PO Box 2349
White Salmon, WA 98672
509-493-4468

1331 Washington Street
Vancouver, WA 98660
360-567-0950
www.newbuildings.org

Energy Performance of LEED® for New Construction Buildings

FINAL REPORT *March 4, 2008*

Prepared by:

Cathy Turner, Senior Analyst
Mark Frankel, Technical Director

Prepared for:

U.S. Green Building Council
Brendan Owens
1800 Massachusetts Avenue NW, Suite 300
Washington DC 20056

Acknowledgements

This report was prepared by New Buildings Institute (NBI) and funded by the U.S. Green Building Council (USGBC) with support from the U.S. Environmental Protection Agency. We thank the many building owners, operators, and designers who assisted in providing data for the study. We also appreciate the following technical reviewers for their generous time and thoughtful comments.

Technical Reviewers

- Center for the Built Environment: Gail Brager
- Pacific Northwest National Labs: Kim Fowler, Mark Halvorson, Dave Hunt, Andrew Nicholls
- Seattle Department of Planning & Development: John Hogan
- U.S. Environmental Protection Agency: Bill vonNeida

Disclaimer
This work was performed with reasonable care and in accordance with the highest professional standards. However, neither NBI nor any entity funding the work make any warranty or representation, expressed or implied, with regard to any analyses or conclusions contained in this report. Neither the funding provided by the project sponsors nor the participation of the reviewers constitutes an endorsement of the views expressed herein.

About NBI
New Buildings Institute is a nonprofit organization with the mission of making buildings better for people and the environment. As a leading think tank on approaches to significantly improve the built environment, NBI serves as a carrier of successful ideas between states and regions, researchers, and the market. We work with the building design, engineering, and owner community, as well as national, regional, state, and utility groups, to promote improved energy performance in commercial construction. Specific project work includes building research, design guidelines, green building performance evaluation, code and policies, and training. For more information, visit www.newbuildings.org.

About USGBC
The U.S. Green Building Council is a nonprofit membership organization whose vision is a sustainable built environment within a generation. Its membership includes corporations, builders, universities, government agencies, and other nonprofit organizations. Since UGSBC's founding in 1993, the Council has grown to include more than 14,000 member companies and organizations, a comprehensive family of LEED® green building rating systems, an expansive educational offering, the industry's popular Greenbuild International Conference and Expo (www.greenbuildexpo.org), and a network of 77 local chapters, affiliates, and organizing groups. For more information, visit www.usgbc.org

Table of Contents

Figures and Tables

Energy Performance of LEED® for New Construction Buildings

Executive Summary

This study analyzes measured energy performance for 121 LEED New Construction (NC) buildings, providing a critical information link between intention and outcome for LEED projects. The results show that projects certified by the USGBC LEED program average substantial energy performance improvement over non-LEED building stock. This Executive Summary briefly summarizes key study findings. See the full report for further detail on study methodology and results.

Study Participants

With the recent exponential growth in annual LEED certifications, the number of occupied LEED buildings now permits meaningful studies of how measured performance meets energy efficiency objectives. All 552 LEED-NC version 2 buildings certified through 2006 were invited to participate in this study. The only requirement for inclusion was the ability to provide at least one full year of measured post-occupancy energy usage data for the entire LEED project. Twenty-two percent (121) of currently certified buildings were able to provide the requested information and are included in the results.

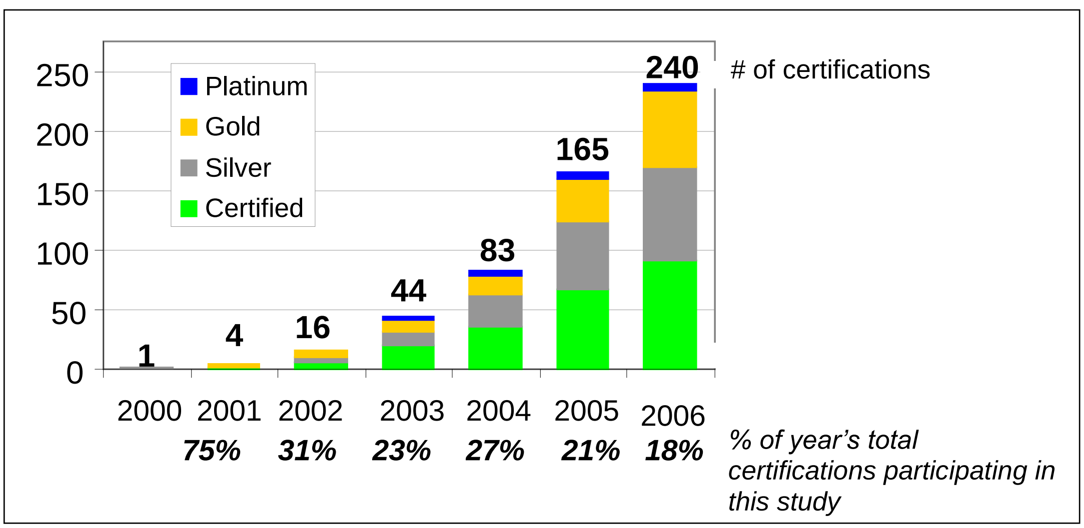


Figure ES- 1: LEED-NC Certifications by Year, and Percent for Each Year in This Study

Results

Measured performance results show that on average LEED buildings are saving energy. The study analyzes whole-building energy usage with three different metrics, each of which is summarized in the following sections and described in further detail in the full report:

- Energy Use Intensity (EUI) comparison of LEED and national building stock

- Energy Star ratings of LEED buildings
- Measured results compared to initial design and baseline modeling

While each metric has inherent advantages and limitations, agreement among the multiple perspectives increases confidence in the overall conclusions.

Energy Use Intensities

The most basic benchmark compares LEED building energy use intensity (in kBtu/sf/yr) to data from all national building stock. National EUI data comes from the Commercial Building Energy Consumption Survey (CBECS), a national survey of building energy characteristics completed every four years by the federal Energy Information Administration. For all 121 LEED buildings, the median measured EUI was 69 kBtu/sf, 24% below (better than) the CBECS national average for all commercial building stock. Comparisons by building activity type showed similar relationships. For offices, the single most common type, LEED EUIs averaged 33% below CBECS.

Figure ES- 2 shows the median EUIs by certification level and the individual measured EUIs for each of 100 participating buildings, excluding those consisting of high energy activity types such as labs, data centers and supermarkets. Note that the median performance of gold and platinum buildings is very close to the interim goals of Architecture 2030, shown here for office buildings at 50% of the CBECS office average.

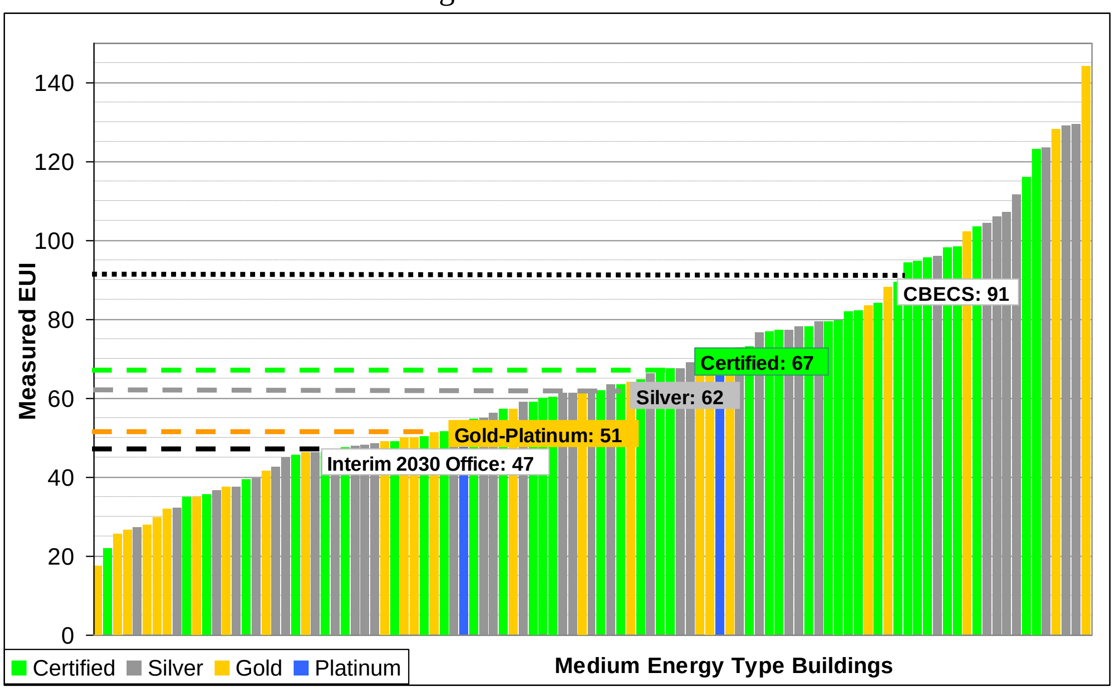


Figure ES- 2: EUI (kBtu/sf) Distribution

The 21 high energy type buildings in the study (not individually shown above) had EUIs up to nearly 700 kBtu/sf, with a median of 238. These activity types were segregated because energy use here is largely driven by the requirements and process loads of occupant activities, as opposed to basic building systems, making their analysis more complex. For purposes and analysis in this study, these high energy use buildings are generally considered separately.

Energy Star Ratings

EPA's Energy Star program rates a building's energy use in relation to existing national building stock for the same activity type. The calculations are further normalized for temperature and other key variables, such as schedule and occupancy. The average Energy Star rating of LEED buildings was 68 (meaning better than 68% of similar buildings), compared with a median rating of 50 for the complete national building stock. Nearly half of LEED buildings had Energy Star ratings of at least 75, meeting the qualification level for an EPA-certified Energy Star building.

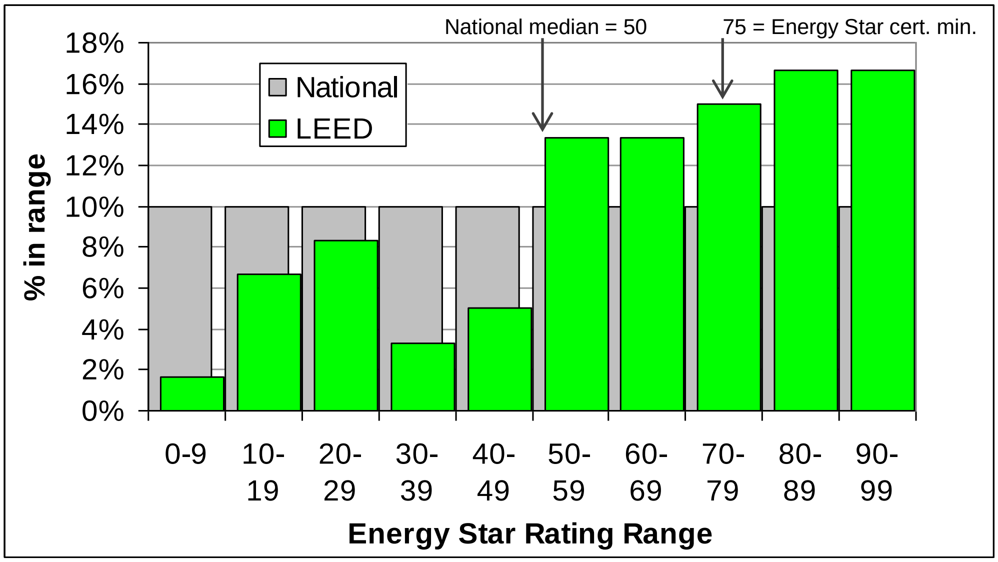


Figure ES- 3: Distribution of Energy Star Ratings

While the average LEED Energy Star Rating is favorable, the figure above shows that one quarter of these buildings had ratings below 50, meaning they used more energy than average for comparable existing building stock. Further investigation of the reasons for these shortfalls holds potential for significant further improvements of overall LEED performance.

Measured Performance in Relation to Modeling

The LEED program awards energy performance points on the basis of predicted energy cost savings compared to a modeled code baseline building. The baseline is generated using the energy cost budget (ECB) approach and performance requirements in the ASHRAE 90.1 standard. Most buildings in this study used the 1999 version of this standard. Measured energy savings for the buildings in this study average 28% compared to code baselines, close to the average 25% savings predicted by energy modeling in the LEED submittals.

Program-wide, energy modeling turns out to be a good predictor of *average* building energy performance for the sample. However, as with the other metrics in the study, there is wide scatter among the individual results that make up the average savings. Some buildings do much better than anticipated, as evidenced by those in Figure ES- 4 with measured EUI below the dotted line. On the other hand, nearly an equal number are doing worse - sometimes much worse.

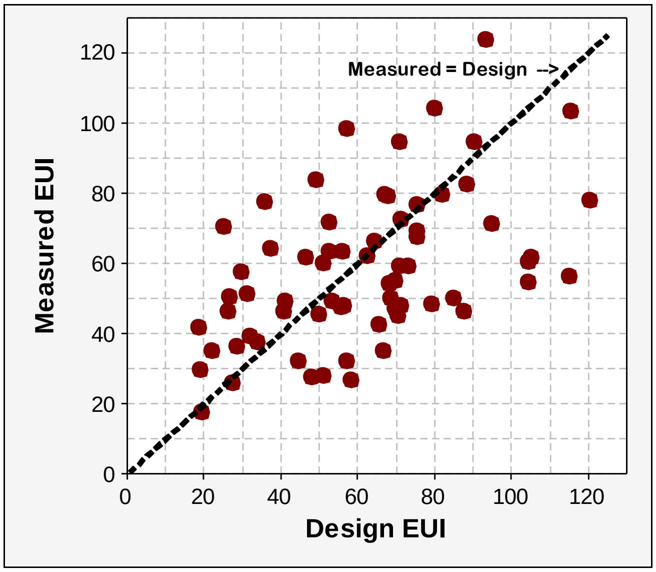


Figure ES- 4: Measured versus Design EUIs
All EUIs in kBtu/sf

At the extreme, several buildings use more energy than the predicted code *baseline* modeling, as shown in the comparison of measured vs. proposed savings percentages in Figure ES-5. This degree of scatter suggests significant room for improvement in energy use prediction accuracy on an individual project basis.

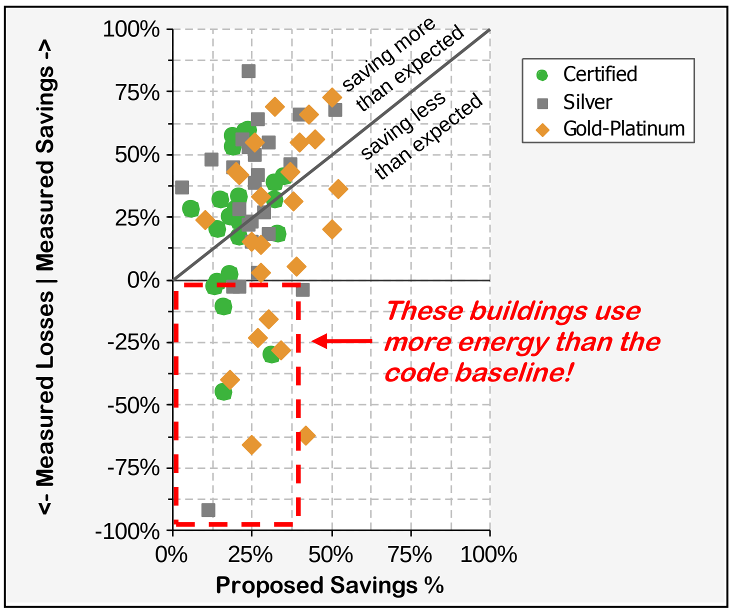


Figure ES- 5: Measured versus Proposed Savings Percentages

Variation in results is likely to come from a number of sources, including differences in operational practices and schedules, equipment, construction changes and other issues not anticipated in the energy modeling process. More in-depth analysis of some of the best and worst performers could identify ways to eliminate the poorer outcomes and communicate lessons from the best results.

Conclusions and Recommendations

1. **On average, LEED buildings are delivering anticipated savings**. Each of three views of building performance show average LEED energy use 25-30% better than the national average, a level similar to that anticipated by LEED modeling. Average savings increase for the higher LEED levels, with Gold/Platinum buildings approaching the interim goal of Architecture 2030.

2. **Within each of the metrics, measured performance displays a large degree of scatter, suggesting opportunities for improved programs and procedures**. Measured EUIs for over half the projects deviate by more than 25% from design projections, with 30% significantly better and 25% significantly worse. Statistically credible, precise quantification of LEED savings will first require narrowing this range of variability. A follow-up study of some of the good and poor performers could identify ways to eliminate the worst results and identify lessons to incorporate from the best results.

3. **More feedback is needed from actual building performance results to design-phase energy modeling**. The current variability between predicted and measured performance has significant implications for the accuracy of prospective life-cycle cost evaluations for any given building. Better feedback to the design community is needed to help calibrate energy modeling results. Follow-up investigation into reasons for measured-to-design deviations, and for the wide variations in modeled baseline performance, could improve future modeling and benchmarking.

4. **Project types with high process loads are problematic.** Lab buildings on average use more than twice as much energy as anticipated in their energy models. Energy use characteristics of high energy building types are apparently not well understood by designers. Neither LEED nor the modeling protocol addresses these projects effectively.

5. **The energy performance baseline used by LEED to define a reference benchmark is not as aggressive as anticipated**. Although the performance baseline used by LEED (ASHRAE 90.1) is generally assumed to deliver buildings with significantly higher performance than the national CBECS baseline, the average performance of the code baseline buildings in this study was close to the average performance of national building stock. Like the measured and predicted building performance values, the baseline performance EUI's occupied a wide range, even within building types. Also, buildings targeting more aggressive energy performance tended to be compared to a more stringent baseline performance standard than more conventional buildings. These issues suggest a need for more comprehensive analysis of the anticipated energy performance of the baseline.

6. **Continued improvements to the LEED program are suggested**. Improvements in LEED program submittal screening, quality control and follow-up are suggested to help encourage and maintain energy savings. Related LEED credits such as Advanced Commissioning and Measurement and Verification (M&V) could be reworked to more directly contribute to better energy performance and provide more directly useful information to owners and operators.

The full report provides more detail on Study Procedures, Participant Characteristics, result analysis for each of the three metrics and recommendations for further study.

This page intentionally left blank.

Energy Performance of LEED® for New Construction Buildings

1 Introduction

This report provides the most comprehensive view to date of post-occupancy energy performance of LEED buildings, providing a critical link between intention and outcome for LEED projects. With the recent exponential growth in annual LEED certifications (Figure 1), the number of occupied LEED buildings now permits meaningful studies of how measured performance meets the overall program objective of more efficient buildings.

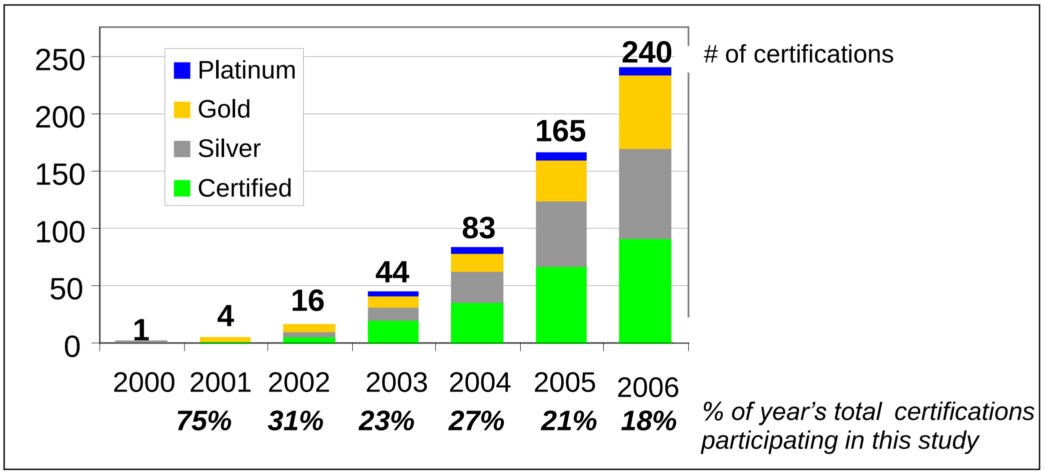


Figure 1: LEED-NC Certifications by Year, and Percent for Each Year Included in This Study

This report compares measured energy usage to a variety of benchmarks, including Commercial Building Energy Consumption Survey (CBECS) averages, Energy Star ratings and modeled energy performance estimates provided as part of LEED submittals. Additional analyses explore the effectiveness and impact of the LEED-NC scoring system by examining measured performance in relation to characteristics such as certification level, Energy and Atmosphere (EA) points achieved, modeling accuracy, year built and climate zone. An analysis of occupant comfort in LEED buildings was also conducted on a subset of the projects. Findings here can also help identify possible changes in procedures and additional analyses that would further improve LEED program and building performance in the future.

This report describes a) Study Procedures; b) Participant Characteristics; c) Results, using the metrics of Energy Use Intensity (EUI), Energy Star ratings and Measured Performance Relative to Initial Modeling; and d) Conclusions and Recommendations. Appendices provide more detail on study procedures, definitions, and back-up data tables.

2 Procedures and Data Sources

All LEED-NC version 2 (NCv.2) buildings were invited to participate. NCv.2 comprises about ¾ of total certifications within the various LEED programs and provides the largest coherent subset on which to base energy analysis. With no restrictions by project type or number of energy points, the only additional requirement for participating was the ability to provide at least one full year of measured post-occupancy energy usage data for the entire LEED project. As of December 2006, 552 buildings had received NCv.2 certification. Of those, 121 (22%) are included in the results presented in this study.

Measured energy usage and basic building information, at the whole building, monthly energy bill level, was supplied for all participating facilities, usually by owners.

Energy Star ratings for eligible building types were obtained using the EPA's Portfolio Manager. These ratings rank a building's energy usage relative to similar buildings across the country, normalized for weather, activity and other key operational characteristics.[1]

Design and Baseline modeled results came from USGBC files for the final LEED project submittals when available.[2]

Figure 2 shows the portion of these buildings for which the various data types were available.

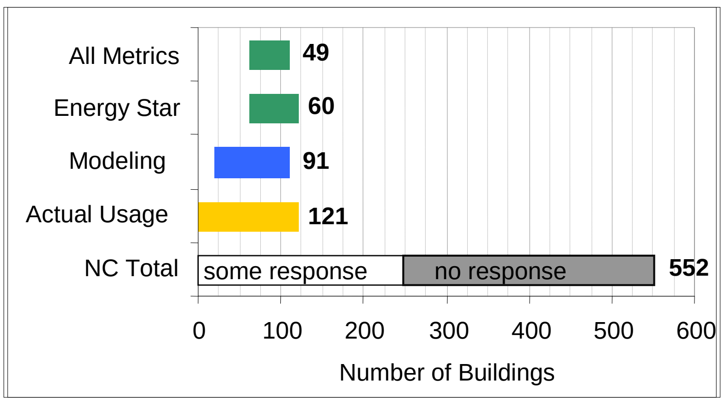


Figure 2: Study Participants by Available Metrics

All information was reviewed for plausibility but not audited or otherwise verified for accuracy and completeness. Additional information on procedures, data sources and considerations can be found in Appendix A: Study Background. [3]

Except where otherwise noted, all EUIs in this study reflect:

- purchased energy only (excluding onsite renewables)
- site energy
- the most recent twelve months available
- all end uses (including plug loads and other miscellaneous equipment)

---

[1] The Energy Star rating system was updated October 1, 2007, to reflect the most recent CBECS survey results and refined calculation methodologies. All ratings reported in this study were calculated *before* this revision. Anticipated changes to individual ratings from the new methodology were small. The difference would not be expected to affect any overall conclusions of this study, although results for individual buildings may vary slightly.
[2] "Baseline" in this report refers to the "budget" calculations of ASHRAE 90.1-based modeling.
[3] For example, a fully occupied facility showing total electricity usage of 1 kBtu/sf was excluded after repeated questions failed to determine whether additional accounts also served the space.

Site vs. Source Energy: As noted above, most results in this report are based on site energy use, as measured at the building. Site usage is the metric most closely related to the building owner's energy bills and is also a prerequisite for calculating the alternate metrics of source energy (measured at the power plant level, including generation and distribution losses incurred before the energy reaches the building) or greenhouse gas emissions. The Energy Star ratings presented do, on the other hand, reflect *source* energy use; one step in their internal calculation is to translate measured site energy to source energy. A separate USGBC research project is currently underway to quantify greenhouse gas emission savings from the LEED program.

Plug and Process Loads: The term "plug load" is used in this report for the category of end uses described as "process loads" in ASHRAE 90.1. Sometimes also referred to as "unregulated" loads, this category includes plug loads, miscellaneous equipment and other activities primarily associated with the functions of the occupants as opposed to the lighting and conditioning of the building itself. For all modeled whole building results, this study assumed plug loads equal to 25% of the total 90.1 baseline energy usage. This is the default value currently used by LEED in modeling energy use. See Appendix D: Plug (Process) Loads, for further discussion.

3 Things to Keep In Mind

Even with 121 participating buildings, data volume can be insufficient for statistically credible differences when subdivided among multiple variables, particularly with high variability in individual performance results. Thus, the study is a beginning, not the final definitive analysis. Many patterns presented in the results of Section 5, showing for example energy usage by climate or by other related credit levels, should be considered approximate and suggestive of areas for further exploration, not precise performance levels. In several cases, similar categories have been grouped to avoid extremely low counts in any one subgroup. For example, results by LEED certification level show gold and platinum levels combined because the study includes only two platinum buildings. In addition, results by number of Energy Optimization points are grouped into four point ranges because there is not enough data for division among the individual 0 through 11 point levels.

None of the three performance metrics used in this study provides a perfect basis for precise determination of savings. However, viewing results from multiple perspectives offers a good general sense of accomplishments thus far, particularly when the general conclusions from multiple metrics agree. This exploratory view provides the basis for designing the structure of more complete future analyses.

<u>What this study is</u>

- A look at actual whole building energy usage of 121 LEED buildings of a wide variety of types, including graphic displays of the range of individual results as well as averages.
- A comparison of whole building energy usage to readily available benchmarks, including national average EUIs, Energy Star scores and initial modeling

- A summary of approximate *average* savings levels of LEED buildings, in relation to benchmarks from the available benchmarks
- A data exploration that suggests
  - Future studies and data refinements to more precisely quantify and better understand results
  - Areas for possible program revisions to better align related credits with energy efficiency

What this study is not

- A statistically robust evaluation of the precise energy savings of LEED buildings. The results show a level of spread within building types and certification levels that can't be explained solely by the building characteristics data available. While differences in averages suggest possible relationships, the variance in the data is too large for statistically significant confidence in the size of those differences.
- An in-depth investigative or diagnostic review of individual building operations and systems to identify reasons for high or low energy usage
- Development of a new benchmark for determining savings for buildings not currently rated by Energy Star
- An evaluation of the assumptions used in the energy modeling for these buildings
- A specific proposal which identifies specific LEED program areas to modify or further study to address results and limitations in this report

Keep these items in mind while reviewing the report. Several areas clearly suggest the need for greater detail and more directly aligned categories for drawing definitive conclusions. While specific limitations of the current data will be mentioned in some of those areas, the more general factors above apply throughout the report and will not be repeated in each section

4 Participant Characteristics

This section summarizes the general characteristics of the studied buildings compared to all LEED-NC buildings. In addition to providing general background on the nature of these buildings, the comparisons show that the characteristics of participating buildings, such as size, energy optimization credits and climate zone, were similar to those of all LEED-NC buildings. In the sections that follow, "2006 Summary" refers to a prior review that examined many relationships and patterns for energy credit achievement and initial modeling projections for all LEED-NC certifications through July 2006, based solely on information provided in the LEED submittal process. "This study" refers to the 121 buildings that also submitted measured post-occupancy energy data in 2007.

4.1 Building Activity Type

While building activity type is one of the most intuitively obvious ways to categorize a building, the variety of terms used, number of buildings with multiple activities and change in activities over time all confound attempts to compare different data sets. This study used current building activity information from owners, which often differed from or clarified the activity type recorded in the LEED submittal. The Figure 3 comparison of building type distribution for this study and for all LEED-NC buildings shows significantly more office buildings and fewer in multi-use and all remaining categories. That difference is largely the result of the more complete information available on the participating buildings. Office buildings are the dominant category in this study and in the LEED building stock as a whole.

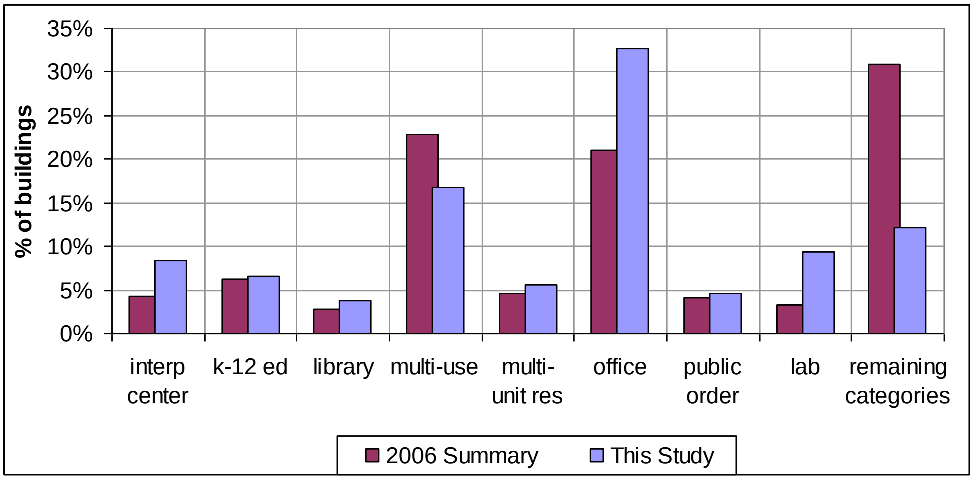


Figure 3: Building Type Distribution
Types with 3 or fewer participating buildings in this study are grouped under "remaining categories."

For the aggregate analyses of this study, building activities were classified into two broad categories. ***Medium Energy Use Activities*** include building types that generally have EUIs in a range similar to that of office buildings. (Measured EUI levels are shown later under Results.) These relatively similar Medium Energy Types form the basis for most of the performance analysis in the study.

Types with ***High Energy Use Activities*** typically have very high process loads (equipment, exterior lighting, etc.) and/or ventilation requirements, such as labs, data centers and recreation facilities. Further discussed in Section 5.4 at the end of the Results section, these types are otherwise excluded from most subsequent comparisons because the activity-related usage confounds analysis at the whole-building level of underlying building system efficiency.

Appendix B contains a more detailed discussion of the nature of CBECS data as a benchmark for this data. Appendix C contains detail on the participating building types, including the numbers by type with modeling or Energy Star information. (See Table 1: Participant Counts by Type, Modeling and Energy Star Availability.)

4.2 Projects by Size

The size distribution for study participants is similar to that of all LEED buildings, with an average size just over 110,000 square feet and about half the buildings in the range of 25,000 – 200,000 square feet. (Figure 4)

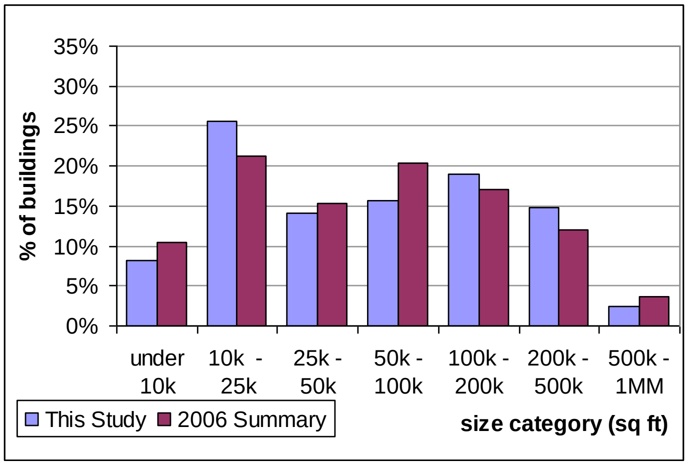
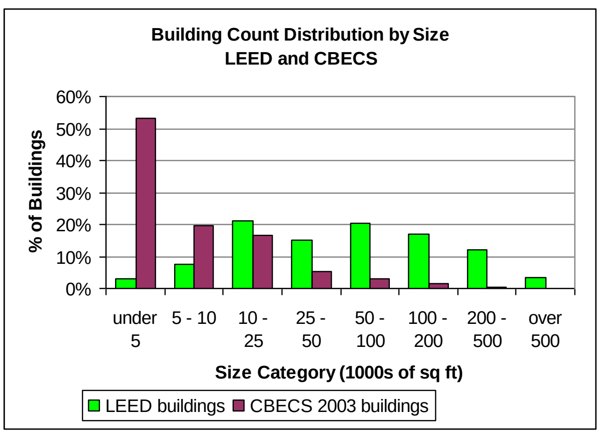


Figure 4: Size Distributions, This Study and All LEED-NC Projects

The above results are in marked contrast to the size distribution for all national building stock as reported by CBECS, with 73% of all buildings below 10,000 square feet and an average size of 14,700. (Figure 5)



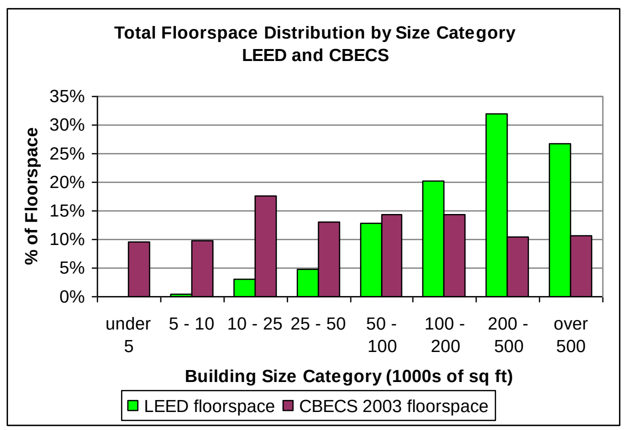


Figure 5: Size Distribution Comparisons, LEED-NC and CBECS
by Building Count and by Floorspace

The significant difference in size distribution between LEED and CBECS building stock is one example of why average LEED and CBECS performance may not be directly comparable. However, while the projects participating in this study were distributed across a wide range of sizes, building size did not appear to be a significant predictor of energy use or savings in this sample.

4.3 By Certification Level

The distribution of participating buildings by certification level, shown below, is similar to that of all LEED-NC buildings. Likewise, the average total Energy Optimization points (EAc1) achieved is at each level is nearly identical between the study buildings and all LEED buildings.

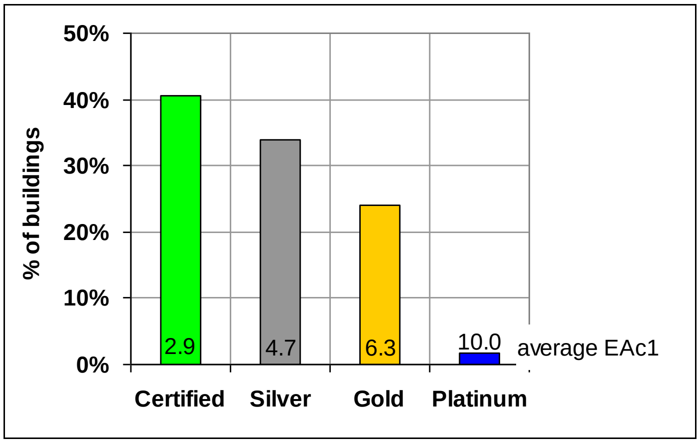


Figure 6: Certification Level Distribution with EAc1 Averages

4.4 By Climate Zone

70% of participating buildings were in cool zone 5 (ASHRAE), including cities such as Denver and Boston, or mixed zone 4, with cities such as Seattle and St. Louis, a similar result to that for all LEED buildings (Figure 7). Because of the low LEED building counts in the hot and cold zones, the energy analysis by climate zone in the following Results section groups together the warm–hot zones and the cold–very cold zones.

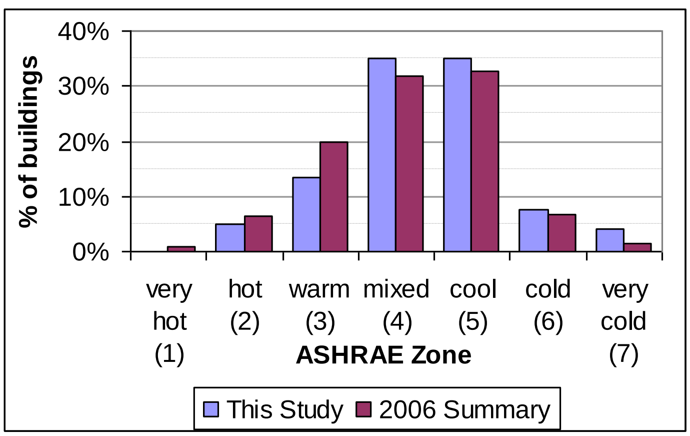


Figure 7: Climate Zone Distribution

5 Results

This section presents the study's measured performance results for three metrics, reflecting the views of building EUI, Energy Star rankings and comparison of modeled-to-measured energy use and savings.

5.1 Energy Use Intensities

The median Energy Use Intensity (EUI) for all LEED buildings is 69 kBtu/sf, 24% below the national building stock average from the 2003 Commercial Building Energy Consumption

Survey (CBECS) for all building types. As noted under Participant Characteristics: Building Activity Type (p. 10), participants were divided by primary activity into two fairly distinct categories: those with high energy activities driven largely by plug or process loads such as labs and data centers, and those with medium energy activities with plug loads more characteristic of an office building. The overall LEED average of 69 kBtu/sf includes 21 High Energy Type buildings, which have a median EUI of 238 kBtu/sf, while the Medium Energy Type average is only 62.[4] (Figure 8)

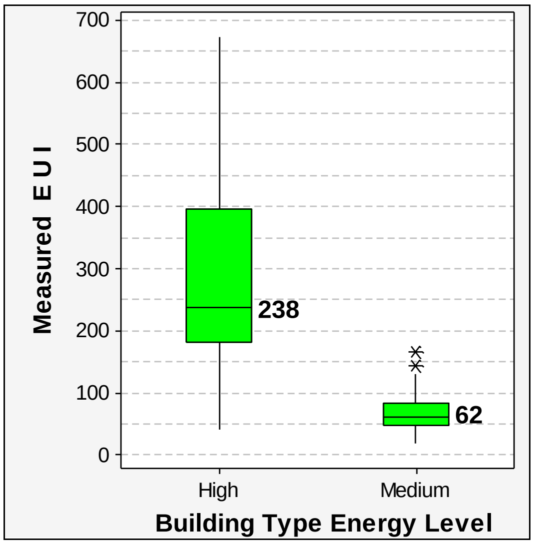


Figure 8: EUI Ranges for High and Medium Energy Type Categories
Boxes show the range of values between the 75th and 25th percentiles. Labeled center line shows median value.
All EUIs in kBtu/sf

The measured performance results in the following sections are based on the Medium Energy Types unless noted otherwise. The wide variability of the High Energy Type results, combined with the confounding effects of interactions between process requirements and basic building systems loads, would require a more complex and detailed analysis of these project types.

Figure 9 shows the measured EUIs for all Medium Energy Type Buildings in this study, along with the overall CBECS national average and LEED medium energy building medians by certification level. Another basis for comparison is the interim goal of the Architecture 2030 Challenge. That program, designed to make all new buildings carbon-neutral by the year 2030, phases in the reduction in fossil fuel use in new buildings over the next 23 years. The first step is for all new buildings and major renovations to reduce greenhouse gas emissions by 50% of the current average. Note that the median performance of gold and platinum buildings is very close to that 2030 interim goal, shown here for office buildings at 50% of the CBECS office average.[5]

[4] LEED building averages throughout this report are medians, to reduce skewing by a few large or small values, particularly in subsets with relatively few data points. See Appendix A, on study background and procedures, for further detail.

[5] Offices comprise one-third of the study buildings in this subgroup excluding the high energy usage types, and have an average EUI near the average for the group. Thus, the CBECS *office* EUI appears an appropriate benchmark for the Architecture 2030 interim goal comparison.

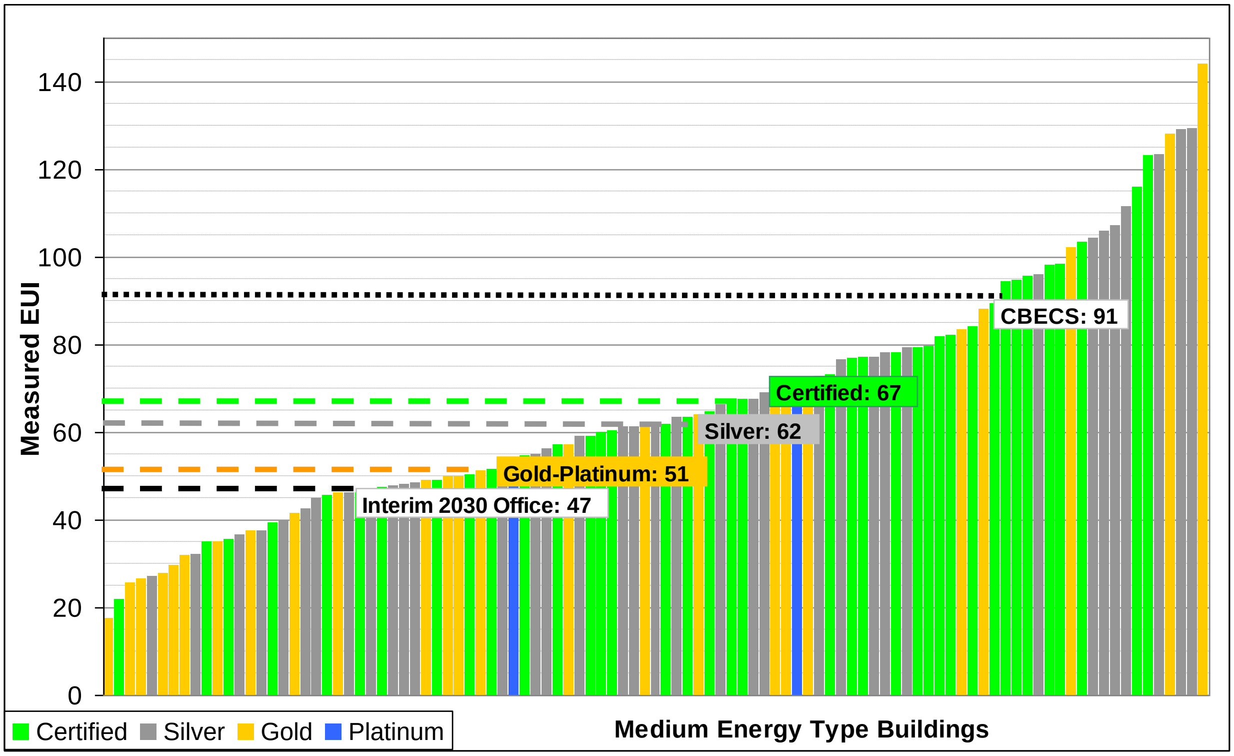


Figure 9: EUIs (kBtu/sf) for Medium Energy Buildings, with Medians by RatingLevel

These averages combine many activity types for buildings in the LEED study, and the overall CBECS average includes all types of commercial building stock, from high energy labs to vacant warehouses. To refine the comparison, the next section looks at ratios by building activity type.

5.1.1 By Type

LEED median EUIs average well below CBECS for each main activity type in the study. The grouping and definition of activity types is not identical for CBECS summaries and the LEED data, making some categories less directly comparable than others and preventing a simple comparison of overall type distribution between the study and CBECS. Offices buildings are the single most common type for the LEED data and do have a direct match in CBECS. For these projects, the LEED median is 67% of the CBECS average.

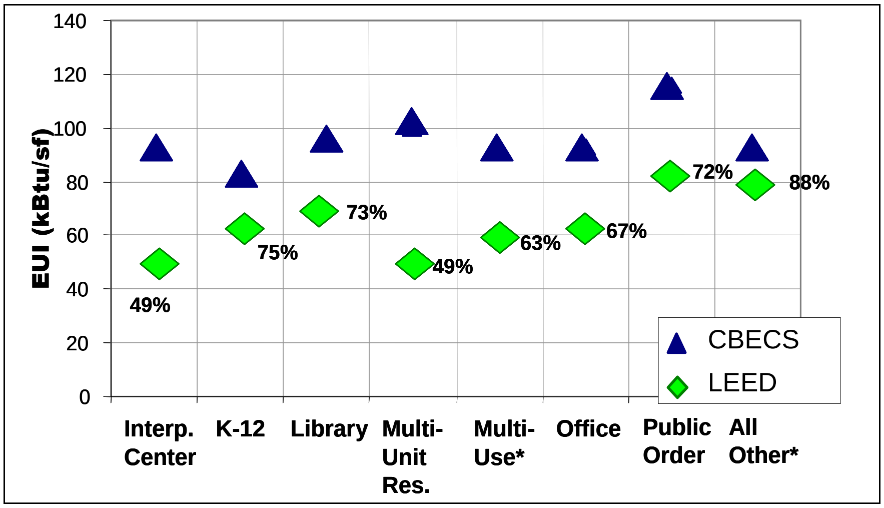


Figure 10: LEED-NC and CBECS EUIs (kBtu/sf) by Type

* CBECS average for all building types combined were used for the Multi-Use and All Other categories.

Some project types above have few data points in this study. Table 2 and Table 3 in the Appendix give more detail on counts, measured EUI levels and ranges by building activity type. That section also contains further discussion of activity types as categorized by CBECS.

5.1.2 By LEED Level

The following graph shows median EUIs improving as LEED levels improve. This suggested trend in medians is encouraging, while the wide scatter within each level shows significant further room for improvement.

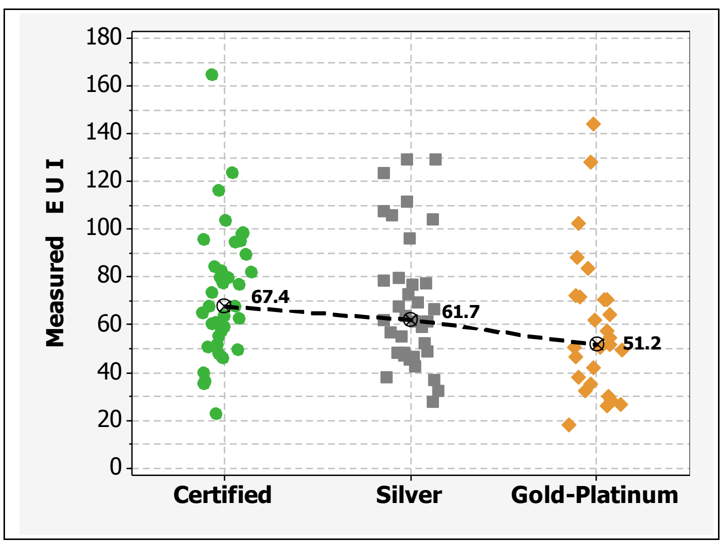


Figure 11: Measured EUIs (kBtu/sf) by LEED-NC Rating Level

These median EUIs, when expressed as a percentage of the overall CBECS average, are 26% lower (better) for certified projects, 32% lower for silver and 44% lower for gold-platinum.[6]

[6] Because the study included only two platinum buildings, gold and platinum results are combined in comparisons by certification level

5.1.3 By Energy Optimization Credit Level

A similar pattern appears when examined by the number of energy optimization points achieved, EA credit 1. The left chart in Figure 12 shows a generally declining (improving) EUI level as EAc1 points increase, although little differentiation appears within the range of 2 to 7 points. The right-hand chart, restricted to office buildings for greater consistency among building types, continues to show a range of results at these middle point levels.

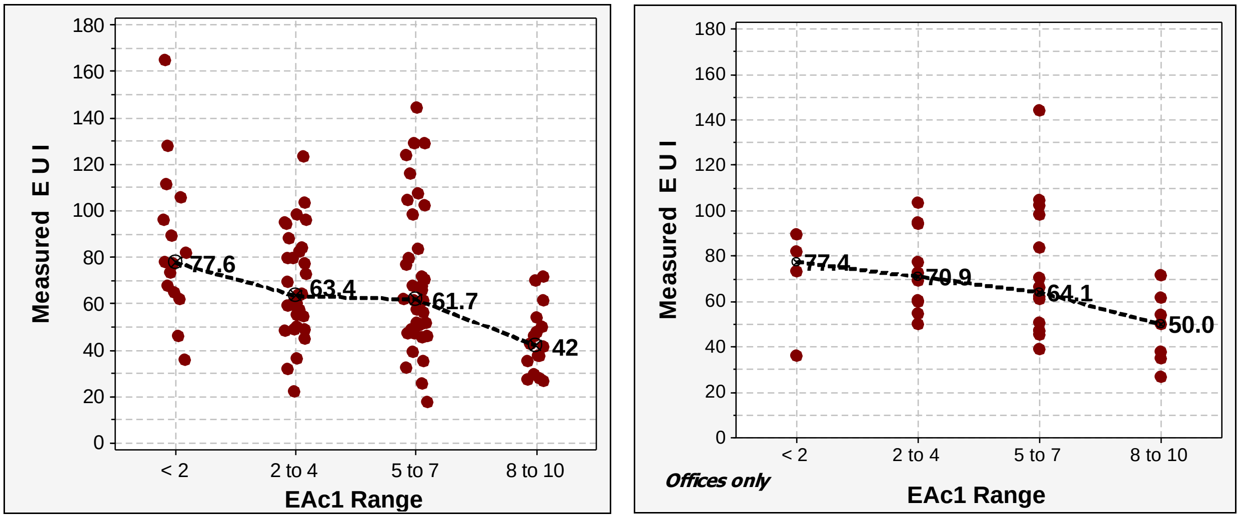


Figure 12: Measured EUIs (kBtu/sf) by EAc1 Point Range

5.1.4 By Climate Zone

For all but the warm-to-hot zones, LEED buildings show significant improvement over CBECS, with median LEED EUIs between 51% and 64% of the CBECS average for those zones. For the warmer zones on the other hand, the median LEED result is virtually the same as CBECS. LEED building counts by zone are shown in the bars in Figure 13. The warmer zone performance result may be partly a function of the relatively few buildings in this zone. But it also raises questions about whether these climates pose additional challenges for achieving energy efficiency, suggesting the need for additional study in this area.

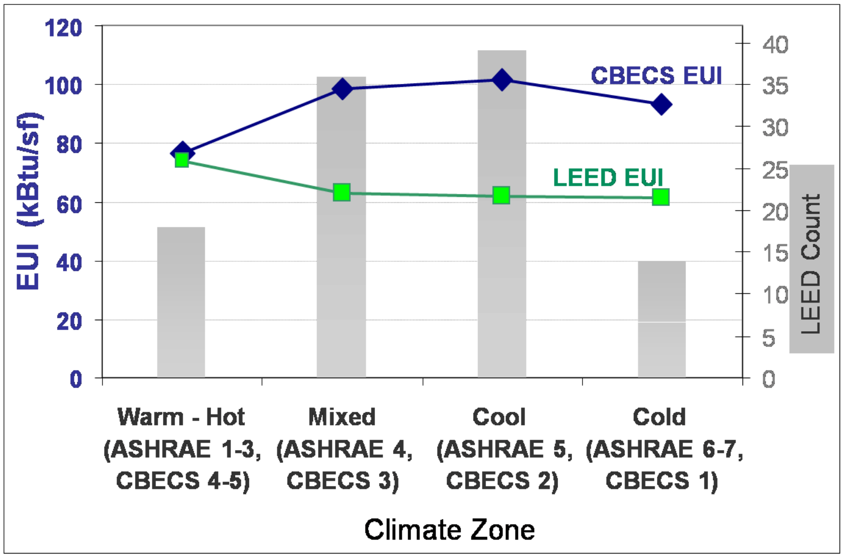


Figure 13: EUIs (kBtu/sf) by Climate Zone

5.2 Energy Star Ratings

Energy Star ratings estimate a building's source energy[7] performance relative to national building stock, normalized for building activity type, temperature and other key factors found from CBECS data to have the most significant correlations with measured energy performance. For example, the input for office building Energy Star Ratings includes average weekly operating hours, the number of occupants and the number of computers. The activity types of about half the buildings in this study made them eligible for Energy Star calculations. For those buildings, Energy Star's normalized results should give a more precise assessment of relative performance than a simple comparison to broad CBECS averages. Furthermore, because each building's rating is normalized to its activity type, it is possible to include all rated building types in result summaries. Thus, the ratings presented in this section are for all 60 participating buildings covered by the rating system, including high energy type supermarket and health care buildings.

The median LEED Energy Star rating was 68, compared to an assumed national building stock median of 50. These ratings represent performance percentiles, so a rating of 50 means 50% of similar buildings perform worse (use more source energy per square foot) than the rated building. The graph below shows that 3/4 of LEED buildings have ratings above the national building stock median of 50. Nearly half (47%) had Energy Star ratings of at least 75, and 17% had ratings above 90. At the other extreme, 15% of the LEED buildings in this study have ratings below 30.

[7] "Source Energy" includes the energy metered at the site plus the amounts lost in power generation, transmission, and distribution.

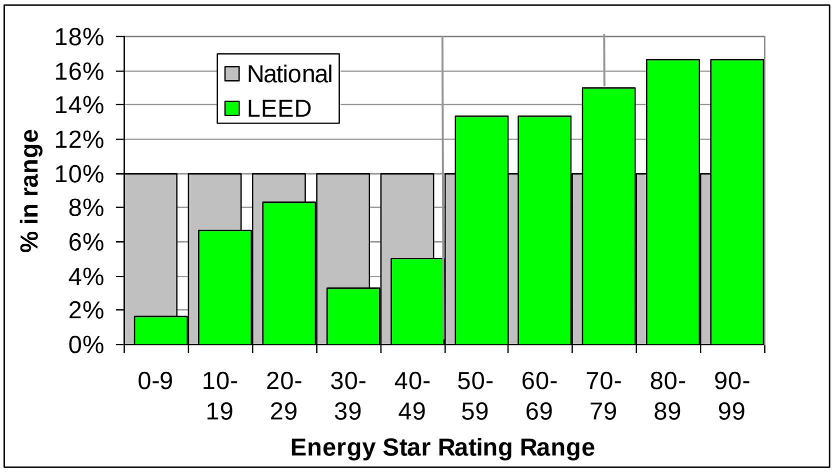


Figure 14: Distribution of LEED Building Energy Star Ratings

5.2.1 By Building Type

As seen in Figure 15 below, the wide range of ratings shown in the above graph does not seem to be a function of building type. There is a significant amount of scatter in the Energy Star ratings even within the office building type alone, which comprised over half the buildings eligible for Energy Star ratings. This category displays nearly as much spread in ratings as the entire group. Table 4 in the appendix provides more detail on the range of performance by type as benchmarked through the Energy Star tool.

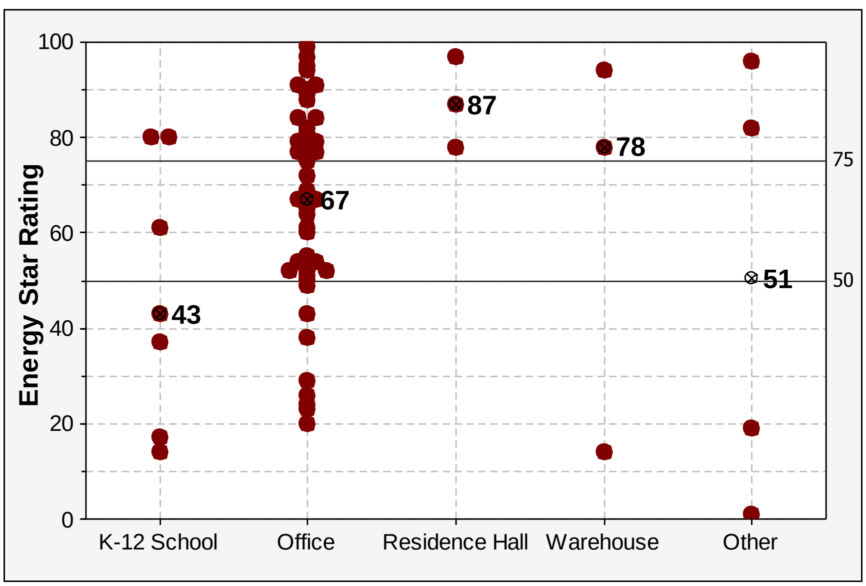


Figure 15: Energy Star Ratings by Type
"Other" includes types with only 1 or 2 buildings

5.2.2 By Energy Optimization Credit Level

Median Energy Star ratings increase for buildings with higher levels of LEED energy optimization points (EAc1), seen in Figure 16. Again, there is a great deal of variability in individual results. While beyond the scope of this study, further investigation of the best practices of highly rated buildings and explanations of those at the other extreme could support improvement of future program performance.

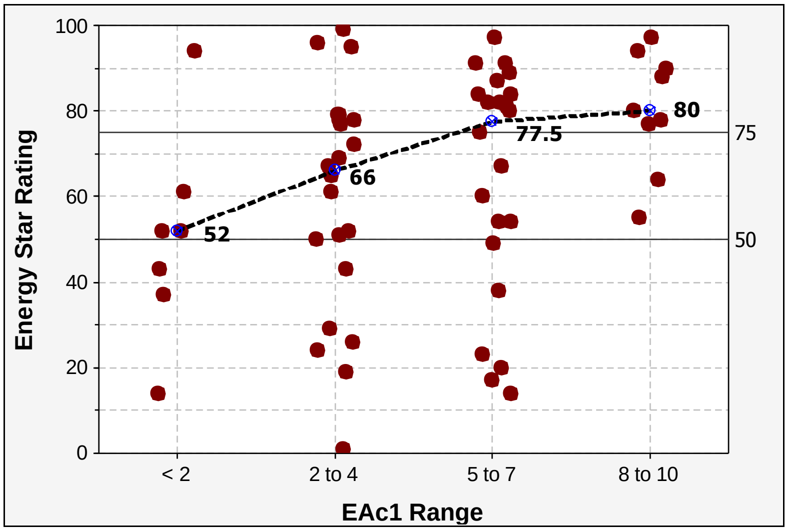


Figure 16: Energy Star Ratings by EAc1 Range

5.3 LEED Measured Performance Relative to Modeling

For the majority of the Medium Energy Type buildings (71), USGBC provided energy modeling data from the information originally submitted by the project to document LEED achievement. This section compares the design intent shown by that data to measured performance. The following definitions are used for this study:

- Proposed savings = $\dfrac{\textit{modeled baseline EUI} - \textit{modeled design EUI}}{\textit{modeled baseline EUI}}$
- Measured savings = $\dfrac{\textit{modeled baseline EUI} - \textit{measured EUI}}{\textit{modeled baseline EUI}}$

To facilitate comparison among projects, the savings amounts are often expressed as a percentage of the modeled baseline. Modeled values are further described in Appendix A: Study Background.

Energy modeling tools, which predict building energy performance, both for projecting actual energy use and for comparing use among alternative design options, are used throughout the design industry. The accuracy of modeling is limited not only by the inherent complexity of buildings, but also by variation in operational factors such as building schedule and occupancy, internal plug loads and weather. Therefore, most professionals in the energy modeling industry are careful to adopt caveats in their predictions or emphasize that modeling is a tool to identify relative energy performance, not to predict actual energy use. Despite these caveats, modeling is widely used to estimate actual future energy use. For example, utilities and code jurisdictions across the country use energy modeling to predict system loads and energy savings associated with specific building performance measures. Individual projects routinely use energy model predictions as a basis for life-cycle cost comparison of alternative construction methods. In this latter case, the cost-benefit calculation is based on specific predictions of actual energy savings in relationship to the fixed initial cost of the efficiency measure; thus the accuracy of the total building prediction becomes inherent in the analysis. Therefore, the predictive accuracy of energy modeling in terms of both relative and actual energy performance becomes critical to the building industry.

This study includes a relatively large sample of buildings with both measured and predicted energy use data. The following sections describe the findings of various comparisons of predicted and measured savings percentages relative to a code baseline and of predicted and measured total energy usage levels.

5.3.1 Program-Wide Predictions

From a policy and planning perspective, program managers at USGBC and various utility and power planning agencies are interested in whether program-wide savings from conservation programs can be predicted and verified. This information is critical to policy and planning for utility load growth and public policy development on energy. To identify program-wide modeling accuracy, the ratio between actual and design EUI was evaluated across the sample.

Figure 17 shows the ratio between measured and design (predicted) EUI by LEED certification level for these projects. Although there is a good deal of spread in the data, the average modeling accuracy in the program is quite good. If all achievement levels are combined, the ratio for the entire sample is 92%. (Note that high energy use buildings are excluded from this analysis; see discussion on pages 15 and 28.)

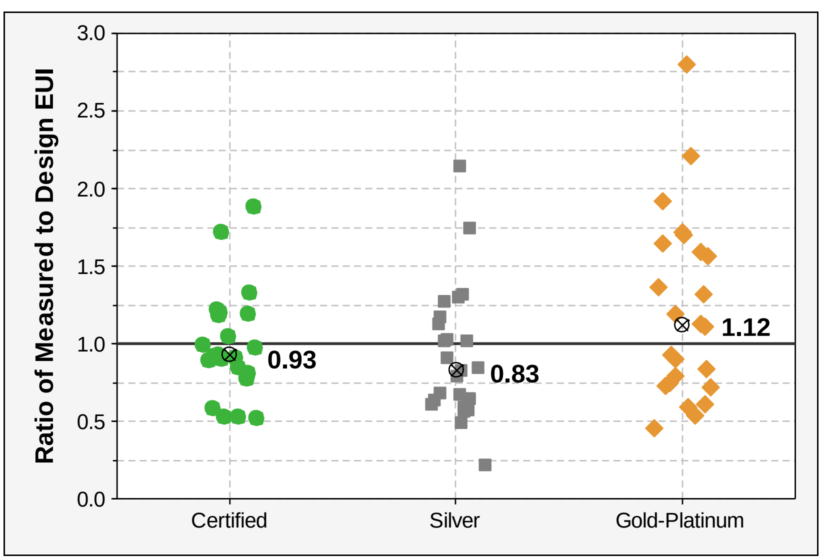


Figure 17: Measured/Design EUI by LEED rating level, with Medians

Likewise, the data in Figure 18 suggests that program-wide predicted relative savings is aligned with the average actual savings outcome of the sample. This figure indicates actual building energy savings (relative to the code baseline) is 28%, close to the average predicted relative savings of 25%. This median savings level is also very near the simple 24% median savings calculated by comparing the LEED sample to the existing building stock on the basis of CBECS EUIs.

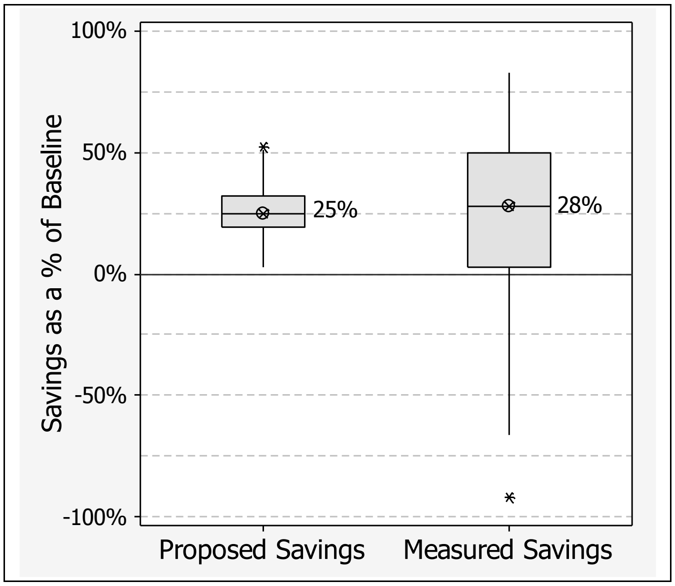


Figure 18: Proposed and Measured Savings Percentages
Boxes show the range of values between the 75th and 25th percentiles

This data suggests the LEED program is not only able to demonstrate significant savings on average but that it is also possible to make projections of total program savings based on program-wide energy modeling results. This finding is a key validation of the effectiveness of the LEED program in delivering energy savings.

5.3.2 Project Specific Energy Performance

Measured and Design EUIs

From a project-specific prediction basis, the conclusions are quite different. Referring again to Figure 17, it is apparent that the ratio of actual-to-predicted energy use varies widely across projects, even within one LEED certification level. In other words, the accuracy of individual energy use predictions is very inconsistent. An alternate view of this same data is provided in Figure 19, which shows the actual/design EUI ratio on the vertical (y) axis, where a value of one represents a project that accurately predicted measured total energy use. The horizontal (x) axis shows design EUI. The ratios (y-axis) on this graph show quite a bit of scatter, ranging from less than 0.5 to more than 2.75. In the former case, the project uses less than half the energy predicted by the modeling, while in the latter case the project uses nearly three times as much. (Results from a similar analysis of high energy building types show even less correlation between predicted and actual outcome, as described in section 5.4.) On an individual project basis, this suggests energy modeling is a poor predictor of project-specific energy performance. Measured EUIs for over half the projects deviate by more than 25% from the design projections, with 30% significantly better and 25% significantly worse.

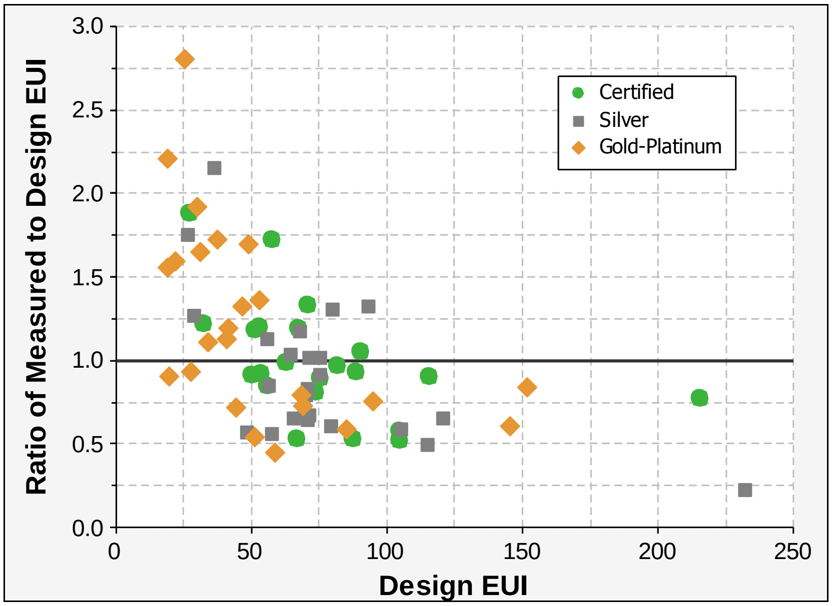


Figure 19: Measured/Design Ratios Relative to Design EUI

Clearly this range of accuracy for energy modeling has the potential for significant adverse impacts on design decision-making, which evaluates alternate energy efficiency strategies based on predicted actual energy savings and life-cycle cost analysis. This also suggests an area of further study and work, which was outside this study scope, to investigate reasons for substantial underperformance. The potential to better align predicted and actual energy outcomes would yield significant benefits to the building industry. A follow-up study to explore specific reasons for exemplary and under-performance is anticipated.

Measured and Proposed Savings

The conclusions are similar for relative *savings* predictions on an individual project basis. Referring to Figure 18, a range of outcomes is again apparent. Fully 25% of the buildings show savings in excess of 50%, well above any predicted outcomes, while 21% show unanticipated measured losses, i.e., measured energy use exceeding the modeled code baseline. More detail on this outcome can be seen in Figure 20, which compares energy savings proposed in the energy model (horizontal axis) with actual savings (vertical axis), all relative to the code baseline developed for each project. Projects that fall on the diagonal line in the top half of the graph demonstrate actual savings that align with predicted savings. Projects above this line save more energy than expected, while projects below save less. Also shown is a horizontal line at zero measured savings. Projects which fall below this line are actually using more energy than was predicted for the code baseline building. Again, the degree of scatter of individual project data recommends caution when using energy modeling as a predictive tool on an individual project basis.

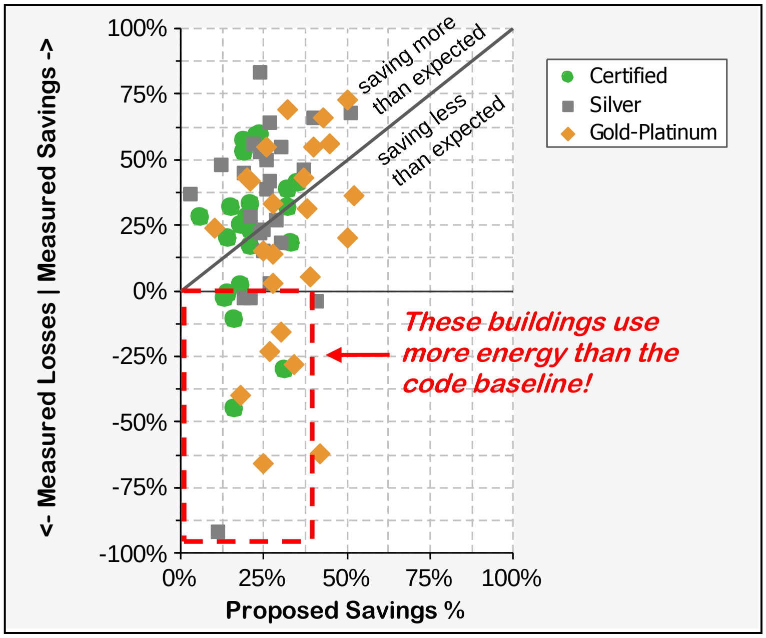


Figure 20: Measured versus Proposed Savings Percentages

The wide range of measured savings is related to a lack of correlation between measured EUI and initial proposed EUI, as displayed in Figure 21. Interestingly, while the measured *savings* are much more widely spread than proposed savings, the measured *EUIs* are actually more tightly grouped than the initial design EUIs. This suggests some component of modeling inaccuracy is related to uncertainty about typical building operating characteristics. Note that buildings with design EUIs below about 40 kBtu/sf (outlined by the red solid rectangle in the figure) tend to have measured results exceeding the design estimate. On the other hand, buildings with design EUIs above about 90 kBtu/sf (outlined by the dotted green rectangle) tend to have measured EUIs lower than the design estimate. Stated differently, projects with more aggressive energy performance goals seem to generate overly optimistic predictions of actual energy use, while higher energy use projects seem more likely to overestimate actual energy use.

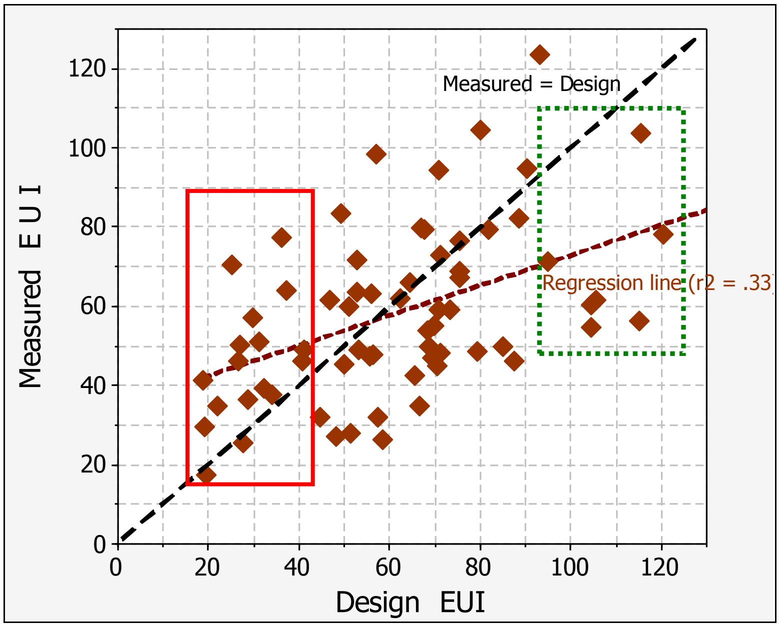


Figure 21: Measured versus Design EUIs (kBtu/sf)

5.3.3 Baseline

A critical component of this evaluation is the code baseline to which projects are compared when predicting relative savings. LEED requires projects to generate a code baseline building using the ASHRAE 90.1 standard. The percentage by which project design exceeds the performance requirements of this standard (uses less energy) determines the number of LEED points achieved in Energy and Atmosphere credit 1, with up to 10 EAc1 points available for projects exceeding the baseline by 60% or more. (One additional point, for a total of 11, can be achieved in the Innovation category of LEED for substantially exceeding the 60% target of EAc1.)[8]

Although there is no way to verify the accuracy of code baseline energy use projections, the range of accuracy of the predicted energy use calculations suggests that baseline calculations are also subject to a level of uncertainty. Nevertheless, an analysis of baseline performance data suggests some interesting issues with respect to the use of modeling for the LEED program and for general planning and goal setting for efficiency and carbon reduction programs.

Baseline Variability by Project Type

Like the predicted energy use values, the code baseline EUIs demonstrate significant variability, even within individual building types. Figure 22 shows the code baseline values generated from the initial modeling in the LEED sample by project type. Office buildings, the most common project type in the sample, provide a good example of this. Modeled code baseline EUIs for office projects range from about 35 kBtu/sf/yr to over 155 - a factor of four variability within a single project type! The submittal data reviewed for this study is not detailed enough to identify the key variables that generate this diversity, but one key factor in this variability was eliminated:

[8] As noted in Appendix A, nearly all of the projects in this study used the 1999 version of ASHRAE 90.1

Unregulated loads were fixed at 25% of total baseline energy for all projects in the study. (While actual variability in unregulated load consumption may contribute to the range of actual energy use seen in the study, using a fixed percentage for these loads in baseline and predicted usage calculations reduces variability in the modeling predictions. Unregulated loads are further discussed in Appendix D: Plug (Process) Loads.

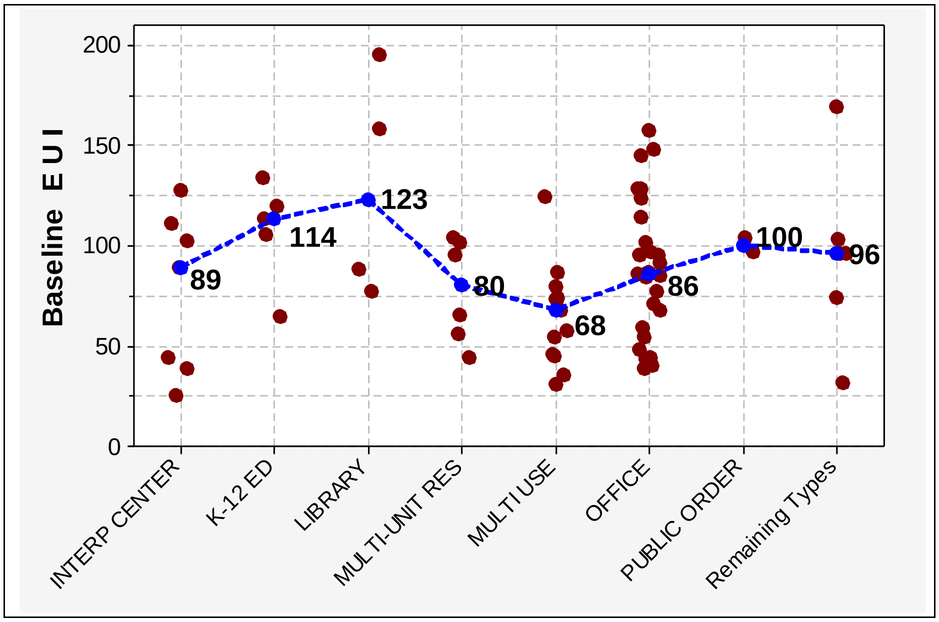


Figure 22: Baseline EUIs (kBtu/sf) by Type

The variability of predicted energy use within and among building types for the code baseline has significant implications for utilities and regional utility planning organizations that use ASHRAE 90.1-derived energy codes as a regional baseline in predicting and planning for energy supply needs.

Baseline Variability by LEED Level

Figure 23 demonstrates another interesting characteristic of the baseline performance levels generated by the 90.1 standard. Projects that set higher energy performance targets seem to be held to a higher baseline standard from which to measure improvement. Projects achieving Gold and Platinum LEED certification levels on average identified a significantly lower EUI "allowance" for the code baseline than did Certified and Silver projects. (Note that LEED achievement level correlates more or less directly with increased energy performance targets, as discussed in the initial results section on Energy Use Intensities.)

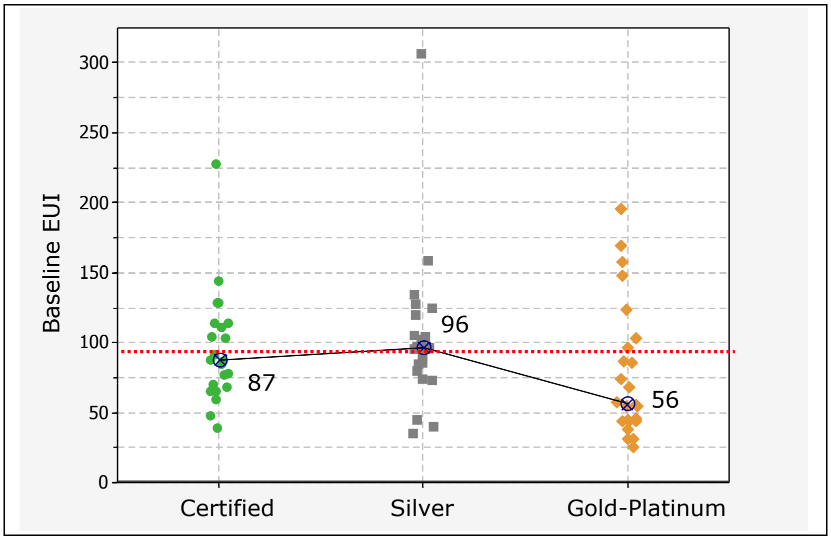


Figure 23: Baseline EUIs (kBtu/sf) by Level

The data itself does not suggest why more aggressive energy performance targets would result in more stringent code requirements for these projects. However, design professionals familiar with the "system map" used in the energy modeling protocol of ASHRAE 90.1 might recognize that initial system selection for the project sets up differing performance requirements for the baseline building. For example, projects that anticipate the use of a ground-source heat pump system must compare to a more efficient code baseline system than projects using an air-cooled system. For projects targeting less aggressive energy performance, this protocol may represent a disincentive for the adoption of more efficient mechanical systems in the context of LEED or other energy incentive programs based on 90.1 modeling.

Performance Levels Implied by Code Baseline

One of the most surprising findings in this study is the relationship between the EUI identified by LEED projects for the code baseline and the average EUI of existing commercial building stock as identified in CBECS and shown in Figure 24. For all project types where the LEED designations align with CBECS project type definitions, the buildings in the LEED sample identified average code baseline performance targets near or above the energy use of the existing building stock. In Figure 24, the mean value for the baseline performance target of LEED office buildings is within 5% of the national building stock. For schools, the mean code baseline value is actually well above national average energy use intensity for school buildings. These energy use code baseline targets, generated with 90.1 by practitioners all over the country working on some of the most advanced buildings being developed, might be considered representative of the stringency of the 90.1 energy standard

This information has significant implications for policies and programs that use ASHRAE 90.1-1999 as a baseline for driving increasing levels of building performance/carbon reduction and suggests the relationship between the stringency of this standard and standard (unregulated) building practice needs significant further study and calibration.

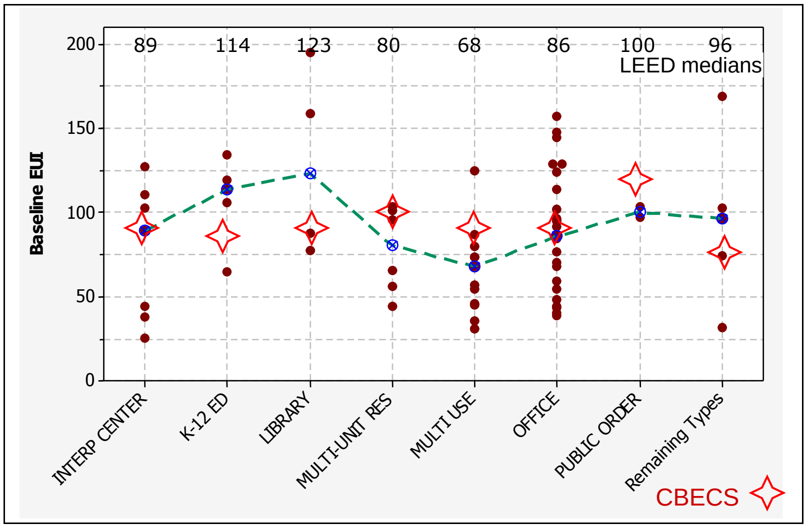


Figure 24: Baseline EUIs (kBtu/sf) by Type, with CBECS Averages

Table 5 in the Appendix shows median values by type for measured and modeled EUIs and for several key ratios among those variables.

5.4 A Note on High Energy Use Building Types

The bulk of this study, including the above findings focus on "medium energy use buildings," as described in the section on Energy Use Intensities above. However, some analysis of the characteristics of "high energy use buildings" was also conducted. These types primarily include data center and lab uses. A key finding on these projects is demonstrated in Figure 25, which shows that alignment between predicted and actual energy use for the high energy buildings is very poor, even on average. In fact, on average these buildings use nearly two-and-a-half times as much energy as was predicted during the design phase.

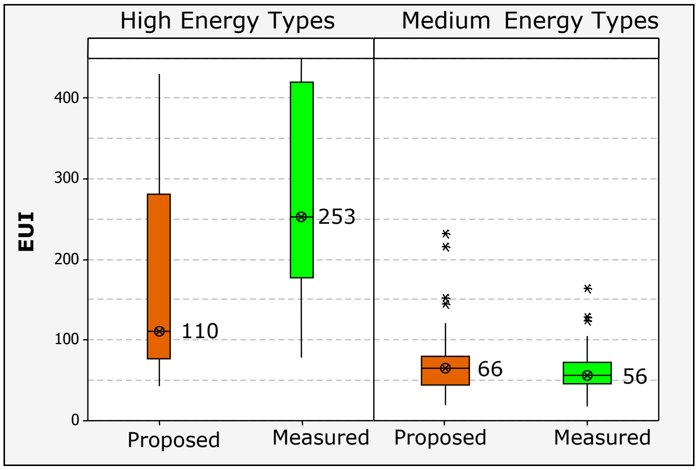


Figure 25: EUIs (kBtu/sf) for High and Medium Energy Type Buildings
Boxes show the range of values between the 75th and 25th percentiles. Labeled center lines show median value.[9]

[9] Median measured EUI shown here differ slightly from those in Figure 8 because the latter included all participating studies while the figure above is restricted just to buildings with available modeling information for comparison.

This discrepancy suggests the actual performance characteristics of these building types are not well understood by the design community. This has significant implications on any life-cycle cost analysis that might have formed the basis of design decisions on cost-effective systems, operating budget predictions, system sizing, load planning and a host of other issues. It is clear there is a need for significant additional research into the performance characteristics for these building types and for direct feedback to the design and owner community. The data also suggests LEED may need to re-evaluate how these project types are treated with respect to energy performance achievement.

6 Related Credit Analysis

Another goal of this study was to explore the relationship between LEED credit achievement patterns and actual energy use. The correlation between achievement of LEED EAc1-energy performance and increasing levels of building energy performance has already been discussed. But what relationships are suggested between other LEED credits and building energy performance? This question was explored for four LEED credits with logical relationship to energy performance levels: EAc3 Additional Commissioning; EAc5 Measurement and Verification; and EQc8.1 and 8.2 Daylight and Views.

Figure 26 compares the actual savings between LEED buildings that achieved each of the above-listed credits and those that did not (non-achievement is designated by a 0; achievement is designated by a 1). The large dots on the graph represent the mean value of actual savings for each column.

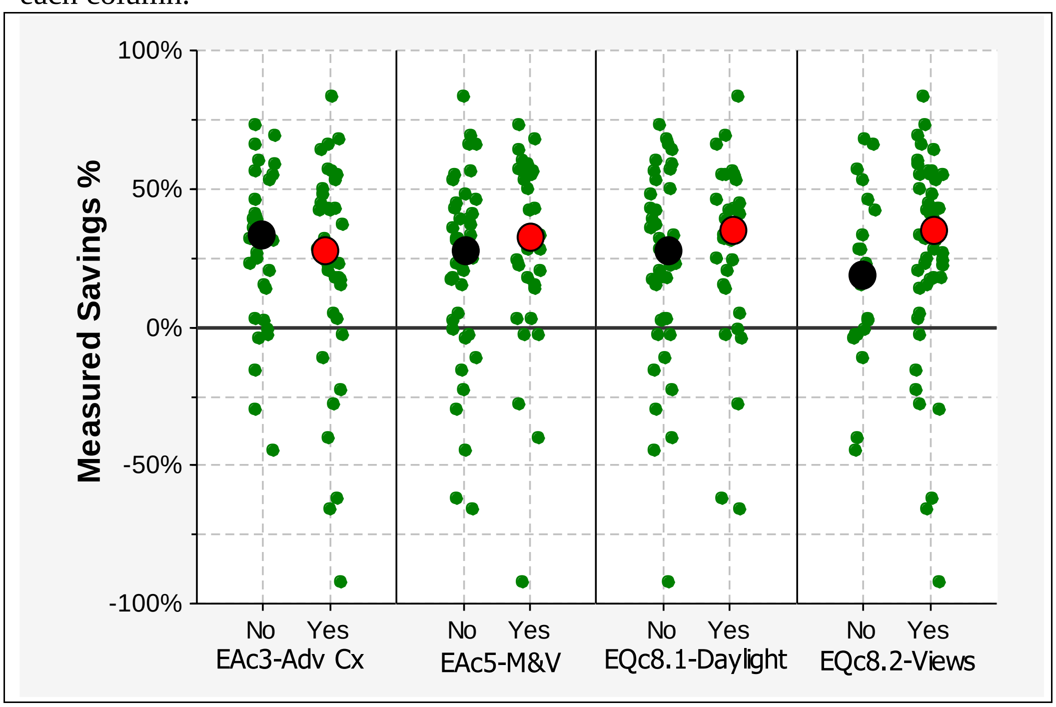


Figure 26: Measured Savings and Related Credits

This sample shows little conclusive impact on energy performance associated with achievement of these credits.

EAc3 Additional Commissioning: It is important to keep in mind that basic commissioning is a LEED prerequisite for all buildings, so the additional commissioning credit represents primarily the impact of commissioning agent design reviews before the construction document phase of the project; the gist of the credit requirement. The lack of a clear performance impact from achieving this credit says nothing about the value of the basic post-construction commissioning.

EAc5 Measurement and Verification: The data reveals no impact on building performance from achievement of the M&V credit. Of note is the fact that although over 40% of the projects in the sample had achieved this credit, and all of the projects had been operational for at least a year, only three participants provided information generated by the M&V process as part of their actual performance documentation.

In the case of the M&V credit, the findings of this study suggest there is a significant missed opportunity for LEED to design this credit in a way that provides useable, ongoing data to the projects that achieve it. As currently designed, the credit requirements entail expensive data collection protocol and equipment, along with a detailed engineering review before any conclusions can be drawn. This level of expense and detail does not facilitate review and use of ongoing performance data by most building operations staff.

EQc8.1 Daylight: The lack of correlation between achieving the daylight credit and improved energy performance in this sample could be related to the fact that credit achievement may entail an increase in window area but does not require the installation of any lighting control system to take advantage of the increased daylight availability and thereby reduce energy use.

EQc8.2 Views: The final credit reviewed showed the largest increase in average energy savings, although still with too much scatter for statistical credibility. The requirements of the view credit have almost no direct relationship to energy, but rather prescribe that 90% of occupied spaces in the building have access to views of the outside through glazing. Perhaps the building configuration impacts of the implied occupant layout may affect daylight availability enough to generate lighting savings from that availability, however this conclusion is speculative.

For these LEED credits clearly intended to improve building performance, the overall lack of correlation between credit achievement and actual savings represents a significant opportunity for LEED to modify them to more directly encourage better energy performance. Further refinement of code baseline modeling guidance may also permit more accurate evaluation of credit-to-performance relationships, since savings are measured as a percentage of the 90.1 modeled baselines.

7 Occupant Survey Results

To provide a more complete view of building performance, participating owners were given the opportunity to survey the perceptions of occupants. Results of these surveys demonstrate whether a high performance building is both energy efficient *and* a contributor to employee productivity. This systematic approach can provide more complete input than simply relying on anecdotal comments or complaints. Further, for buildings that may have problems in some areas, survey results can often help identify the appropriate areas for further investigation.

The brief online survey used, modeled after *Buildings In Use* work done by Jacqueline Vischer (Vischer and Preiser, 2005), asked occupants to rate the key functional comfort areas of acoustics, lighting, temperature and air quality, as well as the overall building. Individual questions within each of category were answered on a 5-point scale, from most comfortable to most uncomfortable.

Figure 27 displays, for each comfort dimension, the average comfort rating for each of the surveyed buildings (green diamonds). A rating of zero is a neutral response, neither comfortable nor uncomfortable. The red arrows show the average normative scores from typical buildings within the 1000-plus cases reviewed under the *Buildings In Use* (BIU) program.

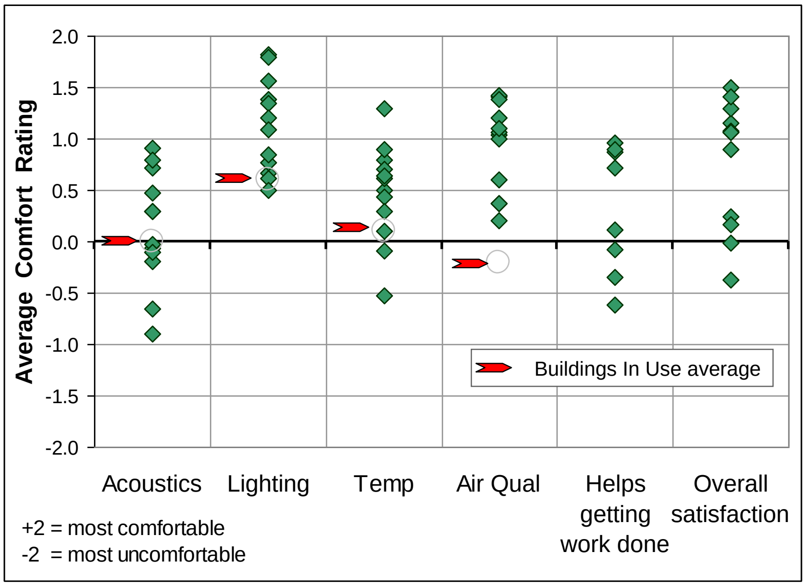


Figure 27: Occupant Comfort Ratings
(BIU averages available only for individual comfort dimensions, not the overall summary metrics)

For each dimension, the majority of LEED building ratings were positive and exceeded BIU normative scores. The lowest rated area, averaging neutral for both LEED projects and all buildings, was acoustics. Such results are typical for office occupant surveys, and often felt to be a result of open office floor plans, common in green and non-green buildings alike.

8 Conclusions and Recommendations

1. **On average, LEED buildings are delivering anticipated savings**. The three views of building performance consistently show average LEED building energy use 25–30% better than national average, a level similar to that anticipated by LEED modeling. Average savings increase as performance goals increase with higher LEED certification levels. Gold and platinum buildings average EUIs are 45% better than non-LEED buildings. This approaches the interim goals of Architecture 2030.

2. **Within each of the metrics, measured performance displays a large degree of scatter, suggesting opportunities for improved programs and procedures**. Measured EUIs for over half the projects deviate by more than 25% from design projections, with 30% significantly better and 25% significantly worse. A handful of buildings have serious energy consumption problems. Statistically credible, precise quantification of LEED savings will first require narrowing this range of variability. A follow-up study of some of the good and poor performers could identify ways to eliminate the worst results and the lessons to be learned from the best.

3. **More feedback is needed between actual building performance results and design-phase performance predictions.** Although energy modeling is a good indicator of program-wide performance, individual project modeling predictions vary widely from actual project performance outcomes. This variability between predicted and measured performance has significant implications for the accuracy of prospective life-cycle cost evaluations for any given building. Better feedback to the design community is needed to help calibrate energy modeling results to actual performance outcomes. Follow-up investigation into the reasons for the deviations could help improve future modeling and benchmarking.

4. **Project types with high process loads are problematic.** Lab buildings use more than twice as much energy as expected. Energy use of high energy building types is not well understood by designers. Neither the LEED program nor the modeling protocol address these projects well.

5. **The Baseline performance standard used by LEED may not be delivering the energy savings anticipated in the industry.** Although the performance baseline used by LEED (ASHRAE 90.1) is generally assumed to deliver buildings with significantly higher performance than the national CBECS baseline, in this study the average performance of the code baseline buildings was close to the average performance of the national building stock. Like the measured and predicted building performance values, the baseline performance EUI's occupied a wide range, even within building types. Also, buildings targeting more aggressive energy performance tended to be compared to a more stringent baseline performance standard than were the more conventional buildings. These issues suggest the relationship between the stringency of the energy standard used by LEED and standard (unregulated) building practice needs significant further study and calibration.

6. **Continued improvements to the LEED program are suggested**. Improvements in LEED program quality control and follow-up are suggested to help encourage and maintain savings. Related LEED credits such as advanced commissioning and Measurement & Verification could be reworked to more directly contribute to better energy performance and provide more directly useful information to building owners and operators.

Appendix A: Study Background

Participant Recruitment

Of the 552 total NC v.2 buildings, 121 (22% of all certifications through 2006) are included in this study. Another 128 owners provided some response but did not meet the requirements for report inclusion for a variety of reasons, including:

- Inability to provide usage data for the LEED project. These were typically cases where 1) the building was part of a campus that was metered only as a whole, 2) the project was a building addition that was not metered separately from the previous space or 3) energy bills included significant outdoor energy (ball field lighting, etc.) that could not be accurately isolated and materially distorted results. Clearly one prerequisite for achieving useful performance feedback is the basic metering of each building.
- Building occupied less than one year.
- A decision not to provide the data, sometimes from a desire to fully complete current building tuning before sharing results.
- Data submitted but ultimately excluded as appearing incomplete or not directly comparable to the modeled LEED project.

Data Sources

Measured energy usage and basic building information was usually obtained directly from owners or managers, at the whole building, monthly energy bill level. To create the largest possible data set while avoiding requests from multiple sources to the same owner, we also include some data from prior studies and published reports.[10]   Of the 121 buildings, 75% provided new data directly for this study. Measured energy here refers to purchased site energy, excluding onsite renewables, for the most recent twelve months provided by the owner.

Energy Star ratings for eligible building types were obtained from EPA's Portfolio Manager. These ratings rank a building's energy usage relative to similar buildings across the country, normalized for weather, activity and other key operational characteristics. Site energy, by fuel, is converted to source energy for these calculations. Sixty of the participating buildings had activity types eligible for an Energy Star rating.

Design and Baseline modeled results came from USGBC files for the final LEED project submittals. Usable modeling information was available for 91 of the 121 participants. In the remaining 30 cases the original modeling could not be found or the recorded results were implausible (for example, expected EUIs below 5 kBtu/square foot), suggesting an error in unit reporting or other transcription problems.

Design and Baseline totals for modeled energy were adjusted to include an estimate of plug loads on a consistent basis. Treatment of plug loads in the original modeling varied widely, because of the historic lack of guidance in this area and the fact that LEED Energy Optimization credits are

[10] Prior published studies were Diamond et al, 2006, which included LBNL analysis of federal building data collected by DOE/FEMP, and Turner, 2006. Other data sources included Energy Star for currently labeled buildings, the Oregon SEED program, and an independently conducted data collection.

calculated from regulated (non-plug) loads. For a better comparison with measured whole-building usage, and for greater consistency with current LEED guidelines, modeled plug loads were included for *all* buildings at the level of 33% of modeled baseline regulated usage (25% of the resulting baseline total usage). See Appendix D for further discussion.

Nearly all the participating projects used the 1999 version of ASHRAE 90.1. Because ASHRAE 90.1-2004 and California's Title 24 apply different performance standards, buildings modeled to those levels (5 of the total) were excluded from aggregate summaries including modeling.

Caveats

Submitted energy and building information was reviewed for reasonability, but not audited or otherwise verified for accuracy and completeness. Procedural checks included:

- Asking for fuels used for each major end use, and questioning missing data if no billings were provided for some fuels mentioned here.
- Asking for space usage by activity, number of tenants, and whether tenants paid bills directly. In a few cases, small retail space was excluded from both square footage and measured energy use, when separately paid bills were not available for that space.
- Questioning preliminary results with very low or very high EUIs
- Sending draft individual building reports to each owner for comment or correction, along with specific questions when key information appeared missing or inconsistent.

The Energy Star rating system was updated October 1, 2007, to reflect the most recent CBECS survey results and refined calculation methodologies. All ratings reported in this study were calculated *before* this revision. Anticipated changes to individual ratings from the new methodology were small. The difference would not be expected to affect any overall conclusions of this study, although results for individual buildings may vary slightly.

Initially modeled results were not calibrated for differences between design assumptions and actual as-built and occupied conditions. Differences may arise in areas such as materials and systems, occupancy levels and schedules, weather and operating procedures. Thus, comparisons of measured to modeling are at best rough indicators of performance in relation to expectations. This summary provides a basis not previously available for further investigation and refinement of modeling protocols, to better align expected and actual performance.

Even with over 120 participating buildings, the data volume can be insufficient for statistically credible differences when subdivided among multiple variables. Thus, many results presented should be considered as approximate and suggestive of areas for further exploration, not as precise performance levels. Expanded performance measurement is needed to refine these results and clarify some of the questions raised by this initial data.

Use of Averages

Medians, denoting the level at which half the observations are higher and half are lower, are used throughout this report to reflect the average results of the LEED buildings. The median is appropriate to reflect the average for small sets of widely scattered results, as is true for several of the subset views presented here. It is less skewed by extreme results than are mean averages (which are calculated as the total of all observations divided by the number of observations). Comparing these study medians to the *mean* averages published for the CBECS database, creates one imprecision in the quantitative savings estimates here.

Appendix B: CBECS Results

By Building Type

Table 1 in Appendix C shows the distribution of building types in this study, based on the types originally specified in the LEED submittal, clarified when applicable with further information. Because these type categories are often not directly comparable to individual CBECS categories, accurate comparison of type distribution is difficult. In general, this study had a higher percentage of office buildings than CBECS (29% versus 18%), about the same percentage of K-12 schools, and a higher percentage of labs and data centers. The "other" plus labs subcategory in CBECS totals less than 3% of all buildings. That group includes, but is not limited to, labs and data centers. In this study, on the other hand, labs and data centers constituted 13% of all participating buildings. [The term "data center" was used broadly here to include all building types with very high computer activity around the clock.] At the other extreme, overall CBECS averages also include vacant buildings and very low energy users such as self-storage facilities (with a combined total of 8% of all buildings), none of which are have counterparts in the participants of this study.

CBECS Results by Year of Construction

All buildings in this study were constructed (or renovated) after 2000, which suggests comparing their performance with *recent* construction from the CBECS study rather than *all* construction. The comparison to all vintages of buildings was chosen because of the lack of a strong CBECS pattern of lower use in newer construction, and because of the relatively small amount of data specifically for 2000 and later buildings in CBECS.   Figure 28 displays the average EUIs from the last four CBECS studies, with results of each subdivided by construction period. With the possible exception of 2000-2003 construction, newer buildings do not display average usage notably lower than the overall average.

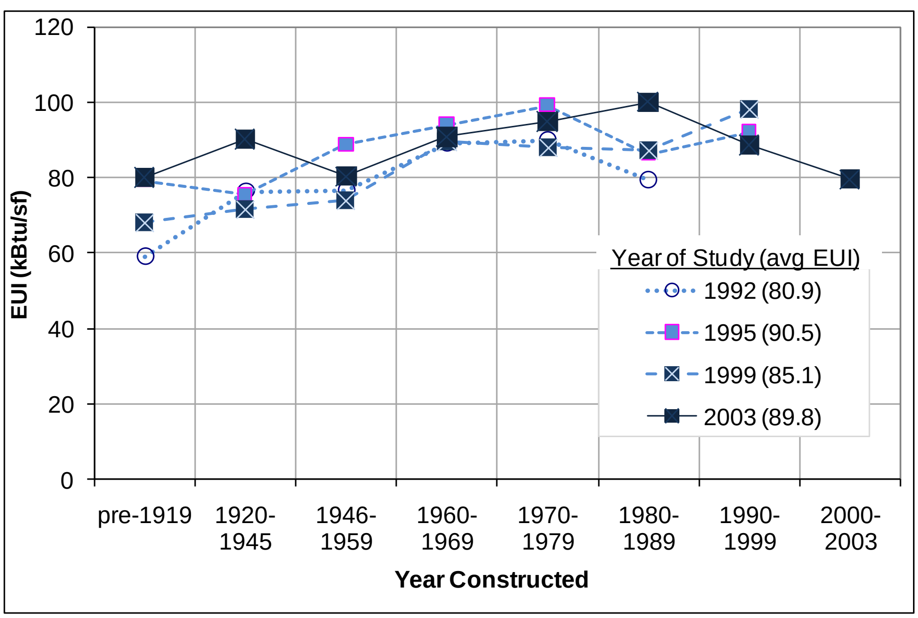


Figure 28: CBECS EUIs by Year of Survey and Year of Construction

The 2000-2003 subset from the latest survey is a small sample for a good comparison basis, with only 410 total observations across all national building stock (8% of the entire survey). Expanding the "recent" construction basis to everything 1990 and later produces overall averages close to all years of construction. As seen in Figure 29, when divided by building type, the 1990 and later CBECS EUIs are sometimes a little lower and sometimes noticeably higher than the averages for all vintages combined.

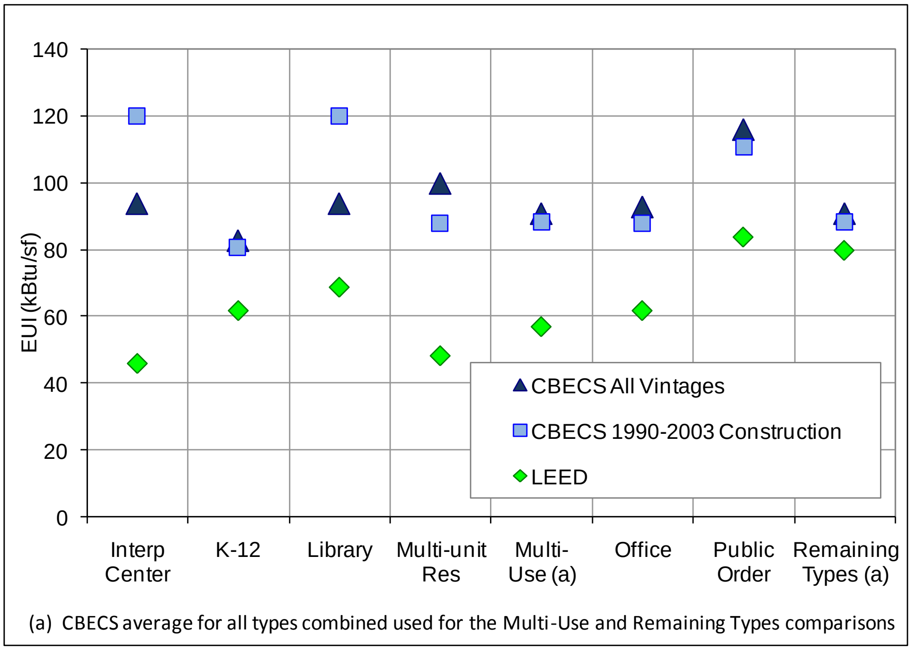


Figure 29: LEED and 2003 CBECS EUIs by Activity Type and Vintage

Appendix C: Detail Tables

Table 1: Participant Counts by Type, Modeling and Energy Star Availability

Activity Type	Total	With Modeling	With Energy Star	With Both
Medium Energy Use Activities				
Interpretive Center	9	7	0	0
K-12 Ed	7	5	7	5
Library	4	4	0	0
Multi Use	18	13	10	7
Multi-Unit Res	6	6	3	3
Office	35	27	33	26
Public Order	5	2	1	1
Remaining Categories*				
Assembly	2	0	0	0
Higher Ed	3	1	0	0
Hotel/Resort	1	0	1	0
Industrial	1	1	1	1
Restaurant	1	0	0	0
Retail	1	1	0	0
Transportation	3	1	0	0
Other	4	3	1	1
Remaining Category Total	*16*	*7*	*3*	*2*
Medium Energy Type Totals	***100***	***71***	***57***	***44***
High Energy Use Activities				
Data Center	6	4	0	0
Health Care	1	0	1	0
Lab	10	9	0	0
Recreation	2	1	0	0
Supermarket	2	2	2	2
High Energy Type Totals	***21***	***16***	***3***	***2***
All Participants	**121**	**86**[11]	**60**	**46**

* Remaining categories include all medium energy types with 3 or fewer participating buildings

[11] Figure 2 showed a total of 91 buildings with modeling. The total of 86 in this table excludes 5 buildings that modeled based on the higher standards of Title 24 or ASHRAE 90.1-2004. As noted earlier, that modeling was excluded from modeled results analysis for greater consistency of assumption basis.

Table 2: LEED and CBECS EUIs (kBtu/sf) by Type

	N	Measured EUI	CBECS (a)	LEED / CBECS
Interpretive Center	9	46.2	94	49%
K-12 Ed	7	61.7	83	75%
Library	4	68.0	94	73%
Multi-Unit Res	6	48.8	100	49%
Multi Use (a)	18	57.3	91	63%
Office	35	62.0	93	67%
Public Order	5	84.0	116	72%
Remaining Types (a)	16	79.6	91	88%
All Medium Energy Types	100	**61.9**	**91**	**28%**
Data Center	6	216	164	132%
Health Care	1	238	188	127%
Lab (a)	10	284	356	80%
Recreation	2	126	164	77%
Supermarket	2	225	200	112%
All High Energy Types	21	238		
ALL	**121**	**69**	**91**	**76%**

(a) CBECS average for all types used for Multi-Use and Remaining Types categories. Labs21 Average used in place of CBECS for Labs.

Table 3: EUI Ranges (kBtu/sf) by Type, all buildings

	N	Minimum	25th Percentile	Median	75th Percentile	Maximum
Interpretive Center	9	26	33	46	87	124
K-12 Ed	7	43	46	62	77	77
Library	4	35	40	68	86	88
Multi-Unit Res	6	32	42	49	52	55
Multi Use	18	18	35	57	66	106
Office	35	27	50	62	84	144
Public Order	5	79	79	84	120	129
Remaining Medium Energy Types	16	30	64	80	121	165
All Medium Energy	**100**	**18**	**47**	**62**	**82**	**165**
Data Center	6	78	138	216.2	519	555
Health Care	1	237.9	*	237.9	*	238
Lab	10	172.6	200	283.8	465	674
Recreation	2	39.6	*	125.5	*	211
Supermarket	2	215.4	*	224.7	*	234
ALL	**121**	**18**	**49**	**690**	**105**	**674**

* Too few data points for quartile determination

Table 4: Energy Star Ratings by type, all buildings with ratings

	N	Minimum	25th Percentile	Median	75th Percentile	Maximum
Interpretive Center	0	*	*	*	*	*
K-12 Ed	7	14	17	43	80	80
Library	0	*	*	*	*	*
Multi-Unit Res	3	78	78	87	97	97
Multi Use	10	14	44.25	64	82	99
Office	33	20	52	75	84	97
Public Order	1	49	*	49	*	49
Remaining Medium Energy Types	3	19	19	64	95	95
All Medium Energy	**57**	**14**	**49.5**	**67**	**83**	**99**
Data Center	0	*	*	*	*	*
Health Care	1	1	*	1	*	1
Lab	0	*	*	*	*	*
Recreation	0	*	*	*	*	*
Supermarket	2	82	*	89	*	96
ALL	**60**	**1**	**49.3**	**68**	**83.5**	**99**

Table 5: Measured and Modeled Median EUIs (kBtu/sf) by Type:
medium energy buildings with modeling

	N	Measured EUI [(a)]	Design EUI	Baseline EUI	Measured / Design EUI	Measured Savings %	Design Savings %
Interpretive Center	7	46.2	51.2	89.2	0.93	33%	32%
K-12 Ed	5	61.7	75.3	113.5	0.65	48%	23%
Library	4	68.0	91.0	123.1	0.57	58%	25%
Multi-Unit Res	6	48.8	61.6	80.2	0.76	43%	26%
Multi Use	13	51.7	48.0	67.9	1.13	15%	24%
Office	27	60.5	64.5	85.8	1.02	28%	25%
Public Order	2	79.4	74.8	100.2	1.07	21%	26%
Remaining Medium Types	7	63.3	71.2	96.2	0.84	24%	25%
All Medium Energy Types	**71**	**56.3**	**65.6**	**86.6**	**0.92**	**28%**	**25%**

(a) The measured median EUIs here differ from those shown in Table 2 because this table includes only the 71 buildings with modeling, while Table 2 includes all 100 Medium Energy Type buildings.

Appendix D: Plug (Process) Loads

ASHRAE/IESNA Standard 90.1 is the basis for LEED modeling done for Energy Optimization (EAc1) points. In the LEED program versions in effect when this study's buildings were certified, EAc1 achievement was based on a subset of Standard 90.1 criteria related to building HVAC systems and lighting, and the USGBC characterized these in the LEED program as "regulated loads". The excluded or "unregulated" energy, also referred to as "process" energy, includes miscellaneous equipment, computers, elevators and similar items. This study uses the general term "plug loads" to refer to the entire category of process uses, which are primarily driven by the equipment and activities of those who work in the building, as opposed to the energy that maintains basic building comfort. In version 2.2, LEED required the inclusion of process loads in the energy performance calculation, at a default of 25% of total baseline energy. Although these loads are now eligible for inclusion in the total energy savings calculations, there is little good information or guidance provided about achieving unregulated load savings.

Previously completed LEED projects were unlikely to attempt any savings in the unregulated load category, and the basic assumptions about the percentage represented by unregulated loads in these projects varied widely. A July 2006 review of available energy modeling from 270 LEED projects showed less than half including any information on plug or miscellaneous loads. Those that did include this information displayed a wide range of assumed plug loads as a percentage of the total code baseline for the building (Figure 30).

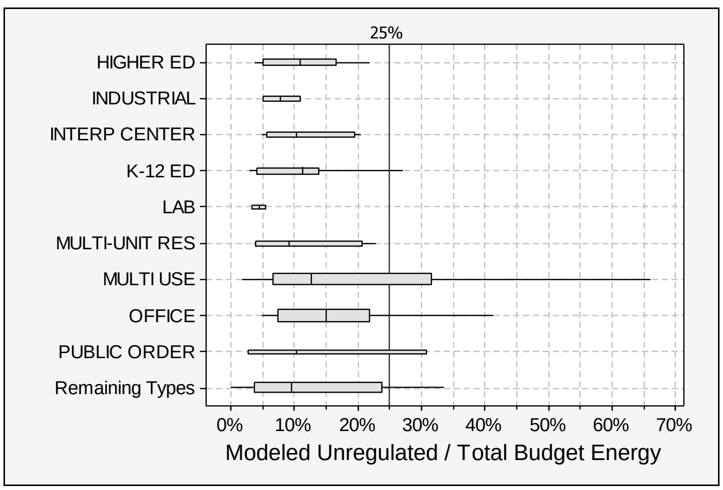


Figure 30: Plug Loads as a Percent of Total Baseline
From 2006 review of all LEED-NC v2 energy modeling
Boxes show the range of values between the 75th and 25th percentiles.

Note that most projects for which plug loads were modeled showed results below the 25% of total baseline assumed by current LEED instructions and ASHRAE 90.1-2004 Appendix G. For better consistency with these guidelines and among projects, the modeled Baseline and Design numbers in this study use, in all cases, the original modeling for regulated loads plus 25% of total baseline. Alternate approaches were considered, including using other percentages for plug load level, or estimating plug load only when the modeled estimate was missing. None of those alternates would have materially changed the overall conclusions of the study, and the approach taken provides the most consistent basis for comparison.

Appendix E: References

Diamond, R., Opitz, M, Hicks, T., Von Neida, B., Herrera, S., 2006, *Evaluating the Energy Performance of the First Generation of LEED-Certified Commercial Buildings*, ACEEE Summer Study on Energy Efficiency in Buildings

Energy Efficiency Administration, *Commercial Buildings Energy Consumption Survey (CBECS)*, http://www.eia.doe.gov/emeu/cbecs/

Turner, C., 2006, *LEED Building Performance in the Cascadia Region: A Post Occupancy Evaluation Report*, Cascadia Region Green Building Council, Portland, OR.

Vischer, J., Preiser, W., eds,, 2005, *Assessing Building Performance*. Elsevier Butterworth-Heinemann, Burlington, MA.