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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The Energy Research and Development Division strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

Energy Research and Development Division funding efforts are focused on the following RD&D program areas:

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- Renewable Energy Technologies
- Transportation

Evidence-Based Design and Operations is the final report for the Evidence-Based Design and Operations project (contract number 500-08-049) conducted by New Buildings Institute. The information from this project contributes to Energy Research and Development Division's Buildings End-Use Energy Efficiency Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

This report presents the results of the Evidence-based Design and Operations research program led by New Buildings Institute from 2008-2013. The program included four technical projects for commercial buildings. The first project developed feedback tools for designers, operators/owners and tenants as aides to reduce building energy use. These tools featured new and unique data analysis capabilities. The other projects included: field measurement to quantify and estimate potential plug load energy savings; validating computer simulation for skylight systems evaluation; and developing a method and software to evaluate rooftop heating and cooling units fault detection and diagnostic protocols.

The research team examined energy bills and conducted site monitoring of 22 new high performance buildings in California to assess measured energy compared to code and design, finding most buildings not better than comparisons. The project also determined the energy use impact of building features and operations through a sensitivity analysis and introduced *FirstView™*, a tool that identified areas to investigate for potential efficiency improvements.

The plug loads study measured the energy use in major categories of office equipment at two buildings. This study then quantified energy savings from implementing conservation strategies, including changes to hardware and software and using messages to influence occupant behavior. The skylight research validated the ability to define and develop accurate computer simulation methods for producing useable skylight photometric data as an alternative to relying solely on physical measurements.

The fault detection and diagnostic study included a market assessment of current products and produced a new protocol evaluator software that determined the accuracy of tools designed to detect faults that impede operating and energy performance of rooftop units. This research helped implement a new mandatory fault detection and diagnostics requirement in Title 24, part 6 (2013).

Keywords: Measured energy performance, commercial building energy efficiency, skylights, plug loads, key performance indicators, fault detection and diagnostics, Sensitivity Analysis, FDD, FirstView, Plug Load Guide

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EXECUTIVE SUMMARY

Introduction

Achieving California's ambitious energy and environmental goals and policies depends, in part, on accomplishing dramatic improvements in the energy efficiency of new and existing commercial buildings. This commitment is evidenced by the existence and progression of advanced building codes and appliance standards and the abundance of utility energy conservation incentive programs. Recent studies on the actual measured energy performance of newer generations of commercial buildings (those designed for high energy efficiency) show a wide range of energy performance; some buildings are performing far below design expectations. For example, the research teams' 2008 study of measured energy performance of Leadership in Energy and Environment Design –New Construction (LEED – NC) buildings found average savings of 28 percent compared to national code, but energy use at one-quarter of the buildings was near or higher than the allowable code baseline level. This performance shortfall must be better understood and corrected so that efficiency "as designed" is in alignment with efficiency "as measured."

Project Purpose

This research improved the measured energy performance of the next generation of California commercial buildings. To accomplish this goal the researchers examined 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 a series of project elements focused on identifying key feedback loops and tools that could better inform designers, operators/owners and tenants (DOTs) about their role in optimizing building performance. The research"connected the DOTs" by identifying the key areas of performance related to each party having a role in energy use.

Project Results

This report summarizes the findings for the *Evidence-based Design and Operation* research program led by New Buildings Institute (NBI) and its subcontractors for the California Energy Commission's research and development program. Research between October 2008 and March 2013, included studies on key performance indicators for whole-building and system-level energy analysis, plug load energy savings strategies, an evaluation methodology for skylight system and materials performance using computer simulation. A methodology for evaluating the effectiveness of fault detection and diagnostic protocols that identify and measure operational faults in rooftop heating, ventilation and air conditioning equipment was also studied.

High Performance Building Measured Performance

In 2008, when this research was proposed, 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. Feedback from occupied buildings can be used by designers to update 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.

The research team used monthly utility bills to assess measured actual vs. designed energy performance of 22 new California buildings whose design targets were intended to significantly exceed simple energy code compliance. Research on these buildings found they performed much better than the national average per building type. More than 70 percent of those eligible for an Energy Star score were in the top 10 percent of like-type buildings nationally. An Energy Star score is a national benchmarking comparison to similar occupancy buildings by climate area and greenhouse gas emissions associated with energy use. The research found little correlation between a building's actual measured energy performance (energy use intensity and Energy Star score) and ratings such as LEED energy points that represent estimated energy performance. Many failed to achieve their original estimated high performance design goals compared to similar buildings in the California Energy Use Survey (CEUS) for Nonresidential Buildings (2006) database. These findings further demonstrated that there is often a discrepancy between expected energy performance and actual measured outcomes.

FirstView, an automated remote energy performance assessment software tool was developed and piloted (beta tested) by 28 companies responsible for more than 4.6 million square feet of commercial floor space. This tool segregated monthly utility bills into energy end-use categories (lighting, plug loads, heating and cooling), each uniquely affected by the actions associated with design, operations and tenants. Its analysis provided insights that can determine if building performance was on track or off target. FirstView could also identify specific problem areas for investigation where energy use was higher than expected.For an office building in Los Angeles, for example, poor or inefficient design features could increase the energy use by 10-20 percent. 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 percent more than necessary in this same building.

Mandatory energy use "disclosure policies" associated with property transactions are becoming widely adopted by local jurisdictions nationwide. These policies make building energy performance transparent so that 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. Without monthly energy bills this information is insufficient for a full performance review. The Energy Star score was good for broad comparisons but did not provide any information which owners could use to determine how energy efficiency could be improved.

Some municipalities have created voluntary programs focused on public disclosure of building energy use and incentivized participation in these programs by giving awards for top energy performers. The research team partnered with StopWaste.Org, the City of Berkeley and two other cities in Alameda County to employ a FirstView building evaluation for all 2013 participants in their *Smart Energy Awards*.

Programs such as Energy Star use measured performance data from utility bills to compare energy performance to national benchmarks, which was an important step in raising awareness

of energy use. Benchmarking programs were important but provided no insights to designers, operators/owners and tenants about what areas to mine for efficiency improvements. Metering and audits were expensive and complex. This project demonstrated that with easy-to-use tools, the simplest data – found in monthly energy bills – could provide useable energy performance feedback to guide actions for energy efficiency.

Plug Load Assessment

The Plug Load Savings Assessment research project characterized the electricity consumption of office equipment plug load devices and identified opportunities for energy savings. Plug loads (miscellaneous electric devices that plug into wall outlets) are one of the largest and fastest growing electric end uses in commercial buildings in the United States. Plug loads in California on average account for 13 percent of total electricity consumption in commercial buildings and 23 percent in offices specifically.

The research team inventoried the type and quantity of plug load devices in two recently LEED-certified buildings in California. A subset (n=100) representing a diversity of office equipment was established to track power use at one-minute intervals for one month. These measurements established the baseline energy use and load profile of the sample set. In the second phase the team implemented energy saving strategies and measures on 39 items and then monitored the energy use on those devices at one-minute intervals for a second month. This enabled the team to estimate the energy savings effects of each efficiency strategy by plug load device category and overall annual savings potential for each of the office building sites.

The baseline office equipment energy use as a percent of the studied set of plug loads per device category was measured as: 1) desktop computers, 70 percent; 2) imaging equipment, 17 percent; 3) monitors, nine percent; and 4) miscellaneous loads, five percent. The first three items accounted for approximately 95 percent of measured energy use.

Five key savings strategy areas produced immediate plug load savings: 1) power management changes set more aggressive power management settings on imaging equipment, enabling computer power management settings; 2) advanced plug strips to stop power flow to peripheral equipment when the primary device was turned off and timers set to turn equipment off at the end of the day and weekends; 3) adjusting monitor brightness to meet user needs without defaulting to the maximum brightness; 4) change occupant behavior by sending notices to staff to turn off equipment at the end of the day and to initiate office energy awareness campaigns or competitions; and 5) equipment procurement strategies involving purchasing the highest efficiency option at the time of equipment upgrade.

This study showed it is possible to significantly reduce plug load energy use in high performance buildings. Measures installed on 24 devices at the small office reduced the energy consumption of the affected plug loads by 46 percent. Measures installed on 15 devices at the library reduced the energy consumption of the affected plug loads by 17 percent. No- and low-cost energy savings strategies could save about 19 percent of total studied plug energy use at the library and 40 percent of the studied plug load energy use at the small office if these findings were extrapolated to estimate potential energy savings for a realistic scenario at each

site. Savings opportunities may be greater in buildings with higher plug load densities. Any strategies that successfully reduce plug loads will be critical for California to reach a policy goal of zero-net energy for newly constructed commercial buildings by 2030.

A number of issues existed related to the study and quantification of savings strategies for plug load energy use. One was the lack of a uniform definition for plug loads. Secondly, meters were sometimes configured in buildings to serve several systems or building areas on the same circuits. This made device or device category energy use harder to determine over time, particularly given the existing lack of knowledge regarding individual device electric load profiles. Submetering individual circuits was expensive, limiting the viability of doing it over extended time periods. It was difficult to know with certainty if some of the strategies employed in this study would persist over time.

Enhanced Skylighting Modeling and Validation

The enhanced skylight modeling and validation project defined, developed and validated accurate computer simulation methods for producing skylight photometric data. Interior lighting accounts for the largest portion of electricity used in California's commercial buildings – almost 30 percent. Commercial building skylight and daylighting products that were integrated with controls that lower electric lights in response to daylight could significantly reduce lighting energy use. The physical measurement methods were constrained by factors including skylight size, sky opening, photometric (light measurement) resolution and available geographical aspects (solar altitude).

The research had two primary tasks in developing validated photometric files: measurement and conducting simulations using the data. The measurement task collected real-world skylight system photometric data and combining it with simultaneous measurement of a variety of sky and solar light conditions. The simulation task used field data from the measurement phase to perform comparable computer simulations of the skylight systems. Three skylight configurations were selected to test a representative range of different optical complexities and installation configurations. The simulation task developed modeling protocols and simulation methodologies and validated these by demonstrating correspondence with the data provided in the measurement tasks.

The researchers created representative computer models for the entire daylighting system: sky and sun source, skylight system geometry and material characteristics, and near-field meter locations. The research team successfully used computer models based on field data to predict skylight systems performance and to produce replicable modeled results. These findings represented new and validated research outcomes that were transferable to manufacturers, researchers and academics.

Rooftop Unit Fault Detection and Diagnostics

The rooftop unit fault detection and diagnostics research project improved the potential energy performance in HVAC roof top units of 5-50 tons in California through three research outcomes: 1) developing and deploying software for evaluating diagnostic protocols that

identify and measure the severity of operating faults in roof top units; 2) conducting a market assessment on the availability, usability and cost-benefit of commercially available FDD products; and 3) proposing a minimum standard for fault detection and diagnosis functionality to Title 24 part 6 of the California Nonresidential Energy Efficiency Standards (Title 24).

Rooftop packaged air conditioners are the predominant HVAC system found on commercial building rooftops in California and throughout the United States, cooling over 60 percent of the commercial floor space. These systems usually do not receive regular and/or thorough preventative maintenance, primarily because of little perceived value by owners and the HVAC service industry. Service calls are generally limited to filter changes and visual inspection or occur as an emergency response to major system component failures that impact occupant comfort. Technicians typically only detect severe and obvious fault conditions even with equipment maintained under formal maintenance contracts because their procedures only involve routine qualitative assessments. This means non-catastrophic faults that cause significant energy waste can go unnoticed for years.

Private sector companies provide a variety of tools to measure the performance of newly installed and operating HVAC equipment but there is no national standard for evaluating the accuracy of available tools or their methods for measuring performance in the field. HVAC service technicians must discern the specific conditions and appropriate tune-up needs of individual roof top units. Having the ability to verify the accuracy of their methods will ensure the work is being done effectively and this will result in energy savings for California.

The final phase of the project developed a proposal to the 2013 Title 24 part 6 buildings standards for fault detection and diagnosis. The research team joined forces with the Codes and Standards Enhancement (CASE) team supported by the California utilities. The collaborative team initially looked at 11 potential fault detection functions. A working group of the Western HVAC Performance Alliance (WHPA) including major HVAC manufacturers, researchers, private engineering company personnel, utility staff and FDD tool providers negotiated a Title 24 submission package on fault detection and diagnosis. This was proposed as a prescriptive measure option but further negotiation led to an approved mandatory measure for all new and replacement roof top units 4.5 tons or larger, which became effective January 2014.

The research met its original scope to develop a software tool for evaluating diagnostic protocols for fault detection and diagnosis that determine high or low refrigerant charge, high or low evaporator airflow, and condenser coil fouling. Three new fault evaluation parameters were added to these initial fault detection and diagnosis conditions thanks to research collaboration with the National Institute for Standards and Testing (NIST): liquid line restriction, non-condensable in the refrigerant circuit, and compressor valve leakage, resulting in nine fault detection areas for the Evaluator tool. Few commercial fault detection and diagnosis tools currently provide detection for these last three faults but tool providers may be motivated to add these to gain market position now that a third-party tool can evaluate their accuracy.

Project Benefits

The projects completed in this study demonstrated several ways to increase energy efficiency and reduce energy use in commercial buildings in California. Reduced energy use will help decrease greenhouse gas emissions that contribute to climate change and air emissions that cause air pollution.

CHAPTER 1: Introduction

This is the Final Program Report (Final Report) for the *Evidence-based Design and Operations* research program (Program) led by New Buildings Institute (NBI) on behalf of the California Energy Commission's Public Interest Energy Research (PIER) program. The research occurred between October 2008 and March 2013.

This Final Report provides an overview of the Program background and the projects within the Program research. Each of the key projects has a Chapter in this Final Report, containing Background (why the research was needed) , Approach (the research tasks details), Findings, Benefits to California ratepayers, Conclusions and recommended Next Steps. An Appendix is included for each research project and contains one or more technical reports. This Final Report and the accompanying technical Appendices are all publicly available at the CEC PIER and the NBI websites[1].

1.1 Background

Public policy in California is pushing for dramatic improvements in the energy efficiency of new commercial buildings through advanced codes and incentive programs. However, the ability of new high performance buildings to achieve their energy efficiency targets is quite variable, with many substantially underperforming when measured energy use is examined. This energy performance shortfall can be considerable and must be better understood and corrected so that efficiency "as designed" comes into alignment with efficiency "as measured."

The goal of this PIER Program was to improve the measured energy performance of the next generation of buildings. To accomplish this goal, NBI directed a linked series of projects that examined the reasons for the variable performance utilizing an evidence-based assessment of high performance buildings. 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.

1.2 The Projects

NBI was the prime research investigator for the Program and also led the project elements related to whole-building performance (Project 2) and fault detection and diagnosis (Project 5), as well as the market connections across all projects. To complete detailed research elements NBI teamed with a series of organizations having specialized expertise. These organizations included PECI for more detailed field-based whole-building performance assessment (Projects 2 and 3); Ecova on the field investigation and understanding of plug load contributions to energy use (Project 3); Architectural Energy Corporation, Daylighting Innovations and the California

[1] www.energy.ca.gov/research/index.html www.newbuildings.org/PIER-research

Lighting Technology Center on improving daylighting predictability and performance (Project 4); and the Western Cooling Efficiency Center and Purdue University on fault detection and diagnostics in unitary HVAC systems (Project 5). Following is a brief introduction to each project.

Project 2: High Performance Building Measured Performance - Documented the performance of a set of California high performance buildings and identified, through modeling and field metering, key performance indicators (KPIs) specific to **designers, operators/owners** and **tenants** . A new performance review tool was developed, tested and applied with design firms and building owners in California. The tool and KPIs help to simplify the prediction of building performance outcomes and can be used to provide prompt, easily understood, actionable performance feedback to designers, owners and tenants of commercial buildings.

Project 3: Plug Load Savings Assessment - Conducted an in-depth assessment in two California office buildings of the energy use of the office equipment plug load items (defined as things such as computers, monitors, imaging equipment, etc., that plug into wall outlets). The project then determined the extent to which plug load energy use was reduced through relatively simple low- and no -cost measures. Findings formed the basis for a new guide entitled *Managing Your Office Equipment Plug Loads* and were shared widely with utilities and policy-making entities to support efforts to reduce this growing area of energy use.

Project 4: Enhanced Skylighting Modeling and Validation - Field-tested skylight product photometrics (characteristics of their ability to transfer light) and materials to establish their lighting performance properties. The research then developed a new modeled (rather than physical) test to produce data on the lighting performance information of skylighting products. The findings can be used by manufacturers to provide more accurate information on their products at less cost compared to the current method of taking physical lighting performance measurements of each skylight product. The research data is also compatible with the IESNA (Illuminating Engineering Society of North America) file formats used by lighting software programs. This allows the results to be integrated into programs widely used by design teams and will lead to more consistent and successful integration of daylighting and electric lighting in commercial buildings.

Project 5: Rooftop Unit Fault Detection and Diagnostics (FDD) - Developed a consensus FDD standard, in conjunction with the team from the California Codes and Standards Enhancement (CASE) effort. The FDD project managed and produced a comprehensive FDD product, market and benefit-cost assessment and stakeholder outreach to establish the commercial and Title 24 viability. Underpinning the goal of advancing FDD technologies into the market for HVAC RTUS, the project developed and deployed a new FDD diagnostic protocol evaluator designed to true up diagnostic service protocols and automated diagnostics.

CHAPTER 2:
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.

2.1 Background

In 2008 NBI conducted a nationwide study[2] to determine if green buildings, specifically those built to the Leadership in Energy and Environmental Design New Construction program (LEED[3]-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 percent better than a code-level building), a significant percentage (25 percent) 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[4]) 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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[2] NBI, 2008 Energy Performance of LEED for New Construction Buildings

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

[4] 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 percent 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 percent to +50 percent.

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[5]. 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

[5] 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.

2.1.1 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.

2.2 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.

2.2.1 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 percent 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 percent 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.

2.2.2 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

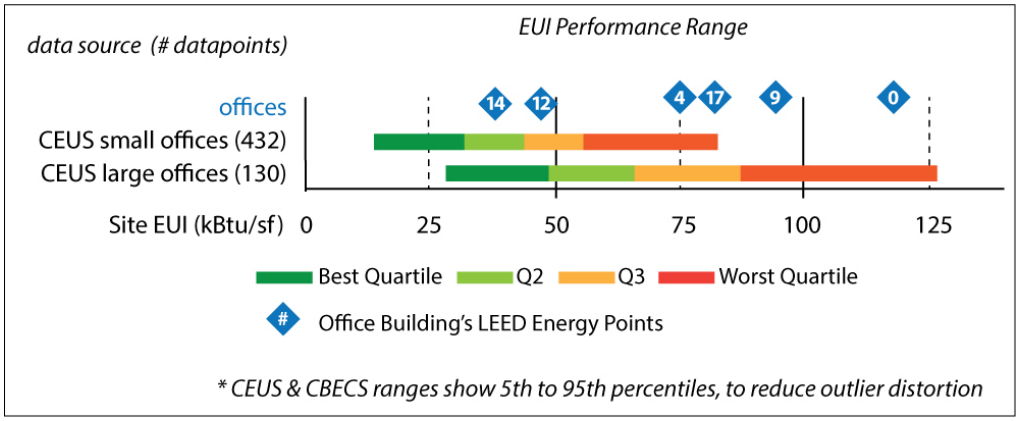
Table 1 shows most of these buildings performed much better than the national average for their type as represented by an Energy Star score. Of those eligible for an Energy Star score, over 70 percent are in the top 10 percent of buildings nationally.

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.

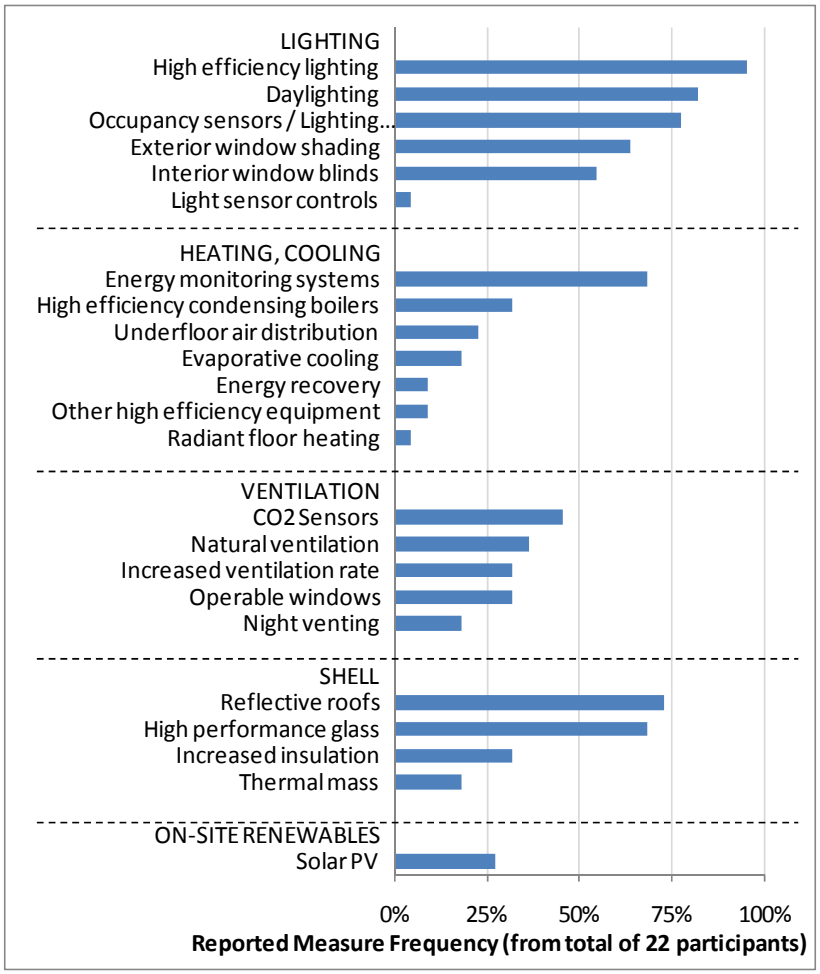
Despite these distinctions, this set of buildings was not exceptionally better in measured energy use than the CEUS buildings despite their high performance energy design intent. The analysis showed little correlation between measured energy performance (EUI and Energy Star score) and ratings based on 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 percent 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.

2.2.3 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[6]. Using only monthly utility bills, building size and location, FirstView creates an Energy Signature[7] 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

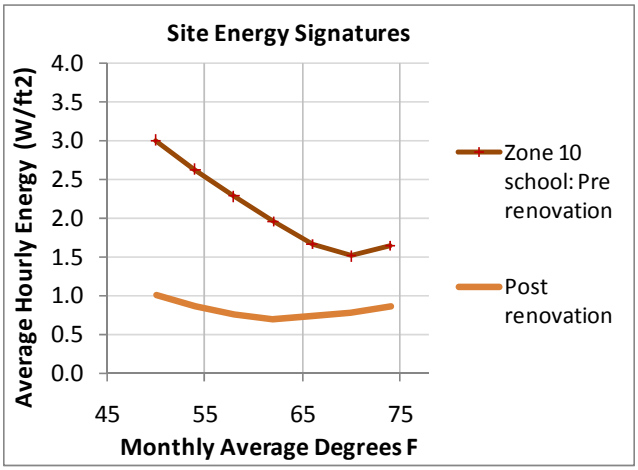


Figure 4 shows a two-year comparison for the same building as compared to a DOE Reference Model. The plot makes clear that the building is using more energy in 2008 than in 2006. Interviews suggested that this resulted from changes in occupancy level. KPIs developed under this research, and presented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

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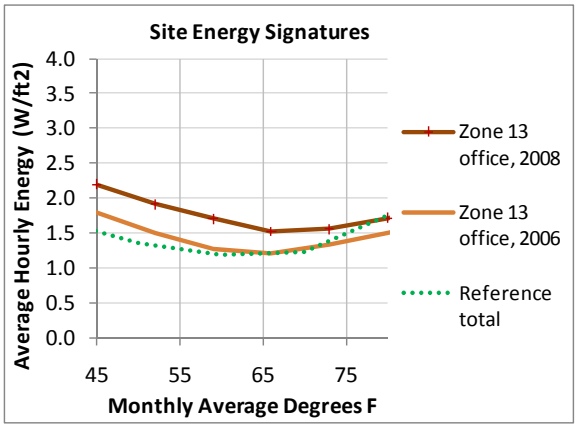
[6] http://newbuildings.org/sites/default/files/FirstViewTool_NBI_aceee2010.pdf

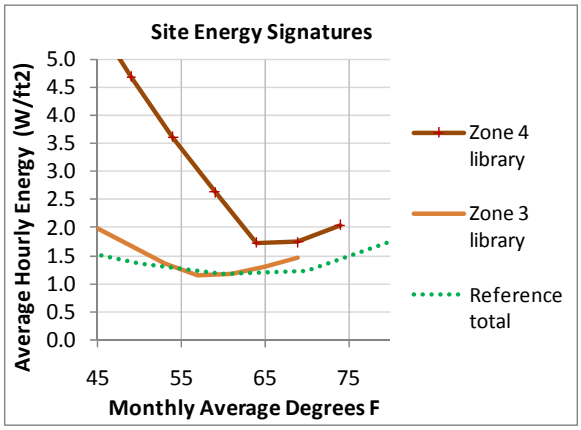
[7] An Energy Signature displays correlations between energy use and basic variables such as temperature and occupancy normalized for square footage.

Figure 4: Office Building Energy Use over Time



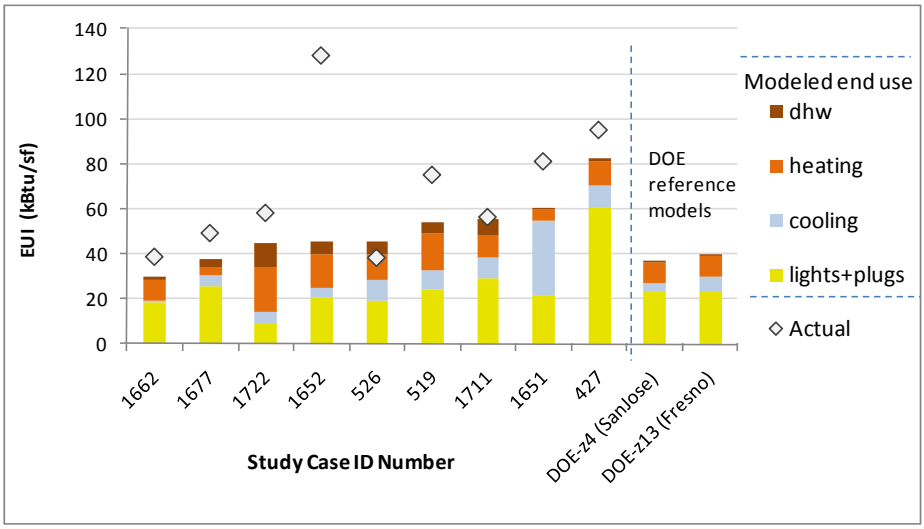
Since FirstView Energy Signatures are both weather and size normalized, multiple buildings can be co-plotted for comparison. This can clearly indicate which building are the more likely candidate for further investigations and improvements. For example, Figure 5 shows two different libraries compared 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



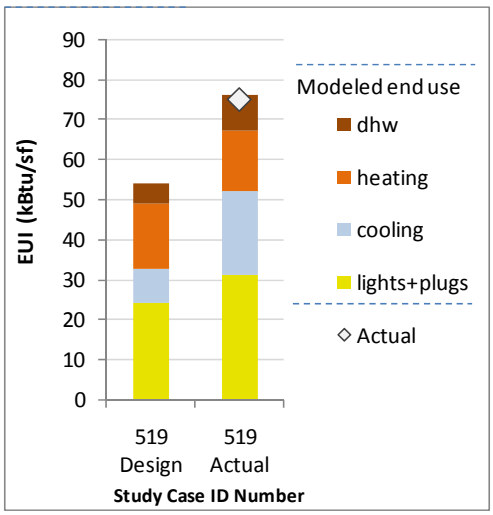
Design Model Comparisons. In addition to plotting and analyzing Energy Signatures, FirstView can analyze and compare measured performance to design model predictions. Of the nine buildings that provided design models for this study, two had measured EUIs very close to design EUI. The remaining seven 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 percent 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 percent better than code-required levels. Low-e glazing, reflective roofing and window-to-wall ratios lower than 20 percent 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[8] 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 percent of respondents believed FirstView could become their process for analyzing energy use or be used to enhance existing processes. Over 70 percent 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

[8] 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 percent of respondents agreed that the diagnostic interpretations from FirstView were very important. A majority of respondents (approximately 60 percent) appreciated the benchmarking comparison to peer buildings. Additionally, almost 60 percent 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.

2.2.4 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.

2.3 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.

2.3.1 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.

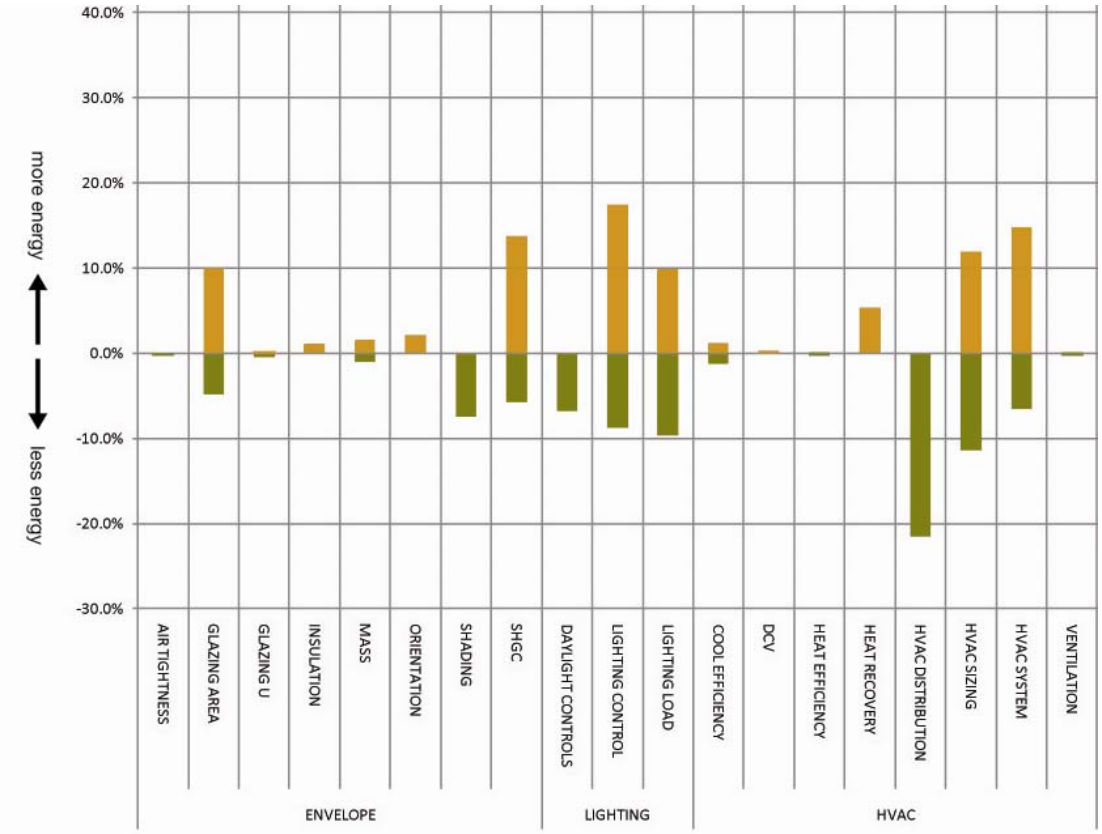
Essentially, the sensitivity analysis was a modeling exercise where each characteristic (such as lighting power density or HVAC system type) had a range of values representing poor, baseline and good practice. Each variable was individually modified from low to high performance; all other characteristics 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.

2.3.2 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.

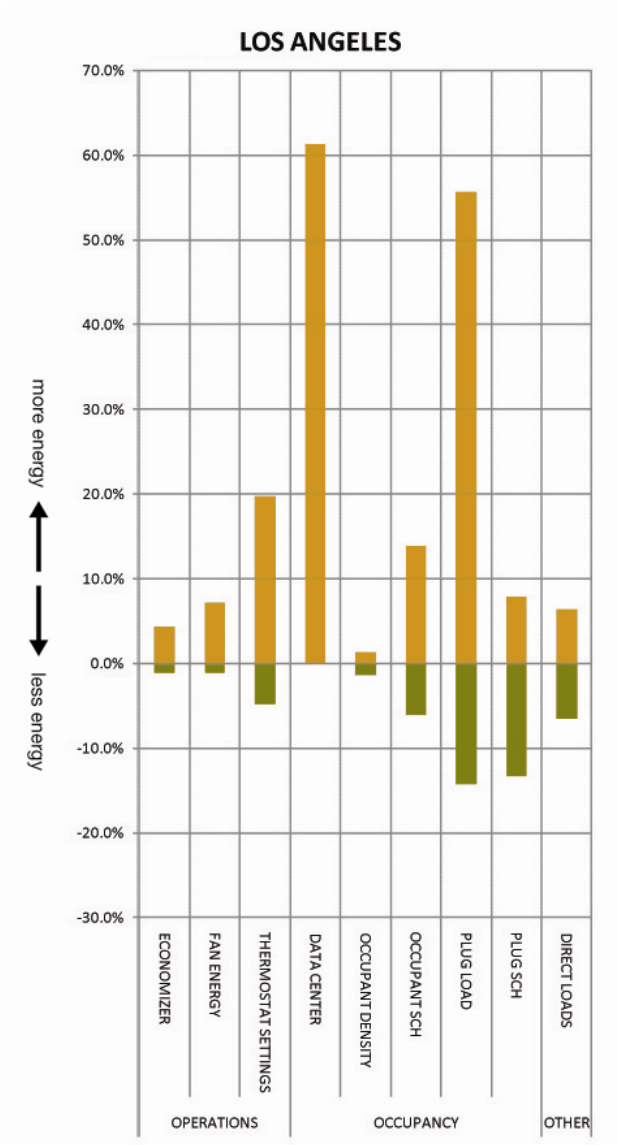
In Figure 8 – building systems - the measures that have the most potential in a building to use 'more' (above the 0 percent line) energy are glazing area, solar heat gain coefficient (SHGC), lighting controls/loads and HVAC sizing/system (type). All have 10 percent or more (but less than 20 percent) 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 percent 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 percent 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.

2.3.3 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

2.4 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.

2.4.1 Approach

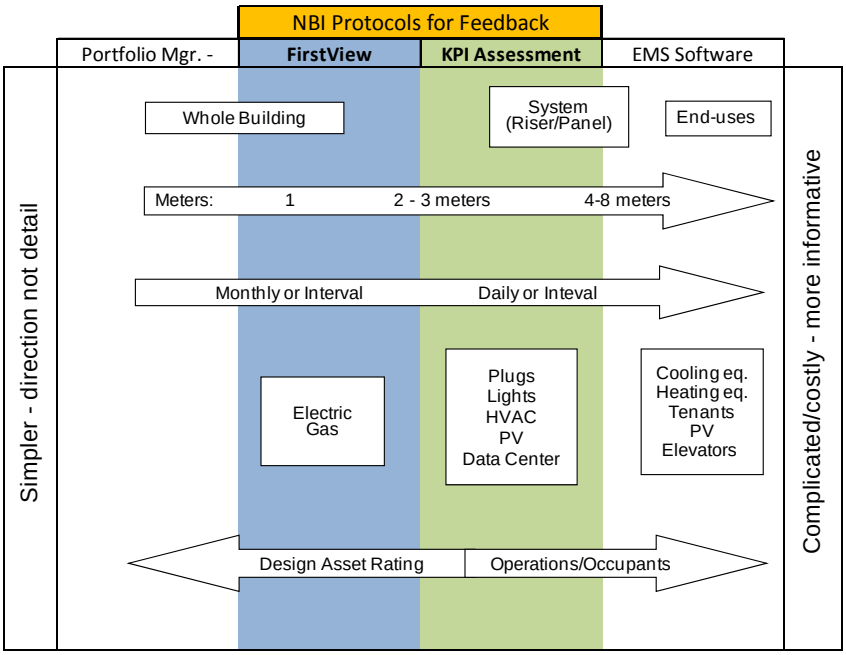
As part of the effort to develop KPIs, NBI instituted system-level[9] metering in two office buildings: a 14,000 sf. office in Oakland, California, and a 5,500 SF office in Vancouver, Washington. Researchers collected system loads by installing sub-meters (advanced interval meters downstream of the main 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.

[9] 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.

2.4.2 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[10]. 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.

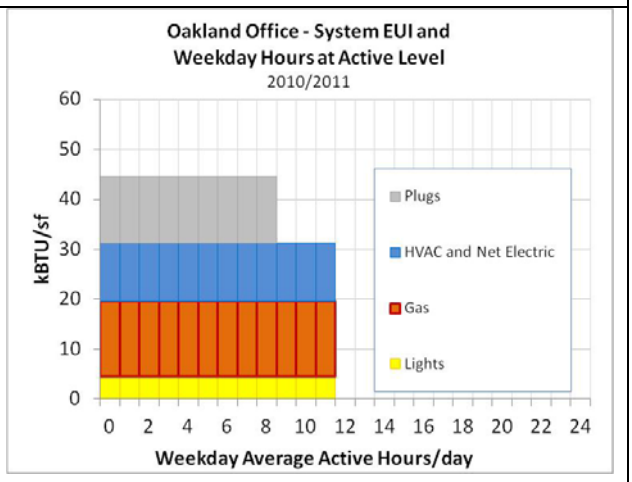
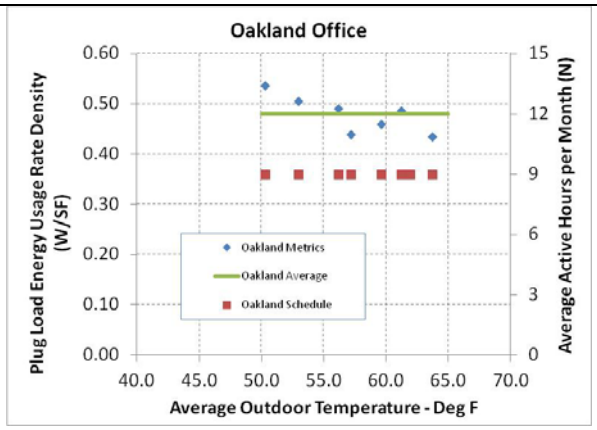
The set of energy key performance indicators in Table 6 shows how nine designer KPIs were used at one research site located in Oakland, California. Some indicators looked at the big picture, such as the System Schedule Annual Energy Use Index, while others provided feedback on areas specific to design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

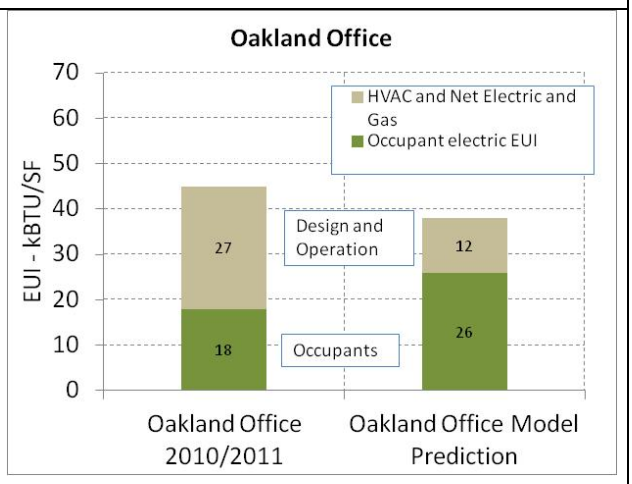
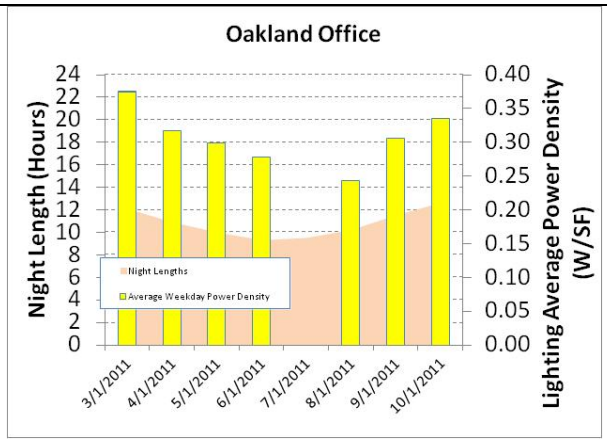
[10] Field metering at NBI Utility Partner *Office of the Future* sites gave additional data and foundation to the selection and validation of the PIER KPIs.

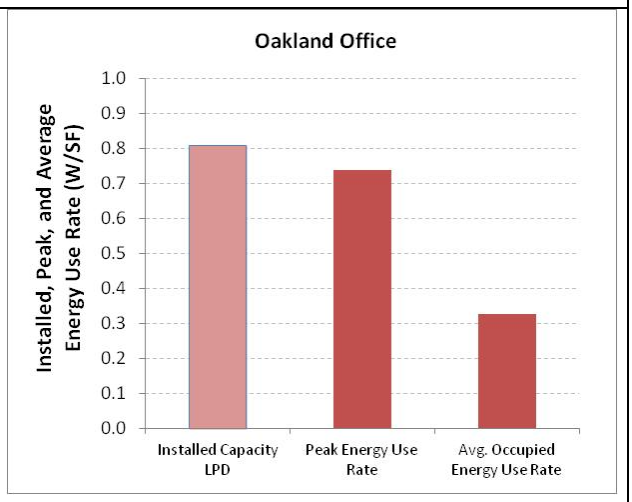
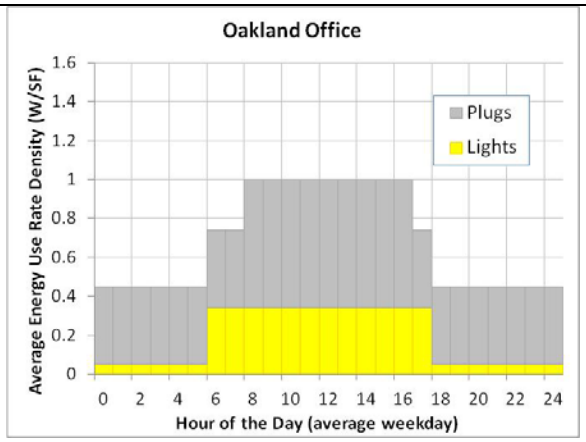
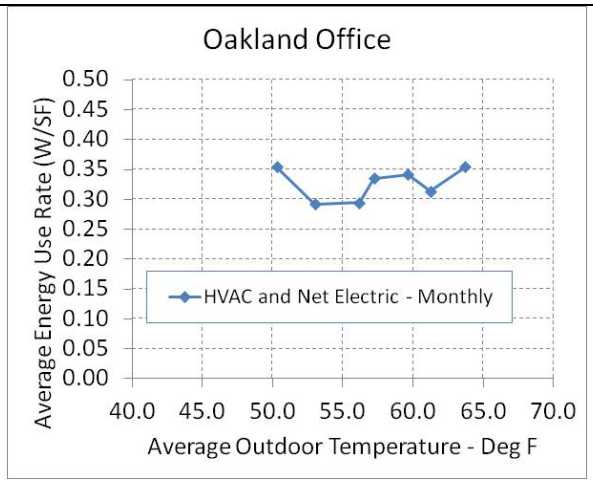
For example, the Daylighting Effectiveness KPI considered whether lighting is turned off or reduced when daylight is available. If the design team included daylight controls in the building, the KPI should indicate a good correlation of reduced electric lighting during daylight hours. Rather than simply 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.	

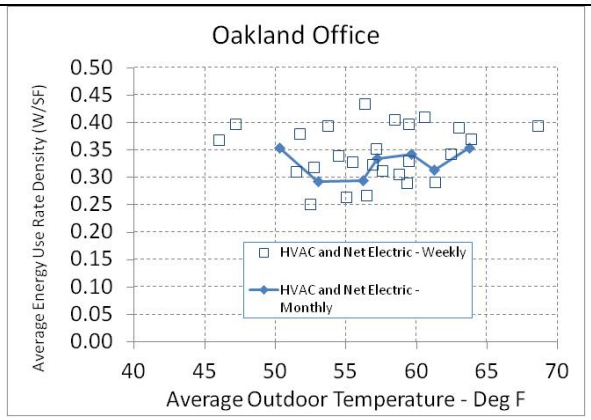
KPI	Inferences	Sample Plot
Operational Consistency	Erratic plot implies that control-related issues might be contributing to increasing heating and cooling energy use. Does not clearly assign responsibility to design and or operation but shows there is reason to doubt the Oakland Office EUI represented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

2.4.3 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
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.

2.5 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.

2.6 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.

2.6.1 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.

CHAPTER 3:
Plug Load Savings Assessment Final Report

3.1 Background

This chapter summarizes the findings from Project 3: *Plug Load Savings Assessment* within the PIER program "Evidence-based Design and Operations." The research occurred from 2010-2012 and was led by Ecova[11] and supported by PECI for field monitoring and New Buildings Institute (NBI) as project manager and market connections lead.

Plug loads (devices that plug into wall outlets) are one of the largest and fastest growing electric end uses in commercial buildings in the United States[12]. Although efficiency improvements are occurring at the equipment and appliance levels, such as EnergyStar standards for copiers and monitors, the growing number of office electronics coupled with the need for faster, more powerful equipment has resulted in an overall increase in plug load energy consumption.

On average, plug loads account for 13 percent of total electricity consumption in California commercial buildings and 23 percent of office building electricity[13]. Office equipment alone is about 74 percent of the plug load energy for such things as computers, monitors, imaging equipment and various peripherals (things such as computer speakers). Plug loads, unlike building design and major energy systems such as lighting, heating and cooling equipment, are not subject to statewide energy codes. This is because of the challenge of regulating energy use that occurs through occupant choices after the issuance of the building permit. This further drives the need to better understand the energy impact of these growing loads and identify methods to meet occupant needs with less energy intensity and demand.

This research characterizes the electricity consumption of office equipment plug load devices in two recently LEED-certified buildings in California and identifies opportunities for plug load energy savings that may be transferable to offices throughout California.

3.1.1 Objectives

The project objective was to estimate the potential to save energy use by employing strategies effecting plug load device consumption which included changes to hardware, software and through deploying information designed to change occupant behavior.

The primary research objectives were to determine the energy used by office equipment plug load device category and to assess the most effective approaches to reduce plug load energy for these devices in office buildings. For the successful energy reduction strategies, a secondary goal was to refine and focus the findings so that utility programs and occupants/owners will

[11] While the lead researchers remained consistent throughout the project, Ecos changed mid-project when it was acquired by Ecova. All work on this project is now attributed to Ecova.

[12] U.S. Energy Information Agency 2008 Energy Outlook Report.

[13] Itron Inc. study resulting in the California Energy Use Survey (CEUS), 2006.

adopt them to create energy savings in California's commercial office buildings. The commercial office category for purposes of this study includes a variety of occupancy types.

3.1.2 Approach

The plug load research team performed the majority of the research at two California buildings - a 95,000 square foot (ft^2) public library in San Mateo and a 14,000 ft^2 small office in Oakland. Both of these buildings were designed for high energy and environmental performance relative to their peer buildings. The design of this study included the following two phases:

1. **Inventory, Identify and Meter Existing Equipment:** Inventory all plug load equipment and identify the subset most applicable across offices. This represented 726 plug load devices. Meter a subset of 100 of the devices representing a diversity of equipment types and uses; placing the highest priority on computers, monitors, imaging equipment and computer peripherals[14] for one month at one-minute intervals. This step established the energy use baseline for these 100 devices.

2. **Apply Energy Reduction Strategies:** Reduce the energy use of a subset of the metered devices by applying energy efficiency technologies or approaches to the end use and re-metering the altered device to determine the savings potential of the strategies. The saving strategies fell into four major categories:

   a) **Power Management Changes**: Computer and imaging equipment have power management settings which can be enabled to reduce energy use

   b) **Advanced Plug Strips/Timers:** Advanced plug strips stop power flow to peripheral equipment when the primary device is turned off. Timers can be set to turn equipment off at the end of the day if it will not be used during the night.

   c) **Adjust Monitor Brightness:** Adjusting monitor brightness to meet user needs without defaulting to the maximum brightness saves energy**.**

   d) **Occupant Behavior (via education and prompts):** These approaches include sending notices to staff to turn off equipment at the end of the day and end of the week and energy awareness information or campaigns.

3.1.2.1 Measurement Methodology

The team identified plug load devices with high energy use and installed meters on 100 of them. Left in place for one month, the meters measured and recorded volts, power, power factor, current and volt amps each minute. Then, 39 of the 100 devices were selected for energy efficiency hardware and software upgrades. 39 of the 100 devices were then metered for a second month.

[14] Determined as the most numerous devices at the two sites and which use the most significant amounts of plug load energy (Mercier, C. and Moorefield, L. Ecova, et al., 2011).

Once the second month of metering was completed, the team compared the energy use of the 39 affected (upgraded) plug loads to the 61 unchanged (control) plug load devices. Both months included 31-day periods with the same number of work and non-work days.

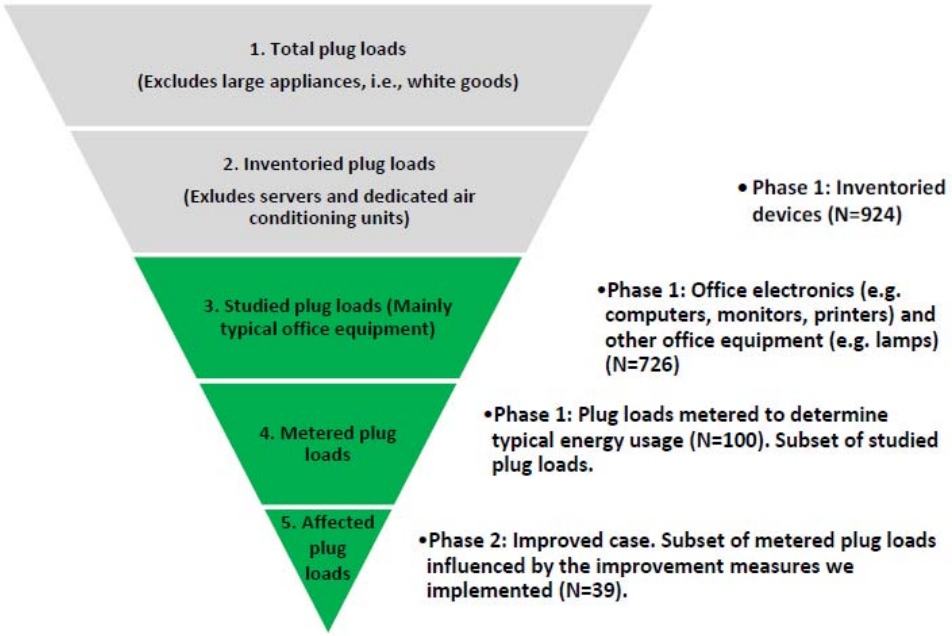
Figure 11 summarizes the tiers of plug load quantities at each step. The total in the top tier includes items subject to California Title 20 Standards for Non-Residential Appliances, such as refrigerators. Refrigerators, and other white goods, were not part of this study.

The second level top to bottom is the inventoried equipment; including all of the unregulated plug load devices, a total of 924 plug in devices at the two offices. This figure excluded servers and any dedicated systems to servers. Data centers and server closets have very specific energy use profiles and were not a part of this research. Data centers are a unique category of plug loads studied in other PIER research. [15]

The third tier are the plug loads identified as primarily office equipment; the subject of this study (726 devices). The metered devices are shown as the fourth tier and the fifth tier shows the 39 plug load devices for which savings strategies were employed.

[15] See NRDC report on server energy use and savings at www.nrdc.org and Department of Energy Data Center energy information at www.eere.energy.gov/manufacturing/datacenters/about.html.

Figure 11: Overview of Study Scope and Methodology



3.2 Technical Outcomes and Findings

The full details of this research discussed here are available in the final Commercial Plug Load Savings Assessment Report- Appendix A-3[16]. In addition to this report, a Plug Load Metering Plan (Metering Plan) was a deliverable developed in this project. The Metering Plan can be used in future plug load related research to guide inventory and assessment protocol in field studies. Other related items were also developed to facilitate these findings reaching the market or influence State energy policy and are described in the Section on Market Connections.

The Metering Plan describes: a) the method for conducting base-case metering, b) the preparation steps taken prior to the site visits c) a list of items that were taken to the sites, d) interview questionnaire, e) a description of the walk-through survey approach, f) detail on how meter tracking was installed g) a description of how data was downloaded and transferred from the devices and lastly) a description of how plug load devices were reconnected. To summarize, the Plug Load Metering Plan provided full metering detail, inventory lists, surveys and templates. , This plan can serve as a model that can be applied in future plug load inventory and metering studies that involve field data collection[17].

3.2.1 Commercial Plug Load Savings Assessment

The Savings Assessment Report describes the primary technical finding from the study. It includes data and information on:

[16] Mercier, C. and Moorefield, L. Ecova, et al., 2011

[17] The Plug Load Metering Plan is part of Appendix A-4.

- Baseline energy use for the building and for plug load device type categories
- Specific descriptions of the energy savings strategies
- Estimated savings for each energy savings strategy employed in the study
- Total plug load energy savings estimates for each site
- A discussion regarding issues that need to be considered when interpreting the data findings (Data Interpretation Issues)

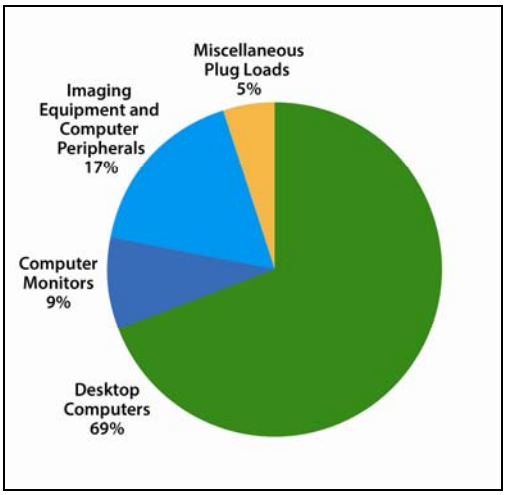
3.2.1.1 Energy Use – Phase 1

The first step in the study involved determining baseline energy use of a select group of device categories. Savings were investigated in phase II of the study. To increase confidence that the metered data collected from the sample was representative of general office equipment energy use, this data was compared with measurements taken in previous PIER research on office plug devices by (Ecova) the lead research team on this project.

Annual energy use by device type was estimated by multiplying the average device category energy use from the one-month metering period in Phase 1 by the total number of those devices inventoried extrapolated for 12 months.

Four categories of office equipment energy use monitored for this study: 1) desktop computers, 2) imaging equipment and peripherals (primarily computer speakers), 3) computer monitors. and miscellaneous loads. Figure 12 shows the percent of the studied plug load's energy use[18] at the Oakland office site per each device category. The San Mateo library site results were similar (within 2-5 percent on each of the three dominant categories).

Figure 12: Percent of the Studied Plug Load Energy Use by Device Category – Office



[18] As shown in
Figure 11, the studied energy use is the energy use for the subset of plug load items determined to be office equipment after excluding servers, dedicated air systems and appliances. For this research the studied energy use represented 726 devices (590 at the library and 136 at the office).

Desktop computers (70 percent) used the majority of the energy in the study sample. When monitors are added to the desktop energy profiles, the energy usage was just under 80 percent of all office equipment plug load that was measured. Imaging equipment and computer peripherals energy use was 17 percent. Computer monitors used 9 percent of subject energy. Miscellaneous items (electric staplers, coffee makers, projectors, etc.) accounted for the remaining 5 percent.

From device inventories at each site and energy use recordings from the metered devices, the estimated plug loads energy intensities were measured at 0.7 kWh/ft^2 per year for the public library and 0.94 kWh/ft^2 per year for the small office. These findings are significantly lower than those calculated from the most recent California Energy Use Survey (CEUS). CEUS shows 2.19 kWh/ft^2 per year for small offices (Itron Inc., 2006)[19]. Two factors may account for the differences between the study samples and the database. First, the CEUS office equipment category includes servers. Servers were excluded from the current study as noted earlier, due to the unique nature of server energy

Second, both the library and small office had lower-than-average densities of office equipment (about 2 PCs/1000 ft^2 at each site). Additionally, interviews with occupants indicated that the office equipment purchased at these particular sites was more energy efficient than what would be considered typical. Studied plug loads at both sites used about 6 percent of each building's total annual energy (electricity plus natural gas)[20].

3.2.1.2 Energy Saving Strategies – Phase 2

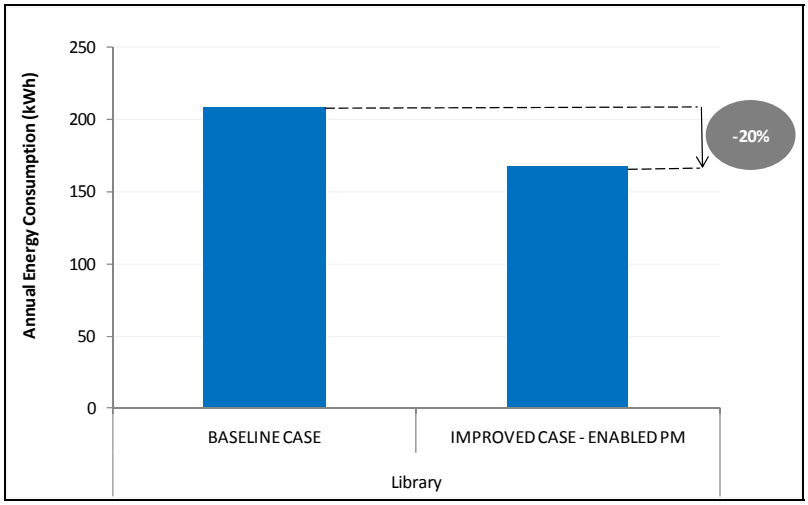
The research team organized the savings solutions into three areas: software, hardware and occupant behavior.

Software — Using aggressive power management settings on all equipment (i.e., keeping the time delay prior to powering down to a lower power mode as short as possible) or using power management software that is controlled by Information Technology (IT) departments and built-in settings that will save energy. If power management software is already installed on the devices as part of the equipment purchase, this solution can be implemented at no cost. This strategy yielded the largest energy savings for no-to-low-cost choices. An example of possible power management energy savings at the library is illustrated in Figure 13 where this strategy yielded a 20 percent reduction in energy use on a printer.

[19] Note that libraries are not a separate category in the CEUS analysis; results for the library were compared to the most similar category, small office.

[20] See section 3.2.1.5 on Data Interpretation Issues - this discusses the challenges of definitions and percent of building energy use for plug loads.

Figure 13: Savings from Setting Aggressive Power Management (PM) Settings on One Printer

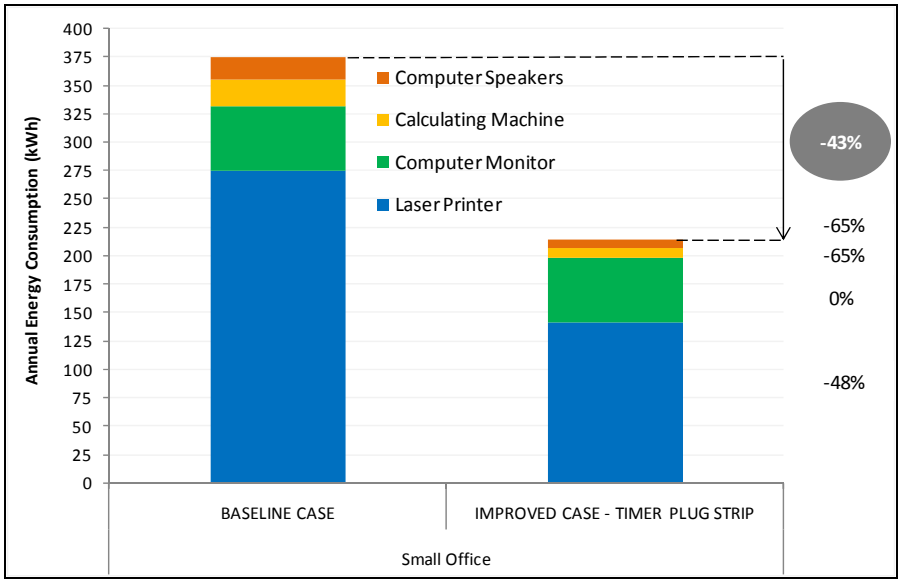


Hardware — There are multiple hardware-related options. The first option employed in this study was to purchase and install advanced power strips and timers for certain devices. These hardware options are a fairly low cost solution.

The largest energy savings came from upgrading existing equipment by replacing the equipment via purchase of more energy efficient models of devices. This only makes financial sense when equipment upgrade is necessary for other reasons besides energy. In that case this high first cost is already a planned expense in the procurement schedule. In this research, one extreme example of least (old) versus most efficient (new) equipment was the replacement of an older inefficient desktop computer with a new micro-sized desktop. The new unit featured basic functionality and was preset or designed to use ultra-low relative power including aggressive power management settings. This action reduced the electricity use of an occasionally used desktop by over 95 percent.

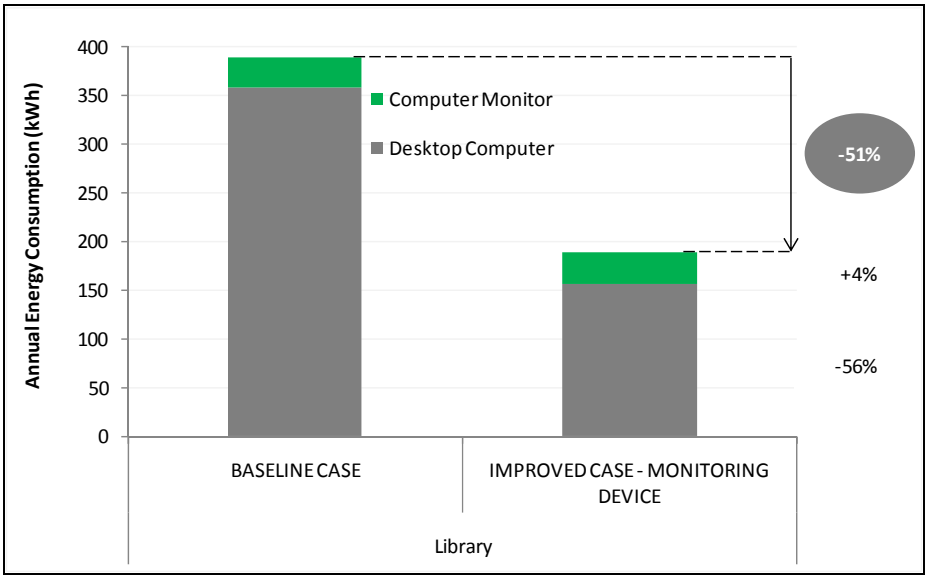
Another example of a hardware savings approach used on several of the devices in this study was the Digital Timer Plug Strip (DTPS). Timer plug strips provided a programmed 'off' period. They are a good option for devices that do not need to draw power at night and on weekends. Figure 14 shows a 43 percent reduction in energy use from a set of devices as a result of DTPS employed at the small office site.

Figure 14: Savings from Digital Timer Plug Strips (DTPS)



Occupant [measures intended to change] use-related Behavior. Simple, easy to-understand, real-time feedback on energy consumption can affect user behavior that will reduce energy consumption. An email reminder to turn off equipment employed in this study reduced desktop computer electricity use by 6 percent on average. Another feedback method/message saved a projected 51 percent of the annual electricity used at each workstation at the library (Figure 15). This message reminded occupants to shut off their computers when they were not working at the office. Other efforts include encouraging users to flip the switch on power strips, turn off devices when not in use and increasing awareness of efficiency settings.

Figure 15: Savings Example from Employing Strategies to Remind Users to Shut off Computers Nights and Weekends (Monitoring Feedback)



The next section discusses some of the key findings for using and combining the savings approaches as applied to the four major energy use device categories used in this study: 1. Desktop Computers, 2. Computer Monitors, 3. Imaging Equipment/Peripherals and 4. Miscellaneous, followed by graphs and tables providing examples of savings details.

1. Desktop Computers

Desktop computers are the largest energy use of the studied plug loads at both sites, representing 68 percent and 69 percent at the library and the small office respectively. Hardware upgrades, software settings and behavior change all appear to be promising strategies for reducing the energy consumption from computers. While many of the desktop computers metered were the same model, energy consumption among the individual units ranged widely. This suggested that energy consumption variance was due to differences in user behavior. Unit power management settings (or lack thereof) were also a factor. The primary opportunity for reducing computer energy use at both sites was to insure that power management settings were enabled.

Enabling and properly programming power management settings is a significant savings opportunity; however, there are some barriers that need to be addressed to ensure energy savings results. User lack of information and education and conflicting practices in IT management policies, can impede energy savings. Power management of some devices can be automated at the IT level with to centrally control power to devices during nights and weekends such as products from Verdiem, 1E WakeUp and many others. Although deploying these software solutions was not part of the scope of this study, the team estimated that this strategy could save 5,540 kWh at the library and 3,270 kWh per year at the small office.

Behavioral-related information measures such as sending email reminders to encourage employees to turn off computers at night and on weekends are worthy of consideration. However, given the timeframe of this study, persistent energy saving from this strategy could not be confirmed.

Finally, as with many electronic devices, significant savings are possible by replacing older computers with highly efficient newest models. The example described above under Hardware, involved replacing an inefficient desktop with a micro-sized unit that contained basic functionality, ultra-low power use and enabled power management settings. In this case power use was reduced by saved 95 percent. While these computers cannot replace all desktops because of applications capabilities, these computers used only for relatively straightforward tasks like email, word processing and internet browsing are suitable candidates for greatly improved systems at the time upgrades via procurement schedules.

2. Computer Monitors

Computer monitors metered at the sites typically consumed somewhat more electricity per year than today's most efficient models. The majority of the monitors were in standby or 'off' mode after business hours and on weekends at both sites, suggesting that power management settings were enabled on most of them, or that users routinely turn off monitors at the end of the day.

Standby power use on monitors metered in this study was typically less than 2 watts. The key monitor savings opportunities at both sites were achieved by adjusting brightness settings in to properly account for ambient light levels and also upgrading equipment at replacement.

3. Imaging Equipment and Computer Peripherals

Most imaging equipment and computer peripherals, such as computer speakers, were used rarely but drew power continuously. The solid-ink multifunction device[21] (MFD) consumed significantly more energy than other devices. By itself it used 6 percent of total studied plug load energy at the small office, and nearly 40 percent of the electricity used in the all imaging equipment category at one of the sites.

An external control device can be incorporated on printers without power management settings so power can be reduced when the device is not in use. These add-on devices are an easy, low-cost way to eliminate the energy used by often-forgotten computer peripherals and imaging equipment. Timers and timer plug strips were the most effective at saving energy and saved up to 43 percent per workstation and are good options to control imaging equipment that is rarely used outside of normal business hours.

4. Miscellaneous Plug Loads

Miscellaneous plug loads such as projectors, coffee makers and vending machines were not numerous, but many of those that were monitored consumed did scale power consumption to usage.

Personal space heaters were frequent at the research sites and high winter energy users. To discourage the use and the need for personal space heaters, the HVAC system should be maintained so that it provides adequate and evenly distributed heat throughout the office. It can be challenging to maintain the desired temperature for all employees given the wide range of user preferences, heat gain or loss from windows, and proximity to vents and thermostats in different areas of a typical office building. If the findings of recent automotive research are any guide, it may prove more energy efficient to heat or cool the seat in which individuals are sitting than the air around them, given how readily the air circulates from one cubicle space to another in open floor plans.[22] Reducing these occupant-driven plug loads for thermal comfort is an important part of moving office spaces to low energy.

3.2.1.3 Savings by Measure

The research team applied individual energy saving measures and actions to those areas identified as high energy users. Table 11 shows the percent saved from the original

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[21] A Multifunction Device (MFD) combines printing, coping, scanning and/or faxing and are becoming the standard over separate equipment for each of these office needs.

[22] See: http://blogs.edmunds.com/strategies/2006/09/keep-your-cooland-perhaps-save-some-gas.html and http://www.sciencedaily.com/videos/2006/0901-cool_car.htm Additional investigation of personal thermal applications are being conducted at Lawrence Berkeley Lab www.lbl.gov and at University of California Berkeley Center for the Built Environment http://cbe.berkeley.edu/.

measurement and as a lifetime potential based on data from EnergyStar. The final column shows the estimated payback in years resulting from implementing the measure or practice based on typical California commercial electricity rates.

Many of the software and behavior measures in Table 11 have short or immediate payback periods. Simple things such as adjusting the onboard computer power settings take little time and have large impacts. Hardware approaches incur more cost, particularly for some of the higher tech equipment so these investments should be leveraged with other procurement needs to reduce the incremental costs.

The dozen measures summarized in Table 11 are grouped by the three strategy categories of hardware, software and behavior. The pre (Baseline) and post (Improved) energy use for the device is shown, followed by the estimated annual energy use and savings.

Table 11: Summary of Measured Plug Load Energy Savings and Paybacks at the Small Office

Type	Energy Saving Measure	Plug Loads Affected (N=24)	Baseline Case Energy Use (kWh per year)	Improved Case Energy Use (kWh per year)	Measured Energy Savings Opportunity (kWh per year)	% Savings	Payback Period at $0.1342 per kWh (years)
Hardware - New Equip.	Replace existing monitor with Top-Ten monitor	LCD monitor	20.0	11.5	8.5	43%	Immediate
	Replace existing monitor with Top-Ten monitor with automatic brightness control	LCD monitor	42.4	21.2	21.2	50%	51
Hardware - Plug Strips and Timers	Install load-sensor plug strip on workstation	LCD monitor, laser printer and computer speakers	113.6	61.4	52.2	46%	4.3
	Install remote control plug strip on workstation	Laser printer	49.5	22.4	27.1	55%	9.7
	Install timer plug strip on workstation	LCD monitor, laser printer, computer speakers and calculator	375.6	214.3	161.3	43%	1.2
	Install timer on imaging equipment	Laser multifunction device	38.9	24.7	14.1	36%	10.5
Software	It to centrally enable computer power management	Desktop computers	The IT administrator did not implement this measure because some staff access their computer remotely.				

Type	Energy Saving Measure	Plug Loads Affected (N=24)	Baseline Case Energy Use (kWh per year)	Improved Case Energy Use (kWh per year)	Measured Energy Savings Opportunity (kWh per year)	% Savings	Payback Period at $0.1342 per kWh (years)
	settings through the IT department						
	Turn down brightness settings of computer monitors	LCD monitor	56.5	53.0	3.5	6%	Immediate
			48.3	35.3	13	27%	Immediate
Behavior	Send Outlook reminders to turn off computers	Desktop computer	103.7	96.6	7.1	7%	Immediate
			90.7	103.6	-13.1	-14%	Immediate
			90.7	62.4	28.3	31%	Immediate
			75.4	74.2	1.2	2%	Immediate
	Install feedback monitoring device on workstation	LCD display, computer, computer speakers	115.4	80.1	35.3	31%	6
	Provide energy report with action steps to reduce desktop computer energy use	Desktop computer	355.6	153.1	202.5	57%	Immediate
Combination	Replace desktop computer with micro-sized desktop and enable power management settings	Computer	485.1	23.5	461.5	95%	Immediate

Figure 16 shows the estimated kWh savings due to implementing these various measures and separates out the no- to low-cost items. It further shows the portion of all savings for the activity or measure. For example, enabling power management settings accounted for 71 percent of the no- to low-cost savings, advanced plug strips contributed 16 percent and occupant behavior approaches another 10 percent. The graph also shows that replacing 90 percent of desktops with highly efficient desktops accounted for 71 percent of the office equipment plug load energy saved in the building.

Figure 16: Summary of Savings at the Small Office

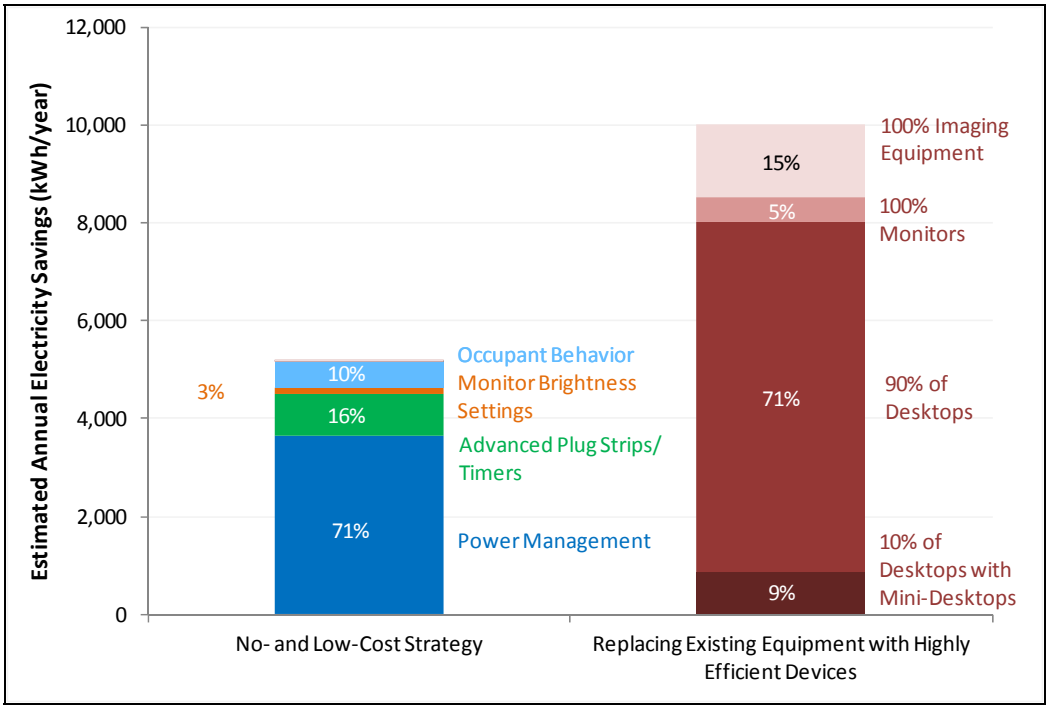


Table 12 is a summary of the total energy savings opportunities. It presents the number of devices studied at each sites, along with the percent of the devices that would be impacted by each savings strategy. The measured savings opportunity from both sites is shown in the right-hand column. An individual measure with high savings can be less valuable than one with a modest savings depending on the number of devices and the baseline energy use for the devices. An important caveat is that this research represents a very small sample size, reducing the ability for broad claims of specific achievable savings at other buildings. The findings do, however, demonstrate consistency in the order of importance of approaches and the key devices to be addressed (see Table 17) that are transferable to most office spaces.

Table 12: Summary Plug Load Energy Savings Opportunities by Individual Strategy

Type	Strategies	Studied Devices		Opportunity[1]		Measured Savings (%)[1] per Device Type
		Library	Small Office	Library	Small Office	
Replace	Replace existing monitors with comparable best-in-class models	218	33	100%	100%	43%
Replace	Replace existing monitors with comparable best-in-class models with Automated Brightness Controls	218	33	100%	100%	37%-50%

Type	Strategies	Studied Devices		Opportunity[1]		Measured Savings (%)[1]
Replace	Replace inefficient MDFs, mailing machines, and laser and inkjet printers, with comparable best-in-class models	40	15	100%	100%	79% Small Office[3] 74% Library[3]
Replace	Replace existing desktop computer with comparable best-in-class models	203	37	100%	100%	88%[4]
Replace	Replace desktop computers by mini-desktops and enabled PM	203	37	20%[4]	10%[4]	95%
Hardware	Load sensor plug strip with computer laser and computer speakers	17 computers speakers/ 28 laser printers/ 82 private monitors	20 computer speakers 9 laser printers 33 monitors	8/17 of computer speakers 11/28 of laser printers 11/82 monitors	15% of computer speakers 3/9 of laser printers[5] 3/33 monitors	46%
Hardware	Install remote control plug strip with laser printer	12 private laser printers	9 laser printers	11/12 of private laser printer	5/9 of laser printers	55%
Hardware	Load sensor plug strip with laser printer and computer monitor in public space of library	16 public laser printers 136 public monitors	n/a	100% public laser printers 16/136 monitors	n/a	14%
Hardware	Use timer plug strip with computer peripherals and laser printers	17 computer speakers 28 laser printers 82 private monitors	6 calculators 20 computer speakers 9 laser printers 33 monitors	8/17 of computer speakers 11/28 of laser printers 11/82 monitors	3/9 of laser printers 3/33 of monitors 5/20 computer speakers and 5/6 calculators	43%

Type	Strategies	Studied Devices		Opportunity[1]		Measured Savings (%)[1]
Hardware	Use timer plug strip and timers with imaging equipment	5 laser MFD 28 laser printers 5 Inkjet printers 2 laser fax	9 laser printers 1 mailing machine 4 Laser MFD 1 Solid Ink MFD	100% imaging equipment	63% laser printer 100% mailing machine, laser MFD and solid ink MFD	10%-36%
Hardware and IT	Enable power management settings for computer or install centralized software method	203	37	13%	62%	50% per inefficient computer
Behavior	Enable more aggressive power management settings for imaging equipment	5 laser MFD 27 laser printers 5 Inkjet printers 2 laser fax	9 laser printers 1 mailing machine 4 laser MFD 1 solid Ink MFD	100%	100%	20%
Behavior	Adjust brightness settings of computer monitors	218	33	100%	100%	12%
Behavior	Outlook reminders to encourage manually unplugging computers	203	37	64/203	100%	6%

Notes on table data:

[1] Savings opportunities are based on measured savings, except in a few cases where we used assumptions from previous commercial studies.

[2] The "Total Estimated Savings" is the number of inventoried devices multiplied by the measured average energy consumption for each device type, the opportunity percentage or the percentage of total inventoried devices that could be affected by this measure, and the measured savings opportunity per device type (%).

[3] This is a weighted average of estimated savings opportunities based in inventoried imaging equipment.

[4] Such computers are by no means intended to replace all desktop applications in an office, but desktop computers that are only employed for relatively straightforward tasks like email, word processing, and internet browsing, could be easily replaced with much less powerful computers.

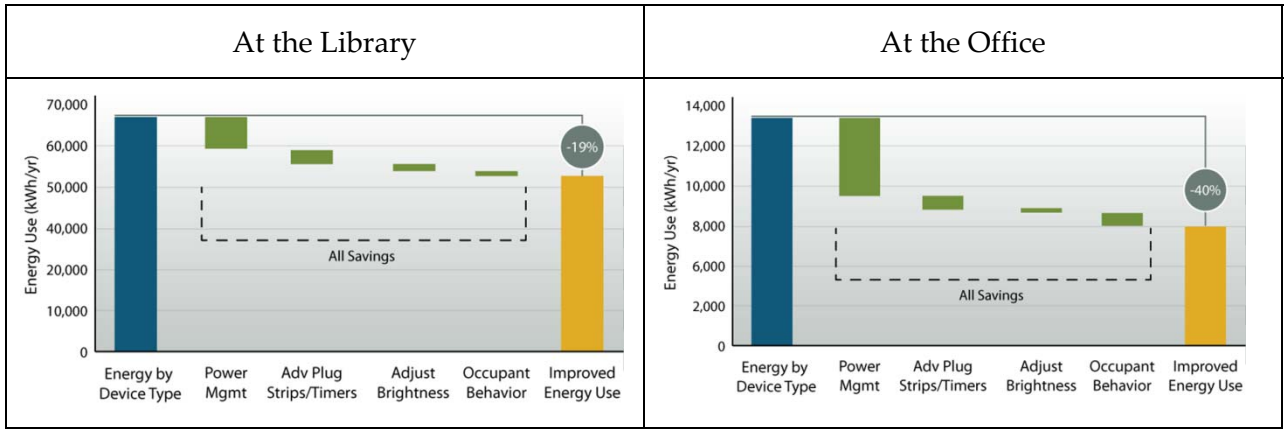
[5] Load-sensor plug strips can only be installed on printers connected to an individual computer. Also, savings will only be achieved if the computer is powered down by the user or automatically at night and on weekends.

3.2.1.4 Total Energy Savings: Studied Plug Loads

The applied strategies and measures showed strong energy reduction opportunities even at these sites that had already adopted green practices and building design. The sum of the applied measures reduced the total studied baseline plug loads by 19 percent at the library and by 40 percent at the office, as shown in

Figure 17 provides the share that each major savings category contributed to the total reduction of studied plug load energy use. Power management (which includes simple modifications to the settings on desktop computers, monitors or imaging equipment) is the greatest contributor to savings at both sites. For both sites, the second area of greatest savings is Advanced Plug Strips and Timers. The other two key areas - Adjustments to Monitor Brightness and Occupant Behavior approaches – contribute less and vary slightly between the two sites but are still two of the four primary methods for savings.

Figure 17: Studied Plug Load Energy Savings from All Strategies and Measures



The important takeaway here is that the three strategies of Power Management, Plug Strips/Timers and Adjusting Monitor Brightness achieve the lion's share of low- to no-cost savings opportunities and should be the first things addressed by any office. Approaches to Behavioral strategies do need to be a part of improvements, but changes can be simple (a prompt or reminder sign) or more complicated (ongoing employee engagement, varying methods of prompts, rewards), so the persistence and cost is highly variable.

What is less obvious, but important to remember, is that percent savings is deceptive and cannot singularly be used to rank savings opportunities. For example the library has only a 19 percent savings, while the office showed a 40 percent savings. Library actual savings were over 12,000 kWhs/year due to its >65,000 kWhs/year annual studied plug load energy use, while the office savings were just over 5,000 kWhs/year –40 percent of approximately 13,000 kWhs/year energy use for the studied plug loads.

3.2.1.5 Data Interpretation Issues

A number of data interpretation issues arose during this research. These include lack of definition of plug loads, plug load metering issues, the impact of the IT structure of the office

(cloud vs. in-house server), and that as other building loads decrease, plug loads become a greater percentage of building energy use. These four issues are briefly defined below.

1. **Lack of Definition.** Plug loads have historically been outside the purview of code-setting bodies, and the number of office equipment devices and personal technologies changes quickly. As a result, there is no industry definition of "Plug Loads." Table 13 shows how three different references (CBECS, CEUS and PIER) account for plug energy use in offices. The two most commonly referenced sources for baseline energy use – CEUS (California) and CBECS (national) - differ significantly in how they categorize plug energy use. A third reference, a 1999 PIER study that contributed to the 2003 PIER Impact Assessment study and this NBI/Ecova study, shows yet another categorization. Due to these varying definitions and percent references, the industry is perplexed and inconsistent when presenting plug load energy use. For the purpose of this study, the research team clearly defined the set of devices (office equipment) and the relationship of those devices to the total plug load items in the building (see Figure 11).

Table 13: Variations in Plug Load Energy Use in Buildings References

CBECS	• Office equip., computers and 'other' • All commercial bldgs – 20% • All non-mall bldgs - 12%
CEUS	• Office equip., misc. equip. • All commercial bldgs – 13% • All offices – 23% (office equip: 20%, misc: 3%)
PIER	• 2003 Impact Assessment Office Equipment – 6% • 2011 Small Oakland office all plug loads – 30% • 2011 Small Oakland office plugs after server closet – 8%

Source: C. Higgins 2011, NBI, PIER Metering and Review of Data Sources

2. **Plug Load Metering Issues.** In standard commercial building electrical wiring the major energy uses and equipment - such as heating, cooling and primary lighting circuits - are isolated at the panel. This allows metering of their energy use by attaching monitoring equipment at the isolated circuit in the panel. The plug loads, however, are blended into other circuits that typically mix many items onto the circuit making it difficult to monitor them as a set. The approach used in this study to overcome this metering complexity is described below in Section 3.2.1.6.

3. **The Office IT Structure.** The two primary IT factors that impact how much energy an office will use are the a) type of centralized computing equipment (server closet vs. data center, etc.) and b) whether the company computing is performed in-house or remotely (referred to as 'cloud computing'). These affect the study, actual use and strategies and direction of energy use trends. Changes in these two factors make the representation of plug loads challenging. This study, as was anticipated, investigated IT software but was unable to do field tests due to participant agreements not to impact the IT systems.

4. **The Problem with 'Percent'.** Percent is always relative while energy savings targets and outcomes are absolute. Without common definitions and industry understanding of the issues presented here, references to percent have less meaning. Percent problems for plug loads come in three forms:

    a. Percent of Building Use. As the energy use of other systems is reduced due to improved design and operations (as is the case with the high performance buildings selected for this study) plug loads naturally represent a larger percent of the load and are often the remaining efficiency to be pursued. The percent of plug loads can seem distorted when compared to the traditional, dated and conflicting references in CBECS and CEUS (Table 13). For example, total 'plug loads' of the studied office was 30 percent of building energy use. This certainly seems large, but when the studied office equipment alone is determined this number drops to 6 percent of total building energy use (see Section 3.2.1.6 below and Figure 18).

    b. Measure Savings. To be relevant, savings must have a scale of measures impacted and baseline assumptions of time and energy. Representing the savings potential of a single measure using a percentage is incomplete. This study cross-referenced all savings against the number of devices impacted and the measured baseline energy.

    c. Targets are Absolute. Energy targets – at the project and the policy level – are typically based on actual savings and outcomes. Saving 40 percent of a small energy use device is only valuable if that device is prolific and the savings widely implemented.

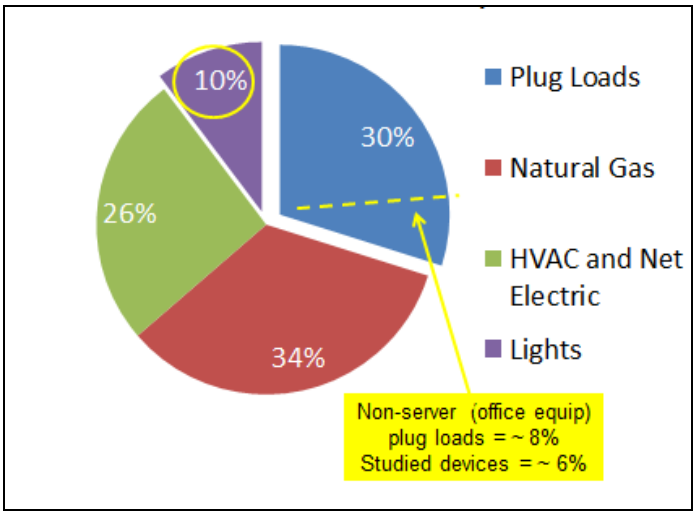
3.2.1.6 The Whole-Building Perspective

The research approach for assessing energy use and savings potential was a very precise 'bottom-up' method which included an inventory of all equipment, elimination of IT-based items (server closet and associated plug in air-conditioner) and major appliances, and direct device monitoring of all remaining items.

In parallel with this Ecova-led device-level assessment, NBI worked at the small office site on a 'top-down' analysis for Project 2 – Key Performance Indicators of High Performance Buildings. This work started with whole-building total energy use and metering at the panel for subsystems to identify the gross plug loads, followed by submetering the server closet and associated air conditioner. This 'deductive' method (starting from total building energy and removing known amounts per metered system) helped identify and verify the plug load portion of the whole-building energy use and the allotment of 'office equipment' plug loads studied for savings strategies. From this 'top-down' metering approach the overall energy use categories were determined.

At the small office Figure 18 shows this building's relatively low percent of lighting energy use (10 percent[23]). The plug loads in turn are much higher than the lighting load – representing 30 percent of total energy load for the building and reflecting the trend discussed above: when primary loads are reduced (such as lighting), plug loads become a larger percent. The 30 percent attributed to Plug Loads in Figure 18 is based on the system metering NBI installed. This total is predominantly the energy use of the server and its direct plug-in air conditioning unit. The non-server plug load energy use is assessed to be 8 percent of the total at this building, while the studied office equipment plug loads devices represent a smaller subset of 6 percent of the whole building after appliances are removed, as shown below.

Figure 18: Plug Loads as a Percent of Whole-Building Energy - Small Office



Source: C. Higgins, NBI, 2012, PIER Metering and Review of Data Sources

Combining the whole-building and system-level metering from Project 2 with Ecova's device-level pre- and post-efficiency strategy metering helps show the bigger picture of office equipment impact. The amount identified in this research of 'office equipment' was 6 percent of whole-building energy use and, coincidentally matches the 6 percent 'office equipment' figure from the 2003 PIER California Impact Assessment (Table 13).

Given this whole-building information, the team determined the savings from the applied measures at each site as a portion of the two buildings' total energy use. The findings of potential energy savings at each site found that these savings represent 1 percent and 2.5 percent of the total building energy use at the library and the small office, respectively as shown in Table 14. When these buildings are ready to upgrade equipment, additional savings could be achieved by replacing those desktop computers that do not require large memories or processor speeds with micro-sized desktops and by replacing other desktop computers, monitors and imaging equipment with the most efficient models.

[23] Average California office lighting = 28% according to CEUS.

Table 14: Summary of Energy Use and Savings for Studied Plug Loads (Office Equipment)

	Energy Use					Savings			
Study Sites in CA	kWh/sf	Total kWh	Btus/sf	% of Whole Bldg Energy Use (all fuels)	% of Whole Bldg Electricity	Total kWh from low-no-cost savings approaches	kWh sf/yr	As a % of Studied Plug Loads per Ecova	As a % of Bldg Total Energy Use per NBI
Library	0.70	66,300	2.4	6%	8%	12,270	0.13	19%	1.1%
Small Office	0.94	13,100	3.2	6%	12%	5,180	0.37	40%	2.5%

3.3 Market Connections

In addition to the two technical products identified in the original research targets and described earlier – the Plug Load Metering Plan and the Savings Assessment Report - three market-centric products were developed: 1) the *Plug Load Best Practices Guide for Offices* (*Guide*), 2) a *Methodology for Reporting Commercial Office Plug Load Energy Usage* Paper (Reporting Methodology Paper) and 3) a Case Study on Office Plug Loads (Case Study). Each provides market value in different ways. The *Guide* helps office managers, tenants and owners understand their plug load energy use with the aim of reducing energy use and cost. The Methodology Paper has a program and policy focus. It suggests the metrics, terminology and metering methods of office plug loads based on this research and can be a tool for discussion and resolution of industry inconsistencies and gaps. The Case Study provides a real-world example of the application and outcomes of both the *Guide* and Methodology Paper recommendations at an office space. Each of these is described below, followed by sections on specific market connections and adoptions.

3.3.1 Plug Load Guide – Best Practices for Offices

This is the nation's first market-based guide on this topic[24]. The information is organized around the five key themes shown to the right. Objectives included increasing the recognition of plug loads as a major energy use, providing measured data on the use and savings potential, and putting actionable guidance on reduction methods in the hands of occupants and efficiency programs. The *Guide* outlines no- and low-cost measures for reducing the energy and costs associated with office equipment plug loads such as computers, monitors and imaging equipment. Office managers, who are the key decision makers in regard to office

5 Steps for Managing Plug Load Energy Use in Offices:

1. **Review.** Identify your needs, inventory your equipment and focus on the devices that use the most energy—usually, that's the equipment you use the most.
2. **Remove.** Eliminate or unplug unnecessary devices.
3. **Replace.** When it's time to replace, purchase the most energy-efficient devices for the job.
4. **Reduce.** Turn it off or power it down when not in use.
5. **Retrain.** Engage staff. Make sure they understand why, when and how to power down.

[24] The researchers did an internet and industry search for similar materials and could not locate any simple guide on the topic of plug load best practices aimed at the occupant or office manager.

equipment operations and purchasing, are the primary audience for the *Guide*. Additional audiences are tenants and building owners or brokers (who could incorporate the guide as part of a green leasing package or promotion).

3.3.2 Plug Load Methodology Paper

The Methodology Paper offers new suggestions and guidance to establish a metering and metrics protocol for office plug loads and includes the results of office metering focused on plug loads. It is largely based on lessons from this PIER research combined with NBI's Office of the Future field findings and other research experience. The Methodology Paper was provided to program and policy entities as a reference for discussions, decisions and adoption on common methods and definitions for plug load energy use and savings representations.

3.3.3 Plug Load Case Study

The Case Study is based on applying the Methodology Paper metrics and recommended approach to assessing the energy savings and outcomes at the PECI office in Portland, Oregon. The PECI office served as a test bed for the metering method, metrics, and to add greater data on the plug load approaches and measured performance for energy efficiency. The Case Study provides owners or office managers of validation of the recommended strategies and outcomes through an applied example in a typical office space. The Case Study can also serve as a supporting document or reference for the program and policy audience in support of the Methodology Paper.

3.3.4 Research Promotion and Outreach

The Savings Assessment Report results and the *Guide,* received attention through the research teams outreach to targeting a variety of users (e.g., building owners, utilities, cities) and approaches (e.g., media releases, announcements from NBI and its allies, articles and presentations). A list of the known publications, entities and utilities promoting this PIER research is shown below; considering the extent of the outreach and the interest, there are undoubtedly others that have picked up on the media and extended the information across additional conduits.

- **Media release**, blog postings and Twitter feeds promoting the *Guide* in July 2012 were shared by ESource, The Kresge Foundation, The Institute for Market Transformation, Healthcare Performance Engineering, CB Richard Ellis Green, Rocky Mountain Institute, Natural Resources Defense Council and PAE Engineers.
- **Industry articles** on, or citing, the results were in *Commercial Property Executive* (CPE), *Real Estate Rama*, *Building Operating Management*, *Environmental Building News, Smart Energy Universe, The Power Factor, Ecova Insider and the Northwest Conduit*
- **A feature article on commercial plug load trends** titled "The Next Frontier" appeared in the September issue of *Commercial Property Executive* magazine (CPE); it references the *Guide* and includes an interview with a staff member[25]. CPE has a subscription base of

[25] A copy of the article can be found at: http://digital.cpexecutive.com/publication/?i=119254

over 30,000 top-level commercial real estate executives, including a mix of investors, developers, financiers and service providers from across the nation and spanning the major property types.

- **Presentations** were made at multiple venues. The Savings Assessment Report findings were a part of presentations at the 2011 and 2012 Behavior Energy and Climate Conference (BECC) meetings in Washington D.C. and Sacramento respectively, and at the October 2012 California Emerging Technology Summit meeting in Irvine. In March 2012 the findings were presented as part of a panel at the ASHRAE High Performance Conference in San Diego and at the ACEEE Market Transformation Conference in Washington D.C. in March 2013.
- **Webinars** highlighted this work in two important presentations. First to a group of 35 NBI stakeholders, mostly utilities and public-purpose providers interested in advancing their efforts to incentivize plug load control measures. Second, to over 200 participants comprised primarily of utilities, consultants, program implementers, and architects and engineers, through a webinar co-hosted by E-Source. Both webinars addressed questions from the attendees and generated a number of follow up inquiries and connections to the research.

3.3.5 Public Programs and Market Adoption

Plug Load Guide. Use of the *Guide* by utilities and the market is facilitated through its design, which provides blank areas on the front and back for co-branding. The *Guide was* co-funded with support NBI, the Northwest Energy Efficiency Alliance and BC Hydro. CEC recognition was required in all cases of use within and beyond California. Specific uses of the *Guide* include:

- **Utilities.** The *Guide* was, or is in the process of being, co-branded for distribution to thousands of office building owners and tenants throughout California through several major utilities (LADWP, SMUD and SCE). PG&E and Sempra received the *Guide* and associated files for customization and are considering its use and distribution through their programs.
- **The Cities of San Francisco and Berkeley**. Both are working on branded versions for distribution to their constituency and through city efficiency and disclosure programs.
- **Ecology Action.** A PG&E program implementer for small and medium commercial buildings in seven Northern California counties, Ecology Action has over 12,000 commercial retrofit projects completed. Approximately 40 percent of their work to date is in offices where they plan to put the Guide in the hands of owners and tenants on behalf of PG&E.
- **Real estate brokers** through **Waypoint** Buildings Group. Waypoint works as a real estate specialist in sustainability and energy efficiency for commercials buildings. They plan to use the *Guide* with clients interested in green tenant leases, and through local chapters of BOMA.

- **CB Richard Ellis** (CBRE).The world's largest manager of commercial real estate, CBRE, has its office of Sustainability in San Francisco. The researchers provided the Director of Sustainability the *Guide* as a tool for their tenants.
- **Consortium for Energy Efficiency (CEE)**. The research team delivered the Methodology Paper to CEEE - a key conduit to the utility industry for program research and alignment on energy efficiency issues and measures - as a topic for their committee work measured performance.
- **ASHRAE.** ASHRAE considers and makes recommendations on metrics and protocols for energy efficiency. The Methodology Paper is in the hands of staff at ASHRAE.
- **NBI PIER Research Site**. The results of all the key research products are publically available on the NBI website and through its Advanced Buildings® Program. NBI's site receives over 45,000 site visits annually seeking information on commercial building energy efficiency.

3.4 Benefits to California

As represented in the research, specific energy savings potential are highly variable by office, and the estimates from this research are based on a very small sample set. Nonetheless, the research did demonstrate that a 19-40 percent reduction in the studied office equipment plug loads was achieved at these two high performance California buildings. To provide some order of potential impact, on a conservative basis, an estimate of just a 10 percent reduction to office equipment energy for office buildings translates into an annual California savings of 316 GWh. When this is applied to all commercial building types – recognizing that office equipment plug load energy potential exists in the majority of commercial buildings[26] - the savings becomes 478 GWh.

In addition, several non-energy benefits accrue, including: extended equipment life (and therefore reduced landfill volume and reduced cost for California offices), improved office comfort due to reduced heat and noise, the potential to downsize HVAC systems due to less heat from equipment, and the opportunity for space savings due to the typically smaller size of efficient equipment as compared to their non-efficient counterparts.

The results of extrapolating the savings across buildings in California are shown in Table 15 below.

[26] Office equipment is typically found in less density in commercial buildings that aren't offices, but the estimate is made as an example and is simply an extrapolation of the conservative 10% reduction across all California commercial buildings.

Table 15: Potential Impact of Office Equipment Plug Load Energy Efficiency in California

	Energy Savings Due to Applying a Percentage Savings to California Office Buildings Plug in Office Equipment (GWh)	
Percent Reduction	**Offices Only**	**All Commercial Buildings**
10%	316	478
25%	790	1196

The research team has worked to put the results in the hands of the office owners and managers, utilities and policymakers; these are groundwork steps toward making potential savings a reality. The next and final section outlines recommendations for continued progress toward California's goals of low- and zero-energy buildings in the area of Plug Loads.

3.5 Conclusions and Next Steps

This research provided the evidence-based data that can be leveraged for market, program and policy objectives relating to plug load energy use and savings. This research was also valuable for highlighting data interpretation issues and providing some clarifications and suggestions for resolution. Some key takeaways are:

- Plug load devices are rapidly growing in offices and are unregulated, so their absolute energy use is increasing.
- Server closets and data centers are very large and discrete energy uses requiring specific approaches.[27]
- This research showed effective approaches to significantly reducing energy use of this set of office equipment. Although the impacts appear small when seen as a percent of whole-building energy in this sample, the plug load strategies and opportunities will likely be greater in other buildings compared with these 'green' buildings.
- The savings levels, in these sites was 1-3 percent of total building energy use, represent an important and largely untouched area of savings. The integrated approach necessary to achieve the low and zero-net energy building targets across California must include these savings.

The clear identification of the following easy-to-communicate sets of three findings are a leap forward in understanding and progress on the sources of plug load energy use and what should be done to reduce it:

- Office equipment plug load energy use in order:
    1. Desktop Computers
    2. Imaging Equipment and Peripherals
    3. Computer Monitors

[27] www.nrdc.org/energy/saving-energy-in-server-rooms.asp

- Approaches to save energy:
    1. Software
    2. Hardware
    3. Occupant Information and Promos

- Priority no–low cost strategies and technologies[28]:
    1. Aggressive Power Management Settings
    2. Plug Strips and Timers
    3. Occupant Information and Prompts

This is the high level of information that benefits California's efforts to communicate effectively to the chain of parties responsible and engaged in plug load energy use. NBI has initiated this information disbursement, but the findings remain available and valuable for use by a wide range of California entities.

3.5.1 Next Steps

The results of this research open new avenues for utility programs and necessitate policy formation. These results also open the door for additional research that will validate and expand upon what was found in this research effort. The next steps and recommendations are presented in three topic areas that align with different audiences: 1) Program Priorities, 2) Regulatory Approaches and 3) Future Research.

Program Priorities. Utility and public entities such as cities or government offices should consider the following within their voluntary efficiency programs:

- **Technology Incentives**. Incent advanced plug strips, timers and/or occupancy sensors focused on computers, monitors and imaging equipment and. IT energy management software programs.

- **Occupant Engagement Methods**. Include occupant engagement strategies such as enabling existing energy management settings, disabling unused equipment, education and awareness campaigns for staff about efficient behaviors and usage patterns, auto prompts to occupants to turn off equipment, and tenant competitions for low energy use.

- **Education and Promotion.** Promote the *Guide* and establish public education based on the recommendations.

- **Targeted Procurement**. Allow only the top efficient office products to be eligible in the program and inform office managers about the Top Ten list and site (www.toptenusa.org). Although EnergyStar labels identify higher efficiency equipment, the Top Ten list, developed by a national consortium of efficiency organizations, helps refine the attributes that make an appliance or equipment in the top ten of its class.

[28] Note: Replacing equipment with low-energy models is a high saving strategy and is low or no cost the time of planned replacement.

Public programs could target, incent or promote the top ten, not just use broad labels such as 'buy EnergyStar'.

- **Cloud Computing.** Encourage strategies to move office computing to the 'cloud'. There are a range of possible outcomes for efficiencies to be realized by switching to virtualization and cloud computing alternatives if done correctly. A recent report by the National Resources Defense Council (NRDC) determined that "running a computer application in the cloud is generally more energy and carbon efficient than running it in your server room because cloud commuting can serve more customers at the same time, achieving economies of scale" (*Is Cloud Computing Always Greener* 2012[29]).

Regulatory Approaches. The regulatory approaches that could be pursued are highly dependent on the type of equipment and current mechanisms available. Within this research NBI wrote a brief paper titled "Plug Load Policies: *in Place, Pending or Possible"* (Policy Paper[30]) to present the methods underway in California and nationally to reduce plug load energy use and recommend next steps.

The major policy areas and current status in California are:

- **Switched Outlets (Control through the Receptacle).** This approach requires that a minimum number of receptacles in a building be on an independent circuit that is capable of being switched off through the use of a controller. In all cases these controlled receptacles are required to be easily distinguishable by occupants from the other, non-controlled receptacles. The three major codes or Standards – ASHRAE, IgCC (within the IECC), and Title 24 – have some requirements that fall under this approach.
    - *Title 24 2013*[31]: At least one controlled receptacle is to be installed within six feet of each uncontrolled receptacle in all buildings. Hotels and motels are required to have at least half of the receptacles in each guest room be controlled.
- **Appliance Standards (Title 20).** Appliance standards are set forth in the National Appliance Energy Conservation Act (NAECA), Energy Policy Act (EPAct) and the Energy Independence and Security Act (EISA). In California appliances must meet the minimum efficiency requirements of Title 20. Title 20 should continue to move toward technologically feasible lower power limits for appliance standards and expand to include electronics that feature standby, sleep and idle modes of operation – particularly for large plug contributors such as computers.
- **Wiring & Metering Approaches**. . The following energy codes and standards feature requirements, based on use thresholds for the wiring and metering of circuits associated with plug load energy use. These can facilitate the ability to access plug load data and, in

[29] www.nrdc.org/energy/cloud-computing-efficiency.asp

[30]Appendix A-4

[31] The Title 24 2013 Standard is scheduled to go into effect January 1, 2014.

turn, make that data visible to commercial building occupants. This 'feedback' loop is a major premise of this research.

  - *Title 24 2013*: There are four different energy thresholds with varying levels of disaggregation requirements for plug load circuits. All commercial buildings with a plug load service between 50 kVA and 250 kVA need to aggregate plug loads separately from other loads in the building. Buildings with a plug load service exceeding 250 kVA need to separate plug loads by floor, type or area. In addition, groups of plug loads exceeding 25 kVA in an area less than 5,000 square feet also need to be on a separate circuit.

- **Task Lighting**. When accounted for in a larger lighting design, task lighting – portable lights plugged in at individual work areas - can be an effective way to reduce overall space lighting energy use by putting the lumens at the work surface. Task lights fall into the plug load category and are therefore difficult to "touch" from a policy perspective.

  - *Title 24 2013* requires all portable lighting systems to be accounted for in the lighting power density (LPD) space limit but provides a budget of .3 watts per square foot for task lighting. The Energy Code of Canada also requires that "supplemental interior lighting provided by movable or plug-in luminaires" be accounted for when determining compliance with installed lighting power limits.

- **Outcome-based Codes Approach.** A code approach that relies less on addressing the building in the construction phase, but more in the operational phase is referred to as an Outcome-Based Code (OBC). Outcome-based codes rely on demonstration of the building meeting a specific target for energy consumption, usually based on at least 12 months of measured energy use data. The targets can be set by building energy simulations or derived from surveys such as CBECS or CEUS.

  Though this code approach is only now in the pilot phase at a few municipalities[32] it offers significant promise in the medium to long term to address the most significant issues around plug loads – their variability among buildings and inability to be regulated in the construction phase. Several hurdles need to be addressed, chief among them the question of enforcement mechanisms available long after the building has been occupied.

- **Reach (or Stretch) Codes.** California's CalGreen has been adopted by over 100 jurisdictions and requires an energy saving level beyond the base energy code (Title 24). Similar actions are underway in Massachusetts and Oregon. At this point, none of the requirements for plug loads in these Reach Codes exceed those in ASHRAE 90.1-2010 or Title 24, but the Reach Codes provide a mechanism for implementing plug code requirements on less than, or in advance of, a full statewide mandatory basis.

[32] Seattle is in the process of having an Outcome-based code pilot program and other cities are considering the approach.

Table 16 summarizes the items currently in regulation in California and by other state and national codes and standards related to reducing plug load energy use.

Table 16: Plug Load Related Items in Codes and Standards

	Switched Outlets	Wiring/Metering	Task Lighting	Energy Star	Relevant Jurisdiction(s)
Title 24 2013	X	X	X		California
ASHRAE 2010	X	X		X	Maryland
IgCC 2012	X	X		X	Rhode Island[33]
Oregon Reach Code		X			Oregon

Summary of these policy-related recommendations for California:

1. Develop and set energy use targets through existing regulatory (Title 24), possible new pathways (outcome based) and voluntary (Reach, Stretch or Green) codes for commercial buildings.
2. Set minimum efficacy ratings for task lighting to encourage emerging technologies such as light-emitting diodes (LEDs)
3. Set default task lighting densities for compliance with Title 24 lighting power densities.
4. Move toward lower power and standby power limits in Title 20 requirements and expand to include electronics.
5. Maintain and enhance appliance efficiency programs while piloting outcome-based approaches.

Future Research. While thorough, this research raises many additional potential areas which, if pursued, will provide valuable insights and needed foundations to achieve California efficiency and zero-net energy targets. Research recommendations include:

- Expand the field investigation of plug load efficiency strategies and savings outcomes in order to increase the set of data samples.
- Include additional building types in next stage of research.
- Include additional types of plug loads with specific research focus divided into:
  - Office equipment
  - Servers and server closets
  - Task lights

[33] Adopted for Public Buildings only

- Perform Designing for Meterability (DFM) field studies and other methods for system-level metering to isolate the plug load energy use in new and existing buildings.
- Investigate the savings potential from behavioral changes and items as energy use and feedback displays.
- Determine the financial impacts and benefits of plug load measures and especially the incremental cost of measures.
- Identify the specific demand energy impacts.
- Research the latest in equipment and technology improvements.
- Identify the optimum outreach, education and behavioral efforts and impacts.

The Plug Load Savings Assessment research findings and the market connection products are valuable resources for today's work in energy efficiency in California and to build on for tomorrow's ongoing efforts.

CHAPTER 4:
Skylight Testing and Validation

The *Enhanced Skylight Modeling and Validation* research project (Skylight Modeling Research) aimed to develop and validate computer methods, as a viable alternative to physical measurements, to produce information on the characteristics of the light from commercial building skylight products. This type of information can assist lighting design professionals when considering how and where to use skylights in building design as a strategy to displace electric lighting with natural light (daylighting).

This report is a summary of the findings from Project 3 - Skylight Modeling Research - funded by the California Energy Commission's Public Interest Energy Research (PIER) program within a broader program called Evidence-based Design and Operation. The research occurred from 2010-2013 and was led by Architectural Energy Corporation (AEC) and the California Lighting Technology Center (CTLC). Daylighting Innovations (DI) performed the simulation work and validation analysis and the CLTC was responsible for the physical measurements with support from DI. Other key technical and match contributors included LTI Optics, Velux, Lambda, Lawrence Berkeley National Laboratory (LBNL) and Daylight Technologies. New Buildings Institute (NBI) was the program manager.

An in-depth report titled *Enhanced Skylight Modeling and Validation* (Skylight Modeling Report) was developed and is included in this document as Appendix A-4. It provides additional details on approach, conclusions and recommendations from this research project.

4.1 Background

Interior lighting accounts for the largest portion of electricity use in California's commercial buildings – almost 30 percent[34]. The last decade of progress in lamp and ballast efficiency is impressive but it is the integration of daylighting controls – controls that reduce the electric lighting in response to daylight – that is one component to meeting policy goals for zero net energy buildings (ZNE) in new construction.

Daylighting designs, which include skylights and daylighting products that are integrated with controls for the electric lights, are recognized as "best practice" by rating systems such as the U.S. Green Building Council's Leadership in Energy and Environmental Design-[for] New Construction (LEED-NC) and is recognized as important conservation strategy in some State energy codes and standards. For example, California's non-residential energy code - Title 24 part six (Title 24) requires daylighting controls in daylit areas larger than 250 ft^2. The purpose of the controls is to lower electricity use through devices such as dimmers, automatic shading systems, or bi-level lighting switches when sunlight is available as a substitute for electric lighting. LEED-NC states that daylight should be introduced into at least 75 percent of regularly

[34] *The California Commercial Energy Use Survey (CEUS), Itron, 2006.*

occupied building areas. The Advanced Buildings *Core Performance Guide*[35]– used by utility new construction energy efficiency programs across the nation - requires that electric lights in daylit areas be designed with control systems to minimize their use with sunlight is available. Building designers need tools to respond to these best-practice market drivers.

An office building in Oakland, California, that was studied through this PIER program (see Chapter 2) provides a quick example of the reason for this research which is intended to increase the use of daylighting in buildings. Occupied in 2006, this building met the standard requirement Title 24 for 'installed' lighting of 0.8 watts per square foot of space (W/sf). Yet due to daylighting controls the measured lighting energy use during occupied periods was only 0.33 W/sf – a 59 percent reduction.

Skylights are an important part of the strategy to accomplish energy reduction through daylighting. Windows by themselves are not always the best source to 'light' the space because daylight quickly diminishes as distance increases away from the window. At least 60 percent of nonresidential ceiling area in California is directly below a roof that can potentially provide access to daylighting, and 90 percent of new floor space is single-story construction[36]. Skylight systems, with controlled electric lights, have a significant potential for saving lighting energy.

Lighting manufacturers provide information about the photometric (light) performance of their luminaires (light systems) in the form of candlepower[37] distribution data. This data is delivered in a specific format validated by the industry technical authority - IESNA - that allows it to serve as input to lighting simulation (software) tools. Building and lighting designers are accustomed to using these simulation tools to review the options for lighting a commercial space and to meet the code and client requirements.

In contrast, skylight manufacturers have very limited information to provide to building and lighting design teams in order to assist them with predicting the performance of skylights and specialty daylighting devices. This is due to a variety of technical, time and cost constraints specific to the current approach for determining the lighting performance of skylights. This current determination method requires taking physical measurements for each skylight product in a photometric laboratory setting.

The absence of widespread photometric information on skylight systems makes it very difficult to accurately compare the performance of different products. This information is critical to determining the optimum position and distribution of these devices in a given space and to for predicting year-round performance of skylights and specialty daylighting devices in building projects. Increasing the use of skylights in commercial buildings depends in part on creating

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[35] http://advancedbuildings.net.

[36] McHugh, 2003. Modular Skylight Wells: Design Guidelines for Skylights with Suspended Ceilings, PIER Report 500-03-082-A-13

[37] Candlepower expresses levels of light intensity in terms of the light emitted by a candle of specific size and constituents and is a common metric in light design.

more replicable, reliable and industry adopted methods that present the lighting performance of skylights in file formats compatible with existing design tools.

4.1.1 Objective

The objective of the project was to define, develop and validate accurate computer simulation methods, as an alternative to physical measurements, for producing skylight candlepower distributions data and useful optical daylighting system (skylight) photometry information in an IESNA compatible format. The candlepower distributions would be applicable for a variety of locations, climates and, provided its material properties are known, skylight types.

This research has the potential to greatly advance both science and technology in the skylight industry by validating a new method for assessing photometric performance that has been slowly maturing over the last 20 years. This method only recently has become realistic and cost-effective due to new measurement and modeling tools. This new method could solve the limitations that exist when relying on physical measurements, i.e., cost, time and technology.

4.1.2 Approach

The project approach was to compare several physical photometric measurements of optical daylighting systems (skylights) to computer models, validating the use of computer simulation to reproduce this photometric information. The project used two main approaches: measurement tasks and simulation tasks.

4.1.2.1 Measurement Task

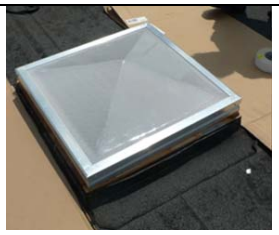
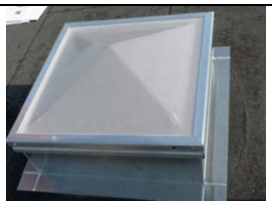
The testing facility for this project was an 18'x18'x18' building owned by the Velux Company located in Greenwood, South Carolina. Velux, a skylight manufacturer, has developed a unique facility that allows measurement of skylight candlepower distributions under real sky conditions. The building shown in Figure 19 was designed to house a custom-built goniophotometer[38] for measuring the luminous intensity distribution that emanates from a maximum 2'x2' skylight. The goniophotometer system within the facility is comprised of sensors, data logging equipment and a computer that controls the overall measurement process and capture. Measurements were performed in July because sun angles are high then and the time of year provided a good chance for mixed sky conditions.

[38] A device used for measurement of the light emitted from an object at different angles.

Figure 19: Velux Test Facility

Three skylight configurations were selected for testing to represent a range of optical complexities and different manufacturers. These products ranged from ones with very simple single optics to more complex systems with multiple optical layers. Figure 20 show images of the three daylight systems that were used.

Figure 20: Skylight Types and Systems Tested

Skylight Type	Selected Products	Image
1 – Basic Skylight: Basic skylight: minimal optics, "low" aspect ratio	Sunoptics[39] pyramid skylight Top prismatic lens White diffuse lightwell	
2 - Moderate skylight: dual optics, "med" aspect ratio	Sunoptics pyramid skylight "light cube" Top and bottoms prismatic lens Reflective lightwell	
3 - Advanced skylight: multiple optics, "high" aspect ratio	Sun Tunnel™[40] Top clear lens Bottom prismatic lens Reflective tubular lightwell	

For this study, the sky distribution measurements were taken on the roof during the same duration of time that the goniophotometer measurements were done inside the building. The CLTC determined the different measurement devices utilized to accurately capture the sky resource.

Four groups of measurements were taken: Group 1 - sky luminance at zenith; Group 2 - sky luminance mapping; Group 3 - global horizontal illuminance; and Group 4 - diffuse horizontal illuminance. Sky zenith luminance measurements were taken to compare and calibrate the sky luminance mapping. In addition, horizontal and diffuse illuminance measurements were taken to further compare and calibrate the captured luminance maps.

Simultaneous measurements were taken on the roof using the luminance camera, luminance meter and horizontal illuminance meter, and in the interior of the facility using the automated goniometer. The time of each measurement was recorded and referenced to a legal time server.

[39] Sunoptics Prismatic Skylights, an Acuity Company, http://www.sunoptics.com/

[40] Velux, http://www.veluxusa.com

The research team also worked on illuminance meter calibration and captured material reflectance measurements.

A total of 32 sets of measurements were taken over three days. The goal was to achieve measurements with low, medium and high sun angles and with clear, partly cloudy and overcast skies to obtain a robust data set for thorough validation. Each measurement set yielded a sky luminance map, assembled from 16 hemispherical photographs taken with different exposures. These images were then assembled into a single high-dynamic range (HDR) image, thus providing an accurate luminance map of the scene.

Zenithal sky luminance was measured for each hemispherical image captured, resulting in 16 measurements per test. These showed some variance, particularly for the higher sun angles with a bright zenith, and were averaged for each test. Both global and diffuse horizontal illuminance measurements were taken.

Material measurements were taken for any onsite elements that would impact the optics of the skylight system, particularly for any exposed wood in the roof and skylight framing, the floor and walls of the goniophotometer room.

Photometric files were obtained for 24 out of the 32 tests. The remaining eight tests had faulty or otherwise unreliable data and were not used for further validation. Of these 24 tests, 12 were chosen for final validation with computer simulation: four for each of the three skylight systems. For each skylight system, a test representing a low, mid and high sun angle was chosen under a clear sky and a partly cloudy condition. This set of 12 skies is used to validate the computer-simulated luminous intensity (discussed in the next section).

4.1.2.2 Simulation Task

The simulation task used field data from the measurement phase to perform comparable computer simulations of the skylight systems. The steps included:

- Processing the sky HDR images and recorded diffuse and global illuminance measurements into complete and calibrated sky luminance maps and sun sources.
- Creating ray-sets for use in forward ray-tracing engines from the sky and sun sources as well as developing the skylight geometric models.
- Developing near-field and far-field photometric simulation approaches.
- Performing Bi-Directional Scatter Distribution Function (BSDF) measurements of the skylight materials and developing BSDF models for each critical optical surface.
- Creating the photometric files for the three skylight systems.

Sky Measurement Processing and Model Creation. Prior to beginning the validation tasks, data from the physical measurements had to be processed into useable forms that represented a hemisphere of sky and that could be incorporated for use in ray-tracing software. To accomplish this, the raw photographs were cropped to represent a perfect hemispherical image with an angular mapping. A negative masking layer was created and applied to the cropped

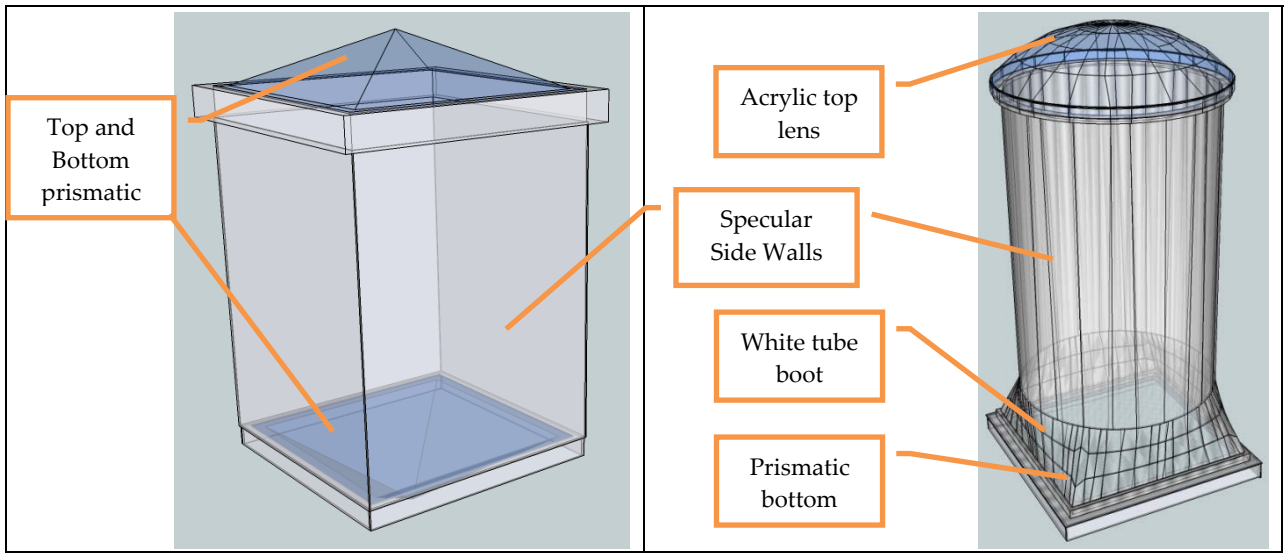
sky and adjusted to match measured sky illuminance. A matching Perez sky[41] was created for the current condition, then adjusted for "sky" shading and applied to a positive masking layer to create a filler patch. Finally, the masked measured and Perez sky models were combined, and a sun definition was added to create a final sky.

Sky Source Ray Set Creation. The research team then took the calibrated sky luminance map and direct solar source and turned it into a form that can be used by the forward ray-tracing programs. Two different approaches were explored in TracePro and Photopia (widely used lighting design software programs): the creation of a continuous ray-set and the application of sky luminance patches to a Tregenza sky patch model.

Geometric Model Development. 3D geometric models were created of the three skylight systems tested (Figure 21). A fairly simple model was created for each skylight system that includes the basic elements as perfect geometric forms (i.e. pyramids, prisms).

[41] A standard used for measured luminance data modeling of the sky named for Richard Perez (University of Albany 1991).

Figure 21: Isometric Diagrams of the Sunoptics Light Box and the Sun Tunnel Geometric Models



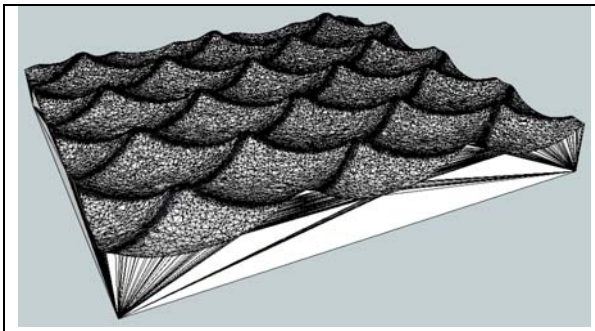
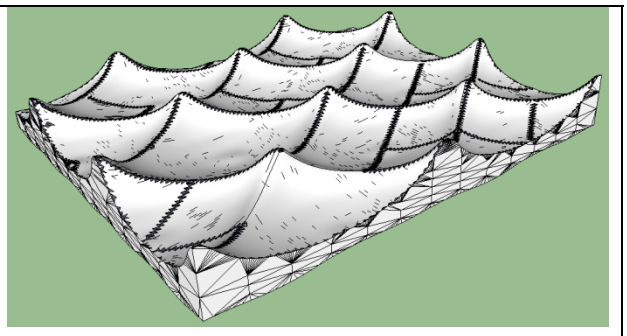
Near-Field vs. Far-Field Comparisons. With performance luminous intensity measurements, it is important to measure the intensity far enough away from the source so it acts as a point source for the given direction. Typically a 5:1 rule (where measurements are taken at least 5x the distance of the maximum dimension of the source) is followed. The physical luminous intensity measurements performed for the skylights are around this 5:1 limit and hence represent more of a "near-field" photometry. The computer simulations have the ability to report absolute "far-field" photometry (measurements are taken at an infinite distance away) as well as near-field photometry.

BSDF Measurements and Modeling. The next step in creating accurate computer models of the skylight systems was to model the optical properties of the surfaces in those systems. Visible reflectance and transmittance measurements were made for any surface that interacts with the optics of the system. Samples of the prismatic lenses were cut from the actual skylights tested and shipped to Lawrence Berkeley National Laboratory (LBNL), LTI Optics and The ScatterWorks for detailed BSDF measurements.

In addition, samples of the Sunoptics box sidewall, Sun Tunnel sidewall and Sun Tunnel boot were measured at LBNL. Samples of both skylight lenses were also sent to a laser scan company, and high-resolution 3D models (Figure 22) were created of each lens, which included many of the minor imperfections in the lens due to the manufacturing process (such as the dimple marks left likely from the injection molding process).

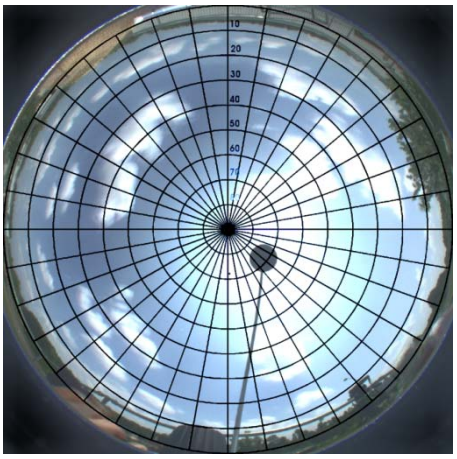
While these various labs and simulation approaches all measured BSDF information, each utilized a different data format and definition standards, thus making comparison and cross use of the data difficult. Due to this, each BSDF generation method was matched with the simulation engine to which it was best suited: Radiance, TracePro or Photopia.

Figure 22: Laser Scan 3D Prismatic Lens Material Models

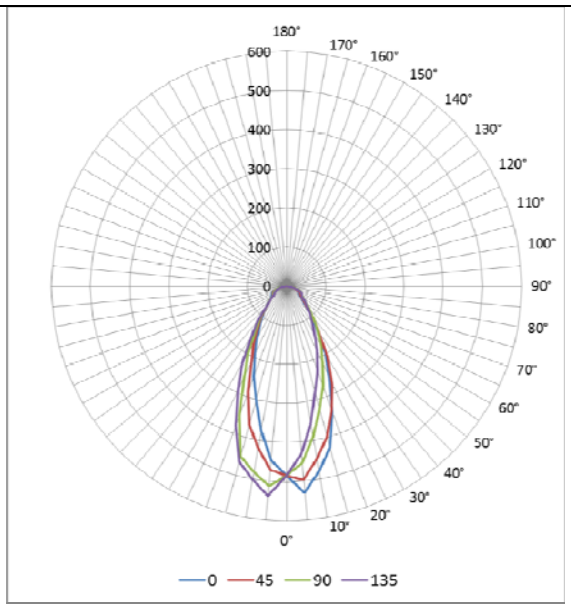
	
Sunoptics prismatic lens	Sun Tunnel prismatic lens

Photometric Creation. The final step was working through various simulation processes and settings using the calibrated sky models and BSDF measurements to create photometric results. This step was done for all three lighting software platforms: Radiance, Photopia, and TracePro. Figure 23 shows an example of a sky image taken at the Velux facility, the physical measurement photometrics, and the simulated photometrics with each software platform.

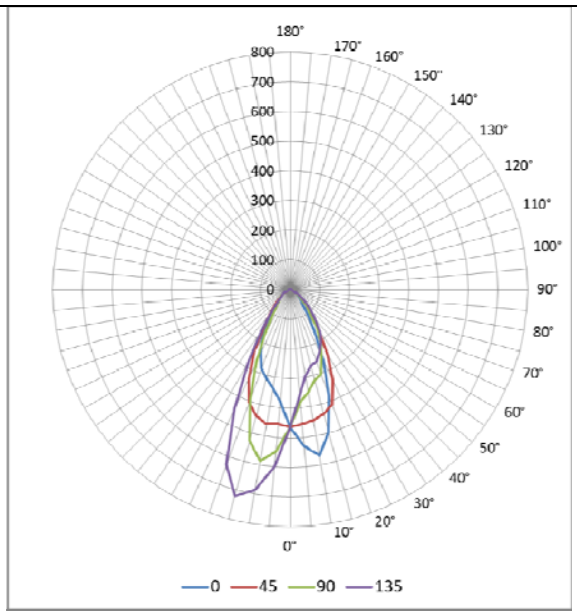
Figure 23: Sky Image 9 (top) with Measured Photometrics and Simulated Photometrics (below) by TracePro, Radiance, and Photopia



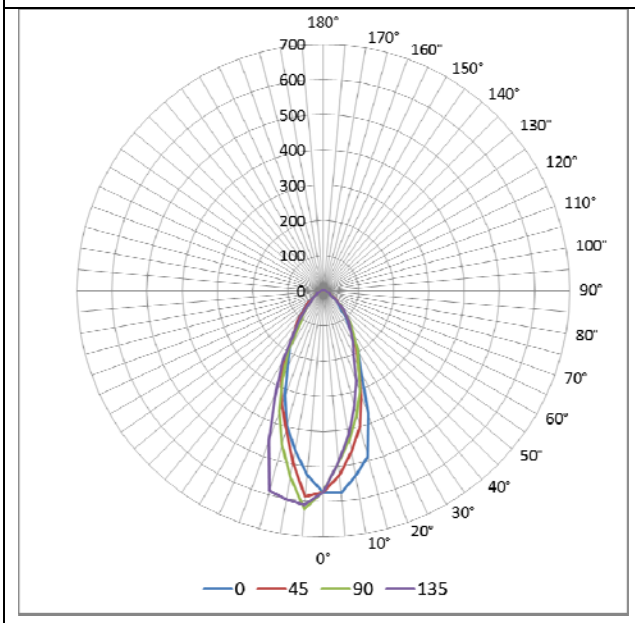
Sky Image 9



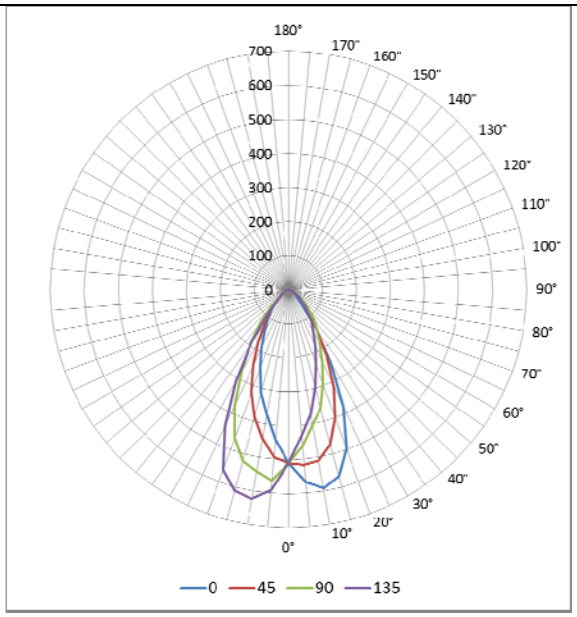
Physical Measurement



TracePro Simulated



Radiance Simulated



Photopia Simulated

4.2 Outcome and Findings

The outcome from the research findings is most significant for skylight manufacturers that use software platforms like Radiance, TracePro and Photopia to simulate the performance of their products and to provide performance data to lighting and daylighting designers. As lighting manufacturers utilize these results and the outcomes become a part of lighting software, building and lighting designers will be able to improve their application of skylights in the built

environment, leading to greater opportunities for energy savings. Other audiences include academic institutes (universities) interested in lighting and daylighting analytics and testing methods.

In response to the interests and needs of these audiences, the Skylight Modeling Report, and the section below in this summary report, present the findings organized by the five areas of investigation:

- Sky measurement and processing
- BSDF measurement and processing
- Simulation and modeling
- Computer simulation advantages
- Overall photometric validation

In-depth information on this project's research is in the full technical report referenced earlier - the Skylight Modeling Report Appendix A-4. The report provides additional details on approach, conclusions and recommendations for the physical measurements, simulation, and validation tasks for the selected skylight systems noted above. Project research activities and the Skylight Modeling Report received valuable input from a project advisory team (PAC) that included representatives from LTI Optics, Velux, Lambda, LBNL and Daylight Technologies.

4.2.1 Sky Measurement and Processing

The research determined a new method for capturing hemispherical sky images that results in valid and useable sky luminance descriptions. Some key findings regarding this new methodology were that:

- The method requires a digital camera with a hemispherical lens and exposure bracketing ability, a shading disc to obscure the solar disc, and simultaneous global and illuminance measurements to calibrate the resulting HDR image.
- It is important that the shading disc for both the camera and the illuminance meter (for the diffuse measurement) block the same solid angle of the sky.
- The illuminance measurements proved to be more useful for calibration of the skylight measured performance with the modeled performance than the zenith illuminance measurements that were more variable.

The new measurement method for cropping, masking, filling in and calibrating the HDR sky images enabled the creation of a new equi-angular hemispherical luminance map valid for use in lighting software. The method for using the calibrated sky luminance map to generate a set of sky and sun rays useable in forward ray-tracing software resulted in a valid sky and sun ray source adjustable by desired density and resolution.

In all measurements it was important to pay careful attention to the orientation of any anisotropic and/or asymmetric optics as they greatly impact the exact optical performance of the system.

4.2.2 BSDF Measurement and Processing

A variety of different visible reflectance and transmittance measurements were taken to access the properties of the skylight systems and materials. Simulations were performed for the main optical materials in the three systems at different locations and angles. The most important locations were the top and bottom prismatic lenses and the side walls of the skylight systems which are highly reflective.

4.2.3 Simulation and Modeling

Various simulation processes and settings were used in creating photometric results using the calibrated sky models and BSDF measurements. Some of the simulation and modeling findings were:

- For the tested skylight products, far-field simulation did not vary much from near-field simulation using TracePro. In forward ray-tracers, far-field simulations and near-field emulators used by Photopia appear to be acceptable alternatives for collecting photometric information.
- An adequate amount of rays is necessary for obtaining smooth and accurate exiting photometrics, particularly using forward ray-tracers.
- For highly specular and reflective systems that exhibit potential for multiple bounces within the system, it is important to simulate adequate bounces.
- Along with a high maximum reflection setting, a low flux threshold setting is recommended to help capture the flux at sharp incoming and exiting angles.
- Using Radiance, adequately high simulation parameters during the generation of both the lens BSDF definitions and system BSDF definitions is critical for accurate tail-end simulations.

4.2.4 Computer Simulation Advantages

Overall, a computer simulation approach avoids the disadvantages of using physical photometric measurements of skylight systems to verify their properties. There are:

- No Size constraints – The simulation methods developed using the three different systems have no size constraints. The daylighting systems could be 1′ to 100′ wide and the software would deal with the simulation equally. Unless optical elements are added to the system, these larger sizes will not significantly impact the simulation time.
- No Sky condition constraints – The simulation methods can use any sky/sun source desired and at any time. Captured sky images can be fed in the simulations or standard algorithmic definitions such as the CIE or Perez standards. Any sky condition can be simulated at any time or any location.

- No Photometric resolution constraints – The simulation methods can produce high resolution photometrics, but not unlimited resolution. The ultimate resolution is dependent on the resolution used in defining all BSDF materials in the systems and on the simulation parameters used.
- Fewer Time constraints – The simulations can be carried out at any time and on any number of computers, drastically improving the accessibility to detailed skylight performance data.

4.2.5 Photometric Valuation

Overall, the simulated photometric distributions matched the general shape of those measured quite well, with the following specific findings:

- The accuracy and detail of any BSDF measurements used to describe optical materials in the system is critical. Isotropic and low resolution representations appear to miss critical optical characteristics of both a single material and an optical system.
- The accuracy of the exact system geometry did not appear to be as critical. This was observed to have a minimal impact on the results where fillets were added to the lens in the Photopia Sunoptics simulations. Also, the tested skylights likely have many imperfections relative to scratches and marks on the lenses as well as dents and marks on the reflective tubes. However, there were no noticeable quirks in the photometric data to indicate any major imperfections in the manufactured geometry.
- All simulation engines (lighting software tools had a limited ability to capture high-angle light leaving the systems.
- All the simulation approaches appeared to adequately describe the general shape of daylight distribution for simple to complex optical skylight systems under a range of sky conditions.
- Time constraints – the simulations can be carried out at any time and on any number of computers drastically improving the accessibility to detailed skylight performance data.

4.3 Market Connections

The market connection work for this project focused on industry players involved in daylighting manufacturing and the design and integration of electric lighting and skylighting systems into the built environment. The following section describes the connections made and those that hold promise for these results to have impact on reducing energy use in California buildings.

The research team shared the results through a variety of promotion and outreach methods as well as through engagement with leading industry and manufactures as described below.

4.3.1 Research Promotion and Outreach

- **Presentations** at various lighting and manufacturer venues will be held in late 2013 and early 2014 by DI and the CLTC.

- **Webinars** were held by AEC and DI with assistance from the CLTC on the results to both the project advisors and the daylighting design community in March 2013. The advisors also joined project webinars in 2011 to review preliminary findings.
- **Industry involvement and articles** citing the results are planned for the *Illuminating Engineering Society of North America*. In particular, Daylighting Innovations and LTI Optics are planning a companion document to the IESNA LM-81-10: "Approved Method: Photometric Testing of Skylights" using Computer Simulation Techniques. It is also planned to encourage IESNA to create a subcommittee with the mission of linking computer simulation of skylights to physical measurements. IESNA is the recognized technical authority on illumination in the U.S. and a critical pathway to the research progress on moving the modeling method into simulation tools.

4.3.2 Market Standards and Simulation Tools

- **Skylighting manufacturers and design teams**. Results from this research are publicly available enabling manufacturers to provide better information about predicted performance to building design teams. In particular, one major skylighting manufacturer – remaining anonymous due to the potential advantage use of these findings may provide - has stated strong interest in funding work to produce this type of data for their spring 2013 product line. This is a major step toward other manufacturers understanding the significance of the research results and getting involved.
- **National Fenestration Rating Council (NFRC)** is responsible for setting the standards for the measurement and metrics associated with fenestration[42] products. Zack Rodgers, research team member from DI, will provide the results of this work to the NFRC in mid-2013 as a reference for the inclusion of daylighting product metrics and the idea of system-level BSDFs.
- **Simulation Software for Daylighting Products.** Three software platforms - Photopia, Radiance, TracePro - provide the ability to simulate skylight performance that generally matches physical measurements. Publication of the research results and continued refinement of the validation methodology and BSDF measurements will increase the rigor of these tools as well as encourage the development of other new tools.
- **Other Daylighting Software.** The resulting system BSDF files and design day photometrics can be integrated into many other lighting/daylighting design and analysis software such as AGI32, Visual, SPOT, OpenStudio, DIVA for Rhino, Energy Plus. At least these three ray-trace software can be used to create the data but a number of other software can make use of the data.
- **Utilities.** The results of this research can inform utility program managers for energy efficiency programs focused on electric lighting and daylighting integration as well as

[42] Fenestration refers to the design and characteristics of windows and other exterior openings of a building.

the ZNE initiatives. Outreach in this area beyond exposure of the program-level advisory group to the research objectives and findings did not occur during this research project.

- **Code Governing and Rating Agencies.** Green building rating systems, energy efficiency codes and standards, and ZNE initiatives provide strong market drivers for adoption of tools that improve the integration of quality daylight into the built environment. These should in turn help the manufacturers find a highly interested audience in the design teams responding to these policy factors.

4.4 Benefits to California

The results and methodologies developed from this project provide more accurate information about the performance of skylighting products and specialty daylighting devices to lighting and daylighting designers, energy consultants and building engineers. This will provide the kind of information necessary for design teams to more consistently and successfully integrate daylighting and electric lighting in their projects. California sales of skylights and lighting controls could increase and expand a small niche of work into a larger employment opportunity based on the large amount of commercial floor space eligible for skylight daylighting.

Table 17 presents the estimates for annual energy and peak demand savings potential of a greater use of skylights in new commercial buildings in California.

Table 17: Potential Annual Energy Savings and Peak Demand Reduction of Greater Use of Skylights in New Commercial Building Construction in California

Commercial Occupancy Types	**Electricity Consumption Savings**	CA interior lighting electricity consumption for appropriate building segments and end uses (GWh/year)	Savings in electricity consumption from proposed research product (%)	Expected penetration into building segment and end use markets (%)
Large Offices	**5.89**	2,945	20%	1.0%
Small Offices	**2.77**	1,386	20%	1.0%
Restaurants	**1.92**	961	20%	1.0%
Retail	**21.23**	4,246	20%	2.5%
Food Stores	**6.17**	1,233	20%	2.5%
Warehouses	**7.43**	1,485	20%	2.5%
Schools	**2.56**	1,281	20%	1.0%
Colleges	**1.58**	790	20%	1.0%
Hospital/ Healthcare	**2.24**	1,119	20%	1.0%
Hotels/ Motels	**1.89**	945	20%	1.0%
Misc.	**5.75**	2,874	20%	1.0%
Residential	**57.74**	28,870	20%	1.0%
Total	**117.16**	48135		
Commercial Occupancy Types	**Peak Demand Savings**	CA lighting peak demand for appropriate building segments and end uses (MW/year)	Savings in peak demand from proposed research product (%)	Expected penetration into building segment and end use markets (%)
Large Offices	**1.15**	575	20%	1.0%
Small Offices	**0.79**	394	20%	1.0%
Restaurants	**0.35**	174	20%	1.0%
Retail	**3.90**	779	20%	2.5%
Food Stores	**0.89**	177	20%	2.5%
Warehouses	**1.56**	312	20%	2.5%
Schools	**0.84**	418	20%	1.0%
Colleges	**0.35**	177	20%	1.0%
Hospital/ Healthcare	**0.34**	172	20%	1.0%
Hotels/ Motels	**0.30**	149	20%	1.0%
Misc.	**1.18**	591	20%	1.0%
Residential	**6.93**	3464	20%	1.0%
Total	**18.57**	7383		

The energy and peak demand savings represented in Table 17 are estimated based on 20 percent savings from integrating skylight systems with controls that turn off electric lighting in the occupied space of various California commercial building types. Market penetration is conservatively estimated at between 1 percent to 2.5 percent depending on building type. These

savings and penetration estimates result in a potential of 117 gigawatt hours of energy and 18 gigawatts of peak energy savings per year in California commercial buildings. Non-energy impacts include increased health and well-being for building occupants and productivity gains. The research results will be in the hands of the daylighting consultants, skylight manufacturers, utilities and policymakers who can make these potential impacts a reality.

4.5 Conclusions and Next Steps

The research team successfully demonstrated and documented the ability to use computer models based on field data to predict skylight performance and produce valid modeled outputs of the performance. Radiance, TracePro, and Photopia were shown to be valid software for simulating the performance of skylight systems given accurate input and careful simulation settings as described in the report.

The research team's engagement with key committees at IESNA and NFRC – the leading organizations responsible for setting the technical standards for lighting and windows/skylights respectively – is a major step toward aligning these standards with the research results. As these organizations adopt the research recommendations, and the photometry files are put to use by skylight manufacturers and through lighting software tools, the use of skylights as daylight strategies to reduce electric lighting will accelerate by design teams.

The simulations can be carried out at any time and on any number of computers drastically improving the accessibility to detailed skylight performance data. Design teams will able to respond to client interest for improved indoor environments and 'green' buildings[43] and help to meet policy drivers in California such as Title 24 and ZNE targets.

4.5.1 Next Steps

Based on the findings from this study the following next steps are recommended.

1. Form an IESNA daylighting sub-committee to develop and publish a companion document to the IES LM-81-10 that outlines an approved method for creating optical daylighting system photometric distributions using computer simulation. The daylighting sub-committee should also develop an approved annual daylight simulation methods that takes into account an optical daylighting systems
2. Coordinate with the National Fenestration Rating Council (NFRC) to expand their rating, certification and labeling efforts to include additional daylighting metrics. Also work with NFRC to implement system photometric information in future daylighting product metric and rating efforts. This is likely an expansion of the Visible Transmittance (VT) metric currently used for fenestration which is a simple measurement of light transmittance at a single perpendicular angle.

[43] By 2015, an estimated 40-48% of new nonresidential construction by value will be green. McGraw Hill, 2012

3. Create an openly available benchmark database with the measured sky and photometry sets for future validation of simulation engines or to validate further refinement of the methods explored in this report. More daylighting benchmarks in general are needed in the daylighting simulation industry to ensure reliable data is being produced and reported to the design industry and this data set could be part of these efforts.
4. Engage and inform daylighting software developers of any daylighting system photometric standard developments and annual simulation standard developments accomplished through activity 1 above. Encourage the adoption and development of software that includes daylighting system photometric data and validated annual calculations. Work with daylight software developers that are already involved in related IESNA daylighting committees.
5. Engage and inform the architectural daylighting design community as to the relevance of having more detailed photometric available when reviewing products and simulating performance. Likely, their main exposure to these advances will be through new labels that reports new daylight metrics on daylighting products and new advances in their lighting software that simply correctly simulates these devices.

CHAPTER 5:
Rooftop Unit Fault Detection and Diagnostics

5.1 Background

This report summarizes the findings from Project 5: *Rooftop Unit Fault Detection and Diagnostics (FDD)* within the PIER program "Evidence-based Design and Operations." The research occurred from 2009-2013 and was led by New Buildings Institute (NBI) as project manager and market connections lead with the Western Cooling Efficiency Center and Purdue University as the major research leads. The full technical reports and products are found in Appendix A-5.

Rooftop packaged air conditioners (RTUs) are the predominant HVAC (heating, ventilation and air-conditioning) system found on commercial building rooftops in California and throughout the United States – cooling over 60 percent of the commercial floor space[44]. These systems do not often enough receive regular and/or thorough preventative maintenance, primarily because of lack of perceived value by owners and the HVAC service industry. Service calls are generally limited to filter changes and visual inspection or occur as an emergency response to major system component failures that impact occupant comfort. Even in the case of equipment maintained under formal maintenance contracts, technicians typically only detect severe and obvious fault conditions because their procedures only involve routine qualitative assessments. This means non-catastrophic faults that cause significant energy waste go unnoticed for years.

Fault detection and diagnostics for RTUs is a developing class of products designed to monitor RTU performance so that faults can be identified and corrected. FDD technology senses key system operating parameters, detects performance degradation, and triggers an alarm that is communicated to some form of fault management tool, the zone thermostat, or appropriate facility personnel. FDDs help maximize the value of investments in energy efficiency systems, extend the life of RTUs and reduce emissions. California's Energy Efficiency Strategic Plan urges the broader application of this technology.

In addition to energy savings benefits, FDD can identify faults in RTUs that can be repaired, leading to increased occupant comfort due to the appropriate ventilation that is linked to improved worker productivity. Additionally, addressing RTU performance degradation faults when they first occur is much less expensive than addressing them when they become catastrophic (which requires expensive component or whole unit replacement).

While tools that can detect and diagnose faults in RTUs are becoming more widely available for air conditioning systems in residential and light commercial products, it is not known how effective these tools are. There is no uniform method or national standard for evaluating how well they work.

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[44] W. Wang, et. al. PNNL December 2011 *Energy Savings and Economics of Advanced Control Strategies for Packaged Air-Conditioning Units with Gas Heat,* pg. vi

This project addressed the need for 1) diagnostic protocol standards to assure the accuracy of commercially available rooftop fault detection and diagnostic tools used in California utility HVAC installation and maintenance programs, 2) current information on the commercial availability of products and services that address the RTU FDD market and 3) a California Title 24 Nonresidential Building Energy Standards code measure supporting FDD being built into new and replacement RTUs.

Since the start of this project additional policy initiatives for optimizing and maintaining HVAC system performance have come into place, including California Senate Bill 758 that addresses deeper energy savings in existing buildings. The FDD work and outcomes described in this report and related Appendices supports these ambitious policies by creating new tools, information and codes that can reduce the energy use of RTUs.

5.1.1 Objectives

The project goals were to reduce the energy performance degradation in rooftop HVAC units (5-50 tons[45] in size) in California and support the persistence of energy/demand savings from utility-sponsored HVAC service programs and high efficiency unit programs. The specific research objectives were threefold:

- Development and deployment of a critically needed software tool for evaluating current diagnostic protocols. (**FDD Protocol Evaluator**)
- Development and market-wide dissemination of information on the availability, usability and cost-benefit (energy and non-energy) of commercially available FDD products that improve RTU field performance and provide ongoing performance monitoring to building operators. (**FDD Technology and Market Review**)
- Development of a minimum standard for FDD functionality for submission as a Prescriptive Measure to the 2013 Title 24 part six Nonresidential Building Energy Efficiency Standards. (**FDD Title 24 Proposal**)

This summary report is organized with a section addressing each of these key objectives and describes the approach, outcomes and findings, and market connections. Additional FDD market efforts are highlighted following these three sections, along with the benefits to California if FDD were adopted and the conclusions and next steps for FDD.

5.2 FDD Protocol Evaluator

A protocol evaluator for FDD was built to establish an industry-supported method to test (evaluate) the algorithms that are used in FDD tools (the tool protocols). This test helps ensure the results from FDD tools to the user are reasonable. The new evaluator test does not include the tool's sensor hardware or the hardware interface.

The development of the diagnostic protocol evaluator component was led by Dr. James Braun with doctoral candidates David Yuill and Howard Cheung, all of Purdue University,

[45] A ton is a unit of heating or cooling for HVAC equipment representing 12,000 BTUs

conducting the analysis, development and testing of the evaluator and software application. In a fortuitous development, researchers from the National Institute of Standards and Technology (NIST) joined the Purdue team. This collaboration resulted in the addition of three new evaluation test areas in addition to those defined in the original project goals. The tool produced through this research is called the *FDD Evaluator 0.1.1* (Evaluator).

5.2.1 FDD Protocol Evaluator: Approach

The research team input data from a large number of test cases (607) from HVAC equipment set up in the Purdue HVAC laboratory with various faults induced into beta versions of an FDD protocol as a means to test and evaluate the protocol responses. Each test case represented a set of conditions that might be encountered by an FDD tool. For each test case there were five possible outcomes:

- *No Response* – the FDD can't be applied, or can't give a diagnosis.
- *Correct* – the FDD response matched the actual condition.
- *False Alarm* – a fault is indicated when no fault is present.
- *Misdiagnosis* – the wrong fault is diagnosed.
- *Missed Detection* – the FDD indicates no fault when a fault is present.

The raw results for evaluation were organized according to the magnitude of the impact that the faults would cause on system performance. Results were presented across a wide range of performance degradation limits. This allowed the research team to choose a fault impact threshold of interest. For example, if the user wished to tolerate (allow) faults that cause less than 5 percent degradation in efficiency, they could then gauge the outcome rates for faults above this level of degradation.

From an analytic perspective, there were several disadvantages to using experimental data for FDD evaluation. Most significant is that existing data was quite limited, and generating new experimental results would have been difficult and costly. To address this, a method was developed to model unitary systems operating with or without the faults included in this project. This method is a hybrid of inverse models (those based on experimental data) and forward models (based on physics alone). The method produces models referred to as 'gray-box' models which use some measurement data, but also use physical laws to extend the model to conditions that were not tested experimentally. These gray-box models treat each component (compressor, heat exchangers, expansion device and piping) of an RTU separately.

5.2.2 FDD Protocol: Outcomes and Findings

The Purdue University team developed a software application which runs on a Windows-based operating system that can determine the types of faults related to the initial target of an FDD tool. This research product is the *FDD Evaluator 0.1.1* (the Evaluator); the tool and all related materials are publicly available on the Purdue FDD website[46]. The technical report, *A Method for*

[46] https://engineering.purdue.edu/FDD_Evaluator

Evaluating Diagnostic Protocols for Packaged Air Conditioning Equipment (Evaluator Report), user guide and comments from reviewers can be found in Appendix A-5 to this report.

The research met its original scope to develop a software tool for evaluating diagnostic protocols for FDD that determine a) high or low refrigerant charge, b) high or low evaporator airflow, and c) condenser coil fouling. Added to these initial FDD conditions (thanks to the research collaboration with NIST) were three new fault evaluation parameters: liquid line restriction, non-condensable in the refrigerant circuit, and compressor valve leakage, resulting in nine fault detection areas for the Evaluator tool. Although few commercial FDD tools currently provide fault detection for these last three conditions, tool providers may be motivated to add these to gain market position now that a third-party tool can represent their accuracy.

Some of the main conclusions of the Evaluator Report include:

- The evaluation method developed here should be applied to FDD protocols of interest to determine whether their performance is acceptable to potential users.
- Model data should be used instead of measurement data in future evaluations to:
    - Control the distribution of faults.
    - Remove the uncertainty from experimental error.
    - Widen the field of potential systems, faults, fault intensities, fault combinations, and driving conditions.
    - Provide datasets that can't be learned, hence gamed, by unscrupulous developers.
- More understanding of the likely distribution of faults in the field is required.
- The Title 24 RCA protocol performs quite poorly, and consideration should be given to removing it from the Title 24 standard.

FDD Evaluator Example. A full example of the Evaluator software applied to a project is located in Appendix A-5. A brief view here is that the Evaluator software outputs four plots: 1) Numerical values tables; 2) False Alarm rates figure; 3) Misdiagnosis rates figure; 4) Missed Detection rates figure. Figure 24 shows the numerical values tables that contain all the output data for the three subsequent plots. The data in the output tables may be copied and pasted to other programs for further analysis.

Figure 25 is an example of the missed detection rates figure with the data listed by percent groups (bins) of the fault impact ratio. The faults shown are based on input date for undercharge and overcharge of the air conditioners refrigeration. The impact is represented on two parts of the air conditioner: the capacity (the amount of cooling being delivered) and COP (the coefficient of performance that is the metric for the efficiency of the unit). The missed detection rates for the 95-105 percent bin are roughly 10 percent (the horizontal or Y axis). There are no Missed Detections for cases in which COP is reduced by more than 15 percent, and none for cases in which capacity is reduced by more than 25 percent.

In general, not detecting a fault that has a small impact could be construed as a positive outcome. However, overcharge of refrigeration for example can present a danger to the

compressor without having a large effect on capacity or COP. Since the only faults that were input in this example were charge faults, a large portion of the tests in the 95-105 percent range will be overcharge cases. Missing these fault detections is important even if the impact on capacity or COP is small. The Evaluator requires a strong understanding of HVAC equipment, the analysis methodology used in the tool, and how to interpret the results. The audience for this highly specialized technical tool does have these abilities; the research provided training materials in the form of the user guide and the examples found in Appendix A-5.

Figure 24: Example Output Table of Numerical Results from the FDD Evaluator 0.1.1

File

Overall Results

Total number of tests	327
No response rate [%]	26

False Alarms

	100%	99%	97.5%	95%	92.5%	90%	87.5%
Responses (capacity)	38	69	88	119	139	153	159
False Alarms (capacity)	10	26	34	51	68	80	85
False Alarm (capacity) rate [%]	26	38	39	43	49	52	53
Responses (COP)	37	70	100	137	153	160	169
False Alarms (COP)	5	23	44	67	80	86	93
False Alarm (COP) rate [%]	14	33	44	49	52	54	55

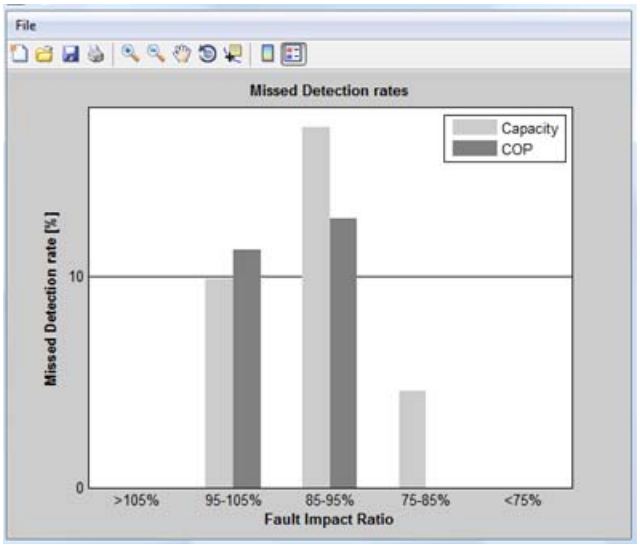
Misdiagnoses

	>105%	95-105%	85-95%	75-85%	<75%
Responses (capacity)	2	73	39	21	12
Misdiagnoses (capacity)	0	3	0	0	0
Misdiagnosis (capacity) rate [%]	0	4	0	0	0
Responses (COP)	0	79	48	8	12
Misdiagnoses (COP)	0	3	0	0	0
Misdiagnosis (COP) rate [%]	NaN	4	0	0	0

Missed Detections

	>105%	95-105%	85-95%	75-85%	<75%
Responses (capacity)	2	81	47	22	12
Missed Detections (capacity)	0	8	8	1	0
Missed Detection (capacity) rate [%]	0	10	17	5	0
Responses (COP)	0	89	55	8	12
Missed Detections (COP)	0	10	7	0	0
Missed Detection (COP) rate [%]	NaN	11	13	0	0

Figure 25: Example of Missed Detection Rates from the FDD Evaluator 0.1.1



Review of the Title 24 Refrigerant Charge and Airflow (RCA) Test. The current California Title 24 (2008) HVAC Refrigerant Charge and Airflow (RCA) diagnostic protocol was used as an experimental test subject during development of the new FDD evaluation methods. The RCA protocol will continue to be the protocol for refrigerant and airflow, in a slightly modified form, in the upcoming Title 24 - 2013 (effective January 2014). This research uncovered some performance flaws in the current RCA.

The RCA is intended only to detect high or low refrigerant charge and low evaporator airflow faults. The airflow diagnostic is intended to ensure that the evaporator has sufficient airflow for the refrigerant charge diagnostics to be applied. This option is available if direct measurement of the airflow is not taken. The RCA protocol is based primarily on manufacturer's installation guidelines and specifications.

Title 24 specifies that the RCA protocol be applied to new residential systems. However, it has been used to a degree as the basis for utility-incentivized installation programs on residential and commercial unitary systems (a single system that provides heating and/or cooling). In addition, the current Title 24 RCA protocol is used by the Home Energy Rating System (HERS) raters, who provide field verification and diagnostic testing to demonstrate compliance with the Title 24 standard.

The RCA has varied with each update of Title 24. The 2013 RCA version included 'looser' tolerances than past RCA code versions when comparing measured and target values of superheat, sub-cooling and temperature split. The temperature-split evaporator airflow diagnostics approach was removed since there are other, easier field methods available to confirm sufficient airflow prior to diagnosing charge faults by HVAC technicians. These generally involve showing by direct measurement that the evaporator airflow is above 300 CFM or in some cases 350 CFM per nominal ton of cooling capacity.

The 'installer' label below refers to the Title 24 protocol. The research team conducted tests of the Title 24 2008 and 2013 and HERS RCA protocols and identified a frequency of missed diagnosis and missed detections that ranged from 25 percent-55 percent (Table 18). As noted in the Evaluator Report, the research team concluded that the Title 24 (08 and 13) RCA protocol "performs quite poorly, and consideration should be given to removing it from the standard." This recommendation has implications for Title 24 that will need to be considered by California regulatory interests in a future Title 24 revision process.

Table 18: Summary of Misdiagnosis and Missed Detection Rates for the RCA Protocol

	2008		2013	
	Installer	HERS	Installer	HERS
Misdiagnosis Rate	26%	25%	32%	29%
Missed Detection Rate	32%	39%	37%	55%

The Evaluator is intended as a benefit to the FDD tool market nationally, providing a quality assurance tool to evaluate the operational and accuracy claims of FDD tool developers and providers. As FDD tool developers see the benefit of testing it is expected they will run their own internal tests to determine how to improve the accuracy of their products. Moving forward, it is hoped that the Evaluator can provide a path to improved FDD performance by illuminating poorly performing FDD approaches, spur further developments and improvement, and provide a tool for FDD developers to use as they explore improvements in their own protocols.

5.2.3 FDD Protocol Evaluation: Market Connections

The Evaluator was produced, and the tool and documentation are now publicly available on the Purdue website[47]. The Evaluator was reviewed by California regulatory and utility participants as well as public stakeholders to determine what next step options were of interest for the Evaluator, its use in California and its implications for the 2013 Title 24 RCA protocol that will be in force January 2014. A summary of the activities and meetings follow:

- FDD tool developers from California and around the nation were invited to submit their products to the Purdue researchers for proprietary testing as the Evaluator was developed.
- A research paper titled "Evaluating Fault Detection and Diagnostics Protocols Applied to Air-cooled Vapor Compression Air-conditioners" was presented at an international HVAC conference at Purdue University in July 2012.
- Public access to the Evaluator software on the Purdue University Herrick Laboratories website and future revisions will be integrated into the Evaluator. Purdue staff may also pursue ANSI Standard status for the Evaluator.
- Researchers held webinars and workshops for invited participants to discuss the research approach in more detail.

5.2.3.1 Final Stakeholder Meetings Overview

A final meeting with California utilities and regulatory staff was held in February 2013 to demonstrate the Evaluator, its potential for use as a screening tool for utility quality installation and maintenance programs, and to discuss issues related to the Title 24 HVAC refrigerant charge and airflow (RCA) diagnostic protocol. The attendees were very interested in the potential of the Evaluator for use in utility programs and by the Energy Commission staff as a benchmark for potential revision to Title 24 in the future.

In addition to the overview of the meeting topics and discussion presented here, two stakeholders provided detailed comments along with recommendations for next steps to further validate and enhance the Evaluator. These comments and related recommendations for next steps were sent to the CEC, CPUC, and utility staff in the codes and standards as well as

[47] Ibid

program evaluation offices. The stakeholder-submitted comments are a part of the Evaluator Report in Appendix A-5.

California utilities have the option of applying the Evaluator to residential and commercial FDD products being considered for use in HVAC-related energy efficiency programs. Both the California Energy Commission (CEC) and California Public Utilities Commission (CPUC) will assess their respective interests in the Evaluator and provide guidance or requirements for the utilities to apply the Evaluator in support of program implementation and evaluation objectives. Regulatory staff can use the Evaluator to determine the range of accuracy of FDD tools on the market to determine the usefulness of tools already on the market.

The concept was that HVAC contractors seeking to participate in ratepayer-supported (utility) HVAC programs would submit diagnostic tools for a pre-qualifying assessment using the protocol Evaluator. The utilities would establish acceptable accuracy threshold within a plus-minus range that the contractors' tools would have to meet. Contractors seeking to participate in the program would have to pre-qualify their tools and/or protocols, which would in turn qualify them for program participation. Tools that did not meet the established thresholds would have to be revised to be eligible for re-test and reconsideration.

The meeting discussions involved a significant concern about the Title 24 2008/2013 RCA protocols referenced earlier related to the apparent limits of their accuracy as reported in the Evaluator Report. There were several areas of consensus among participants for what needs to be considered by various authorities including regulators, utilities, HVAC contractors and manufacturers, as listed below.

1) Consider development of a performance goal in Title 24 for fault detection protocols for new HVAC equipment installations to replace the current prescriptive RCA protocol approach. The metrics for a performance approach should be identified and assessed with goal development for submission in time for the 2016 Title 24 revision process that begins in 2013. A key impetus for making this change is the unacceptable rates of missed faults, misdiagnosis, false alarms and no response found by the Purdue research team testing the RCA protocol.

   An underlying issue is related to the HVAC industry's superheat table values. While not all manufacturers subscribe to the table values, many do and the tables are commonly used in the HVAC contracting industry. A senior HVAC industry engineer noted in a 2006 CEC-sponsored meeting that the superheat values needed a formal industry review in part because newer equipment had different operating temperatures and pressures that needed to be accounted for in the tables. PIER-sponsored research on charge checking at lower temperatures found anomalies in the superheat tables at certain conditions.[48] In addition, the current tables refer primarily to conditions in equipment charged with R22 refrigerant, which has been replaced in newer units with R410a.

[48] Temple, Keith A., Expanded Test Protocols for Low Ambient Testing of Unitary AC Systems, BERG Project Final Report, Grant 54921 A/06-09B, September 2008 (revision date February 2009)

Manufacturers have previously opposed methods that conflicted with their specifications. In this case, it may be time to move beyond the industry tables to provide a more useful approach to RCA in California.

2) Engage HVAC manufacturers about the RCA issue noted above around the tables and their underlying usefulness in both Title 24 as applied to new equipment and proper application to existing units being addressed in HVAC maintenance programs. The focus on the RCA and new equipment is primarily corrective. The California investor-owned utilities have moved beyond the RCA as a program initiative for existing equipment and now include a comprehensive set of maintenance measures that include controls, the economizer (for rooftop units) and airflow, with refrigerant charge last on the list. Stakeholders suggested that the CEC and CPUC, along with the utilities, take the first step in contacting industry representatives perhaps starting with the leading industry association, the Air-Conditioning, Heating, and Refrigeration Institute (AHRI).

3) Create a field characterization on the incidence and prevalence of non-condensables, liquid line restrictions and compressor valve leakage with related simulation analysis to provide a more robust set of results for inclusion in the Evaluator tool. Some laboratory work on the energy impact of non-condensables and liquid line restrictions is already underway through the CPUC.

   Due to the potential for refrigerant (a potent greenhouse gas) leakage either from non-condensables repair that requires evacuating, flushing and refilling the refrigerant lines, and refrigerant escape through compressor valve leakage, a greenhouse impact assessment of the magnitude of these leakage pathways should be done. Purdue University researchers have begun working to model multiple levels of multiple simultaneous faults. Additional data is needed on multiple fault prevalence, incidence and energy impacts in order to build a simulation model to move beyond the more costly experimental approach.

4) Test other vendors HVAC diagnostic tools, many companies want their diagnostic protocols tested and need assurance that confidentiality will be protected. Purdue has already implemented a secure test system with one vendor and is offering the same secure approach to others. Data inputs are sent to the tool vendor, with vendor product output results provided to Purdue. In this way the researchers have no direct access to confidential information in the vendors' protocols.

5) Expand the Evaluator fault data library; for example there is currently only one data set on faults for non-condensables. Purdue researchers are working to build a simulation approach that will reduce or eliminate the need for experimental measurements that are time consuming and expensive, but provide acceptable levels of certainty and accuracy in the Evaluator. *Note:* A dataset of test results from 200 HVAC units has been made available by PG&E (Pacific Gas and Electric Company) staff for use in a demonstration of the Evaluator that will be made available to stakeholders and the public on the Purdue University FDD website.

Additional Research. Additional financial support from the CEC and/or utilities along with some continued support from NIST could be used for the following work specific to the evaluation of FDD protocols:

- Evaluation of other fault detection protocols, as a way of testing and refining the evaluation approach.
- Fault evaluations using simulation data.
- Assessment of simulation data as a replacement for experimental data.
- Assimilation of the simulation data into the application software.
- Development of simplified figures of merit for FDD protocols.
- Enhanced user interface for the application software.

5.3 FDD Technology and Market Review

Dr. Kristin Heinemeier, Western Cooling Efficiency Center (WCEC) was lead researcher for the market and technology assessment working with graduate student assistance. The work was to develop a summary of information on the availability, usability and cost-benefit (energy and non-energy) of commercially available FDD products. The full research report titled "Rooftop HVAC Fault Detection and Diagnostics: Technology and Market Review" (FDD Review Report) is located in Appendix A-5.

5.3.1 FDD Technology and Market Review: Approach

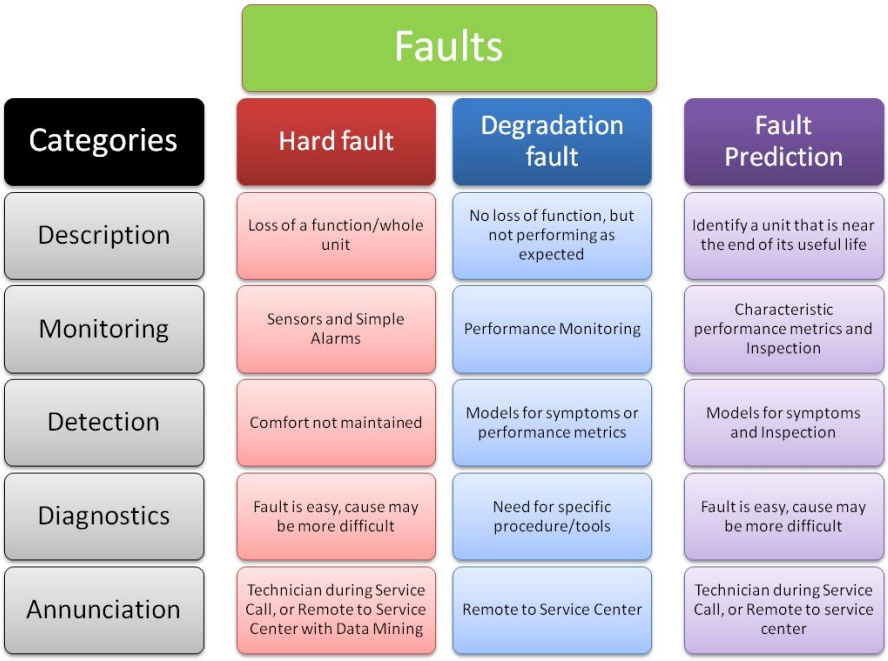
The research team undertook a comprehensive review of available FDD products, services and facility management behaviors related to HVAC operations and maintenance to identify and prioritize the faults that can be detected by a set of currently (or shortly) available diagnostic tools, and to evaluate the available tools. This work was the foundation for defining the minimum FDD requirements that were proposed, vetted with stakeholders, modified and ultimately adopted into the 2013 Title 24 California Standards (see Section 5.4).

The approach included input from colleagues and contacts to support the initial identification of new FDD products or approaches either already in the market or on a path to commercialization. Interviews with tool developers and HVAC contractors provided important information on how much contractors and customers currently know about FDD and what does or does not interest them in this type of functionality.

The project researchers reviewed all the information on RTU FDD products available in the market through 2011. The field is undergoing rapid change with the introduction of new products and further refinement of existing products and approaches, so the results do not represent the complete current state.

A framework of functionality was developed to help define the types of FDD tools currently available or in development. A set of criteria was developed for the attributes likely to be successful in the marketplace or to be successfully implemented in California's Title 24 energy standard. Project team members sought out examples of FDD tools that are available in the market and categorized these. The research then determined what faults each can identify and the kinds of data required for each tool. The results are illustrated in Figure 26.

Figure 26: Fault Categories for Rooftop Unit Diagnostics



5.3.2 FDD Technology and Market Review: Outcomes and Findings

The researchers identified the minimum requirements for FDD, including communications options for RTUs that enable cost-effective energy/demand savings. The full FDD Review Report has extensive information on the faults affecting FDDs, the criteria for evaluating the products includes the magnitude of savings, cost effectiveness, frequency and probability of faults, reliability of products, maintenance issues and definitions, Table 19 shows the FDD products and related services that were initially identified. Some were on the market, some in development stages. Others went through changes in structure and brand name.

Table 19: FDD Products by Developer

Tool Name	Data	Model	Status	Developer
FDSI Insight V.1	Refrigerant	Quantitative	Available	Field Diagnostics, Inc.
Sentinel/Insight	Refrigerant	Quantitative	Beta	Field Diagnostics, Inc.
ClimaCheck	Refrigerant	Quantitative	Available	ClimaCheck Inc.
SMDS	Air	Qualitative	Pilot	Pacific Northwest National Laboratory
Sensus MI	Air	Qualitative	Available	University of Nebraska
NILM	Power	Qualitative	Pilot	Massachusetts Institute of Technology
Low Cost NILM	Power	Timeseries	Pilot	Massachusetts Institute of Technology
Virtjoule	Power	Timeseries	Developing	Virtjoule Inc.
Low Cost SMDS	Air-Power	Timeseries	Developing	Pacific Northwest National Laboratory

Update to the above table: Sensus, MI changed its name to 'Ezenics.' Field Diagnostic Services, Inc. FDD-related products and services have been integrated into a new suite of products. Virtjoule is available on the market. Pacific Northwest National Laboratory's (PNNL) low-cost SMDS is moving toward commercialization.

A list of the faults that each of the above listed tools can detect is shown in Figure 27.

Figure 27: Description of Faults Detected by FDD Tools

O	Basic FDD
X	Extended FDD

	FDSI Insight V.1 Production	Sensus MI	ClimaCheck	SMDS	NILM	Low Cost NILM	Sentinel/Insight Beta Testing	Virtjoule	Low Cost SMDS
Low Airflow	O	O	O		O	O	O	O	
Low/High Charge		O	O		O	O	O	O	
Sensor Malfunction	O	X	O	O			O	X	
Economizer not Functioning	O	X	X	O			O	O	
Compressor Short Cycling	O	X	O		O	O	O	O	O
Excessive Operating Hours	O	X	O				O	O	O
Performance Degradation		O	O	O	O	O	O	O	O
Insufficient Capacity	O	X	O				O	X	O
Incorrect Control Sequence	O	X	O		O	O	O	O	
Lack of Ventilation	O	X		O			O	X	
Unnecessary Outdoor Air	O	X	X	O			O	X	
Control Problems	O	X	O	O			O	O	
Failed Compressor	O	O	O	O	O	O	O	O	
Stuck Damper	O	O	O	O			O	X	
Slipping Belt	O	O	O		O		O	O	
Leaking Valves			O		O		O	X	
Unit Not Operational	O	X		O	O	O	O	O	O

Table Note: 'Extended FDD' indicates the tool has additional fault detection functions that can be specially enabled if the customer chooses.

More recently, a new product class of RTU retrofits performance monitoring-enabled controllers and commissioning tools have entered the RTU market: the Honeywell JADE Economizer product has been on the market in 2012. In February 2013 Belimo announced availability and pricing of its ZIP Economizer unit. Both offer technician-friendly communications interfaces which allow the user to either set up a newly installed RTU including demand control ventilation or provide a customer with continuous automated maintenance services with limited remote monitoring options. Both tools are fully featured to dramatically improve the quality of new/replacement RTU installation commissioning as well as ongoing performance maintenance. In essence, each provides monitoring of critical RTU functions and can act to a limited degree as a fault detection system.

HVAC Contractor Interview Summary. Interviews were conducted with HVAC contractors in Sacramento and the San Francisco Bay Area. Contractors were asked about their current maintenance business and whether or not they could imagine using automated, embedded FDD of the type being described in this report. Key findings included:

- The sale of a maintenance contract and the relationship between the technician/contractor and the customer is essential. While this type of contract could form the basis of a diagnostic offering in the marketplace, there is considerable skepticism about the ability of an automated FDD tool to do what it promises, especially to reduce the need for service calls. Few contractors are using anything like automated or embedded FDD today. There is, however, a perceived benefit to using a given FDD tool (portable or embedded) if it adds to the customer's perception of a contractor's professionalism and use of state-of-the-art tools. A tool that makes a contractor more efficient when providing routine servicing will be valued, especially if it can eliminate the need for service calls in between routine seasonal maintenance.
- FDD value should be looked at over the lifetime of a system and a customer relationship since it may help prepare the customer for equipment replacement decisions. Especially for certain customer segments, higher quality retail for example, a premium could be charged for a service contract that was enabled by FDD.
- While it is possible to put sensors on almost everything, one would have more issues with the sensors over time than with the parts.
- The economizer is the first thing the contractor will disable, due to complexity versus benefits. If it costs $500-$1,000 to fix it, the choice will be made to disable rather than repair it. This is due to a lack of knowledge regarding the value of energy savings and a price for energy that does not compel action. The economizer is more likely to get fixed if the customer knows and values the energy that can be saved. The same could be said of the technician/contractor not knowing the value of a functional economizer.
- Contractors are motivated to try to avoid service calls between regular service calls. A maintenance technician will typically have 20 hours per week to do service. They must get to as many customers as possible and will typically do 5-6 calls per day. Better FDD on each system could make the technician faster and more confident.

- Most HVAC businesses are not currently using energy performance monitoring tools. New FDD tools could enable better interaction with the contractor and their customer due to the ability to professionally represent more detail on the equipment efficiency.
- One way contractors could see FDD being delivered is via an automated report generated on a scheduled basis sent to a designated person. This should not overload customers and technicians with data. An indication could be provided about overall performance and another about energy consumption. Different information levels include: 'idiot' light, an alarm if efficiency goes under a certain threshold and performance efficiency metrics for each unit.
- The system must deliver what it promises. One needs to factor in false-alarm rates to determine whether or not more calls are being avoided or created. False alarms are an unrecoverable cost for the contractor.
- Survey respondents can see a premium of 10 percent for a very good field diagnostic device, especially if they have a critical environment or are a more sophisticated customer. Maintenance contract customers have a long-term view and do analysis on a whole-building level.

5.3.3 FDD Technology and Market Review: Market Connections

The FDD Review Report is available at the Purdue website and at the NBI research website. The list below describes the activities to disseminate the report:

- The HVAC contractors involved in interview phase of the work received notice of the report availability.
- The report was shared with FDD tool providers at Title 24-related meetings, and at various state and national energy conferences.
- The research team has been active in the Western HVAC Performance Alliance (WHPA) Subcommittee on FDD and has referenced the results and made the report available through WHPA.
- Results and findings from the report have been a part of presentations by FDD tool developers and researchers including ClimaCheck, Ezenics, Field Diagnostic Services, Inc., Dr. Haorong Li (University of Nebraska), California utility staff working on Methods of Test for FDD, and HVAC manufacturers.

5.4 FDD for Title 24 Proposal

NBI's Mark Cherniack was overall project lead for the work to move FDD findings into code. NBI and WCEC staff collaborated with Matt Tyler and Amber Buhl, PECI, who had the responsibility to conduct the FDD savings and benefit-cost analysis for Title 24 on behalf of the California utilities Codes and Standards Enhancement (CASE) program. The financial and energy savings analysis was supported by Martyn Dodd, EnergySoft, LLC, who provided the Title 24 compliant energy analysis software, EnergyPro, to run the cost-effectiveness analysis.

5.4.1 FDD Title 24 Proposal: Approach

The final mandatory measure proposal was negotiated through a working group of the WHPA FDD Subcommittee including PIER and CASE project team members, utility representatives, engineering firm representatives, HVAC FDD developers, major HVAC manufacturers and related researchers. The progress toward a Title 24 proposal and the ultimate approval required the researchers, along with their CASE colleagues, to conduct the following activities:

- Obtain input from industry stakeholders on desired capabilities of FDD tools and service models for making best use of FDD tools.
- Identify appropriate technologies for detecting and diagnosing faults in commercial building RTUs by inventorying the faults that occur in RTUs and their performance impacts and frequency.
- Determine the requirements for tools in each category in the framework by analyzing the types of tools that would be found in each category.
- Gain industry input on the implementation of FDD through conference calls and site visits to manufacturing facilities including Lennox, MicroMetl (economizer manufacturer) and Trane.
- Determine how much energy would be saved in California RTUs by using FDD tools, and the cost-effectiveness of this use.
- Use an industry-centric consensus approach to develop and negotiate with key stakeholders to draft a measure for the 2013 California Title 24 Nonresidential Building Energy Standard that will be implemented in January 2014.

Cost-Effectiveness. The PIER project and CASE program teams collaborated extensively on the cost-effectiveness analysis with the following approach:

- Estimating the impact of various different faults on the efficiency of a single RTU. This impact was determined from literature on the impacts of various faults imposed in laboratory conditions on the RTU's Energy Efficiency Ratio (EER) from previous research work.
- Modeling of the impacts of a reduced EER on the annual energy use and peak demand. This modeling was done using the US Department of Energy's EnergyPlus building energy simulation software for prototypical office buildings in a range of California climates and then weighted by saturation. Additional modeling with Title 24 compliant energy simulation software was completed with EnergyPro v5.1.
- Calculating the Time-Dependent Value (TDV) of the annual energy savings per ton of cooling, using CEC procedures (net-present value over the Equipment Useful Life (EUL) taking the marginal value of energy at any hour of the year into account).
- Assuming probabilities for various factors: probability that a fault will occur during a given year (based on analysis of fault incidences in the PECI RTU AirCare Plus

program), probability that an FDD technique will identify the fault, probability that the fault would have been detected absent the FDD system, and probability that the fault will be addressed once detected.

- Applying these probabilities to the TDV annual energy savings per ton.
- Estimating the cost of implementing an FDD tool.
- Estimating the present value of maintenance cost savings.
- Calculating a Benefit-to-Cost ratio and Total Resource Cost.

As initially proposed, a Title 24 'Prescriptive Measure' was developed, reviewed by key stakeholders and submitted for adoption consideration in the 2013 Title 24 Nonresidential Building Energy Efficiency Standards revision by the CEC. A prescriptive measure is an option under code that is encouraged but is not required. However, the working group that helped negotiate the measure came to a consensus decision to focus the RTU FDD measure on detecting economizer and related airflow faults and submit the proposal as a 'Mandatory Measure' (rather than Prescriptive) for Title 24 thus strengthening the potential impact.

The HVAC industry representatives in the working group were confident that the industry would be ready by January 2014 to implement economizer FDD, a key area for achieving and maintaining energy savings in RTUs. The proposal stated that every new or replacement RTU (4.5 tons or larger) requires FDD functionality.

5.4.2 FDD Title 24 Proposal: Outcomes and Findings

The mandatory measure for FDD in RTU units in the state of California (to be effective in January 2014) was approved by the CEC in May 2012. Field compliance acceptance test requirements were developed along with a form for a manufacturer's option to pre-certify whole equipment lines to meet compliance objectives. This form helps local jurisdictions to enforce this level of technical compliance with fewer burdens by the certification requirements and increase compliance checking.

The full mandatory measure language approved by the CEC and an explanation of the requirements prepared by the research team is in Appendix A-5. A synopsis is:

FDD Title 24 Summary. All newly installed air-cooled unitary direct-expansion units[49], equipped with an economizer and with mechanical cooling capacity of 4.5 tons or more shall include a Fault Detection and Diagnostics (FDD) system in accordance with criteria specified in the code subsections. Sensors shall be permanently installed to monitor system operations as follows: outside air, supply air, and return air, and refrigerant charge. The faults required by

[49] Air-cooled unitary direct expansion units include packaged, split-systems, heat pumps, and variable refrigerant flow (VRF), where the VRF capacity is defined by that of the condensing unit.

FDD systems under the new Title 24 mandatory measure are listed below, along with a brief description and why it is important. The fault conditions in the Title 24 FDD requirement are:

A. *Air temperature sensor failure/fault.* This failure mode is a malfunctioning air temperature sensor, such as the outside air, discharge air or return air temperature sensor. This could include miscalibration, complete failure either through damage to the sensor or its wiring, or failure due to disconnected wiring. Reporting of sensors faults is found in many RTUs today.

B. *Not economizing when it should.* In this case, the economizer should be enabled, but for some reason it is not providing free cooling. This leads to an unnecessary increase in mechanical cooling energy. Two examples are the economizer high limit setpoint is too low, say 55degF, or the economizer is stuck closed.

C. *Economizing when it should not*. This is opposite to the previous case of not economizing when it should. In this case, conditions are such that the economizer should be at minimum ventilation position but for some reason it is open beyond the correct position. This leads to an unnecessary increase in heating and cooling energy. Two examples are the economizer high limit setpoint is too high, say 80degF, or the economizer is stuck open.

D. *Damper not modulating.* This issue represents a stuck, disconnected or otherwise inoperable damper that does not modulate open and closed. It is a combination of the previous two faults: not economizing when it should and economizing when it should not.

E. *Excess outdoor air.* This failure mode is the economizer provides an excessive level of ventilation, usually much higher than is needed for design minimum ventilation. It causes an energy penalty during periods when the economizer should not be enabled, that is, during cooling mode when outdoor conditions are higher than the economizer high limit setpoint. During heating mode, excess outdoor air will increase heating energy.

A key component of the Title 24 measure is that notice of a given fault be delivered directly from the RTU to operating or service personnel or to specific zone thermostat in the building that is tied to the RTU. Performance degradation faults are more prevalent than catastrophic faults that can shut down a unit entirely. It is therefore important to provide notice as soon as possible so they do not go unnoticed until scheduled maintenance. The measures does not prescribe the method of signaling the fault directly from the rooftop unit. HVAC manufacturers are free to choose an appropriate option. As a result of the CEC adopting this measure, some major HVAC manufacturers have indicated they will be ready with the appropriate equipment integrated with FDD capabilities before the January 2014 implementation of the revised Title 24 standards.

The analysis and outcomes of the cost-effectiveness were promising. The statewide savings were estimated to be significant, with a 15-year life cycle net savings of over $8M for California buildings, and a benefit/cost ratio of 2.0 (greater than 1.0 is positive so a 2.0 is a significant

positive benefit). Thus it was found that FDD for RTUs is a cost-effective measure, appropriate for inclusion in Title 24. The full study of energy and demand savings leading to the cost-effectiveness conclusions is a part of the FDD Review Report located in Appendix A-5.

5.4.3 FDD Title 24 Proposal: Market Connections

The research team engaged with California and industry stakeholders on the Title 24 proposal through the following activities:

- HVAC manufacturer onsite visits with Lennox, Trane and MicroMetl (major economizer manufacturer): Tyler, Texas. November 2010.
- Nonresidential HVAC Stakeholder Meetings held throughout California in April and December 2010 and in April 2011.
- FDD Roundtable: Western Cooling Efficiency Center, Davis, California. July 2010.
- California Emerging Technologies Summit: Pasadena, California. November 2010.
- ASHRAE[50] Winter Meetings and involvement with the ASHRAE Technical Committees (TC) - TC 8.11 and 7.5 and 90.1 Mechanical Subcommittee: Las Vegas, Nevada. January 2011 and Dallas, Texas. January 2013.
- ESource Web Conference sponsored by CEC on Updating Rooftop Unit performance. December 2011.
- California Commissioning Collaborative Technical Seminar Series via webinar. August 2012.
- Joint Electric Power Research Institute-Bonneville Power Administration National Energy Efficiency Technology Summit: Portland, Oregon. September 2012.
- California Emerging Technologies Summit: Pasadena, California. October 2012.
- Architectural Engineering Institute (AEI)/ASHRAE Expo, Presentation on FDD in RTUs and Split Systems, Omaha, Nebraska. March 2013.

In addition to the events listed above, the following links addressed the Title 24 measure following its approval by the CEC in May 2012.

- Home Energy Pros Blog http://homeenergypros.lbl.gov/profiles/blogs/ca-title-24-will-require-rtus-to-have-automated-fault-detection
- Western HVAC Performance Alliance http://www.performancealliance.org
- Facilities Net http://www.facilitiesnet.com/hvac/article/HVAC-Research-Leads-To-Revisions-in-Title-24--9894
- Engineered Systems http://digital.bnpmedia.com/display_article.php?id=1229183

[50] American Society of Heating Refrigerating and Air-Conditioning Engineers

- Western Cooling Efficiency Center Connections http://wcec.ucdavis.edu/wp-content/uploads/2012/12/2012_Q4_CoolingConnection.pdf

5.5 Benefits to California

There are multiple benefits from the ability to have FDD present in HVAC equipment. First is the direct cost-effectiveness from the California utility and ratepayer perspective. The estimated financial benefit cost for the Title 24 FDD measure for utility ratepayers is projected for a 54,000 Btu/h (5-ton) unit and shown in Table 20.

Table 20: Estimated Financial Benefit for FDD

Area of Assessment	Est. Benefit
Incremental Installed Cost	$1,600
Incremental Annual Maintenance	($74)
PV of Annual Maintenance	($878)
Total Incremental Cost	$722
PV of Energy Savings	$1,197
Lifecycle Cost Savings	$475
Benefit/Cost Ratio	1.7

The assumed incremental installed cost is believed to be on the high side for the type of FDD functions that are required in the Title 24 measure. Manufacturers do not provide the material costs needed for a more precise installed cost estimate. These FDD features can be installed on both the lower cost electromechanically controlled RTUs and the higher cost microprocessor-controlled units. The installed cost estimate here provides a margin of error to account for direct costs and any difference between the costs for installing the measures in the two types of equipment. The incremental cost used here is likely lower than actual and will result in the FDD requirement having a better Benefit/Cost Ratio than estimated.

Potential energy and cost savings to California are projected to be 2.01 kWh/sf/yr and $1.05/sf/yr. Applying the unit estimates to the statewide estimate of new commercial building construction of 92.79 million square feet per year results in the following statewide savings estimates, as shown in Table 21.

Table 21: Potential California Energy and Dollar Savings from FDD

Statewide Savings	Electricity Savings (kWh)	TDV Total $	Demand Savings (kW)
1st-Year Savings	1,577,138	$551,962	823
15-Year Savings	23,146,289	$6,568,344	12,818

The project results are in the hands of the California utilities, policymakers (CEC and CPUC), diagnostic tool providers, and HVAC manufactures and contractors, all of whom have a role in making these potential benefits a reality. The principal impacts will be in the small to medium-size office, public assembly and retail building sectors (<100,000 sf in size), which collectively represent approximately 60 percent of commercial buildings types having hundreds of thousands of RTUs in service.

5.5.1 National Benefits

As noted, one of the fundamental rationales for the FDD project was that there was no national standard for judging the effectiveness of any FDD tool or approach. However, work on a key part of a national standard is now underway. Developing a nationally recognized standard method to test (Method of Test) FDD protocols is critical to help advance the technology. It would allow regulatory organizations, such as the CEC, and utilities (for energy efficiency objectives) to give meaningful specifications for FDD requirements. It would guide users of FDD – including equipment manufacturers, facility managers, utility incentive managers and equipment owners – to make informed decisions about whether to use FDD, for what purpose, and which approach might work best for them.

A proposal to establish national standards for Methods of Test for RTU FDD was made by the NBI-WCEC PIER project team to ASHRAE and was accepted. At its January 2012 meeting ASHRAE established the Standards Project Committee 207 for "Laboratory Method of Test of Fault Detection and Diagnostics Applied to Commercial Air-Cooled Packaged Systems." The 30- member Committee meets in person every year at the two main ASHRAE meetings and through regular conference calls in the interim. It is hoped that a method can be developed and agreed upon by 2015, if not sooner.

The national impact of the project has generated high-level visibility in the US HVAC industry, with a number of HVAC companies represented on the Committee both as voting and non-voting members. The Committee is active and has formed three ongoing working groups.

The California utilities also need their own Method of Test to satisfy state regulatory requirements and ensure an accurate approach to evaluating the effectiveness of FDD tools. Southern California Edison staff, on behalf of the California utilities, has been leading the development of Methods of Test for both commercial and residential FDD tools. The residential test is complete and awaiting review by the WHPA Subcommittee on In-field/Onboard Fault

Detection and Diagnostics. The commercial test method is nearing completion and will also go through Subcommittee review.

Based entirely on the success of the Title 24 RTU FDD mandatory measure, the Pacific Northwest Energy Codes Group (NW Codes Group) representing Idaho, Montana, Oregon and Washington has proposed a nearly identical mandatory measure for the 2015 International Energy Conservation Code (IECC) and the International Green Construction Code (IgCC). The major difference from the NW Codes Group proposal and the Title 24 measure is a lower threshold for the requirement. The NW Codes Group proposes setting a 2.75-ton minimum level rather than the 4.5-ton minimum size limit set in Title 24 for requiring the economizer FDD capabilities.

5.6 Conclusions and Next Steps

Key short and longer-term benefits were achieved in the project. The development of an initial method to evaluate the accuracy of FDD performance protocols and related tools used in optimizing the energy performance of HVAC equipment, both for commercial rooftop and residential systems, is a major step toward improving RTU performance. The FDD Market Review brought to light existing FDD options and characteristics as well as insights from HVAC contractors with regard to FDD. This research engagement contributed to requests from HVAC contractors, made through the various committees and forums noted in this report, to learn more about FDD products, capabilities and costs.

In January 2014, the RTU FDD mandatory measure for most types of HVAC systems at or larger than 4.5 tons will come into force. This is a major step forward ensuring better equipment performance, lower consumer costs and reduced greenhouse gas emissions from power plants.

A number of detailed recommendations have been made by key stakeholders for further testing, validation and enhancement of the Evaluator. Funding for these recommendations could be provided through collaboration of the CPUC, CEC and the utilities. These organizations and staff will need to assess the use of the Evaluator in relation to quality control objectives in utility HVAC installation and maintenance programs, as well as specific implications for Title 24 RCA protocol changes. Title 24 is the natural channel to establish and promote the effectiveness and benefits of the Evaluator given the need to optimize air conditioning, which is by far the major driver of peak summer electricity demand in California.

There is stakeholder consensus on changing the Title 24 RCA protocol from a prescriptive to a performance-based protocol. Any direct standards work on a revised protocol will have to be accomplished within the 2016 Title 24 revision schedule. Utility staff has already expressed interest in applying the Evaluator to tools and protocols in use in current HVAC efficiency programs. In addition, the utility and CEC Codes and Standards Enhancement (CASE) program should consider supporting the specific recommendations for improving and further validating the Evaluator.

Further steps have been proposed to support the development of compliance acceptance approaches for field inspections for the 2013 Title 24 mandatory economizer FDD measure. The

HVAC contractors must have a workable method to ensure the FDD is set up and operating properly at the time of installation. Experienced contractors will help draw up the options for compliance methods to be sent out to codes training channels for the January 2014 new code implementation date.

The Title 24 FDD measure has had direct national impact through the formation of an ASHRAE Special Projects Committee (207) on the "Laboratory Method of Test of Fault Detection and Diagnostics Applied Commercial Air-Cooled Packaged Systems." The Committee is actively working on the technical criteria for defining the fault conditions and thresholds with a goal to produce a recognized Method of Test by 2015, if not sooner.

In California and the Northwest, utility and energy market transformation agencies have been bringing FDD and related performance monitoring and control products into testing in the field through emerging technology programs. The increase in general market interest in FDD in California has been in part driven by the PIER FDD program work from the expected benefits of having an effective quality control protocol in the diagnostic Evaluator, new products through the Title 24 RTU FDD measure as well as national standards impacts from the Title 24 FDD measure. The program has been a clear success in achieving its stated objectives.

For the future, fault detection for other critical HVAC system components, primarily refrigerant cycle and closely related airflow problems, need to be added as Title 24 requirements for RTUs. Commercially available products with these fault notices are available now, but only on a very small number of the highest efficiency and highest cost models.

Several new control and FDD-related products are being studied through California utility Emerging Technology initiatives. With most new RTUs remaining on the rooftops for 15 or more years, expanded assessment by the CEC and utilities is needed on how to address the hundreds of thousands of RTUs not covered by the 2013 Title 24 FDD requirements (since they apply only to new and replacement units). Retrofit products with some fault detection are already available, and more will be entering the market on a regular basis.

The potential for FDD to reduce energy consumption and peak power and to improve equipment life is still largely untapped. New FDD products and methods should continue to be supported through research and encouraged through policy.

End Note: NBI's website dedicated to FDD includes all the outcomes of this PIER research: http://newbuildings.org/fault-detection-and-diagnostics

GLOSSARY

Acronym/Term	Definition
ACEEE	American Council for an Energy-Efficient Economy
AEC	Architectural Energy Corporation
ANSI	The American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAC	Building Automation Control
BEARS	Building Energy Asset Rating System
BSDF	Bi-Directional Scatter Distribution Function
BTU	British Thermal Unit
BTU/sf/yr	BTUs per square foot per year
CASE	Codes and Standards Enhancement
CAMP	California Advisors on Measured Performance
CBRE	CB Richard Ellis
CEC	California Energy Commission
CEE	Consortium for Energy Efficiency
CFM	Cubic feet per minute (used to express air volume in this context)
CIE	International Commission on Illumination
CIEE	California Institute for Energy and Environment
CLTC	California Lighting Technology Center
CO_2	Carbon Dioxide
CPUC	California Public Utilities Commission
DCV	Demand-Controlled Ventilation
DFM	Designing for Meterability
DI	Daylighting Innovations
DOE	U.S. Department of Energy

Acronym/Term	Definition
DOT	Designer, Owner/Operation and Tenant
EIA	US Energy Information Administration
EISA	Energy Independence and Security Act
EMCS	Energy Management Control Systems
EMS	Energy Management Information System
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act
ERM	Energy Resource Management
EUI	Energy Use Intensity (also Energy Use Index)
EUL	Equipment Useful Life
FDD	Fault Detection and Diagnostics
FirstView	Energy Performance Assessment Tool
GSA	U.S. General Services Administration
HDR	High Dynamic Range
HERS	Home Energy Rating System
HVAC	Heating, Ventilation and Air-Conditioning
IECC	International Energy Code Council
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America
IT	Information Technology
KPI	Key Performance Indicator
kWh	Kilowatt hour
kWh/sf/yr	Kilowatt hour per square foot per year
LADWP	Los Angeles Department of Water and Power
LBNL	Lawrence Berkeley National Laboratory
LED	Lighting-Emitting Diode

Acronym/Term	Definition
LEED-EA	Leadership in Energy and Environmental Design – Energy and Atmosphere
LEED-NC	Leadership in Energy and Environmental Design for New Construction
Low-e	Low-emissivity. Emissivity is the relative ability of a surface to emit energy by radiation. Low-e refers to windows that have a surface that reduces the energy loss (through radiation) from the building.
LPD	Lighting Power Density
MC	Market Connection
MFD	Multifunction Device
MOU	Memorandum of Understanding
NAECA	National Appliance Energy Conservation Act
NBI	New Buildings Institute
NFRC	National Fenestration Rating Council
NIST	National Institute for Standards and Technology
NRDC	Natural Resources Defense Council
NZE	Net Zero Energy
OBC	Outcome-Based Code
PG&E	Pacific Gas and Electric Company
PIER	Public Interest Energy Research
PNNL	Pacific Northwest National Laboratory
RCA	Refrigerant Charge and Airflow
RTU	Rooftop Unit (packaged air conditioners)
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
SHGC	Solar Heat Gain Coefficient
SMUD	Sacramento Municipal Utility District
TDV	Time-Dependent Value

Acronym/Term	Definition
UA	Heat loss coefficient
USGBC	United States Green Buildings Council
WCEC	Western Cooling Efficiency Center
WHPA	Western HVAC Performance Alliance
ZNE	Zero Net Energy

Acronym/Term	Definition / Explanation
Anisotropic	Refers to something with physical properties that vary in different directions
Benchmark	A standard against which something can be measured or assessed
Candlepower	Expresses levels of light intensity in terms of the light emitted by a candle of specific size and constituents
CBECS	Commercial Buildings Energy Consumption Survey - National sample survey that collects information on the stock of U.S. commercial buildings, their energy-related building characteristics, and their energy consumption and expenditures
CEUS	California End Use Survey - Comprehensive study of commercial sector energy use, primarily designed to support the state's energy demand forecasting activities. A stratified random sample of 2,790 commercial facilities was collected from the service areas of Pacific Gas and Electric, San Diego Gas & Electric, Southern California Edison, Southern California Gas Company, and the Sacramento Municipal Utility District.
Energy Model	A software program that calculates the energy use of various energy using systems within a building. The resulting 'model' is used by design firms to compare the energy impact of system options, estimate the energy use of a building and its systems, and as a compliance tool to demonstrate a buildings meets the requirements of a code, policy or program.
Energy Star	A joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy helping save money and protect the environment through energy efficient products and practices.
Energy Star Portfolio	An interactive energy management tool that allows you to track and assess energy and water consumption across your entire portfolio of

Acronym/Term	Definition / Explanation
Manager	buildings in a secure online environment. Enter energy consumption and cost data into your Portfolio Manager account to benchmark building energy performance, assess energy management goals over time, and identify strategic opportunities for savings and recognition opportunities
Energy Star Score	A national building energy use ranking against comparable buildings
EUI	Energy Use Intensity (or Index) is a metric of total building energy use commonly used in benchmarking. EUI is the sum of all fuels used in the building per year divided by the building's floor space and is expressed in thousands (kilos) of British Thermal Units (BTUs) per square foot (sf) of occupied space per year
Fenestration	Refers to the design and characteristics of windows and other exterior openings of a building
Goniophotometer	A device used for measurement of the light emitted from an object at different angles
LEED	Developed by the U.S. Green Buildings Council, LEED (Leadership in Energy and Environmental Design) is a voluntary, consensus-based, market-driven program that provides third-party verification of green buildings. A suite of nine rating systems for the design, construction and operation of buildings, homes and neighborhoods.
LEED Energy & Atmosphere Points	LEED Energy and Atmosphere credits encourage energy efficiency through improved glazing, better insulation, improved daylighting design / lighting power density reduction, high-efficiency HVAC&R equipment selection, renewable energy production, and building commissioning.
Multifunction Device	One device which combines printing, coping, scanning and/or faxing.
Perez Sky	A standard used for measured luminance data modeling of the sky named for Richard Perez
Plug Loads	Devices that plug into wall outlets
Title 24	Title 24 California is the 24th part of the California Code of Regulations (CCR). According to Title 24 building standards, any construction of a new building or alterations made to an existing building have to meet the standards stated in the Title. The standards were adopted as a way to regulate an energy crisis that the state was experiencing.

APPENDICES:
Evidence-Based Design and Operations PIER Program

Appendices attached in CEC-500-2014-062-APP.