Sustainable Cities and Society 17 (2015) 15–21

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Energy use assessment of educational buildings: Toward a campus-wide sustainable energy policy

Duzgun Agdas[a,*], Ravi S. Srinivasan[b], Kevin Frost[c], Forrest J. Masters[d]

[a] Civil Engineering and Built Environment School, Queensland University of Technology, Brisbane, Australia
[b] M.E Rinker, Sr. School of Construction Management, University of Florida, Gainesville, FL, USA
[c] Department of Ocean Engineering, Texas A&M University, College Station, TX, USA
[d] Engineering School of Sustainable Infrastructure and Environment, University of Florida, Gainesville, FL, USA

ARTICLE INFO

Article history:
Available online 9 March 2015

Keywords:
Energy efficiency
Building rating systems
Sustainable energy policy

ABSTRACT

The purpose of this article is to assess the viability of blanket sustainability policies, such as Building Rating Systems in achieving energy efficiency in university campus buildings. We analyzed the energy consumption trends of 10 LEED-certified buildings and 14 non-LEED certified buildings at a major university in the US. Energy Use Intensity (EUI) of the LEED buildings was significantly higher (EUI_{LEED} = 331.20 kBtu/sf/yr) than non-LEED buildings ($EUI_{non\text{-}LEED}$ = 222.70 kBtu/sf/yr); however, the median EUI values were comparable (EUI_{LEED} = 172.64 and $EUI_{non\text{-}LEED}$ = 178.16). Because the distributions of EUI values were non-symmetrical in this dataset, both measures can be used for energy comparisons—this was also evident when EUI computations exclude outliers, EUI_{LEED} = 171.82 and $EUI_{non\text{-}LEED}$ = 195.41. Additional analyses were conducted to further explore the impact of LEED certification on university campus buildings energy performance. No statistically significant differences were observed between certified and non-certified buildings through a range of robust comparison criteria. These findings were then leveraged to devise strategies to achieve sustainable energy policies for university campus buildings and to identify potential issues with portfolio level building energy performance comparisons.

1. Introduction

Widespread reduction in building energy use will be a critical part of lowering green house gas emissions, and ultimately slowing global warming trends (IPCC, 2014). In the U.S., building industry accounts for over 40% of the annual energy demand and 40% of CO_2 emissions (USDOE, 2012). This paper presents an analysis of energy use of a large portfolio of buildings co-located at a major American university. The findings suggest that campus-wide sustainable building energy policies may benefit from de-emphasizing the role of 'blanket' classification schemes. Among others, incorporating expert measurement procedures to quantify outcomes of energy use (e.g., CO_2 emissions) can provide a more effective approach in reducing the overall energy use, and ultimately achieving effective sustainability policies.

1.1. Building design and energy efficiency

Several building energy improvement programs exist to promote energy efficiency. For example, the United States (US) Environmental Protection Agency (EPA) Energy Star program is a voluntary program developed to identify and promote a performance-based approach for new and existing buildings (https://www.energystar.gov/). The EPA's Target Finder is a web-based tool that uses the 2003 U.S. Energy Information Agency's Commercial Building Energy Consumption Survey (CBECS) data (EIA, 2003) to estimate projected Energy Use Intensities (EUI) based on the building occupancy type, area, fuel source and use derived from energy simulations. Examples of energy codes include California's Title 24 (California Energy Commission, 2013) and the International Energy Conservation Code (IECC), which has been adopted by several states in the U.S. (ICC, 2012).

Regardless of these efforts, what brought the topic of energy efficiency into the attention of masses has been adoption of Building Rating Systems (BRS) with their promise on improved energy efficiency. In the US, the two major BRS are the Leadership in Energy and Environmental Design (LEED) guidelines of the US Green Building Council (USGBC) and Green Globes of the Green Building Initiative—the former with the significant market share.

* Corresponding author. Tel.: +61 7 3138 8303.
E-mail address: duzgun.agdas@qut.edu.au (D. Agdas).

http://dx.doi.org/10.1016/j.scs.2015.03.001
2210-6707/

Building energy performance that primarily focuses on operational energy use is a major component in BRS. For example, 27% and 39% of the total points in the latest LEED and Green Globes rating systems are assigned to energy performance credits respectively (Srinivasan, 2013; USGBC, 2014).

Building energy use—and efficiency thereof—is a complicated phenomena affected by numerous *operational and design* characteristics. Architectural building design and, in a lesser extent, construction principles can significantly affect the overall energy use and efficiency (Ihm & Krarti, 2012; Sozer, 2010). Interestingly, the university policies reviewed for this study did not classify any design characteristics to be followed for increased energy efficiency. The closest adopted policy to a fundamental design-driven energy savings is the adoption of LEED building standards as the defining guidelines for new construction and major renovation activities. LEED and the other BRS are not necessarily design criteria, but benchmarks for building design and operation characteristics compared to different baselines for performance. Regardless, in most cases, LEED rating systems and others have been accepted to be the *de facto* design guidelines for energy efficiency and ultimately overall sustainability of the certified buildings. LEED rating system is the most widely accepted and adopted BRS in the U.S. with a total of over 44,000 registered and certified buildings since 2001. Note that this sum does not differentiate between the two—registration is a pre-requisite to certification but not necessarily guarantees it.

2. Energy efficiency comparisons of LEED and non-LEED buildings

Due to its widespread adoption and emphasis on promised energy savings, portfolio level energy performance assessment of LEED buildings have been the most prolific line of literature for performance-based energy consumption research. Turner and Frankel (2008) compared the operational efficiencies of recently constructed LEED certified buildings to non-certified buildings in the CBECS database (EIA, 2003), finding that the median EUI values of LEED certified buildings were 24% less than the national average. They extended their analysis to account for climate, building size, certification level, and building type and concluded that for all the analyses conducted, LEED buildings were found to be more energy efficient than non-LEED buildings.

Since then, several studies have re-analyzed the data to address the lack of completeness (∼25% of the data were reported originally) and to add statistical rigor. Newsham, Mancini, and Birt (2009) stratified the data by building description and expected energy demand. *T*-tests results showed that LEED buildings were 18-39% more efficient than their non-LEED counterparts; however, one-third of LEED buildings required more energy. No significant relationship between building energy, consumption trends, and LEED certification levels and energy credits were found in this study (Newsham et al., 2009). Subsequently, Scofield (2009) rejected the conclusion that LEED certified buildings were more energy efficient, comparing site (energy used by the building) and source (incorporates the off-site losses associated with distribution and generation) energy consumption data. Scofield further argued that building size should also be used in the comparisons—because of the relative significance of renewable energy production as a fraction of overall energy use—and showed that they can alter the results when area-based weighting is used in computations.

Results from an evaluation of electricity and water consumption of U.S. Navy LEED buildings, showed that nine of the eleven buildings evaluated did not meet the 30% energy savings goal set by the administration, whereas only two of the nine buildings have not met the water saving goals when compared to similar buildings under Naval Command (Menassa, Mangasarian, El Asmar, & Kirar, 2012). The authors also stated that the majority of the Naval LEED buildings were consuming more electricity than the comparable buildings from CBECS data. Lastly, Scofield (2013) compared energy efficiency of 21 office LEED buildings to a large dataset of 953 non-LEED buildings and concluded that LEED buildings did not show any energy improvements when compared to non-LEED buildings. The author, however, identified differences in energy performance among different certification levels, for example, gold certified buildings were found to save source energy whereas silver certified and basic certified buildings were not.

In the following sections, we discuss the energy efficiency of a large LEED educational portfolio, i.e., buildings situated in a university campus setting, and discuss the implications of adopting LEED building rating system as a blanket policy on overall energy performance and how well the design component of energy efficiency is met by this policy.

3. Energy efficiency in higher education buildings

Higher education institutions have been early and comprehensive adopters of building energy efficiency and sustainability policies. For example, more than 680 universities have signed the American College and University Presidents' Climate Commitment (AUPCC) agreement, which requires participating institutions to reduce greenhouse gas emissions. University campuses are an excellent study set to assess the design and enforcement of sustainability and energy efficiency policies. The building stock is usually highly uniform and maintained by the same entity under a standard set of policies and best practices in energy use. The variations are generally confined to the construction time and details of building functionality combinations (e.g., teaching, research, laboratory, administration). This is a sharp contrast to majority of commercial construction (the most common projects that seek BRS certification), as there are multiple parties involved throughout project life cycle with different levels of engagements and priorities. Another benefit of study campuses is the extensibility of results. A brief review of the Association for the Advancement of Sustainability in Higher Education (AASHE) website—which outlines university energy policies—revealed that the generally accepted best operational practices in energy efficiency (e.g., temperature set points for HVAC systems, multiple/individual zones for controls, assigning individual responsibilities for saving energy, etc.) are, for the most part, consistent across universities. Interestingly, LEED certification appears to be the most prominent design related guideline; although, as discussed earlier, the certification guidelines are not necessarily devised to serve this purpose.

Although the LEED energy efficiency topic has been analyzed in great detail in earlier literature, no clear conclusions were drawn about energy performance of LEED buildings; thus, their capacities as a de facto design consideration criteria. We provide detailed analyses of energy consumption of 10 LEED-certified and 14 non-LEED educational buildings, all of which are located on main campus of the University of Florida (UF), in Gainesville, Florida. Monthly consumption data for chilled water, steam, and electricity for 2013 were used to analyze energy consumption trends to assess the viability of BRS-based blanket sustainable energy policies for university campuses.

3.1. Building descriptions

UF has one of the largest LEED educational building portfolios with 29 LEED-certified buildings (Dougherty, 2010). Because multiple comparable non-certified buildings to LEED-certified buildings exist on campus with available data, a realistic comparative assessment of energy performance was feasible. Ten LEED-certified buildings and 14 non-LEED buildings were chosen for the study. The LEED-certified structures were all constructed after 2001, and the non-LEED structures were constructed as early as the 1950s—it is likely that there have been significant modifications to the older structures through maintenance and rehabilitation operations. The initial selection of these buildings was based on *data availability* and *end user functionality* similarities of buildings. Focusing on buildings within a single campus provided the following improvements to the issues addressed in the literature:

- *Location/Climate:* The buildings are located on the main UF campus located in Gainesville, FL, which eliminated all probable differences induced by different climate zones and local regulations building on energy performance (Menassa et al., 2012; Oates & Sullivan, 2012). Although there are generic adjustments for regional climatic differences—Energy Star assumes four climates for the U.S., and IECC identifies eight climate zones for the U.S.—they are not specific enough to sufficiently address the differences in building energy characteristics due to climatic differences and local regulations that might affect energy performance.
- *Data availability and reliability:* Details of building space classification and monthly energy use data was made available to the research team. The data was furnished by a single source, reducing reliability issues often found when using multiple data sources. This provides a significant improvement in data consistency, as the majority of the data used in earlier studies are based on voluntary submissions by building owners with no control over data reliability and collection methods and accuracy. Other studies, such as that performed by Menassa et al. (2012) had to limit their discussions to electricity and water due to lack of available data on other energy sources.
- *Consistent facilities management:* Because the same office—under standardized measures and guidelines—maintains all UF buildings and oversees their energy consumption, effects of inadequate or improper facilities management (Newsham et al., 2009) as a factor affecting energy performance can be ruled out.
- *Similar building characteristics:* An important issue with building type-based assessment is the shortcomings of the generic building level classification. An obvious example would be the term "office". An office space represents a different physical space use for different industries, resulting in different energy demands. Improvements to the building level space classification were made possible by comparing buildings that are similar in size and functionality.

3.2. Data collection and analysis

To control for the building characteristics that affect energy consumption and increase the granularity of the overall assessment, the 24 buildings analyzed in this study were assigned to 10 subgroups—one subgroup per each LEED building. Each LEED building was compared to two non-LEED buildings with the most similar space classifications—i.e. building functionality. On few instances same non-LEED buildings were assigned to different subgroups due to data availability (These buildings are noted in Table 2). This classification was based on building use space classifications described in Post-Secondary Education Facilities Inventory and Classification Manual (USDoE, 2006). Of the thirteen defined categories defined in this publication, the most common space classifications for the analyzed portfolio were: *classroom, teaching laboratories, office, and research laboratories.*

Electricity, chilled water, and steam consumption data for 2013 were analyzed to calculate site EUI. Energy star thermal energy conversions reference document was used to convert different inputs to standard energy performance metrics such Btu or Joules (i.e. 1 kWh of electricity is 3.412 kBtu) (EPA, 2014b). The subject buildings were part of centralized loops that provided for chilled water and steam for the HVAC systems. To account for the cooling related energy demands, the chilled water used for cooling was converted to energy demand (i.e. 12,000 Btu/ton hours). Steam related energy consumption was also used in EUI computations (i.e. 1194 Btu/lb). Monitoring was available for all of the buildings; however, in few cases multiple buildings were on the same monitoring device—a single meter was used for measuring consumption for more than one building. In these cases, the energy use associated to a single building was assumed to be linearly correlated to its Gross Square Foot (GSF) area, i.e. if two buildings with the same GSF were on a single electricity meter, each was assumed to consume half of the total electricity used. This was the case for only non-LEED buildings; thus, was deemed to be acceptable as it is the impact of LEED certification that we analyzed.

4. Results and discussions

Table 1 shows that the mean EUI of the LEED buildings was significantly larger (EUI_{LEED} = 331.20 kBtu/sf/yr) than non-LEED buildings ($EUI_{non\text{-}LEED}$ = 222.70 kBtu/sf/yr); however, the median EUI values were comparable (EUI_{LEED} = 172.64 and $EUI_{non\text{-}LEED}$ = 178.16). Because the distributions of EUI values were non-symmetrical in this dataset, this difference is understandable within the groups; yet, they could lead to different results if the conclusions on energy efficiency were made based on different centrality measures. This was also evident when EUI computations exclude outliers (outside of $\pm 1.0\sigma$ of the sample mean), EUI_{LEED} = 171.82 and $EUI_{non\text{-}LEED}$ = 195.41. We have also reported the GSF-Weighted EUI averages for both the raw ($EUI_{GSF\text{-}LEED}$ = 372.55 and $EUI_{GSF\text{-}non\text{-}LEED}$ = 240.03) and no-outlier data set ($EUI_{GSF\text{-}LEED}$ = 177.32 and $EUI_{GSF\text{-}non\text{-}LEED}$ = 181.54), an analysis conducted by Scofield (2009) and used in CBECS reporting. Average EUI values for LEED and non-LEED groups increased when they are weighted by GSF—for both raw and processed data sets. This is consistent with the conclusions Scofield (2009) draw about larger buildings having greater EUIs. Regardless of the centrality measures chosen for assessment, both arithmetic and GSF-weighted averages were higher than those of the CBECS values reported in earlier literature—average EUI values for CBECS office type buildings was 92.8, and the mean and median for university type buildings was 155.3 and 130.7 respectively (EIA, 2003; EPA, 2014a)—indicating further analyses were required before meaningful conclusions could be drawn.

To increase the granularity of the energy use numbers, an assessment of relative energy performance of LEED buildings within their subgroups were conducted. This process produced mixed results. Of the ten LEED certified buildings assessed, two performed better than the two non-LEED buildings in their subgroup, five performed worse than the two comparable non-LEED buildings in their subgroups, and the remaining three performed in between (Table 2). The results were unexpected as the certified buildings are more recent, equipped with more modern appliances and anticipated to be more efficient than older buildings with comparable functionality and space use.

Chilled water use accounted for 0% to 72% of the building energy demand. Electrical loads accounted from 10% to 100% of the total energy demand. Steam related energy consumption accounted from 0% to 60% of the total energy use (Table 2). These results suggest that a significant part of the energy used in the buildings is for cooling purposes and this is expected—steam is used for room temperature regulation as part of the HVAC system not necessarily for heating during winter, as the buildings are located in a subtropical

Table 1
Descriptive statistics of building portfolio.

Group	Data	Mean	Median	Min	Max
LEED	Raw data	331.20	172.64	68.36	1206.40
	No outliers	171.82	147.23	68.36	307.43
GSF weighted LEED	Raw data	372.55	–	–	–
	No outliers	177.32	–	–	–
NON-LEED	Raw data	222.70	178.16	61.93	543.34
	No outliers	195.41	177.44	116.13	312.91
GSF Weighted NON-LEED	Raw data	240.03	–	–	–
	No outliers	181.54	–	–	

Table 2
Energy use and sources for the building portfolio.

ID	EUI	Chilled Water (%)	Electrical (%)	Steam (%)	ID	EUI	Chill Water (%)	Electrical (%)	Steam (%)
1.1	122.33[a]	72.41	22.64	4.95	6.1	68.36[b]	60.92	31.23	7.85
1.2	61.93	63.46	33.52	3.01	6.2	116.13	54.17	22.73	23.10
1.3	116.13	54.17	22.73	23.10	6.3	161.64	62.45	16.78	20.78
2.1	731.09[a]	37.23	12.72	50.04	7.1	172.13[a]	51.72	23.33	24.94
2.2	362.95	38.47	26.67	34.86	7.2	116.13	54.17	22.73	23.10
2.3	543.34	51.37	23.75	24.88	7.3	165.94	51.71	20.65	27.65
3.1	116.94[b]	61.18	38.82	0.00	8.1	1206.40[a]	59.35	19.78	20.87
3.2	172.18	58.41	39.05	2.54	8.2	238.11	36.88	24.36	38.75
3.3	178.87	58.65	15.65	25.70	8.3	280.12	39.74	24.56	35.70
4.1	120.03	45.27	27.03	27.70	9.1	294.19	67.34	32.66	0.00
4.2	161.64	62.45	16.78	20.78	9.2	238.11	36.88	24.36	38.75
4.3	116.13	54.17	22.73	23.10	9.3	312.91	44.62	14.94	40.44
5.1	173.16	61.66	13.69	24.65	10.1	307.43[a]	74.30	18.37	7.33
5.2	161.64	62.45	16.78	20.78	10.2	177.44	46.04	30.20	23.76
5.3	204.49	62.43	18.03	19.55	10.3	141.70	0.00	100.00	0.00

[a] The worst performance within the subgroup.
[b] The best performance within the subgroup.

climate. Gainesville, FL has a warm and humid climate with average temperatures of 70–90 F (21–32 °C) with average humidity levels of 40–100%. Further analysis indicated that the average HVAC related energy use—chilled water and steam consumption compared to the total energy consumption—was approximately 5% higher for LEED buildings, whereas electricity consumption was approximately 5% higher for non-LEED buildings.

Because the directional comparison of building energy demands (i.e. whether LEED buildings use more energy than non-LEED buildings) was inconclusive, an independent *t*-test (Field, 2009) was used to analyze whether there are significant differences among the measured EUI values of building portfolio (Table 3). The statistical analyses were conducted using R software (R Development Core Team (2008). Although, on average, LEED buildings' EUI values are higher than those of non-LEED buildings for the raw data set, *t*-test results were not significant, indicating the differences in EUI values are statistically invalid. The same conclusion was valid for the processed data group. In addition, we have conducted a paired *t*-test using the LEED building EUI paired up with the average of the two non-LEED buildings as done in earlier literature (Newsham et al., 2009; Scofield, 2009). This test too has not indicated significant energy consumption differences between the data groups. These results are significant as the seemingly substantial differences in means (for the raw data set) seem to stem from few significant discrepancies in energy demands for a few buildings—especially the newer laboratory type buildings with significant energy requirements—rather than a consistent trend for the whole building portfolio.

The fifth assessment of LEED and non-LEED buildings was in terms of seasonal energy consumption demand fluctuations. A common criticism for LEED buildings has been the use of non-efficient building façade that might reduce the overall energy efficiency of building. Few studies discussed that in residential buildings that are located in cooling dominated climates such as Florida; increasing glazed façade area on a building could increase energy demand by 10–20% (Lstiburek, 2008; Tereci, Ozkan, & Eicker, 2013). To assess the validity of this, seasonal data from each building was analyzed. If the hypothesized inefficiencies were valid for the educational buildings analyzed, higher fluctuations in seasonal energy demands in LEED buildings should occur. For each of the 24 buildings analyzed, monthly energy demands were compared, and the Coefficient of Variation (COV) values were computed for each building's energy demand. The average COV of LEED buildings seasonal energy use was 21%, whereas the average COV of non-LEED buildings was 14%. Of the ten LEED buildings seven had the highest COV within their subgroups, one performed the best and the remaining two performed in between. Although the evidence is not conclusive, it appears the arguments by Lstiburek (2008) and Tereci et al. (2013) are supported in this data set.

On average, LEED buildings required more energy than the non-LEED counterparts; however, median energy consumption (which can be considered a better centrality measure because of the asymmetric distribution of the EUI values) figures favored LEED buildings. LEED buildings are equipped with more modern appliances and equipment, and energy efficiency incorporated into the design, yet the data analyses do not favor LEED certification in terms of energy efficiency of the buildings. A possible explanation to this may be that the changing functionality of the buildings and user comfort considerations that might have affected the overall efficiency. Energy efficiency is only one part of the green building standards. There is also a strong emphasis on user comfort and quality of life, which add a dimension to the functionality of the buildings that was not part of the building design criteria until recently—this is particularly more relevant as CBECS data was published in 2003. There is evidence from literature (i.e. electricity comparison numbers from Menassa et al., 2012) that newer

Table 3
Energy comparisons of LEED and non-LEED buildings.

Data source	Data	Average EUI	Test score	Df	*p*-value
LEED buildings	Raw data	331.20	0.91	10.46	0.38
Non-LEED buildings		222.70			
LEED buildings	No outliers	171.82	−0.67	11.67	0.52
Non-LEED buildings		195.41			
Paired *t*-test	Raw data	–	1.34	9	0.21

buildings can have significantly higher energy demands than the existing national average. It should also be noted that the CBECS data, although it is a national database, might not represent the actual, current energy use. Apart from the decade old data set, the most commonly used "office" type buildings EUI data was computed from 976 buildings out of 823,840 (~0.1%). Moreover, as the data indicated, majority of the energy on UF campus is spent on cooling. This is not a trivial observation as the details of national database—location of the reported buildings, energy use categories etc.—might have indicated different results. Another possible explanation for the skewed data set is the significantly higher energy requirements of the newer research buildings. The changing demands of advanced research labs on energy are apparent in the data set as newer laboratory type buildings have significantly higher energy. A fourth reason for the unexpected results is the inherent learning curve of the advanced instrumentation installed in newer buildings. Perhaps within time, operational policies and best practices can reflect the different requirements of modern technologies that can lead to effective promotion and management of high performance buildings through effective energy policy setup for university campuses and large portfolio buildings. Nevertheless, energy and sustainability managers of large portfolio of buildings can potentially gain from the suggestions discussed based on this study and real-world experiences of the authors in the following section.

5. Campus-wide sustainable building energy policy: recommendations

A common path to fulfill building energy optimization credit for both LEED and Green Globes in the US is complying with ASHRAE 90.1-2010 Standard, Appendix G. An important characteristic of this protocol is that a hypothetical building is modeled, which is derived from the proposed building model with inputs from the standard. In other words, the hypothetical baseline-building model that complies with Appendix G protocol may not fully represent the actual building under investigation. Although there are no published articles related to the number of hours spent in the development of building energy models that comply with the protocol, anecdotal evidence suggests that experts spend an overwhelming amount of time and effort in this process. The Appendix G protocol is an elaborate and detailed compliance structure that provides, if not all, most of the details required to model and compare the baseline and proposed energy models. However, the time necessary to model the baseline building and comply with the protocol is often substantial. In the interest of building owners and large portfolio managers, this time typically used to model baseline building and comply with the protocol could otherwise be spent on improving the energy efficiency of the proposed building model, i.e., perform any additional energy simulations that may be required to fine-tune the energy systems for maximum efficiency. This is more important especially for large portfolio managers who have limited time and resources, but still have to promote and manage high performance buildings owing to energy costs and larger sustainability goals. It should be noted that both BRSs offer other options to move away from complying with this protocol and still achieve a rating certificate.

Energy policy of campus-wide sustainability initiatives and large portfolio buildings require not only a sustainable framework that takes into consideration long-term goals such as promoting energy efficient buildings, both newly constructed and those that undergo renovation, but also manage the energy efficiency of the buildings effectively overtime in a consistent fashion. In this line, there are several enablers that may be directly implemented in a campus-wide sustainable building energy policy. These enablers are a direct translation of the authors' experiences and should be considered as suggestions only.

Unwavering focus on Carbon Dioxide (CO_2) emissions: Among others, one of the internationally accepted measures for highly effective building assessment is to address CO_2 emissions directly. This is in line with Architecture 2030 Challenge wherein architects stay focused on the priority of designing carbon neutral buildings and communities by 2030, i.e., building will not operate on fossil fuel GHG-emitting energy (www.architecture2030.org). On one hand, LEED does not have an energy credit that directly addresses CO_2 emissions, i.e., direct point allotment for building projects showing reduction in CO_2 emissions over a baseline. Energy optimization credit uses energy consumption values for determining percentage of improvement over baseline. On the other hand, as an example, Green Globes' Path C: Building CO_2 emission per ANSI/GBI 01-2010 Standard offers credit option in a more direct manner using a Baseline Equivalent Emissions Rate (BER) and Proposed Equivalent Emission Rates (PER). While BER is determined by Energy Star Target Finder, PER is calculated using a building energy model that conforms to the requirements outlined in Section 506, 2009 IECC or ANSI/ASHRAE/IESNA Standard 90.1-2007, Appendix G, Section G2.2 and Table G3.1. Although compliance with Standard 90.1 seems similar to Path B, there is one notable difference: BER calculations do not require a model of the hypothetical base building which, as previously discussed, is a time-consuming task (Srinivasan, 2013). Using options similar to this in energy consumption, building stakeholders can focus on improving a proposed building's energy consumption, and compare them with actual building data rather than laboring over base building model protocols. The Green Globes here was used as an example in this discussion and not necessarily to promote any product. However, simplified procedures can be developed by energy and sustainability managers that use building emissions rates as alternative evaluation mechanisms.

Nonetheless, if campus-wide sustainable building energy policymakers do not wish to pursue any variants of building rating systems, there are other options, paths for future that can be influential in reducing overall energy use as discussed below.

- *Energy star target finder and portfolio manager:* University energy personnel can use the "College/University" building type option and related inputs to evaluate the building performance. If this is a new building, an energy simulation may be performed using one of the U.S. Department of Energy recommended tools without the need of a baseline energy model requirement. In the case of an existing building, annual energy use can be input to determine the building's relative performance to other similar buildings' from 2003 CBECS data. It also appears that a new iteration of this data set (for 2012) is in the works and should be published soon to allow a better comparison for potentially altered energy use numbers.

- *Certification vs. operational efficiency:* One of the main arguments in prescriptive process of BRS is the marketing power—increased marketability because of potential energy savings and increased user comfort—these may bring to the structure of interest as a justification to pre-operational awarding of certification. With measurement and verification as building owners are not likely to have the in-house expertise or dedicate funds for outsourcing this. A third and unlikely cause may be the potential deviations from the planned baselines in energy use may also have also supported pre occupation award of certification or added costs of achieving these pre certification levels. In any of these cases, the university campuses differ in the owner and operational ownership—as discussed earlier in this article—allowing for a sole focus on operational/measured energy improvements rather than prescriptive certification awarding. Setting simple thresholds for energy performance, using the existing energy data, for new construction and major renovations can improve the overall performance significantly. There are numerous technologies that show significant promise with little investment in operational best practices (Brooks et al., 2014). Note that the savings using improved operational efficiency are also easier to measure, as building managers can compare the energy use numbers to derive conclusions on energy efficiency.
- *ASHRAE building energy quotient program:* ASHRAE's new tool-based rating methodology for building energy use is the Building Energy Quotient (bEQ) program. While the proposed building's estimated energy use and intensity are determined using the ANSI/ASHRAE/IESNA Standard 90.1-2007 performance method, the baseline energy usage and intensity for Energy Star eligible buildings are derived from Energy Star Target Finder, and other buildings types directly from CBECS data.
- *Increased focus on building energy efficiency:* The mean and median site EUIs from CBECS data for "College/University" building type were 155.3 and 130.7 respectively. (EIA, 2003; EPA, 2014a,b). Note that mean and median for EUI values UF LEED and non-LEED buildings exceeded these numbers. In other words, on average both LEED and non-LEED buildings, based on this case study, performs worse that the median "College/University" buildings surveyed in 2003. It should be noted that building use and characteristics change drastically over time, and as discussed earlier it is quite likely the recent changes will increase the overall energy demand. Moreover, data was collected from a subtropical climate with potentially higher energy demands than the national average due to additional cooling requirements. Regardless, this is a not a trivial matter to be ignored, rather should alert energy managers to discuss the larger question of whether certified buildings are truly energy efficient, and policy makers need to decouple building energy efficiency studies from the larger rating system framework for better control of energy consumption. The significance of the energy efficiency subject should warrant it to be a focal emphasis in new building design, rather than being part of an umbrella sustainability measures as in the case of BRS.
- *Architectural design for energy efficiency:* There is a need for further analysis of a holistic building design optimization for maximizing building energy efficiency. There are a limited number of studies on analyzing effects of architectural design choices and their effects on building energy efficiency (Ihm & Krarti, 2012; Sozer, 2010; Tereci et al., 2013), but there is room for greater improvement through comprehensive assessment on fundamental design alternatives and their effect on energy performance. There are numerous reasons for this lack of holistic assessment, none more significant than the issues with the computational efficiency and accuracy of building energy simulation. Building energy simulation algorithms were historically developed for sizing HVAC equipment, particularly for new, commercial buildings. Actual energy use typically differs from the estimation primarily for two reasons: weather, unregulated loads and schedule discrepancies; and modeling issues. Typical weather data used in the modeling tools consist 10-year average data points that fail to reflect the actual weather conditions. Similarly, plug load densities are major assumptions acquired from standards developed a decade ago, which may not represent current developments in equipment. Operating schedule, including occupant behavior, inaccuracies affect the simulation accuracy significantly. In the case of modeling issues; errors and inadequacies in the building model, inputs, and standard operational assumptions can affect the simulation accuracy greatly (Christensen et al., 2010; Polly, Kruis, & Robert, 2011). The other major hurdle to be overcome is the computational demand and time to run individual simulations. In reality, a meaningful simulation based energy assessment requires hundreds, if not thousands of energy simulations to run to obtain meaningful sensitivity results that can improve decision-making. However, the recent advancements made in increased processing power, and opportunities provided with parallel and cloud computing, this drawback is no longer a significant factor (Agdas & Srinivasan, 2014).

6. Conclusions

A large portfolio of buildings at a major American university was analyzed to compare operational energy demands of LEED buildings to those of non-LEED buildings. Confining the subject buildings to a single location alleviates some of the cited shortcomings of the studies with a similar scope; effects of climatic influences, building functionality profiles, consistency of facilities management on building energy performance are addressed. No clear trends in energy savings of LEED buildings was observed (both at the portfolio and at individual building level), but the opposite was also not confirmed bringing some questions on the validity of blanket policies in consistently improving or impacting energy performance. BRS implementation for improved energy efficiency of campus buildings has been the most common path for the analyzed university policies. Considering the ineffectiveness of these in achieving energy efficiency as well as the differences in ownership structures—when compared to commercial buildings—performance based energy efficiency measures can be instrumental in achieving sustainable energy policies for universities in the US. The recommendations suggested in this paper, such as a focus on CO_2 and devising performance benchmarks for building energy consumption are few examples of easy to implement, yet effective methods of improving energy performance, and ultimately achieving sustainable campuses.

There are few further research questions that need to be addressed to improve the viability of portfolio level building energy performance assessment that is essential in verifying the improvements in energy performance. An important factor that might play role in building energy performance is the building functionality and use. There has been a paradigm shift in recent years what buildings provide for the users in terms of physical space and comfort, and it is undeniable these factors will play a role in energy performance. Another important factor to consider is the impact of architectural design choices on energy performance. Without properly addressing these micro factors as well as macro factors that are addressed in this article (i.e. climate), portfolio level energy assessment has little to offer as there are simply too many factors that can affect the energy performance.

7. Future research

The analysis conducted here represents data from one campus and generalizability of the results to differing geographic regions and countries is limited. Data from different campuses from the US, and other parts of the world can improve our understanding of building energy performance under different conditions, and lead to better energy related policy and decision-making.

Acknowledgments

The authors wish to thank John Lawson and Dustin Stephany of the University of Florida (UF) Energy Department for their help in data collection and input in constructing the article. The work presented in this article was in part supported by Florida Energy Systems Consortium (FESC). The opinions presented here are those of the authors and do not reflect those of UF Energy Department or FESC.

References

Agdas, D., & Srinivasan, R. S. (2014). Building energy simulation and parallel computing: Opportunities and challenges. In A. Tolk, S. D. Diallo, O. Ryzhov, L. Yilmaz, S. Buckley, & J. A. Miller (Eds.), *Proceedings of the 2014 Winter Simulation Conference* Savannah, GA, December 7–9,

Brooks, J., Goyal, S., Subramany, R., Lin, Y., Middelkoop, T., Arpan, L., Carloni, L. & Barooah, P. (2014), An experimental investigation of occupancy-based control of commercial building climate. *IEEE Conference on Decision and Control*, December 2014 (accepted).

California Energy Commission. (2013), *Building energy efficiency standards*, Available at: ⟨http://www.energy.ca.gov/2012publications/CEC-400-2012-004/CEC-400-2012-004-CMF-REV2.pdf%3E⟩. Accessed 01.09.14.

Christensen, C., Roberts, D., Polly, B., Bianchi, M., Kruis, N. and Anderson, R. (2010), *Building energy simulation accuracy*, NREL presentation, Available at: ⟨http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ns/c22_building_energy.pdf⟩ Accessed 13.01.15.

Dougherty, B. (2010), The role of leed green building rating system in higher education: Recent trends and status, briefing prepared for The Center for Green Schools.

Field, A. (2009). *Discovering statistics using SPSS*. Thousand Oaks, CA: SAGE Publications.

Ihm, P., & Krarti, M. (2012). Design optimization of energy efficient residential buildings in Tunisia. *Building and Environment*, *58*, 81–90.

International Code Council (ICC) (2012), *International energy conservation code*, Available at: ⟨http://publicecodes.cyberregs.com/icod/iecc/2012/⟩. Accessed 14.09.14.

Intergovernmental Panel on Climate Change (IPCC) (2014), *5th Assessment report*, Available at: ⟨http://www.ipcc.ch/report/ar5/⟩ Accessed 14.09.14.

Lstiburek, J. W. (2008). Why green can be wash? *ASHRAE Journal*, 28–36.

Menassa, C., Mangasarian, S., El Asmar, M., & Kirar, C. (2012). Energy consumption evaluation of U.S. Navy LEED-certified buildings. *Journal of Performance of Constructed Facilities*, *26*(1), 46–53.

Newsham, G. R., Mancini, S., & Birt, B. J. (2009). Do LEED-certified buildings save energy? Yes, but. . .. *Energy and Buildings*, *41*(8), 897–905.

Oates, D., & Sullivan, K. T. (2012). Postoccupancy energy consumption survey of Arizona's LEED new construction population. *Journal of Construction Engineering and Management*, *138*(6), 742–750.

Polly, B., Kruis, N. and Robert, D. (2011), *Assessing and improving the accuracy of energy analysis for residential buildings*, NREL Report 50865, Available at: ⟨http://www.nrel.gov/docs/fy11osti/50865.pdf⟩. Accessed 13.01.15.

R Development Core Team (2008). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria.

Scofield, J. H. (2009). Do leed-certified buildings save energy? Not really. . .. *Energy and Buildings*, *41*(12), 1386–1390.

Scofield, J. H. (2013). Efficacy of LEED-certification in reducing energy consumption and greenhouse gas emission for large New York City office buildings". *Energy and Buildings*, *67*, 517–524.

Sozer, H. (2010). Improving energy efficiency through the design of the building envelope. *Building and Environment*, *45*(12), 2581–2593.

Srinivasan, R.S. (2013), *Building energy performance options of Green Globes for new construction*, white paper, Rinker School of Construction Management, University of Florida.

Tereci, A., Ozkan, S. T. E., & Eicker, U. (2013). Energy benchmarking for residential buildings. *Energy and Buildings*, *60*(0), 92–99.

Turner, C. and Frankel, M. (2008), *Energy performance of leed for new construction buildings*, New Buildings Institute for US Green Building Council.

US Department of Education (USDoE) (2006), Postsecondary education facilities inventory and classification manual (ficm): 2006 edition, NCES 2006-160.

US Department of Energy (USDOE) (2012), *2011 Building energy data book*, Available at: ⟨http://buildingsdatabook.eren.doe.gov/docs/DataBooks/2011_BEDB.pdf⟩. Accessed 23.09.14.

US Energy Information Administration (EIA) (2003), *The energy index for commercial buildings*. Available at: ⟨http://buildingsdatabook.eren.doe.gov/CBECS.aspx⟩ Accessed 01.01.15.

US Environmental Protection Agency (EPA) (2014a), *US energy use intensity by property type*, Technical Reference, Available at: ⟨https://portfoliomanager.energystar.gov/pdf/reference/US%20National%20Median%20Table.pdf⟩. Accessed 01.01.15.

US Environmental Protection Agency (EPA) (2014b), *Thermal energy conversions*, Technical Reference, Available at: ⟨https://portfoliomanager.energystar.gov/pdf/reference/Thermal%20Conversions.pdf⟩ Accessed 01.01.15.

US Green Building Council (USGBC) (2014), *LEED Credit Library* Avaiable at: ⟨http://www.usgbc.org/credits⟩. Accessed 23.09.14.