Does LEED save energy? A case study of LEED at UC Berkeley

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ABSTRACT

The United States faces many environmental challenges associated with high levels of energy use in the country, much of which is used in buildings. Although there is no consensus on the definition of environmental sustainability, most certification schemes aim to reduce the environmental impact of buildings by providing guidelines to minimize resource and material use and pollution while also improving the indoor environment. Leadership in Energy and Environmental Design (LEED), an internationally recognized green building certification scheme, plays an important role in bringing sustainability to the forefront of building design; however, there is little academic research on the energy performance of LEED buildings after occupancy and the effectiveness of LEED in reducing energy use. To investigate whether LEED certification is associated with site and source energy savings and GHG emissions reductions, I compared post-occupancy energy use from three LEED-NC projects on the UC Berkeley campus to energy use in conventional buildings, LEED energy models, and pre-LEED building energy use. In this study, LEED buildings generally used less energy than conventional buildings, and they performed as expected or better than the energy models in two out of three cases. My analysis also demonstrates LEED's inconsistency in producing predictable results. This case study suggests that the LEED energy models can be fairly accurate if the assumptions of the building post-occupancy situation in the model are true. Although LEED does not guarantee energy savings, and it can be difficult to determine how a building will perform from design-phase models and assumptions, at UC Berkeley, LEED buildings have performed as well as or better than expected.

KEYWORDS

sustainable design, post-occupancy evaluation, energy efficiency, energy conservation, green buildings

INTRODUCTION

The United States faces many environmental challenges associated with high levels of energy use in the country, including the rising importance of energy independence and reducing greenhouse gas emissions from fossil fuel consumption. Much of this energy is used in buildings. In the US, residential and commercial buildings used 70% of electricity in 2010 and produced 40% of carbon dioxide emissions in 2009 (U.S. EIA 2012). Most environmental impacts come from when buildings are occupied (Junnila et al. 2006). Buildings have a long life span, averaging thirty-five years, so they have far-reaching impacts on energy use patterns (Sam Borgeson, personal communication 2011). As a major energy consumer and greenhouse gas producer, buildings present an important and cost-effective opportunity to reduce the human ecological and carbon footprints (Granade et al. 2009). To encourage more environmentally sustainable or green building design, numerous green building certification programs have appeared internationally in the past few decades (Lee 2012).

Although there is no consensus on the definition of environmental sustainability, most certification schemes aim to reduce the environmental impact of buildings by providing guidelines to minimize resource and material use and pollution while also improving the indoor environment (Lee 2012). Leadership in Energy and Environmental Design (LEED), developed in 2000 and implemented by the U.S. Green Building Council (USGBC), is an internationally recognized certification scheme that targets seven different areas of environmental design (USGBC 2011). Even though LEED certification is a comprehensive assessment that addresses energy use, energy efficiency and conservation and greenhouse gas emissions reductions are critical components of the certification requirements (USGBC 2011). LEED requires a minimum energy performance and offers many energy efficiency and renewable energy credit options in the Energy and Atmosphere (E&A) section, seeking to reduce greenhouse gas emissions through improve building energy efficiency and using renewable energy sources (USGBC 2011).

LEED plays an important role in bringing sustainability to the forefront of building design, but there is little academic research on sustainable building energy performance after occupancy and thus the effectiveness of LEED in reducing energy use (Moschandreas and Nuanual 2008). Different studies come to conflicting conclusions; some suggest that LEED does save energy (Turner and Frankel 2008, Newsham et al. 2009), while others conclude that LEED does not generate statistically significant energy savings (Scofield 2009). However, the results from Turner and Frankel (2008), one of the largest studies on LEED energy use to date, and Newsham et al. (2009), which reanalyzes the Turner and Frankel study with more statistical rigor, are both suspect because they compare median LEED energy use intensity (EUI) with mean conventional building EUI, two different statistics that cannot be accurately juxtaposed (Scofield 2009); additionally, the two studies calculate building-weighted mean EUI rather than an area-weighted mean, which results in much lower total energy use than the actual energy use recorded by meters when calculated backwards from the mean. Despite the controversy around the link between LEED and energy savings or GHG reductions, there is some consensus that although many LEED buildings use less energy than conventional buildings, a significant number of certified buildings, especially larger ones, use substantially more energy than conventional buildings (Scofield 2009, Turner and Frankel 2008); additionally, certification level does not appear to correlate with energy use per unit area (Turner and Frankel 2008, Diamond et al. 2006). In general, studies show that most LEED buildings perform as or better than modeled, but some buildings do not (Turner and Frankel 2008), but uncertainty surrounds the actual environmental impact of green buildings because of the young age of many certification schemes and lack of research on post-occupancy building performance.

The University of California, Berkeley (UC Berkeley or Cal) prides itself for being sustainable and currently houses six LEED-New Construction and Major Renovations (LEED-NC) buildings, ranging from Certified to Gold (Green.Facilities Services 2012). In addition, all new buildings and large renovation projects will be built according to LEED New Construction standards (UC Berkeley 2011). It is important for a budget-constrained university such as Cal to invest in building to green certification standards that are cost-effective. The actual post-occupancy energy impacts of LEED certification must be carefully evaluated, because LEED certification should not be pursued if it does not reduce energy use.

To investigate if LEED certification generates site energy savings, I compared post-occupancy EUI per square foot and per capita from three LEED-NC buildings at UC Berkeley with data from conventional buildings over 1.5 to 5 years, depending on the age of the LEED project. From monthly billing data, I calculated the total average EUI per month as well as monthly EUI to see seasonal variation for a finer-grained picture of energy consumption in each building in my sample. I then compared LEED data with regional averages of energy consumption from the 2006 California Commercial End Use Survey (CEUS) and the US Energy Information Administration's (EIA) 2009 Residential Energy Consumption Survey (RECS). I also compared LEED buildings' post-occupancy energy use with their pre-construction energy models of expected energy performance, which at minimum should comply with ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) or state baselines, depending on what version of LEED under which individual projects were certified. These energy models are required for certification and are used to predict energy savings. Additionally, models are based on assumptions that may prove to be untrue, for example with occupant plug loads. Lastly, for Durant Hall, the only Major Renovation project that maintained the building's original area, I analyzed pre- and post-LEED conversion EUI to see how energy use changed due to certification.

METHODS

Study site and sample

To see if LEED buildings save energy, I analyzed the energy consumption of three LEED-NC projects on the UC Berkeley campus: Durant Hall, Blum Hall/Naval Architecture building, and University Village (UVA) (Table 1). The main campus operates Durant and Blum Halls, while Residential and Student Services Programs (RSSP) manages UVA (Green.Facilities Services 2008). I analyzed electricity use in Durant and Blum Halls and both electricity and natural gas use at UVA. Although Durant and Blum use steam for heating purposes, Blum Hall does not have a steam meter and Durant Hall's meter is possibly recording incorrect data (Ben Palaima, personal communication 2/12/2013). Because my sample size is so small, I did not conduct statistical tests. Only half of University Village, the West Village, is LEED-certified, but the Village only has one electricity and natural gas meter each for the entire Village.

LEED versus conventional buildings

Data collection

To compare energy use data between LEED and conventional buildings, I collected total building energy use data from UC Berkeley Physical Plant-Campus Services (PP-CS) for Durant and Blum Halls and UVA, and from RSSP for ECEC (Ben Palaima, personal communication 2012-2013). The monthly billing data includes electricity (kWh) and/or natural gas (therms) use for the entire project. Depending on the age of the LEED project, I analyzed between one and five years of data. I then compared the LEED buildings to average office and household energy consumption I found average energy consumption data for office buildings in PG&E's service sector from the California Commercial End-Use Survey (CEUS), which was published in 2006. I included all offices and small office (less than 30,000 square feet) in my analysis. For residential energy use, I used 2009 California averages from the US Energy Information Administration (EIA) Residential Energy Consumption Survey (RECS) to compare UVA with the average Californian household, the average Western multi-family rented household, and households in a marine climate. The "Western" designation includes Colorado, Idaho, Montana, Utah, Wyoming, Arizona, New Mexico, Nevada, California, Alaska, Hawaii, Oregon, and Washington. The data from both reports include total annual energy use for all fuel types used in each building type category.

Data analysis

To see if LEED certification generates energy savings, I compared the EUI of LEED projects and their paired conventional buildings. From monthly billing data of electricity consumption, I calculated monthly EUI per square foot in kBtus and summed the various fuel sources to find total energy consumption per square foot for each building. I compared total mean monthly EUI across all months as well as mean monthly EUI per year to see whether the LEED or conventional buildings used more energy overall. I also plotted monthly EUI in line graphs for a finer analysis of yearly and seasonal fluctuation.

Pre-LEED versus post-LEED

Data collection

To determine how LEED certification affected energy consumption in Durant Hall, a major renovation rather than a new construction project, I analyzed seven years of data prior to conversion to LEED, from mid-2001 to mid-2008. The data was provided by PP-CS.

Data analysis

I converted Durant Hall's pre-conversion data into kBtu per square foot per month and compared it to post-LEED monthly EUI and median monthly EUI to see how LEED certification changed energy use.

LEED model vs. post-occupancy energy performance

Data collection

To investigate if the LEED projects on campus are performing as expected, I obtained the pre-construction energy model for Durant Hall from the Cal Capital Projects department, which oversees the LEED process on campus, and for Blum Hall from Gensler, the architectural firm that documented Blum Hall's LEED certification process. These models, which are required for E&A credits, generate a prediction of average annual and monthly energy use in kBtu. The models incorporate parameters like climate, daily use schedules (e.g. lighting, occupancy, and plug-load schedules), building materials, and building systems (e.g. heating, cooling), and plug loads. Because the models are run before the project is completed, the models contain the modeler's assumptions about energy use that may not actually reflect the post-occupancy situation of the building, such as plug loads and even the HVAC system that is actually installed. Most of these factors will not differ drastically in the completed project, but plug loads can be variable, and the University may not implement or may substitute some aspects of the designs due to financial reasons. Buildings may also not be built exactly as they were designed, which could change factors influencing energy use, such as air leakage. LEED certification is based on these models rather than post-occupancy energy use; thus, the models do not necessarily reflect actual energy use in certified buildings.

Data analysis

I compared the design, standard baseline, and actual EUI per month and median monthly EUI by plotting the data to depict differences in energy performance. For Blum Hall, I used the model from the Energy and Atmosphere Credit 1 Step 1 calculations, which considers district steam to be purchased energy and excludes the energy efficiencies of equipment not in the building (e.g. district steam generation equipment) (USGBC). This results in a stringent energy and cost savings calculation.

Interviews

To analyze and better understand occupants' energy use behaviors and attitudes behind the energy use trends revealed in the data, I interviewed the facilities managers of Durant and Blum Halls as well as a volunteer analyzing energy use at University Village. I asked them about daily and seasonal operating schedules, lighting use, thermal comfort, and other sources of energy consumption. I also asked questions about occupants' attitudes toward energy conservation.

RESULTS

LEED versus conventional buildings

Comparing the LEED buildings to the California Commercial Energy-Use Survey (CEUS) and the national Residential Energy Consumption Survey (RECS), I found that the LEED buildings vary widely in their energy performance relative to conventional buildings in PG&E's service area. Blum Hall uses less than half as much energy as similar conventional office buildings and Durant Hall did not use less energy compared to similar office buildings

(Figure 1). University Village uses more energy than the average California household and similar households, but emits almost as much GHGs as the average Western multi-family rented household (Figure 2).

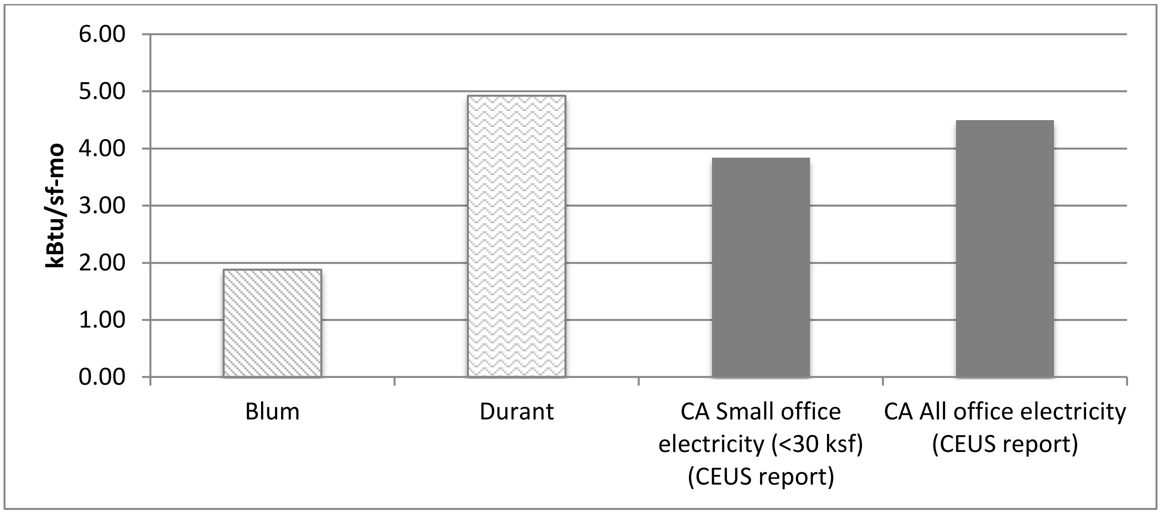

Fig. 1: Mean monthly energy use intensity (EUI) of LEED post-occupancy and conventional office buildings. On a square foot basis, Blum Hall uses about half as much energy as an average office building, but Durant Hall uses more than average.

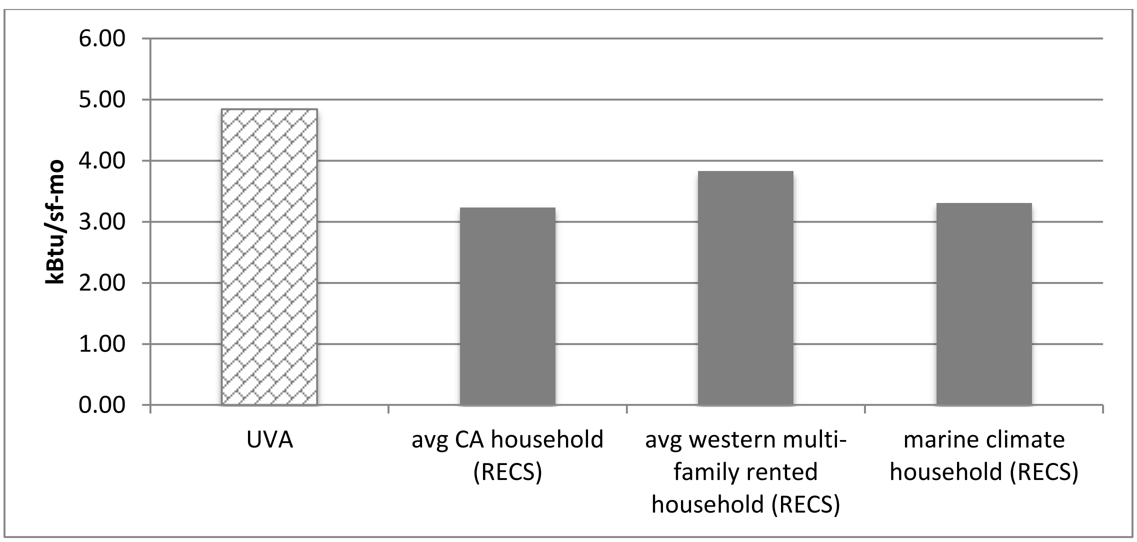

Fig. 2: Mean monthly EUI of LEED post-occupancy and conventional residential buildings. The entire Village uses more energy than the average similar household.

Blum Hall uses a mean of 1.88 kBtu of electricity per square foot per month (kBtu/sf-mo), while other California small offices (less than 30,000 square feet) uses a mean of 3.84 kBtu of energy per square foot per month and all offices in California uses a mean of 4.49 kBtu per square foot per month (CEUS). Durant Hall uses a mean of 4.92 kBtu of electricity per square foot per month, more energy than all offices and small offices only.

University Village as a whole uses a mean of 4.85 kBtu of energy (electricity and natural gas) per square foot per month, while the average California household uses 3.23 kBtu/sf-mo, the average Western[1] multi-family rented household uses 3.83 kBtu/sf-mo, and the average household in the same climate zone (marine climate) uses 3.31 kBtu/sf-mo (Residential Energy Consumption Survey, or RECS).

Pre-LEED versus post-LEED

I found that Durant Hall uses more electricity per square foot per month after LEED certification than it did prior to the major renovations that took place between 2008 and 2011. Pre-renovation, the building uses a median of 2.31 kBtu/sf-mo while post-renovation the building uses 4.92 kBtu/sf-mo (Figure 3). Even at a high point in December 2002, when the building uses 4.57 kBtu/sf, the old building never uses as much energy as the renovated building, where the lowest monthly energy use was 4.68 kBtu/sf in July 2011. Energy use in the old building is erratic from late 2002 to mid-2003 for unknown reasons (Figure 4).

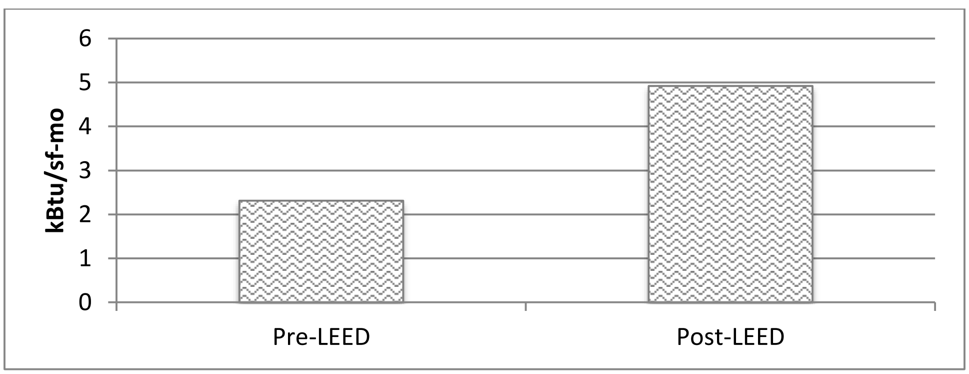

Fig. 3: Pre- vs. post-LEED renovation median energy use. Durant Hall uses more energy per square foot after renovation and LEED certification, but building use and occupancy also changed drastically.

[1] RECS' "Western" designation includes Colorado, Idaho, Montana, Utah, Wyoming, Arizona, New Mexico, Nevada, California, Alaska, Hawaii, Oregon, and Washington.

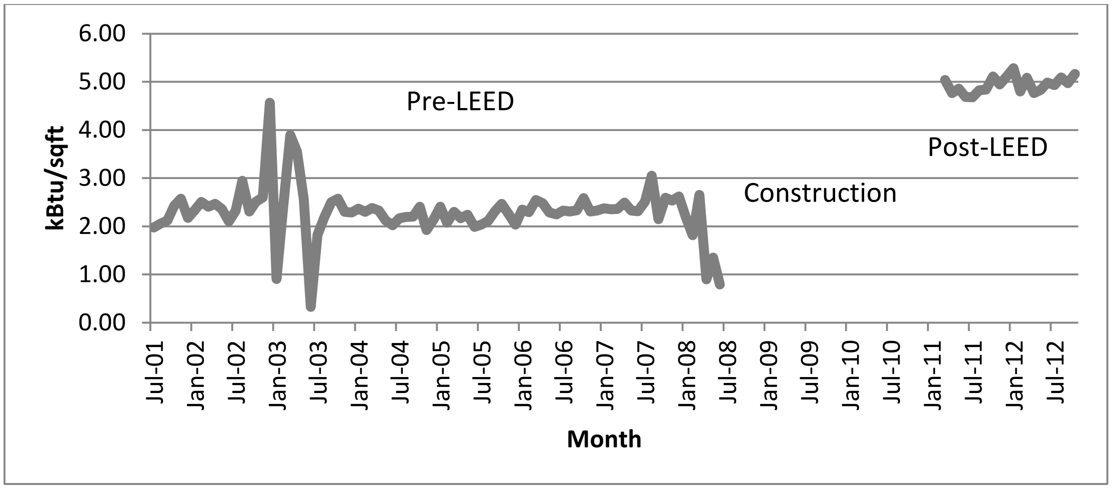

Fig. 4: Durant Hall EUI pre- and post-LEED certification.

LEED model vs. post-occupancy energy performance

Durant Hall

I found that Durant Hall is performing as proposed in the LEED energy model, while Blum Hall is actually using less energy than expected. Durant Hall uses slightly more electricity per month than projected (4.92 kBtu/sf-mo vs. 4.80 kBtu/sf-mo), but is still performing much better than the baseline scenario (5.69 kBtu/sf-mo) (Figure 4). The building is also using more energy than expected in the winter, but less in the summer (Figure 5).

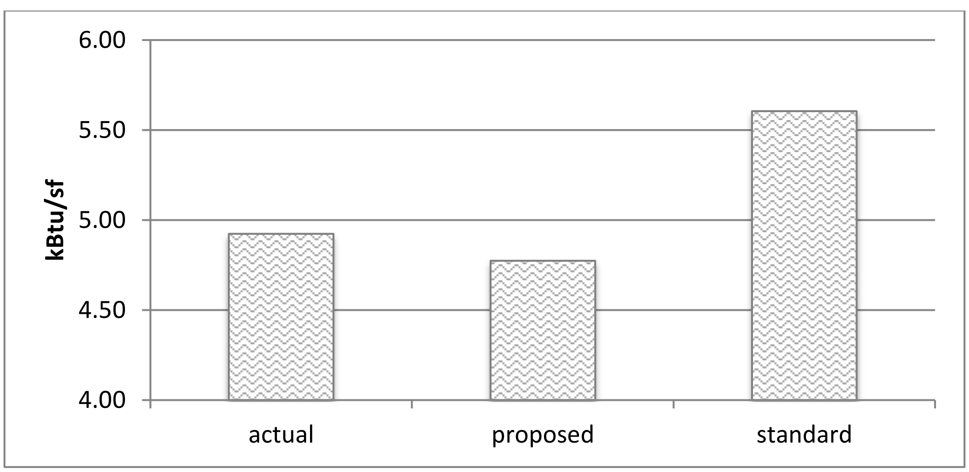

Fig. 5: Durant Hall post-occupancy vs. LEED model median EUI.

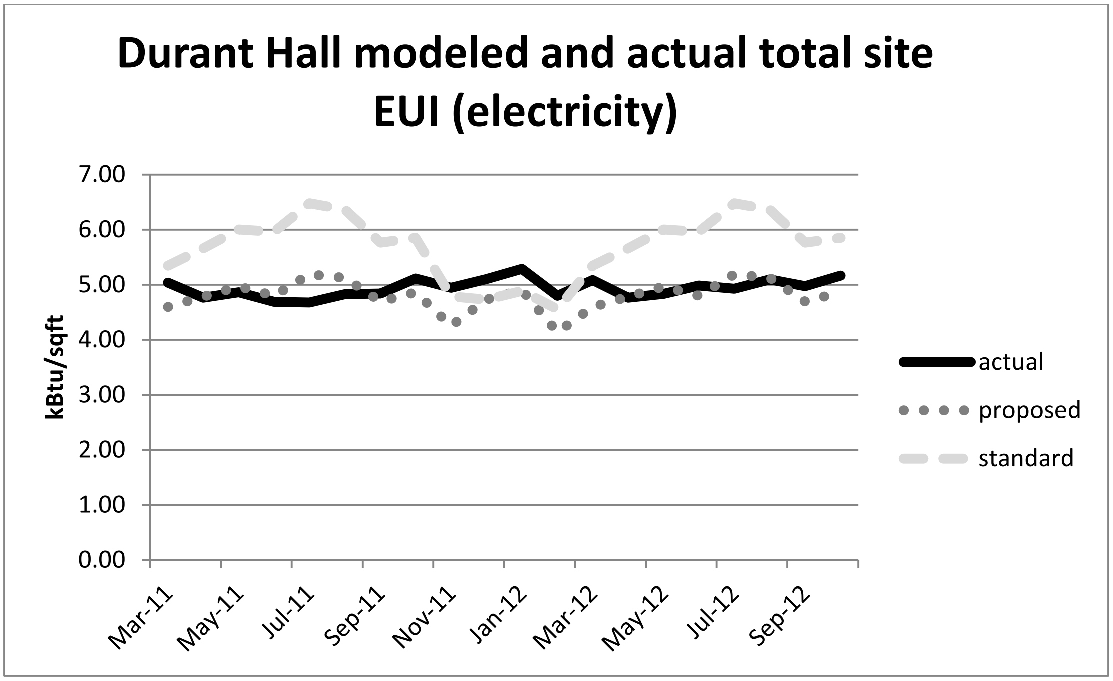

Fig. 6: Durant Hall modeled and actual total site EUI. Energy use is slightly higher in the winter than projected.

Blum Hall

Blum Hall uses 1.88 kBtu/sf of electricity a month, but it was projected to use 2.26. The baseline model uses 3.23 kBtu/sf-mo (Figure 7). The building also shows the same seasonal pattern as Durant Hall, using less energy in the summer and more in the winter, whereas the model predicted higher energy use in the summer and less in the winter (Figure 8).

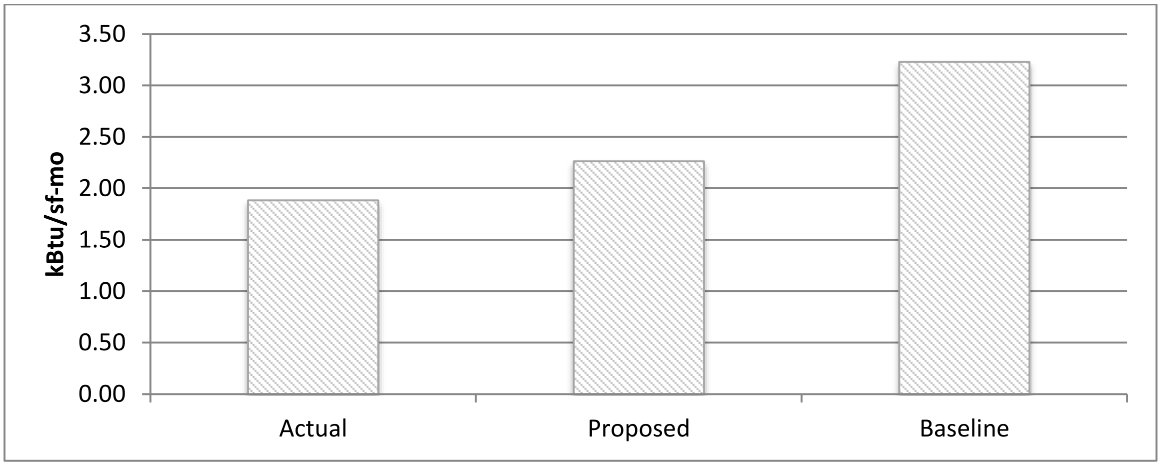

Fig. 7: Blum Hall post-occupancy and LEED model median EUI.

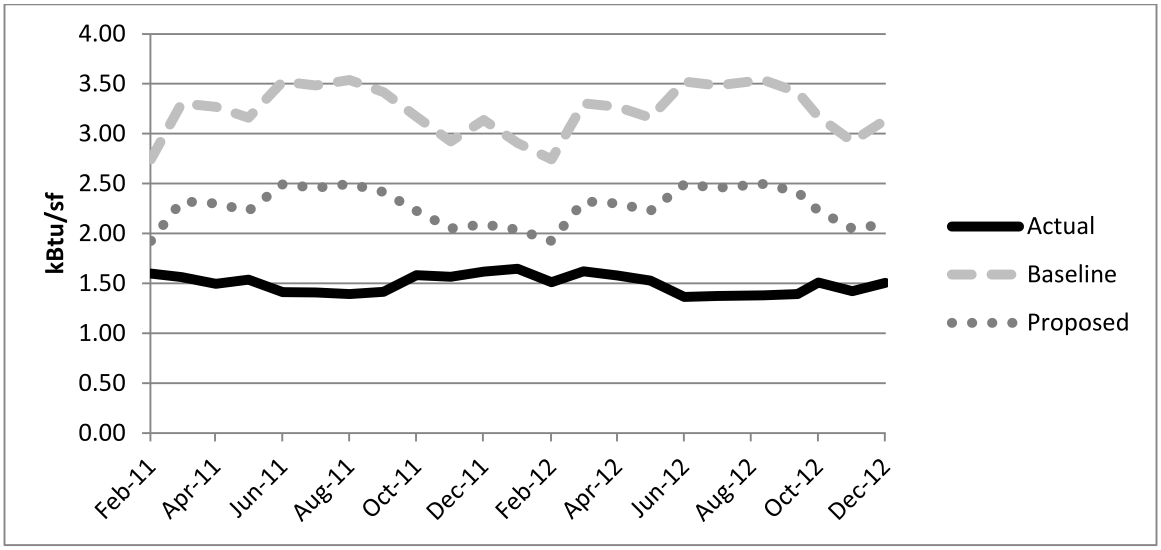

Fig 8: Blum Hall monthly post-occupancy and modeled EUI.

DISCUSSION

Much controversy still surrounds the actual impact of LEED certification on energy use because the program is still relatively young and has not been extensively researched. Each of the projects I studied showed different trends in energy use, similar to the varied and inconclusive results of other studies (Turner and Frankel 2008, Scofield 2009), so firm conclusions cannot be drawn about the impact of LEED on building energy use. A discussion of each of the three UC Berkeley LEED-NC projects demonstrates that LEED appears to be correlated with energy savings and climate benefits. In this study, LEED buildings generally performed better than conventional buildings in using less energy, and they performed as expected or better than the energy models in two out of three cases. My analysis demonstrates LEED's inconsistency in producing predictable results. My analysis also suggests that the LEED energy models can be fairly accurate if the assumptions of the building post-occupancy situation in the model are true. There are also opportunities for greater energy savings by targeting occupant energy use behaviors. Each of the three projects is discussed below.

Blum Hall

Blum Hall's low energy consumption compared to both conventional small office buildings and the energy model suggests that 1) the building saves more energy than expected, or 2) the model overestimated energy use in the building. The actual energy use could be due to greater efficiency, greater conservation, or lower occupancy levels than expected (Cotera 2011). In this case study, LEED saved energy compared to conventional buildings, and post-occupancy energy use is actually lower than even the model predicted. Some energy efficiency measures in the building include extensive use of natural daylight and individual thermal controls, which may contribute to low energy use (Fountain et al. 1996, Leslie 2003). Interestingly, the model predicted higher energy use in the summer and lower in the winter, the opposite of the observed trend. This may be because the model over-estimated occupancy and occupancy-related energy use in the building during the summer. The building is closed to the general public during the summer months, reducing the population of students using the general study area.

Durant Hall

Although Durant Hall is using more energy than conventional buildings on a per area basis, the building is not necessarily less efficient. The building is using as much energy as was predicted in the energy model, so, with the limited data available, it is probably safe to conclude that the building is operating very similarly to the assumptions in the model. Durant Hall has high occupancy levels because the building has open offices, which allows more cubicles than private offices; additionally, as the home of the College of Letters and Science Deans' Office, the building has many visitors and the conference rooms are in use regularly throughout the week (Josh Mandel, personal communication 4/10/2013). High occupancy contributes to higher than average energy use. Durant Hall uses more energy after renovation than before in part because of much higher occupancy in the new building than the old, and new, modern electrical and mechanical systems that replaced previously limited and old ones (Sally McGarrahan, personal communication 2/28/2013). The old building was home to the East Asian Library, and had very few offices and much storage space. The new building has many more offices on all floors now rather than a library and so has higher occupancy than previously. Durant's model also predicted higher energy use in the summer and lower in the winter, whereas the building actually uses less in the summer and more in the winter.

Durant Hall could be saving more energy. Most people do not bother to turn off the lights when they leave a room because the lights have occupancy sensors (Josh Mandel, personal communication 4/10/2013); however, the delay between when occupants leave the room and when the occupancy sensor turns the lights off presents an opportunity to save more energy if occupants would manually turn off the lights in empty rooms (Pigg et al. 1996).

UVA

UVA uses more energy than the average California residence, which is surprising in light of numerous socio-demographic studies on energy use behavior in the West that generally find that higher-educated families are more environmentally educated and conscious (Diamantopoulos et al. 2003). The high energy use could be due to: 1) the electricity use data recorded by the meter includes outdoor lighting, which is not included in energy consumption for normal apartment units, or 2) the diverse population of international students that live in the Village does not represent the composition of values and attitudes of the American population, The residents come from very different backgrounds and probably have different values and attitudes towards energy conservation despite being well-educated. Additionally, the students are not billed for their energy use, appliances are aging, and some design aspects do not make sense energetically, such as an excess of lights (Jenny Orlova, personal communication 2/26/2013). All of these factors may contribute to higher energy use (Counihan and Mentzow 1981). It is impossible to determine LEED's effect on energy use because UVA only has one meter for electricity and natural gas usage for the entire village, including outdoor lighting and other energy uses not associated with the residential units.

However, there are many opportunities to save energy at the Village. Nature Village, an organization led by residents, is already studying energy use and actively working to reduce energy use at UVA. From their preliminary energy audit results, it appears that residents set their thermostat four degrees higher than the Department of Energy (DOE) recommends in the winter (Jenny Orlova, personal communication 2/26/2013, DOE 2012). Some residents still use incandescent light bulbs rather than more efficient compact fluorescent light bulbs (CFLs) (Jenny

Orlova, personal communication 2/26/2013). The University could also invest in more efficient appliances in East Village, which is older and not LEED certified. Even though UVA uses more energy than average now, energy use can be reduced through a number of different strategies.

Limitations and Future Directions

A case study approach allowed me to investigate the reasons behind the trends in energy use in the three projects, which can provide insight into energy use in other LEED buildings. As a case study, the quantitative energy use results are not generalizable to the entire LEED population. However, my study provides three examples of the range of scenarios that other studies have encountered. Durant and Blum are the best-case scenarios where the LEED energy model accurately predicted actual energy use and the building uses less energy than conventional buildings, respectively, whereas UVA demonstrates the shortcomings of LEED-NC to monitor post-occupancy building performance and determine if LEED produced environmental benefits; without separate submetering of the East and West Villages, there is no definitive way to determine the effects of LEED certification on energy use, although it is most likely that West Village is using more energy than predicted. In general, my study and others indicate that buildings need better and more detailed monitoring of energy use to be able to see where energy is being used and to target energy use reduction programs. For example, the campus lacks sub-metering, particularly at UVA, to accurately determine where energy is being used and thus where inefficiencies might arise. Because UVA is not submetered, it is currently impossible to differentiate between energy use in East (uncertified) and West (certified) Villages to see how LEED affected energy use. Submetering different areas within buildings, such as energy intensive portions, or different energy uses, such as lighting, would allow noise reduction in the data and better targeting of energy conservation and efficiency programs. Energy use data on a finer scale, such as on a daily or hourly basis rather than monthly, would also improve understanding of energy use patterns in buildings. Greater transparency and accessibility to energy data is necessary to facilitate more research on building energy use. In Turner and Frankel's study, the researchers were only able to access adequate data for 21% of the LEED-NC population (Turner and Frankel 2008). In my own study, I was unable to acquire data from one other eligible building. Although Cal is moving towards greater transparency through the myPower program and energy dashboard, the data itself is still hard to obtain and the dashboard still does not contain all the buildings on campus. Reliable occupancy data is also often missing, especially for Cal buildings. Without adequate occupancy data, some comparisons are difficult and inadequate. Even though Durant Hall uses more energy on an area basis after renovation, in this case a per capita comparison of energy use would be more informative because of the change in occupancy. Better occupancy records would allow researchers to compare energy use between populations of differing sizes in the same area for a more holistic view of energy use in buildings. Naturally, buildings with higher population densities will use more energy, but the increased energy use is not necessarily a reflection of energy waste. Some of these limitations, such as lack of data, will diminish as more buildings are certified and age, enabling more reliable and informative quantitative analyses beyond the case study approach, but building managers also need to improve data collection to fully understand energy use in LEED buildings.

There is much more research to be done in the LEED and energy use field as more buildings are certified under LEED and mature. UC Berkeley has just certified two buildings under New Construction and one under Commercial Interiors. LEED models and post-occupancy energy use need to be studied more to understand what factors contribute to an accurate model, and what aspects of the modeling process need to be improved to produce more accurate results. To study where the model and post-occupancy diverge, data on post-occupancy energy use, post-occupancy surveys on occupants' energy use attitudes and behaviors, and differences between design plans and final constructed buildings need to be recorded and analyzed to understand if there are general trends in results that could suggest a systemic flaw in the modeling process, or if the variation seen is more random. Occupancy is often the least predictable, especially for office buildings that are rented to unknown tenants, whereas on campus occupancy can be more readily and accurately estimated, which could contribute to the generally accurate models seen in the three projects included in this study.

Broader Implications

Controversy over the legitimacy of LEED's claim to be green still abounds, as LEED certification is only just over a decade old and there is still little research on post-occupancy energy use in LEED buildings. Critics question not just LEED's ability to produce energy savings, but whether LEED buildings actually meet their objectives to reduce environmental impacts and improve occupant comfort. Common criticisms include rewarding easy points rather than actually reduce the environmental impact of buildings, not including simple but effective techniques for reducing energy use, and, especially for energy use, not including any requirements for post-occupancy monitoring to corroborate pre-construction predictions. Instead of focusing on specific practices and pre-construction, could instead score based on results to reduce the number of certifications earned from targeting easy points rather than truly environmentally friendly practices. LEED has sought to rectify this by requiring at least 2 EAc1 points for energy efficiency since 2007. Even so, according to the NBI study, the average Energy Star rating of LEED buildings is 68, or only 68% better than similar buildings—this means that LEED on average does not even garner an Energy Star rating, which is awarded to the top quartile (at least 75 points) of buildings (Turner and Frankel 2008). Even though 47% of the buildings in the NBI study buildings would receive Energy Star rating, 15% scored 30 or less (Turner and Frankel 2008). LEED is not solely focused on energy efficiency, and project managers have leeway in determining which points to achieve, but energy efficiency is an important part of green building and LEED (energy is in the name, after all), and for so many "green" buildings to be worse than the median building is disappointing, misleading, and mocking of the goal of green buildings to have a smaller impact on the environment. Green buildings should perform among the best of the building stock, and although currently many LEED buildings are indeed energy efficient, too many are not (Gifford 2009).

My results, however, suggest that LEED can guide the construction of energy efficient buildings with careful implementation and suggest why LEED on campus is generally effective from information gathered from interviewing building managers. This study supports the idea that LEED buildings do save energy, strengthening the UC policy to build all new construction on campus to LEED standards. Although LEED currently does not take post-occupancy performance into consideration for certification, it is beneficial for Cal to conduct post-occupancy analyses of building performance to ensure that buildings are performing as expected and generating expected savings and other benefits. UC Berkeley should monitor post-occupancy as more buildings are certified to see if buildings continue to show the same trends in reduced energy use seen in this study; if not, LEED is not necessarily worthwhile to pursue, as it is expensive to certify with LEED.

Conclusions

LEED does not guarantee energy savings, and it can be difficult to ascertain how a building will perform from design-phase models and assumptions; however, at UC Berkeley, LEED buildings have performed as or better than expected. LEED can and does produce buildings that save energy, but the energy models and post-occupancy monitoring still need to be refined or implemented, or consistent improvement over the conventional building stock. The trends seen in this study, although positive, are too varied to draw any definite conclusions about the impact of LEED on energy use; with more data, it will become clearer how LEED measures up to its “green building” claims. The certified office buildings on campus are performing as well or better than expected, and therefore may be a good investment for the campus from an energy perspective.

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APPENDIX A: LEED project information

Table A1: UC Berkeley LEED projects (Green.Facilities Services 2008, Maclay 2008, Anwar 2010, Family Student Housing 2011, RSSP 2008, Facilities Link personal communication 2012)

Name of Project	Date completed	LEED certification level (energy points earned)	Square footage	Occupancy	Use	Energy efficiency measures
Blum Hall/Naval Architecture Building (Blum Hall)	2010	LEED 2.2 Silver (4/17)	16,695	~27	Offices, conference rooms, and open study areas	Skylights, daylight sensors, natural ventilation, passive airflow, energy-saving landscaping
Durant Hall	2010	LEED 2.2 Silver (6/17)	11,539	~30-35	Administrative and conference rooms	Natural lighting, efficient lighting
University Village (UVA)	2008	LEED 2.1 Certified (6/17)	845,830	~2800	974-unit housing community consisting of 1-, 2-, and 3-bedroom units for students and their families	Radiant heating, good insulation, double paned windows, natural ventilation instead of air conditioning, fluorescent lighting, gas clothes driers