Title
Evaluating the energy performance of the first generation of LEED-certified commercial buildings

Author
Diamond, Rick

Publication Date
2006-05-01

LBNL-59853

Evaluating the Energy Performance of the First Generation of LEED-Certified Commercial Buildings

[1]Rick Diamond, [2]Mike Opitz, [2]Tom Hicks,
[3]Bill Von Neida, [4]Shawn Herrera,

[1]Lawrence Berkeley National Laboratory
Environmental Energy Technologies Division
Indoor Environment Department
Berkeley, CA 94720

[2]U.S. Green Building Council
Washington, DC

[3]U.S. Environmental Protection Agency
Washington, DC

[4]U.S. Department of Energy
Washington, DC

May 2006

This work was funded by the Federal Energy Management Program of the US Department of Energy under Contract No. DE-AC02-05CH11231 and the US Environmental Protection Agency.

Evaluating the Energy Performance of the First Generation of LEED-Certified Commercial Buildings

Rick Diamond, Lawrence Berkeley National Laboratory
Mike Opitz and Tom Hicks, U.S. Green Building Council
Bill Von Neida, U.S. Environmental Protection Agency
Shawn Herrera, U.S. Department of Energy

ABSTRACT

Over three hundred buildings have been certified under the Leadership in Energy and Environmental Design (LEED) rating system for sustainable commercial buildings as of January 2006. This paper explores the modeled and actual energy performance of a sample of 21 of these buildings that certified under LEED between December 2001 and August 2005, including how extensively the design teams pursued LEED energy-efficiency credits, the modeled design and baseline energy performance, and the actual energy use during the first few years of operation. We collected utility billing data from 2003-2005 and compared the billed energy consumption with the modeled energy use. We also calculated Energy Star ratings for the buildings and compared them to peer groups where possible. The mean savings modeled for the sample was 27% compared to their modeled baseline values. For the group of 18 buildings for which we have both modeled and billed energy use, the mean value for actual consumption was 1% lower than modeled energy use, with a wide variation around the mean. The mean Energy Star score was 71 out of a total of 100 points, higher than the average score of 50 but slightly below the Energy Star award threshold of 75 points. The paper discusses the limitations inherent to this type of analysis, such as the small sample size of disparate buildings, the uncertainties in actual floor area, and the discrepancies between metered sections of the buildings. Despite these limitations, the value of the work is that it presents an early view of the actual energy performance for a set of 21 LEED-certified buildings.

Background

In the past 10 years, "green" buildings have been the subject of much debate in the practitioner and academic communities. Can one demonstrate that these buildings perform differently from other new buildings? Do they use less energy and water, and do they provide more benefits to users in terms of productivity and health? Recent work has attempted to address some of these questions in evaluations of "high-performance" buildings (Torcellini et al. 2004), the review of occupant satisfaction in green buildings (Heerwagen 2000), and efforts to make standard protocols for green building assessment (Fowler 2004).

The emergence of green rating systems such as the U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) rating system provides an opportunity to compare quantitatively the energy performance of LEED buildings to non-LEED buildings. Because the LEED certification process requires a simulation of the building's energy performance to qualify for energy-efficiency points, we can compare the modeled energy savings for the designed building with its basecase reference model. For this paper we also compare the simulated whole building energy consumption with the actual billed energy consumption.

Our rationale for evaluating the performance of these early LEED-certified buildings was to provide a quantitative assessment of their actual and simulated energy performance. There are many reasons why buildings do not perform as modeled, for example, changes in design and construction, as well as operation and maintenance issues that can all affect the energy use of the actual building. But if we want to go beyond specifying green buildings features at the design stage, to building and operating truly green buildings, then we will need to understand better how these buildings perform when built and occupied. Verifying that green buildings have met their design expectations for energy performance is just one step towards moving the existing commercial building market towards a more sustainable enterprise.

Data Sources and Buildings Characteristics

The LEED family of green building rating systems for commercial buildings currently includes three published products: LEED-NC (new construction and major renovations), LEED-CI (commercial interiors/tenant fit-outs), and LEED-EB (existing buildings/ongoing operations). As of January 2006, 303 buildings were certified under the LEED-NC rating system. LEED-NC has been available to the market longer than LEED-CI or LEED-EB, and several agencies of the U.S. federal government were early adopters of LEED-NC.

Data Sources. We drew on two sources of utility billing data for this study. The first was an appeal by USGBC to the building owners of all LEED-NC certified buildings, looking for volunteers to contribute data on their building's energy use. This process led to the identification of seven buildings in the Pacific Northwest, all of which had prior utility bills available (Turner 2006). We collected the data for the second dataset, the Federal LEED-NC buildings, by contacting each federal agency, and tracking down the persons responsible for reporting the utility consumption. We received billing data from fourteen of the 20 Federal LEED-NC certified buildings by this approach. For the remaining six buildings either the owners were non-responsive [n=1] or the buildings were not individually metered [n=5].

We collected the modeled energy data, for both the as-designed building and the basecase building, from the LEED certification files submitted to USGBC. Additional data on the building type, size, use, awarded LEED points, etc., were also collected from the USGBC files, both from the available data on the LEED websites, as well as the paper files submitted to USGBC.

We generated the Energy Star scores from an "unofficial" version of the Energy Star whole-building rating tool, so these are illustrative, not verified Energy Star numbers. The Energy Star tool ranks buildings on a 1-100 scale with respect to other buildings having a similar usage type based on the annual source energy use (i.e., primary fuel, not site energy). The tool estimates source energy from site energy using standard conversion factors that depend on fuel type. We benchmarked the multifamily buildings using the Energy Star tool for dormitories/residence halls as an approximation because Energy Star does not offer a multifamily building rating tool at this time. Also, because Energy Star is not appropriate for laboratory facilities, we used a comparison group of 36 EPA laboratories for the four laboratory facilities included in this analysis.

Building Characteristics. Table 1 shows the buildings characteristics for the 21 buildings in this study, grouped first by non-federal buildings and then federal buildings. The buildings are a mixture of office, library, mix-use and multifamily residences.

Table 1. Building Characteristics

ID#	Building Type	Ownership	Gross Floor Area [ft^2]	City	State
1	Office	Non-federal	18,000	Portland	OR
2	Library/office	Non-federal	411,987	Seattle	WA
3	Office/retail	Non-federal	70,000	Portland	OR
4	Library	Non-federal	22,000	Portland	OR
5	Multifamily	Non-federal	32,206	Seattle	WA
6	Multifamily/mixed	Non-federal	220,400	Portland	OR
7	Multifamily	Non-federal	64,000	Portland	OR
8	Office	Federal	6,100	Palmer	AK
9	Office	Federal	18,812	Argonne	IL
10	Office	Federal	8,380	Caribou	ME
11	Office	Federal	125,550	Lakewood	CO
12	Office	Federal	52,240	Youngstown	OH
13	Office/mixed	Federal	72,000	Grand Canyon	AZ
14	Office	Federal	17,000	Pt. Hueneme	CA
15	Office	Federal	52,100	Burien	WA
16	Lab	Federal	95,322	Morrisville	NC
17	Lab	Federal	70,440	Chelmsford	MA
18	Lab	Federal	71,955	Kansas City	KS
19	Lab	Federal	335,597	Oak Ridge	TN
20	Education	Federal	78,815	Prewitt	NM
21	Multifamily	Federal	368,350	Great Lakes	IL

The 7 non-federal buildings range in size from 18,000 ft^2 to 412,000 ft^2, with an average gross floor area of 120,000 ft^2. The 14 federal LEED-NC buildings include an equally diverse group of building types, with the most frequent being office [n=8], followed by laboratory [n=4], and then education, and multifamily. The federal projects range in size from 6,100 ft^{2}to 368,000 ft^2, and have an average size of 98,000 ft^2. While the two groups of buildings are different in geographical distribution and use, they represent a similar range of sizes. This sample represents less than 10% of the current LEED-NC certified stock, and since it is made up of either buildings from one region of the US (the Pacific Northwest) or federal facilities, it is likely to be an unrepresentative sample, and as such, it is only a preliminary guide to how LEED buildings in general are performing as a group.

The Energy Criteria for LEED-New Construction (NC) v2.0/2.1

The LEED-New Construction (NC) rating system has a possible 17 of 64 total points under the category of "Energy and Atmosphere" in LEED-NC version 2.0/2.1 (buildings certified under LEED-NC v1 were not included in this study). There are also three prerequisites for fundamental building system commissioning, minimum energy performance, and CFC reduction in HVAC equipment. The single most significant energy credit, Energy & Atmosphere credit 1 (EA-c1), is for optimizing energy efficiency, and has a total of 10 points available, the single largest potential source of points for the entire LEED-NC rating package.

The intent of the energy efficiency credit is to reduce the energy cost of the proposed design compared to the energy cost for a baseline building. The baseline building is defined following the Energy Cost Budget Method described in Section 11 of the building standard for energy performance, ASHRAE/IESNA 90.1-1999 or local code, whichever is more stringent. The design-to-basecase comparison only includes certain energy end uses, namely HVAC systems, building envelope, service hot water systems, lighting and other specified systems. Not included in the basecase are most other equipment and plug loads. New buildings that are 20% better than basecase get 2 points; buildings 30% better get 4 points, and so on up to a maximum of 10 points for 60% or better than basecase. Because EA-c1 points are awarded based on simulated cost of only the regulated energy components, not whole-building energy cost, modeled results must be interpreted with care when comparing them to actual energy bills. In our data set typically the whole-building model results were available as well, which is what we use for these comparisons.

In addition to the 10 points for optimizing energy efficiency, there are an additional 7 energy points available for on-site renewable energy (n=3), additional commissioning, ozone protection, measurement and verification, and green power purchases.

Interactions between EA-c1 (energy efficiency) and EA-c2 (on-site renewable energy) complicate our analysis slightly. LEED's energy efficiency points are based on the *purchased* energy that falls within ASHRAE/IESNA's regulated scope, not the *total* regulated energy. Thus, if a building employs on-site renewable energy systems in the design case, LEED allows the project team to deduct the renewable production from the regulated energy total in the design case, which contributes to points earned under EA-c1. In essence, LEED doubly encourages on-site renewables by allowing them to contribute to two separate energy credits. Our analysis accounts for this complication in the applicable buildings by comparing actual purchased energy only to design purchased energy. On-site renewables directly offset site energy consumption, and so are also fully recognized within the Energy Star rating.

Energy Analysis

Table 2 shows our energy analysis for these buildings. The first column is the building identification number. The second column is the modeled energy use intensity (EUI), which is the energy use per unit floor area, for the whole building as designed. The mean value for the modeled whole-building EUI is 111 kBtu/ft^2-yr. The third column is the modeled basecase design, which is a simulation of the whole building with the energy-saving features removed. The basecase values here are for the whole building, not just the ASHRAE/IESNA-specified end uses, so we can do a meaningful comparison to the whole-building design and billed values. The mean value for the basecase buildings was 145 kBtu/ft^2-year. The fourth column is the ratio of the modeled design to the basecase, and shows the percent savings for the buildings. The mean ratio for these 17 buildings is 73%, leading to a mean savings of 27%. The fifth column shows the actual whole-building energy consumption per unit floor area from the utility billing data (only purchased energy; any on-site generation is excluded). The mean EUI based on the energy bills is 124 kBtu/ft^2-year. The sixth column shows the ratio of billed to modeled consumption; for the 18 buildings for which we have both values this ratio has a mean of 99%, implying that as a group the actual buildings use about the same amount of energy as modeled.

Table 2. Modeled and Actual Site Energy Consumption, with Energy Star Ratings and LEED Energy Points for the 21 LEED-NC Buildings in this Study

ID#	Modeled Whole Building Design [KBtu/f²-yr]	Modeled Whole Building Basecase [KBtu/f²-yr]	Modeled Design/ Basecase [%]	Actual Whole Building Purchased [KBtu/f²-yr]	Actual Whole Building Purchased /Modeled [%]	Energy Star Score	LEED Energy Efficiency Points	Total LEED Energy Points
1	63	81	78	47	75	82	5	6
2	76	114	67	52	68	81	6	9
3	35	54	65	61	174	69	4	5
4	66	95	69	98	148	NA	3	6
5	154[b]	212	73	48	--	64	3	4
6	69	94	73	48	70	57	4	7
7	56	86	65	44	79	66	3	5
8	68	89	76	78	115	17[c]	4	6
9	52	77	68	48	93	95	4	6
10	168	205	82	158	94	2[c]	4	5
11	69	89	78	69	100	72	4	8
12	79	--	--	73	92	52	0	1
13	125	172	73	22	18	99	2	3
14	113 total	157	72					
14[a]	66 purchased		--	70	62	64	10	14
15	265	127	87	128	48	7[c]	1	4
16	171[b] total	219	78			NA	3	
16[a]	162 purchased			507	--	NA	3	6
17	353			357	101	NA	--	--
18	267	496	54	271	101	NA	2	3
19	149[b]	208	72	290	--	NA	3	6
20	27	32	84	33	123	55	2	2
21	46			103	225	16[c]	--	--
N	18	18	17	21	18	12	19	19
Mean	111	145	73	124	99	71	3.5	5.6
Med.	69	105	73	70	94	68	3	6
SD	90	102	8	124	46	14	2	3
Min.	27	32	54	22	18	52	0	1
Max.	353	496	87	507	225	99	10	14

[a]These buildings have on-site PV, so their total and purchased are different.
[b]These buildings have only the regulated end-uses in the model, not whole building.
[c]Energy Star doesn't account for the large plug loads in these buildings, so their totals are not included in the average.

The seventh column shows the Energy Star scores for the 12 buildings without excessive plug loads. The average Energy Star score for the sample is 71 out of a possible 100 points, far higher than the average score of 50, but less than the 75 needed to earn the Energy Star building award. Four of the 12 buildings with Energy Star scores qualified for Energy Star. Columns eight and nine are the number of LEED-NC v2.0/2.1 points the design achieved for energy efficiency and total Energy & Atmosphere, respectively. The energy consumption numbers are all site energy, while the Energy Star score is based on source energy.

In addition to the mean values for these data, we also show the median, standard deviation, and minimum and maximum values. The high standard deviations reflect the small sample sizes and the wide range of values, forcing us to be cautious in inferring too much from these results.

Figure 1 shows a comparison of simulated and actual performance for the 18 buildings in our sample for which we have both values. With perfect agreement between the two, all points would fall on the 45 degree line shown. The modeling data suggest that the most significant outlier in Figure 1 was due to large modeled equipment loads that were not realized in the actual building.

Figure 1. Modeled Energy Use Intensity (EUI) versus actual EUI for 18 buildings in our sample.

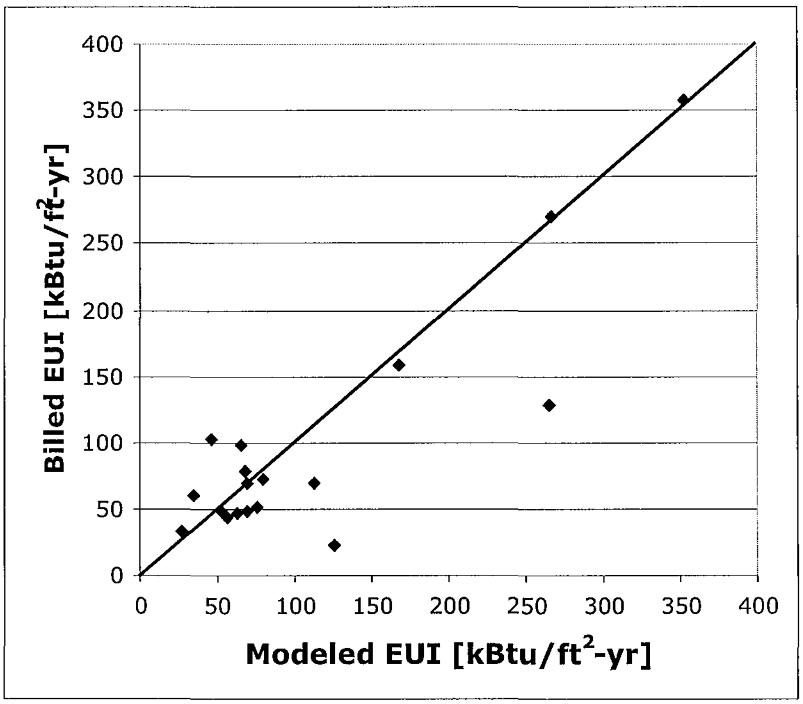


Figure 2 looks in more detail at a comparison of simulated and actual performance for one of the buildings in our sample over a three-year period. In this case, the actual average monthly consumption is nearly the same as the simulated design building. One characteristic of this all-electric building is that consumption has not increased over the three years for which we have billing data.

In comparison, if we look at one of the larger buildings (Figure 3), we see that energy use, particularly electricity use in the computer facility, is increasing dramatically over time.

Figure 2. Simulated and Billed Monthly Whole Building Energy Use for One of the Federal Office Buildings, 2002 - 2005.

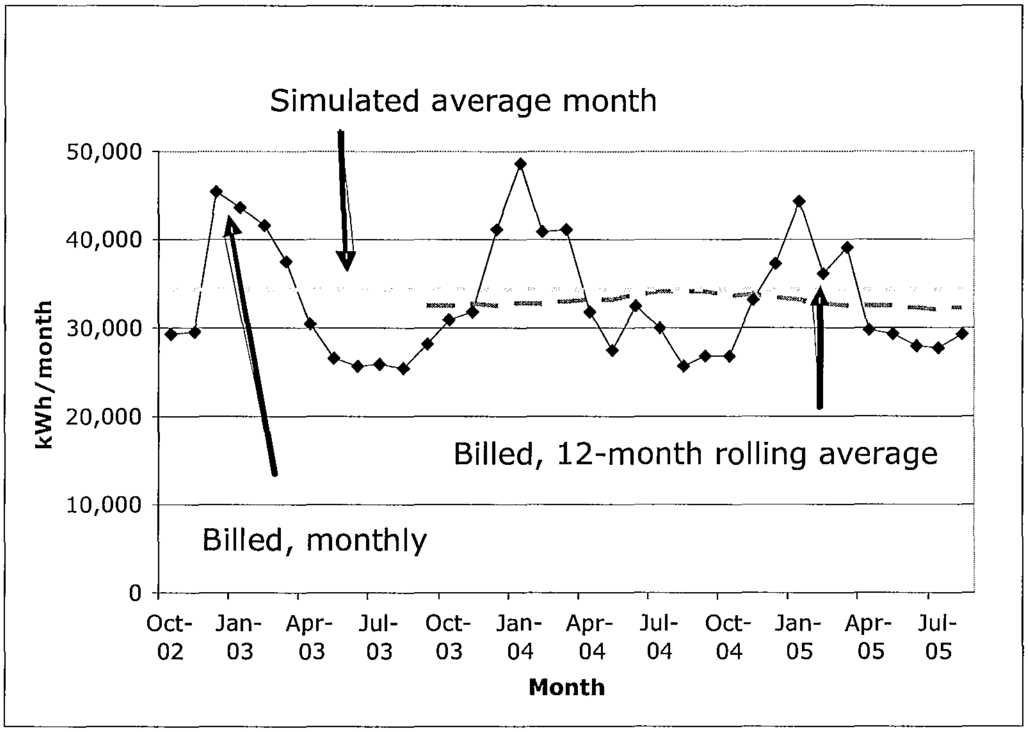


Figure 3. Energy Use (Electricity and Steam) for a Federal Laboratory/Office Building, 2003-2005.

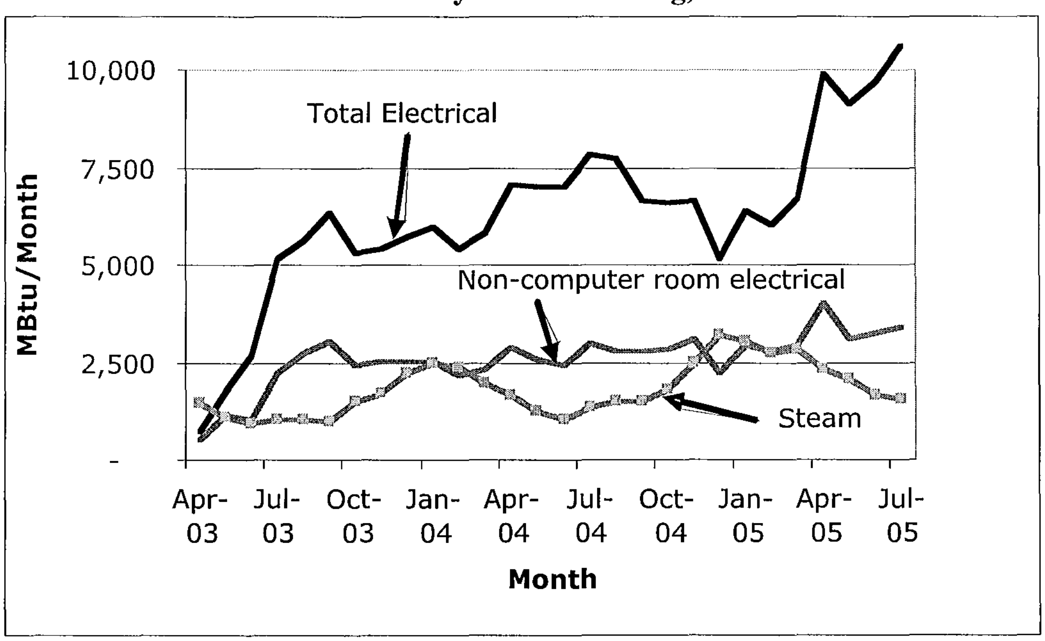
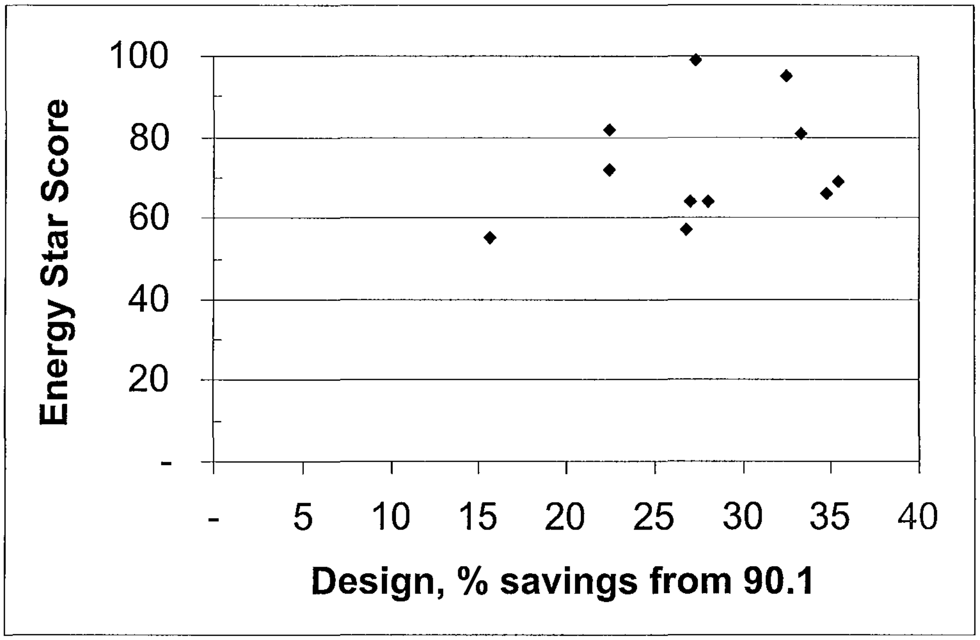


Figure 7. Energy Star Score Versus Design Performance Relative to ASHRAE/IESNA Standard 90.1.



Discussion

The energy analyst can ask several questions in looking at simulated and actual building energy data: What is a meaningful basis for comparison? Should the measured energy consumption be compared to other new buildings of similar type, or to the modeled consumption for that specific building? And what set of measured data is a reasonable unit—the first year of building occupancy, or the most recent year? Are the number of LEED-NC energy efficiency points or total energy points correlated with actual energy consumption? Because our study sample had both federal and non-federal buildings, we could also ask whether there were differences in energy consumption between these two groups.

There are many difficulties in answering these questions. For example, the comparisons between modeled and actual consumption can be complicated for several reasons: the building as actually built can differ dramatically from the one modeled at the design stage. Different occupancy patterns and densities, number or type of equipment (especially computers and related hardware) can all make these comparisons difficult to interpret. Were the buildings poorly modeled, or was a lack of commissioning responsible for the discrepancies? Has the usage of the space changed because of a change in organization mission or requirements? Despite all these potential reasons for differences, several of the buildings were within 10% of their design values. We can tentatively hypothesize that LEED buildings tend to have better agreement between design simulations and actual energy use than typical buildings; such agreement is one indicator of overall design and construction quality.

We are also aware of the limitations of this study, and again caution against extending the conclusions too broadly. Our sample of 21 buildings was only 7% of the 300 certified LEED-NC buildings at the time. The sample is not a random sample, but one biased by two factors, availability of data from the Pacific Northwest and the large number of Federal LEED-certified buildings. These buildings represent a broad cross-section of building types, not all of which are easily comparable. Definitions of "whole building," "energy use," and even "floor area" are not standard. We have tried to be as careful as we can to show where the data come from and what they represent, but there are always challenges in this type of analysis.

Despite these limitations, we feel we can conclude the following:

1. For the 17 buildings for which we have both whole-building basecase and design whole-building simulations, the mean simulated energy savings was 27% (SD=8%).
2. For the 18 buildings for which we have both simulated whole building design and actual purchased energy, the actual consumption was lower than simulated by 1% (SD=46%)
3. The number of LEED energy efficiency points did not correlate with actual energy savings.
4. For the 12 buildings for which we had sufficient data, the "equivalent" Energy Star scores had a mean value of 71, which was slightly below the Energy Star award threshold of 75, but higher than the whole-stock average value of 50. Four of the 12 buildings had scores higher than 75, and would qualify for Energy Star.
5. For the subset of 9 federal buildings and 8 non-federal buildings, the federal buildings had higher design and basecase modeled energy consumption, smaller predicted savings, lower actual energy use than modeled, and higher Energy Star scores than the non-federal buildings.

Recommendations and new research

One of our recommendations is the call for a more comprehensive collection and publication of modeled vs. actual energy consumption data. Several efforts have started this process, e.g., DOE's High Performance Buildings Database, and the New Building Institute, but a coordinated effort with fully documented data would be invaluable. Not only do we need a central compilation, but consistent applications for how the data are defined, normalized, compared, and reported.

Such an effort could go a long way towards addressing the problem we identified earlier about closing the gap between design simulation and actual performance. Factors such as increasing plug loads, the need for commissioning, and good operations and maintenance are all a call to industry to develop better tools and practices to reduce this gap. Such a database could also help answer questions of whether consumption tracks with connected load, and the need for system power density guidelines.

Our final recommendation is to note that reducing energy consumption is only one element of sustainable building design, and we hope that in the future, evaluations of LEED and other green buildings can incorporate additional aspects of materials and resource consumption to asses more fully their sustainable performance.

Acknowledgements

The authors would like to thank all the energy analysts, modelers, building owners, managers and staff who helped provide the data for this work, but who are to numerous to list here. We are also grateful to the reviewers, including Mark Mendell and Michael Apte from LBNL, as well as the two anonymous reviewers, who made several helpful suggestions to this draft. This work was funded by the Federal Energy Management Program of the US Department of Energy under Contract No. DE-AC02-05CH11231 and the US Environmental Protection Agency.

References

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) 1999. "ASHRAE/ANSI/IESNA Standard 90.1-1999: Energy Standard for Buildings Except Low-Rise Residential Buildings." New York, NY and Atlanta GA: ASHRAE/ANSI/IESNA.

Fowler, K.M. 2004. "Building Cost and Performance Measurement Data." PNNL-SA-43119. *Greenbuild 2004 International Conference and Expo*, Portland, Oregon.

Heerwagen J. 2000. "Do Green Buildings Enhance the Well Being of Workers?" Environmental Design+Construction 3(4):24-30.

Office of the Federal Environmental Executive, (OFEE), 2003. "Sustainable Federal Buildings" Closing the Circle News, Fall Winter 2002 Issue 28. http://www.ofee.gov/eo/closing2.htm

Office of the Federal Environmental Executive (OFEE). 2003. "The Federal Commitment to Green Building: Experiences and Expectations." http://www.ofee.gov/sb/fgb_report.html

Payne, Christopher and Beverly Dyer. 2004. "Federal Participation in LEED," *Greenbuild 2004 International Conference and Expo*, November 2004. Portland, Oregon.

Torcellini P. et al., 2004. "Lessons learned from the field evaluation of six high-performance buildings." *Proceedings* of the 2004 ACEEE Summer Study. Washington DC: ACEEE.

Turner, Cathy. 2006. "LEED Building Performance in the Cascadia Region: A Post Occupancy Evaluation Report. Cascadia Green Building Council.

U.S. Green Building Council (USGBC). 2003. "Green Building Rating System for New Construction & Major Renovations" (LEED-NC™) Version 2.1 http://www.usgbc.org/Docs/LEEDdocs/LEED_RS_v2-1.pdf

U.S. Environmental Protection Agency and U.S. Department of Energy, Energy Star Building Rating Program. http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager