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GREEN ROOF AS A TECHNOLOGY TOWARDS SUSTAINABILITY: A PERSPECTIVE OF BENEFITS OFFERED

K.A.L. Dasuni[1], Thanuja Ramachandra[2] and M.N. Zainudeen[3]

ABSTRACT

Green roof is a building envelop embedded concept to compensate the consequences of green losses due to building constructions with its numerous benefits in all environmental, economic and social aspects. But the application of green roofs in Sri Lankan buildings is seemed to be limited due to the deficiency in comprehensive awareness of the benefits of the green roof concept among construction stakeholders. Though the global studies on green roof application are widespread among different green roof types, their results do not indicate any consistency between green roof application and climate. This warrants the current study to investigate the benefits offered by green roofs in the local context. A thorough literature synthesis had initially conducted to review the green roof concept, types of green roofs, and benefits offered. Subsequently, a preliminary investigation was performed to identify the green roofs available in Sri Lanka. Thereafter, the case study strategy was adopted to evaluate the benefits of intensive and semi-intensive green roof types through interviews. The collected data were analysed using manual content analysis. Analysis revealed that both intensive and semi-intensive type offers key benefits such as energy conservation, and stormwater run-off reduction in the Sri Lankan context. In addition, the intensive type offers benefits such as carbon emission control, and absorption of urbanized noise which can be aligned with the main criteria of sustainable sites, energy & atmosphere, and indoor environment quality of green rating systems. Therefore, the study suggests that an adequate recognition to green roof implementation in the green rating systems would enhance the green roof application and thereby contribute to achieving sustainability of buildings in terms of these criteria.

Keywords: *Benefits; Green Roof; Intensive; Semi-intensive.*

1. INTRODUCTION

The world is competing itself due to the rapid technological developments and population growth (Dareeju, et al, 2011). Even though growth and development are considered as unavoidable constraints, actions need to be made to minimize their negative impacts (Clark, et al., 2008). Climatic changes are considered as one of the key negative impacts which could be observed nowadays (Kompas, et al., 2018). Further, authors stated that it

[1] Undergraduate, Department of Building Economics, University of Moratuwa, Sri Lanka, dasunikodi@gmail.com
[2] Senior Lecturer, Department of Building Economics, University of Moratuwa, Sri Lanka, thanujar@uom.lk
[3] Former Senior Lecturer, Department of Building Economics, University of Moratuwa, Sri Lanka, nisazd2014@gmail.com

can affect economies of the countries physical and mental health of the Lack of green space is one of the leading causes of abnormal climatic changes (Hossain, et al., 2019). To this end, green roofing concept introduces a building envelope embedded green element which can be used to increase the green space (Mowla, 2010). A green roof can be considered as a roof area with soil and other layers which has vegetation on its topmost surface (Abass, et al., 2020).

A rapid urbanization can be observed in Tropical Sri Lanka (Halwatura, 2013). A higher rate of converting non-built lands into built lands can be observed in 2000s than 1990s (Subasinghe, et al., 2016). Halwatura (2013) stated green roofs could be a positive solution for forthcoming impacts on both environment and social due to rapid urbanization rates in Sri Lanka.

There are different green roof types as intensive, semi-intensive and extensive based on the soil layer depth and vegetation available (Fernandez-Cañero, et al., 2013). However, their benefits can differ with green roof types (Francis and Jensen, 2017). Furthermore, according to Semaan and Pearce (2016), there is no consistency is observed with the benefits of green roofs with climatic conditions and the location of they installed. Moreover, benefits offered by green roofs are comparable even with the same climatic conditions (Manso, et al., 2021). Hence, findings of global studies on green roofs cannot be adapted as it is for the Sri Lanka context.

To date, only a few studies have examined the different aspects of green roofs in the Sri Lankan buildings. Halwatura (2013) and Dareeju, et al. (2011) investigated the benefits offered by extensive green roof type while Nadeeshani, et al. (2021) assessed the life cycle carbon emission of an intensive green roofs based in Sri Lanka. However, other benefits offered by intensive type were not explored locally. Further, there is less attention given to the semi-intensive green roofs in the studies (Vacek, et al., 2017). This study therefore compares the benefits offered by each green roof type towards recommending the suitability of different green roof types as a sustainable technology.

2. LITERATURE REVIEW

2.1 INTRODUCTION TO GREEN ROOFS

A green roof can be described as a rooftop garden with natural or established vegetation embedded on the top of a soil layer and considered as a good vegetative solution for urbanization that provides value for money (Abass, et al., 2020). Composition of a green roof can vary upon climatic conditions and customer expectations (Bianchini and Hewage, 2012). However, the basic components of a green roof are vegetation, growth medium, filter layer, drainage layer and water proofing (Abass, et al., 2020).

2.2 TYPES OF GREEN ROOFS

According to Fernandez-Cañero, et al. (2013), intensive, semi-intensive and extensive are the three main types of green roofs where intensive type has the thickest growth medium. Further, extensive type can be considered as the modified version of early roof gardens with a thinner growth medium and minimum maintenance requirements while semi-intensive type has intermediate properties and characteristics of both other types (Vacek, et al., 2017) .

Figure 1 elaborates the longitudinal sections of intensive, semi-intensive and extensive green roofs highlighting the different growth medium thicknesses and different vegetation used (Fernandez-Cañero, et al., 2013). Further, Table 1 has tabulated the different features of each green roof type illustrated in Figure 1.

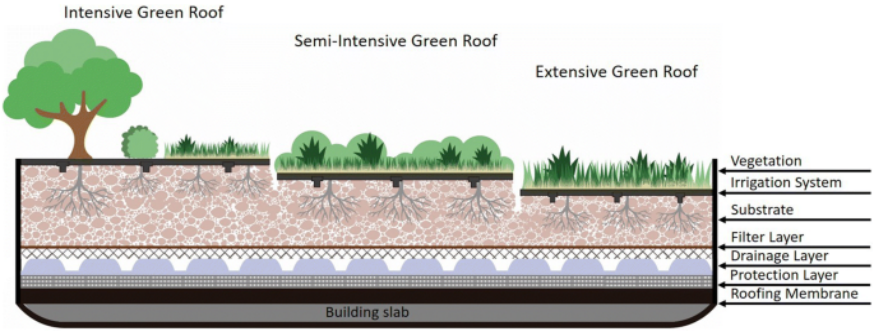

Figure 1: Longitudinal sections of each green roof type

Source: Calheiros and Stefanakis (2021)

Table 1: Features of green roof types

Roof type	Intensive	Semi-intensive	Extensive
Height	More than 20cm	12 - 25 cm	6 - 20 cm
Weight	200 - 500 kg/m^2	120 - 200 kg/m^2	60 - 150 kg/m^2
Vegetation	Trees, herbaceous plants, shrubs, coppices, grass	Shrubs, coppices, grass, herbaceous plants	Grass
Drainage	Separate layer	Separate layer	No separate layer
Irrigation	Required	Required	Not compulsory
Accessibility	Often accessible	Partially accessible	Often inaccessible
Maintenance	Regularly	Periodically	Rarely

Sources: (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL), 2002; Theodosiou, 2009; Fernandez-Cañero, et al., 2013; Abass, et al., 2020)

2.2.1 Benefits of Green Roofs

Green roof is considered as a convenient application of green technology for the urban green space increments and sustainable achievement which can tackle many issues and serves multiple benefits (Meulen, 2019). Those benefits could contribute in achieving economic, social and environment sustainability (Rosasco and Perini, 2019). Table 2 had identified benefits offered by green roofs under each identified sustainable category.

Table 2: Benefits of green roofs

	Benefit	Source
Economic	Energy consumption reduction	[1], [2], [3], [4]
	Enhancement of market value of building	[5], [6]
Social	Improvement of physical and psychological health of occupants	[7], [8]
	Enhancing aesthetic appearance of building	[9]
	Absorption of urbanized noise	[10]

	Benefit	Source
Environmental	UHI effect mitigation	[11]
	Carbon emission reduction	[4], [12]
	Air pollution mitigation	[13]
	Stormwater run-off reduction	[14]
	Expansion of eco and bio-diversity	[7]

Sources: [1] Aboelata (2021); [2] Halwatura (2013); [3] Jaffal, et al; [4] Nadeeshani, et al. (2021); [5] Bianchini and Hewage (2012); [6] Ichihara and Cohen (2011); [7] Hossain, et al. (2019); [8] Meulen (2019); [9] Mowla (2010); [10] Connelly and Hodgson (2013); [11] Razzaghmanesh, et al. (2016); [12] MacIvor, et al. (2016); [13] Velasco, et al. (2016); [14] Vacari, et al. (2019)

Energy consumption reduction is considered as one of the economic benefits of green roofs. According to Aboelata (2021), intensive roof saves more energy than extensive in Arid climate. Halwatura (2013) stated that extensive type saves more energy than conventional roof and the saving increases with the soil thickness of the roof. Further, Nadeeshani, et al. (2021) recorded a 89.95% saving in annual energy demand by an intensive roof compared to conventional roof.

The monthly rental value of a building can increase by 16.2% when a green roof is embedded to a building (Ichihara and Cohen, 2011). According to Bianchini and Hewage (2012), intensive and extensive green roofs can increase the property value by 5%-8% and 2%-5% respectively.

Hossain, et al. (2019) have identified green roofs as a successful solution to improve public health since the vegetation can clean their surroundings. The noise absorption and sound insulations of green roofs may improve the comfort of the occupants inside by reducing vibrations by 3 dB (Meulen, 2019).

A building receives significant attraction by embedding a green roof into its designs (Mowla, 2010). However, the impact of building aesthetic appearance is subjective (Everett and Lamond, 2019). Further authors stated that some people may not willing to see the vegetation on their rooftops. According to Meulen (2019), extensive type may have lesser attraction compared to other green roof types by their users.

According to Connelly and Hodgson (2013), a green roof can reduce noise level from 10-20 dB compared to a conventional roof. The vegetation type on green roof is significant in determining the ability of green roof in noise absorption (Peng and Jim, 2013). Vegetation embedded structures can address the Urban Heat Island (UHI) effect as vegetation can reduce air temperature through evaporation since green roofs accelerate the evapotranspiration of an area due to the availability of soil and trees on top of it in order to reduce UHI effect (Razzaghmanesh, et al., 2016). Nadia (2020) stated that only two intensive roofs used for the study were efficient in UHI effect mitigation while extensive type was more efficient in other cases. Energy consumption reduction ability of green roofs reduces fossil fuel combustion indirectly and reduces carbon emissions (MacIvor et al., 2016). Chenani, et al., 2015) concluded that life cycle carbon emission of green roofs is lesser than the conventional roofs. In the Sri Lankan context, Nadeeshani, et al. (2021) calculated 78.71 $kgCO_2m^{-2}$ annual carbon emission saving in intensive roof than a conventional roof.

Green roof is an innovative solution for the purification of polluted air since photosynthesis process of plants can reduce CO_2 concentration of the air (Velasco, et al., 2016). Further, the vegetation can absorb the fine dust particles of the atmosphere (Shafique, et al., 2018). However, trees are considered more prevalent in capturing dust particles than other vegetation types (Chen, et al., 2006). Hence, vegetation type on a green roof may vary the air pollution mitigation ability of that green roof.

Green roofs may successfully manage the stormwater runoff with their extensive capacity for water retention (Manso, et al., 2021). Further according to authors, intensive green roofs show higher water retaining ability compared to extensive type However, Nardini, et al. (2012) experienced similar retention capacity in both intensive and extensive roof types. According to the authors, that similarity could be due to the higher retaining ability of herbaceous modules than shrubs. Vacari, et al. (2019) stated that the maximum retention was observed in the lowest rainfall conditions in Brazil. Further, studies based on humid climates such as tropical rainforest and humid continental show deceleration in stormwater run-off reduction (Manso, et al., 2021). According to Hossain, et al. (2019), green roof vegetation promotes wildlife in the urban areas by allowing their access to the roof and providing habitats. It can be significantly involved in expanding eco and bio-diversity (Peng and Jim, 2013). Authors stated that it is difficult to quantify the effect of green roofs in that expansion.

The literature evidenced that studies had focused on different benefits offered by green roofs. However, most of the studies had not attempted to identify the existence and extent of each benefit based on the green roof type. Therefore, the results do not reflect any appropriate specific green roof type/s each of the identified benefits.

3. METHODOLOGY

Initially a preliminary investigation was conducted through internet survey, interviews with green roof contractors, regulatory bodies and site visits to identify the available green roofs in Sri Lanka. Accordingly, 5 intensive, 12 semi-intensive and 13 extensive green roofs application were identified. As evidenced in the literature, benefits of green roofs mainly depend on their location, function of the building, roof structure and number of stories. Of the 30 cases with green roofs, due to access restrictions, two case studies, an intensive and a semi-intensive green roof were selected for the study. Both roofs were located on top of car parks of apartment buildings. Intensive green roof was at Colombo while semi-intensive roof was at Galle, and both were in the similar climatic conditions. Key project participants involved in each green roof design, construction and maintenance were interviewed to identify the benefits experienced in the Sri Lankan context. Table 3 presents the profiles of the interviewees. As per the Table, interviewees included mostly architects and engineers of over 10 years of experience.

Table 3: Profiles of the interviewees

Roof Type	ID	Designation	Experience
Intensive	R1	Chief Architect	25 years
	R2	Landscape Architect	28 years
	R3	G Contractor - Managing Director/Design Head	22 years
	R4	Quantity Surveyor	22 years

Roof Type	ID	Designation	Experience
Semi-intensive	R5	Landscape Architect	15 years
	R6	Design Engineer	11 years
	R7	Maintenance Engineer	18 years

4. FINDINGS AND DISCUSSION

Identified participants were asked to comment on the benefits they experienced in the respective green roofs where they engaged, under the three main categories such as economic, social and environmental. Their views are summarised and presented in the following sections.

4.1 ECONOMIC BENEFITS

Energy consumption reduction

According to the opinions of all respondents employed in the intensive green roof building, a significant energy consumption reduction was achieved in the car park area due to the presence of green roof. There was no single ventilation mode installed for the entire car park area. The temporary site offices located below the car park area had installed some cooling units. However, R1 stated that "we have installed air conditioning machines only for air purification since the site offices are closed units, otherwise, the area is much cooler".

The respondents further expressed that the environment of the surrounding premises located at the same level as intensive roof also cooler than a typical same level building. Therefore, it was concluded that a substantial energy consumption reduction can be observed with the case of intensive roof.

In the cases of semi-intensive roof also, the car park area was not with any kind of ventilation. "The soil layer is adequate for our car park cooling premises" was added by R6. According to R6, even the vegetation on the semi-intensive green roof is lesser, the 450mm soil layer provides adequate insulation properties to the car park area. Therefore, semi-intensive roof also reduces energy consumption for cooling of the car park area.

Enhancement of market value of the building

1095 apartment units of the project are located at the peripheral of the green roof area. Having an intensive green roof was instrumental in selling all those apartments by adding value to the entire project. According to R2 respondent, the apartment units were sold in a shorter period of time. "Our marketing division specifically mentioned that the void period was lesser than in a typical apartment project. Customers were keen on the availability of green roof" added by R2 respondent.

According to respondents of semi-intensive green roof, the existence of green roof was not a market tool for the apartment units. The buyers/investors were more driven by the nearby coastal line than the presence of the roof area. R7 respondent highlighted that, "the less attractiveness could be due to the less accessibility and small roof garden area. Further, vegetation areas are inaccessible to the occupants". Therefore, it is considered that the green roof was not significant in enhancing the market value of the property.

4.2 SOCIAL BENEFITS

Improvement of physical and psychological health of occupants

One of the main benefits considered in designing an intensive green roof was improvement of physical and psychological health of the occupants. According to R1, respondent, urban migrations may affect migrators' children and old parents vulnerably. "Closing to the natural environment is essential to improve physical and psychological health of the children. As well, it helps to balance health conditions of adults. Hence, accessible garden areas are significant". Intensive green roof facilitates this requirement as it allows the occupants to play, walk, gather as recreational space.

However, according to respondents of semi-intensive green roof, it could not observe a significant contribution by green roof to the psychological and physical health improvement of the occupants. Occupants do not use the area as much as the designers expected. According to R6 respondent, limited access to roof area was the hindrance for this negative effect. "A non-green rooftop garden with more accessibility could be more effective than having a green area with limited accessibility" was added by R6 respondent. Hence, semi-intensive roof was not significant in regards of this benefit.

Enhancement of aesthetic appearance of the building

The respondents stated that the intensive green roof has been adding more calmness to the entire project. "Even though grass and shrubs are not visible to outside well, tress can be observed from far away" was mentioned by R2. Ultimately, this aesthetic appearance had boosted the selling rate of the apartment units also.

However, semi-intensive green roof is not visible to the outside. According to R5, "beauty of a green roof should not only visible for its occupants. If anyone can capture it at a glance, then it can consider as an additional aesthetic appearance". Further, the vegetation area also limited in the semi-intensive green roof and have not influenced the buyers' decisions.

Absorption of urbanized noise

According to R1, "plants can absorb noise through its stem, leaves, woods and branches. The availability of more plants absorbs more noise". The R2 elaborated the same further by adding "tree stems have special ability to reflect sound waves due to the rigidity of the stems. Sound waves might not able to vibrate more rigid stems and reflect back to its source". Therefore, the absorption becomes effective with the intensive green roof.

However, the respondents of semi-intensive green roof expressed that the sound attenuation of green roof is not considerable. There are no differences in building sound levels before the roof installation and after. Further, R5 commented that "the shrubs do not show any significance in absorbing the sound waves". Hence, this benefit was not identified in the semi-intensive green roof.

4.3 ENVIRONMENTAL BENEFITS

UHI effect mitigation

UHI effect mitigation could not be clearly examined in both intensive and semi-intensive green roofs. According to R3, *"the green roof is located comparatively at a lower height than to its surrounding apartment buildings. Apartment roof decks are not installed with any green roofs. Hence, the effect mitigation may not clearly visible in this green roof"*.

However, according to R6, *"the mitigation could be observed by the below car park area even though it is less significant"*. However, none of the participants could realize UHI effect mitigation ability of the selected green roofs.

Carbon emission control

According to R1, intensive green roof was used as a carbon emission controlling strategy. The green roof provides access to its occupants for recreational facilities. Further, trees provide shading to occupants and have been saving a large amount of fuel combustion and state resource depletion while reducing related carbon emissions.

In the semi-intensive green roof, carbon emission control ability was not identified clearly. According to R5, the roof area has limited access to its occupants. There were no any shadings caused by the roof vegetation. Therefore, the recreational facilities and the carbon emission control could be observed in a limited scale.

Air pollution reduction

The well-known process of air purification by plants is photosynthesis. According to R1, *"purifying atmosphere by photosynthesis is obvious. But the absorption of dust and other toxic particles and gases need to be evaluated further"*. None of the respondents was not definite on the air purification ability and capacity of the intensive green roof.

Respondents of the semi-intensive green roof were also not confident on the air purification ability and capacity of the green roof. R6 emphasized that *"even there are lesser trees in semi-intensive roof compared to intensive roof, a higher density of shrubs and turf may affect the photosynthesis and carbon sequestration processes significantly"*. However, purification ability was not able to be defined in semi-intensive type as well.

Stormwater runoff reduction

Both intensive and semi-intensive green roof are located in tropical rainforest climatic region. The respondents of intensive roof stated that stormwater is well managed by the permeable space of the green roof. Collection of water become limited due to soil layer and vegetation layer. The filtered excess water is transport through drain boards to the peripheral drain line. Hence, any stormwater overflowing cannot be observed.

According to the respondents of semi-intensive green roof, the roof is adequate enough to collect and transfer stormwater without any overflowing. R6 highlighted that, *"higher thickness (450mm) of the soil layer is the main reason for this proper stormwater management. Soil retains excess water and filter smoothly. Even vegetation is comparatively less, the adequate soil thickness provides better performances"*.

Expansion of eco and bio-diversity

There are numerous indigenous plants have been planted on the intensive roof. All respondents representing intensive roof opined that the expansion of both eco and bio-diversity are supported by the green roof. According to R1, *"even this area is highly congested, verities of species can be observed in the roof area. The human accessibility does not show any influence on the expansion of species"*. Further, R3 added *"controlled pruning helps to minimize the artificial nature of the trees, providing more habitats for the species"*. Hence, the expansion of bio-diversity also succeeded with intensive roof.

In the semi-intensive roof, the respondents identified expansion of eco-diversity as a benefit. However, the bio-diversity was not experienced by the respondents. According

to R5, *"bio-diversity expansion was concerned in the design phase and it could not experience after installing roof. However, this could be due to the limited space of the roof area. The species may not get adequate security here"*.

Wind barrier

The plants of intensive roof are acting as a natural wind barrier of the area. According to R2representing intensive roof, *"we could experience a lesser wind blowing from the peripherals with trees. Scaevola plants were well resistant to the wind blowing since its early stages and protected other plants also"*. Therefore, it can be concluded that an intensive roof could act as a wind barrier.

In the semi-intensive roof, none of the respondents agreed with the action of vegetation as a wind barrier. Especially, R7 expressed that *"even it says shrubs can act as wind barriers, its performances can be varied according to its planting pattern. When the shrubs have planted as a hedge, it acts as a good wind barrier rather than single shrubs that had planted alone"*. There are no hedges of shrubs in the semi-intensive roof, but few shrubs together as bunches. Therefore, they cannot perform as a wind barrier.

Dust barrier

In the opinion of R1 representing intensive green roof, any kind of vegetation can collect dust at least up to a certain extent. However, the amount of dust collected could vary according to the type of the leaf, the number of leaves available and the surface area of the leaves. *"Evergreen, rough and hairy, fast-growing trees could be highly responsive to the dust collection"* was added by R1. Intensive roof is with evergreen vegetation; hence, it can act as a dust barrier.

There are no trees available in semi-intensive roof except few temple trees. Further, the combination of vegetation is limited in semi-intensive green roof. However, according to the respondents, the available vegetation is adequate enough to act as a dust barrier. Especially, Orchidaceae plants are roughly enough to retain dust. Moreover, most of the vegetation is evergreen. Therefore, the semi-intensive roof also can act as a dust barrier.

Table 4 summarises the benefits obtained by implementing each selected green roof type.

Table 4: Benefits of selected green roof types

	Literature		Interviewees	
Benefit	**Intensive**	**Semi-intensive**	**Intensive**	**Semi-intensive**
Economic benefits				
Energy consumption reduction	[1], [2]	[1]	R1, R3	R6
Enhancement of market value of the building	[3]	-	R2	x
Social benefits				
Improvement of physical and psychological health of occupants	-	-	R1	x
Enhancement of aesthetic appearance of the building	[4]	-	R2	x
Absorption of urbanized noise	-	-	R1, R2	x

	Literature		Interviewees	
Benefit	**Intensive**	**Semi-intensive**	**Intensive**	**Semi-intensive**
Environmental benefits				
UHI effect mitigation	[5]	-	-	-
Carbon emission control	[2]	-	R1	x
Air pollution mitigation	-	-	-	-
Stormwater runoff reduction	[6]	-	R2	R6
Expansion of eco-diversity and bio-diversity	-	-	R1, R3	R5*
Wind barrier	-	-	R2	x
Dust barrier	-	-	R1	R7

Sources: [1] Aboelata (2021); [2] Nadeeshani et al. (2021); [3] Ichihara and Cohen (2011); [4] Mowla (2010); [5] Razzaghmanesh, et al. (2016); [7] Nardini, Andri, and Crasso (2012)

*only eco-diversity (-) No sufficient literature (x) Not identified the benefit

As seen from Table 5, most of the benefits including all economic and social benefits of green roofs recognized in the global literature were identified by the respondents of intensive type. Further, the respondents have experienced some of the environmental benefits which were identified in the global context. However, only a limited social and environmental benefits could be experienced by the semi-intensive green roof type respondents. Therefore, it could be observed that more benefits are offered in intensive type than semi-intensive type.

5. CONCLUSIONS

The study aimed to explore the benefits of green roofs through two cases of intensive and semi-intensive green roofs implemented in Sri Lanka. Respondents of both cases evident that intensive green roof offer more benefits than semi-intensive green roof. Accordingly, enhancement of market value of the building, improvement of physical and psychological health of occupants, enhancement of aesthetic appearance of the building, absorption of urbanized noise, carbon emission control, expansion of bio-diversity and wind barrier are the benefits specifically identified for the intensive type by the respondents while energy consumption reduction, stormwater runoff reduction, expansion of eco-diversity and dust barrier had identified as the common benefits offered by both types. In addition, intensive type offers benefits under all economic, social and environmental categories while semi-intensive type offers benefits only under economic and environmental categories. Further, both roof types offer more environmental benefits than other categories. Given these benefits of green roof types, effective implementation depends on the cost of alternative types of green roofs. However, the current study has limited to benefits of green roofs. Thus, a further study is recommended to evaluate the costs and benefits of available types of green roofs. Further, in terms of benefits, the current study has compared the benefits of green roofs qualitatively based on a single case study of intensive and semi-intensive types. Therefore, it is expected the future study to extend with more case study of considered types of green roofs as intensive, semi-intensive and extensive.

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