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Article

Evolution of the (Energy and Atmosphere) credit category in the LEED green buildings rating system for (Building Design and Construction: New Construction), from version 4.0 to version 4.1

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Abstract: LEED (Leadership in Energy and Environmental Design) is a certification program for quantitatively assessing the qualifications of homes, non-residential buildings, or neighborhoods in terms of sustainability. LEED is supported by the U.S. Green Building Council (USGBC), a nonprofit membership-based organization. Worldwide, thousands of projects received one of the four levels of LEED certification. One of the five rating systems (or specialties) covered by LEED is the Building Design and Construction (BD + C), representing non-residential buildings. This rating system is further divided into eight adaptations. The adaptation (New Construction and Major Renovation) or NC applies to newly constructed projects as well as those going through a major renovation. The NC adaptation has six major credit categories, in addition to three minor ones. The nine credit categories together have a total of 110 attainable points. The Energy and Atmosphere (EA) credit category is the dominant one in the NC adaptation, with 33 attainable points under it. This important credit category addresses the topics of commissioning, energy consumption records, energy efficiency, use of refrigerants, utilization of onsite or offsite renewable energy, and real-time electric load management. This study aims to highlight some differences in the EA credit category for LEED BD + C:NC rating system as it evolved from version 4 (LEED v4, 2013) to version 4.1 (LEED v4.1, 2019). For example, the updated version 4.1 includes a metric for greenhouse gas reduction. Also, the updated version 4.1 no longer permits hydrochlorofluorocarbon (HFC) refrigerants in new heating, ventilating, air-conditioning, and refrigeration systems (HVAC & R). In addition, the updated version 4.1 classifies renewable energy into three tiers, differentiating between onsite, new-asset offsite, and old-asset offsite types.

Keywords: LEED; green buildings; energy and atmosphere; USGBC; v4; v4.1

1. Introduction

Around 90% of today's buildings are expected to remain in operation in 2050 (EEA, 2022). Considering direct global CO_2 emissions data for 2021 from the major 4 sectors of: (1) power (electricity generation), (2) industry, (3) transportation, and (4) buildings; the share of the buildings sector was the smallest. It had a share of 8.7% (with respect to the sum of 34.44 Gt CO_2). The electricity sector was the largest in terms of direct CO_2 emissions (42.78% share, 14.39 Gt CO_2) (IEA, 2023). This is illustrated in **Figure 1**. Such a small fraction of the buildings sector may give a false impression that they have an insignificant role in anthropogenic (not natural, but human-caused) CO_2 emissions, and that they do not contribute to global warming and, more broadly, to climate change (Marzouk, 2021a, 2024; Stefkovics and Zenovitz, 2023).

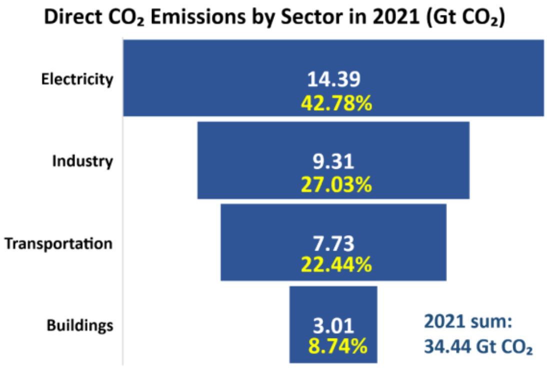

Figure 1. Direct carbon dioxide emissions by sector in 2021 (IEA, 2023) (International Energy Agency).

However, the buildings sector actually has a very large carbon footprint when indirect CO_2 emissions are added to the direct ones. In 2021, the share of the buildings sector in the combined direct, indirect, and embodied CO_2 emissions together was about one-third. This share consists of about 9% due to the use of fossil fuels in operating the buildings (direct CO_2 emissions), 19% because of generating electricity and heat for operating the buildings (indirect CO_2 emissions), and about 6% because of the production of cement, steel, and aluminum used as construction materials for new buildings (embodied CO_2 emissions). In terms of energy consumption, buildings in 2021 were responsible for 30% of global final energy consumption, with almost 135 EJ (37,500 TWh) of energy used in buildings. Electricity represented about 35% of building energy use (such as space cooling) in 2021 (IEA, 2022a).

When inspecting the difference between residential and non-residential buildings with respect to 2021 emissions due to energy consumption and operational processes, residential buildings have more contribution than non-residential buildings, for either direct emissions or indirect emissions. The ratio is 2.11 for direct emissions, 1.42 for indirect emissions, and 1.60 for both direct and indirect emissions combined (IEA, 2022b).

Setting minimum energy performance standards and establishing building energy codes help in improving the energy efficiency of buildings (both residential and non-residential), thereby reducing the CO_2 emissions caused by them. Certification programs that define green (sustainable) buildings form another way to encourage adopting high-efficiency low-emissions buildings or improving their operation and maintenance. Such certification programs address sustainability factors; such as energy use, water use, indoor environment quality, and waste; while focusing on reducing the harmful environmental impacts and increasing the comfort of occupants (Doan et al., 2017; Freitas and Zhang, 2018; Suzer, 2019). Examples of green building certification programs include EDGE (Excellence in Design for Greater Efficiencies) by the International Finance Corporation (IFC) (Marzouk, 2023; Purba and Latief, 2024), BREEAM (Building Research Establishment Environmental Assessment Method) by the UK-based BRE Group (Dubljević et al., 2024; Maqbool et al., 2023), Mostadam by the Ministry of Housing in the Kingdom of Saudi Arabia (Asaad et al., 2024; Balabel et al., 2024), ENERGY STAR by the U.S. Environmental Protection

Agency (Banerjee et al., 2024; Park et al., 2024), and Green Globes by the Green Building Initiative (GBI) (Kalefa and Gado, 2024; Lai et al., 2024).

LEED (Leadership in Energy and Environmental Design) certification program for green buildings is considered the most common among different certification programs recognized internationally (Pushkar and Verbitsky, 2018). It was developed by USGBC (U.S. Green Building Council), with the first version (LEED v1.0) released in 1998 (Awadh, 2017). This was followed by other versions, and version 4 (LEED v4) was released in 2013 (Lessard et al., 2018). In 2019, a study was performed (Amiri et al., 2019) regarding the usefulness of LEED certification with regard to improving the energy efficiency of buildings, which is addressed in the Energy and Atmosphere (EA) credit category of the LEED certification program. In their study, they examined 44 published articles (which are of sufficient quality to be covered by the Web of Science indexing service) that are related to the real energy consumption of LEED-certified buildings. They suggested that the EA credit category of LEED v4 needs to be modified since they reported examples of buildings that were certified according to v4 while actually not found to be showing satisfactory energy efficiencies when compared to similar buildings not having the LEED certification. In a recent study (Goodarzi and Shayesteh, 2024), 797 LEED-certified projects (classified as new constructions) in the USA were analysed by investigating online certification data collected from the USGBC website. The analysis utilized a developed model based on the predefined relationships between the overall LEED score and the LEED credit categories, such that the 'actual' contribution of each credit category to the overall sustainability level can be estimated. When comparing the 'actual' contributions with the 'expected' contributions of the different credit categories, some inconsistency was identified. This suggests a need for redefining some criteria or changing their weights in v4 of LEED. LEED v4.1 was released in 2019 (Dhuoki and Çağnan, 2021) without totally replacing v4, so buildings can be registered for certification according to the criteria of LEED v4 or according to LEED v4.1 (USGBC, 2022). Although daylight control in a building can impact its energy consumption as well, where some illumination energy can be saved if natural light is efficiently integrated with the building design (De Rubeis et al., 2024), LEED v4 and LEED v4.1 treat the daylighting performance in a separate credit category, which is (Indoor Environmental Quality) or (EQ) (Hanafy, 2023). As of 30 December 2023, the online database of LEED shows 95,439 (compared to 91,648 on 31 May 2023) certified projects worldwide (in any of the 4 possible LEED certification levels), and 73,790 (compared to 72,136 on 31 May 2023) other projects that were registered (applied for LEED certification) but whose certification process is still in progress. The term (project) in LEED may refer to a residential building, a commercial or institutional building, a part of a building, a community/neighbourhood, or even a city; depending on the scope of the certification.

This study aims to familiarize the reader with the LEED certification program for green buildings, and emphasize changes in its Energy and Atmosphere (EA) credit category for the New Construction and Major Renovation (NC) adaptation under the Building Design and Construction (BD + C) rating system, as the LEED certification program evolves from v4 to v4.1. Although USGBC has issued a document clarifying changes in the LEED system between v4 and v4.1 for the Building Design and

Construction rating system (USGBC, 2013), the highlighted changes are very brief, and also simplified by disregarding small changes for the EA credit category. For example, it was mentioned that the compulsory target of (Building-Level Energy Metering) in the EA credit category did not change in v4.1 compared to v4, but there is actually a small change that occurred in v4.1 through deleting a small part of the requirement statement, making it simpler.

2. LEED structure

Table 1 lists the rating systems (specialties) in the mature version 4 of LEED and the newer version 4.1 of LEED (USGBC, 2023a). There is a total of 5 rating systems in either version. Each rating system is further divided into two or more adaptations (variants) (USGBC, 2022). The Building Design and Construction rating system is common in v4 and v4.1. It has the largest number of adaptations in either v4 or v4.1. This rating system is for buildings representing either a new construction or a major renovation of existing construction. Unless the building project is a Core and Shell type (has an exterior shell and core mechanical/electrical/plumbing equipment, but no final interior items), at least 60% of the project's gross floor area (GFA) must be complete by the time of certification. The entire building's GFA must be included in the assessment process.

Table 1. Rating systems available in LEED v4 and v4.1 (USGBC, 2014, 2024a, 2024b).

Index	Rating System (Specialty)	
	LEED v4	**LEED v4.1**
1	Building Design and Construction (BD + C)	Building Design and Construction (BD + C)
2	Interior Design and Construction (ID + C)	Interior Design and Construction (ID + C)
3	Building Operations and Maintenance (O + M)	Building Operations and Maintenance (O + M)
4	Neighborhood Development (ND)	Cities and Communities
5	Homes Design and Construction*	Residential BD + C

* The Homes Design and Construction rating system in LEED v4 may also be viewed as two additional adaptations under the Building Design and Construction (BD + C) rating system, which are: (1) Home and Multifamily Lowrise (single-family homes, and low-rise multi-family homes with one to three stories), (2) Multifamily Midrise (multi-family homes with four or more stories).

Table 2 lists the eight adaptations of the (Building Design and Construction) rating system of LEED, which are the same in either version 4 or version 4.1.

Table 2. Adaptations available in the (building design and construction) rating system in LEED v4 or v4.1 (USGBC, 2023d, 2023e).

Index	Adaptation	Explanation
1	New Construction and Major Renovation (NC)	This adaptation excludes buildings that mainly serve pre-college educational, retail, data centers, warehouses and distribution centers, hospitality, or healthcare uses.
2	Core and Shell Development (CS)	It is the appropriate adaptation if more than 40% of the GFA is incomplete at the time of certification.
3	Schools	It is primarily for pre-college educational institutions. Optionally can be used for higher education institutions or non-academic buildings located on school campuses.

Table 2. (*Continued*).

Index	Adaptation	Explanation
4	Retail	It is for buildings with the purpose of conducting retail sales of consumer goods.
5	Data Centers	It is for building with more than 60% of the GFA designed specifically for high-density computing equipment.
6	Warehouses and Distribution Centers	It is for buildings used for storing goods, storing manufactured products, storing merchandise, or storing raw materials.
7	Hospitality	It is for buildings dedicated to hotels or similar businesses that provide short-term lodging (with or without food).
8	Healthcare	It is for hospitals that operate 24 h a day, seven days a week, and provide inpatient medical treatment.

In all adaptations of the (Building Design and Construction) rating system of LEED v4 or v4.1, there are certain criteria (targets) arranged in nine categories, which are referred to as credit categories. When achieving a criterion is compulsory, this criterion is referred to as a prerequisite. When achieving a criterion is not compulsory, this criterion is referred to as a credit. A prerequisite or a credit may offer more than one option (or case) for satisfying it. Furthermore, more than one path may exist within an option. Each credit is assigned a fixed number or a range of attainable points, such that the project can earn one or more credit points when fully or partly achieving a credit. The distribution of points over the credit categories is not the same for all adaptations. In the NC adaptation, the distribution of credit points is provided in **Table 3**. For all adaptations of the (Building Design and Construction) rating system of LEED v4 or v4.1, the total attainable points are 110. For the NC adaptation, the Energy and Atmosphere (EA) credit category is the largest in terms of the allocated points. Its share in the total credit points is 30%, which is more than twice the share of the second largest credit category; which is either (Location and Transportation) or (Indoor Environmental Quality), where either of them has a share of 16 points or 14.55%.

Table 3. Credit categories in the (new construction and major renovation) adaptation, under the (building design and construction) rating system in LEED v4 or v4.1 (USGBC, 2023d, 2023e).

Index	Credit Category	Maximum Attainable Points	Percentage of the Total
1	Integrative Process (IP)	1	0.91%
2	Location and Transportation (LT)	16	14.55%
3	Sustainable Sites (SS)	10	9.09%
4	Water Efficiency (WE)	11	10.00%
5	Energy and Atmosphere (EA)	33	30.00%
6	Materials and Resources (MR)	13	11.82%
7	Indoor Environmental Quality (EQ)	16	14.55%
8	Innovation (IN)	6	5.45%
9	Regional Priority (RP)	4	3.64%
	Total	110	100.00%

The LEED certification level depends on the cumulative number of earned credit points by the project after its assessment (Owens et al., 2013; Rani and Chopra, n.d.).

There are four LEED certification levels (DOE, 2024; Ismaeil, 2024; Thompson, 2022) as shown in **Table 4**, which are identical in LEED v4 and LEED v4.1. It may be useful to mention that only whole points can be earned (no fractions are awarded).

Table 4. Certification levels in LEED v4 or v4.1 (Thompson, 2022).

Index	Certification Level	Required Points
1	LEED Certified	40–49
2	LEED Silver	50–59
3	LEED Gold	60–79
4	LEED Platinum	80 and above

3. Energy and atmosphere (EA) credit category

The scorecard (or checklist) of the NC adaptation, under the (Building Design and Construction) rating system in LEED v4 or v4.1 was made available by USGBC as downloadable spreadsheets (as Microsoft Excel files) (USGBC, 2023d, 2023e). They list the prerequisites and credits (and the corresponding attainable points in each credit) for each credit category. **Table 5** provides a summary of these details for the EA credit category only, while comparing v4 and v4.1 of LEED (USGBC, 2024). The numbering of the codes (or labels) assigned to each prerequisite or credit (such as the numbers 1 and 2 in EA4p1 and EA4p2, or in EA4c1 and EA4c2) are not official, but used here in this study arbitrarily to facilitate the mapping of the prerequisites or credits between v4 and v4.1 (Duser, 2020). Such numbers reflect a legacy style and were official in the earlier version of LEED (v3 or 2009).

Table 5. Prerequisites and credits in the EA credit category of the NC adaptation, under the (building design and construction) rating system of LEED v4 or v4.1 (USGBC, 2024).

Index	LEED Version 4			LEED Version 4.1		
	Code	**Title**	**Points**	**Code**	**Title**	**Points**
1	EA4p1	Fundamental Commissioning and Verification	-	EA41p1	Fundamental Commissioning and Verification	-
2	EA4p2	Minimum Energy Performance	-	EA41p2	Minimum Energy Performance	-
3	EA4p3	Building-Level Energy Metering	-	EA41p3	Building-Level Energy Metering	-
4	EA4p4	Fundamental Refrigerant Management	-	EA41p4	Fundamental Refrigerant Management	-
5	EA4c1	Enhanced Commissioning	6	EA41c1	Enhanced Commissioning	6
6	EA4c2	Optimize Energy Performance	18	EA41c2	Optimize Energy Performance	18
7	EAc3	Advanced Energy Metering	1	EAc3	Advanced Energy Metering	1
8	EA4c4	Enhanced Refrigerant Management	1	EA41c4	Enhanced Refrigerant Management	1
9	EA4c5	Demand Response	2	EA41c5	Grid Harmonization	2
10	EA4c6	Renewable Energy Production	3	EA41c6	Renewable Energy	5
11	EA4c7	Green Power and Carbon Offsets	2	-	-	-
	Total		33			33

In LEED v4 or v4.1, the number of EA prerequisites is the same, which is four. The total attainable credit points for the EA credit category also remain unchanged at

33 points while the LEED program evolves from v4 to v4.1. One noticeable difference is the merging of two credits in v4 (designated here by the codes or labels EA4c6 and EA4c7, having 3 points and 2 points; respectively) into one credit in v4.1 (designated here by the code or label EA41c6, having 5 points). In v4, renewable energy utilization was treated differently based on the location of the renewable energy source, with onsite (self-generated) renewable energy covered by EA4c6, while offsite (purchased) renewable energy as well as purchased renewable energy certificates and purchased carbon offset certificates covered by EA4c7. In v4.1, onsite and offsite renewable energy or purchased renewable energy certificates are grouped together and are covered collectively by EA41c6. EAc3 did not have any change at all in v4.1 compared to v4. Thus, it is given a common code (rather than two different ones, such as EA4c3 for v4 and EA41c3 for v4.1).

4. Change analysis per component of the EA credit category

In this section, individual prerequisites and credits within the EA credit category are analyzed by highlighting changes in v4.1 compared to v4 of LEED for the NC (New Construction and Major Renovation) adaptation, under the (Building Design and Construction) rating system.

4.1. EA4p1 versus EA41p1 (fundamental commissioning and verification)

The EA41p1 maintained the overall structure of EA4p1. Only minor changes happened in v4.1, as given below.

Change 1: The reference NIBS Guideline 3-2012: Building Enclosure Commissioning (BECx) for exterior enclosures was replaced by ASTM E2947-16: Standard Guide for Building Enclosure Commissioning.

Change 2: The heading (Commissioning Authority) became (Commissioning Authority Qualifications).

Change 3: The statement (In all cases, the CxA must report his or her findings directly to the owner) replaced another one in v4.

4.2. EA4p2 versus EA41p2 (minimum energy performance)

Although EA4p2 and EA41p2 have identical titles, they are almost totally different in the described requirements. The intent of this prerequisite was extended in v4.1 by adding: (1) promoting resilience, and (2) reducing GHG emissions. In v4, the aim was mainly to achieve the best level of energy efficiency, and this was retained in v4.1.

EA4p2 has 3 options, while EA41p2 requires one type of compliance with ANSI/ASHRAE/IESNA Standard 90.1–2016: Energy Standard for Buildings Except Low-Rise Residential Buildings (or a USGBC-approved equivalent standard).

EA41p2 introduces the PCI (performance cost index) concept, requiring it to be less than or equal to PCIt (performance cost index target). The PCI and PCIt are related to either the annual energy cost saving or the GHG emissions.

The PCI (performance cost index) is a non-dimensional ratio computed as (for the case of energy cost).

$$\text{Performance Cost Index (PCI)} = \frac{\text{Proposed Building Performance (PBP)},\ \$/\text{year}}{\text{Baseline Building Performance (BBP)},\ \$/\text{year}} \quad (1)$$

The Proposed Building Performance (BBP) can be calculated using Appendix G in the 90.1 energy standard (ASHRAE, 2019). A PCI value of 1.0 means that the building is designed exactly at the energy cost level of the 90.1 energy standard. A PCI value of 0.0 means that the building has net-zero energy costs (Rosenberg and Hart, 2016). It should be noted that the PCI by itself is not enough to decide if the building is compliant or not with the 90.1 energy standard. Instead, it is compliant if

$$\text{90.1 standard compliance condition: PCI} \leq \text{PCIt} \quad (2)$$

The PCIt (performance cost index target) represents the maximum PCI (performance cost index) for a proposed design to be compliant (but least efficient) with the 90.1 energy standard. The PCIt depends on the building type and the climate zone (e.g., 1B or very hot and humid, as in Riyadh in Saudi Arabia; 8 or subarctic, as in Fairbanks in Alaska; 3C or warm and marine, as in San Francisco in California). The PCIt can be calculated using a formula with the aid of lookup tables.

The PCI percentage improvement is the relative difference between PCI and PCIt, with respect to PCIt. Therefore,

$$\text{Percentage Improvement in PCI (beyond 90.1 standard)} = 100\% \frac{\text{PCIt} - \text{PCI}}{\text{PCIt}} \quad (3)$$

The EA41p2 covers a similar performance metric to the energy cost PCI, which is the GHG emissions PCI. This is another new component that was not present in EA4p2.

4.3. EA4p3 versus EA41p3 (building-level energy metering)

In LEED v4.1, the requirement in this prerequisite has only one simplifying change from the counterpart in v4, where the phrase (or typical occupancy, whichever comes first) in the text (for a five-year period beginning on the date the project accepts LEED certification or typical occupancy, whichever comes first.) was deleted. Therefore, using typical occupancy as a possible condition to start sharing the energy consumption data and (if metered) electrical demand data with USGBC was removed in v4.1.

4.4. EA4p4 versus EA41p4 (fundamental refrigerant management)

Change 1: It is interesting that the (intent) of EA41p4 changed from the brief statement of EA4p4 (To reduce stratospheric ozone depletion) to an expanded one as (To reduce ozone depletion and global warming potential ... while minimizing direct contributions to climate change). Thus, the revised statement shows clear attention with regard to global warming.

Change 2: Instead of prohibiting chlorofluorocarbon (CFC) refrigerants only within new HVAC & R systems in v4, hydrochlorofluorocarbon (HCFC) refrigerants within new HVAC & R systems also became prohibited in v4.1. While replacing CFCs with HCFCs can solve the problem of stratospheric ozone depletion, HCFCs are not valid long-term alternatives due to their high global warming effects (Benhadid-Dib and Benzaoui, 2012; Kwak et al., 2024; Mitrakusuma et al., 2024).

Change 3: The phase-out conversion before project completion when reusing existing HVAC & R equipment was needed only for CFC refrigerants in v4, but it is needed for CFC and/or HCFC refrigerants in v4.1.

4.5. EA4c1 versus EA41c1 (enhanced commissioning)

Change 1: The heading (Commissioning Authority) in v4 changed to (Commissioning Authority Qualifications) in v4.1.

Change 2: The CxA in v4.1 can be (an employee of the design or construction firm who is not part of the project's design or construction team). This is an added possibility that was not available in v4.

Change 3: This credit has two options. While the first option did not change in v4.1 compared to v4, small changes occurred in the second option. Such as the updated reference from (ASHRAE Guideline 0–2005: The Commissioning Process) to (ASHRAE Guideline 0–2013: The Commissioning Process), which supersedes its immediate previous version of 2005.

Change 4: The reference (NIBS Guideline 3–2012: Building Enclosure Commissioning (BECx)) of the second option in v4 was replaced by (ASTM E2947-16: Standard Guide for Building Enclosure Commissioning) in v4.1.

Change 5: The term (commissioning authority) in the second option was replaced by a more specific description as a (qualified independent member of the design or construction team responsible for building enclosure commissioning).

Change 6: The term (construction documents) in the second option was made more specific as (construction documents for enclosure systems).

Change 7: Some tasks in the second option were grouped and became applicable only for (specialty enclosure systems with controls and automation).

Change 8: The task (Develop an on-going commissioning plan) in the second option was clarified as (Develop an on-going enclosure commissioning plan for maintenance, renewal and revitalization cycles).

4.6. EA4c2 versus EA41c2 (optimize energy performance)

This is the most important credit in the EA credit category for the NC adaptation, in terms of the available points, representing 54.55% of all the attainable EA points (18 points out of a total of 33 points).

As was the case in EA4p2 and EA41p2, the identical title for EA4c2 and EA41c2 does not reflect the significant changes that occurred in v4.1 compared to v4. The two options in v4 became three options in v4.1.

The intent in v4.1 has an additional aim of reducing GHG emissions, which is totally missing in v4.

The first option in EA41c2 utilizes PCI and PCIt for energy cost, and also utilizes PCI and PCIt for GHG, with more credit points rewarded when the percentage improvement increases. The energy cost and GHG emissions have equal importance in the first option, with half of the credit points (9 of 18) can be attained when the energy cost is reduced by 45% (if new construction) or by 40% (if major renovation), and the other half of the credit points (9 of 18) can be attained when the energy cost is reduced by 80% (if new construction) or by 65% (if major renovation). In addition, NC projects can earn an extra point referred to as exemplary performance (EP) point if the percentage improvement in the energy cost is 50% (if new construction) or 45% (if major renovation), and an extra EP point if the percentage improvement in the GHG emissions is 100% (if new construction) or 80% (if major renovation). The percentage improvement is the relative reduction in PCI below PCIt (for either energy cost or GHG emissions).

It should be noted that not all LEED credits allow EP points. Thus, the EA41c2 (through its updated first option) is an exceptional credit. In LEED v4.1, a maximum of 2 EP points is allowed (USGBC, 2023c). The EP concept was not introduced in LEED v4.1 for the first time, but it was already existing in LEED v4 (USGBC, 2023b).

4.7. EAc3 (advanced energy metering)

This credit is the only one in the EA credit category for the NC adaptation of the LEED Building Design and Construction rating system that did not have any change in version 4.1 relative to version 4.

4.8. EA4c4 versus EA41c4 (enhanced refrigerant management)

In either EA4c4 or EA41c4, there are two options. The first option is the same for both versions. To earn the single point of this credit through its first option, the LEED project must either avoid any refrigerants or use only refrigerants that have ozone depletion potential (ODP) = 0, and global warming potential (GWP) < 50. The GWP is an index used to quantify the global warming contribution of a gas based on the ratio of its greenhouse radiative effect to that of an equal amount of CO_2 as a reference greenhouse gas (GHG), considering a duration of typically 100 years (Danny Harvey, 1993; Sgarbossa et al., 2020; Slingo and Slingo, 2024). Thus, the GWP of CO_2 is 1.0 (Eling et al., 2024; Tong et al., 2024). The ODP is a similar number but expresses the loss of the stratospheric ozone layer (protecting against harmful ultraviolet radiation) caused by a gas compared to the CFC refrigerant R11 (CFC-11, trichlorofluoromethane, CCl_3F) (Dincer, 2018; Kuczyński and Chliszcz, 2024; Ladke and Choudhari, 2016). Thus, the ODP of R11 is 1.0 (Nandagopal, 2024; Shen et al., 2024).

Despite these similarities, several changes occurred in v4.1 of this credit compared to v4, as explained below.

Change 1: The intent of the credit became more stringent, by upgrading (To reduce ozone depletion) to (To eliminate ozone depletion), and also became broader by adding another aim of reducing global warming potential.

Change 2: In the second option of EA41c4, compliance with (ASHRAE Standard 15-2019: Safety Standard for Refrigeration Systems)—or a USGBC-approved equivalent—as applicable to the project scope, became mandatory.

Change 3: In the second option of EA41c4, it became mandatory to develop and implement a refrigerant management plan regarding leak detection and end-of-life disposal for HVAC & R systems having 0.225 kg or more refrigerant.

Change 4: New instructions were added for the "Retail" adaptation of projects (these are outside the scope of this study which focuses on the NC adaptation). For example, stores with commercial refrigeration systems are not permitted to use any refrigerants that cause ozone depletion (this was part of the first option in EP41c4).

4.9. EA4c5 (demand response) versus EA41c5 (Grid Harmonization)

The change in the credit title from (Demand Response) to (Grid Harmonization) is a favorable generalization and makes the purpose of the credit clearer. Demand response (DR) in the electricity market is an optimization model that adjusts the electric load of a participating consumer in response to real-time electricity prices or based on incentives to the customer for reducing or shifting electric consumption (Conejo et al., 2010; Motta et al., 2024; Yang et al., 2024). It has an economic benefit for the consumer, and also increases the flexibility of the power system (O'Connell et al., 2014; Seatle and McPherson, 2024). Demand response schemes allow improved dependability of the electric energy system, particularly with large-scale electrification of transportation (introducing extra variability in the demand), integrating variable renewable energy sources into the electric grid (introducing extra variability in the generation) (Allehyani et al., 2024; Khan et al., 2024; Liao et al., 2024; Marzouk, 2022d, 2022a; Meng et al., 2024; Roy and Das, 2024).

Change 1: The intent in v4.1 has a small addition of (more affordable) in the phase (make energy generation and distribution systems more affordable and more efficient).

Change 2: Some changes occurred in the first case of v4.1, such as requiring participation in an existing DR program, rather than just designing a system with DR capability and contractual commitment (as in v4).

Change 3: Some changes also occurred in the second case of v4.1, such as changing the case title from (Case 2. Demand response program not available) in v4 to (Case 2. Demand Response Capable Building) in v4.1.

Change 4: A new (third) case or option was added in v4.1.

4.10. EA4c6 (renewable energy production) and EA4c7 (green power and carbon offsets) versus EA41c6 (renewable energy)

The intent of EA41c6 combines parts of the intent of EA4c6 (reduce the environmental and economic harms associated with fossil fuel energy) and the intent of EA4c7 (reduction of greenhouse gas emissions).

While EA4c6 focuses on the self-generation of renewable energy, such as electricity generated by a photovoltaic system or a wind turbine that is owned by the project (De et al., 2024; Lage et al., 2024; Marzouk, 2021b, 2022b, 2022c). EA41c6 accommodates both self-generation and third-party generation. EA4c7 addresses the procurement of renewable energy generated by a commercial supplier as well as renewable energy certificates (RECs). These items are included in EA41c6.

The RECs or EACs (energy attribute certificates) represent tradeable standardized certificates that facilitate renewable energy generation (Chuang et al., 2018; Narula, 2013; Sawhney, 2024). A producer of green electricity (electricity from renewable energy resources) can sell this green electricity to an electricity distribution company, while also obtaining one REC issued for every MWh of the green electricity supplied to the grid (Girish et al., 2015; Lee and Xydis, 2024). Thus, RECs are derived commodities that can be sold separately from the generated green electricity itself (Irfan, 2021). RECs can be purchased to verify compliance with certain governmental obligations or to voluntarily support renewable energy utilization (Holt and Wiser, 2007).

The relation between EA41c6 and the pair (EA4c6 and EA4c7) is not just merging two credits into one. EA41c6 has a very different structure. For example, renewable energy is divided into 3 tiers. Tier 1 is for onsite renewable energy generation (either generated onsite, or RECs that are retained and not sold). Tier 2 is for new offsite renewable energy (either the generation assets built within the last 5 years, or contracted with expected future operation within two years of the building's occupancy). Tier 3 is for older offsite renewable energy (it includes also captured bio-methane, which is a new element in v4.1). Offsite renewable energy (tiers 2 and 3) must be generated by renewable electricity assets in the same country as the LEED project.

The number of credit points earned depends on the percentage of renewable energy with respect to the total annual energy use by the LEED project, and also depends on the tier. Tier 1 is treated preferentially, with only 20% use enables earning all the 5 points in the EA41c6 credit (1 point earned for a percentage of only 2%). On the other hand, a higher percentage of 50% is needed if tier 2 renewable energies are used to earn the same 5 points (1 point earned for a percentage of 10%). For tier 3, the maximum number of possible points that can be earned is only three, and this happens if 100% of the site energy is procured using this tier (1 point earned for a percentage of 35%).

USGBC provides a free calculator spreadsheet (as a Microsoft Excel file) that aids in computing the points in EA41c6 (USGBC, 2023f). This calculator also has useful notes. For example, captured bio-methane in tier 3 means biogas (e.g., from landfills or sewage treatment plants) captured offsite and delivered to the LEED project for onsite combustion. Also, renewable fuels (e.g., biofuels or agricultural crops) can be considered as tier 1 renewable energy sources if they are captured (or harvested) and also utilized onsite at the LEED project. Offsite renewable energy generation can be counted in tier 1 (onsite) if its output or a share of it is dedicated to the LEED project.

5. Summary of EA Changes in LEED (v4 → v4.1)

Table 6 lists the ten components of the Energy and Atmosphere (EA) credit category examined here for LEED v4.1, and a qualitative description of the depth of change made in each component, as LEED evolved from v4. One component remained totally unchanged, six components were subject to small changes, while the three components were largely revised.

Table 6. Summary of the level of change in the four prerequisites and six credits of the EA credit category of LEED v4.1, Building Design and Construction, NC Adaptation when updated from LEED v4.

Type	Title	% of total points (33)	Level of change (v4 → v4.1)		
			None	Minor	Major
Prerequisites	Fundamental Commissioning and Verification	-		✓	
	Minimum Energy Performance	-			✓
	Building-Level Energy Metering	-		✓	
	Fundamental Refrigerant Management	-		✓	
Credits	Enhanced Commissioning	18.18%		✓	
	Optimize Energy Performance	54.55%			✓
	Advanced Energy Metering	3.03%	✓		
	Enhanced Refrigerant Management	3.03%		✓	
	Grid Harmonization	6.06%		✓ (renaming)	
	Renewable Energy	15.15%			✓ (merging)

6. Conclusions

LEED (Leadership in Energy and Environmental Design) is a certification program for sustainable (green) buildings. It consists of some credit categories through which a construction project is evaluated through the number of accumulated points in credits provided that some prerequisites are satisfied first. This study considered the Energy and Atmosphere (EA) credit category for the New Construction and Major Renovation (NC) adaptation under the Building Design and Construction (BD + C) rating system of LEED. The EA credit category is the most important one in terms of attainable credit points within it (33 points, only 7 points below the minimum of 40 overall credit points to reach the first level of LEED certification for the construction project). The main aim of the study was to analyse the changes that occurred between the rating system version 4 (v4) and the rating system version 4.1 (v4.1) of the LEED program. This analysis showed that major changes occurred in the energy performance component (as a prerequisite and as a credit), and in handling renewable energy. The study also provides a general overview of the LEED system for readers who are not familiar with it.

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