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Review

Are LEED-Certified Buildings Energy-Efficient in Practice?

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Abstract: Depletion of natural resources and climate change are undoubtedly the biggest challenges that humankind faces today. Here, buildings have a crucial role since they consume the majority, i.e., 30% to 40% of the total energy resources. Green building certification is one of the solutions to limit the energy use in buildings. In addition, it is seen to indicate a consideration for sustainability aspects in construction. LEED is the most widely used certificate worldwide. However, recently some critics have raised doubts about LEED and whether it actually implies sustainability. Most of the criticism has been targeted to the energy aspects of LEED. Nevertheless, there is no consensus on the usefulness of LEED: is it really beneficial for the environment, and is it worth of the money and time invested on the certification process? In this study a critical analysis of the literature to find an answer to this question is presented. Altogether 44 peer reviewed articles dealing with the abovementioned issue were selected out of 164 search result. Based on the studied material, the different aspects of LEED from the viewpoint of energy-efficiency are discussed. From the 44 reviewed articles, ten articles state that LEED certificate indicates energy efficiency while eight papers end up with an opposite conclusion. The rest of the papers do not take any stand on this matter. The study showed that energy efficiency of LEED-certified buildings is questionable especially at lower levels, i.e., certified. Therefore, it is recommended to modify the Energy and Atmosphere category of LEED in order to improve the actual energy performance of buildings.

Keywords: Leadership in Energy and Environmental Design; energy performance; green building; sustainable construction; review

1. Introduction

During the past years environmental issues have become one of the most important concerns of human being [1,2]. This has resulted in the implementation of new measures to monitor and indicate environmental burden as well as inventing new solutions to limit environmental emissions [3–6]. Continuous need of energy and increasing demand of natural resources in both developing and developed countries is making the situation even worse [7,8].

Buildings are one of the main consumers of energy [9–11]. According to building sector, in the US and UK buildings use 45% and 42% of the entire energy countrywide, while in OECD countries the corresponding share is 31% [1]. Due to the high energy consumption, it is necessary to make plans and set rules for minimizing the use of energy by buildings [12–14]. Therefore, numerous domestic and international green building certification systems have been constructed and are already in common use [15–19]. The British Building Research Establishment Environmental Assessment Method (BREEAM) is the first one of such certification systems and adopted worldwide. While the American Leadership in the Energy and Environmental Design (LEED) system created in 1998 by the US Green Building Council (USGBC), is most common. Other certification systems include the Green Standard

for Energy and Environmental Design (G-SEED, Korea), the Green Star (Australia) and Comprehensive Assessment System for Built Environment Efficiency (CASBEE, Japan) [20]. In addition, there are several voluntary standards for energy efficiency in buildings, such as Passivhaus (see [21–23]) or Energy Star (see [3]).

Currently, LEED has become the most famous certification system for buildings and it is applied all over the world [24–28]. The USGBC [29] defines LEED system as follows: “LEED (Leadership in Energy and Environmental Design) is the most widely used green building rating system in the world. Available for virtually all building project types, from new construction to interior fit-outs and operation & maintenance, LEED provides a framework that project teams can apply to create healthy, highly efficient, and cost-saving green buildings. LEED certification is a globally recognized symbol of sustainability achievement.” The certificate results in additional expenses in building projects [30]. One of the reasons for studying the real performance of LEED-certified buildings is gaining of information on energy efficiency of these buildings in return of higher investments of time and money.

LEED has played a significant role in improving the green building certificate system in the world [31–33]. It tries to decrease negative impacts on the environment and maximize energy efficiency [31,34,35]. In addition to many studies that show the benefits of LEED, some researchers criticize it by highlighting that it has not significantly reduced the energy use in buildings and it will not reach the energy-efficiency goals set for the future [26,36–43]. Therefore, the aim of this study is to critically analyze the scientific literature dealing with LEED system in order to conclude whether LEED certificates (1) really imply energy efficiency, (2) enhance the reduction of greenhouse gas (GHG) emissions and (3) are beneficial from the viewpoint of overall environmental impact of buildings.

1.1. LEED Certificate

LEED, first published as LEED version 1.0, was originally developed to be a building rating system only for new construction (NC) [44]. The second version, LEED NC v2.0, was published in 2001, followed by an update LEED NC v2.2 in 2005. The third version from year 2009, at present the most widely adopted version of LEED, included a collection of rating systems for design, construction and operation of different types of buildings. The latest version, LEED version 4, was released in 2013.

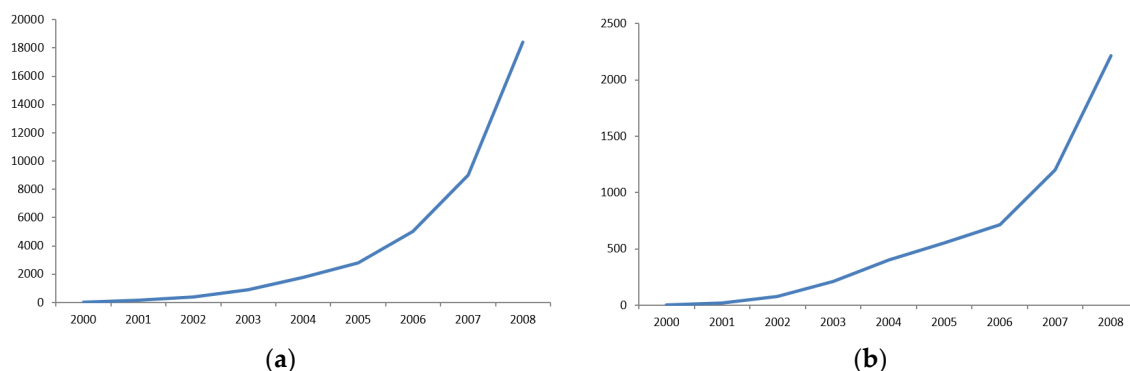
LEED includes five main certification types, namely LEED Building Design and Construction; LEED Interior Design and Construction; LEED Neighborhood Development; LEED Building Operations and Maintenance; and LEED for Homes. The certification level depends on the points allocated on the basis of how well a building fulfils the specific criteria in the different assessment categories (see below) and includes the following: Certified (40–49 points), Silver (50–59 points), Gold (60–79 points), and Platinum (80+ points).

Points are allocated to six categories: Sustainable Sites (SS), Energy and Atmosphere (EA), Water Efficiency (WE), Indoor Environment quality (IEQ), Material and Resources (MR), and Innovation (INNO). Among these categories energy-related credits (EA) dominate with a share of almost 30% of the overall certification score [33,43,45]. Therefore, a high score in the EA category usually results in a higher level of LEED certificate [10,15,46]. The allocation of credits has changed in different versions as shown by the comparison between LEED v2.2, v3 and v4 (Table 1). For example, compared to LEED v2.2, in LEED v3 the share of the credits allocated to category EA increased by 7% while those of category IEQ decreased by 8%. In addition, a new credit category indicating regional priority was added into LEED 2009. In LEED v4, the category SS is divided into two categories of Sustainable Sites (SS) and Location and Transportation (LT). In addition, one credit is allocated to a new category of Integrative Process (IP).

Wu et al. [33] studied altogether 3412 building projects which had a LEED 2009 certificate. The majority of these, i.e., 2770 buildings (81.1%) were located in US, 126 (3.7%) in China, 53 (1.6%) in Turkey, 40 (1.2%) in Brazil, 34 (1%) in Chile, and 30 (0.9%) in Germany. In fact, majority of LEED certified buildings are located in US. The number of LEED-certified and LEED-registered buildings has been constantly increasing worldwide as shown in Figure 1a,b.

Table 1. Category-specific points in LEED v2.2, v3 (2009), and v4 [29].

Categories	LEED v2.2	LEED v3 (2009)	LEED v4
Location and Transportation (LT)	-	-	16 (14.6%)
Sustainable Sites (SS)	14 (20.3%)	26 (23.6%)	10 (9.1)
Energy and Atmosphere (EA)	17 (24.6)	35 (31.8)	33 (30)
Water Efficiency (WE)	5 (7.3)	10 (9.1)	11 (10)
Indoor Environment Quality (IEQ)	15 (21.7)	15 (13.6)	16 (14.5)
Material and Resources (MR)	13 (18.8)	14 (12.7)	13 (11.8)
Innovation (ID)	5 (7.3)	6 (5.5)	6 (5.5)
Regional Priority (RP)	-	4 (3.7)	4 (3.6)
Integrative Process (IP)	-	-	1 (0.9)
Total	69	110	110

**Figure 1.** Number of (a) LEED-registered and (b) LEED-certified buildings from 2000–2008 [29].

Additional expenses of LEED-certified buildings have been estimated to vary from 2% to 10% of the total costs [3]. Uğur and Leblebici [47] reported that the additional construction costs of two LEED-certified buildings, one having a Gold and the other a Platinum level certificate, were 7.43% and 9.43% of the total costs. On the other hand, LEED-certified buildings have a rent premium of 3–5% and a sale premium equal to 25% [48]. In addition to the rent and sale premium, the LEED-certified buildings have other advantages arising from lower operating expenses related to the use of water and energy, maintenance, insurance, management, and security [48–51]. It is worth adding that some features of buildings do not require spending extra money but can be considered in the design phase [52–55]. For example, east–west orientation design is helpful in gaining the maximum benefit from sunlight [51].

1.2. Other Certificates

Several additional certification systems have been adopted around the world or at national levels. Comparisons of these have been presented in several review papers (see, [56–58]). Below some of the most common alternative systems are briefly described.

BREEAM is the oldest green building certificate [57]. BREEAM includes the following certificates: BREEAM New Construction, BREEAM International New Construction, BREEAM In-Use, BREEAM Refurbishment, and BREEAM Communities. The assessment categories cover issues related to management, energy, health and wellbeing, transport, water, materials, waste, land use and ecology, and pollution [57]. The five certification levels include Pass, Good, Very good, Excellent, and Outstanding.

Green Building Index (GBI), a Malaysian certificate, considers energy efficiency, indoor environment quality, materials and resources, sustainable site planning and management, water efficiency, and innovation as indicators of sustainability [56]. This certificate can be used for new construction and existing building, data center, retail, hotel, resort, and township. The certification levels are Certified, Silver, Gold, and Platinum.

Green Star, an Australian green building certificate, was launched in 2003 by Green Building Council of Australia [58]. It includes the following categories: Energy, Transport, Management, Indoor Environment Quality, Water, Materials, Emissions and Innovation, and Land Use and Ecology [58]. It has five certification levels: Minimum Practice (One star), Average Practice (Two stars), Good Practice (Three stars), Best Practice (Four stars), Australian Excellence (Five stars), and World Leadership (Six stars).

2. Methodology

The review was conducted by searching for scientific English journal articles that discuss the actual energy consumption of LEED buildings. Web of Science was used as the search engine. The selection of the reviewed papers was based on PRISMA diagram. Initially the phrases “LEED” AND “Energy” were searched through the title for the time period of all years until January 24, 2019. This resulted in 160 hits. These were complemented with four additional papers that discussed the study issue. At the next stage, other than scientific papers, e.g., meeting abstracts, letters, and conference proceeding papers were excluded, which reduced the number of papers to 111. Then, 63 of the results were removed through records screening. It is necessary to mention that LEED acronym has also been used in other contexts and thus none of the sources for the year 2000 and before were related to Leadership in Energy and Environmental Design. Lastly, the full-text articles of the remaining papers were assessed for eligibility. By omitting papers that were not related to the topic of the review, finally 44 research papers remained. The selection process is summarized in Table 2.

Table 2. Selection procedure of the scientific papers studied in the review.

	Selection Basis	Number of Remaining Papers
1	Search terms: “LEED” AND “Energy”	160
2	Adding 4 papers based of previous knowledge	164
3	Exclusion of non-peer reviewed papers	111
4	Screening the records	48
5	Exclusion of irrelevant papers after the full-text assessing for eligibility	44

3. Results and Discussion

3.1. General Findings

The 44 studied articles are mainly focused on US and Canada (Figure 2). Undoubtedly, most LEED-certified projects are located in US but it is vital to conduct more research in other parts of the world when enough data is available.

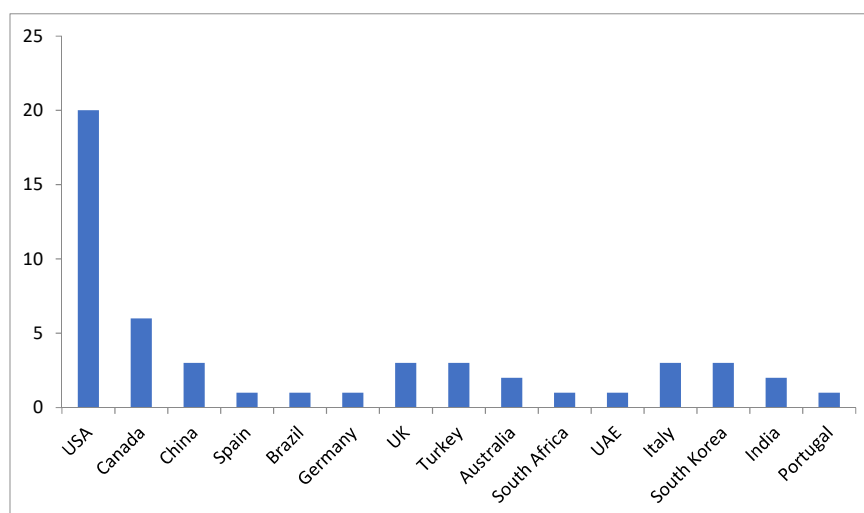


Figure 2. Distribution of selected papers that have location for conducted research.

The results from these studies are contradictory: while some papers support the use of LEED and confirm that LEED-certified buildings use less energy compared to non-certified ones, others state the opposite (Table 3). Some studies took no stand on this aspect.

Right from the very beginning of the LEED system, the common assumption was that it will reduce energy consumption of buildings and limit GHG emissions [26,59,60]. In order to support this assumption, the USGBC commissioned the New Buildings Institute (NBI) in 2006 to study the energy use of buildings that were LEED-certified. The results showed that on the average, LEED-certified buildings consume 25% to 30% less energy compared to conventional buildings [36,61].

Newsham et al. [61] re-analyzed the energy-consumption data for LEED-certified buildings supplied by NBI and found that such buildings used 18–39% less energy per floor area compared to conventional buildings. However, around one third the LEED-certified buildings used in fact more energy than the conventional buildings. Moreover, the energy performance correlated only weakly with the certification level or points that the LEED-certified buildings earned at the design phase.

Scofield [36] divided the energy use of buildings in two categories, namely source energy (initial fuel used to produce either electricity or transportation fuel) and site energy (electricity or fuel consumed within a property). He ended up with different results than Newsham et al. [61] in reporting a lower use of site energy by LEED-certified buildings compared to conventional buildings, the difference being about half of that reported by NBI. In addition, Scofield state that there is no difference between LEED-certified and conventional buildings in terms of source energy use.

Scofield [37] further examined the data concerning buildings in the New York City in 2011. This data covered 953 office buildings, of which 21 were LEED-certified as per the local law 84 of New York City. Regarding energy use and GHG emissions, LEED-certified buildings showed no difference compared to other buildings with the same type, time frame, and geographical and climate region. While Silver and Certified LEED buildings in this research underperformed, Gold certified LEED buildings outperformed in energy use by 20%.

Scofield and Doane [38] cross-listed the Chicago benchmarking data including 1521 commercial buildings, with the database of USGBC in order to find 132 properties in Chicago that were LEED-certified. The research showed that LEED-certified buildings used equivalent amount of source energy than the buildings without LEED certificate, but their use of site energy was slightly lower.

Chen et al. [62] studied three LEED-certified office buildings in China in order to assess their energy performance. One of these buildings was located in Beijing and two in Shanghai. The results showed a reduction in energy use in these buildings from 2 to 5%.

The review shows that several studies have been conducted around the world that deal with the energy efficiency of LEED-certified buildings. The studied buildings vary in their characteristics, e.g., size, type of occupants, location and climate zone, among others. Some studies confirm that LEED certification reduces the level of energy use while some studies have ended up with quite opposite results. Small sample size and different characteristics of buildings are crucial parameters that influence these findings.

Table 3. Main findings documented in the study material.

Author	Country	Support LEED	Main Findings
Scofield [36]	USA	No	<ul style="list-style-type: none"> • LEED-certified buildings use the same amount of source energy as non-certified ones • LEED-certified buildings use 10–17% less site energy than non-certified ones which is almost half of the figure provided in the NBI report
Newsham et al. [61]	USA	Yes	<ul style="list-style-type: none"> • LEED-certified buildings use an average of 18–39% less energy compared to non-certified ones • Despite the average saving, 28–35% of LEED-certified buildings use more energy than non-certified
Scofield [37]	USA	No	<ul style="list-style-type: none"> • LEED-certified buildings in the NYC with Certified and Silver level LEED certificate use more energy than non-certified buildings • Gold level LEED-certified buildings in the NYC used 20% less energy compared to non-certified
Issa et al. [49]	Canada	-	<ul style="list-style-type: none"> • LEED-certified schools used 37% more electricity than conventional ones • LEED-certified schools used 56% less gas than conventional ones
Scofield et al. [38]	USA	No	<ul style="list-style-type: none"> • LEED-certified buildings in Chicago are not more energy efficient in using source energy compared to non-certified buildings • Use of site energy of LEED-certified buildings in Chicago is 10–12% less than that of non-certified buildings
Chen et al. [62]	China	Yes	<ul style="list-style-type: none"> • Three LEED-certified office buildings in China lead to 2–5% reduction in energy use compared to non-certified buildings
Sabapathy et al. [44]	India	Yes	<ul style="list-style-type: none"> • LEED-certified buildings use average of 34% less energy, which results in a 8% cost reduction in Bangalore (India)
Uğur and Leblebici [47]	Turkey	Yes	<ul style="list-style-type: none"> • Two LEED-certified buildings in Turkey with a Gold or Platinum level had 31% and 40% lower energy use than non-certified buildings, but 4.43% and 9.43% higher construction cost respectively
Cubi and Keithet [63]	-	-	<ul style="list-style-type: none"> • Certificates such as LEED can cause emissions reduction if they distinguish carbon footprint from energy use, i.e., if they separate site energy from source energy • Certificates should require objective measurements of real performance of buildings
Kern et al. [39]	Brazil	No	<ul style="list-style-type: none"> • In a Gold LEED-certified building in Brazil, consumption of energy and water measured during the first year of occupancy, was higher than indicated at the design phase; a downward trend is seen over time, however • Occupants are satisfied with temperature and lighting of LEED-certified buildings
Reichardt [31]	USA	Yes	<ul style="list-style-type: none"> • LEED-certified office buildings have seriously significantly lower operating costs but they have higher rents

Table 3. Cont.

Author	Country	Support LEED	Main Findings
Fuerst [3]	USA	Yes	<ul style="list-style-type: none"> • LEED-certified buildings have the cost premium of 2 to 10%, in return they benefit from reduced operating costs and improved productivity • The majority of LEED-certified buildings are in the categories of New Construction (NC) and Commercial Interiors (CI)
Michael et al. [59]	South Africa	Yes	<ul style="list-style-type: none"> • A LEED certified hotel in South Africa has reduced carbon footprint, operating costs and improved air quality
Dermisi and McDonald [64]	USA	Yes	<ul style="list-style-type: none"> • LEED-certified properties have a premium sale of 23% compared to non-certified ones
Fuerst and McAllister [48]	USA	Yes	<ul style="list-style-type: none"> • LEED-certified buildings have a rent premium of 3 to 5% and sale price premium of 18 to 25% • LEED-certified buildings have benefits including lower operating costs, reputation benefits and higher productivity
Jeong et al. [26]	South Korea	No	<ul style="list-style-type: none"> • Buildings certified by G-SEED (A South Korean green building certificate) and LEED have no significant energy saving compared to non-certified ones; this result is contradictory to the assumption of energy saving of 10 to 15%
Al-Ghamdi and Bilec [15]	-	-	<ul style="list-style-type: none"> • Regarding source energy, emissions of energy consumption of a 43,000 ft² (equivalent to 3995 m²) office building modelled by Building Information modelling (BIM) ranged from 394 ton to 911 ton CO₂ equivalent in 400 different locations of the world
Heidarinejad et al. [65]	USA	-	<ul style="list-style-type: none"> • Heating used the majority and lighting the lowest amount of energy in 134 US. LEED NC office buildings
Fuertes and Schiavon [66]	USA	-	<ul style="list-style-type: none"> • In terms of plug loads energy, 40% of 660 LEED Commercial Interiors (CI) and 429 LEED New Construction (NC) used 10.8 and 16.1 W/m² for their peak plug load estimates • The average plug loads energy consumption of 68% of the buildings was 10.8 W/m²
Chen et al. [62]	China	Yes	<ul style="list-style-type: none"> • Three LEED-certified buildings in China, one in Beijing and two in Shanghai, used 2 to 5% less energy compared to non-certified buildings
Chokor and Asmar [40]	USA	No	<ul style="list-style-type: none"> • Regarding actual predicted energy consumption, there is not significant difference between LEED-certified and non-certified buildings
Menassa et al. [41]	USA	No	<ul style="list-style-type: none"> • Statistical analysis showed that 9 of 11 LEED-certified buildings for the United States Navy did not achieve the goal of 30% electricity consumption saving
Wedding and Crawford-Brown [42]	USA	No	<ul style="list-style-type: none"> • There is inconsistency between the actual and expected energy consumption of LEED-certified buildings • Revisions are suggested to LEED's Energy & Atmosphere (EA) credit in order to minimize the variation and magnitude in energy performance of LEED-certified buildings

3.2. Detailed Results

3.2.1. The Question of Source and Site Energy

One of the main criticisms about LEED-certified buildings relates to the source of energy considered in the evaluation, i.e., whether they use site energy (electricity or fuel consumed within a property) or source energy (initial fuel used to produce either electricity or transportation fuel). The amount of site energy consumed by a property can be simply found via monthly utility bills. But in order to calculate the amount of source energy, it is necessary to consider all phases of energy production including transportation. It is, therefore, vital to understand whether one should use site energy or source energy as a basis in the calculation of points.

For example, Scofield [36] criticized the reanalysis of Newsham et al. [61] that compared the energy efficiency of LEED-certified with non-certified buildings. Scofield [36] demonstrated that source energy used by LEED-certified buildings is equivalent to non-certified buildings and therefore, the GHG emissions of the LEED-certified buildings are in fact not compared with non-certified ones. Another study on office buildings in New York City ended up with similar results, and showed that LEED-certified buildings with Certified and Silver level certificate actually consume more source energy than non-certified ones while only buildings with the Gold level certificate use 20% less source energy [37]. On the other hand, Scofield and Doane [38] state that LEED-certified buildings use 10–12% less site energy. However, they also highlight that it is necessary to consider the use of source energy instead of site energy in order to rule in the GHG emissions.

Is it then justified to judge the energy efficiency based on source energy? The answer is mainly based on the location of project. In some developed countries it is possible to select the type of energy when buying it. It is correct to judge the energy efficiency in these countries by source energy. However, it seems incorrect in countries where there is no opportunity to select the type of energy because source energy is based on city council's or government's policies in these countries. Imagine that a city receives its energy from three different sources. The northern part of the city has nuclear power, the center has natural gas and the southern part has electricity available. The availability of the energy sources comes from the policy of the government or maybe of the city council. A new construction project is about to start in the city. If the stakeholders decide to implement the construction project in the northern part of the city they will automatically get the best outcome in the LEED scoring system for source energy usage because nuclear power has the lowest GHG emission compared to other sources of energy [31]. Hence, when the allocation of the points in the LEED certificate is based on source energy, most clients tend to implement the construction project in the city (or part of it), region or country where nuclear power is available. This can result in the development of only some parts of a city, region or country.

The factor for converting site energy to source energy is 1.05 for natural gas, meaning that the off-site loss is 5% when delivering the energy to the buildings; In the case of electricity, the factor is 3.14, which means that source energy used by building is 3.14 times higher than site energy [38]. However, as the example above demonstrates, source of energy is under the control of governments or city councils.

The government is responsible for determining the energy policy and promoting the use of clean energy. Governments can impose a carbon tax or provide incentives, which serve as means to implement the policy and drivers to reach the set objectives for energy use [3]. Depending on the location and characteristics of the building, it is possible to produce on-site renewable energy using solar panels or wind power, among others. LEED system could be modified so that it is possible to earn extra points from using on-site renewable energy sources in the case of limited sources of energy.

The designers of buildings often face with the fact that the cost of energy is a major boundary condition that limits their choices. For example, in 2004, the price of natural gas was the same in West Virginia and Vermont, but cost of electricity in Vermont was double, compared to West Virginia [63]. Such differences force the designers to ignore GHG emission and focus only on the costs of energy

(site energy). This problem again arises from the policy decisions made by policy-makers and planners of energy systems at the regional or country level.

It is worth noting that the buildings with a low level of LEED certificate, especially those at the lowest level (Certified) do not differ from the non-certified buildings in the use of source energy. Therefore, their GHG emissions and environmental impact are also almost equivalent [3]. There are clients who are just searching for eco-certification, and so they try to get the lowest level certificate [3]. Fortunately, the statistics show a trend that the share of LEED-certified buildings having a certificate at a higher level is increasing (Figure 3).

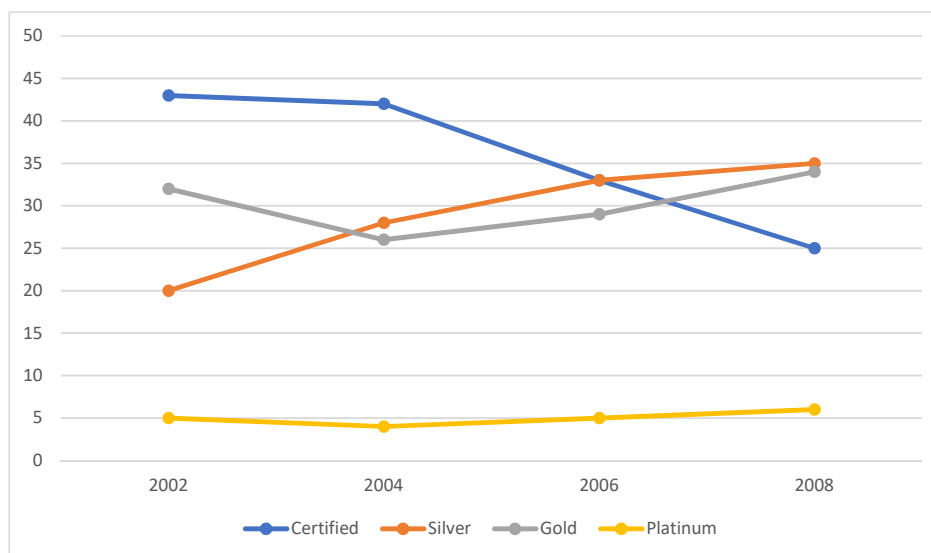


Figure 3. Distribution of different level of LEED-certified buildings (%) [29].

When source energy is an issue, it is necessary to conduct a more detailed study to find out how it should be handled in the LEED system. For example, coal, which is the main source of energy in some countries, is classed into four different types: bituminous, lignite, anthracite, and peat. Furthermore, oil is divided into residual fuel oil and diesel; renewable sources are divided into four groups, including biomass, mix photovoltaic, wind power plant, and heat geothermal probe; and hydropower covers three types of plants, namely run-of-river power plant, reservoir power plant, and storage power plant [15].

3.2.2. The Issue of the Weighting System

The other issue relates to the ‘building weighted’ system used by Newsham et al. [61]. This means classifying buildings as small, medium, and large instead of using their gross area (GA). In addition, Scofield [36] believes that the NBI report has compared median energy use of LEED-certified buildings with mean energy use of non-certified ones. Only in the case of all samples of the same size, the result will be equal which is practically almost impossible. Related to the size categories, it is worth mentioning that in US, the small and large size buildings differ from each other in terms of GA; half of the 4.9 million buildings are less than 5000 ft² (equivalent to 465 m²) while their contribution to the estimated total surface area of 72 billion ft² (equivalent to 6689 million m²) is only 9% [36].

In their study, Newsham et al. [61] excluded 21 LEED-certified buildings from the total number of 121 because these buildings had unusual use of energy. Such an exclusion is not scientifically justifiable and can lead to biased study results. Maybe if all of the 121 LEED-certified buildings were considered in this study, the GA-weighted energy-efficiency of the LEED-certified buildings would have been lower compared to the non-certified buildings. Alternatively, it can be concluded that LEED does not imply energy-efficiency in all cases.

3.2.3. The Issue of Representativeness and Comparability

The result from comparing two groups of samples is reliable when both groups are as similar as possible. However, when comparing two groups, i.e., LEED-certified and non-certified buildings, with each other, several parameters should be taken into account. Here the age and size of the building, climate zone, type of use, and occupants' awareness are all important factors.

Most of the previous studies on LEED focus on office buildings while there are very few studies on other type of buildings, e.g., residential houses. The study by NBI included 121 LEED-certified buildings. These cover 22% of the total number (552) of the certified buildings in US [37], of which 21 were excluded. The selection procedure is also an issue. In the case of the NBI study, the LEED-certified buildings were not randomly selected [37]. This will result in bias since it can be assumed that mainly those occupants who are pleased with their buildings are willing to participate in the study.

LEED-certified buildings are new and so, they benefit from the new technology and tend to fulfill the requirements of the customers, who are nowadays often well aware of environmental aspects. Comparing these new buildings with older, non-certified ones will lead to biased results. It should be considered that buildings are continuously improving and they are more resource-efficient than in the past. For instance, the use of two-layer glasses with light-weight plastic frame windows was previously rare in the city of Tehran (Iran) while today almost all buildings are using this type of windows.

The occupant's behavior is an important factor in the studies that compare certified buildings against non-certified [49]. Expectations of LEED-certified buildings might be higher than of other buildings because the occupant thinks that his/her building is energy efficient and so, he/she does not need to save energy in the daily activities. According to Issa et al. [49], retrofitted schools consumed more energy compared to non-retrofitted schools when the expectation was quite the opposite. The reason for this unexpected result was that the occupants' behavior changed. For example, the occupants might be willing to use some spaces that they did not use before retrofitting or they might increase the temperature since they believe that the new heating system is very energy-efficient.

The occupants' awareness in LEED-certified buildings is sometimes lower compared to occupants in non-certified buildings with lower level of technology [67]. It is necessary for occupants to know how the facilities in their building can work most efficiently. As an example, Brown and Gorgolewski [67] gathered occupants' opinions about the high-tech heating, ventilation, and air conditioning (HVAC) system of their LEED-certified building through a questionnaire. The occupants recognized some problems with noise caused by fans, but most of them did not know what an HVAC system is or they were not familiar with the instructions of the system.

3.2.4. The Issue of Factual Energy-Efficiency

One of the main challenges concerning the energy-efficiency of LEED-certified buildings is their actual performance. A building might be energy-efficient in its design phase but not in the operation phase [39]. Stoppel and Leite [43] studied two buildings and found that the designed building over-predicted the use of energy by 14% and 25% in theory. One reason for the difference can be changes made in the construction phase based on client's requirement or change request of building without any notice. LEED does not include strict inspection system for construction phase. Recently, LEED has established a system for monitoring the use of energy in new buildings that pursue a LEED certificate in order to find out the actual performance of certified buildings. This is one way to conduct post-occupancy evaluation (POE). POE could be improved by creating a system to gather occupants' opinions through questionnaires in order to complement the data on the energy-efficiency at the use phase [67].

PROBE (post-occupancy review of buildings and their engineering), which was first adopted in the UK in 1990s, was the first formative study using POE [67]. Generally, POE tries to evaluate success and failure of the buildings and receives occupants' feedback in order to correct repeated mistakes. The University of California Berkeley's Centre for Built Environment maintains a POE database that includes 600 buildings located in North America [67]. This data is beneficial for the research on POE

of buildings including LEED-certified ones. It would be beneficial to have a similar databank also in other parts of the world.

4. Conclusions and Further Research

The general public has become more aware of the environment and concerned about the limited natural resources and climate change. In addition, the continuous rise of energy prices makes it vital to construct energy-efficient buildings. Therefore, the idea of green building has been gaining increasing acknowledgement during recent years. Due to the rising appreciation of sustainable development, buildings which have been designed to use less energy and advanced coordinated technologies to cut the energy demand and consumption are progressively favored contrasted with traditional buildings.

The LEED certification system for buildings was originally created primarily for the purpose of increasing the energy-efficiency of buildings. This certificate is a scoring-based system, which allocates points to buildings based on six assessment categories. One of the most important categories is Energy and Atmosphere that covers almost 30% of the total amount of the credits. This literature review revealed that the opinions on LEED certification as an indicator of energy-efficiency are controversial. One of the main challenges in the evaluation as per the LEED certification relates to the use of site energy vs. source energy. In countries that do not have the possibility of selecting energy type, the source of energy is under control of governments or city councils and depends on the local, regional or national energy policy and decision making in the planning phase of the energy system for a building. However, LEED could be further developed so that one can earn extra points by using renewable energy sources in locations without alternative energy sources.

When comparing buildings with LEED-certificate against those without LEED certification, reliability of the results becomes an issue. Factors, such as age and size of the building, type of use, climate zone, and occupants' awareness are important factors to consider. The buildings to be compared should also be randomly selected. Including only buildings whose owners have volunteered to participate in the comparison, can cause bias to the results.

LEED certification reduces the use of energy especially in the case of buildings having higher levels of certificate, such as Gold or Platinum. While the consumption of energy by the building having a certificate of the lowest level (Certified) appears to be almost similar to that of non-certified buildings. However, due to a lack of data from different locations worldwide, it is not possible to give a clear answer to the question on the actual energy efficiency of LEED-certified buildings. Most of the papers studied in this review are focused on US, which has the longest history of adopting the LEED system. LEED has later on been widely adopted also in other parts of the world, recently particularly in China. However, only very limited data from other countries have been published in scientific papers. Therefore, it would be useful to focus further LEED studies on other locations of the world when data becomes available. Continuous improvement of the LEED system is also needed in order to reach its main goal of being a guarantee of environmental performance.

It is worth noting that LEED is not just about energy-efficiency. It includes five additional categories, which could be evaluated and discussed. For example, the MR category (materials) has hardly been studied despite the fact that it covers almost 13% of the credits in LEED 2009. Research on this category could help decrease the use of natural resources and the overall environmental impact.

Future research should also consider how various factors, such as the age and size of the building, the type of use, climatic zone and the behavior of occupants affect the actual energy performance of certified and non-certified buildings. In order to find out the real performance of buildings, post-occupancy evaluation (POE) is an efficient tool. The outcome of any design of project will be shown in the operation phase, and it is possible to evaluate it by POE. On the other hand, life cycle analysis (LCA) can be used to assess the overall environmental impact. Hence, LCA will be a way of calculating GHG emissions and finding new and innovative solutions to limit them. POE and LCA of LEED-certified buildings can, therefore, be attractive topics for further studies.

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