Energy Research and Development Division
FINAL PROGRAM REPORT

High Performance Buildings Measured Performance and Key Performance Indicators

Part of the Evidence-based Design and Operations PIER Program

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EXECUTIVE SUMMARY

This Project Report (Final Report) summarizes the findings for the Plug Load Savings Assessment project within the *Evidence-based Design and Operation* research program (Program) led by New Buildings Institute (NBI) and its subcontractors for the California Energy Commission's Public Interest Energy Research (PIER) program. The research period was October 2008 through March 2013 and included studies on plug load energy use and savings strategies.

Achieving California's ambitious energy and environmental goals and policies will depend in part upon achieving dramatic improvements in the energy efficiency of new and existing commercial buildings. The commitment to these goals is evidenced by the existence and progression of advanced building codes and appliance standards, and the proliferation of utility energy conservation incentive programs. However some recent studies on the actual measured energy performance of newer generations of commercial buildings (those designed for high energy efficiency) evidence a wide range of energy performance; some buildings are performing far below design expectations. For example, NBI's 2008 study of measured energy performance of Leadership in Energy and Environment Design –New Construction (LEED – NC) buildings[1] found average savings of 28% compared to national code, but energy use at 1/4 of the buildings was near or *higher* than the allowable code baseline level. This performance shortfall needs to be better understood and corrected so that efficiency "as designed" comes into alignment with efficiency "as measured."

Objective. The goal of the research was to improve the measured energy performance of the next generation of California commercial buildings. To accomplish this goal the researchers examined the reasons for the variable energy performance through an evidence-based assessment of high performance buildings (those built to energy efficiency targets beyond code requirements). These assessments were made through a series of project elements focused on identifying key feedback loops and tools that can better inform **designers, operators/owners** and **tenants** (DOTs) about their role in optimizing building performance. The fundamental theme of the Program was to 'connect the DOTs' by identifying the key areas of performance related to each party having a role in the ultimate energy use.

Background. At the time this research was proposed in 2008 there was no simple, effective feedback system for capturing and analyzing system-level measured energy results (i.e., actual use) in a way that informed owners, operators and tenants of the impact of their actions on energy use. For designers, feedback from occupied buildings can inform and improve future design work for new or renovated facilities. Feedback can guide owners when making investments in energy equipment and controls and provide guidance for operational practices once buildings are occupied. Occupants can learn to recognize and change their activities to decrease energy use.

[1] Energy Performance of LEED® for New Construction Buildings, NBI 2008

Approach. The research team began by using monthly utility bills to assess measured actual vs. designed energy performance of a set of 22 new California buildings whose design targets were intended to significantly exceed simple -energy code compliance. Next, site investigations were done on a subset of 12 buildings to discern physical and operational characteristics. The researchers extensively evaluated the energy use impact of various efficiency measures. This Sensitivity Analysis, coupled with system-level (i.e. lighting, HVAC, plug loads, etc.) measured energy use at two sites helped identify the key performance indicators (KPIs) that simplify the representation of building energy performance.

Results: Whole-Building Energy Use. Research on the initial set of 22 buildings found they performed much better than the national average per building type. Of those eligible for an Energy Star score[2], over 70% were in the top 10% of like-type buildings nationally. But the research found little correlation between a building's actual measured energy performance (EUI[3] and Energy Star score) and ratings such as LEED energy points that represent estimated energy performance. Compared to similar buildings in the CEUS[4] database, many failed to achieve their original *estimated* high performance design goals. These findings further demonstrate that there is often a discrepancy between expected energy performance and actual measured outcomes.

Results: A Building Performance Review Tool. Building on a pre-existing spreadsheet energy analysis tool, an automated remote energy performance assessment software tool called FirstView was developed and refined as part of this project. FirstView's evolution was piloted (beta tested) by 28 companies responsible for over 4.6 million square feet of commercial floor space. This tool applies an inverse-modeling method to segregate monthly utility bills into energy end-use categories (lighting, plug loads, heating and cooling, etc.), each uniquely affected by the actions associated with design, operations and tenants. Its analysis, shown in graphic form, provides insights that can determine if building performance is on track or off target. Where energy use is higher than expected, FirstView can identify specific problem areas for investigation.

Results: Sensitivity Analysis. The Sensitivity Analysis work in this project investigated, through extensive modeling runs, how variations in physical features, HVAC and lighting systems, operational practices and tenant behavior patterns affect building energy use. Findings from this analysis provided a scale of impact for each item and correlated corrective actions to one or more of the DOTs. Findings from this work also reinforced the need for stringent energy codes because design decisions are so key in affecting energy use. For example, for an office

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[2] An Energy Star score is a national benchmarking comparison to similar occupancy buildings by climate area and greenhouse gas emissions associated with energy use.

[3] Energy Use Intensity (EUI) is the sum of all fuels used in the building per year divided by the building's floor space and is expressed here in British Thermal Units (BTUs) per square foot (sf).

[4] The California Energy Use Survey (CEUS) for Nonresidential Buildings (2006) represents a survey of measured energy use by building type.

building in Los Angeles[5], poor or inefficient design features can increase the energy use by 10-20%. Yet in this same building the Sensitivity Analysis revealed that poor operational practices (such as using incorrect outside air and thermostat settings) and uniformed occupant behavior could combine to increase energy use by up to 50-60% more than necessary.

Results: Key Performance Indicators (KPIs). The KPIs were expressed as metrics that characterize occupancy patterns and how HVAC controls, lighting, daylighting and plug loads are working and contribute to whole building energy use. Each metric is a descriptor, and the rating of that metric, and its graphical representation of the data measuring the metric give clues as to whether or not the problem may be design related or related to the actions of tenants or facility operations. For example, the KPI" Daylighting Effectiveness" indicates the degree to which electric lighting energy use is reduced when daylight is available. When a lighting system design includes daylighting controls, the KPI should indicate a correlation of reduced electric lighting during daylight hours. These KPIs drill down and give feedback as to the reasons for differences between measured energy use and design energy use expectations, and indicate how operations or tenant activities factor in that difference.

Market Connections and Policies. Mandatory energy use 'disclosure policies' associated with property transactions are becoming widely adopted by local jurisdictions nationwide. By making the energy performance of buildings transparent, parties in real estate transactions are better informed. Most of these policies require commercial building owners to provide their building's size, annual Energy Use Intensity (EUI) and Energy Star score. But without monthly energy bills this information is insufficient for a full performance review. For owners, the problem is that the Energy Star score, while good for broad comparisons, does not provide any information on how energy efficiency can be improved.

Some municipalities have created voluntary programs focused on public disclosure of building energy use and incentivize participation in these programs by giving awards for top energy performers. In this study, the research team partnered with StopWaste.Org, the City of Berkeley and two other cities in Alameda County to employ FirstView building evaluation for all 2013 participants[6] in their *Smart Energy Awards*[7]. The Sensitivity Analysis work in the study described above was highlighted in a range of publications and presentations to broad audiences. The KPI data and metrics were part of numerous presentations at conferences such as ACEEE, ASHRAE and the World Energy Engineering Conference. FirstView continues to be discussed at industry panels on performance feedback such as the National Market Transformation Conference and

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[5] The impact of any feature will vary depending on the use and locations of the building. The Sensitivity Analysis covered climate areas throughout the U.S.

[6] FirstView is able to plot an energy signature and disaggregate energy end uses for many building types. For office buildings the web tool goes further to compare the reference building to that of other office buildings.

[7] http://www.co.alameda.ca.us/sustain/news/awards.htm

was the basis for the first performance assessments on actual energy feedback to LEED-NC participants[8].

Conclusions. This research clearly indicates that building energy performance is not solely a product of a building's design and construction; actual performance is driven in large part by operations and occupant energy use behaviors. Reviews of 22 California buildings built for high energy performance clearly showed they were not exceptionally better in *measured* energy use, despite their original *estimated* high performance energy design based on software models.

Programs such as Energy Star use measured performance data from utility bills to compare energy performance to national benchmarks – an important step in raising awareness of energy use. But while important, benchmarking programs provide no insights to designers, operators/owners and tenants about what areas to mine for efficiency improvements. Metering and audits are expensive and complex. This project demonstrated that with easy-to-use tools, the simplest data – that found in monthly energy bills – can provide useable energy performance feedback to guide actions for energy efficiency.

Arising from the same issues articulated in this research, approximately 8-12 private sector tools with remote energy performance review abilities are now available[9]. The research team anticipates that the findings, tools and market outreach work of this project will improve building energy performance by filling the energy use feedback gap and help accelerate market action toward implementing efficiency improvements.

The full technical studies from this research are available at www.newbuildings.org/pier-research.

[8] USGBC Building Performance Partnership

[9] Examples are Retroficiency, FirstFuel, and Noesis

1. High Performance Buildings Measured Performance

This chapter summarizes the findings from Project 2: *High Performance Buildings Measured Performance* within the PIER program "Evidence-based Design and Operations." The research occurred from 2009-2013 and was led by New Buildings Institute (NBI) and supported by Portland Energy Conservation Inc. for field monitoring.

1.1 Background

In 2008 NBI conducted a nationwide study[10] to determine if green buildings, specifically those built to the Leadership in Energy and Environmental Design New Construction program (LEED[11]-NC) – a voluntary program with points for energy efficiency well beyond code levels - actually achieved the energy savings intended by their design. While many of these buildings (121 in the 2008 study) did achieve high energy performance (an average of 28% better than a code-level building), a significant percentage (25%) did not. Achieving the energy performance that is designed into buildings is a critical function of ensuring energy resource conservation, greenhouse gas emissions reduction, healthy indoor air quality and lower energy costs for California ratepayers.

The design and construction of new 'high performance' buildings - those designed to high energy efficiency targets aimed at using far less energy than comparable or simply code-compliant buildings - has become increasingly prevalent. Yet there remains an inability to "connect the DOTs" on measured energy performance. Connecting the DOTs is the theme of this research and refers to the three key groups with responsibility for a building's measured (actual energy use on the utility bills) energy performance – the **Designers**, **Operators/Owners** and **Tenants** (the DOTs).

In California, the state energy code has become progressively more stringent to encourage higher energy performance. Title 24 part six is the energy code for newly constructed buildings, establishing establishes an energy budget for a building based upon its occupancy type and climate zone. Every three years the code is revised to lower energy budgets (EUIs[12]) commensurate with advances in energy efficiency technologies for lighting, heating, ventilation and air conditioning (HVAC), building envelope and domestic hot water. The overarching goals of having California-specific building codes and appliance standards is to lower energy costs for ratepayers, ensure healthy buildings and reduce greenhouse gas emissions that contribute to climate change.

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[10] NBI, 2008 Energy Performance of LEED for New Construction Buildings

[11] LEED certifies new commercial construction buildings as being more environmentally friendly or 'green' in areas that include energy efficiency.

[12] An energy budget is expressed as an Energy Use Intensity (EUI) in thousands (kilos) of British thermal units (BTUs) per square foot (SF) of occupied space per year or kBTUs/sf

Efforts like the California utilities' program for energy efficiency in new commercial construction - Savings By Design - and the national green building program LEED-NC rely on the results from energy software (modeling) to estimate energy consumption. By comparing the modeled energy budget to the energy code, these popular programs use models to determine if the building 'as designed' meets the program criteria for being high performance. Generally, energy and green building programs target energy use that is 15-30% lower than a building built to a code level, depending on program.

Once occupied and operating, design teams and owners participating in these efficiency programs rarely learn if their building met the energy performance predicted in the design. While utility bills provide some general insight about energy consumption, their ability to help identify what may be causing differences from targets and potential areas to improve is very limited.

Only a few broad studies have been performed on the measured energy performance of new commercial buildings designed for high efficiency. All have shown, like the recent LEED study cited earlier, a wide range of actual performance levels; some have revealed performance far worse than design expectations. For example, a 1994 study by Lawrence Berkeley National Laboratory (LBNL) saw energy use differing by a factor of over four for 28 new commercial buildings participating in a Northwest program called Energy Edge. A 2003 NBI study of 157 California commercial buildings showed as-constructed savings (using California's energy code as a baseline) ranging from -100% to +50%.

This disparity between expectations and apparent energy use can be linked to actions in the design, construction, commissioning, occupancy and operation stages. At the time this research was proposed, a good feedback system did not exist for capturing and parsing post-occupancy energy results in a way that informed each party of the role their actions play and how they may affect future performance. For designers, that feedback can inform and improve future designs. It can guide building owners in their investments and direct operation practices. And occupants can learn how to recognize and change the way their activities are increasing energy use.

Currently the primary energy review methods involve extensive investments in energy information systems that monitor all the energy-using parts of a building via sensors, wiring, computer analysis and/or a physical audit by a professional energy engineering company. These approaches are beyond the funds, and needs, of most commercial buildings – the majority of which are small and medium in size[13]. And while whole-building actual energy use information arrives each month in the form of a utility bill, it provides no insight on which aspects of the building are using energy and where to pursue efficiency improvements.

The premise of the research presented in this chapter - Project 2 in "Evidence-Based Design and Operations" - is that designing a building to high energy standards by itself does not guarantee high energy performance. Tenant behavior - particularly in the case of the use of plug-in devices

[13] Less than 50,000 square feet. Source: Energy Information Agency 2003

- as well as facility operations and maintenance practices affect energy use and performance. Identifying the areas of energy use, level of impact, and metrics and feedback methods appropriate to each of the DOTs can help close the loop on which actions and activities directly impact energy performance once a building has been constructed and occupied.

While benchmarking programs like the U.S. Environmental Protection Agency's (EPA) Energy Star Portfolio Manager use measured performance data to compare a particular building's energy use to national benchmarks for similar buildings, it gives no additional insights into what areas to investigate for further energy efficiency improvements. Metering and audits are expensive, and it is difficult to know where to start or what to do to assess and improve energy performance.

1.1.1 Objective

This project's objective was to identify typical patterns affecting energy performance outcomes in high performance buildings and develop easily understood metrics and feedback directed to the designers, owner/operators and tenants, thus connecting the 'DOTs' of energy performance. Armed with this information, the DOTs can directly and effectively participate in efforts to improve building performance, increasing the number of buildings that are not only designed to high performance standards but also truly meet or exceed these goals.

The project tasks included documenting the performance of a set of California high [energy] performance buildings, developing and using a software tool to identify critical indicators and simplify the representation of building energy performance (specifically how and why energy is used). The key indicators are often tied to operational practices and tenant behavior.

The research focus was to design performance reporting via a simple-to-use analysis tool that provides easily understood and actionable feedback that can lower energy use. This tool has applications and relevance for the DOTs and other commercial building professionals. This information will allow these groups to directly and effectively participate in efforts to improve building performance, thereby increasing the number of buildings that are not only designed to high performance standards but also truly meet or exceed objectives.

The research involved three tasks: 1) **Measured Performance Assessment** of a set of recently constructed buildings in California that targeted high energy performance, 2) **Sensitivity Analysis** that assessed how 'sensitive' the energy use of buildings is (the magnitude of change) in response to changes of efficiency measures and practices, and 3) identification and development of **Key Performance Indicators** of energy performance relative to each of the DOTs. This project summary presents each of these areas with a section on Approach, Outcomes and Findings, and Market Connections, followed by sections on Benefits to California and Conclusions.

1.2 Measured Performance Assessment

The Measured Performance Assessment task involved two phases: a) an initial view of the energy performance of buildings – individually and compared to benchmarks, and b) site assessments of approximately half of the initial set of buildings.

1.2.1 Approach

The research team began its work by conducting outreach to utility program managers, design firms, building operators, the California Chapter of the United States Green Building Council (USGBC) and American Institute of Architects (AIA) chapters. California commercial buildings less than five years old and designed to 'high performance' standards were recruited for this study. In this case, 'high performance standards' meant those buildings designed to incorporate LEED criteria, Savings by Design targets and/or energy performance targets at least 20% above the California Title 24 non-residential energy code in place at the time of construction.

An example of LEED energy criteria is Energy and Atmosphere credit 1 (EA 1) that encourages the building to exceed the mandatory provisions specified in sections of ASHRAE 90.1 in order to maximize energy performance. Savings by Design is a voluntary incentive program for design teams and owners within California investor-owned utility service territories to design buildings that model 15-30% better than the State's building code. During the outreach phase, preliminary information on over 75 buildings was gathered, and 22 were selected for the study. These buildings were constructed from 2004 to 2006, had detailed information on characteristics and energy use, and expressed interest in participating in the study.

The next step was to compare the energy performance of these relatively newly constructed buildings to similar buildings in California and the United States. This was done remotely, i.e., without a site visit. The team collected and reviewed basic information on building characteristics, conducted phone interviews with tenants and operators, reviewed utility bills, and used a new remote energy analysis tool called FirstView™ to better understand how the buildings were operated and used by tenants. Using FirstView, NBI provided building owners (and their utilities) with reports specific to their building. Researchers also correlated each building's specific design and operational characteristics to actual energy performance.

The remote assessments helped identify the features and systems that would be the most informative focus of additional data gathering. A further subset of 12 buildings was chosen for Site Assessments - onsite visits to gather detailed data. This data was used to generate individual performance assessments, identify strategies to potentially reduce energy use, estimate potential energy savings from employing those strategies and gain important insight for understanding cross-cutting lessons that formed the basis for analysis and development of feedback systems.

1.2.2 Measured Performance Assessment Findings and Outcomes

Common energy efficiency benchmarks against which the energy use of a building is compared include the as-designed model of the building's energy use, building energy codes or standards, scores established under green or energy efficiency programs such as LEED or Energy Star, and/or similar type occupancy buildings (sometimes referred to as 'peer' buildings). Data sources often cited to provide peer building comparisons include the Commercial Building Energy Use Survey (CEBES) and the California End Use Survey (CEUS), both of which are based on data from metered building energy use.

Energy Compared to Benchmarks. Table 1 summarizes the energy intensity benchmarking results for the latest year for which energy data was available in each of the 22 buildings. The following is a list of some of the factors and challenges to keep in mind when reviewing the table and comparison categories:

- Measured EUI for each project includes total energy (gas and electric) used per square foot over a 12-month period.
- If renewable energy is present, the building energy must be represented as the energy use *exclusive* of renewables (i.e., how much does the building actually use).
- Energy Star and LEED EA credits (points shown) are based on *source* EUI, which is calculated from the site EUI and considers the energy impact of the fuel mix. A building with a lower carbon fuel mix for its source of energy - such as most fuel coming from hydro-provided electricity versus a large portion of fuel from coal – would have a better *source* EUI and thus potentially higher Energy Star or LEED EA points.
- The CEUS rankings are based on *site* EUI - the energy used only at the building - and represent the building compared to like buildings in this California CEUS data set of measured performance. The CEUS rankings are done with Lawrence Berkeley National Laboratory's (LBNL) Energy IQ benchmarked relative to existing California building stock. Some factors regarding using this ranking method are described after the table.
- Energy Star ratings are only available for those building types included in Portfolio Manager (office and K-12 education). Portfolio Manager does not address assembly or university educational buildings, so in the table these buildings do not have Energy Star scores.

Table 1: Remote Measured Performance Assessment Results for 22 Participant Buildings

ID	Building Type	Size (SF)	City	Utility	Measured EUI kBTU/SF	Energy Star Score (0-100)	LEED EA Points (max 18)	CEUS rank (0- 100)
427	Office	594,000	Sacramento	SMUD	95	80	9	15
1683	Education-general	20,000	San Marcos	SDG&E	28		9	58
1711	Public Assembly-general	62,000	Calabasas	SCE	56		0	23
1650	Public Assembly-general	9,000	Newport Beach	SCE	18		18	74
1716	Education-K-12 School	72,000	Los Altos	PG&E	30	98	18	57

ID	Building Type	Size (SF)	City	Utility	Measured EUI kBTU/SF	Energy Star Score (0-100)	LEED EA Points (max 18)	CEUS rank (0- 100)
519	Office	72,000	Bakersfield	PG&E	75	75	4	7
1715	Office	72,000	Bakersfield	PG&E	117	24	0	8
1742	Education-K-12 School	242,000	San Diego	SDG&E	46	92	16	14
1652	Education-general	82,000	Claremont	SCE	128		0	1
1658	Courthouse	496,000	Fresno	PG&E	54	87	14	73
1719	Library	19,000	San Jose	PG&E	84		1	15
1662	Library	96,000	San Mateo	PG&E	38		13	32
1678	Education-K-12 School	75,000	Santee	SDG&E	33	90	15	48
1679	Education-K-12 School	56,000	Santee	SDG&E	26	98	18	61
1680	Education-K-12 School	62,000	Santee	SDG&E	24	98	18	65
1681	Education-K-12 School	63,000	Santee	SDG&E	21	99	18	70
1682	Education-K-12 School	33,000	Santee	SDG&E	35	97	18	32
526	Office	107,000	San Diego	SDG&E	38	88	14	59
1642	Recreation	60,000	Rohnert Park	PG&E	62		0	22
1677	Office	14,000	Oakland	PG&E	49	84	12	39
1651	Office	624,000	Torrance	SCE	81	93	17	34
1722	Recreation	32,000	Palo Alto	PG&E	58		0	22

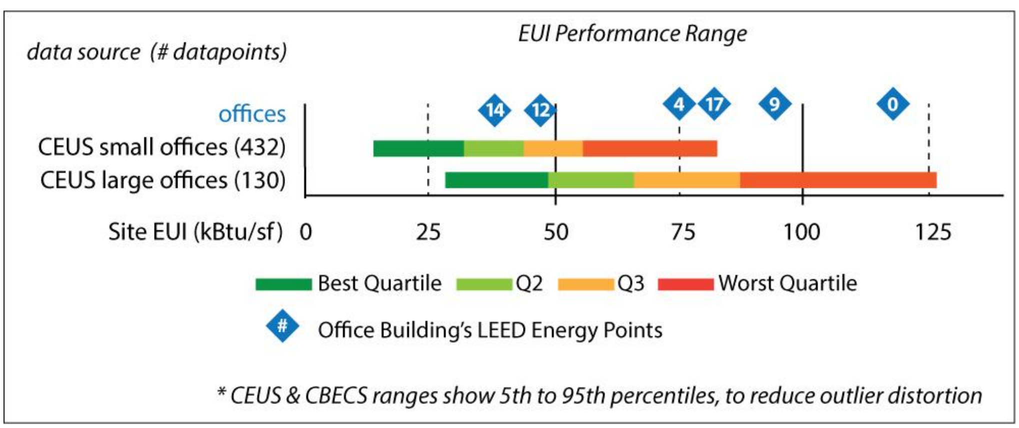
Table 1 shows most of these buildings performed much better than the national average for their type as represented by an Energy Star score. Of those eligible for an Energy Star score, over 70% are in the top 10% of buildings nationally.

The rankings within CEUS shown in Table 1 are highly variable, despite all buildings having targeted high performance in energy efficiency. For office buildings and schools this comparison gives a very different impression of performance levels than did Energy Star ratings, with the results spread across the entire CEUS range rather than being in the top tier due to their high performance objectives, as seen in Table 1. This difference could be related to several factors:

- For offices, CEUS benchmark varies by size (less or greater than 150,000 square feet), so it is important to apply the correct reference aligned with the building size.
- A lack of normalization in the CEUS percentiles for characteristics such as schedule, office equipment density, etc.
- California's more aggressive code requirements logically lead to a more challenging peer group than the national Energy Star benchmark.
- The small size of the data sample here, which is only illustrative, is not large enough to be broadly representative.

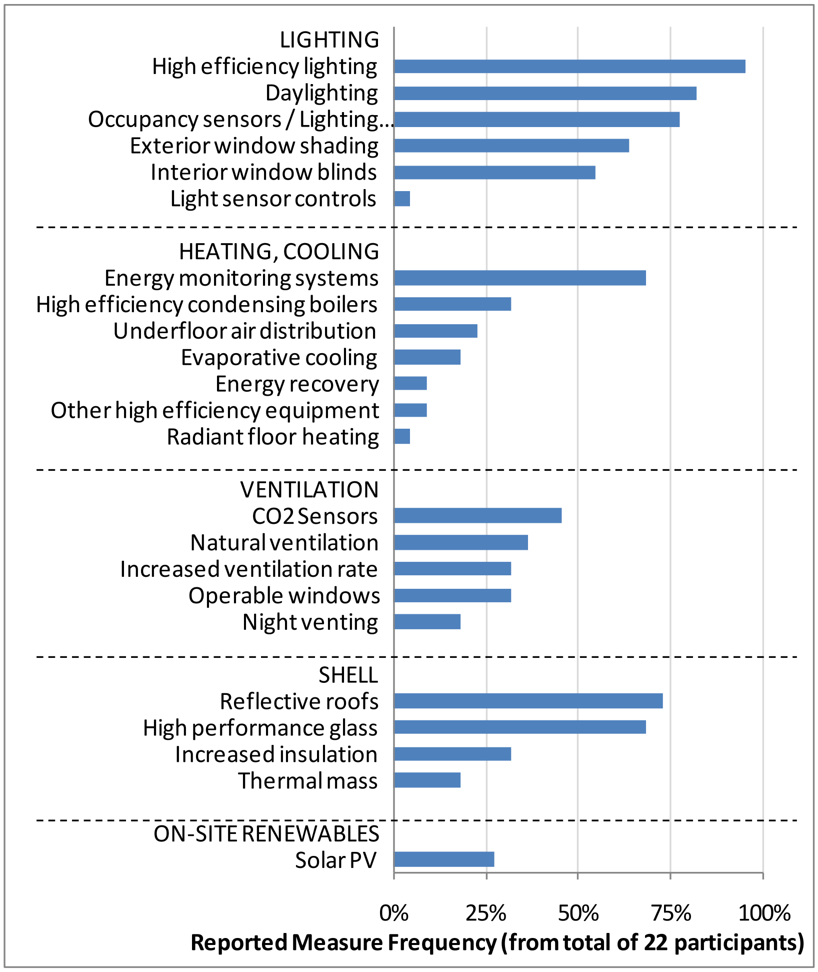
Despite these distinctions, this set of buildings was not exceptionally better in measured energy use than the CEUS buildings despite their high performance energy design intent. The analysis showed little correlation between measured energy performance (EUI and Energy Star score) and ratings based on estimates and models such as LEED energy points. As illustrated in Figure 1, buildings with similar LEED energy and atmosphere points (which are based on energy models, note the building's diamonds with 14, 12 and 17 LEED points) varied by 25-50% in EUIs and widely compared to the CEUS benchmarks. The further demonstrates the variations between how the building was expected to perform and its actual measured outcomes and validated the need for the research outcomes on measured performance feedback.

Figure 1: Whole Building Energy Performance of Six Studied Offices Compared to CEUS



Efficiency Measures. In addition to monthly utility bills and building characteristics, participants reported the energy conservation equipment or characteristics found in each of the 22 high performance buildings. Figure 2 summarizes the percentage of buildings reporting the presence of various efficiency measures.

Figure 2: Percent of Buildings Reporting Energy Conservation Measures



Benchmark comparisons as well as system characteristics were summarized in individual building reports provided to study participants. The reports were intended to provide the first feedback loop to designers, owners/operators and tenants, helping them understand how their building is using energy and provide actionable feedback on energy performance. These reports were based solely on a remote analysis and included feedback from a new tool called FirstView, piloted as part of this research. The FirstView tool is further explained below.

1.2.3 New Performance Review Tool: FirstView

The initial performance assessments of the 22 buildings were done strictly from data provided to the research team via email from the design team, owner or operators using an evolving new tool called FirstView. Because it does not require a site visit, this type of review is often referred to as a 'remote' assessment or 'touch-less audit'. The ability to determine energy performance from simple data (monthly bills) and without the cost of a site visit is one of the key objectives of FirstView and other remote assessment tools.

FirstView Description and Examples. At this phase of the research FirstView was a sophisticated but limited spreadsheet internal to NBI, developed with initial funding from the

U.S. Environmental Protection Agency[14]. Using only monthly utility bills, building size and location, FirstView creates an Energy Signature[15] that helps to disaggregate and analyze end-use (system-level) patterns of energy use not revealed by whole-building energy use data. FirstView's signature and graphics direct users to specific system areas, revealing potential energy efficiency problems and increasing understanding of benchmarking results relative to other similar buildings.

Three specific examples from the research buildings noted below explain how FirstView Energy Signatures can uncover clues in measured performance data that can be used to reveal changes in operations or tenant actions that can save energy.

Figure 3 represents an analysis of a school's pre- and post-renovation FirstView Energy Signatures. Changes were made in heating, electric baseload and HVAC controls and/or economizer operation. As seen in the chart, the heating slope (on the left side of the plot), is significantly steeper before the retrofit. This suggests inefficient heating equipment and/or excessive ventilation rates or leakages. Additionally, the lowest point on each line, which indicates the magnitude of electric baseload, suggests improved lighting efficiency and/or reduced use of excessive reheat. Finally, the fact that the lowest point on the graph occurs at a lower temperature suggests an improvement in HVAC controls and/or economizer operation, thus reducing the need for mild temperature conditioning.

Figure 3: School # 1687 Before and After Renovation

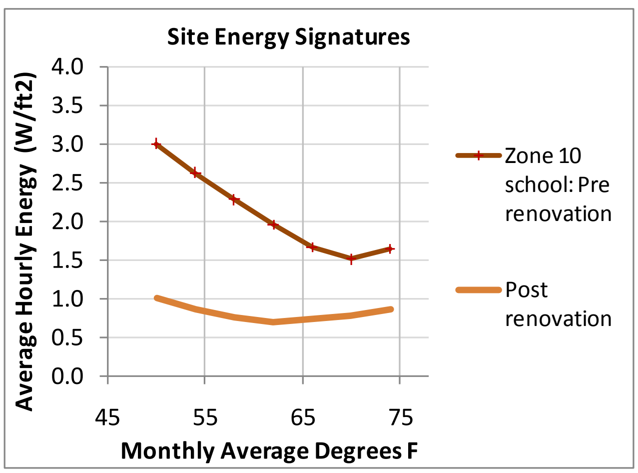


Figure 4 shows a two-year comparison for the same building as compared to a DOE Reference Model. The plot makes clear that the building is using more energy in 2008 than in 2006. Interviews suggested that this resulted from changes in occupancy level. KPIs developed under this research, and presented in the next section, would have identified the increased occupancy without the interview.

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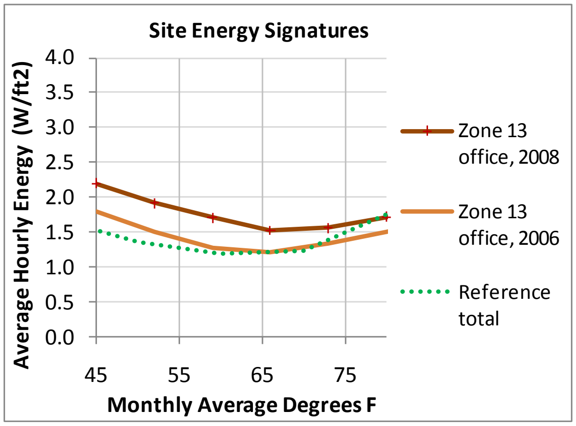
[14] http://newbuildings.org/sites/default/files/FirstViewTool_NBI_aceee2010.pdf

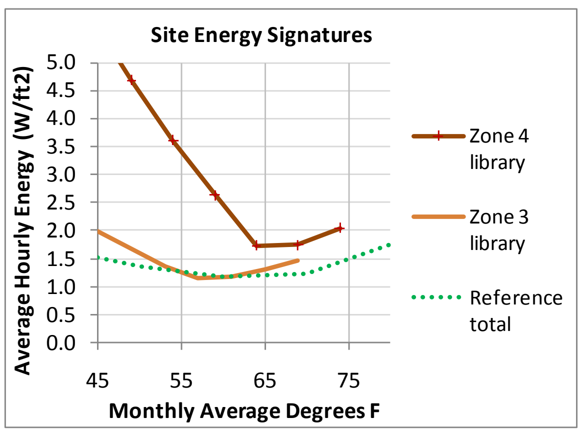
[15] An Energy Signature displays correlations between energy use and basic variables such as temperature and occupancy normalized for square footage.

Figure 4: Office Building Energy Use Over Time



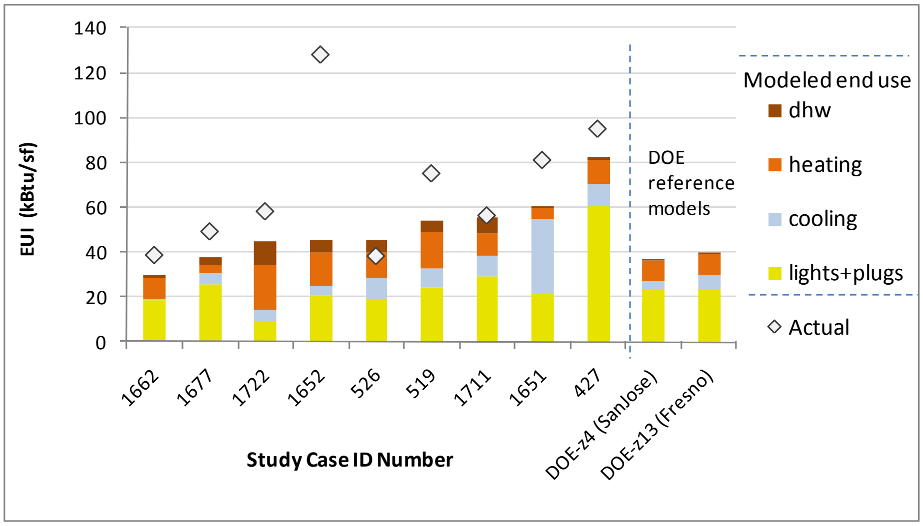
Since FirstView Energy Signatures are both weather and size normalized, multiple buildings can be co-plotted for comparison. This can clearly indicate which building are the more likely candidate for further investigations and improvements. For example, Figure 5 shows two different libraries compared to each other and to a DOE Reference Model. The steep heating slope on the Zone 4 library draws attention and is a higher priority for a full audit or investigation.

Figure 5: Two Library Energy Signatures - Zone 4 Bldg. # 1791 and Zone 3 Bldg. # 1662



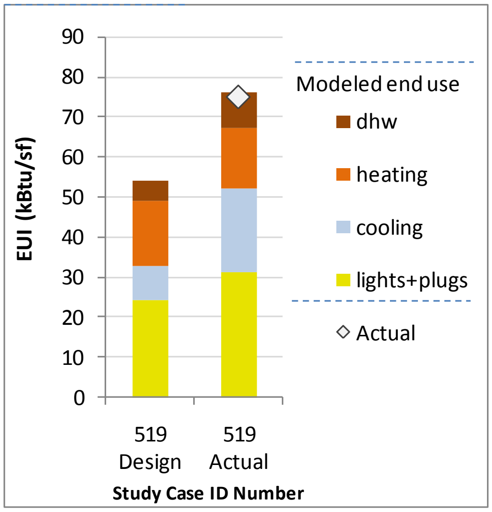
Design Model Comparisons. In addition to plotting and analyzing Energy Signatures, FirstView can analyze and compare measured performance to design model predictions. Of the nine buildings that provided design models for this study, two had measured EUIs very close to design EUI. The remaining seven had measured EUI that exceeded the modeled design EUI (Figure 6). These findings were consistent with a 2008 NBI study of LEED-NC buildings that also found noticeable differences between designed and modeled energy use. While the total EUI of the nine study case buildings in Figure 6 was derived from the design model, the modeled end-use areas – domestic hot water (dhw) heating, cooling, lights+plugs - are estimates made through the modeling. While this shows measured whole building EUI the FirstView results can further explore the end use assumptions compared to measured results and provide the design team this comparative data, which in turn informs future project assumptions.

Figure 6: Participant Design Models Compared to Measured EUI Totals



FirstView's disaggregation of both predicted and measured loads can be used to compare to a model's results and further pinpoint inconsistencies between expectations and reality. Occupant schedules, plug loads and the hours of use for lighting are often mentioned as reasons for an over-prediction of energy savings in models. In many cases this is true. Yet as shown in Figure 7, domestic hot water and cooling energy are also of concern. The ability to pull out this detail helps pinpoint opportunities to employ specific energy efficiency strategies related to tenant practices or operations and maintenance.

Figure 7: Design versus Actual End Use Split



Diagnostics. FirstView diagnostics are mathematical thresholds of performance revealed in the algebra underlying the Energy Signature plot. As part of this work analysts set diagnostic thresholds for office buildings to allow for comparison in six functional areas (electric baseload, gas baseload, controls, reheat, heating impact of shell/ventilation and cooling efficiency). FirstView automatically compares a reference building to these thresholds, identifying which specific sub-areas may hold opportunities for improvement. For example, the total heating impact of shell and ventilation is graphically represented in the heating slope. When this heating slope is steeper than expected based on comparison to the reference building FirstView can 'flag' the item. These automated flags make FirstView a valuable tool in communicating with commercial building professionals because it can quickly direct attention to inefficiencies associated with high ventilation rates, high lighting and plug load use, controls scheduling, simultaneous heating and cooling, etc.

Site Assessments. Site assessments on 12 of the 22 buildings provided additional insights into the performance levels uncovered during the remote assessments. Specifically, site visits confirmed that operation and maintenance significantly impact energy performance in relatively-low-energy-use-by-design buildings.

Interviews conducted with occupants onsite found many were unaware of their building's design features. In some instances this ignorance led to underutilized strategies (such as natural ventilation) or disabled strategies (like daylighting controls). When possible, future occupants should be engaged in the building design process so they are aware of the energy efficiency design strategies that are effectuated by thoughtful building operations.

With regard to systems, site assessments suggested that complex systems with controls do not necessarily ensure energy savings. In order to realize energy savings, these systems and their controls must be thoroughly studied, understood, calibrated and tested (through functional testing or commissioning) to ensure achievement of energy-related design intent. Optimal system performance also requires a trained building operator.

Controls continue to be a challenge. On the mechanical side, demand-controlled ventilation strategies were frequently observed to be nonfunctional (either controls strategies were not set up properly, or setpoints were overridden). And while lighting systems and occupancy sensors were functioning 20-30% below code lighting power density (LPD) levels, daylighting controls designed to use natural light to displace electric lighting during the daytime were either not installed or nonfunctional at 9 of 12 sites.

Most sites had superior building envelope features; only minimal design flaws and construction issues were noted by design team or facility staff. Roof and wall insulation levels were typically observed to be 10-20% better than code-required levels. Low-e glazing, reflective roofing and window-to-wall ratios lower than 20% were consistently observed. Both automatic and manual shading devices obtained less than ideal energy savings because occupants didn't know how or when to employ them or the systems were made with materials that did not adequately reduce glare. Finally, researchers noted a wide diversity of plug load devices in use and underutilization of plug load energy-use reduction strategies, such as computer energy management software.

FirstView Pilot Test. Once the remote assessments confirmed that FirstView would be a valuable market tool, the next step was to transform the early spreadsheet version into a 'beta' tool accessible via the web. The work to refine and automate FirstView, rigorously test the beta version through a pilot and collect follow-up information via user surveys is a significant outcome of this project.

More than 70 individuals and entities were solicited to join the FirstView web tool pilot, which focused on California office buildings that use both gas and electric (two fuel buildings) and had minimal process loads and constant seasonal occupancy. A total of 28 companies participated in the pilot, half of which represented firms from or doing business in California. The pilot test was national in order to a) solicit firms outside of California that do business in the state, b) increase participation and c) recognize the support of other funders toward FirstView.

Table 2 lists FirstView pilot participants with work in California and additional participants whose insights have added to the overall lessons learned in the pilot.

Table 2: FirstView Pilot Test Participants

With Work in California					Additional National/International Participants			
	Organization	**City**	**State**			**Organization**	**City**	**State**
1	Carbon Lighthouse	San Francisco	CA		1	Self-proprietor	Eugene	OR
2	Ecology Action	Santa Cruz	CA		2	Mesa Point Energy	Louisville	CO
3	City of San Francisco Dept. of Environment & Energy	San Francisco	CA		3	National Trust for Historic Preservation	Seattle	WA
4	Friends of San Francisco Environment	San Francisco	CA		4	Microgrid	Portland	OR
5	EHDD	San Francisco	CA		5	Energy RM	Portland	OR
6	Cadmus Group	Irvine	CA		6	BC Hydro	Vancouver	BC
7	ZGF Architects	Portland	OR		7	Cascade Energy	Portland	OR

With Work in California					Additional National/International Participants			
	Organization	City	State			Organization	City	State
8	SERA Architects	Portland	OR		8	Victoria University	Wellington	New Zealand
9	Student	San Francisco	CA		9	BOMA	Vancouver	BC
10	UC Davis	Davis	CA		10	NorthWrite	Lake Oswego	OR
11	Waypoint Building Group	San Francisco	CA		11	National Grid	Waltham	MA
12	Jonathan Rose Companies	New York	NY		12	University of Pennsylvania	Philadelphia	PA
13	City Planning Dept.	Berkeley	CA		13	Portland State University	Portland	OR
14	Glenborough Properties	San Mateo	CA		14	Vermont Energy Investment Corp.	Proctor	VT

Pilot participants submitted 45 buildings[16] representing over 4.6 million square feet of commercial office real estate, approximately 2.3 million square feet of it in California.

FirstView User Survey. NBI requested all participants in the FirstView beta test take a short survey to share their thoughts in the following four areas: overall impressions, user experience, recommended features and improvements, and demographics. Feedback from online surveys and phone interviews was generally positive. Over 80% of respondents believed FirstView could become their process for analyzing energy use or be used to enhance existing processes. Over 70% had been using Energy Star Portfolio Manager or a simple spreadsheet to track monthly energy use.

Feedback from respondents can be categorized generally into the following key themes:

- ***Target Audience*** - Results were more meaningful and understood when an experienced analyst could explain the results and implications. On their own, FirstView reports were

[16] Participants were ensured that specific building names, exact size and owners' input in the FirstView beta web tool would be confidential.

considered too technical for building 'end users' such as owners, tenants or even utility account managers. In its current form, the FirstView report template requires a level of interpretation from someone who understands the underlying technical nuances.

- ***Reporting Diagnostics*** - Especially with the 'end user' audience, the simple diagnostics (low, medium, high) were insufficient to explain next steps. The separate document entitled "Understanding FirstView Results," was inadequate. Most users recommended that suggested areas for further investigation be woven into the report instead of in a separate document.

- ***Building Types*** - The FirstView beta test was for office buildings with gas heating, electric cooling, limited process loads and constant seasonal occupancies. This became a problem for a number of users who input all-electric buildings. While NBI has developed a version of the calculation engine for all-electric buildings, this was not included in the beta web tool. For those users who encountered the 'one-fuel building' error, NBI manually uploaded their data into the all-electric calculation engine and provided results to the end user via email. Subsequent to the initial beta test, NBI updated the website to include the capability to analyze all-electric buildings.

- ***Comparisons*** - Over 80% of respondents agreed that the diagnostic interpretations from FirstView were very important. A majority of respondents (approximately 60%) appreciated the benchmarking comparison to peer buildings. Additionally, almost 60% believed the tool should include the opportunity to trend a building's performance from year to year. Designers appreciated the ability to compare design model results to actual measured performance results.

- ***Data Collection*** - Collecting monthly utility usage information is always the most difficult part of analyzing measured performance. After the data had been assembled, data entry took only 30 minutes, yet this process was called 'tedious' and remained a significant barrier to widespread use of the tool. Subsequent to the beta test, NBI updated the website to allow for uploading of a matrix of data instead of the original individual data point entry process.

- ***Explanation of Key Concepts*** - FirstView introduces a number of new concepts, such as an Energy Signature and a peer building comparison called a spectrum. Respondents suggested the introductory presentation and collateral material available online helped them understand these concepts.

- ***Technical Web Programming*** - The beta test revealed some technical bugs in the web tool. With the exception of the one-fuel building error noted above, NBI successfully addressed these errors.

Overall, feedback from the FirstView beta test was positive. Participants helped NBI identify those that have already collected monthly utility bill information as a high priority target market. This includes those who use Energy Star Portfolio Manager and those are involved in voluntary benchmarking awards or the USGBC's Building Performance Partnership (BPP) program. Other audiences include resource conservation managers at municipal governments as well as 'early-adopter' engineering and auditing firms.

1.2.4 Measured Performance Assessment Market Connections

The intent of the market connections work was to improve the relevance and applicability of the research and increase the adoption of findings. NBI connected this research with the market by engaging market actors directly as advisors, engaging actual buildings in the Measured Performance Assessments and FirstView beta test and leveraging utility and energy disclosure programs in California. Additionally, NBI has made efforts to commercialize FirstView, engaging new customers and new marketplace approaches. While the assessments (22 buildings) and beta test (45 buildings) have already been described in detail, the other market connections work is described below.

Advisors. NBI assembled the California Advisors on Measured Performance (CAMP), a group of leading commercial building professionals representing 23 different firms and organizations that offered their perspectives on various measured performance efforts. CAMP members are listed in the Acknowledgements Section:

CAMP members provided insights into current best practices in the area of Measured Performance, identified buildings for participation in the research, and served as a sounding board for new approaches recommended by NBI.

Utility Program Integration. Program integration is a critical part of the market connections work. This included connecting back to utility Savings by Design programs and other regional and national programs promoting the use of measured performance feedback. This includes presenting the research results to utilities in California and at national conferences like the American Council for an Energy Efficiency Economy (ACEEE) Summer Study and Market Transformation Symposium.

As one outreach method the initial building solicitation for participants went through the roster of California utilities and yielded some of the final participants. Representatives from Pacific Gas and Electric Company's (PG&E) Savings by Design, Sempra's Emerging Technologies program and the Sacramento Municipal Utility District (SMUD) were all part of CAMP. California utilities were informed of the participants in their service area and the research results.

The major utilities - Southern California Edison, PG&E, SMUD and Sempra - participated in meetings and webinars at which NBI presented the FirstView technology, and they were invited to participate in the FirstView beta test. NBI followed this up with email correspondence and multiple phone calls to targeted individuals within the utility. Still, the California utilities did not directly participate in the FirstView beta test. However, Ecology Action, a consulting firm that serves as a third-party implementer of utility efficiency programs, did test the tool, as did as StopWaste.Org, which provides energy efficiency services within Alameda County. They found it to be quite useful as a 'no-touch' diagnostic and a way to potentially priorities and target efficiency programs.

Public Policy Integration. Integration of performance feedback tools like FirstView into local and state-level [energy performance] disclosure policies is one possible link to codes and standards demonstrated through this work. The FirstView beta test included a representative from the City of San Francisco responsible for implementing that city's mandatory disclosure policy for commercial buildings. He noted that under their disclosure policy the City receives an annual portfolio manager score and verification that an engineering audit was performed on each building. Disclosure currently addresses only large buildings, but since they do not receive the monthly utility bills as required to run FirstView, it is difficult to integrate it into the current policy.

The representative from San Francisco suggested NBI coordinate with an EPA Energy Star Portfolio Manager since most buildings are collecting this information in that format. Another idea was to create a San Francisco office 'spectrum' and require a formal audit only if a building is above a certain defined threshold. This could minimize the overall cost of implementing the disclosure policy and focus auditing resources where most needed. NBI's work that preceded FirstView began under a contract with the U.S. Environmental Protection Agency, and the research continues to try to align with EPA regarding integration with the Portfolio Manager tool. This will continue to be an important market tool to align with and is the reason FirstView's input data is the same as that for Energy Star Portfolio Manager.

Other California municipalities are not as far along in disclosure policies as San Francisco. NBI is currently working with StopWaste.Org and the City of Berkeley on their voluntary disclosure program. Berkeley and other Alameda County municipalities have asked StopWaste.Org to organize the information collected as part of mandatory disclosure policies. This could be an important avenue to connecting the FirstView tool to California public policy.

PIER resources have made FirstView available to those buildings in Alameda County that participate in an annual Energy Benchmarking awards program. NBI partnered with StopWaste.Org, the City of Berkeley, and other cities in Alameda County to integrate FirstView into this Benchmarking program. As outlined in a formal Memorandum of Understanding, NBI agreed to train local representatives on FirstView and gave them free access and some support to the web tool for 2013 so they can download data and create reports for their program participants. NBI also supported the development of a comprehensive communications platform to promote the awards program

Additional FirstView Users. By leveraging this PIER work, NBI has a number of other partners who have used or plan to use FirstView.Table 3 summarizes these public partners and the number of buildings involved.

Table 3: Summary of FirstView Tool Users

Partner Organization	Number of FirstView Reports	Notes
Alameda County Benchmarking Awards	80	Goal of 40 organizations and 80 buildings in Alameda County
USGBC's Building Performance Partnership Program	275	86 of the reports were for California buildings
Rocky Mountain Institute's Portfolio Challenge AT&T Buildings	34	3 of the reports were for California buildings
City of Seattle	50	All city libraries and fire stations analyzed for the staff resource conservation manager
NSTAR	10	Utility is investigating opportunity associated with using FirstView as a way to prioritize energy efficiency programs.
Center for Energy and Environment – Minnesota	30	Estimated number during 2013
Seattle 2030 District	75	Estimated number during 2013

A Path to New Products. Another unique connection of FirstView to the market involves a new financing structure to create power purchase agreements. This is the focus of a private-sector firm, Energy Resource Management (ERM). NBI maintains a Memorandum of Understanding with ERM, which patented the FirstView engine technology and serves as a gateway firm to a major breakthrough in performance tracking. ERM is currently working with the Oregon Public Utility Commission, Northwest Energy Efficiency Alliance, Energy Trust of Oregon, Seattle City Light and others interested in leveraging the FirstView calculation engine to support a secondary tool – DeltaMeter - to verify savings under a Power Purchase Agreement model.

1.3 Sensitivity Analysis

Once the assessments were completed, researchers attempted to determine what metrics were most useful to collect, weighing the value of the information gathered and the cost of audits and metering to obtain the data. A sensitivity analysis helped discern the relative magnitude of energy impact that modifications to design, operation and tenant behavior measures and characteristics have on total building energy use.

1.3.1 Approach

Using the U.S. Department of Energy (DOE)/National Renewable Energy Laboratory mid-size office prototype as a representative building type, researchers defined a set of 28 distinct features representing physical, operational and occupant characteristics of buildings that affect total energy use. These characteristics included physical features, heating, ventilation and air-conditioning (HVAC) and lighting system characteristics, operational practices and tenant behavior patterns. These 28 features are shown below in Figure 8 (19 features relative to design) and Figure 9 (9 features relative to operations and tenants).

The goal was to identify the physical and operational characteristics that are the most significant predictors of energy performance (the key performance indicators) for a building in a particular climate zone.

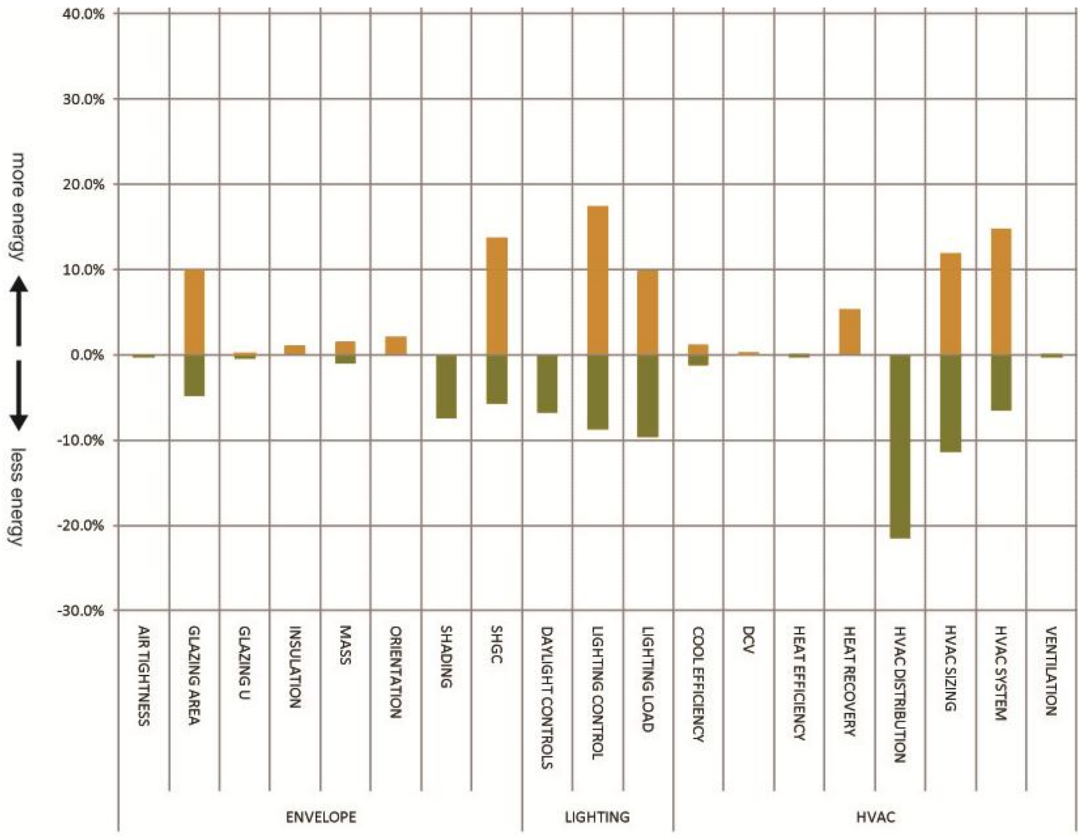
Essentially, the sensitivity analysis was a modeling exercise where each characteristic (such as lighting power density or HVAC system type) had a range of values representing poor, baseline and good practice. Each variable was individually modified from low to high performance; all other characteristics were kept at the baseline performance level in order to evaluate the impact on total building energy use. To more accurately represent interactive effects, researchers analyzed packages of good and poor measures to represent various combinations of these strategies. The results of 20,000 model runs in 16 different U.S. climate zones showed the range of performance and sensitivity that each of the characteristics had on performance.

1.3.2 Sensitivity Analysis Findings and Outcomes

Results of the modeling scenarios showed the relative magnitude of various design, operations and use characteristics on energy use in the climate zone for California used in the analysis - Los Angeles California Climate Zone 6.

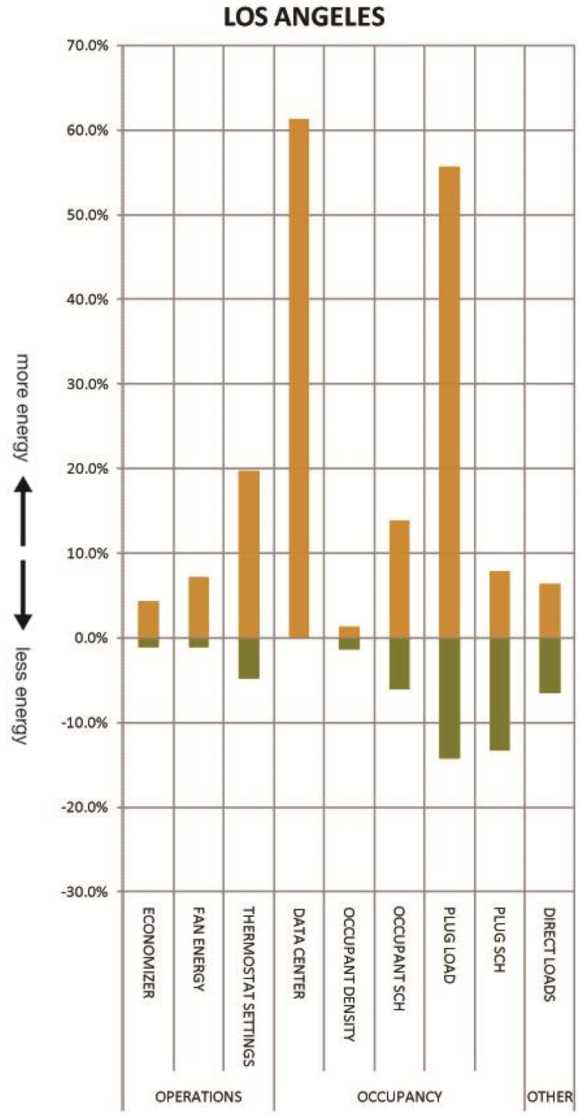
In Figure 8 – building systems - the measures that have the most potential in a building to use 'more' (above the 0% line) energy are glazing area, solar heat gain coefficient (SHGC), lighting controls/loads and HVAC sizing/system (type). All have 10% or more (but less than 20%) impact, which is significantly more than any other area of the building system itself. With regard to the HVAC distribution, ground-loop heat exchanger systems with water-to-air heat pumps saved energy in all climates, but the effect was greater in heating climates such as Los Angeles. VAV systems increased the energy use in all dry climates due to increased re-heating demands and fan energy.

Figure 8: Sensitivity of Envelope, Lighting and HVAC Measures in Los Angeles



In Figure 9 –building areas affected by occupants – the four areas that exceed 10% impact are thermostat settings, data centers, occupant schedules and plug loads. Of these, two – data centers and plug loads – have potential adverse impact on energy use of 50% or more. The presence of even a small data center has a huge impact on total building energy use, which implies that the assumptions about data center operating characteristics are critical to any analysis.

Figure 9: Sensitivity of Operational and Occupant Characteristics



A key outcome of the sensitivity analysis is that although the market generally assigns responsibility for building energy performance to the design team, this study shows that operational and tenant practices have a very significant impact on building energy use. Importantly, these activities (such as plug load use and data centers) are not currently addressed in any codes.

1.3.3 Sensitivity Analysis Market Connections

The Sensitivity Analysis received widespread attention in the media. More than 700 users have viewed the Sensitivity Analysis on NBI's website. In addition, it has been highlighted in nine publications and six presentations, summarized in Table 4 and Table 5.

Table 4: Sensitivity Analysis Media – Nov. and Dec. 2011

Publication	Title and Hyperlink to Article
GreenSource	*"The Next Frontier in Green Building"*
Environmental Design + Construction	*"Impact of Design Decisions, Operations and Tenants on Building Energy Use"*
Environmental Building News	*"Occupant Engagement–Where Design Meets Performance"*
RealEstateRama	*"NBI study shows impact of design decisions, operations and tenant behavior on building energy use"*
FacilitiesNet	*"NBI Study: The Impact Of Design Decisions, Operations And Tenant Behavior On Building Energy Use"*
Construtech	*"Paying Attention to Energy Consumption"*
BetterBricks Blog	*"Atlas Shrugged: The Burden of Energy Performance"*
GreenBuilding News	*"Energy Use Study Examines Design Features, Operations and Tenant Behavior"*

Table 5: Sensitivity Analysis Presentations

Presentation Event	Date
NBI Stakeholder Briefing Webinar	October 2011
Build Boston Exhibit	November 2011
ASHRAE High Performance Building Conference	March 2012
ACEEE Symposium on Market Transformation	April 2012
ACEEE Summer Study on Buildings	August 2012
Emerging Technologies Conference	October 2012

1.4 Key Performance Indicators

The KPI work used all of the research described above along with system-level metering on two buildings to expand beyond whole-building metrics. KPIs are specific metrics that can be compared to ranges of performance that buildings should aim to meet. These are based on observations of commercial building attributes and the correlating monthly utility metered data.

1.4.1 Approach

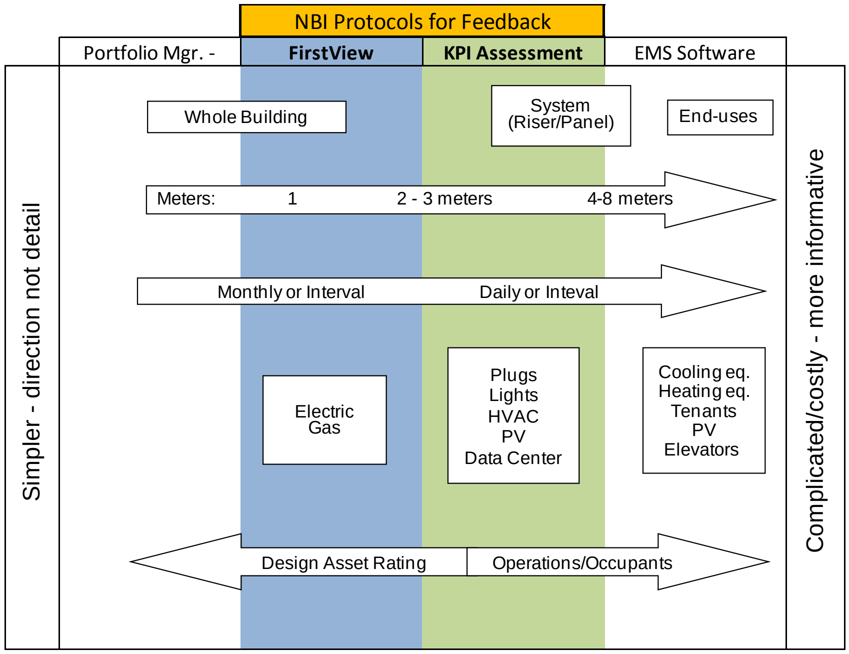
As part of the effort to develop KPIs, NBI instituted system-level[17] metering in two office buildings: a 14,000 sf. office in Oakland, California, and a 5,500 SF office in Vancouver, Washington. Researchers collected system loads by installing sub-meters (advanced interval meters downstream of the main utility meter) at key points where system loads were aggregated.

NBI focused on creating KPIs that could be benchmarked against other buildings, a design model, or compared against past utility bills or system metering. The work did not seek to replicate the functionality of more complex and expensive Energy Management Information Systems (EMIS) that provide day-to-day feedback to building operators, Energy Management Control Systems (EMCS), Building Automation Control (BAC) systems that provide a level of control and correction, or occupant dashboards that provide occupant feedback on usage. The site visits to the two buildings did review building automation system data, however, the focus was on providing high-level key information in the absence of, or as a complement to, the more complex and expensive monitoring methods.

The various levels of building performance assessment had distinct levels of detail, time periods and costs/effort, as shown in Figure 10. The diagram section titled "NBI Protocols for Feedback" in Figure 10 represents the overlay of the project approach within the larger context of performance review and metering.

[17] Systems are the distinct energy use functions in buildings such as the heating, ventilation and air conditioning (HVAC), lighting and plug loads.

Figure 10: Levels of Metering and Analysis Progressing from Whole Building to Systems



As with any other numerical calculation of energy usage, KPIs are usually only useful when placed in the context of comparisons to expected or historical behavior. Each indicator provides a piece of evidence. The intention is that all key indicators be used as clues and combined with other analyses, such as FirstView, to reveal a final assessment. Broadly these comparisons are to a large data set of similar buildings (benchmarking), a private portfolio of similar buildings, historical data and/or design model expectations.

1.4.2 Technical Findings and Outcomes – The KPI Metrics

This section provides an overview of identified KPIs for each of the DOT audiences. The KPIs were defined based on metered data at the two buildings plus other measured performance field research conducted by the team over the previous five years[18]. The first target audience for feedback is the design team – both architects and engineers. Designers are typically removed from the actual outcomes of the buildings they design. The whole-building metrics of EUI described earlier can provide an overall sense of the building compared to their whole-building design estimates but do little to distinguish what aspects are affecting energy use.

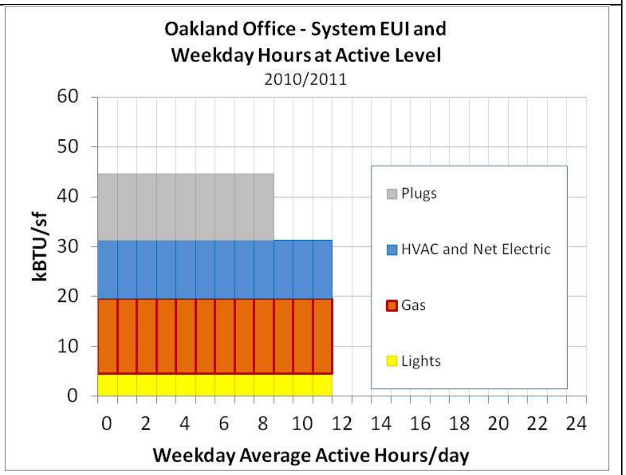
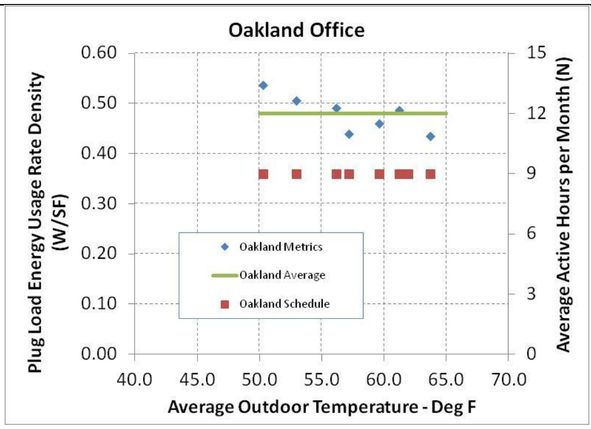
The set of energy key performance indicators in Table 6 shows how nine designer KPIs were used at one research site located in Oakland, California. Some indicators looked at the big picture, such as the System Schedule Annual Energy Use Index, while others provided feedback on areas specific to design such as the Daylighting Effectiveness indictor or the overall Lighting Design metric.

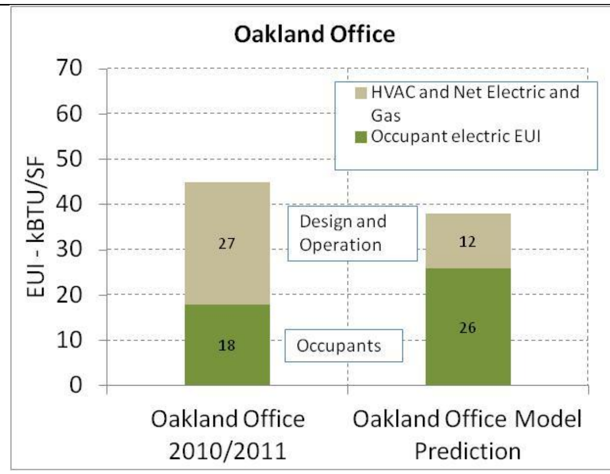
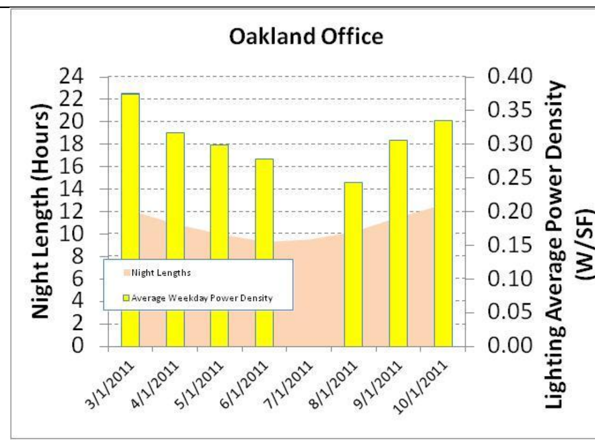
[18] Field metering at NBI Utility Partner *Office of the Future* sites gave additional data and foundation to the selection and validation of the PIER KPIs.

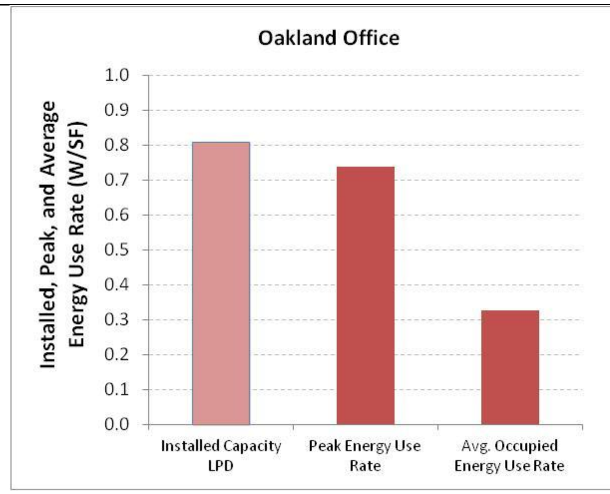
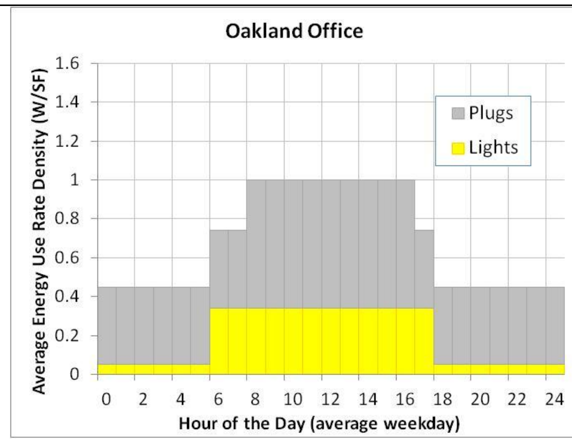
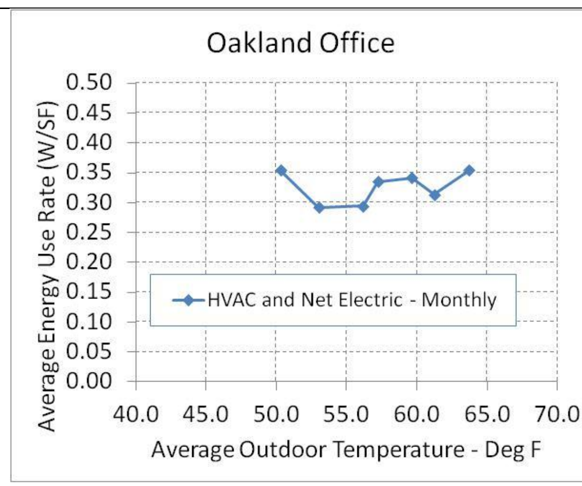
For example, the Daylighting Effectiveness KPI considered whether lighting is turned off or reduced when daylight is available. If the design team included daylight controls in the building, the KPI should indicate a good correlation of reduced electric lighting during daylight hours. Rather than simply say the building is using more energy than designed based on a whole-building metric, these KPIs drill down and give feedback on the reasons the energy use differs from design intent.

Other designer KPIs focused more on occupancy – such as Occupant Stability and Occupant Usage - paying attention to both weekly and annual patterns and subsystem-level use. Understanding occupancy-related KPIs assists the design team in learning whether lighting and plug load KPIs are within expected design parameters. Providing both design and occupancy KPIs gives a design firm feedback on its role in a building's energy performance.

Table 6: Example of Designer KPIs Applied to an Oakland Office Building

KPI	Inferences	Sample Plot
System Schedule Annual Energy Use Index (EUI)	Oakland building may be occupied 12 hours per day, though the plug-load schedule infers there is significant use only 8 hours per day. One can see that even though the lighting has a longer schedule, the plug load is significantly larger.	
Occupant Stability	The magnitude of the plug loads (diamonds) in the Oakland office was decreasing slightly while the schedule hours (squares plotted on Right Y-axis) remained the same. This suggests occupancy was moderately stable with no drastic changes.	

KPI	Inferences	Sample Plot
Occupant Usage	Particularly notable are the Off Hours and Weekend Ratios which demonstrate what proportion of energy used during occupied hours is used at night and on weekends, respectively.	Off-Hours Ratio 70% Weekend Ratio 78%
Design and Operations Versus Occupants	The top portion shows the annual EUI attributed to the systems HVAC and Net Electric and the Gas use (Design and Operation), while the bottom section shows the annual EUI for the plug load and lighting systems (Occupants). Since the Oakland office also had annual EUI data from its design model, we can plot this for comparison. The percent of HVAC and net in the original model prediction was 32% of the total energy use however HVAC measured energy use was 60%.	
Daylight Effectiveness	Lighting energy use in Oakland responds very well to daylight hours. As the daylight hours increase in the mid-chart summer months you see a correlated decrease in the column bars that represent average lighting power use. *Note – no data was collected in July in the example graph*	

KPI	Inferences	Sample Plot
Overall Lighting Design/ Performance	The lighting performance at the Oakland site - expressed in lighting power density (LPD) – is performing at 50% better than the installed design LPD (just over 0.3 watts (W) /sf versus design of 0.8 W/sf)	
Lighting and Plug Load Design Equivalence	Oakland data reflects the difference in the lighting and plug load schedule seen in the indicators above. Without this comparison these indicators only serve as a further representation of the relative magnitudes and schedules of the lighting and plug loads.	
HVAC and Net Electric Balance Point	This particular indicator was not clear in the Oakland site.	

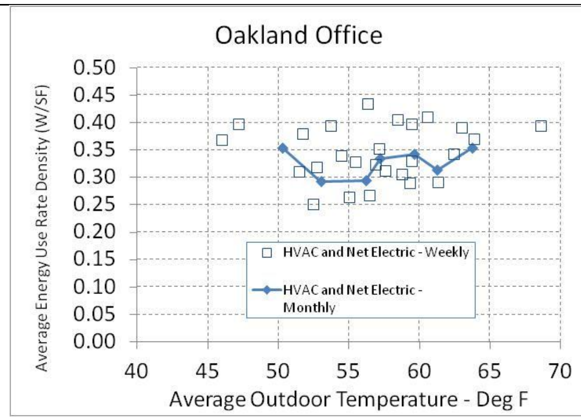
KPI	Inferences	Sample Plot
Operational Consistency	Erratic plot implies that control-related issues might be contributing to increasing heating and cooling energy use. Does not clearly assign responsibility to design and or operation but shows there is reason to doubt the Oakland Office EUI represented its best possible performance for the given occupancy.	

Table 7 the designer KPIs from system-level metering are again presented in a format that is also used to explain operator KPIs (Table 8) and occupant KPIs (Table 9). These tables provide the overall KPI purpose and a description of what to look for. As seen in the research site example plots in Table 7 above, the KPIs require some base understanding of building systems and energy use along with experience interpreting the indicator compared to a target or outcome desired by the audience. The interests and outcomes vary by audience, but in all cases this short list of KPIs can be fairly quickly put in place and learned if system-level data is available.

Table 7: Nine KPIs for Designers

	Key Performance Indicator	Purpose	What to Look For*
1	Schedule Visualized Annual System Energy Use Index (EUI)	Indicates what system is responsible for the most usage and its approximate schedule of typical activity.	Verify these are in line with expected values from the design or portfolio benchmarks. Ensure HVAC and net electric is not far outside lighting or plug load.
2	Tenant Stability	Provides insight through plug load use on the occupancy density or hours changed (thus not 'stable') compared to the design estimates or to a previous year or dataset during the year of performance review.	Check if actual tenant usage is outside of expectations to determine if occupancy is a cause of variations in actual energy use versus design estimates.

	Key Performance Indicator	Purpose	What to Look For*
3	Tenant Usage	Provides more detail and assessment of how occupant usage impacts the building energy use and is a way to assess the magnitude of occupant usage compared to benchmarks.	Look at Off-Hours ratios – which should be low - to determine if energy is being consumed in hours of low occupancy.
4	Design and Operations Versus Tenants	Provides a numerical assessment of how close the design and operation values are to the tenants' actual usage values.	Compare the ratio of design and operations to occupant usage to assess if actual energy use is far from estimates.**
5	Daylight Effectiveness	Determines if the daylight design and controls are effective.	Lighting energy use should be varying with the length of nights if controls are enabled. Use historical trends of this KPI as the baseline.
6	Overall Lighting Design Performance	Determines the accuracy of the lighting design expressed in lighting power density (LPD) actual usage.	The actual LPD should be equal to or less than the design LPD.
7	Lighting and Plug Load Design Equivalence	Checks the performance of the lighting and plug load systems in metrics similar to those of a design model.	The watts should be as low as possible (targets are from the design model or industry standard) and the inactive values should be a reduction compared to active.
8	HVAC and Net Electric Balance Point	Uses an energy signature to determine a key attribute of the magnitude of the HVAC and net electric contribution toward the building energy use. Tracks changes in simultaneous heating and cooling.	A decreasing balance point indicates that simultaneous heating and cooling or common area base load is being reduced. Should ideally be near zero.

	Key Performance Indicator	Purpose	What to Look For*
9	Operational Consistency	Checks the consistency in operational settings.	Using an energy signature, erratic weekly data compared to the expected, historical or modeled trend line indicating that operational controls or functions may be playing an adverse role in energy use.

KPI Table End Notes:

**KPIs 'targets' vary by building type, use etc. They are usually readily available for a particular building from the design team based on the design model or from an operator based on settings or historic trends.*

**For this KPI, HVAC and Net Electric represent the Design and Operations portion of energy use versus the Occupant Load which is extracted from plug and base load data. In the Oakland building example (Table 6) the design model estimated 32% for the Design and Operations portion of total energy use (12 EUI out of an estimated total 38 EUI) while the actual energy use at the building for this portion was 60% of the total (27 EUI out of a total actual EUI of 45). This may be explainable due to as-operated changes in the building compared to design, or it may indicate an error or weakness in the design assumptions by the design team of the façade or HVAC system. The objective is to provide the feedback that raises the question and can, in the case of the design team, improve subsequent modeling inputs. For operators, it can direct them to control problems that may be able to be corrected in real time for real energy improvements.

Table 8 describes the operator KPIs derived using system-level metering. The underlying metrics of these indicators are similar to the design metrics but differ in subtle ways that provide operators with more specific feedback in areas they can influence. Ideally operators would review these metrics a minimum of quarterly to ensure the building stays on target for energy performance.

Table 8: Five KPIs for Building Operators

	Key Performance Indicator	Purpose	What to Look For
1	Operational Schedule Consistency	Compares lights, plugs and HVAC schedules to ensure alignment and also establish occupancy stability.	The HVAC and net electric schedule should be less than or equal to the plugs and lighting.
2	Lighting and Common Area Usage	Compares metrics of common area and lighting base load usage to reveal savings opportunities that the operator can address or track.	All metrics should be as low as possible.
3	Daylight Effectiveness	Similar to the design KPI this compares occupied lighting performance with night lengths (less use on short nights) to establish daylight controls functionality.	Lighting energy use should be varying with the length of nights if controls are enabled. Use historical trends of this KPI as the baseline.
4	HVAC and Net Electric on Unoccupied Days	Provides an indicator of unnecessary HVAC operation when no tenants are present.	Maintain at zero for all months.
5	Operational Stability	Similar to the design KPI this indicator reveals operational inconsistency through a comparison of monthly and weekly data.	Using an energy signature, erratic weekly data compared to the expected, historical or modeled trend line indicating that operational controls or functions may be playing an adverse role in energy use.

Tenant KPIs provide feedback on energy-use trends in a way that makes for easy comparison to other, similar sites. Tenant KPIs, shown in Table 9, should be shared with occupants on a regular basis so they might take actions to reduce their energy usage. The use of consistent metrics will increase the relevance of comparisons to other facilities.

Table 9: Three KPIs for Tenants

	Key Performance Indicator	Purpose	What to Look For
1	Tenant Plug Load Feedback	Provide a means to show occupants how their plug load usage compares to other like-type occupants and track performance.	As low as possible for all metrics or in line with benchmark targets.
2	Tenant Lighting Feedback	Provide a means to show occupants how their lighting usage compares to that of like-type occupants and track performance.	As low as possible for all metrics or in-line with benchmark targets.
	Off-Hours Ratio (embodied within the two metrics above)	Demonstrates the periods of occupancy highlighting the energy use in unoccupied time periods as a ratio of full occupancy.	The ratio should be very low with little to no energy use during unoccupied schedules.
3	Tenant Schedule Assessment	Provide the tenants with an idea of how the building is used day to day.	Watch for consistency. This can ensure that If the metrics above change the tenant schedule was not the cause.

1.4.3 Key Performance Indicators Market Connections

While the formal outreach for the KPI work is just beginning, NBI and its team has brought the PIER research into many prominent venues (listed in Table 10). In all cases NBI sought to a) inform attendees about the value of benchmarking and measurement, b) demonstrate actual data from the research, c) describe methods and tools (KPIs and FV) available or in process and d) meet with and solicit market partners for the project.

Table 10: Measured Performance, Feedback, KPI and FirstView Presentations

Presentation Event	Date
ASHRAE Winter Conference	January 2012
NBI Stakeholder Webinar: Office Plug Loads Energy Use and Savings Opportunities	January 2012

Presentation Event	Date
ASHRAE High Performance Building Conference	March 2012
Garrison Institute Climate, Buildings and Behavior Symposium	May 2012
NBI Stakeholder Webinar: FirstView diagnostic tool for building energy performance	May 2012
PIER Outreach Webinar: FirstView Beta Test	June 2012
NBI Stakeholder Webinar: Plug Load Best Practices Guide	September 2012
ACEEE Summer Study on Buildings	August 2012
World Energy Engineering Conference	October 2012

NBI's website section on Measured Performance includes information on the PIER research as well as more specifics on KPIs and FirstView. Approximately 200 unique users have viewed the KPI report, and 384 unique users have visited the FirstView webpage. The two-page FirstView overview and report example have been downloaded over 30 times and the technical paper over 60 times. By spring 2013 NBI will have a dedicated page with the most market-relevant reports, resources and tools from this PIER research, links to related work and promotion to the 7,000-plus efficiency allies on NBI's communication lists.

Having team members that frequently interact with key stakeholders will continue to bring the results forward after the formal contract period ends is a highly valuable aspect of the PIER work.

1.5 Benefits to California

The *High Performance Buildings Measured Performance and Feedback* research built up the knowledge, tools and understanding of data associated with measured performance of buildings in California. As such it worked as a market transformation approach rather than development a single specific technology with savings per unit. Based on this, specific quantification of savings to the State of California is not available. Despite the inability to quantify direct energy savings, the work brings significant benefits to California, as summarized below.

Measured Performance Assessments. This research is the first of its kind to characterize and represent the gap between measured and predicted energy performance in newly constructed high performance buildings in California. It continues to drive attention to the value, yet absence, of measured performance feedback. This research builds on work NBI has done for the USGBC and confirms that, for various reasons, buildings do not necessarily perform as energy models predict. Since most utility efficiency programs are based on predicted performance, this research has significant implications for future actions.

Sensitivity Analysis. The research supported a comprehensive energy modeling exercise that characterized the variability associated with a wide assortment of building characteristics, operations and occupant behaviors. The Sensitivity Analysis provides a broad perspective on how buildings use energy and what aspects of building energy performance deserve more attention in design, operation and policy strategies. Significantly, the study demonstrates the dominant impact operational and tenant practices have on building energy use. Without measured performance feedback these groups have no method to detect possible problems and potential improvements that can benefit their interests and those of the energy community. Subsequent work on the topic of energy measure sensitivity in California was funded through PG&E's zero-net-energy (ZNE) program. ARUP, the contractor on the PG&E work, referenced this PIER research and conferred with NBI toward their final analysis.

Key Performance Indicators. The research proposed Key Performance Indicators along with measurement guidelines and metrics that have broad applicability in California. They included the reason for 'designing for meterability' as a critical pathway so that data can be most easily collected in a way that best supports a dialogue in the industry and eventually public policy.

This KPI work also identified the impact of plug loads to overall building energy use for the two sites studied and served as a top-down cross check for the device-level metering outcomes of Chapter 3 – Plug Load Savings Assessment within this report.

In addition to the KPI report, NBI developed web-based guidance on KPIs and a Metering and Metrics Protocol. One recommended metric to address plug loads is to consider a ratio of plug-load equipment left on at night or during presumed unoccupied hours compared to levels kept on during occupied hours. A lower ratio indicates equipment is being properly controlled and/or turned off at night or on weekends.

FirstView Performance Feedback. Finally, development of the FirstView tool demonstrated a scalable and affordable energy performance feedback mechanism. Since many disclosure policies are dovetailing with Energy Star Portfolio Manager, tools that align with the same data are in a good position to provide more information about where to target energy audits and improvements from these limited data inputs. Furthermore, in addition to benchmarking and disclosure, utilities can utilize remote performance assessment tools to prioritize their efforts in energy efficiency, thus reducing the programmatic costs associated with managing these programs.

1.6 Conclusions and Next Steps

The commercial building market knows little about how buildings actually perform. New construction programs like Savings By Design and LEED rely on modeled energy consumption (expressed as percentage better than code) to predict performance. This current PIER research confirmed that the actual performance of even those buildings designed to 'high performance' standards varies from predicted results.

This project also demonstrated, by both modeling and site-metered data, that a building's energy use is a product not only of its design and construction, but is also driven in great part by operations, occupants and use. Yet there is a critical lack of feedback to designers, tenants and even operators about how their actions directly impact ongoing building performance, particularly in the case of existing buildings. This *High Performance Buildings Measured Performance and Feedback* research project aimed to close the feedback loop in an effort to identify measured performance metrics that would be meaningful to designers, operators and tenants.

Some programs such as Energy Star Portfolio Manager rely on measured performance data to compare to national benchmarks. However, beyond a whole-building benchmarking score they provide no insights into what areas merit further investigation to mine for energy efficiency improvements. Metering and audits are expensive, and it is difficult to know where to start or what to do.

This research investigated a small yet compelling data set that clearly makes the case for the importance of incorporating measured performance and feedback in a way that informs and inspires action. It helped identify the metrics, reporting tools and procedures necessary to ensure prompt, easily understood and actionable performance feedback to each particular interest group. For example, designers need to know how their newly constructed building's measured EUI compares to the predicted EUI. They should also understand how occupancy patterns vary from market assumptions.

New tools can provide this type of feedback quickly and at low cost. One example is FirstView, a diagnostic and comparison tool supported through this research. FirstView is unique in that it creates a simplified and self-calibrating energy model. It automatically segregates monthly utility bills into energy end-use categories associated with design, operations and occupants. It provides insights that can determine if a building's energy performance is on track or off target. If the latter, FirstView can identify particular areas warranting further investigation.

Based on the same issues and industry needs seen by NBI in its 2008 proposal for this PIER research, the market has recently progressed from having little to no resources for performance review to having a number of new and emerging tools. At least 8-12 companies have entered the market with performance review tools. This validates the research concept but complicates the role and future of FirstView in a more private-sector market. As a nonprofit, NBI's focus is to spur market change where needed and create resources and tools to fill gaps.

The research team anticipates that this work, and the increase in new players in this area, will more rapidly close this building performance feedback gap, providing understanding and action toward improvements.

1.6.1 Next Steps

NBI recommends the following next steps to enhance the findings of this research project:

- Expand the dataset on measured performance to include more new and existing buildings.
- Focus on buildings that participate in utility incentive programs like Savings by Design. For buildings that receive funding from these programs, consider standard data collection approaches so information can be accessed for additional research. Also

consider requiring a follow-up submittal of measured performance to confirm that results align with predictions.

- Promulgate standardized industry metrics on measured performance as outlined in the KPI report. Consider 'outcome-based codes' to ensure performance.
- Engage in policy discussions about the importance of plug loads, new metrics (as suggested through this work), and the need to design for easy meterability. Encourage regulations to address these three topics in future iterations of Title 24.
- Encourage the use of diagnostics and advanced benchmarking tools such as FirstView that use an Energy Signature to analyze benchmarking data. This could include:
    - Explain the concept of using Energy Signatures broadly through targeted market channels and a media strategy, including industry events and media placements.
    - Support the integration of FirstView into voluntary and mandatory benchmarking programs in California. Work with StopWaste.Org, an organization focused on what to do with collected benchmarking data in Alameda County; this could serve as a model for others.
    - Expand aggregate building data sets so that system-specific diagnostic thresholds and peer building comparisons expand beyond offices to other building types.
    - Encourage public buildings to use a tool such as FirstView to analyze overall portfolio performance and identify high-priority opportunities for audits and further action.