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Green Roofs and Green Building Rating Systems

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ABSTRACT

The environmental benefits for green building from the Leadership in Energy and Environment Design (LEED) and Ecology, Energy, Waste, and Health (EEWH) rating systems have been extensively investigated; however, the effect of green roofs on the credit-earning mechanisms is relatively unexplored. This study is concerned with the environmental benefits of green roofs with respect to sustainability, stormwater control, energy savings, and water resources. We focused on the relationship between green coverage and the credits of the rating systems, evaluated the credits efficiency, and performed cost analysis. As an example, we used a university building in Keelung, Northern Taiwan. The findings suggest that with EEWH, the proposed green coverage is 50–75%, whereas with LEED, the proposed green coverage is 100%. These findings have implications for the application of green roofs in green building.

***Keywords* -** Green building, green roof, green building rating system, LEED, EEWH

I. INTRODUCTION

Taiwan faces serious urbanization and overexploitation of land resources because of the country’s economic development (Kalnay and Cai 2003; Kim et al., 2013). Natural habitats have been covered with concrete, and urbanization has negatively affected the urban environment (Booth et al., 2002; Borselli et al., 2010; Hester et al., 2013). Green space has been replaced. Green roofs are used in buildings to promote water conservation (Getter et al., 2006; Oberndorfer et al., 2007), improve the environment, regulate the microclimate, and mitigate the heat island effect (Del Barrio, 1998). Green roofs have gradually become an important trend in green buildings. To quantitatively assess the performance of green buildings, many countries have developed green building rating systems. Green roofs are quite important as they play a significant role in site development (Nektarios et al., 2011), irrigation, flood control (Mentens et al., 2006; Teemusk et al., 2007), and mitigate the heat island effect (Oberndorfer, 2007; Takebayashi, 2007).

A “Green Roof” is defined as a roof with plant growth on the roof surface, which ranges from spontaneous growth of moss to full-scale garden with shrubs and trees (Scholz-Barth, 2001). From bottom to top, the layers of a green roof comprise the water proofing membrane, water-storage and drain layer, filter layer, and growing medium and vegetation (Fig. 1). The waterproofing membrane and root-protection layer are placed at the bottom of the plot to protect the building from moisture and roots. The water-storage and drain layer are used to store rainwater in arid conditions and drain storm water, respectively. This layer can effectively decrease the storm water volume and reduce the heat island effect. The filter layer prevents the washing out of the growing medium. The growing medium layer also decreases the stormwater volume and reduces the heat island effect. The thickness of the medium depends on structural constraints and the type of vegetation. The latter should be native or adapted plants.

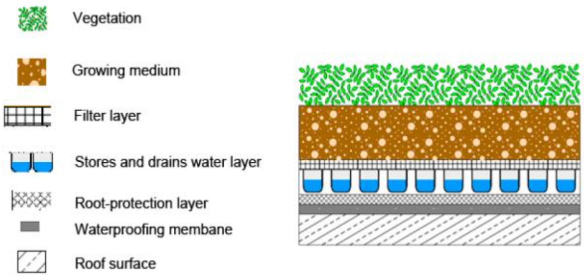

Figure 1 Constituent layers of a green roof

In the 20th century, many developing countries developed green building techniques and established green building rating systems, such as the UK Building Research Establishment Environmental Assessment Method, Australia’s National Australia Building Environmental Rating System, Japan’s Comprehensive Assessment for Building Environmental Efficiency, and the US Leadership in Energy and Environment Design (LEED). The latter’s influence is global. The building blocks of the Taiwan green building rating system are Ecology, Energy, Waste, and Health (EEWH). This study discusses and compares the EEWH and LEED rating systems.

II. EEWH & LEED

In 1999, Taiwan's Ministry of the Interior, Architecture, and Building Research Institute (ABRI) developed the EEWH green building rating system. The EEWH system is based on nine assessment indexes: biodiversity, greenness, water conservation, energy savings, CO2 emissions reduction, waste reduction, water resources, indoor environmental quality, and garbage and sewage improvements. There are five levels (credits) in EEWH: certified level (12–26), copper level (26–34), silver level (42–52), gold level (42–52), and diamond level (≥53); the total credit score is 100.

In 1995, the U.S. Green Building Council published LEED. LEED is a system for rating the design, construction, operation, and maintenance of green buildings, homes and neighborhoods. There are six assessments: sustainable sites (SS), water efficiency (WE), energy and atmosphere (EA), materials and resources (MR), indoor environmental quality (IEQ), and innovation in design (ID). There four levels (credits) in LEED: certified level (40–49), silver level (50–59), gold level (60–79), and platinum level (≥80); the sum of credits is 110.

III. Environmental Benefits of Green Roofs

Regardless of using EEWH or LEED, green roofs can improve the built environment. Green roofs are critical for earning credits in rating systems and are indispensable parts of green buildings. This study is based on EEWH-BC V8 (ABRI, 2012) and LEED 2009 (USGBC, 2009).

3.1 Green roofs in EEWH

In the nine assessment indexes of EEWH, there are up to four indexes associated with green roofs: greenness, water conservation, energy saving, and water resource.

(1) Greenness

Greenness uses the plants' photosynthesis capacity as a part of the evaluation criteria. According to weather conditions, tree shape, and leaf area, analysis of the CO2 fixation capacity as green conversion efficiency standards can be performed. The weighted criteria and greening credits are calculated as follows:

$$\begin{aligned}&\text{Greenness credits}\\&= 6.81 \times \left(\left(\mathrm{CO_2}\ \text{fixation calculated value} - \text{standard}\right)/\text{standard}\right)\\&+1.5\end{aligned}$$

Eq. (1)

$$\begin{aligned}&\mathrm{CO_2}\ \text{fixation calculated value}\\&= \sum \left(\text{plants}\ \mathrm{CO_2}\ \text{fixation value} \times \text{area}\right)\end{aligned}$$

Eq. (2)

For the CO2 fixation capacity, one can refer to the EEWH-BC manual. Because the soil layer is thin, green roofs are often used to grow lawns, vines, low-growth shrubs, etc. The use of shrubs can increase to enhance the CO2 fixation capacity.

(2) Water conservation

Water conservation is basically rainwater catchment capacity; it enhances microbial activity and improves the environment. Water conservation depends on the soil layer porosity. Green roofs control the runoff volume, delay the runoff peak time, and reduce the risk of urban flooding. The weighted criteria and water conservation credits are calculated as follows:

$$\begin{aligned}&\text{Water conservation credits}\\&= 4.0 \times \left(\left(\text{calculated value} - \text{standard value}\right)/\text{standard value}\right)\\&+1.5\end{aligned}$$

Eq. (3)

$$\text{calculated value} = \frac{\text{water conservation after development}}{\text{water conservation before development}}$$

Eq. (4)

The water conservation can be calculated by using the medium volume and type.

(3) Energy savings

Energy savings is a necessary index of EEWH-BC. Energy savings include the building shell, HVAC, and lighting systems. Green roofs improve the building shell energy performance.

Energy savings should be more than 20% of the benchmark for current energy efficiency regulations. Therefore, the key to energy savings is the roof insulation. The weighted criteria and energy saving credits are calculated as follows:

$$\begin{aligned}&\text{Energy saving credits}\\&= a \times \left(\left(0.08 - \text{building shell energy efficiency}\right)/0.80\right)\\&+ 2.0\end{aligned}$$

Eq. (5)

$$\begin{aligned}&\text{building shell energy efficiency}\\&= \frac{\text{building shell energy calculated value}}{\text{building shell energy standard value}}\\&\le \text{building shell energy calculated value} = 0.8\end{aligned}$$

Eq. (6)

For the definition of the weighting factor a, the reader should refer to the EEWH-BC manual.

(4) Water resources

Taiwan has an average annual rainfall of more than 2600 mm. However, because of increasing industry and business requirements and high population density, the water amount per person is only one-sixth of the world’s average. Taiwan is defined as a water-scarce country by the UN, and green roof irrigation only compounds the problem of water scarcity. Therefore, green roofs should make use of plants that do not require much water and combine them with automatic and water-saving irrigation systems. Moreover, green roofs should harvest rainwater and use graywater for irrigation.

Water resource is one of the indexes of EEWH-BC. The weighted criteria and water-saving credits are calculated as follows:

$$\text{Water resource credits} = 2.5 \times (\text{water resource indexes - 2.0})/2.0 + 1.5 \quad \text{Eq. (7)}$$

$$\text{water resource indexes} = A + B + C + D + E + F \quad \text{Eq. (8)}$$

where A is the toilet credit; B is the urinal credit; C is the public lavatory faucet credit; D is the bath or shower credit; E is the rainwater or graywater credit; and F is the air-conditioning credit.

3.2 Green roof in LEED

In LEED, there are up to five sub-indexes associated with green roofs: 1) sustainable sites: site development–maximize open space (SSC5.2); 2) sustainable sites: stormwater design–quantity control (SSC6.1); 3) sustainable sites: heat island effect–roof (SSC7.1); 4) water efficiency: water-efficient landscaping (WEC1); and 5) energy and atmosphere: optimize energy performance (EAC1).

(1) Sustainable sites: site development–maximize open space (SSC5.2)

Open space provides habitat for vegetation and wildlife. Plants that support insects and other pollinators can help sustain populations higher up the food chain. Open space also minimizes the urban heat island effect, increases infiltration, and connects humans population to the outdoors. If the area is already developed, the roof area can be green.

To earn one credit, the development footprint should be minimal, the vegetated open spaces within the project boundaries should exceed local zoning requirements by 25%, or the vegetated open space should equal 20% of the project’s site area. To earn two credits, the open space must exceed the local zoning requirements by 50%, or the vegetated open space must equal 40% of the project’s site area.

(2) Sustainable sites: stormwater design–quantity control (SSC6.1)

Stormwater is a major source of water pollution. Roads and parking lots produce stormwater runoff that contains sediment and other contaminants, such as atmospheric materials, pesticides, fertilizers, vehicle fluid, and mechanical equipment waste. Furthermore, municipal systems that transport and treat water runoff require significant infrastructure and maintenance. Green roofs provide effective on-site management practices and allow stormwater infiltration, thereby reducing the volume and intensity of stormwater flows.

To earn credits, the postdevelopment peak discharge rate and quantity should not exceed the predevelopment peak discharge rate and quantity for one- and two-year 24-h storms.

(3) Sustainable sites: heat island effect–roof (SSC7.1)

The use of dark, nonreflective roofing surfaces contributes to the heat island effect by absorbing the sun’s warmth. Ambient temperatures in urban areas are accordingly elevated, thereby increasing cooling loads, electricity consumption, emissions of greenhouse gases, and pollution. The heat island effect is also detrimental to site habitats, and plants and animals may not thrive in areas affected by it.

One credit is earned for a vegetated roof that covers at least 50% of the roof area. Two credits are earned for 100% coverage.

(4) Water efficiency: water-efficient landscaping (WEC1)

Landscape irrigation practices consume large quantities of potable water. Therefore, improved landscaping practices can dramatically reduce and even eliminate irrigation requirements. Maintaining or re-establishing native or adapted plants on building sites fosters self-sustaining landscapes that require minimal addition of water and attracts native wildlife, creating a building site that is integrated with the natural surroundings.

LEED and EEWH aim at water efficiency, watering frequency reduction, high-efficiency irrigation, and use of alternative water sources. To calculate the credits for the percentage reduction in potable or natural water use, a baseline water-use rate for the project is established and then the as-designed water-use rate is calculated. The evapotranspiration is based on the landscape, species, density, and microclimate. To earn two credits, the water demand for landscape irrigation must be reduced by 50%. For four credits, no potable water should be used. Nonetheless, if the green area is less than 5% of the base area no credits are earned.

Table 1 Comparison of the EEWH and LEED rating systems

Environmental Benefits	**EEWH** Ecology, Energy, Waste, and Health (ABRI, 2012) (Taiwan)		**LEED** Leadership in Energy and Environment Design (USGBC, 2009) (U.S.A.)	
Sustainable Site	Index-2 Greenness	Use plant photosynthesis capacity as evaluation criterion according to sunshine, weather conditions, tree shape, leaf area, and CO$_2$ fixation capacity.	SSC5.2 Development–Maximize Open Space	Planting native and adaptive plants. Use green coverage area in the evaluation criteria.
			SSC7.2 Heat Island Effect–Roof	Improve the heat island effect. Use green coverage area in the evaluation criteria.
Stormwater Control	Index-3 Water Conservation	Use the water conservation formula to calculate the retained runoff volume of green roof.	SSC6.1 Stormwater Design–Quantity Control	Use the water conservation formula to calculate the retained runoff volume of the green roof.
Energy Saving	Index-4 Energy Saving	Energy savings include the building shell, HVAC, and lighting systems. Green roofs improve the building shell. The energy performance is part of the evaluation criteria.	EAC1 Optimize Energy Performance	Simulate the whole building energy using the ASHRAE 90.1 standard. Use the Green Roof Energy Calculator to calculate the energy cost savings.
Water Resource	Index-5 Water Resource	The water resources index formula is based on whether rainwater or graywater is used.	WEC1 Water-Efficient Landscaping	Use alternative water sources and native and adaptive plants. Use the water reduction in the landscape irrigation in the evaluation criteria.

(5) Energy and atmosphere: optimize energy performance (EAC1)

LEED energy efficiency simulations of the whole building and cost-saving calculations are based on the ASHRAE 90.1 standard. LEED is different from EEWH in that regard because it targets the building shell energy consumption. Green roofs in LEED can use the green roof energy calculator (Sailor, 2008) to calculate and compare the annual energy performance between green roof and nongreen roof buildings.

3.3 Rating system comparison

The EEWH and LEED rating systems are compared on the basis of the four categories of environmental benefits: sustainable site, stormwater control, energy savings, and water resources. The rating system comparison is listed in Table 1.

In the sustainable site category, the evaluation criteria of LEED and EEWH are completely different. LEED uses the green coverage area percentage, whereas EEWH uses the plant photosynthesis and the CO2 fixation capacity. In the energy saving category, LEED simulates the energy of the whole building by using the green roof energy calculator, whereas EEWH use the energy performance formula.

IV. Case study

A university building in Keelung, Northern Taiwan is used as the case study. The efficiency of the credit concept and cost are assessed.

Figure 2 Location of the building

4.1 Background

National Taiwan Ocean University (NTOU) evaluated the feasibility of increasing the number of green roofs on campus to increase green space and to included it in the Taiwan Sustainable Campus

Program [23]. Therefore, a section of the Harbor and River Engineering Department building was evaluated (Fig. 2). This is a single five-story building. The catchment area and green roof is 564 m2, the medium is 30 cm thick, and the plant used is Eremochloa ophiuroides (centipede grass). A rainwater harvesting system was used for irrigation.

Table 1 lists the major meteorological data used in this study. The mean annual rainfall in the Keelung area is 3659 mm. During the past 20 years (1993–2012), the northeast monsoon in the fall and winter is responsible for the rainy seasons in Keelung, with considerably lower rainfall present in the summer. Fig. 4 shows that the irrigation requirements are high from July to September on account of strong ET effects of the vegetation during the summer.

Table 2 Hydrological and Meteorological Data

Average annual data of the Keelung weather station (1993–2012)	
Rainfall	3595 mm
Sunshine	139.7 days
Temperature	22.4 °C
Atmospheric Pressure	1011.2 hPa
Wind Speed	2.8 m/s
Humidity	78.9 %

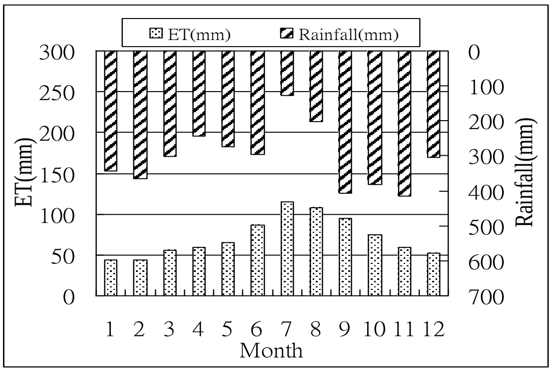

Figure 3 Monthly average rainfall and ET

4.2 Rating systems credits

Using green coverage percentages of 0%, 25%, 50%, 75%, and 100% the EEWH and LEED rating systems are evaluated.

(1) EEWH credits

The EEWH credits are for greenness, water conservation, energy savings, and water resources, as shown on Fig. 4.

For the greenness index, if the green coverage is 0%, no credit is earned; for 25% green coverage, no credit is earned; for 50% green coverage, one credit is earned; for 75% green coverage, two credits; and for 100% green coverage, two credits. For the water conservation index, if the green coverage is 0%, no credit is earned; for 25% green coverage, no credit; for 50% green coverage, one credit; for 75% green coverage, two credits; and for 100% green coverage, two credits. For the energy saving index, if the green coverage is 0%, no credit is earned; for 25% green coverage, no credit; for 50% green coverage, no credit; for 75% green coverage, one credit; for 100% green coverage, one credit. For the water resource index, if the green coverage is 0%, no credit is earned; for 25% green coverage, no credit; for 50% green coverage, one credit; for green 75% coverage, two credits; for 100% green coverage, two credits.

Using EEWH, if the green coverage is 0%, the total credit is zero; if the green coverage is 25%, the total credits are four; if the green coverage is 50%, the total credits are six; if the green coverage is 75%, the total credits are nine; and if the green coverage is 100%, the total credits are still nine.

(2) LEED credits

LEED assigns credits for site development–maximize open space, stormwater design–quantity control, heat island effect–roof, water-efficient landscaping, and for optimizing the energy performance, as shown in Fig. 5.

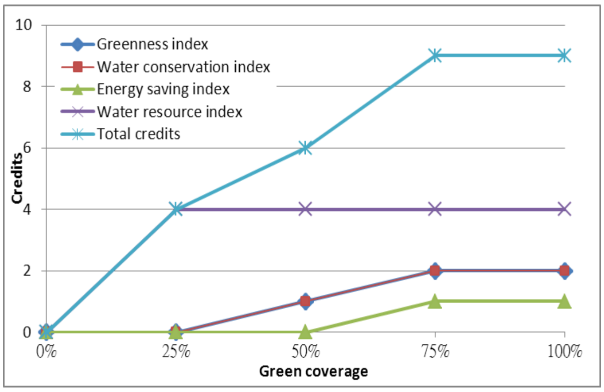

Figure 4 EEWH credits for the case study building

For the site development–maximize open space credit, if the green coverage is 0%, no credit is earned; for 25% green coverage, no credit; for 50% green coverage, one credit; for 75% green coverage, one credit; and for 100% green coverage, two credits. For the stormwater design–quantity control credit, if the green coverage is 0%, no credit is given; for 25% green coverage, one credit; for 50% green coverage, one credit; for 75% green coverage, one credit; and for 100% green coverage, one credit. For the heat island effect–roof credit, if the green coverage is 0%, LEED assigns no credit; for green coverage 25%, no credit; for 50% green coverage, one credit; for 75% green coverage, two credits; for green coverage 100%, two credits. For the water-efficient landscaping credit, if the green coverage is 0%, LEED assigns no credit; for 25% green coverage, four credits; for 50% green coverage, four credits; for 75% green coverage, four credits; and for 100%

green coverage, four credits. For the optimize energy performance credit, if the green coverage is 0%, LEEDS assigns no credit; for 25% green coverage, no credit; for 50% green coverage, no credit; for 75% green coverage, no credit; and for 100% green coverage, one credit.

Using LEED, if the green coverage is 0%, the total credit is zero; if the green coverage is 25%, the total credits are five; if the green coverage is 50%, the total credits are six; if the green coverage is 75%, the total credits are seven; and if green coverage is 100%, the total credits are still eleven.

4.3 Credits efficiency

The credits based on the two systems and the analysis of the efficiency of the credits with respect to green coverage are discussed and shown in Fig. 6.

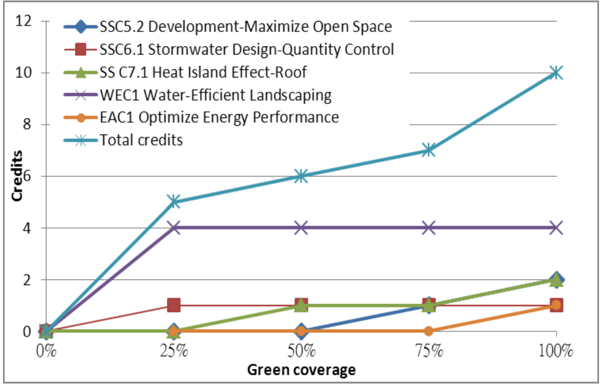

Figure 5 LEED credits for the case study building

4.3 Credits efficiency

The credits based on the two systems and the analysis of the efficiency of the credits with respect to green coverage are discussed and shown in Fig. 6.

Using EEWH, if the green coverage is 0%, the credits efficiency is 0%; if the green coverage is 25%, the credits efficiency is 4.0%; if the green coverage is 50%, the credits efficiency is 6.0%; if the green coverage is 75%, the credits efficiency is 9.0%; and if the green coverage is 100%, the credits efficiency is 9.0%. Using LEED, if the green coverage is 0%, the credits efficiency is 0%; for 25% green coverage, the credits efficiency is 4.5%; for 50% green coverage, the credits efficiency is 5.5%; for 75% green coverage, the credits efficiency is 6.4%; for 100% green coverage, the credits efficiency is 9.1%. When the green coverage is 25% to 50%, the credits are nearly equal; for 75% green coverage, the EEWH credits are greater than LEED by 3.6%. The EEWH assigns more credits for 75% green coverage, whereas there no significant differences (0.1%) at 100% green coverage between LEED and EEWH.

4.4 Cost analysis

In this study, we evaluate the green roof environmental benefits based on LEED and EEWH. The purpose is to investigate what it costs to earn the credits of each rating system. In Taiwan, the established cost for green roofs is $USD 66.67/m2 (Chen, 2013). To establish the rainwater harvesting system cost, we have to consider the green coverage percentage. If the green coverage is 25%, the cost is $USD 1667; for 50% green coverage, the cost are $USD 2333; for 75% green coverage, the cost is $USD 3000; and if the green coverage is 100%, the cost is $USD 3333. We look at the cost per credit with respect to green coverage.

Using EEWH, if the green coverage is 0%, the cost is $USD 0/per point; for 25% green coverage, the cost is $USD 2758/per point; for 50% green coverage, the cost is $USD 3511/per point; for 75% green coverage, the cost is $USD 3456/per point; and for 100% green coverage, the cost is $USD 4533/per point. Using LEED, if green coverage is 0%, the cost is $USD 0/per point; for 25% green coverage, the cost is $USD 2427/per point; for 50% green coverage, the cost is $USD 3862/per point; for 75% green coverage, the cost is $USD 4887/per point; and if the green coverage is 100%, the cost is $USD 4488/per point.

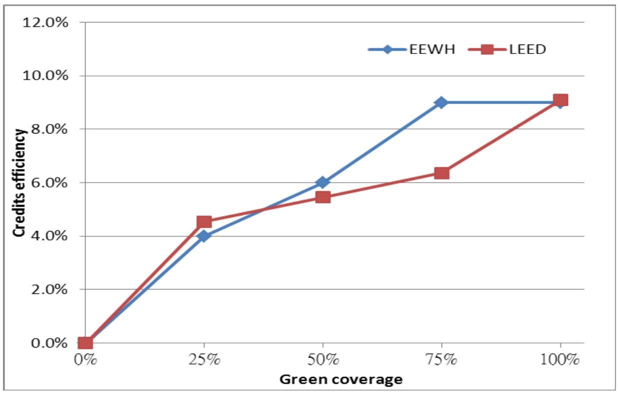

Figure 6 EEWH & LEED credits efficiency

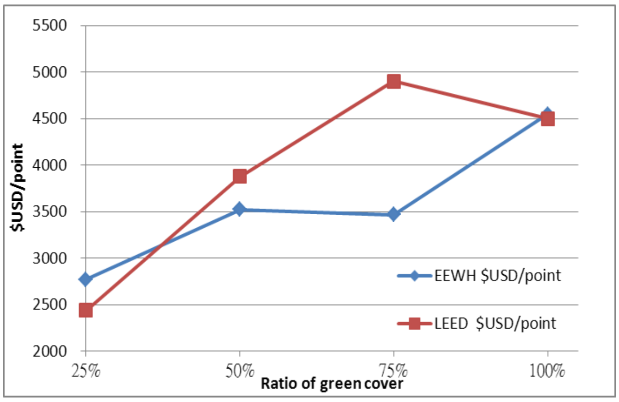

Figure 7 Cost analysis of EEWH & LEED

Because there are no more credits for ≥75% green coverage when using EEWH, the segment cost increases significantly. Because there are significantly increased credits at 100% green coverage for LEED, the segment cost markedly decrease. On the basis of the earned credits and cost, EEWH is recommended for 50–75% green coverage and LEED is recommended for 100% green coverage.

V. Discussion and conclusions

This is a preliminary study of the environmental benefits of green roofs according to green building rating systems. A major finding is the difference in credit efficiency between EEWH and LEED. The results indicate that the rating system and green coverage should be considered in the cost analysis. As case study, we considered a NTOU building in Keelung, Northern Taiwan. Green roofs with 50–75% green coverage are proposed for EEWH and 100% green coverage for LEED. This type of analysis could offer specific advice for green building practices and systematize the credit-earning mechanisms.

Despite the EEWH and LEED rating systems advantages, they do have limitations. First, the EEWH credits are limited for ≥75% green coverage and the LEED energy savings are indirectly calculated by auxiliary models. Particularly challenging is the green roof management for maintaining the environmental benefits. It is important to discuss whether there are environmental benefits of the two systems that are not considered. This study has demonstrated that credit efficiency is critical. However, whether this also applies to other rating systems cannot be determined from the results of this study. Further research is therefore required. Finally, this study has clarified several issues or has at least paved the way for new research projects that will add to the study of green building rating system.

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