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Impact of different LEED versions for green building certification and energy efficiency rating system: A Multifamily Midrise case study

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HIGHLIGHTS

- Energy consumption change from applying different LEED versions were investigated.
- Four analysis scenarios were compared using different versions of ASHRAE Standard.
- A case study of a mid-rise multi-family building was conducted using energy simulation.
- Residential buildings could benefit from LEED v4 due to the low prerequisite.
- Renovation buildings are highly incentivized regardless of LEED version used.

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ABSTRACT

Various versions of the Leadership in Energy and Environmental Design (LEED®) have been introduced with the addition of more stringent sustainability parameters and credit scoring schemes over the past decade. Such changes in LEED versions strongly affect the energy performance and LEED scores of the target building in the LEED certification process. Therefore, to validate and improve the current LEED version, it is crucial to investigate and compare the impact of different LEED versions on the building energy performance and scoring scheme. However, researches comparing the sustainability metrics for mid-rise multi-family buildings are rare. Therefore, this paper investigates the potential changes in the energy performance resulted from applying different LEED versions (i.e., LEED v3 and v4) for the Energy and Atmosphere (EA) category. Towards this end, a case study was carried out with energy modeling and simulation using TRACE 700 to compare the changes in the energy performance of four analysis scenarios applied to an existing mid-rise multi-family building located in Ohio. Results showed notable changes in LEED points when different versions of LEED using different ASHRAE Standards (i.e., ASHRAE Standards 90.1-2007 and 90.1-2010) are applied for the building energy analysis. In particular, mid-rise multi-family buildings could benefit from LEED v4 in terms of LEED credits as the prerequisite for the minimum energy performance improvement in EA category became significantly lenient compared to LEED v3. On the contrary, when the percentage energy performance improvement is over 34%, mid-rise multi-family buildings would benefit from LEED v3 as it becomes difficult to gain more points for similar energy performance improvement in LEED v4 compared to LEED v3. Various stakeholders including USGBC and government can benefit from using the key findings of this study for improving the LEED certification and national energy standards.

1. Introduction

Buildings accounts for 30–40 percent of the total energy use in developed countries. The U.S. consumed about 40 percent of the total energy in residential and commercial buildings in year 2015 [1,2]. Besides, the building energy demand is growing every year because of the population growth, increasing services, and desired comfort resulting in increase of energy bills [3–5]. One way to mitigate the increased energy demand and cost is to shift the supply towards renewable energy and to realize energy efficiency in buildings [6]. To address the most important factors of energy efficiency measures in the existing and new buildings, various green building standards and certifications

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have been developed by different institutes in various countries [7,8]. The main goal of these standards and certifications is to evaluate the sustainability and energy performance of the building. Such green building standards and certifications are adjusted to the temporal, spatial, and cultural environment where the building was originally designed and tend to have own means of awarding scores to the building [9].

The most widely known and utilized green building certification in the U.S. is the Leadership in Energy and Environmental Design (LEED®) developed by the United States Green Building Council (USGBC) [10]. LEED offers a variety of rating systems based on the market, building, and construction. Depending on these criteria, the LEED certification is classified into the following five types: "LEED Building Design & Construction", "LEED Interior Design and Construction", "LEED Neighborhood Development", "LEED Building Operations and Maintenance", and "LEED for Homes". LEED's adaptability outside the U.S. is also gaining momentum and accordingly, LEED has been partially customized and applied in various countries around the world [11]. Since the inception of LEED in 2000, various versions of LEED have been introduced with the addition of more stringent sustainability parameters and credit scoring schemes. The most recent version is LEED version 4 (v4) which supersedes all older versions such as v2.0, v2.2, and v3. Among five types of LEED certification, the residential rating system referred as "LEED for Homes" has gone through three major changes. First, in year 2008, the oldest version for "LEED for Homes" was introduced to evaluate the energy performance of the residential building based on the International Energy Conservation Code (IECC) [12]. Second, in year 2010, it was modified and recognized as a separate rating system under "LEED for Homes Multifamily Midrise" (i.e., LEED v3) to compare the energy performance with a baseline set by American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 90.1-2007 instead of the IECC [13,14]. Applying ASHARE Energy Standard 90.1-2007 to the newer version of "LEED for Homes" made it more relevant to mid-rise multi-family buildings, since ASHARE Energy Standard 90.1-2007 was established for buildings more than four stories. Third, the latest version, released in year 2015, utilizes ASHRAE Standard 90.1-2010 for designing the baseline building and predominately addresses following residential constructions; single-family homes, low-rise multi-family (up to three stories) buildings, and mid-rise multi-family (up to six stories) buildings, under "LEED BD + C (Building Design and Construction): Homes and Multifamily Lowrise | Multifamily Midrise" (i.e., LEED v4) [15,16]. Such changes in LEED versions would very much affect the calculated energy performance and LEED scores of the target residential building in the LEED certification process. Therefore, to validate the current LEED version and improve the LEED certification in a positive way, it is crucial to investigate and compare the impact of different LEED versions on the building energy performance and the scoring scheme.

In this regard, there have been many previous studies dealing with the LEED certification and other relevant green building certifications. Researchers have compared various green building certifications such as Building Research Establishment Environmental Assessment Method (BREEAM) for the United Kingdom (UK) [17,18], LEED for U.S. [19,20], Building Environmental Assessment Method (BEAM) Plus for Hong Kong [18,21], the Institute for Innovation and Transparency of Contracts and Environmental Compatibility (ITACA) protocol for Italy [22], Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) for Japan [23], and Green Standard for Energy and Environmental Design (G-SEED) for South Korea [9,24]. Some studies have compared these certifications focusing on the scoring scheme related to the reduction of the building energy consumption. In addition, previous studies have utilized various building energy simulation tools such as the QUick Energy Simulation Tool (eQUEST) [25], EnergyPlus [26], Integrated Environmental Solutions-Virtual Environment (IES-VE) [27] and Thermal Analysis Simulation (TAS) [28] to calculate LEED scores with a focus on the high-rise multi-family buildings [29]. However, studies comparing different versions of a single green building certification related to the mid-rise multi-family building are rare. Therefore, this paper mainly focuses on a specific category in LEED for Homes, the Energy and Atmosphere (EA), with an aim to compare and investigate any potential changes in the annual energy consumption and cost resulting from applying different versions of ASHRAE Standard 90.1 used for LEED v3 and v4, respectively. To show the impact of applying different versions of the LEED certification, this study conducted a case study of a mid-rise multi-family building in the U.S. Towards this end, this study used the building energy simulation tool to model and compare the energy performance of four different analysis scenarios generated according to building construction types and LEED versions. In addition, this study aims to help understand the implication of changes in the energy performance of the mid-rise multi-family building on LEED credits.

2. LEED energy and atmosphere (EA) category

LEED is heavily weighted to encourage energy efficiency in the building performance by allocating the maximum points to the EA category (i.e., 37 out of total 110 points in LEED v4 and 38 out of total 136 points in LEED v3). In general, for all LEED certifications, there are some mandatory requirements referred as "prerequisites" and optional requirements referred as "credits" against which the points are awarded [30]. Within the EA category, prerequisites entail "minimum energy performance" and "testing & verification" while credits entail "optimize energy performance", "domestic hot water distribution", and "refrigerant management". About 34 points (25%) and 30 points (27%) of the total points are allocated towards achieving the EA Credit: "optimize energy performance" for LEED v3 and "annual energy use" for LEED v4, respectively. Therefore, this paper focused on an assessment of prerequisite and credit related to this energy performance. A project is eligible for scoring points towards this credit after meeting the prerequisite for the minimum energy performance improvement in the proposed building by 15% for LEED v3 and 5% for v4 over the baseline building as shown in Table 1.

The baseline building is the reference building, against which the performance improvement of the proposed building is calculated. The baseline building is calculated according to the building performance rating method of USGBC's residential midrise simulation guidelines based on Appendix G of ANSI/ASHRAE/IESNA Standard 90.1 (with errata but without addenda) using a building energy simulation tool for the whole building project. A proposed building includes all the design change and improvement anticipated based on the construction drawings. A proposed building should meet the mandatory provisions in Sections 5.4, 6.4, 7.4, 8.4. 9.4, and 10.4 of ASHRAE Standard 90.1 and should exceed the minimum code compliance requirement under Performance Rating Method (PRM) [31,32]. The major distinction between different LEED versions, LEED v3 and v4, lies in using different versions of ASHRAE Standard 90.1 for setting a baseline building. In order to achieve a maximum LEED certification points, various building energy simulation tools are required to perform energy analysis. Tools such as Trane Air Conditioning Economics (TRACE) 700 by Trane [33], eQUEST, EnergyPlus, IES-VE, and TAS are few suggested simulation tools by the USGBC. Among these various simulation tools, TRACE 700

Table 1
LEED points awarded for improving energy performance in LEED EA category by different LEED versions.

LEED v3		LEED v4	
% Reduction above Standard 90.1-2007	LEED Points	% Reduction above Standard 90.1-2010	LEED Points
15%	prerequisite	5%	Prerequisite
16–50%	3–34	6–60%	1–30

Fig. 1. Target building for the case study.

is an advanced building energy simulation tool to document compliance with ASHRAE Standard 90.1 or validate the building's eligibility for the LEED certification. These simulation tools are continuously being updated to reflect the most recent changes in energy standards and to meet the requirements for simulation software set by ASHRAE Standard 90.1 and the LEED certification.

3. Case study

3.1. Selection of a target building

To assess the building energy performance of a specific building for the case study, this study selected a target building for the case study (refer to Fig. 1). As shown in Fig. 1, the target building is a four-storey mixed-use mid-rise building with the total floor area of 953 m^2, located in a historic district of Over-the-Rhine, Cincinnati, Ohio in the U.S. The target building for the case study is an all-electric building located in IECC climate zone 4A. According to the IECC climate zone definitions, climate zone 4A is a mixed humid temperature zone with cooling degree days less than 2500 calculated at 10 °C and heating degree days greater than 3000 calculated at 18 °C. The building is comprised of four two-bedroom dwelling units (i.e., residential spaces), an office space, and an unconditioned storage space as follows: (i) residential spaces in the first half of the first floor and entire second, third, and fourth floor; (ii) office space in the first half of the basement and the second half of the first floor; and (iii) storage space in the second half of the basement. The building also has an attic space in the fourth floor which is unoccupied and unconditioned. Total space breaks up to 52% residential space, 18% office space, 7% stairs, 22% storage space, and less than 1% mechanical room. The residential, non-residential, and stair spaces are conditioned spaces equivalent to 735m^2 and the storage and support spaces are unconditioned spaces equivalent to 218m^2. This building is already approved by USGBC reviewer and has been scrutinized for accurate inputs, assumptions, and modeling technique. The proposed building design is performing at 48.3% lower annual energy cost over the baseline building set by ASHRAE Standard 90.1-2007. The building was under renovation with approved energy model in August 2016 and this study only considers design changes made by August 2016.

3.2. Generation of analysis scenarios

To directly compare the building energy performance of applying different versions of the LEED certification, this study generated the analysis scenarios. Analysis scenarios were generated based on the type of building construction (i.e., renovation and new construction) and the version of the LEED certification (i.e., LEED v3 and v4). This study generated analysis scenarios based on the aforementioned two criteria for the following reasons: (i) two types of building construction was considered, as the standard for modeling the baseline building for renovation and new construction are different within the same LEED version; and (ii) the latest two versions of LEED certification was considered, as LEED v3 and v4 adopts ASHARE Energy Standard 90.1 for modeling the baseline building which is suitable for evaluating the energy performance of mid-rise multi-family buildings. As shown in Table 2, a total of four analysis scenarios (i.e., scenarios 1 to 4) were generated for comparing the building energy performance with different LEED versions. First, scenarios 1 and 2, where the type of building construction is renovation, applied different versions of ASHRAE Standard, ASHRAE Standard 90.1-2007 and 90.1-2010, respectively, with existing envelope for modeling the baseline building in building energy simulation tool. Meanwhile, scenarios 3 and 4, where the type of building construction is new construction, fully applied different versions of ASHRAE Standard, ASHRAE Standard 90.1-2007 and 90.1-2010, respectively, for modeling the baseline building in building energy simulation tool.

Table 2
Analysis scenarios for comparing the building energy performance with different LEED versions.

Scenario	Building construction type	LEED version	ASHRAE Standard version
Scenario 1	Renovation	LEED v3	Existing envelope ASHRAE Standard 90.1-2007
Scenario 2		LEED v4	Existing envelope ASHRAE Standard 90.1-2010
Scenario 3	New Construction	LEED v3	ASHRAE Standard 90.1-2007
Scenario 4		LEED v4	ASHRAE Standard 90.1-2010

The baseline building and annual building energy performance of four different analysis scenarios has been modeled and simulated using a building energy simulation tool called TRACE 700. As mentioned above, TRACE 700 is an advanced building energy simulation tool which is specialized in and supports modeling a project based on ASHRAE Standard 90.1 for the LEED certification.

3.3. Establishment of energy model inputs and assumptions

Requirements for energy modeling should comply with the simulation guidelines given by Appendix G of ASHRAE Standard 90.1 and ENERGY STAR Multifamily High Rise (MFHR) Program for developing the baseline and proposed building design. The proposed building design should be also developed based on the inputs from the construction document. Therefore, this study established energy model inputs and assumptions based on the simulation guidelines given by Appendix G of ASHRAE Standard 90.1 and ENERGY STAR MFHR Program and the construction document of the target building for the case study. Furthermore, the followings have been also considered for establishing the energy model inputs and assumptions. First, the energy model for the baseline and proposed building used the construction document for developing the input geometries and the latest Typical Meteorological Year (TMY) collection, TMY3, for applying the full year weather data of Cincinnati [34]. Second, operation schedules for lighting, receptacles, and plug loads are assumed to be the same throughout the energy model. Third, the electricity rate of 9.12 cents/kWh is used for annual energy cost calculation based on the commercial average retail price of electricity by state obtained from U.S. Energy Information Agency (EIA). All other inputs and assumptions are kept constant and uniform for all the distinct building orientation except for the performance

Table 3
Summary of energy model inputs for the baseline and proposed building design.

Energy model inputs		Proposed building of scenarios 1, 2, 3, and 4	Baseline building of scenario 1	Baseline building of scenario 2	Baseline building of scenario 3	Baseline building of scenario 4
Building envelope	Roofs	R-38 attic roof wood framed (U = 0.16)	Existing attic roof with 0″ insulation (U = 3.42)	Existing attic roof with 0″ insulation (U = 3.42)	R-20 continuous insulation entirely above deck (U = 0.27)	R-20 continuous insulation entirely above deck (U = 0.27)
	Walls	Type 1: Existing 12″ Brick wall (U = 0.97) Type 2: Existing 12″ Brick Wall + R7.2 insulation wood framed (U = 0.43) Type 3: Existing 12″ Brick wall + R3.1 insulation metal framed (U = 0.55) Type 4: Existing12″ Brick wall + R15 insulation wood framed (U = 0.26)	Existing 12″ Brick Wall (U = 0.97)	Existing 12″ Brick Wall (U = 0.97)	R-13 + R-7.5 continuous insulation steel framed (U = 0.36)	R-13 + R-7.5 continuous insulation steel framed (U = 0.36)
	Floors	Existing exposed uninsulated (U = 0.62)	Existing exposed uninsulated (U = 0.62)	Existing exposed uninsulated (U = 0.62)	Steel Joist insulated (U = 0.22)	Steel Joist insulated (U = 0.22)
	Windows (vertical glazing)	Type 1: ASHRAE 90.1-2007 Table A8.2 unlabeled (U = 7.10, SHGC < 0.81) Type 2: Windows Storm (U < 2.33, SHGC < 0.40) Type 3: Aluminum storefront (U < 2.56, SHGC < 0.44)	ASHRAE 90.1-2007 Table A8.2 unlabeled (U = 7.10, SHGC = 0.81)	ASHRAE 90.1-2007 Table A8.2 unlabeled (U = 7.10, SHGC = 0.81)	Nonmetal framing (U = 2.27, SHGC = 0.40) Metal framing (curtainwall/storefront) (U = 2.84, SHGC = 0.40)	Nonmetal framing (U = 2.27, SHGC = 0.40) Metal framing (curtainwall/storefront) (U = 2.84, SHGC = 0.40)
	Opaque doors	Swinging (U = 3.97)	Swinging (U = 3.97)	Swinging (U = 3.97)	Swinging (U = 3.97)	Swinging (U = 3.97)
HVAC	Heating & Cooling equipment	Unit 101/302: PTHP (EER = 12.1, COP = 3.4) Unit 202/301: PTHP (EER = 12.3, COP = 3.4) Office basement: PTHP (EER = 12.1, COP = 3.4) Office first floor: PTHP (EER = 13.4, COP = 3.4)	PTHP (EER = 9.105, COP = 2.81)	PTHP (EER = 9.5, COP = 2.9)	PTHP (EER = 9.105, COP = 2.81)	PTHP (EER = 9.5, COP = 2.9)
	Air handling unit fan supply power	2.8 W/cmm, 3.3 W/cmm, 3.6 W/cmm, 4.7 W/cmm, 5.1 W/cmm	3.2 W/cmm	3.2 W/cmm	3.2 W/cmm	3.2 W/cmm
	Exhaust fan power	0.23 cmm/W	0.07 cmm/W	0.07 cmm/W	0.07 cmm/W	0.07 cmm/W
Lighting	Interior Lighting	Unit 101: 7.5 W/m^2, Unit 202: 6.5 W/m^2, Unit 301: 4.3 W/m^2, Unit 302: 5.4 W/m^2	Units/Offices:11.8 W/m^2	Units/Offices:11.8 W/m^2	Units/Offices:11.8 W/m^2	Units/Offices:11.8 W/m^2
		Offices: 11.8 W/m^2, Stairwell: 3.7 W/m^2	Stairwell: 6.5 W/m^2	Stairwell: 7.5 W/m^2	Stairwell: 6.5 W/m^2	Stairwell: 7.5 W/m^2
		Storage: 8.6 W/m^2, Electrical/Mechanical: 16.1 W/m^2	Storage: 8.6 W/m^2 Electrical/Mechanical: 16.1 W/m^2	Storage: 6.8 W/m^2 Electrical/Mechanical: 10.2 W/m^2	Storage: 8.6 W/m^2 Electrical/Mechanical: 16.1 W/m^2	Storage: 6.8 W/m^2 Electrical/Mechanical: 10.2 W/m^2
	Exterior lighting	0.9 kW, 0.57 kW	0.9 kW	0.57 kW	0.9 kW	0.57 kW

Note: R refers to resistance value; U refers to conductivity (W/m^2·K); SHGC refers to solar heat gain coefficient; PTHP refers to packaged terminal heat pump; EER refers to energy efficiency ratio; COP refers to coefficient of performance; and cmm refers to cubic meter per minute.

changes in energy model inputs illustrated in Table 3.

3.3.1. Building envelope

The target building is facing north and it is assumed that there is no shading due to the tree canopy or building. The total fenestration area is 16.3% of the gross wall area. As shown in Table 3, energy model input values for the building envelope (i.e., roofs, walls, floors, windows, and opaque doors) of the baseline building are in accordance with Table 5.4.4 Building Envelope Requirements for Climate Zone 4 (A, B, C) from ASHRAE Standard 90.1. As the simulation guidelines given by Appendix G of ASHRAE Standard 90.1 requires to use the existing envelope for the baseline building under renovation, the baseline building design of scenarios 1 and 2 is modeled with the existing envelope and not as per the Building Envelope Requirements for Climate Zone 4 (A, B, C) from ASHRAE Standard 90.1. Some of the east facing walls are not exposed to ambient weather, hence behave as adiabatic walls exposed to the interior mass and are modeled as partitions. The roof, wall and windows are improved throughout the entire building in the proposed building design as per Table 3.

3.3.2. Heating, ventilation and air conditioning (HVAC)

The Heating, Ventilation and Air Conditioning (HVAC) system for the baseline building design is type 2 which is an electric operated packaged terminal heat pump (PTHP) with a constant volume fan. All Air Handling Units (AHU) associated with the PTHP have energy rate modeled as 3.2 W/cmm (cubic meter per minute) based on ASHRAE Standard 90.1 for the baseline building design. The operation of the fan cycles with the occupancy. The ventilation in residential units is achieved by infiltrating equal amount of cmm that is exhausted from the exhaust fan of the bathroom and kitchen equal to 1.27 cmm for a two-bedroom unit, exhausted continuously for 24 h per day. Other Spaces have a minimum required ventilation of 0.42 cmm per person based on default ASHRAE Standard 62.1. Air infiltration rate of 0.1 ACH (air changes per hour) is used both in the baseline and proposed building design and adds to the ventilation of the building. The heating and cooling temperature set points were specified as 21.11–22.22 °C and 25.55–26.66 °C respectively. The baseline HVAC equipment should be modeled using the minimum efficiency levels as described in ASHRAE Standard 90.1 and could be oversized by 15% for cooling and 25% for heating.

3.3.3. Lighting

The interior lighting of the proposed building design is calculated from the actual construction documents and that of the baseline building design is taken from Table 9.6.1 Lighting Power Densities Using the Space-by-Space Method of ASHRAE Standard 90.1. The office lighting has been modeled identically for both baseline and proposed building design as no lighting design was available for the office spaces. The operational schedule of the residential unit lighting is 2.34 h per day and that of stairwell lighting is 24 h per day. The exterior lighting has been also applied uniformly in both baseline and proposed building design and is modeled with an operational schedule of 12 h per day.

3.3.4. Receptacles

The case study conducted in this study includes power associated appliances such as the refrigerator, dishwasher, clothes dryer and washer, kitchen stove, and office equipment loads. The baseline building design has all standard efficiency appliances and proposed building design has energy star refrigerator and dishwasher and standard efficiency dryer, washer, and electric stove. All the appliances are in-unit. The annual energy consumption of appliances is taken from simulation guidelines by ENERGY STAR MFHR Program and is calculated to be about 3.2 W/m^2 for the baseline building against 3.1 W/m^2 for the proposed building in residential units. Plug loads in non-residential spaces like stairwell and storage are modeled at 2.2 W/m^2 and those in office spaces at 16.1 W/m^2 for both baseline and proposed building design.

3.3.5. Domestic hot water demand and efficiency

The residential units have an 93% efficient electric in-unit 151 L storage water heater for the proposed building design. The water heater for the baseline building design has been calculated to be 88% using Eq. (1) from Table 7.8 Performance Requirements for Water-Heating Equipment of ASHRAE Standard 90.1. The hot water consumption was calculated manually by U.S. Environmental Protection Agency (EPA) Performance Path Calculator [35] which is based on per person hot water consumption of 95 L and faucet flowrate of 9.5 lpm (liters per minute) for lavatory sinks and showerheads of the baseline building design and 5.7 lpm and 7.6 lpm for residential units of the proposed building design. Office space restroom and kitchenette water calculations are neglected as building is primarily a residential building.

$$EF = 0.91{-}0.004996\ V \tag{1}$$

where EF stands for Energy Factor (%) and V stands for the storage volume (L).

3.3.6. Energy consumption and cost

For full year energy modeling for each analysis scenario, the energy cost budget report from TRACE 700 is used as shown in Fig. 2. The information from the energy cost budget report is used to analyze annual energy consumption and cost for the energy consumption categories such as lighting, space heating, space cooling, heat rejection, fans, receptacles, and stand-alone base utilities. All the values in this report are calculated in million Btu per year and are converted to equivalent kWh units. First column of the 'Alternative-2 Baseline' and 'Alternative-1 Proposed' indicates the total energy consumption for each energy consumption category. Second column indicates the percentage contribution of each energy consumption category on the overall energy consumption of the baseline building design. The last column indicates the peak energy consumption of each energy consumption category. The report also calculates the number of heating and cooling unmet load hours for both baseline and proposed building design and they should not exceed total of 300 unmet load hours in each case.

4. Results

For all four analysis scenarios, energy consumption in each energy consumption category has been calculated for both baseline and proposed building design as listed in Table 4. The energy consumption associated with conditioned and unconditioned spaces in all categories have been summed up and presented as a single value. The base utilities include the energy associated with the exterior lighting and the domestic hot water. The annual energy consumptions of all analysis scenarios are slightly different because of the assumptions used as inputs. These energy consumption results are utilized to calculate the building energy performance for each energy consumption category and analysis scenario. Then the percentage energy performance improvement achieved by proposed building design over the baseline building design are calculated using Eq. (2) and compared for each analysis scenario.

$$PEPI = \frac{EP_{baseline}{-}EP_{proposed}}{EP_{baseline}} \times 100 \tag{2}$$

where $PEPI$ stands for the percentage energy performance improvement (%); $EP_{baseline}$ stands for the energy performance of the baseline building; and $EP_{proposed}$ stands for the energy performance of the proposed building.

Table 5 compares the percentage energy performance improvement and LEED points awarded for four different analysis scenarios. LEED points scored for each analysis scenario are quite different although the percentage energy performance improvements are almost same between scenarios 1 and 2 (i.e., renovation) and scenarios 3 and 4 (i.e., Note: The percentage displayed for the "Proposed/ Base %" column of the base case is actually the percentage of the total energy consumption.

* Denotes the base alternative for the ECB study.

		* Alt-2 BASELINE-Ex 2010			Alt-1 PROPOSED		
		Energy 10^6 Btu/yr	Proposed / Base %	Peak kBtuh	Energy 10^6 Btu/yr	Proposed / Base %	Peak kBtuh
Lighting - Conditioned	Electricity	51.0	7	10	35.9	70	8
Lighting - Unconditioned	Electricity	5.4	1	2	5.4	100	2
Space Heating	Electricity	232.3	34	529	43.4	19	165
Space Cooling	Electricity	52.4	8	107	27.2	52	31
Heat Rejection	Electricity	11.7	2	8	4.4	37	4
Fans - Conditioned	Electricity	125.4	18	16	50.7	40	7
Receptacles - Conditioned	Electricity	82.8	12	9	81.2	98	9
Receptacles - Unconditioned	Electricity	5.6	1	1	5.6	100	1
Stand-alone Base Utilities	Electricity	116.2	17	14	95.2	82	12
Total Building Consumption		**682.7**			**349.0**		

		* Alt-2 BASELINE-Ex 2010	Alt-1 PROPOSED
Total	**Number of hours heating load not met** **Number of hours cooling load not met**	35 20	60 81

	* Alt-2 BASELINE-Ex 2010		Alt-1 PROPOSED	
	Energy 10^6 Btu/yr	Cost/yr $/yr	Energy 10^6 Btu/yr	Cost/yr $/yr
Electricity	682.7	18,243	349.0	9,325
Total	**683**	**18,243**	**349**	**9,325**

Fig. 2. Snapshot of the energy cost budget report from TRACE 700.

new construction). Scenario 1 achieved 48.2% energy performance improvement and received 34 points under LEED v3 whereas scenario 2 achieved 48.8% energy performance improvement and received 26 points under LEED v4. Scenario 3 achieved 14.2% energy performance improvement but did not qualify for any LEED points because it could not meet a minimum 15% energy performance improvement as per LEED v3 EA category prerequisite requirements. Meanwhile, scenario 4 still received 9 points with similar energy performance improvement (i.e., 14.6%) because LEED v4 EA category prerequisite is modified to 5% energy performance improvement instead of 15% proposed in LEED v3. Results showed that the scenario using ASHRAE Standard 90.1-2010 (i.e., scenario 4) has been proven to be more beneficial for new construction whereas that using ASHRAE Standard 90.1-2007 (i.e., scenario 1) has been proven to be more beneficial for renovation of this target building in terms of LEED points. In terms of percentage energy performance improvement, the annual energy performance has been

Table 4
Energy consumption by energy consumption category calculated using TRACE 700.

Energy consumption category (kWh)	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Baseline building	Proposed building	Baseline building	Proposed building	Baseline building	Proposed building	Baseline building	Proposed building
Lighting	16,328	12,371	16,538	12,095	16,316	12,361	16,538	12,095
Space Heating	66,514	12,756	68,070	12,730	14,232	12,756	14,666	12,730
Space Cooling	16,082	7972	15,345	7979	11,289	7972	16,538	12,095
Heat Rejection	3584	1276	3431	1275	1402	1276	1352	1275
Fans	36,764	14,849	36,756	14,850	16,519	14,849	16,516	14,850
Receptacles	25,911	25,446	25,911	25,446	25,911	25,446	25,911	25,446
Base Utilities	35,488	29,355	34,043	27,909	35,488	29,355	34,043	27,909
Total (kWh)	200,670	104,024	200,095	102,283	121,158	104,014	119,821	102,283
Cost ($/yr)	18,301	9487	18,249	9328	11,050	9487	10,928	9328

Table 5
Percentage energy performance improvement and LEED EA credit for different scenarios.

Scenario	percentage energy performance improvement	LEED points awarded in LEED EA category
Scenario 1	48.2%	34 points
Scenario 2	48.8%	26 points
Scenario 3	14.2%	0 points
Scenario 4	14.6%	9 points

improved for both scenarios 2 and 4 by 0.6% and 0.4%, respectively, compared to scenarios 1 and 3 which are modeled by referencing ASHARE Standard 90.1-2007.

5. Discussion

To investigate the impact of different LEED versions (i.e., LEED v3 and v4) in more detail, this study conducted various comparative analysis as follows: (i) the impact of different LEED versions on LEED points; (ii) the impact of different LEED versions on energy performance improvement by energy consumption category; and (iii) the impact of different LEED versions on energy consumption change for the baseline building by energy consumption category.

Fig. 3 illustrates the distribution of LEED points for LEED v3 and v4 in accordance to the percentage energy performance improvement achieved. LEED points awarded from LEED v3 linearly increase up to 46% energy performance improvement once the prerequisite of 15% minimum energy performance improvement is achieved. For LEED v4, the minimum threshold for the energy performance improvement is reduced to 5%, but the points thereafter increase linearly up to 19% energy performance improvement and then also continuously increases with lower rate up to 59% energy performance improvement. After the intersection point of LEED v3 and v4 (i.e. 34% energy performance improvement), it becomes difficult to gain more points for similar energy performance improvement in LEED v4 compared to LEED v3. It shows that following LEED v4 would make client eligible to qualify for EA category with lower target energy performance improvement but would award points more stringently with higher target energy performance improvement. Scaling EA credit points to the lower number for LEED v4 (i.e. 30 points) from the LEED v3 (i.e. 34 points) does not necessarily mean the overall contribution percentage has diminished as well.

Fig. 4 illustrates the percentage energy performance improvement in individual energy consumption categories of all analysis scenarios. For renovation, the percentage energy performance of scenario 2 has increased in lighting, space heating and base utilities categories whereas it has decreased in space cooling and heat rejection categories in comparison to scenario 1. Same trends are observed when comparing scenarios 3 and 4 which are the case of new construction. The categories which are unaffected by the change of ASHRAE Standard versions were found to be fans and receptacles. As mentioned above, fan energy requirements for the baseline building design of all analysis scenarios were same at 3.2 W/cmm. Similarly, receptacles were also modeled identically in all four analysis scenarios. It is evident that the major energy consumption categories are space heating and heat rejection, and the associated fan energy to move and emit the heated and cooled air. Since the baseline building design reflects the existing condition of the building envelope in scenarios 1 and 2, a higher energy performance improvement was resulted for these energy consumption categories in scenarios 1 and 2 compared to scenarios 3 and 4. This suggests that the building envelope is one of the major contributing factors in deciding the annual energy demand for the building.

Fig. 5 illustrates the percentile change in energy consumption made by applying the newer version of ASHRAE Standard (i.e. ASHRAE Standard 90.1-2010) to the older version (i.e. ASHRAE Standard 90.1-2007) for each energy consumption category. Changes have been observed in the energy model when applying the newer version of ASHRAE Standard in constructing the baseline design. Each light gray bar indicates the percentile variance between scenarios 1 and 2 (i.e. renovation) whereas each dark gray bar indicates the percentile variance between scenarios 3 and 4 (i.e. new construction). The negative percentile change indicates that the annual energy consumption has increased whereas the positive percentile change indicates that the annual energy consumption has decreased by applying ASHRAE Standard 90.1-2010 over 90.1-2007 for the baseline building. In particular, the lighting energy consumption has increased by applying the newer version of ASHRAE Standard for the baseline building, the reason being the minimum lighting power density requirement has increased for the space type such as offices and stairwell and has decreased for the space type such as storage and electrical/mechanical rooms in ASHRAE Standard 90.1-2010 compared to 90.1-2007. The reason of reduced energy consumption for space cooling and heat rejection is that the minimum cooling efficiency requirement for PTHP has increased from 9.105 EER to 9.50 EER and heat rejection COP has also increased from 2.81 to 2.9 in ASHRAE Standard 90.1-2010. Thus the baseline building constructed using ASHRAE Standard 90.1-2010 gets the advantage of higher efficiency equipment resulting in reduced annual energy consumption. The minimum requirement for the exterior lighting has

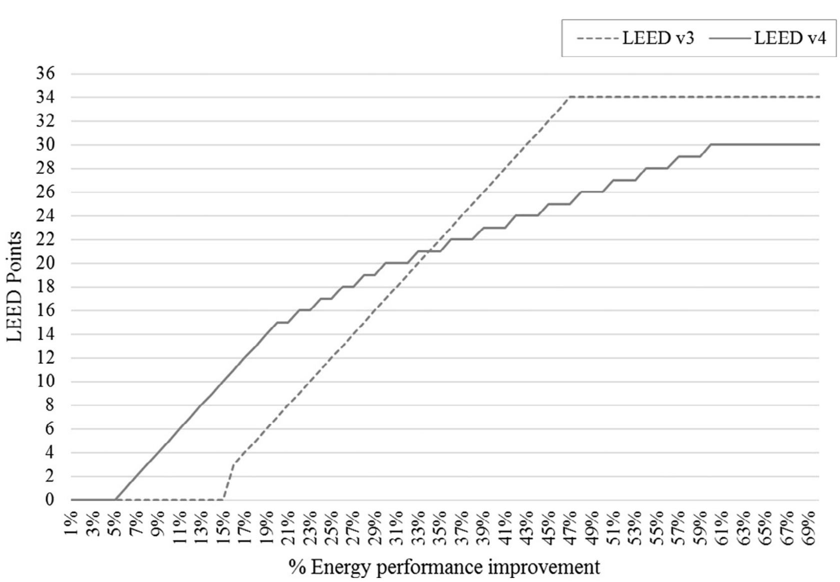

Fig. 3. The distribution of LEED points by the percenatge energy performance improvement for LEED v3 and v4.

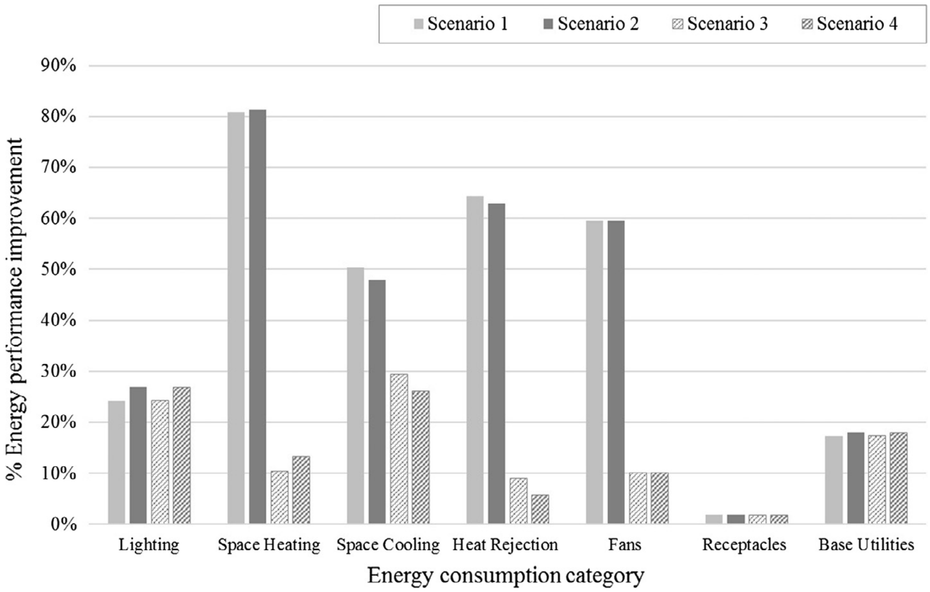

Fig. 4. The percentage energy performance improvement by the energy consumption category.

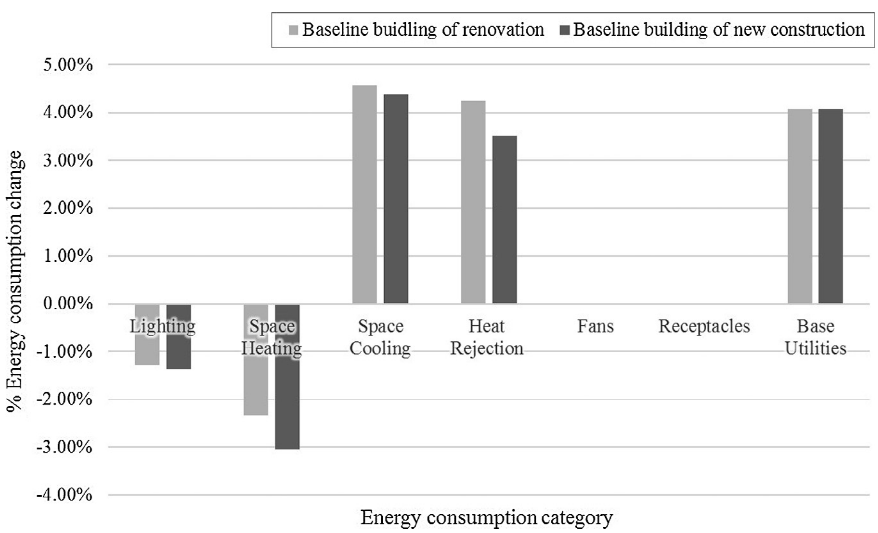

Fig. 5. The percentage energy consumption change for the baseline building of renovation and new construction.

become stricter in ASHRAE Standard 90.1-2010 thus the baseline building design with ASHRAE Standard 90.1-2010 showed decrease in annual energy consumption for base utilities.

From the above results, it can be concluded that the overall increase in annual energy consumption for any baseline building design is a benefit in terms of energy savings because of the greater annual energy difference between the baseline and proposed building design. Specifically, the overall annual energy consumption of the baseline model with ASHRAE Standard 90.1-2007 exceeded the energy consumption of the baseline model with ASHRAE Standard 90.1-2010. This trend indicates that the latest ASHRAE Standard is becoming stringent and allows to consume less energy in buildings.

6. Conclusions

By comparing the impact of applying different LEED versions, LEED v3 and v4, this study showed that mid-rise multi-family buildings pursuing "LEED for Homes" certification could benefit from LEED v4 as the prerequisite for the minimum energy performance improvement in EA category is reduced from 15% in LEED v3 to 5% percent in LEED v4. LEED certification is getting lenient with the prerequisite in EA category as demonstrated earlier in this study that for nearly equivalent energy performance improvement, LEED v3 could not obtain any points while LEED v4 could earn 9 points, inflating the energy performance of the building. Though the energy code gets stringent every three years with the release of newer versions of ASHRAE Standard, ASHRAE Standard 90.1-2010 has been proven to be beneficial for the energy performance improvement over the baseline building design for the target building. However, the energy allowances (i.e. minimum energy requirement) have become strict in energy consumption categories such as HVAC and exterior lighting but have become flexible in energy consumption category such as interior lighting. Thus combination of LEED v4 with ASHRAE Standard 90.1-2010 does not necessarily have negative implication on the scoring of LEED points. Another major learning from this study is that regardless of LEED versions or ASHRAE Standard used, the renovation buildings are greatly incentivized. Three times better energy performance improvement was achieved in the target building of the case study for renovation when compared to new construction. In general, a renovation building has more capability to realize higher energy performance improvements when compared to new construction building. As shown in the case study, scenarios 1 and 2 (i.e., renovation) achieved 48.5% energy performance improvement and received 30 points on average whereas scenarios 3 and 4 (i.e., new construction) could only achieve 14.4% energy performance improvement and only received 4.5 points on average. Not only USGBC but also industry and government can use the key findings of this study for various applications as follows: (i) USGBC can modify and improve the scoring scheme of future LEED version which could actually promote green buildings and nearly-zero energy building; (ii) stakeholders (e.g., building owners, consultants, and investors) in the relevant industry can benefit from earning more LEED points for new construction or renovation of their assets during the LEED certification process; and (iii) the government can revise and determine national energy standards which could encourage the energy efficiency in buildings. The possible extension of this research paper would be to utilize a different type of building with more advanced heating and cooling equipment to investigate the true reflection of the energy performance improvement when applying ASHRAE Standard 90.1-2010 to the baseline model.

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References

[1] Bhattacharya M, Paramati SR, Ozturk I, Bhattacharya S. The effect of renewable energy consumption on economic growth: evidence from top 38 countries. Appl Energy 2016;162:733–41.

[2] Park H, Lee M, Kang H, Hong T. Development of a new energy benchmark for improving the operational rating system of office buildings using various data-mining techniques. Appl Energy 2016;173:225–37.

[3] Asdrubali F, Baldinelli G, Bianchi F, Sambuco S. A comparison between environmental sustainability rating systems LEED and ITACA for residential buildings. Build Environ 2015;86:98–108.

[4] Koo C, Hong T, Lee M, Park H. Development of a new energy efficiency rating system for the existing residential buildings. Energy Policy 2014;68:218–31.

[5] Koo C, Park S, Hong T, Park H. An estimation model for the heating and cooling demand of a residential building with a different envelope design using the finite element method. Appl Energy 2014;115:205–15.

[6] Choi J-K, Bakshi BR, Hubacek K, Nader J. A sequential input–output framework to analyze the economic and environmental implications of energy policies: gas taxes and fuel subsidies. Appl Energy 2016;184:830–9.

[7] Gourlis G, Kovacic I. Building Information Modelling for analysis of energy efficient industrial buildings – a case study. Renew Sustain Energy Rev 2017;68(Part 2):953–63.

[8] Jiru TE. Combining HVAC energy conservation measures to achieve energy savings over standard requirements. Energy Build 2014;73:171–5.

[9] Jeong J, Hong T, Ji C, Kim J, Lee M, Jeong K. Development of an evaluation process for green and non-green buildings focused on energy performance of G-SEED and LEED. Build Environ 2016;105:172–84.

[10] U.S. Green Building Council (USGBC), LEED| US Green Building Council; 2017. Available at < http://www.usgbc.org/leed > [January 1, 2017].

[11] Becchio C, Corgnati SP, Fabrizio E, Monetti V, Seguro F. Application of the LEED PRM to an Italian existing building. Energy Procedia 2014;62:141–9.

[12] Mao X, Lu H, Li Q. A Comparison Study of Mainstream Sustainable/Green Building Rating Tools in the World. 2009 International Conference on Management and Service Science, Wuhan; 2009. p. 1–5.

[13] U.S. Green Building Council (USGBC). LEED® for Homes Rating System Multifamily Mid-Rise|; October 2010. Available at < http://www.usgbc.org/resources/leed-homes-multifamily-midrise-v2010-current-version > [January 1, 2017].

[14] ASHRAE, ASHRAE Standard Energy Standard for Buildings Except Low- Rise Residential Buildings, Atlanta; 2007. ISSN 1041-2336.

[15] Kibert CJ. Sustainable construction: green building design and delivery. John Wiley & Sons; 2016.

[16] ASHRAE, ASHRAE Standard Energy Standard for Buildings Except Low- Rise Residential Buildings, Atlanta; 2010. ISSN 1041-2336.

[17] Schwartz Y, Raslan R. Variations in results of building energy simulation tools, and their impact on BREEAM and LEED ratings: a case study. Energy Build 2013;62:350–9.

[18] Lee WL. Benchmarking energy use of building environmental assessment schemes. Energy Build 2012;45:326–34.

[19] Alshamrani OS, Galal K, Alkass S. Integrated LCA–LEED sustainability assessment model for structure and envelope systems of school buildings. Build Environ 2014;80:61–70.

[20] Azhar S, Carlton WA, Olsen D, Ahmad I. Building information modeling for sustainable design and LEED® rating analysis. Autom Constr 2011;20(2):217–24.

[21] Chen H, Lee WL. Energy assessment of office buildings in China using LEED 2.2 and BEAM Plus 1.1. Energy Build 2013;63:129–37.

[22] Baglivo C, Congedo PM, Fazio A. Multi-criteria optimization analysis of external walls according to ITACA protocol for zero energy buildings in the mediterranean climate. Build Environ 2014;82:467–80.

[23] Gu Z, Wennersten R, Assefa G. Analysis of the most widely used Building Environmental Assessment methods. Environ Sci 2006;3(3):175–92.

[24] Jeong J, Hong T, Ji C, Kim J, Lee M, Jeong K, Koo C. Improvements of the operational rating system for existing residential buildings. Appl Energy 2017;193:112–24.

[25] Xing J, Ren P, Ling J. Analysis of energy efficiency retrofit scheme for hotel buildings using eQuest software: a case study from Tianjin, China. Energy Build 2015;87:14–24.

[26] Yi H, Srinivasan RS, Braham WW. An integrated energy–emergy approach to building form optimization: use of EnergyPlus, emergy analysis and Taguchi-regression method. Build Environ 2015;84:89–104.

[27] Lim Y-W, Heng CYS. Dynamic internal light shelf for tropical daylighting in high-rise office buildings. Build Environ 2016;106:155–66.

[28] Neroutsou TI, Croxford B. Lifecycle costing of low energy housing refurbishment: a case study of a 7 year retrofit in Chester Road, London. Energy Build 2016;128:178–89.

[29] Zhu D, Hong T, Yan D, Wang C. A detailed loads comparison of three building energy modeling programs: EnergyPlus, DeST and DOE-2.1E. Build Simul 2013;6(3):323–35.

[30] Komurlu R, Arditi D, Gurgun AP. Applicability of LEED's energy and atmosphere category in three developing countries. Energy Build 2014;84:690–7.

[31] Roderick Y, Mcewan D, Wheatley C, Alonso C. Comparison of energy performance assessment between LEED, BREEAM and Green Star. Eleventh International IBPSA Conference; 2009.

[32] Hong T. A close look at the China Design Standard for Energy Efficiency of Public Buildings. Energy Build 2009;41(4):426–35.

[33] Trane, TRACE 700 Version 6.3.3.3. Available at < http://www.trane.com > [January 1, 2017].

[34] Wilcox S, Marion W. Users manual for TMY3 data sets. Colorado: National Renewable Energy Laboratory (NREL); 2008.

[35] U.S. Environmental Protection Agency (US EPA). Performance Path Calculator; 2010.