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AN OUTLINE PROCESS FOR EVALUATING THE ENERGY PERFORMANCE OF GREEN CERTIFIED BUILDINGS - A REVIEW OF CASE STUDIES

T. Morgan[1], P.N. Kio[1], C.J. Anumba [2], E. Amoyaw-Brown [2] and D. L. Cohen[3]

[1] Sustainability and the Built Environment Program, College of Design, Construction, and Planning, University of Florida, Gainesville, FL, U.S.A
[2]College of Design, Construction, and Planning, University of Florida, Gainesville, FL, U.S.A
[3]School of Architecture, University of Florida, Gainesville, FL, U.S.A

ABSTRACT: Green building certifications (GBCs) have become an important area of focus in the built environment, addressing environmental issues. However, many existing GBCs used globally are not suitable for tropical climates, as they are not explicitly designed to address the unique environmental conditions and requirements of these regions. The study reviewed existing Green Building Certifications (GBCs) and the challenges of adapting them in tropical areas. The literature indicated that a significant challenge in these regions was the lack of evidence supporting the efficient application of GBCs. To address this, a comparative analysis was conducted on certified green building case studies at a large public institution. Two groups, consisting of certified and non-certified green buildings, were analyzed for significant differences in their 7-year audited energy data. A Welch two-sample t-test was performed to determine whether there was a significant difference between the energy use intensity means of the two independent groups. The results demonstrated that certified buildings had significantly higher energy performance. Subsequently, the study proposed a decision-making outline process for selecting GBCs specifically tailored for tropical regions. The findings present a workflow that leverages existing data to achieve energy-efficient buildings in tropical climates.

1. INTRODUCTION

Sustainable buildings are promoted worldwide through the implementation of green building certifications (GBCs). These standards developed by construction authorities, international organizations or private consultancy companies assess and verify the sustainability and greenness of buildings, (Lee *et al.*, 2013; Nguyen, Toroghi, and Jacobs, 2016). Since the 1990s, national GBC indices have been developed worldwide as effective metrics for sustainable buildings (Shan and Hwang, 2018). GBCs include explicit performance thresholds that buildings must meet to be certified, they also include guidelines to help teams meet or exceed the performance thresholds (Mattoni *et al.*, 2018). GBCs educate individuals on how eco-friendly and environmentally viable a building is. Rating systems, such as Building Research Establishment Environmental Assessment Method (BREEAM), and Leadership in Energy and Environmental Design (LEED) provide processes for assessing the efficiency and environmental impact of a building (Newsham, Mancini and Birt, 2009; Altomonte and Schiavon, 2013; Matisoff, Noonan and Mazzolini, 2014).

GBCs have become very important as they help building owners establish baselines against which to calibrate future performance; benchmarking by providing a basis for comparison with competitors; decision-making by establishing a basis to choose among different solutions and documentation to capture evidence that complies with sustainable rules and regulations (Eisenstein *et al.*, 2017). However, most of these green rating systems do not focus on local geographic conditions (Boschmann and Gabriel, 2013). . Using these rating systems in the tropics generalizes the environmental and cultural context of these regions and could lead to challenges in implementing these rating system standards in tropical regions.

Some GBCs consider local geography, the Green Star was developed when there was a shift towards green buildings for Australia, New Zealand, and South Africa regions. After 2008, tools designed for nations in the Northern "colder" hemisphere were modified for tropical countries (Wagner, 2014). The geographical limitations of the first and second generations of GBC systems, such as LEED and BREEAM, limit their implementation in regions beyond their jurisdiction (Olanrewaju et al., 2022). The nature of the tropical climate poses unique challenges for sustainable design. Hence, there is a need to provide an outline process to bridge the gap between global sustainability standards/ goals and regional realities.

This manuscript analyzed the different GBC systems, their shortcomings in tropical regions, and green building case studies to provide an outline process for implementing GBC in the tropics. This research explored the challenges of implementing GBCs in the tropics by reviewing literature and analyzing certified green buildings in a large public institution. Subsequently, the study proposed an outline process for GBCs tailored to tropical regions. This outline process aligns with the tropical dynamics and addresses the issue of building efficiency and affordability in developing countries by integrating local materials, energy-efficient strategies, and climate-responsive design principles. The findings of this research contribute to the advancement of sustainable design and construction in tropical climates, offering a pathway for more inclusive and region-specific green building practices.

1.1 Literature Review on Green Building Certifications in the Tropics

An electronic search was conducted on the Dimensions database, the keywords included “green building certification” and “tropics”. The search yielded 567 documents, and the Bibliometrix open-source tool was used to conduct a comprehensive science mapping analysis. The articles were filtered for the period between 2015 to 2024 resulting in 370 documents.
Figure 1 shows the annual scientific production (frequency of production). Most papers were published in 2024, 2020, and 2022 with 61, 56, and 46 documents respectively. The annual scientific production chart shows the growing interest in green building articles from the year 2015 to 2024, The top three countries were the USA, China, Malaysia, and Singapore (tied) with 26, 23, and 22 respectively. The recent trending topics in GBC publications include adaptation and energy.

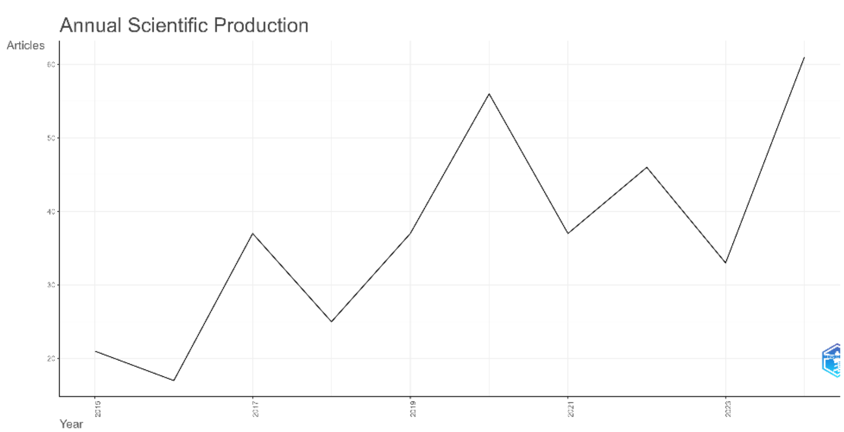

Figure 1: Annual scientific production (source: Bibliometrix)

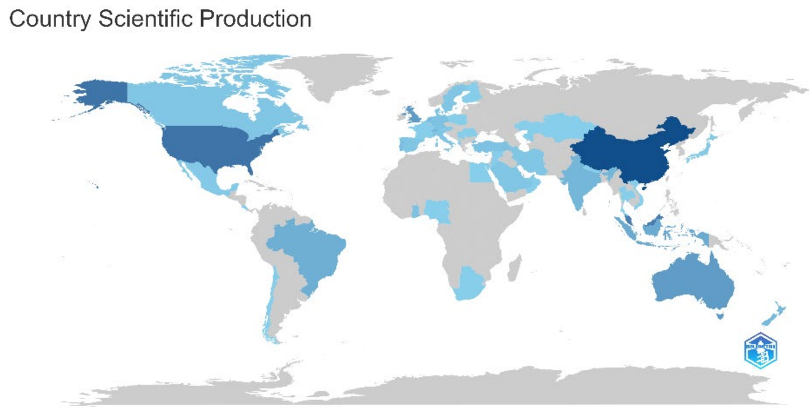

Figure 2: Countries scientific production (source: Bibliometrix)

1.2 Overview and Analysis of Prominent Sustainability Certification Methods

As part of the green transition of the built environment, many countries and international organizations have developed various green building rating systems aimed at improving the sustainability and life-cycle performance of buildings and mitigating the impacts on the environment. Sustainability certification approaches establish standardized frameworks for assessing and promoting ecologically responsible building practices. To promote sustainable development, these certifications concentrate on occupant well-being, material selection, water conservation, and energy efficiency. There are numerous globally recognized certification programs. The U.S. Green Building Council (USGBC) reported that between January 2017 and December 2021, over 36,835 projects earned LEED certification, covering 4.63 billion gross square feet of space (Cascone, 2023). USGBC's LEED rating system, which was created in the United States, is now the most used globally. Its building ratings include Certified, Silver, Gold, and Platinum. BREEAM is used mostly in Europe to evaluate the life cycle impact of a building. The WELL building standard is a rating system created by the International WELL Building Institute (IWBI) in the United States. It uses seven factors to examine the features of a building that impact the health of occupants. Other rating systems that are well known but are not used as much as LEED, BREEAM, and WELL include Living Building Challenge, Green Star, Green Globes, DGNB, EDGE, and BEER (Jeong *et al.*, 2017) and Passive House, Table 1.
To ensure that these frameworks remain applicable and efficient in tropical regions, factors such as climate-responsive design, locally accessible materials, and biodiversity protection with adjustments centered on ventilation, shading techniques, and community involvement must be prioritized. The GBCs, besides contributing to reducing the consumption of energy, carbon, and water, and the production of waste, also verify the level of sustainability that a project achieves according to the guidelines defined for each standard (Romano and Riediger, 2019).

Table 1: Review of Existing Green Building Certifications

Certification Method	Focus Areas	Strengths	Regions of Influence
LEED	Energy, Water, Materials, IEQ	Broad applicability	Global
BREEAM	Lifecycle Assessment, Ecology	Holistic	Europe, Global
WELL	Human Health and Well-being	Focused on building attributes	Global
Living Building Challenge	Regenerative Design	Performance-based	Global
Green Star	Energy, Materials, IEQ	Focused on community-level	Australia, New Zealand
EDGE	Resource Efficiency	Cost-effective	Developing Countries

Passive House	Energy Efficiency	High-performance buildings	Europe, Global

1.3 Shortcomings of GBCs in Tropical Regions

Buildings are one of the leading contributors to resource consumption and environmental emissions, accounting for about 50% of raw material use, 71% of electricity consumption, 16% of water usage, and 40% of waste sent to landfills (Oduyemi, Okoroh, and Fajana, 2017). A large amount of literature has been published about the challenges of adopting GBC systems in developing tropical countries. Chan et al. (2017) identify five underlying grouped barriers to green building technologies adoption in developing countries, namely: government-related, human-related, knowledge and information-related, market-related, and cost and risk-related barriers. The results of his research indicated that the most dominant barrier is government-related challenges, which reveals the impact of the government's support for green building policy implementation in developing tropical countries (Simpeh *et al.*, 2023a). Another research conducted by Chen et al. (2017) examined the passive design approaches across five green building rating systems (BREEAM, LEED, CASBEE, BEAM, and GBL-ASGB). The results of the research showed that most green building rating systems tend to focus on traditional whole-building energy simulation approaches but undermine passive design strategies. LEED, in particular, allocates fewer credits for passive design strategies, which creates a bias in favor of mechanical ventilation. This approach does not favor African countries due to the climate. Examples are Nairobi and Mombasa in Kenya, where passive design is more favorable and energy efficient than mechanical ventilation (Chelang'at and Lawrence, 2024).

African countries have challenges with adopting GBCs in the building sector. According to a study by (Simpeh *et al.*, 2023a), the challenges encountered in the implementation of GBC in South Africa include a lack of performance indicators for evaluating green buildings, lack of green material testing/ certification, the non-suitability of Western techniques, green buildings' lower return on investment, and lack of relevant local green building data. Other challenges are a lack of evidence to inform valuations, inadequate data regarding the benefits of green buildings, and difficulty in measuring, identifying, evaluating, and verifying green building performance. Ismaeel (2018) researched LEED adaptation in the Middle East and North Africa (MENA) regions. Although the study identified Egypt as one of the LEED principal adopting countries in Africa, it had only 15 certified buildings, Table 2. In Ghana, global GBCs have been used to certify only seven green buildings (Kumah *et al.*, 2022a). This is a very small number compared to other developed countries such as the United States of America (USA) and the United Kingdom (UK), with over 195,000 LEED-certified projects and 13,842 certified green buildings, respectively (U.K. Green Building Council, USGBC). The outline process in this study provides data on existing GBCs and green building case studies to improve the adaptation of GBCs in Africa.

Table 2: Shortcomings of GBCs in Tropical Regions

Location	Type of Certification	Certified Projects	Challenges (Gaps) with Implementing Certification	Authors
Egypt	LEED	15	Limited resources Climate barriers	(Ismaeel, 2019)
South Africa	LEED	33	Lack of performance indicators Lack of relevant local building data Non-suitability of Western techniques	(Simpeh *et al.*, 2023b)
Algeria	LEED	1	Inadequate regulatory frameworks Lack of government support	(Ismaeel, 2019)
Morocco	LEED	4	Governmental barriers Cultural barriers	(Ismaeel, 2019)
Tunisia	LEED	1	Lack of government support Lack of awareness	(Ismaeel, 2019)

Ghana	LEED	7	Lack of green building policies Climate barriers	(Kumah *et al.*, 2022b)

2. METHODOLOGY

This research utilizes qualitative and quantitative research methods to develop a GBC outline process for a green building in the tropics. The study investigates the efficacy of green building case studies with the EUI indicator and analysis of existing literature to achieve its objectives. EUI is calculated by dividing the total energy consumed by the building in one year (measured in kBtu or GJ) by the total gross floor area of the building (measured in square feet or square meters). The methods include a literature review of existing GBCs, and a comparative analysis of green-certified buildings and non-certified buildings using a Welch two-sample t-test. It was used to determine whether there was a significant difference between the means of the two independent groups based on their 7-year EUI data. Thereafter, an outline process was proposed for GBCs in the tropics, Figure 3.

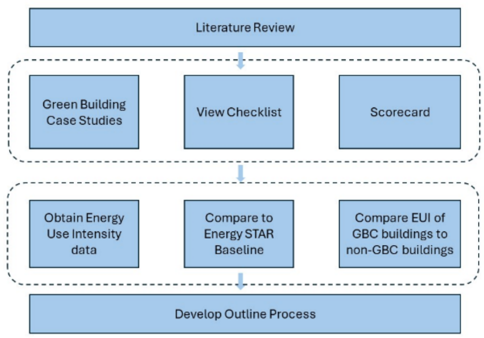

Figure 3: Research diagram for the study

3. RESULTS AND DISCUSSION

3.1 Comparative Analysis of LEED-Certified Green Buildings and Non-Certified Buildings

LEED-certified buildings consist of categories such as new construction, commercial interior, new construction retail, schools, interior construction, and homes categories, with new construction dominating the other LEED categories. To understand the relationship between GBCs and the performance of the buildings, a survey of certified buildings on a university campus was conducted. The LEED New Construction category had the highest number of certified buildings. Primary data was obtained from energy audits on the institution's website. 7-year EUI data for 42 buildings were collected and the study aimed to determine if there was a significant difference between the annual EUI for the buildings, (n=168 per group).

Table 3: Data on certified and non-certified buildings from 2017 to 2024. GSF_GBCs - Floor area of certified green buildings; EUI_GCBs - average energy use intensity of certified green buildings; GSF_non-CBs - Floor area of non-certified buildings; EUI_non-CBs - average EUI of non-certified buildings.

GSF_GCBs (ft^2)	EUI_GCBs	GSF_nonCBs (ft^2)	EUI_nonCBs
44097	52.3	47628	57.90
88306	39.47	83432	96.55
91882	297.53	99461	71.07
72724	63.6	75279	181.06
60216	54.12	59799	71.52
23635	82.49	26058	124.28

88511	44.61	74299	177.76
342961	120.13	213028	86.17
104885	68.89	109656	254.63
17032	81.78	17674	59.04
13250	37.09	13672	62.22
141486	160	146427	56.23
56352	82.8	55505	255.60
11342	66.68	11318	65.60
122838	59.3	124526	67.25
138704	63.19	197046	111.26
18977	68	20258	28.70
439085	34.66	422676	154.30
19375	58.27	26322	82.52
11789	12.3	10309	352.27
93018	144.88	70493	149.45

The ENERGY STAR Portfolio Manager provides a reference EUI for energy comparison between a property's energy use to the national median (or mid-point) energy use of similar properties. This data is utilized during benchmarking while focusing on the primary function of the buildings. The national median source EUI is a recommended benchmark metric for all buildings and recommends that the median EUI for university buildings is 84.3 kBtu/ft². The 7-year averages of certified green buildings were compared to the national median source EUI, and 4 out of 21 exceeded the national median source EUI, Figure 4. These four buildings were health and medical facilities which have strict thermal comfort requirements and specialty equipment.

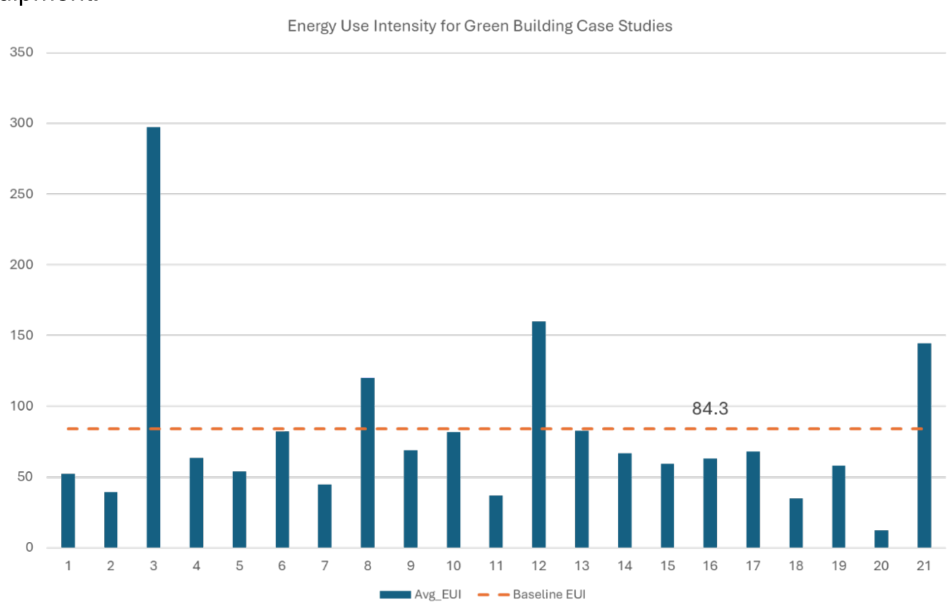

Figure 4: Energy comparison to reference EUI for Green-certified buildings

3.1.1 Data analysis

The annual EUI data of the two groups was plotted to show the trends, Figure 5a. Certified buildings had lower EUI for most of the years except from 2020 to 2021. The EUI differentials from 2017 – 2020 were higher than those of 2020 – 2024. A boxplot showed that the non-certified buildings had a higher variance of 552.44 and the maximum variance of 323.36 occurred at the EUI of the certified buildings.

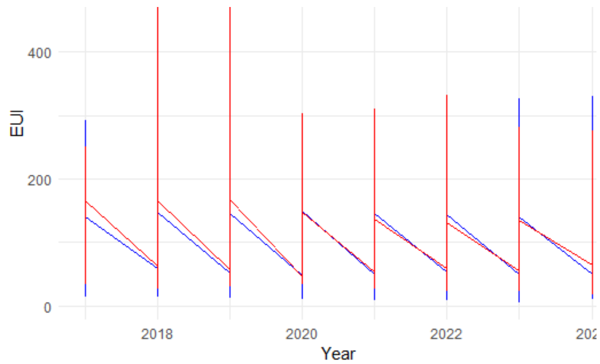

Figure 5a: Trend lines comparing annual data of the groups; blue line- certified buildings; red line – noncertified buildings

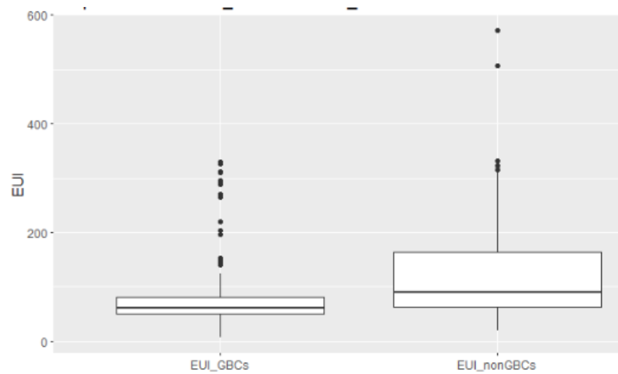

Figure 5b: Boxplot of the groups

3.1.2 Welch t-test

There were two hypotheses for the test. The null hypothesis was that the mean EUIs of the two groups were equal while the alternate hypothesis stated that there was a significant difference between the means. The Welch Two Sample t-test results indicated a significant difference between the mean EUI values of certified buildings and noncertified buildings. The test statistic (t = -5.0558) suggested that the mean EUI for the certified buildings is significantly lower than that for the non-certified buildings. With the degrees of freedom calculated at 305.73, the extremely small p-value (7.397e-07) provided strong evidence against the null hypothesis, leading to its rejection. The difference in the EUI means is statistically significant and supports the alternate hypothesis that the true difference in the means is not equal to zero. In addition, the 95% confidence interval for the difference in means ranges from -57.8568 to -25.4379, which does not include zero. This interval confirms that EUI values for the certified buildings are consistently lower than those for the non-certified buildings. The sample estimates show mean EUI values of 80.51196 for the certified buildings and 122.15929 for the non-certified buildings, highlighting the greater energy efficiency of the certified buildings. These findings underscore the significant energy performance advantage of the certified buildings.

3.2 Outline Process for Certified Green Buildings in the Tropics

The certified LEED New construction buildings displayed a significantly higher energy performance. Therefore, this study proposed an outline process to evaluate the performance of certified green buildings. The stages of the outline process include reviewing existing GBCs of buildings and then comparing EUIs of similar building types to their national median EUIs to test their performance. Thereafter, the high-performing buildings could be the basis for designing new building types.

The outline process includes the following steps:

i. Review current certified buildings GBCs in the region.
ii. Validate the performance of the certified buildings by comparing their EUI to the national median EUI or other established references.
iii. Test by conducting statistical analysis to determine evidence of significant differences in EUI between groups.
iv. Incorporate sustainable techniques from the validated certified buildings such as passive design, renewable energy use, effective water management, and shading techniques.

This outline ensures that efficient energy performance is achieved. The inclusion of the outline process in achieving GBC in tropical climates ensures that GBC systems evolve to suit a wider range of climates.

4. CONCLUSIONS

Green Building Certifications (GBCs) have been widely adopted, and this study aimed to provide evidence of their efficacy. The 7-year energy use intensity (EUI) data of two groups of buildings at a large public university were compared. Results from a Welch two-sample t-test demonstrated greater energy efficiency in the certified buildings, with mean EUIs of 80.51196 for certified buildings and 122.15929 for non-certified buildings. Subsequently, an outline process was developed to investigate the performance of current GBCs and apply findings to future developments. This study highlighted the importance and contribution of GBCs to the architecture, engineering, and construction industries. Future studies will focus on evaluating the correlation between the EUIs of validated GBCs and buildings' energy performance.

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