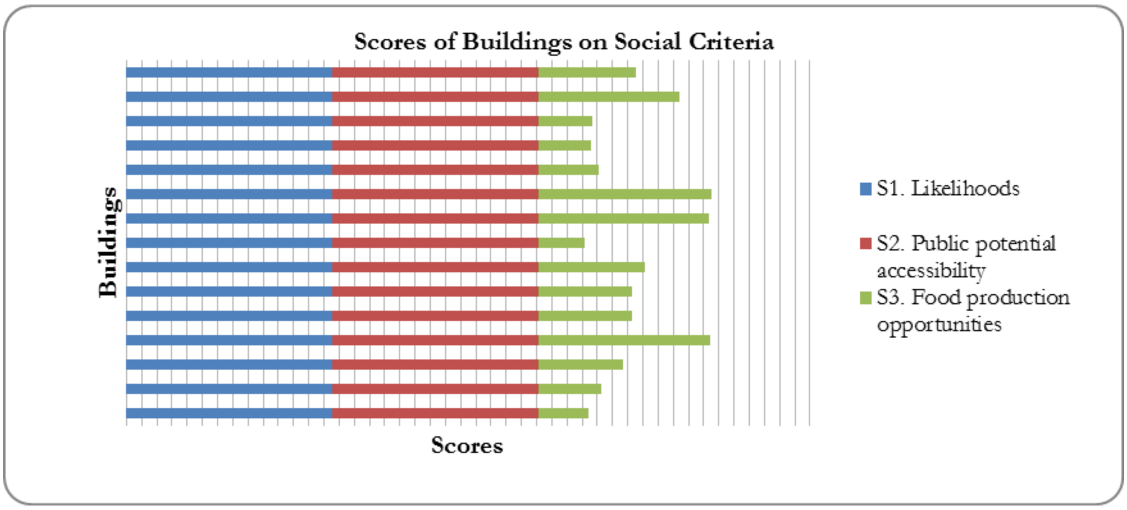


Fig. 6. Scores of buildings with regards to social criteria.

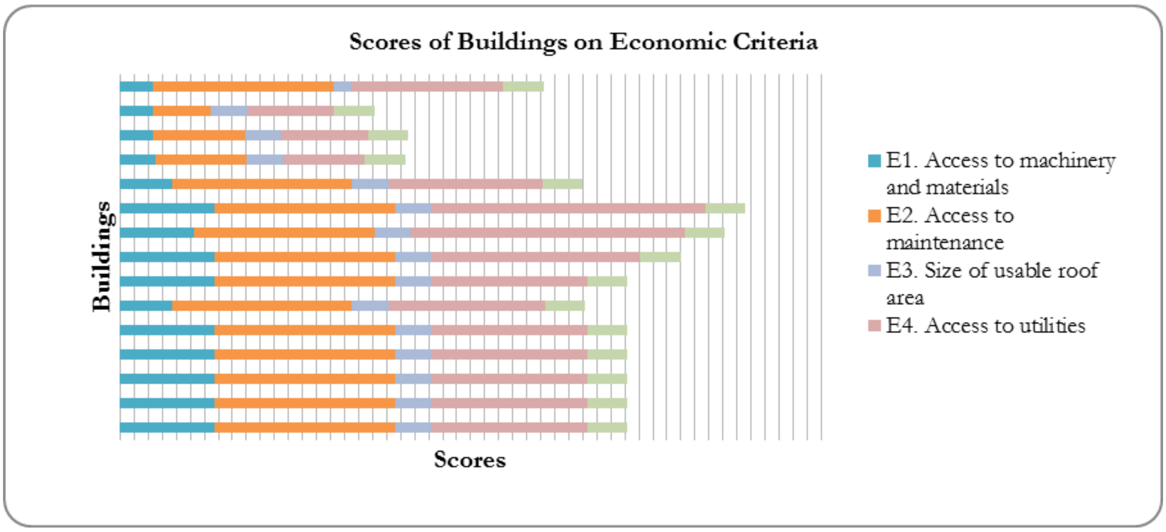


Fig. 7. Scores of buildings with regards to economic criteria.

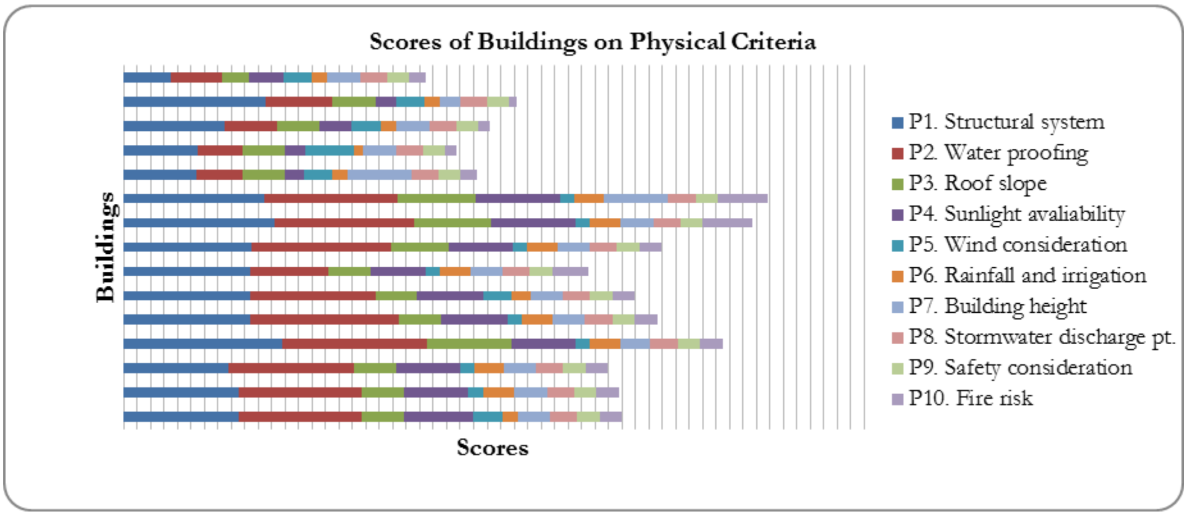


Fig. 8. Scores of buildings with regards to physical criteria.

4.4. Analysis of Potential Green Roof Impacts

In this section, the benefits from green roof were estimated for both individual building and the wider urban environment, as shown in Table 7. The benefits were first identified through reviewing of literature on related cases and those which can be quantified were estimated based on the conceptual design of 'extensive' green roof. The conceptual design was developed from the concept of simple design for easier replication with low installation and maintenance cost by reference to design guidelines. Creeping sedums were selected as they need only shallow growing media leading to low installation cost and also maintenance due to their drought tolerance. The depth of growing media was proposed to be 75 mm thick (approximately 3 inches), a standard thickness for shallow growing media on extensive green roof. The other materials were chosen based on the America Hydrotech's extensive garden roof requirement as it was easy to replicate. It consisted of roof protection sheet, moisture retention mat, drainage panel, geotextile filter sheet, 1.5 mm thick waterproofing membrane and 75 mm thick growing medium, which were laid out respectively. The growing medium was composed of a mixture of slate, sand and organic matter. The benefits in terms of economic were considered conservative estimates where current pricing conditions and values based on the conceptual design on one square meter.

Table 7. Potential benefits of green roofs.

Category	Benefit	Private	Public
Urban heat island (UHI)	It was realized that small scale green roof had less influence to UHI as urban heat island phenomenon is large scale and benefits are more evident only if a large surface of area was greened such as parks, gardens, and large scale of green façade or roof.		✓
Air quality improvement	In this study, it was estimated that 860.63×10^{-3} baht could be saved for one square meter of green roof where NOx emission credit was assumed as 3.375/ kg based on 2005 market value and 1 m^2 of green roof could remove 8.5×10^{-3} kg/m^2 of pollutants. As of the size of campus-wide retrofitting, approximately 136.87 kg of pollutants could be saved which was about 13,859 baht in terms of monetary value. Similar to UHI effect, benefit, the air quality improvement needs a larger scale to have significant impacts on the environment.		✓
Energy saving	This potential benefit contributes to GHG emission as well as being an economic gain to the tenants. In this study, the main energy use was from cooling (air-conditioning) the buildings and was assumed that total annual energy saving for air-conditioning could be reduced at least 2% if extensive green roof was replaced with conventional roof with leaf area index of 1. The results show that a tenant could be able to save approximately 1.5 to 3.9 kWh for 1 m^2 of green roof depending on the coverage and functions of a building.	✓	✓
Stormwater management	Another potential benefit that could be provided to the study area from green roof was that stormwater runoff control affected by reducing flow volume and rate. Rain water was to be absorbed by growing medium and drainage layer or taken by plants while the volume and rate of water runoff to the ground was to be reduced. From this process, not only flood and water pollution could be reduced (environmental benefit) but also size of sewer pipes for stormwater could be reduced, thereby having economic benefit to the owners. In this case, based on the materials used for green roof, it was found out that 80 litres/m^2 of water could be retained with runoff coefficient of 0.95. As there is no regulation (and elsewhere) yet on incentives for retaining stormwater in the study area, economic returns could not be estimated.	✓	✓
Biodiversity	By retrofitting the existing roofs with green roofs, the campus could have the opportunity to maintain and enhance its ecosystem as well as partly fulfil the city vision for conservation of biodiversity.		✓
Construction and maintenance	Vegetation on green roof is able to minimize typical damage from expansion and stresses from extreme temperature changes, reducing the need to replace roofing materials which could lead to a	✓	

Category	Benefit	Private	Public
	considerable economic benefit and environmental benefit. The renovation of roofing would have to be realized in the 35 years as the green lengthens the coating lifetime of typical 15 years [35].		
Property value	Retrofitting existing structures with green roof could have the opportunity to increase the property value due to increasing aesthetic appearance. However, in this study, estimation of the property value was excluded as the study area is an educational institution owned by the public where it was difficult to determine the current market property values.	✓	
Food production	Limited numbers of existing structures such as B9 and B10 had the potential to produce urban food due to the structural capacity supporting the extra medium needed for food growth and extra maintenance needed to grow fruits, vegetables and herbs. Growing foods on green roofs would provide opportunities to enable self-sustenance on the campus.	✓	
Aesthetic	By adopting green roofs to the existing structures, the campus could improve the visual aspect through masking the typical roofs with green and colourful vegetation, contributing to well-being of inhabitants and enhancing property value.	✓	✓
Health	Having vegetation in the surroundings could bring up enhanced sense of well-being to inhabitants by reducing noise annoyance and improving aesthetics which may further lead to reducing stress-related psychological symptoms while at the same time, improving respiratory diseases, lower heart disease rate and blood pressure through better air quality, lower temperature fluctuation in buildings as well as better humidity control.	✓	✓

Green roofs offered environmental, economic and social benefits, ranging from urban heat island (UHI) impact reliefs to amenity benefit for building community. From Table 7, public benefits such as UHI and air quality improvement appeared to have less significance impact on the environment as those impacts were macro scale and needed a greater size of green roof to tackle. It was found that the campus could gain private quantifiable benefits as energy saving, stormwater management, construction and maintenance cost, and yet unquantifiable benefits such as urban food production opportunity, aesthetic and health benefits. In this study, only quantifiable benefits were estimated comparatively through the impacts of buildings with and without green roofs in campus. In the context of campus-wide retrofitting, it was found that energy usage could be reduced at least by 2% which would constitute 62,000 kWh. Note that the structures with the highest potential were proposed to have a full green roof coverage, while those with the lowest potential were ranked for 50% coverage and the rest for 75% coverage. Thus, the total annual estimated energy usage could be reduced to approximately 3,100,000 kWh from 3,250,000 kWh, the total annual estimated energy usage without green roofs. For stormwater, it was estimated that the stormwater volume which could be retained would increase to about 1,272 kiloliters if the campus had installed the extensive green roofs (prior to retrofit less than 37.85 kiloliters). This would bring the campus an economic gain if stormwater utility incentives in future. Compared to conventional roofs, the campus could save replacement or renovation cost for roofing system by replacing it with the green roof in long term. The replacement or renovation would have to be done every 35 years after the process while the conventional roof would need to be renovated every 20 years, resulting in greater maintenance and renovation cost.

5. Conclusions and recommendations

The potential of each building for green roof retrofit was strongly influenced by the physical assessment factors, showing that physical aspect was still the most important in green roof retrofitting assessment compared to social and economic aspects. As per the assessment, 47% of selected buildings were “viable” to retrofit while other 47% which were mostly academic buildings were “possibly viable” and in need of additional installation or repair to the existing structures. The remaining 6% which were multi-storied dormitories Types 1 and 2 were not in suitable condition to be retrofitted with the green roof. Stand-alone concrete framed structures with flat roof and easier accessibility to operation and maintenance were likely to have more potential than the others. From identification of potential benefits, it was found that campus could reduce at least 2% on energy usage, while also able to retain stormwater. Other private (individual) benefits included reduction on maintenance, increased property value, aesthetic, health and food production while public benefits included tackling urban heat island, air quality improvement, stormwater management and potentially, waste management. It appeared that public benefits such as reducing urban heat island effect contributing to climate change mitigation, conserving biodiversity and improving air quality had a relatively small influence to the environment for a single micro scale green roof as those benefits are mainly significant at a macro scale.

The study contributes to the efforts of researchers and property professionals to determine the potential of building stocks for the green roof retrofitting, both at micro and macro scales, in terms of evaluation methodology and assessment criteria as well as of an integrated approach. Also, the study of potential benefits can be used as initial data for studying cost-benefits of green roof retrofitting under the scenario of tropical climate setting. Due to the availability of data, limitations can be found in evaluation of the existing buildings with criterion such as structural capacity, load bearing capacity and estimation of the potential benefits in terms of quantity. It should be noted that the size of participants in this study was limited and did not include other stakeholders such as the policy makers, real estate agents, building owners who may influence the selection of criteria. Future studies should cover alternative materials for green roof design to be more environmental and economic friendly and how to measure the poorly quantifiable benefits of green roof such as biodiversity conservation, aesthetics and health improvement.

Acknowledgement

The authors would like to acknowledge Norwegian Ministry of Foreign Affairs (NMFA) for financial support and Department of Physical Planning, AIT and other related departments and organizations for expert consultations and providing required secondary data.

References

[1] United Nations Environment Programme, UNEP, "Foreword: Building opportunities for tackling climate change," in *Buildings and Climate Change: Summary for Decision-Makers*. Paris, France, 2009, pp. 3.

[2] United Nations Human Settlement Programme , UN Habitats, "Energy is all pervasive," in *Sustainable Urban Energy: A Sourcebook for Asia*. Nairobi, Kenya, 2012, ch. 1, pp. 15-52.

[3] Intergovernmental Panel on Climate Change, IPCC, "Residential and commerical buildings," in *Climate Change 2007: Mitigation*. Cambridge University Press, 2007, ch. 6 , pp. 387-446.

[4] J. Hills, "Retrofitting existing buildings: The low cost, high volume solution to climate change," *Sustainability Asia Pacific*, no. 4, pp. 11-15, 2011.

[5] Building and Construction Authority, BCA, "Introduction," in *Existing Building Retrofit*. Singapore, 2010, p. 6.

[6] S. J. Wilkinson and R. Reed, "Green roof retrofit potential in the central business district," *Journal of Porpoerty Managment*, vol. 25, no. 5, pp. 284-301, 2003.

[7] D. Banting, D. Hitesh, L. James, and M. Paul, "Report on the environmental benefits and costs of green roofing," Ryerson University, Ontario, Canada, 2005.

[8] N. Carroll, "The thermal and rainwater runoff performance of an extensive green roof system," M.S. thesis, Dept. Of Mechanical Engineering, University of Strathclyde Engineering, Glasgow, UK, 2010.

[9] Greater London Authority, "Living roofs and walls," Greater London Authority, London, UK, 2008.

[10] T. Carter and A. Keeler, "Life-cycle cost-benefit analysis of extensive vegetated roof systems," *Journal of Environmental Management*, vol. 87, no. 3, pp. 350-363, 2008.

[11] T. Carter and C. Butler, "Ecological impacts of replacing traditional roofs with green roofs in two urban areas," *Journal of Cities and the Environment*, vol. 1, no. 2, pp. 9-17, 2008.

[12] N. H. Wong, S. F. Tay, R. Wong, C. L. Ong, and A. Sia, "Life cycle cost analysis of rooftop gardens in Singapore," *Journal of Building and Environment*, vol. 38, pp. 499-509, 2003.

[13] N. H. Wong, Y. Chen, C. L. Ong, and A. Sia, "Investigation of thermal benefits of rooftop garden in the tropical environment," *Journal of Building and Environment*, vol. 38, pp. 261-270, 2003.

[14] M. Kohler, M. Schmidt, F. Wilhelm Grimme, M. Laar, V. Lúcia de Assunção Paiva, and S. Tavares, "Green roofs in temperate climates and in the hot-humid tropics—Far beyond the aesthetics," *Journal of Environmental Management and Health*, vol. 13, no. 4, pp. 382-391, 2002.

DOI:10.4186/ej.2017.21.7.57

[15] K. Liu and B. Baskaran, "Thermal performance of green roofs through field evaluation," in *Proceedings of 1st North American Green Roof Conference: Greening Rooftops for Sustainable Communities*, Chicago, 2003, pp. 273-282.
[16] S. Alcazar and B. Bass, "Energy performance of green roofs in a multi storey residential building in Madrid," in *Proceedings of 3rd North American Green Roof Conference: Greening Rooftops for Sustainable Communities*, Washington, DC, 2005.
[17] B. A. Currie and B. Bass, "Estimates of air pollution mitigation with green plants and green roofs using the UFORE model," in *Proceedings of 3rd North American Green Roof Conference: Greening Rooftops for Sustainable Communities*, Washington DC, 2005, pp. 495-411.
[18] S. W. Peck and C. Callaghan, "Greenbacks from green roofs: Forging a new industry in Canada," Canada Mortgage and Housing Corporation, Ottawa, Canada, 1999.
[19] H. Yamada. (2008). *How is Energy Usage Reduced by Green Roof and Wall* [Online]. Avaliable: http://www.g-sky.com/Benefits_EnergySavings_Detailed.aspx [Accessed: 16 July 2014].
[20] S. Afrin, "Green skyscraper: Integration of plants into skyscrapers," M.S. thesis, Dept. Of Urban Planning and Environment, KTH Royal Institiute of Technology, Stockholm, Sweden, 2009.
[21] G. Grant, L. Engleback, and B. Nicholson, "Green roofs: Their existing status and potential for conserving biodiversity in urban areas," *English Nature Research Reports*, vol. 498, pp. 9-59, 2003.
[22] D. Gedge and G. Kada, "Bugs, bees and spiders: Green roof design for rare invertebrates," presented at the *Second Annual Greening Rooftops for Sustainable Communities Conference, Awards and Trade Show*, Portland, Oregon, 2004.
[23] *AIT Now an International Intergovernmenal Organization, as New Charter Comes into Force* [Online]. Avaliable: http://www.ait.ac.th/news-and-events/2012/news/jan/ait-now-an-international-intergovernmental-organization-as-new-charter-comes-into-force#.WMY6K9J97IU [Accessed: 7 March 2017].
[24] *President Moots AIT as a Safe, Secure and Sustainable Campus* [Online]. Avaliable: http://www.ait.ac.th/news-and-events/2012/news/president-moots-ait-as-a-safe-secure-and-sustainable campus#.WMY5ZdJ97I U [Accessed: 7 March 2017].
[25] Thailand Meterological Department. (2008-2013). *Annual Weather Summary* [Online]. Avaliable: https://www.tmd.go.th/en/ [Accessed: 20 October 2013].
[26] Office of Facility and Assest Managment, OFAM, "Blueprints and campus map," AIT, Thailand.
[27] Jones Lang LaSalle, JLL, "From obsolescence to resilience: Creating value through strategic refurbishment and asset management," Melbourne, Australia, 2005.
[28] ARUP, "Existing buildings: Survival strategies," Melbourne, Australia, 2008.
[29] C. Okoliand and S. D. Pawlowski, "The Delphi method as a research tool: an example, design considerations and applications," *Journal of Information and Management*, vol. 42, pp. 15-29, 2004.
[30] T. L. Saaty, "Decision making with the analytic hierarchy process," *Int. Journal of Services Sciences* , vol. 1, no. 1, pp. 83-98 , 2008.
[31] K. D. Goepel, "Implementing the analytic hierarchy process as a standard method for multi-criteria decision making in corporate enterprises—A new AHP Excel template with multiple inputs," in *Proceedings of the International Symposium on the Analytic Hierarchy Process*, Kuala Lumpur, Malaysia, 2013.
[32] Green Roof Energy Calculator v.2.0 [Online]. Avaliable: https://sustainability.asu.edu/urban-climate/green-roof-calculator/ [Accessed: 25-28 Februry 2014].
[33] Next Level Stormwater Management. *Green Roof Stands Up to Near Hurrican Wind* [Online]. Avaliable: http://www.nlsm.ca/xeroflor-green-roof-stands-up-to-near-hurricane-winds/ [Accessed: 20 December 2013].
[34] W. Savyas, B. Russell, and J. Cardy, "Feasibility study of demonstration sites: green roofs, walls and facades," Growing Green Guide, Australia, 2013.
[35] K. Perini and P. Rosasco, "Cost-benefit analysis for green facades and living wall systems," *Journal of Building and Environment*, vol. 70, pp. 110-121, 2013.