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# A review of the green building rating systems

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**Abstract.** Green buildings have received much attention since the early 90s due to increasing concerns over the sustainability of buildings. The rise of green buildings spurred the need to systematically evaluate hence certify those buildings using a set of established criteria. This led to the emergence of numerous green building rating systems. This review compares 10 popular green building rating systems to identify their similarities, differences and the potential future studies in this area. It identifies 17 evaluation criteria as the basis of comparison and ranks the importance of the most common criteria based on their average weights across the rating systems of interest. This review shows that energy efficiency, indoor environment, health and wellbeing, sustainable siting, material efficiency, water efficiency and innovation as the most prevalent evaluation criteria in descending average weights. This study identifies the future need to probe into the implementation of the rating systems and the building performance ensuing such implementation. It is also crucial to understand the barriers in popularizing green building awards or certification. This review contributes to both the knowledge and practices of green building rating.

Keywords: Green buildings, rating, sustainability, energy, performance

## 1. Introduction

Conventionally, the construction and occupation of buildings are linked to numerous environmental impacts. The building sectors comprising residential and commercial structures consumed approximately 20% of the world's energy in 2018 and their energy consumption has been projected to increase by 1.3% per year to 22% in 2050 [1]. Increase in buildings' energy consumption is largely contributed by developing countries due to increasing energy demand driven by intensifying urbanization as well as better access to electricity and income [2]. Though industrial sectors were still the largest energy consumer, drawing about 40% of the global energy in 2018, the increase is projected to be in the range of 0.5% and 1.1%, leading to a decline in its overall share of energy consumption to 35% by 2050 [1].

The building and industrial sectors are in fact intricately related with building materials such as iron, steel, aluminium and paints coming from the industrial sectors [1, 2]. Taking the production and transportation of building materials into consideration, energy consumption of buildings would surpass the estimated energy consumption of 20% [1]. Electricity channelled to residential buildings are mainly used for space heating and cooling, water heating as well as refrigeration while electricity



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distributed to commercial buildings are used mainly to power computers and office equipment, refrigeration, space cooling system and ventilation [1, 3]. The increasing use of light emitting diode (LED) bulbs and compact fluorescent lamps has and will continue to reduce electricity intensity for lighting [1, 3].

While being energy-demanding, buildings also emit greenhouse gases [4]. It has been estimated that buildings and construction, including upstream power generation, contribute to 39% of the total CO<sub>2</sub> emitted [5]. In addition, buildings consume water and produce wastewater concurrently. Every year, about 13.6% of total potable water, equivalent to 15 trillion gallons, is used by buildings [5]. Construction of buildings generates demand for construction materials whose production emits greenhouse gases. In fact, greenhouse gases are emitted throughout the entire building lifecycle, from extraction and processing of raw materials, transportation of construction materials to demolition of buildings at the end of their service life [6]. Besides, demolition of building produces copious waste. The EPA estimated that the US produced 548 million tons of construction and demolition (C&D) debris in 2015 and this was double the amount of municipal solid waste produced in the same year. Demolition waste comprised 90% of the C&D waste generated [5].

The environmental impacts associated with buildings have resulted in interest to make buildings more energy efficient and environmental friendly. This sparked off the green building movement calling for integration of sustainability into the design and construction of new buildings as well as retrofitting of existing buildings [7]. Sustainable building embeds building life-cycle probing the adoption and synergy of green practices. The emergence of green buildings gives rise to practices, technology and techniques to reduce environmental and health impacts of building while tapping into renewable energy to provide electricity [8]. Not only that, green buildings also optimize the use of plants and trees, reduce rainwater run-off, utilize environmental friendly materials and promote recycling of waste materials [9]. The US green building movement culminated in the establishment of the United States Green Building Council (USGBC) in 1993 to encourage sustainable design, construction and operation of buildings [7]. The USGBC saw the need to set standards for green buildings which led to the subsequent inception of the Leadership in Energy and Environmental Design (LEED). The LEED has thence evolved into a comprehensive set of standards delving into the design, operation, maintenance, innovation as well as social functions of green buildings [10].

Though widely used today, LEED is not the first green building rating system to be developed. The Building Research Establishment's Environmental Assessment Method (BREEAM) was launched in 1990, four years before the release of LEED [11]. Since then, many other green building rating systems were introduced. For instance in 1996, the Building Environmental Assessment Method (BEAM) of Hong Kong was developed by the BEAM Steering Committee which later collaborated with other major players to form the Hong Kong Green Building Council (HKGBC). The HKGBC, in 2010, released an upgraded version of BEAM, called the BEAM Plus [12]. Subsequent to LEED, other regional green building rating systems such as the Comprehensive Assessment System for Built Environment Efficiency (CASBEE) of Japan, the Green Mark (GM) of Singapore and the Green Building Index (GBI) of Malaysia were also launched [13].

The rating systems generally cover the common attributes such as energy efficiency, water efficiency, material efficiency, indoor environmental quality enhancement, waste reduction as well as operations and maintenance optimization [9, 13]. However, the emphasis may vary in different rating systems. There have been multiple studies conducted to examine individual rating system in detail [14] or compare multiple rating systems [7, 9, 13]. Numerous studies have compared LEED and BREEAM [7, 8, 15]. Other studies extended beyond the two to include comparison with regional rating systems. Aye and Hes, for example, compared LEED, BREEAM and Green Star (GS) of Australia [16] while Geng et al. included BEAM, CASBEE, and Assessment Standard for Green Building (ASGB) of China in the comparison [17]. There are studies which compare multiple rating systems including that of Awadh which compares 6 rating systems [18] and that of Illankoon et al. comparing 8 rating systems [19]. Most studies include LEED in the comparison probably because LEED is most widely used. Though numerous studies on green rating systems have been conducted,

there is an apparent lack of comparison of the popular rating systems across a comprehensive list of evaluation criteria and a lack of clarity in the weights used for comparison since different categories of the same rating system may have different weights allocated for the evaluation criteria.

## 2. Method

This review compares 10 green building rating systems. The rating systems were identified by running a search through the ‘Google Scholar’ engine on literature related to green building rating systems over the past 10 years. The keywords used in the search consisted primarily of green building rating systems, green building rating, green building certification and LEED, and secondarily of green building and green certification which yielded a wider array of search results. The rating systems that were most frequently subject to studies, hence most frequently appearing in the search were extracted. They are, not in sequence of study frequency, listed below:

- LEED
- BREEAM
- CASBEE
- GS
- ASGB
- BEAM
- Green Globes (GG) of Canada
- GM
- GBI
- Indian Green Building Council (IGBC) of India

This review provides general details of the rating systems encompassing the initiators, the countries of origin and the rating categories. This review examined the evaluation criteria of the rating systems and generated a list of common criteria as the basis of comparing the rating systems [13]. Zooming into six most common criteria, this review identified the weights allocated by each rating system on the criteria and presented the average weight for each criterion.

## 3. Results and Discussion

General information of the green building rating systems compared in this study are presented in table 1. Different green building rating systems provide different categories of certification, hence different rating tools. The most common categories are the certification of new buildings, existing buildings, interiors and communities, though some rating systems, particularly ASGB, GM, GBI and IGBC make a detailed distinction between the types of building (Table 1). CASBEE and IGBC differentiate communities into categories such as urban development, cities, residential societies and green townships. This demonstrates a trend of increasingly specific rating systems to purpose-fit different types of development rather than a one-size-fit-all rating system [9].

It is also noteworthy that the green building rating systems were initiated by private, member-based organizations except GM of Singapore and ASGB of China (Table 1). This could mean that governance and regulation may be a concern of the rating systems. However, in most instances, there is a third-party assessment by independent bodies on the outcomes of green building assessments to ensure objectivity and transparency [18]. More studies are needed to delve into the implementation of the rating systems particularly the governance, reliability and the effectiveness of audits encompassing objectivity and transparency to conclude unbiased implementation of the rating systems. The pursuit of green building certification also faces the challenges of resistance to change and costs, and it is worthwhile to carefully examine these challenges to promote green building certification [9]. While table 1 shows the most commonly studied green building rating systems in the past decade, many other regional rating systems have been developed for example, the Estidama Pearl Rating System (EPRS) of Abu Dhabi and the Global Sustainability Assessment System (GSAS) of Qatar.

**Table 1.** General description of the green building rating systems reviewed.

Green Building Rating System	Initiator	Rating Tools/ Categories	Country
LEED [10]	US Green Building Council	LEED v 4.1 BD+C (design and construction of full buildings) for new construction and major renovation, core and shell development, schools, retail, data centres, warehouses and distribution centres, hospitality as well as healthcare LEED v4.1 ID+C (interior design and construction) for commercial interiors, retail and hospitality LEED v4.1 O+M (operational and occupied buildings) for existing buildings and existing interiors LEED v4.1 Residential for single family and multifamily homes as well as multifamily homes core and shell. LEED v4.1 Cities and Communities for cities and communities	US
BREEAM [11]	Building Research Establishment (BRE)	BREEAM – Communities; BREEAM (International or UK) – New Construction; Home Quality Mark (HQM); Civil Engineering and Public Realm (CEEQUAL) Version 6; BREEAM In-Use; BREEAM Refurbishment and Fit-Out – Homes and commercial buildings	UK
CASBEE [20]	Japan Sustainable Building Consortium	CASBEE for Buildings (New Construction) 2014; CASBEE for Buildings (Existing Buildings) 2014; CASBEE for Buildings (Renovation) 2014; CASBEE for Market Promotion 2014; CASBEE for Commercial Interiors 2014; CASBEE for Temporary Construction 2007; CASBEE for Urban Development 2014; CASBEE for Cities 2013; CASBEE for Cities – Worldwide use 2015; CASBEE for Detached Houses (New Construction) 2014; CASBEE for Dwelling Unit (New Construction) 2014	Japan
GS [21]	Green Building Council Australia	Green Star – Communities, for precinct planning and development; Green Star – Design & As Built, for building design and construction ; Green Star – Interiors, for fitout design and construction; Green Star – Performance, for building operations and maintenance	Australia
ASGB [17]	Ministry of Housing and Urban-Rural Development of People's Republic of China	Evaluation Standard for Green Industrial Building (2013); Evaluation Standard for Green Office Building (2013); Assessment Standard for Green Store Building (2015); Evaluation Standard for Green Hospital Building (2016); Assessment Standard for Green Hotel Building (2016); Assessment Standard for Green Museum and Exhibition Building (2016); Assessment Standard for Green Retrofitting of Existing Building (2015); Assessment Standard for Green Building (2014); Assessment Standard for Healthy Building (2016)	China

**Table 1.** General description of the green building rating systems reviewed (continued).

Green Building Rating System	Initiator	Rating Tools/ Categories	Country
BEAM [22]	Hong Kong Green Building Council	BEAM Plus New Buildings; BEAM Plus Existing Buildings; BEAM Plus Interiors; BEAM Plus Neighbourhood	Hong Kong
GG [23]	Green Building Initiative	Green Globes for New Construction; Green Globes for Existing Buildings; Green Globes for Sustainable Interiors	Canada
GM [24]	Building and Construction Authority	Green Mark Scheme for the categories of 1) New non-residential buildings, 2) Super low energy, 3) New residential buildings, 4) Transit stations, 5) Existing non-residential buildings, 6) Existing residential buildings, 7) Landed houses, 8) Existing schools, 9) Healthcare facilities, 10) Laboratories, 11) Infrastructure, 12) District, 13) Healthier workplaces, 14) Office interior, 15) Restaurants, 16) Supermarket, 17) Retail, 18) Data centre, 19) Overseas projects – new developments, 20) Overseas projects – existing buildings, 21) Circular economy/ sustainable construction	Singapore
GBI [25]	Greenbuildingindex Sdn Bhd	Non-Residential New Construction (NRNC); Residential New Construction (RNC); Non-Residential Existing Building (NREB); Industrial New Construction (INC); Industrial Existing Building (IEB); NRNC – Data Centre, Retail, Hotel, Resort; NREB – Data Centre, Retail, Hotel, Resort, Historical Building; GBI Township	Malaysia
IGBC [26]	Indian Green Building Council	IGBC Green New Buildings; IGBC Green Existing Buildings; IGBC Green Homes; IGBC Green Affordable Housing; IGBC Green Residential Societies; IGBC Green Schools; IGBC Green Factory Buildings; IGBC Green Data Center; IGBC Green Campus; IGBC Green Villages; IGBC Green Townships; IGBC Green Cities; IGBC Green Existing Cities; IGBC Green SEZs; IGBC Green Landscapes; IGBC Green Mass Rapid Transit System; IGBC Green Existing Mass Rapid Transit System; IGBC Green Affordable Housing	India

Table 2 shows the criteria used in the 10 green building rating systems. The criteria represent the key areas of evaluation. There may be overlapping between areas such as sustainable siting, and land use and outdoor environment. Placing a mark on a criterion in Table 2 means the rating system puts a significant emphasis on the particular criterion in contrast to it being a small component under an overarching criterion.

**Table 2.** Comparison of the criteria of green building rating systems.

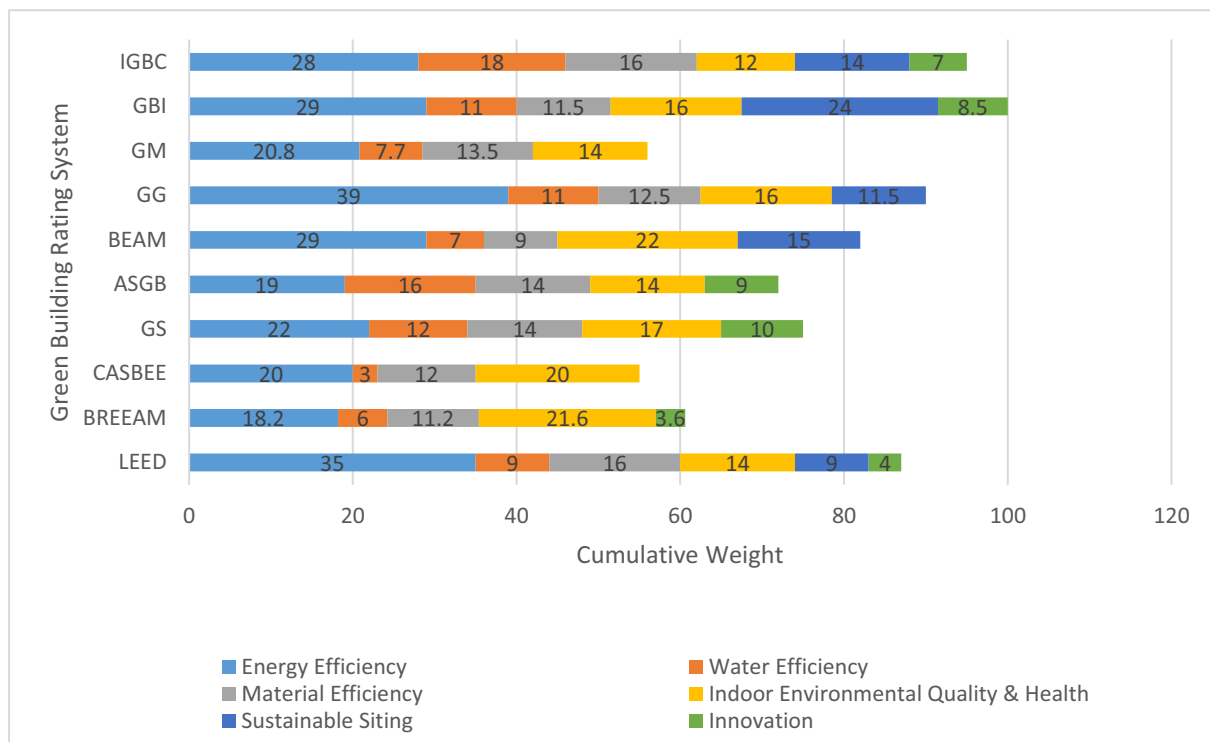
Criteria	LEED	BREEAM	CASBEE	GS	ASGB	BEAM	GG	GM	GBI	IGBC
Energy Efficiency	●	●	●	●	●	●	●	●	●	●
Water Efficiency	●	●	●	●	●	●	●	●	●	●
Material Efficiency	●	●	●	●	●	●	●	●	●	●
Indoor Environmental Quality, Health and Wellbeing	●	●	●	●	●	●	●	●	●	●
Sustainable Siting	●					●	●		●	●
Innovation	●	●		●	●				●	●
Land Use and Outdoor Environment		●	●	●	●					
Waste Management		●		●				●	●	
Construction Project Management		●		●	●		●	●		
Transport		●		●	●					
Integrative Process	●					●				
Pollution		●								
Sustainable Architecture and Design										●
Offsite Environment			●							
Climate Consideration								●		
Regional Priority	●									
Advanced Green Efforts								●		

Note: ● indicates that the criterion has been significantly addressed in the green building rating systems



Table 2 shows a range of criteria used in green building rating systems and the range may expand if more rating systems were to be included in this comparison. Four criteria that all the rating systems compared cover are energy efficiency, water efficiency as well as indoor environmental quality, health and welfare. Certain rating systems such as GM and BREEAM use health and wellbeing to represent the wider domain of noise, indoor air quality, spatial quality and thermal comfort while others use indoor environmental quality to capture the more specific indoor air, noise and thermal aspects. Sustainable siting and innovation are also emphasized in many of the rating systems though in rating systems such as BREEAM, sustainable siting is an extremely small component of the overarching land use and outdoor environment [11]. Besides, waste and project management also makes regular appearance in green building rating systems.

Figure 1 compares the weights of the six most prevalent green building rating criteria for new buildings. It shows GG and LEED having a comparatively higher weighting for energy efficiency than other rating systems while IGBC and ASGB allocate relatively higher weight for water efficiency. For all rating systems compared, the weights of material efficiency vary within a narrower range of 9 to 16. BEAM, BREEAM and CASBEE put considerable emphasis on indoor environmental quality, health and well-being [20, 24, 27]. GBI, however, emphasizes sustainable siting strongly (Figure 1).



Note: GBI and GM have separate weights for new residential and non-residential buildings. The weights above are the average of the two.

**Figure 1.** Weights of six most prevalent green building rating criteria for new buildings.

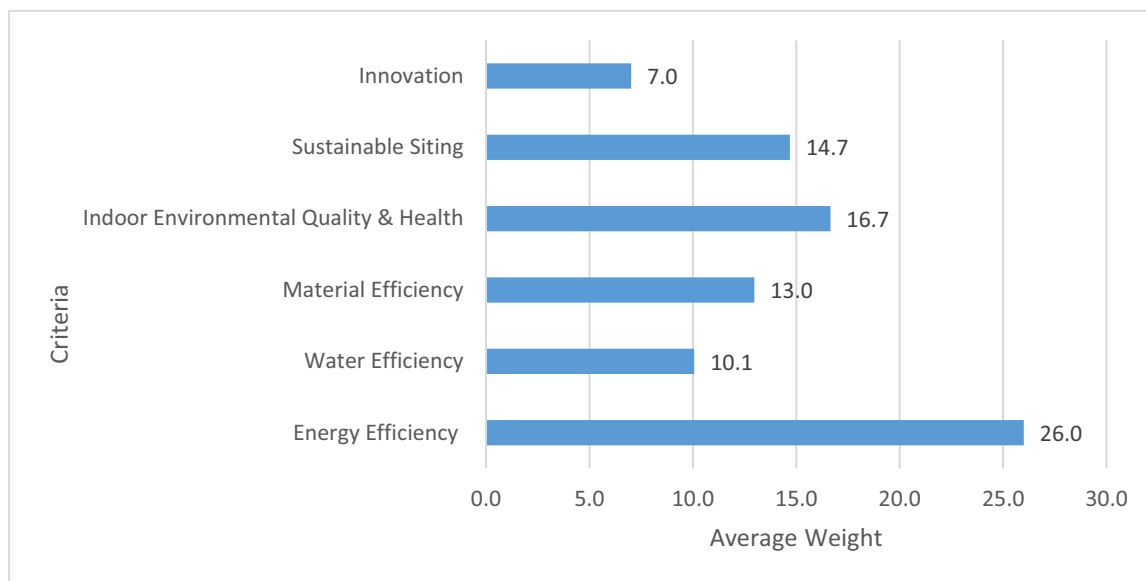
All the rating systems compared fall short of a cumulative weight of 100% except GBI whose evaluation criteria revolve only around the predominant six. Other rating systems include criteria beyond the six most prevalent ones. This is largely in line with the findings of Shan and Hwang though the values of the weights differ as the authors did not indicate the rating categories from which the weights were sourced [13].

Figure 2 shows the average weights for each of the six rating criteria. Energy turns out to have the highest average weight (26%), followed in descending sequence by indoor environmental quality,



health and well-being (16.7%), sustainable siting (14.7%), material efficiency (10.1%), water efficiency (10.1%) and innovation (7%). Shan and Hwang also revealed energy as the most highly weighted criterion in their study but the weights for other criteria in descending order are site, indoor environment, land and outdoor environment, material, water and innovation. While Shan and Hwang compared 15 green building rating systems encompassing most of those in this study, the rankings are largely in agreement with this study [13].

The six criteria in Figure 2 also aligns with the review findings of Illankoon et al. revealing seven main criteria namely energy, site, indoor environment quality, water, material, waste and pollution as well as management from eight rating systems reviewed, all covered in this study [9]. Energy is in fact the most common and predominant criterion [28].



**Figure 2.** Average weights of the six most prevalent criteria of green building rating systems.

Nonetheless, perceived importance of the criteria may differ with types of building. Kim and Osmond, in their survey among hospital staff, patients and visitors, showed indoor environmental quality was perceived as the most important criterion for certification of green healthcare building [29]. Illankoon et al. opined that the current green building rating systems, while extensively address environmental and social sustainability, do not seem to confer equal attention to economic sustainability [19]. Besides, there is a lack of comprehensive definition for certain aspects related to design, particularly passive design strategies [30].

In addition to the limitations of green building rating systems, this study also has inherent limitations. The criteria named differently in different rating systems may address overlapping aspects for instance between sustainable siting and land use as well as between climate consideration, integrative process and construction project management. This study does not map to a detailed extent the similarities between the criteria named differently, though it does merge criteria of obvious resemblance such as indoor environmental quality, and health and wellbeing. In view of the sheer number of green building rating systems, this study is limited by only looking at the popular ones. In Malaysia alone, besides the most widely used GBI, other tools such as MyCREST and GreenRE also exist while in India, there is also Green Rating for Integrated Habitat Assessment. This may call for comparison of regional green building rating systems in the future.

#### 4. Conclusion

This study compares 10 green building rating systems across 17 criteria and found that the most prevalent criteria used are energy efficiency, indoor environmental quality, health and wellbeing, sustainable siting, material efficiency, water efficiency and innovation in descending average weights. This study contributes to better understanding of the most common green building rating systems used around the world. It highlights the differences in the evaluation criteria and weights of the criteria to enable developers or building managers to pay due attention to the criteria most pertinent to the rating systems of interest. It recommends the examination of overlapping aspects within a rating system to continuously improve efficiency of the rating system. It also recommends the expansion of economic aspects in the rating systems. For future study, there is a need to look at how perceived importance of the green building rating criteria aligns with the allocated weights. It is also interesting to examine how the green buildings in different countries perform in terms of sustainability, in comparison to non-green buildings. This study also points to the need to look at implementation of the rating systems and the barrier towards implementing them.

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