

How Accurate is Energy Modeling in the Market?

Mark Frankel and Cathy Turner, New Buildings Institute

ABSTRACT

NBI has recently completed a study of whole building energy use of over 120 completed LEED buildings nationwide. This paper presents an analysis of a subset of this research, focusing on the use of energy modeling as a predictor of building performance for this building sample. As part of this analysis, NBI reviewed modeling results for approximately 90 buildings that used the ASHRAE 90.1 Standard as a modeling baseline, and predicted building energy savings compared to this standard¹. An analysis of the baseline, predicted, and actual energy use for these buildings yields a fascinating set of data with significant implications on the use of this standard as a predictive tool and code baseline. The results of the analysis also impact ongoing national discussions about how the design industry can respond to the Architecture2030 challenge and other carbon reduction goals.

The data set has been analyzed in the context of building size, type, and climate, and the results suggest the need for modifications to energy code and regional load projection policy considerations, building life cycle cost analysis, and the practice of energy modeling. Areas of significant additional research topics are also indicated. The goal of this session is to present the results of this study, and to solicit an informed discussion of the far-reaching implications of the data.

Introduction

Study Description

This paper explores the relationships between predicted and actual energy performance of a set of approximately 90 buildings that have achieved a LEED Rating. In a study conducted for the USGBC, actual energy use data from one year of building operation was compared to energy modeling predictions generated as part of the LEED certification process. A larger study compares the energy use of LEED buildings to national benchmark data such as Energy Star and CBECS². This analysis focuses on a subset of these LEED buildings for which both actual energy use data and information from the energy modeling process was available. The goal of this analysis was to evaluate whether the energy modeling information generated as part of the LEED submittal process accurately predicted actual building performance. The analysis is not meant to address the technical capabilities or limitations of energy modeling as a tool.

Ninety-one buildings provided both metered energy use and energy modeling information for this study. Of these buildings, 20 were project types that are characterized by very high energy use, such as laboratory, data center, and health care projects. These ‘high energy use’ projects are analyzed separately from the main data set, which consists of projects more typically related to office-type uses, and referred to as ‘medium energy use’ projects below.

¹ *Energy Performance of LEED NC Buildings*, Mark Frankel and Cathy Turner, March 2008, USGBC.

² All CBECS (Commercial Building Energy Consumption Survey) data in this report is from the 2003 version of this information.

It should be noted that the building data sample was not randomly generated. All completed LEED buildings were asked to provide energy performance data. Approximately half of the buildings (~250) responded to the request. For a large percentage of the non-respondents, current building contact information was not available, and the data request may never have reached someone in a position to provide the data. Of the responding buildings, 120 were able to actually gather and provide energy use data. Inability to collect the data was the primary reason cited by projects that responded initially, but did not provide data. For 90 of the buildings that could provide energy use data, the LEED submittal files contained enough information about energy modeling to compare the results to actual outcome. Analysis of this subset is the basis of the observations in this paper.

Modeling Variables

A key goal of this study is to determine whether the use of energy modeling by design teams in practice (specifically for LEED in this sample) leads to information that accurately predicts project performance. This is not the same thing as identifying whether modeling tools have the technical capability to predict building performance. That question is outside the scope of this study.

In practice, energy modeling is based on a series of assumptions about building characteristics that are based on physical characteristics and anticipated use patterns. The validity of assumptions about building use patterns is the focus of follow-up work to this study currently underway. These assumptions represent limitations of the modeling data that was available to this project that should be kept in mind in the context of the comparisons below. Although these factors affect the accuracy of the modeling, in practice the lack of good data about these assumptions represent typical flaws in energy modeling as practiced across the industry, and are not confined to this analysis. In effect, the modeling data reviewed in this study was based solely on design-phase modeling predictions, rather than on energy modeling data calibrated to actual building operating parameters.

Unregulated Loads

The current LEED program (v2.2) requires projects to model unregulated loads (i.e. plug and equipment loads) at 25% of total energy use. This is a ‘rule of thumb’ requirement adopted by LEED to prevent ‘gaming’ of plug loads in total energy use calculations for LEED certification. The validity of this assumption is not the subject of this analysis. In reviewing LEED submittal data, projects which did not include plug loads, or which assumed plug loads significantly different from this level were eliminated from the analysis. In cases where plug loads in the energy model were within about 5% or less of the requirement, the plug load assumptions were changed to match the rule of thumb guidelines. This introduces an inaccuracy in the data, since the offset impacts of these loads on heating and cooling were not accounted for in this protocol.

Schedule

No attempt was made to align actual building operating schedule with the assumptions of the design energy modeling. This is an outcome of a calibrated energy modeling process, but is extremely rare in general practice.

Weather

The weather data used by the original modeling was not verified, or calibrated to the actual weather period from which the utility bills were provided.

These factors represent typical limitations of the energy modeling process as practiced in the design industry. It is certain that the variability in accuracy of energy modeling as discussed below is attributable in part to these factors.

Modeling Terminology

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 =
$$\frac{\text{mod eled baseline EUI} - \text{mod eled design EUI}}{\text{mod eled baseline EUI}}$$
- Measured savings =
$$\frac{\text{mod eled baseline EUI} - \text{measured EUI}}{\text{mod eled baseline EUI}}$$

To facilitate comparison among projects, the savings amounts are often expressed as a percentage of the modeled baseline.

Energy modeling tools are used throughout the design industry to compare energy use among various design options. The value of these tools to inform design comparisons is widely recognized, and there is little debate that the energy modeling tools in use today are generally able to accurately identify more effective design strategies from the perspective of *relative* energy use.

At the same time, energy modeling tools are often used to predict *actual* energy use of buildings. The output of energy models is expressed in terms of predicted energy use, and these predictions are therefore used to estimate total building energy use characteristics. Even project teams which are using the modeling tool primarily to compare *relative* energy performance of design alternatives typically express the comparison in relationship to predicted actual energy savings and measure cost, and this sets up an inherent prediction of actual building energy use in the comparison.

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, building system or equipment operating strategies, 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, planners at utilities and code jurisdictions across the country use energy modeling to predict system loads and energy savings associated with specific building performance measures. Utilities widely use energy modeling predictions as the basis for individual project incentives, or as a basis for alternative energy code compliance (such as the ASHRAE 90.1 ECB methodology used by the USGBC LEED program).

Individual projects routinely use energy model predictions as a basis for life-cycle cost comparison of alternative construction methods. 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.

Predicted Performance

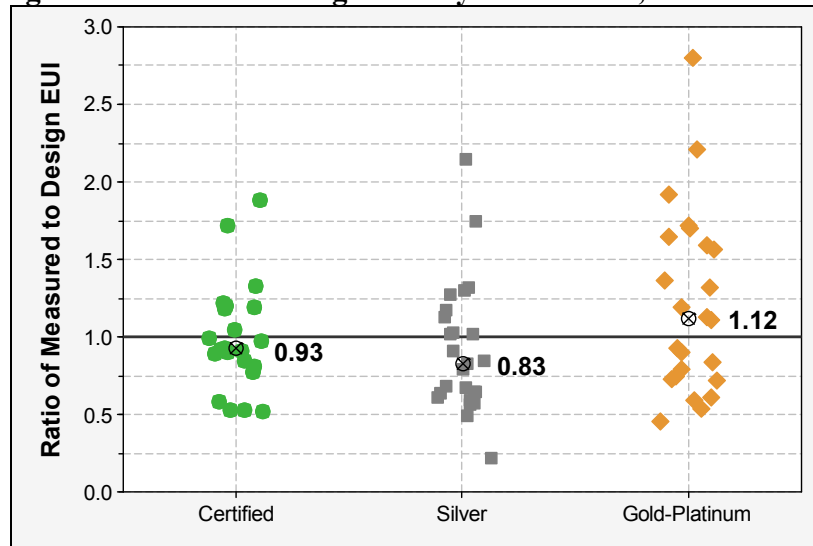
Program-Wide Predictions

The first metric is a comparison of predicted total energy use with actual total energy use for all of the buildings participating in the study. This comparison identifies how accurately the energy modeling used by the design teams predicted the total energy use of the sample on aggregate.

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 (measured) and design (predicted) energy use intensity (EUI, expressed in kBtu/sf/yr) was evaluated across the sample.

Figure 1 shows the accuracy of energy modeling for the sample of LEED projects analyzed, expressed as a ratio between measured and design EUI by LEED certification level. 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 this data represents only the ‘Medium’ energy use projects. ‘High’ energy use buildings are discussed in section 0 below.

Figure 1. Measured/Design EUI by LEED level, with Medians

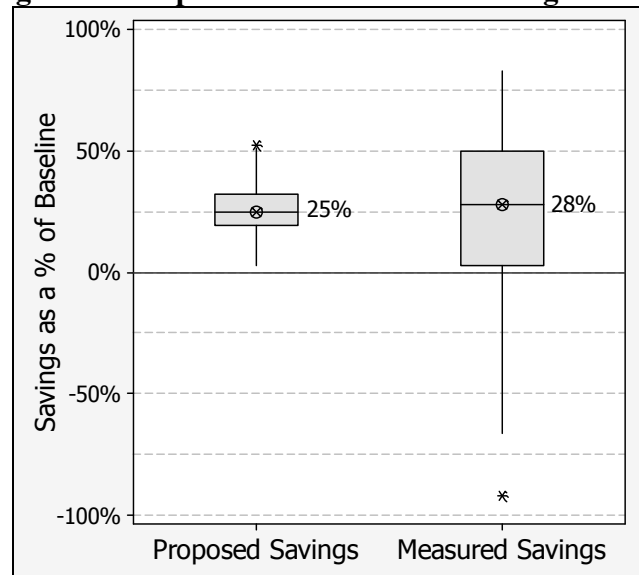


The basis for achieving energy performance points in LEED (EA credit 1) is a comparison of energy savings relative to a code baseline project developed in parallel by the design team as a basis for comparison. The code baseline used by LEED is the ASHRAE 90.1 Standard. The LEED buildings that participated in this study had been operating for at least a year, and almost exclusively used the 2001 version of the ASHRAE standard as a basis for comparison.

The second metric shown is a comparison of the accuracy of the average savings percentage across the sample, relative to the code baseline. Figure 2 shows that actual the actual savings outcome for the projects, based on operational data, was much more spread out than predicted performance, but on average was very close to, and slightly better than, predicted savings. In other words, from a program-wide standpoint overall modeling predictions were a good representative of actual program savings. The implications of the data variability will be discussed below.

One important note is that the actual measured average savings compared to code of 28% is very close to the savings of the larger sample relative to national performance data in the Commercial Building Energy Consumption Survey. Overall, the LEED building stock represented by this sample demonstrated an average EUI that was 24% better than the CBECS average EUI.

Figure 2. Proposed and Measured Savings Percentages



Boxes show the range of values between the 75th and 25th percentiles

Project Specific Energy Performance

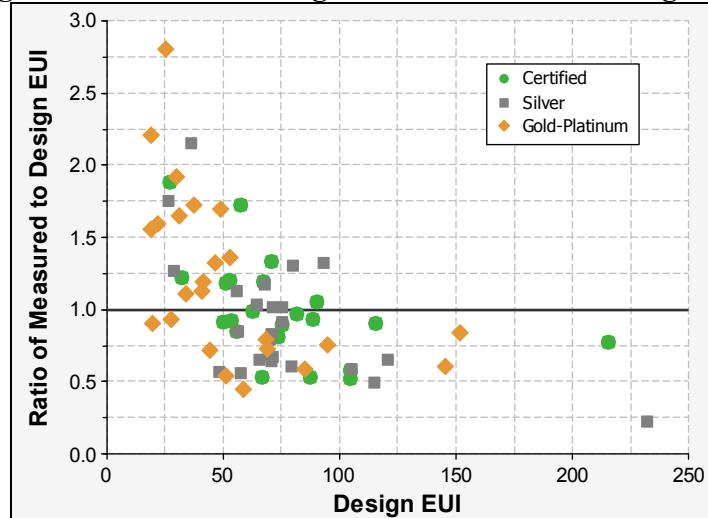
Measured and Design EUIs

From a project-specific prediction basis, the conclusions are quite different. Referring again to Figure 1, 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 project energy use predictions is very inconsistent. An alternate view of this same data is provided in Figure 3, which shows the actual/design EUI ratio on the vertical (y) axis, where a value of one (1) 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 0.) On an individual project basis, this suggests that energy modeling as implemented in the LEED program 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.

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. A question not addressed by this study is the extent to which the modeling used to demonstrate LEED achievement is also used to make design decisions. Based on market perception of the modeling process, it is unlikely that building designers and owners recognize the potential variability of the prediction accuracy. 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 of these projects is underway.

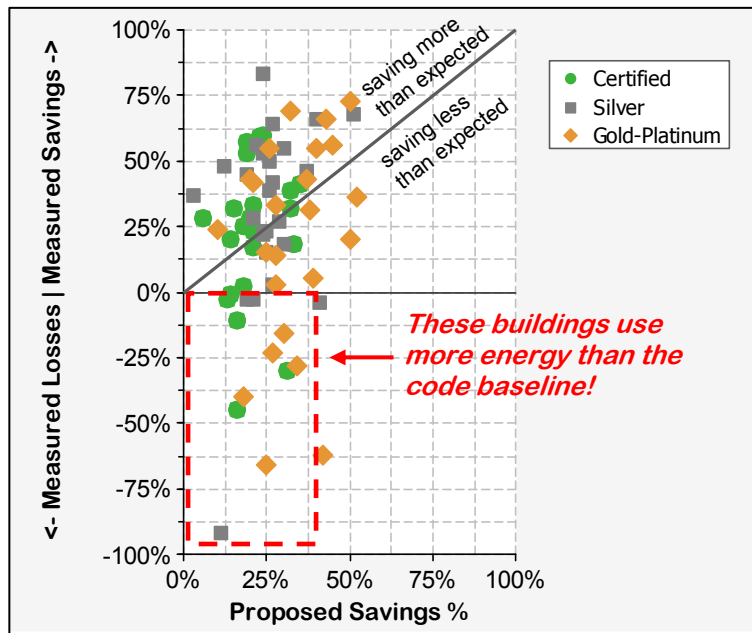
Figure 3. Measured/Design Ratios Relative to Design EUI



Measured and Proposed Savings Percentage

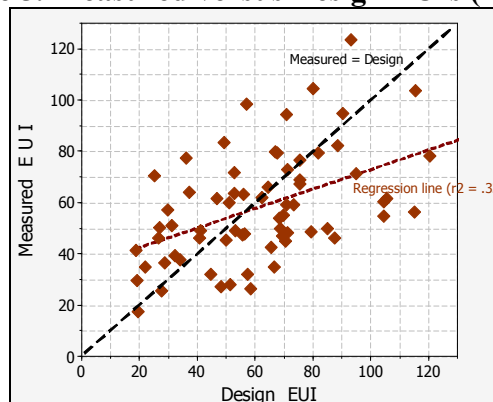
The conclusions are similar for *relative* savings predictions on an individual project basis. Referring to Figure 2, a range of outcomes is again apparent. Fully 25% of the buildings show savings in excess of 50%, well above any predicted outcomes, while 21% show unanticipated measured losses, i.e., measured energy use exceeding the modeled code baseline. More detail on this outcome can be seen in Figure 4, 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 4. 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 5. 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 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 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 projects anticipated to be higher energy users seem more likely to overestimate actual energy use.

Figure 5. Measured versus Design EUIs (kBtu/sf)

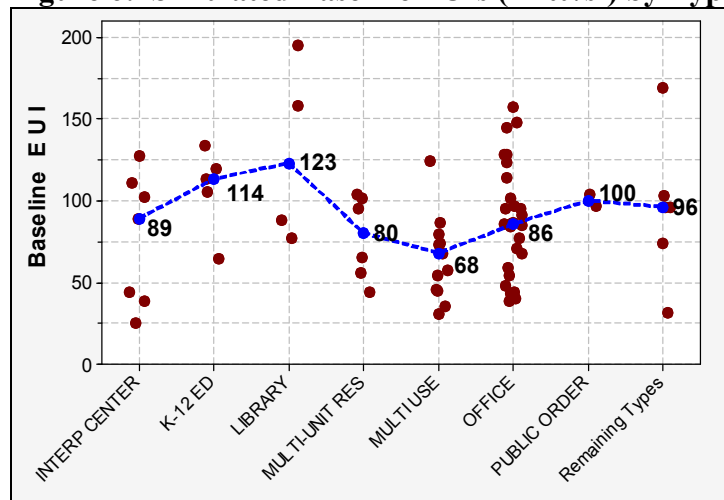


Baseline Variability by Project Type

Like the predicted energy use values, the code baseline EUIs demonstrate significant variability, even within individual building types.

Figure 6 shows the code baseline values generated from the initial modeling in the LEED sample by project type. (The dashed line shows the mean value for each type) Office buildings, the most common project type in the sample, provide a good example of this variability. 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 that might impact this, unregulated loads, was kept constant in this analysis. Unregulated loads were fixed at 25% of total baseline energy for all projects in the study (for both baseline and predicted energy use). Note that the variation was high within climate types, although the sample was not large enough to accurately represent climate variability.

Figure 6: Simulated Baseline EUIs (kBtu/sf) by Type



From

Figure 6 it is clear that the requirements of the ASHRAE 90.1 standard lead to highly variable interpretations of the stringency of this standard. This variability 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.

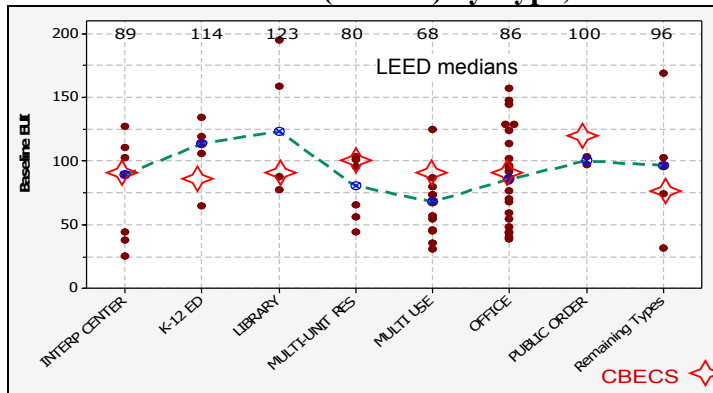
Performance Levels Implied by Code Baseline

Perhaps the most significant issues to arise from this data 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. This is shown in Figure 7, in which the CBECS average EUI for each project type shown in the figure above is included in the same graph. 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 the case of office projects, the mean value for the baseline performance target of LEED 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 are generated using Standard 90.1 by practitioners all over the country, working on some of the most advanced buildings being developed. Rather than an academic analysis of the stringency of ASHRAE 90.1, this data represents the stringency of Standard 90.1 in practice. As such, it suggests that this standard is much less stringent than is widely believed, since it seems to deliver building performance on par with the national stock of existing buildings.

This information has significant implications for policies and programs that use ASHRAE 90.1 as a baseline for driving increasing levels of building performance/carbon reduction, and also has implications for the use of the ASHRAE 90.1 Standard in achieving the goals of the widely recognized Architecture 2030 Challenge³. The relationship between the stringency of this standard and common or unregulated building practice needs significant further study and calibration.

Figure 7. Simulated Baseline EUIs (kBtu/sf) by Type, with CBECS Averages



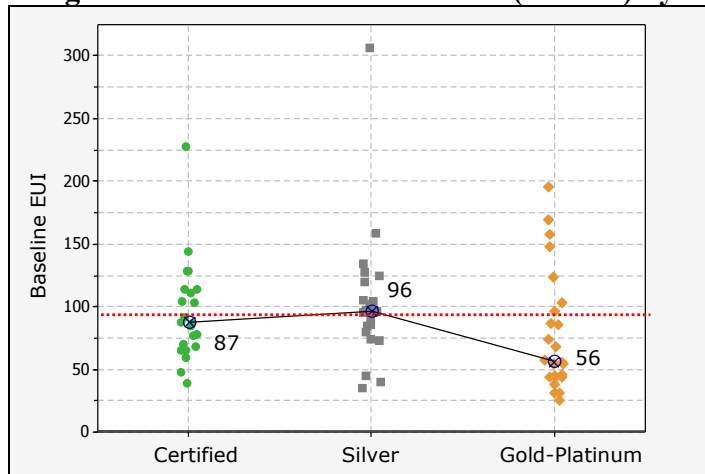
Baseline Variability by LEED Level

Another characteristic of the baseline performance levels generated by the 90.1 Standard is demonstrated in

³ The Architecture 2030 Challenge targets sequential reductions in building energy use, starting with a 50% reduction by 2010, and culminating with net zero building energy use by 2030. It has been adopted by the AIA, ASHRAE, the USGBC, and hundreds of state and local municipalities as a performance target for buildings.

Figure 8. 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 certification level correlates more or less directly with increased energy performance targets; the higher the certification target, the more energy performance is targeted by the design team.)

Figure 8. Simulated Baseline EUIs (kBtu/sf) by Level



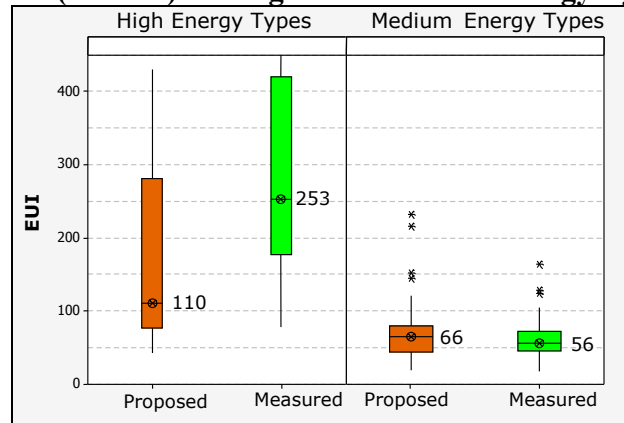
The data itself does not suggest why more aggressive energy performance targets would result in more stringent code requirements for these projects. However, design professionals familiar with the “System Map” used in the energy modeling protocol of ASHRAE 90.1 might recognize that initial system selection 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.

Modeling Accuracy in High Energy Use Building Types

The bulk of this study, including the above findings focus on “medium energy use buildings,” as described in the introduction above. However, some analysis of the characteristics of “high energy use buildings” was also conducted. These types primarily include data center and lab uses in this sample. A key finding on these projects is demonstrated in

Figure 9, 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 9. 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.

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 and ASHRAE may need to re-evaluate how these project types are treated with respect to energy performance achievement.

Summary

Although in aggregate the energy modeling in the sample above accurately predicted sample-wide energy savings (except for high energy buildings), the degree of variation in predictive accuracy on individual projects was substantial. It is clear that much work needs to be done to better align energy modeling accuracy with actual building performance outcome if this tool, as currently implemented, is to effectively serve the design community in delivering high performance buildings. The wide variability of energy modeling accuracy on an individual project basis implies significant flaws in any life-cycle energy savings comparisons undertaken by the affected projects, and calls into question how effectively this tool is used to predict the performance outcome of any given project. There is a clear need for better data on actual building use characteristics to better correlate modeling inputs with building use characteristics.

The data also suggests that the use of the ASHRAE 90.1 energy performance standard, as interpreted by general users in the design industry, does not deliver predicted baselines that are substantially better than standard practice. This conclusion seems to be at odds with the general perception of 90.1 as a standard that is much more stringent than typical industry practice.

References

Energy Performance of LEED NC Buildings, Mark Frankel and Cathy Turner, March 2008, NBI.

LEED 2.2 Reference Guide, USGBC, 2005

Commercial Building Energy Consumption Survey, US Energy Information Agency, 2003