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California Publicly-Owned Utilities (POUs) – LBNL 'Beyond Widgets' Project Task-ambient lighting and occupancy-based plug load control System Program Manual

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California Publicly-Owned Utilities (POUs) – LBNL 'Beyond Widgets' Project Task-ambient lighting and occupancy-based plug load control

System Program Manual

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Energy Technologies Area

September, 2017

California Publicly-Owned Utilities (POUs) – LBNL ‘Beyond Widgets’ Project

Task-ambient lighting and occupancy-based plug load control

System Program Manual

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Disclaimer

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EXECUTIVE SUMMARY

Overview

This program manual contains detailed technical information for implementing an incentive program for task-ambient lighting and occupancy-based plug load control. This manual was developed by Lawrence Berkeley National Laboratory, in collaboration with the California Publicly-Owned Utilities (CA POUs) as a partner in the 'Beyond Widgets' program funded by the U.S. Department of Energy Building Technologies Office. The primary audience for this manual is the program staff of the various CA POUs. It may also be used by other utility incentive programs to help develop similar programs.

It is anticipated that the content of this manual be utilized by the CA POU staff for developing related documents such as the Technical Resource Manual and other filings pertaining to the roll-out of an energy systems-based rebate incentive program.

Task-Ambient Lighting and Plug Load Control Systems

The design and operating principle of the selected system is that by providing desk-top task lighting, it is possible to reduce the lighting output from (and therefore the electrical power to) overhead light fixtures – to supplement light levels in the work area, office occupants can place their desktop light in the appropriate location for their work tasks. Simultaneously, all non-critical desktop equipment (including the desktop lighting) will be occupancy-based, and so will operate on an as-needed basis. As such, night time loads for occupancy-controlled equipment will be zero, as power will cease to be provided following a prescribed period of office / cubicle vacancy (known as timeout).

Two distinct technology packages – Technology Package 1 (TP1) and Technology Package 2 (TP2) - were specified for testing according to two separate market needs – a 'basic', minimally intrusive system that would not trigger California Title 24 Code and an 'advanced' system that requires electrical work and therefore necessitates compliance with the latest version of Title 24.

Cost effectiveness of the proposed systems was estimated on the basis of energy performance of the separate system elements (lighting and plug loads respectively) seen in field testing, and evaluating potential energy savings and energy cost savings for relevant DOE Reference Building models for California (see Table 1). From those results, LBNL derived some estimates for simple payback, to confirm that the systems as specified were worth proceeding with in principle.

Table 1: Original Estimates for Task Ambient Lighting and Plug Load Control Energy Savings

Tech Package Type	Base EUI (kWh/sqft/yr)	Lighting Energy Saving (kWh/sqft/yr)	Plug Load Energy Saving (kWh/sqft/yr)	Post-Measure EUI (kWh/sqft/yr)	Whole Building Energy Savings (%)	Estimated Simple Payback (yrs)
Tech Package 1 (Basic)	15.9*-22.6**	1.89	0.89	13.1-19.8	12-18%	5.7-9.2
Tech Package 2 (Advanced)	15.9*-22.6**	3.2	1.25	11.4-18.1	20-28%	6.9-16.3

*Average small office, California

**Average large office, California

This exercise was followed by some in-depth market segmentation and potential analysis by DNV GL. Feedback from the market analysis confirmed significant potential for the proposed systems across California, based on using existing building condition as the energy baseline - Total Resource Cost (TRC) ranges from 0.90 to 1.75 for TP1 and from 0.93 to 1.64 for TP2 for retrofit projects. For replace-on-burnout, TRC ranges from 1 to 2.2 for TP1 and from 1.1 to 1.8 for TP2. The estimates for adoption potential have been updated with these results, and are presented in Table 2.

Table 2: Adoption potential (GWh savings at 10 years)

Region	**Tech Package 1 (low)**	**Tech Package 1 (high)**	**Tech Package 2 (low)**	**Tech Package 2 (high)**
Northern California	0	277	0	319
Southern California	0	323	130	372

Note: The total potential for each region within California is not equal to the sum total potential savings from packages 1 and 2, but rather the maximum value in the table for each region.

Testing of the specified systems was completed in the highly-instrumented occupied testbed at LBNL, under a before-and-after, baseline and test regime, whereby there were three periods of baselining, totaling 5 months, and 3 periods of testing, for two months each, totaling a period of 6 months. From the test results, we have extrapolated energy performance for baseline and test conditions for a year, with the difference between the two representing the annual energy savings.

Results of Testing

There were measurable energy savings arising from each of the tested technology packages, and these were extrapolated to represent annual energy saving, are summarized in Table 3. These results were broadly in line with the performance expected, and therefore in principle meet the requirements of a prospective rebate program.

The two discreet system elements (overhead lighting and plug load control respectively) however, did not perform as anticipated. Energy savings from plug load control were lower than anticipated, and it is possible that with heavy task light use (i.e. switched on for the entirety of occupied hours), those savings could be reduced to around zero. However, the critical point to note here is that although savings on plug load operations were minor, it is the integrated nature of the proposed systems packages that unlock previously unaccessed energy savings from overhead lighting. This would not occur with a component level / piecemeal approach, even if utilizing identical equipment.

In addition, the test results presented here exclude the incremental additional energy savings of daylight dimming – including these would further support the economic case for both variants of TP2. The whole building energy results stated reflect a situation whereby 100% of a commercial office building is dedicated to office space (i.e. no conference rooms, break rooms etc.) Adjustments to how these estimates are interpreted to real buildings will be necessary on a case by case basis.

Table 3: Energy Savings for Specified Technology Packages versus DOE Reference Buildings

	Energy Savings (kWh/sqft/yr) - Small	Energy Savings (kWh/sqft/yr) - Large	Energy Cost Savings ($/sqft/yr) - Small	Energy Cost Savings ($/sqft/yr) - Large	Whole Building Energy Savings - Large	Whole Building Energy Savings - Small
Tech Package 1 - Basic	2.80	3.16	0.45	0.51	14%	18%
Tech Package 2(a) - Adv	2.52	2.82	0.41	0.45	12%	16%
Tech Package 2(b) - Adv	3.23	3.61	0.52	0.58	16%	20%

An important element of identifying potential customer sites is to provide a list of key, basic criteria that must be met in order to be considered as appropriate opportunities for implementing the specified systems.

It is anticipated that a second, more detailed level of screening would then be carried out using the specific calculator developed as part of the project. The calculator relies on basic data from the user to characterize the existing building conditions and lighting systems, and operating regimes to generate an estimate of energy savings from each of the tested technology packages. The results are based on the results of FLEXLAB® testing, and have been verified with data collected from field demonstrations known to LBNL, and also references outputs of simulation modelling of the FLEXLAB® occupied testbed.

<u>Post-Installation Activities</u>

Following implementation of projects, the next step is to verify operations against design intent and energy performance against projections. Reference to the International Performance Measurement and Verification Protocol (IPMVP) guidelines represents the most effective route to assessing which performance verification option will work for individual sites – it will depend on the scale of retrofit and the size and type of building. There is clear guidance as to which options are likely more appropriate for customer sites for this type of system and reflecting the realities of cost-effectively verifying performance to a degree of accuracy acceptable to the customer sites and the Utilities offering the rebate incentive.

For the purposes of enduring systems performance, we summarize good practices in terms of preparation for installation, implementation and commissioning and enduring operations and maintenance to ensure that both the customer and the Utilities get best value for their investments.

1 Introduction

This program manual contains detailed technical information for implementing an incentive program for task-ambient lighting and occupancy-based plug load control. This manual was developed by Lawrence Berkeley National Laboratory, in collaboration with the California Publicly-Owned Utilities (CA POUs) as a partner in the 'Beyond Widgets' program funded by the U.S. Department of Energy Building Technologies Office. The primary audience for this manual is the program staff of the various CA POUs. It may also be used by other utility incentive programs to help develop similar programs.

It is anticipated that the content of this manual be utilized by the CA POU staff for developing related documents such as the Technical Resource Manual and other filings pertaining to the roll-out of an energy systems-based rebate incentive program.

This document contains the following sections:

Section 2 contains a description of the selected system technologies and the performance specification of the two system package options.

Section 3 outlines the site requirements for candidate sites in order that system operation be most cost-effective (i.e. having ensured that simpler, cheaper energy efficiency gains have already been accessed).

Section 4 describes the expected energy impacts of the specified systems, and the methods and metrics utilized during testing and performance validation, and also presents the results of testing.

Section 5 compares the results of the customer assessment method with the results of testing, indicating the magnitude of variance between the assessment framework and likely real-world performance.

Section 6 outlines the various measurement and verification methods that can be brought to bear at customer sites following installation of the specified systems.

Section 7 contains guidance for customer sites and utilities with regards to maintaining energy performance of the installed systems.

Section 8 provides instruction and training for utilities program staff on the key facets of start-up, operation and successful longevity of a program based on the system specified for this program.

1.1 Summary of Systems Selection and Markets, CA POUs

The CA POU's are a group of municipal, city or rural district utilities subject to local public control and regulation. Their mission is to optimize benefits to local customer owners. There are currently 38 POUs in 14 of the 16 different climate zones within California, ranging in scale from a few thousand customers for many POUs, to a few million in the case of Los Angeles Department of Water and Power. Overall, these utilities provide approximately 25% of the electricity required in California.

Figure 1: California Utility Service Territories - POUs

2 System Technology Description

2.1 System Features

Following discussions with CA POU utility representatives and their members, and taking into consideration results of market segmentation analysis, the technology package selected consists of task-ambient lighting with occupancy-based plug load control. This package was selected because of its applicability to all utilities regardless of location or size.

The design and operating principle of this system is that by providing desk-top task lighting, it is possible to reduce the lighting output from (and therefore the electrical power to) overhead light fixtures. To supplement light levels in the work area, office occupants can place their desktop light in the appropriate location for their work tasks. Simultaneously, all non-critical desktop equipment (including the desktop lighting) will be occupancy-based, and so will operate on an as-needed basis. As such, night time loads for occupancy-controlled equipment will be zero, as power will cease to be provided following a prescribed period of office / cubicle vacancy (known as timeout).

The features of the proposed systems are outlined and described below. A suite of technology package options, also described, was developed from the desired features, with each subject to testing and performance validation according to the option features.

Overhead Lighting and Lighting Controls

Technology Package 1 – 'Basic' System Features

Some or all of the following:

- Selection of appropriate power-rated lamp / lamp type for delivering overhead lumens for task / ambient condition
    - Low-wattage fluorescent tubes
    - LED replacement tubes
    - Use of in-situ controls to dim existing lamps to meet lower ambient lighting requirements
- Manual operation via switching
- Sweep / timeclock-based auto-off for after-hours / weekend periods
- In-situ controls

Technology Package 2 – 'Advanced' System Features

- Occupancy controls
    - Switches on in response to occupancy at either zone or cubicle level (controls package dependent)
- Dims to specified (background/ambient) level in vacant areas / cubicles of zone
- Task lighting and ambient lighting upgrade
    - Installation of occupancy-controlled task lighting at workstation level
    - Overhead lighting relamping or light fixture replacement to achieve ambient light level condition

Task Lighting

Technology Package 1 & Technology Package 2 Features

- Installation of task lighting at workstation level, placement as desired by the occupant
- Manual control via on-lamp switch (possibly multi-level)
- Occupancy controls via controlled power outlets (see below)
    - Power provided to lamp automatically in response to occupancy

Plug Load Controls

- Occupancy control
    - Operates in response to occupancy at individual workstation level
    - Occupant preferences accommodated via override and sensitivity settings, if desired

Note that the presence of central networked controls and control systems (for either lighting and / or plug load controls) shall be specific to the technology package option and the in-situ infrastructure prior to the retrofit (Note at the time of writing, this was not universally the case in our analysis).

2.2 System Performance Specification

Ambient (Overhead) Lighting and Lighting Controls

The overhead lighting retrofit should comprise some or all of the following elements:

1. Light fixtures
2. Lamps
3. Dimming ballasts or LED drivers
4. Panel and remote mounted load control relays and dimmers
5. Power supplies
6. Routers, controllers, processors and servers
7. Analog and digital input and output modules
8. Emergency lighting control

The primary objective is to control overhead lighting output by either a) lighting power density de-rating via lamp change-out or b) tuning existing lamps for a lower lumen output. Both of these approaches are consistent with the task-ambient strategy, where general or background lighting is provided by ceiling mounted fixtures and task–specific lighting is provided on-demand by personal desktop lamps. Illuminance at the workplane from task and ambient lighting together should be based on current Illuminating Engineering Society recommendations and user preferences.

Additional specific requirements:

1. Light fixture (or luminaire) may be either in-ceiling or surface-mounted ‘troffer’ (available in various dimensions) or ceiling hung ‘pendant’ fixture
2. Lamps for use in retrofit projects should have a minimum rated lamp life of 68,000 hours[1]

[1] L_{70} (LED) or based on 12-hour start with instant start ballast (fluorescent)

3. Minimum initial delivered lumens will vary according to number of lamps, but a rough guide should be for 1' x 4' to provide 1500 initial lumens, and for 2' x 4' to provide 3000 initial lumens. 2' x 2' fixtures should provide 2000 initial lumens. The minimum Luminaire Efficacy Rating (LER) should be at least 100 lumens/Watt.[2]

4. Operating (i.e. tuned) lumen output for lamps and fixtures should be capable of meeting an average light level of 200 lux at the floor plane[3]

5. Where drivers are installed or replaced, efficiency rating for driver technologies should be 0.83 (digital ballasts) and >80% (LED drivers)

6. For projects that incorporate dimming elements of lighting controls, related to institutional tuning, daylight dimming and demand response, electronic ballasts or LED drivers shall be capable of providing flicker-free dimming from 100% to 5%. Step dimming from 100% to at least one present level between 70% and 10% should be an available option to support appropriate tuning according to site requirements / user preferences. There should be no phase-cut dimming. Communications protocols such as DALI, DMX/RDM, Zigbee and EnOcean are among the viable options.

7. For systems with integrated lighting controls, this may comprise some or all of: occupancy sensors, photosensors (daylight dimming), lumen management and load shedding capability

8. Where implemented, all networked system sensors and controls shall be programmed to ensure minimal lamp cycling (and associated reduced lamp life and occupant distraction) and should be capable of easy recalibration to accommodate changes in environment/preferences. They should be calibrated to ensure that IES guidelines[4] are maintained. The control system should be capable of controlling multiple zones using the input from a single sensor, allowing separate or adjustable settings for each control zone. The system should allow for variable target setpoints according to user need. The location and number of the photosensors should be optimized by the control system supplier.

<u>Occupancy-based Plug Load Control, including Task Lighting</u>

Plug load control and occupancy-based task lighting shall comprise the following elements:

1. One occupancy-sensor controllable electrical receptacle, consisting of 120V outlets and / or USB power

2. Resettable circuit breaker

3. Desktop LED task light (recommended max power of 8 Watts)

4. Power-on indicator light (preferred)

The primary objective is to control plug loads according to usage patterns defined by a) user / building operating schedules and occupancy at individual work locations. The objective is to minimize operating hours for office plug loads, particularly desktop equipment such as monitors. Provision of task lighting powered via the smart outlet aims to meet task level illuminance requirements while allowing lower ambient lighting LPD.

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[2] Design Lights Consortium Technical Requirements V4.2, 2017

[3] Based on Table 32.2, IES Handbook, 10th Ed, assuming a conservative user group (ref. >65 age group)

[4] For example, for commercial offices, 30 foot-candles on the workplane.

Figure 2: LED Task Light Example

Additional specific requirements:

5. The controllable receptacle should consist of at least two power outlets and assumes a minimum of one controllable receptacle for each workstation – this will enable management of most common desk-based plug loads (monitor, task light, cell phone charger, coffee maker, etc.). Computers and laptops may also be included on the controlled receptacle; however the energy savings calculations and estimates on this system currently exclude these devices due to likely user preferences to not have their devices controlled by occupancy.
6. The instructions for installation and operation should be intuitive and simple to understand – it should be possible for someone not previously familiar with the technology to make modifications to control settings.
7. Optional - Remote access and control may be provided for smart outlets via a web-based interface, and will allow programming of individual outlets according to user preferences, including, but limited to schedule.
8. Control options shall include one or more of the following:
    a. Schedule / timer
    b. Remote manual switch
    c. Occupancy sensor - this sensor could either be a) an integral or remote part of the smart outlet package or b) utilize occupancy signals from the appropriate sensor that is part of the overhead lighting controls package.
    d. The LED task light should have a manual on-off switch

Figure 3: Controlled Receptacle (mounted on receptacle with extension cord) and Occupancy Sensor (Technology Package 1)

Implementation of this system should also be seen as an opportunity to improve energy performance of desktop equipment not proposed for occupancy-based control (mainly laptops and computers). These proactive steps should include implementation of hibernate / sleep settings in accordance with good practice guidelines.[5]

3 Candidate Site Requirements

Utility customer site requirements to apply for the incentive program should include the following.

At a minimum:

- Standard set of commercial office equipment of 1990's/00's era, e.g. laptops, desktop computers, flat screen monitors, etc.
- 9ft+ floor-to-ceiling height, ideally with dropped ceiling/plenum
- Existing overhead lighting system with T12, T8 or T5 light fixtures, either lay-in or pendant hung
- Overhead lighting system zone covers the same area as the workstations incorporating task lighting and plug load controls (i.e. the existing lighting controls don't impact adjacent spaces such as conference rooms)
- Existing switch based or networked lighting controls
- Average daily occupancy a minimum of 8 hours a day, 5 days a week
- Recommended minimum scale of installation should be 20 work cubicles / offices.[6]

Optional:

- Network access to workstations for occupant level feedback software or network access to a common display for workstation area feedback

[5] https://www.energystar.gov/products/low_carbon_it_campaign/put_your_computers_sleep
[6] Due to the cost of the control server and communication gateway, the cost of implementing plug-load control is a function of the scale of installation.

4 Energy Impacts

4.1 Customer Energy Impacts

4.1.1 Baseline Case

The CA POUs identified the following target market segments for this system package: commercial offices of all sizes. The technology packages are intended for both retrofit and new construction projects.

The baseline building type for our energy performance estimates are the DOE reference buildings post-1980 vintage, in ASHRAE Climate Zone 3B.

Based on the published results of field testing, LBNL applied the sumtotal energy savings from the two discreet subsystems – a) lighting and b) plug load control - that make up the proposed system, to the model baseline to provide an estimate for overall system savings and energy savings at the whole building level. These field test results comprise work completed under a previous project conducted for the U.S. Department of Defenses' ESTCP program and the U.S. General Services Administration's Green Proving Ground program, and were thought to be conservative assumptions given the deep dimming of the overhead lighting to ambient levels.

Table 4: Original energy savings estimates for lighting and plug load control technology packages

Tech Package Type	Base EUI (kWh/sqft/yr)	Lighting Energy Saving (kWh/sqft/yr)	Plug Load Energy Saving (kWh/sqft/yr)	Post-Measure EUI (kWh/sqft/yr)	Whole Building Energy Savings (%)	Estimated Simple Payback (yrs)
Tech Package 1 (Basic)	15.9*-22.6**	1.89	0.89	13.1-19.8	12-18%	5.7-9.2
Tech Package 2 (Advanced)	15.9*-22.6**	3.2	1.25	11.4-18.1	20-28%	6.9-16.3

*Average small office, California
**Average large office, California

4.2 Market Energy Impacts

Market Segmentation analysis determined that the "systems tend to be cost-effective from the utility Total Resource Cost (TRC => 1.0) perspective for office building applications for the Northern and Southern California POUs." This is based on assumptions relating to the utility avoided costs – which refers to elimination or significant delay of utility expenditures on infrastructure upgrade and fuel costs due to a reduction in consumption by customers – rather than the system costs or savings on a per square foot basis.

The market analysis estimated technical potential, economic potential and adoption potential as separate outputs. As the TRC=>1 for both the technology package 1 (basic) and technology package 2 (advanced) systems, it was assumed that technical potential was equal to economic potential. For both technology packages, an upper and a lower bound of energy savings were estimated, to account for uncertainties, existing building systems and energy use intensity, and performance of the new systems.

Table 5: Technical (and economic) potential (GWh savings)

Region	Tech Package 1 (low)	Tech Package 1 (high)	Tech Package 2 (low)	Tech Package 2 (high)
Northern California	0	835	0	960
Southern California	0	972	547	1,118

Note: The total potential for each region within California is not equal to the sum total potential savings from packages 1 and 2, but rather the maximum value in the table for each region.

Table 6: Adoption potential (GWh savings)

Region	Tech Package 1 (low)	Tech Package 1 (high)	Tech Package 2 (low)	Tech Package 2 (high)
Northern California	0	277	0	319
Southern California	0	323	130	372

Note: The total potential for each region within California is not equal to the sum total potential savings from packages 1 and 2, but rather the maximum value in the table for each region.

4.3 FLEXLAB® Assessment Testing and Validation

4.3.1 Methodology

The Technology Package 1 (TP1) and Technology Package 2 (TP2) systems were intended to satisfy two distinct California market needs.

TP1 was specified such that the plug-and-play nature of the overhead lighting retrofit does not trigger Title 24 Code. As such the intention is that energy savings claimed for the incentive be based on a comparison with an existing building baseline condition. Given the range of possible existing building conditions that relate to vintage size, climate zone etc., the baseline used here was defined as average small and large offices for each of the major utility service territories[7], to satisfy an appropriate range of baseline conditions.

In addition, measured baseline conditions in the testbed included a combination of assumptions relating to baseline operations, and for a small subset of these, some calculated from a combination of assumptions in the space and lab bench tests on alternate overhead lighting fixture types. Last, to complete the representation of existing building conditions within the proposed assessment method (see Technology Assessment for Customers Section), some data analysis included calculations to adjust for different site conditions such as using a specific installed LPD, fixture spacing and operating hours or based on conditions experienced at field sites.

TP2 was defined such that modifications-in-place or alterations trigger the Title 24 Code - as such energy savings were assessed against a minimal compliant Title 24 (T24) baseline, as well as the existing building condition. Test results are presented with comparisons of system energy performance against T24 and existing building condition baselines. The test methodology for TP2 is identical to that for TP1.

[7] This approach was taken as this data is freely available and published online

Table 7 identifies the specific baseline and test conditions for each of the TP options. Results of testing reflect comparison of installed test conditions for each of the technology packages and a combination of calculations, measured data and historical market data for the existing building and T24 baseline conditions.

As noted in the table, all of the technology packages are currently anticipated to be applicable for buildings with troffers or pendant overhead lighting.

Each system was tested at pilot scale prior to rolling out the full-scale test in FLEXLAB®'s occupied testbed. This allows a period of familiarization with the software (graphic user interface, programming, process of controls activation and commissioning techniques) and testing of hardware and installation techniques.

The period for testing each TP option was 2 months, doing 'before-and-after' analysis (baseline condition is measured, followed installation and measurement of the multiple test conditions). The 2-month period reflected the full schedule of testing for the various TP options and the degree of baselining required in order to provide confidence in the results.

When compared to the alternative of side-by-side testing (running test and baseline conditions concurrently) this proved to be important as it means that the same cohort is assessed in test and baseline cases, and therefore user behavior can be assumed to be relatively constant. It also supports a greater sample size for both test and baseline conditions and so provides greater confidence in the results.

A comparison of the baseline data with test condition data supports estimates of annual energy savings for each system type (basic or advanced).

On the plug load side, it was necessary to normalize the data for occupancy for a fair comparison. This normalization process necessarily led to a reduced sample cubicle size (versus the maximum available within the baseline and test) due to observations of inconsistent occupancy and to some extent, inexplicable load differences within individual cubicles between baseline and test or inexplicable load deviations within the test period.

Figure 4 illustrates the FLEXLAB test bed space, indicating the locations of cubicles (walls annotated on drawing, shaded blue areas indicate some of the work area locations) relative to the baseline condition pendant lighting fixtures. The testbed is bounded on the two long sides by private offices and office cubicles that were not included in the test and as such does not fall within the 'traditional' definition of the daylit zone. It can be seen from the results of test 3 however, that due to the prominent location of the building, and the office wall design which incorporates glazing in the top-most section, that there is substantial daylighting potential in the testbed space during occupied hours especially via the southwest exposure. As the specified systems are intended or open offices in general, we have removed the impact of daylight dimming from the results (particular to test 3), and suggest that daylight dimming offers energy savings over and above those presented here, with the precise amount being a function of the perimeter-to-core ratio of the space in which systems are implemented.

Figure 4: Plan View of Testbed, showing all 18 open office cubicles

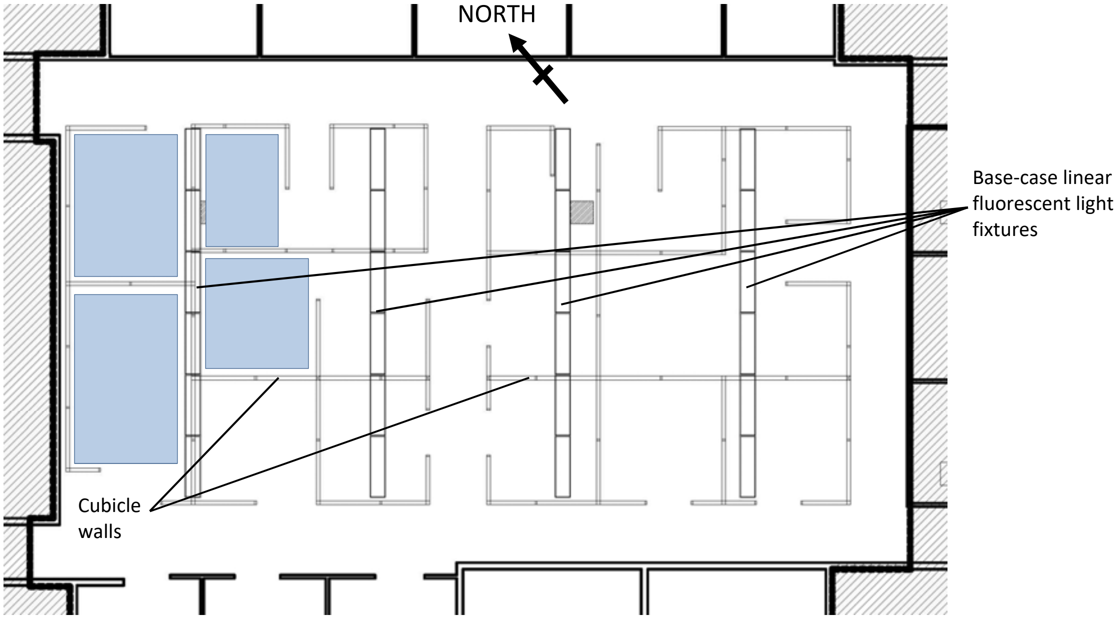


Table 7: FLEXLAB®® Technology Packages and Testing Program

	Test	Baseline Condition #1	Baseline Condition #2	Tested Technology Package
1a	*Technology Package 1 – [Existing bldg. baseline]* Existing fixtures with LED lamp replacement only to reduce overhead LPD, existing switch/time clock lighting controls only, occupancy plug load control Applicable for troffers and pendant fixtures	Overhead Lighting: Existing overhead lighting in FLEXLAB® testbed space (T5), manual control switches Plug loads: Manual operation / switching of desktop plug loads, existing task lighting	Overhead Lighting Fixture type, quantity and operating hours determined to represent the LPD of empirical existing CA office building data – (e.g. CEUS or GPG measured). No additional controls. Plug loads: Same as baseline #1	Overhead Lighting: Linear LED lamp replacement (including integrated driver) in existing fixtures[8], no additional controls Plug loads: Scheduled operation, occupancy sensor-based control, task lighting throughout. Occupancy sensor-based control of all non-computer (desktop or laptop) loads.
1b	*Technology Package 1 – [Existing bldg. baseline]* Existing fixture with LED lamp replacement only to reduce overhead LPD, existing occupancy controls on overhead lighting, occupancy plug load control	Overhead Lighting: Same as 1a Plug loads: Same as 1a	Overhead Lighting Same as 1a Plug loads: Same as 1a	Overhead Lighting: Linear LED lamp replacement (including integrated driver) in existing fixtures, scheduling and occupancy controls Plug loads: Same as 1a

[8] Assumes implementation of task ambient lighting strategy, so significant reduction in installed LPD from overhead fixtures

	Test	Baseline Condition #1	Baseline Condition #2	Tested Technology Package
	Applicable for troffers and pendant fixtures			
2a	*Technology Package 2a – [Title 24 baseline]* Existing fixture adding tuning / occupancy controls, occupancy plug load control Applicable for troffers and pendant fixtures.	Overhead Lighting Title 24 compliant (LPD-based) overhead lighting with: • Manual on/off • Scheduling • Occupancy controls • Tuning Plug loads: Same as 1a.	N/A	Overhead Lighting: Addition of controls to existing (T5 pendant) fixtures: • Manual on/off • Scheduling • Tuning • Occupancy controls • Daylight dimming in perimeter offices, none in the core Comparison against both baseline conditions. Test bench results will allow for T8 lamp-based fixtures evaluation as well Plug loads: Same as 1a
2b	*Technology Package 2b – [Title 24 baseline]* Existing fixture reduced	Overhead Lighting Same as 2a	N/A	Overhead Lighting: Retrofit of T5 LED replacement tubes:

	Test	Baseline Condition #1	Baseline Condition #2	Tested Technology Package
	LPD via LED lamp retrofit and adding scheduling / tuning / occupancy controls, plug load control. Applicable for troffer and pendant fixtures.	Plug loads: Same as 1a		• Manual on/off • Scheduling • Tuning • Occupancy controls • Daylight dimming in perimeter offices, none in the core Comparison against both baseline conditions Plug loads: Same as 1a
3	*Technology Package 2b – [Title 24 baseline]* Light fixture replacement with reduced LPD, scheduling/ occupancy controls/daylight dimming, plug load control. Applicable for troffer and pendant fixtures.	Overhead Lighting: Same as 2b Plug loads: Same as 1a	Overhead Lighting Same as 2a Plug loads: Same as 1a	Overhead Lighting: LED fixture replacement with: • Manual on/off • Scheduling • Occupancy controls • Tuning • Daylight dimming in perimeter offices, none in the core Comparison against both baseline conditions. Results also apply to the

	Test	Baseline Condition #1	Baseline Condition #2	Tested Technology Package
				retrofit kit use-case. Plug loads: Same as 1a

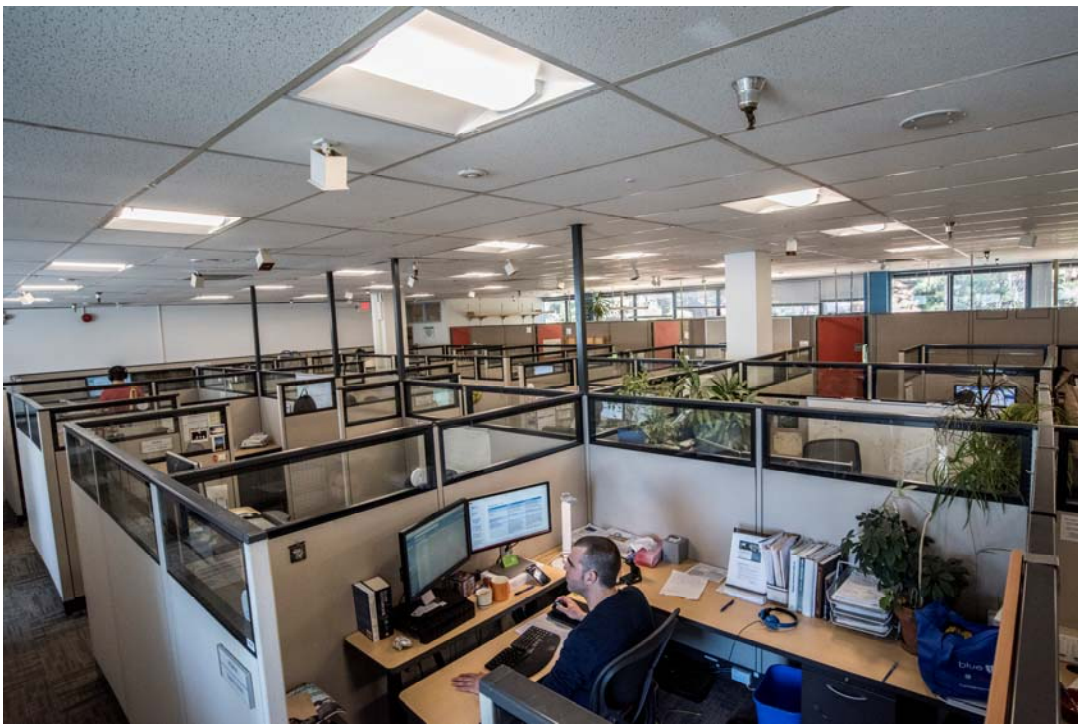
4.3.2 Measurement strategies

Data Collection

Data gathered for each of the tests comprised of fixed and variable components of the measured space. Fixed values include characteristics inherent to the measured space such as floor area, maximum occupancy and installed lighting power density. Variable values reflect the dynamic use of the space, such as occupancy at any one time, and resultant equipment power use, and the direct impact this has on energy use at any point on time.

Data was measured at a highly granularity – i.e. electricity metered per single light fixture (in this case two x 8 foot lengths for pendants or single fixture for troffers) or per each single duplex power receptacle.

Figure 5: Overview of Occupied Testbed



Metrics Measured

- Installed power (Watts, converted to Watts / square-foot)
    - Overhead Lighting
    - Plug loads
- Energy Use Intensity (kilowatt-hours / square-foot /year)
    - Occupied
    - Unoccupied
    - Total

- Digital Lighting Management (DLM) curve setpoint (%)
    - Setpoint on notional 0-100% power supply range to achieve desired lumens output
- Occupancy / vacancy (0 or 1 for individual work areas / cubicles)
    - Measured in-situ by FLEXLAB® control system (Test 1 control signal and cross-check for other tests)
- Occupied hours / occupancy (% of 'traditional office hours') as a function of total occupant capacity.
    - Sum product of occupancy data at the workstation level for baseline and test periods, used for comparison in analysis to 100% occupancy conditions

Figure 6: Cubicle Occupancy Sensors, Technology Package 2(a) – left, installed in ceiling – and 2(b) – right, furniture mounted

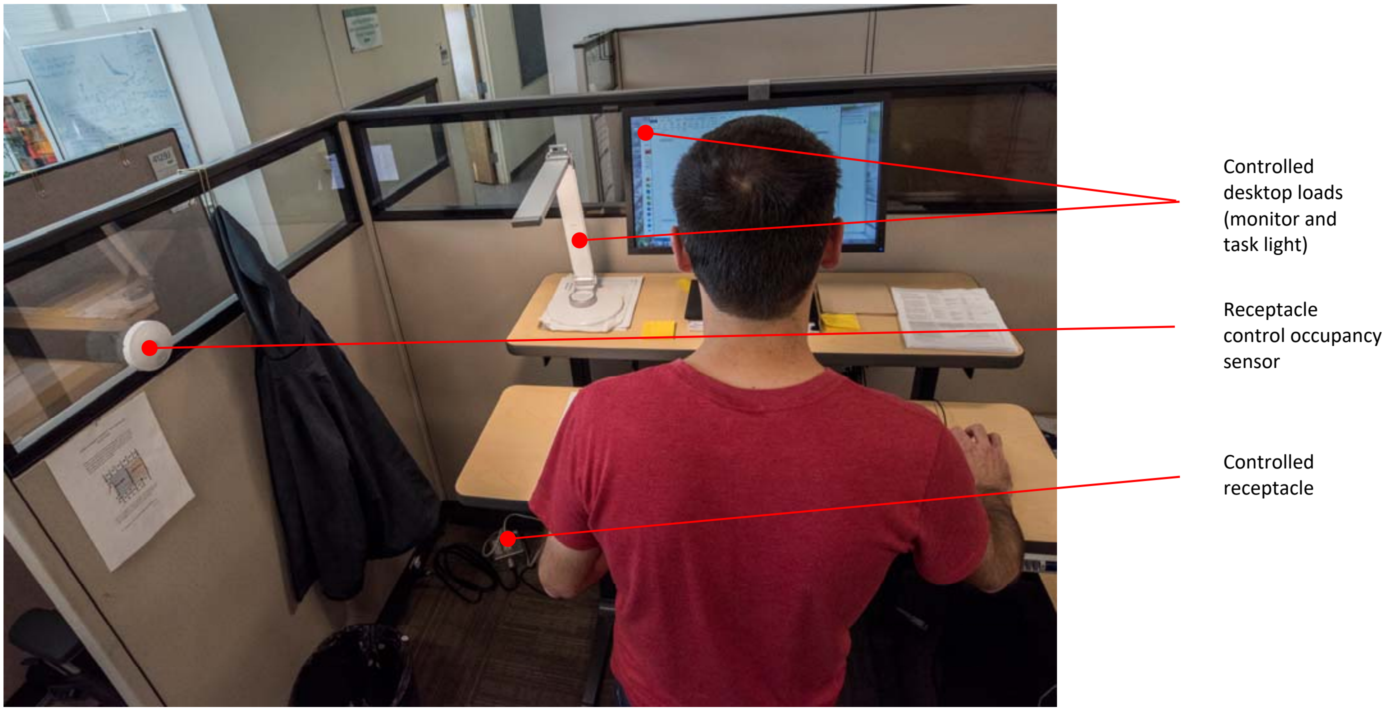
Measurement

Data shall be measured and collected via a) existing recording and metering infrastructure in the test space and b) proprietary software associated with the technology packages being tested.

Data Analysis

Analysis of systems performance shall be conducted via a direct comparison of energy use under 'baseline' and 'system test' conditions. The proposed analysis method shall account for variations in important factors - mainly occupancy - between baseline and test conditions. Analysis methods for each technology package will also cover a range of existing or baseline conditions where appropriate, and in determining these appropriate comparisons, assumptions will be gathered from literature and other data sources such as benchmarking tools such as EnergyIQ / CEUS, from web-based resources such as CBECS, or collected during real building field technology demonstrations such as GSA's GPG projects.

Figure 7: Occupancy plug load control



4.3.3 Testing and assessment results

Results are presented below for energy performance of each of the 3 technology packages.

The results indicate that the task-ambient lighting strategy results in significant energy savings versus the measured baseline and for 'average' existing commercial office buildings in California, using published data for large commercial office energy use in four California utility service territories.

Plug load energy use is reduced significantly for loads that may be controlled at the cubicle level – which for this analysis assumes all equipment except for desktop and laptop computers. Control of energy intensive office equipment such as copiers / printers / scanners is not included here, although these equipment types are considered good opportunities for reducing equipment power use.[9]

The whole building energy results stated reflect a situation whereby 100% of a commercial office building is dedicated to office space (i.e. no conference rooms, break rooms etc.) Adjustments to how these estimates are interpreted to real buildings will be necessary on a case by case basis.

[9] http://www.gsa.gov/portal/mediaId/197383/fileName/GPG_Plug_Load_Control_09-2012.action

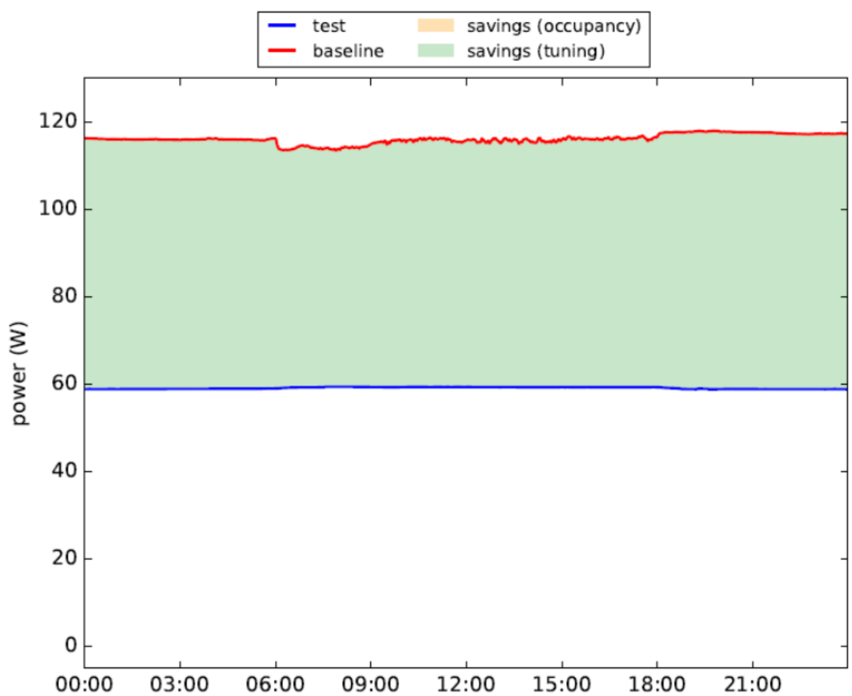
<u>Test Results - Technology Package 1</u>

Table 8: Overhead Lighting Energy Savings

Commercial Office	Baseline (kWh/sqft/yr)	Test EUI (kWh/sqft/yr)	Lighting Energy Savings (kWh/sqft/yr)	% Savings	Test EUI + Sweep (kWh/sqft/yr)	Lighting Energy Savings (kWh/sqft/yr)	% Savings
Existing Building Baseline	7.28	3.34	3.94	54%	1.19	6.09	84%
T24 Baseline	2.60	3.34	(0.74)	-29%	1.19	1.41	54%
DOE Reference Building - Small	3.8	3.34	0.46	12%	1.19	2.61	69%
DOE Reference Building - Large	4.1	3.34	0.76	18%	1.19	2.91	71%
SMUD	4.73	3.34	1.39	29%	1.19	3.54	75%
SCE	4.7	3.34	1.36	29%	1.19	3.51	75%
SDGE	4.45	3.34	1.11	25%	1.19	3.26	73%
PGE	4.24	3.34	0.90	21%	1.19	3.05	72%

Table 8 shows energy savings for overhead lighting. Savings reflect reduced lighting power density arising from installation of LED replacement tubes, as illustrated in Figure 8, which shows a comparison of the test with the measured baseline. In comparison with the DOE reference buildings and data on California office buildings there are significant energy savings.

Figure 8: Technology Package 1 Overhead Lighting Energy Savings



Note that the results indicate the energy impact of implementing an operating schedule for building operations (the delta between Test EUI and Test EUI with ‘sweep’). It is considered likely that scheduled based operations would already be in place at potential customer sites.

Table 9: Plug Load Energy Savings, Controlled Outlets

Commercial Office	Controlled Baseline EUI (kWh/sqft/yr)	Plug Load Savings (kWh/sqft/yr)	% Savings
Existing Building Baseline	0.95	0.20	22%
T24 Baseline	0.95	0.20	22%
DOE Reference Building - Small	N/A	N/A	N/A
DOE Reference Building - Large	N/A	N/A	N/A
SMUD	N/A	N/A	N/A
SCE	N/A	N/A	N/A
SDGE	N/A	N/A	N/A
PGE	N/A	N/A	N/A

Table 9 contains energy savings results for controlled plug loads (all desktop and office / cubicle equipment items except computers) - savings are significant in proportional terms, but modest in terms of units saved. The savings that accrued reflect the benefit of equipment shut-off during unoccupied periods (see Figure 9), which are principally after hours during the week and during weekends.

Figure 9: Illustration of Energy Savings from Plug Load Occupancy Control

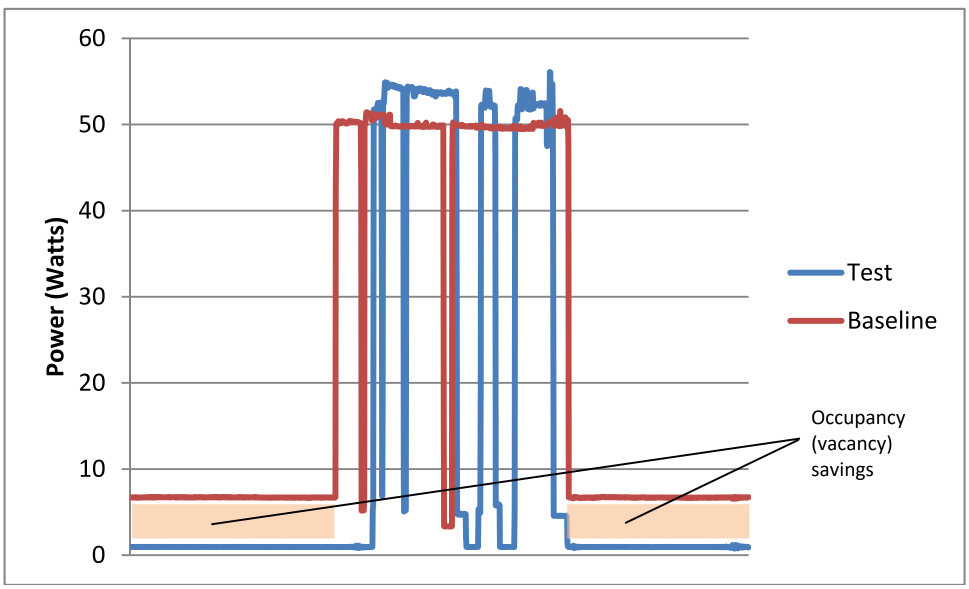


Table 10: Plug Load Savings, Controlled and Uncontrolled Outlets

Commercial Office	Total Baseline EUI (kWh/sqft/yr)	Plug Load Savings (kWh/sqft/yr)	% Savings	Anticipated Test EUI (kWh/sqft/yr)
Existing Building Baseline	4.28	0.20	5%	4.07
DOE Reference Building - Small	4	0.19	5%	3.81
DOE Reference Building - Large	5.4	0.26	5%	5.14
SMUD	5.04	0.24	5%	4.80
SCE	3.37	0.16	5%	3.21
SDGE	2.96	0.14	5%	2.82
PGE	3.72	0.18	5%	3.54

Table 10 presents the overall picture with regards to plug load savings, confirming that computer load is a key focus for load management and reduction. For FLEXLAB testing, it is assumed that computers and laptops are not candidates for plug load control due to numerous issues related to necessary overnight use and problems with initialization and software following unconventional (power interruption-based) shutdown of machines.

Table 11: Total Combined Lighting and Plug Load Energy Savings

Commercial Office	Energy Savings (kWh/sqft/yr)	Energy Cost Savings ($/sqft/yr)	System Energy Savings	WB Energy Savings - Large	WB Energy Savings - Small
Existing Building Baseline	6.29	1.01	54%	N/A	N/A
T24 Baseline	1.61	0.26	29%	7%	10%
DOE Reference Building - Small	2.80	0.45	36%	N/A	18%
DOE Reference Building - Large	3.16	0.51	33%	14%	N/A
SMUD	3.78	0.61	39%	16%	23%
SCE	3.67	0.59	45%	15%	23%
SDGE	3.40	0.55	46%	14%	21%
PGE	3.22	0.52	40%	13%	20%

* Overhead lighting energy savings include implementation of sweep, based on 60 hour working week

Table 11 presents the overall energy savings arising from testing of Technology Package 1. It is clear that savings compared to the measured baseline and 'average' California office buildings are significant, and are within the range predicted prior to the start of testing.

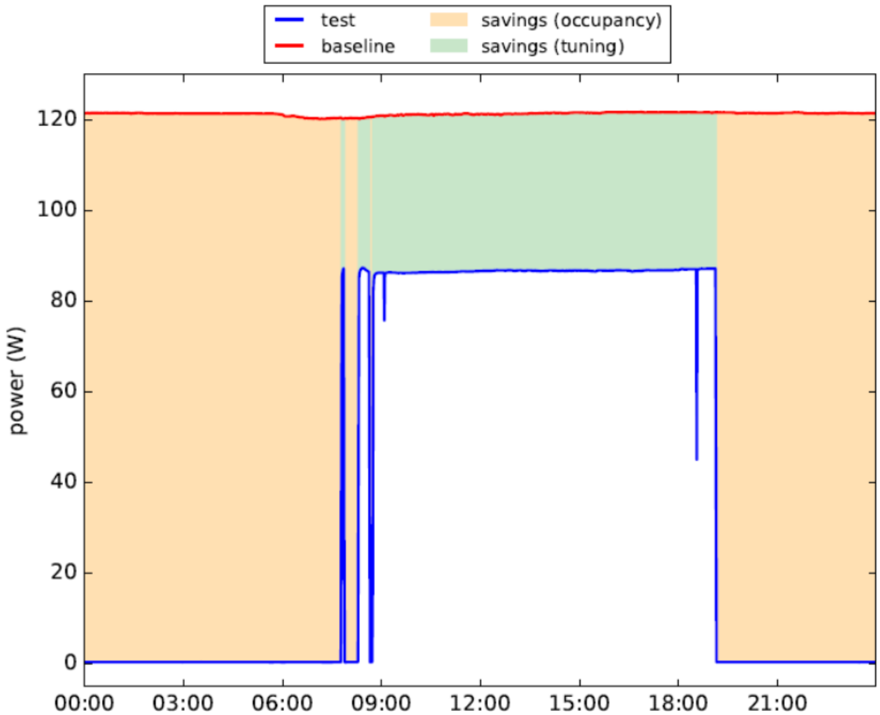
Test Results - Technology Package 2(a)

Table 12: Overhead Lighting Energy Savings

Commercial Office	Baseline (kWh/sqft/yr)	Test EUI (kWh/sqft/yr)	Lighting Energy Savings (kWh/sqft/yr)	% Savings	Test EUI + LEDs (kWh/sqft/yr)	Lighting Energy Savings (kWh/sqft/yr)	% Savings
Existing Building Baseline	7.32	2.00	5.32	73%	1.26	6.05	83%
T24 Baseline	2.63	2.00	0.63	24%	1.26	1.37	52%
DOE Reference Building - Small	3.80	2.00	1.80	47%	1.26	2.54	67%
DOE Reference Building - Large	4.10	2.00	2.10	51%	1.26	2.84	69%
SMUD	4.73	2.00	2.73	58%	1.26	3.47	73%
SCE	4.7	2.00	2.70	57%	1.26	3.44	73%
SDGE	4.45	2.00	2.45	55%	1.26	3.19	72%
PGE	4.24	2.00	2.24	53%	1.26	2.98	70%

Table 12 shows energy savings for overhead lighting. Savings reflect zone-level occupancy control strategy in place and a lower operating lighting power density for the adopted task-ambient lighting approach, as shown in Figure 10. The performance difference between the Test results and Title 24 baseline reflects this operating LPD reduction alone – all other controls options are the same across the two options.

Figure 10: Technology Package 2(a) Overhead Lighting Energy Savings



In comparison with existing 'average' buildings more significant energy savings can be seen, and against the measured baseline, which provides occupant control via manual switches only, the savings were very significant indeed. Given the low percentage of existing building with lighting controls already installed, there is reason to believe that there is significant potential for savings against the existing condition. There is also potential for significant on-top savings (~15%) were the option of LED replacement lamps added to this technology package.

Table 13: Plug Load Energy Savings, Controlled Outlets

Commercial Office	Controlled Baseline EUI (kWh/sqft/yr)	Plug Load Savings (kWh/sqft/yr)	% Savings
Existing Building Baseline	0.87	(0.01)	-1%
T24 Baseline	0.87	(0.01)	-1%
DOE Reference Building - Small	N/A	N/A	N/A
DOE Reference Building - Large	N/A	N/A	N/A
SMUD	N/A	N/A	N/A
SCE	N/A	N/A	N/A
SDGE	N/A	N/A	N/A
PGE	N/A	N/A	N/A

* At present, there is no clear mandated energy baseline for plug load control – beyond providing the infrastructure to support that means of control, there is no energy performance target, so we have assumed a baseline identical to the measured baseline.

Table 13 contains energy savings results for controlled plug loads (all desktop and office / cubicle equipment items except computers). It indicates that for this technology package, the benefits of plug load control are counteracted by the infrastructural load of the system (sensors and controllers) to the extent that energy savings are zero.

Table 14: Plug Load Savings, Controlled and Uncontrolled Outlets

Commercial Office	Total Baseline EUI (kWh/sqft/yr)	Plug Load Savings (kWh/sqft/yr)	% Savings	Anticipated Test EUI (kWh/sqft/yr)
Existing Building Baseline	3.62	(0.01)	0%	3.63
T24 Baseline	3.62	(0.01)	0%	3.63
DOE Reference Building - Small	4	(0.01)	0%	4.01
DOE Reference Building - Large	5.4	(0.02)	0%	5.42
SMUD	5.04	(0.01)	0%	5.05
SCE	3.37	(0.01)	0%	3.38
SDGE	2.96	(0.01)	0%	2.97
PGE	3.72	(0.01)	0%	3.73

Table 14 presents the overall picture with regards to plug load savings.

Table 15: Total Combined Lighting and Plug Load Energy Savings

Commercial Office	Energy Savings (kWh/sqft/yr)	Energy Cost Savings ($/sqft/yr)	System Energy Savings	WB Energy Savings - Large	WB Energy Savings - Small
Existing Building Baseline	5.31	0.85	49%	N/A	N/A
T24 Baseline	0.63	0.10	10%	3%	4%
DOE Reference Building - Small	1.79	0.29	23%	N/A	11%
DOE Reference Building - Large	2.09	0.34	22%	9%	N/A
SMUD	2.72	0.44	28%	11%	17%
SCE	2.69	0.43	33%	11%	17%
SDGE	2.44	0.39	33%	10%	15%
PGE	2.23	0.36	28%	9%	14%

Table 15 presents the overall energy savings arising from testing of Technology Package 2(a). It is clear that savings compared to the measured baseline and 'average' California office buildings are significant. Energy savings would be greater still than presented if LED replacement tubes were included as part of the package – see below.

Table 16: Total Combined Lighting and Plug Load Energy Savings, adding LED tubes

Large Office	Energy Savings (kWh/sqft/yr)	Energy Cost Savings ($/sqft/yr)	System Energy Savings	WB Energy Savings - Large	WB Energy Savings - Small
Existing Building Baseline	6.04	0.97	55%	N/A	N/A
T24 Baseline	1.35	0.22	22%	6%	9%
DOE Reference Building - Small	2.52	0.41	32%	N/A	16%
DOE Reference Building - Large	2.82	0.45	30%	12%	N/A
SMUD	3.45	0.56	35%	14%	21%
SCE	3.43	0.55	42%	14%	21%
SDGE	3.18	0.51	43%	13%	20%
PGE	2.97	0.48	37%	12%	18%

Test Results - Technology Package 2(b)

Table 17: Overhead Lighting Energy Savings

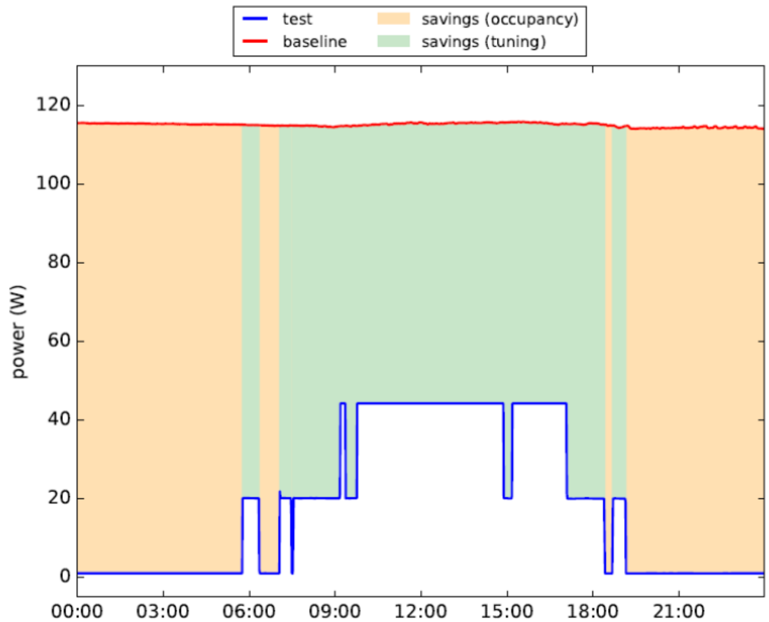
Commercial Office	Baseline (kWh/sqft/yr)	Test EUI (kWh/sqft/yr)	Lighting Energy Savings (kWh/sqft/yr)	% Savings
Existing Building Baseline	7.28	0.78	6.50	89%
T24 Baseline	2.64	0.78	1.86	70%
DOE Reference Building - Small	3.8	0.78	3.02	79%
DOE Reference Building - Large	4.1	0.78	3.32	81%
SMUD	4.73	0.78	3.95	83%
SCE	4.7	0.78	3.92	83%
SDGE	4.45	0.78	3.67	82%
PGE	4.24	0.78	3.46	82%

Table 17 shows energy savings for overhead lighting. Savings reflect the occupancy control strategy in place at the zone level, and the autonomous nature of individual fixtures in which they dim up in response to proximate occupants, and dim down in response to vacancy following a time out period, as shown in Figure 11.

Although the overhead lighting fixtures were installed in a core area, there was sufficient natural light in the space to support a small amount of daylight dimming. The energy impacts of daylight dimming have been removed from the results presented here.[10]

[10] This package is anticipated for implementation in open office areas, a large proportion of which might be beyond the daylit zone, so removing the impact of daylighting is consistent with a conservative approach whereby daylight dimming is not assumed possible.

Figure 11: Technology Package 2(a) Overhead Lighting Energy Savings



In comparison with existing 'average' buildings, this has the highest savings of the technology packages. Against the measured baseline, which provides occupant control via manual switches only, again savings were very significant indeed.

Table 18: Plug Load Energy Savings, Controlled Outlets

Commercial Office	Controlled Baseline EUI (kWh/sqft/yr)	Plug Load Savings (kWh/sqft/yr)	% Savings
Existing Building Baseline	1.09	0.20	19%
T24 Baseline	1.09	0.20	19%
DOE Reference Building - Small	N/A	N/A	N/A
DOE Reference Building - Large	N/A	N/A	N/A
SMUD	N/A	N/A	N/A
SCE	N/A	N/A	N/A
SDGE	N/A	N/A	N/A
PGE	N/A	N/A	N/A

Table 18 contains energy savings results for controlled plug loads (all desktop and office / cubicle equipment items except computers) - savings are significant in proportional terms, but modest in terms of units saved.

Table 19: Plug Load Savings, Controlled and Uncontrolled Outlets

Commercial Office	Total Baseline EUI (kWh/sqft/yr)	Plug Load Savings (kWh/sqft/yr)	% Savings	Anticipated Test EUI (kWh/sqft/yr)
Existing Building Baseline	3.78	0.20	5%	3.58
T24 Baseline	3.78	0.20	5%	3.58
DOE Reference Building - Small	4	0.21	5%	3.79
DOE Reference Building - Large	5.4	0.29	5%	5.11
SMUD	5.04	0.27	5%	4.77
SCE	3.37	0.18	5%	3.19
SDGE	2.96	0.16	5%	2.80
PGE	3.72	0.20	5%	3.52

Table 19 presents the overall picture with regards to plug load savings.

Table 20: Total Combined Lighting and Plug Load Energy Savings

Commercial Office	Energy Savings (kWh/sqft/yr)	Energy Cost Savings ($/sqft/yr)	System Energy Savings	WB Energy Savings - Large	WB Energy Savings - Small
Existing Building Baseline	6.70	1.08	61%	N/A	N/A
T24 Baseline	2.06	0.33	32%	9%	13%
DOE Reference Building - Small	3.23	0.52	41%	N/A	20%
DOE Reference Building - Large	3.61	0.58	38%	16%	N/A
SMUD	4.22	0.68	43%	17%	26%
SCE	4.10	0.66	51%	17%	25%
SDGE	3.83	0.62	52%	16%	24%
PGE	3.66	0.59	46%	15%	23%

Table 20 presents the overall energy savings arising from testing of Technology Package 2(b). It is clear that savings compared to the measured baseline and 'average' California office buildings are significant. Energy savings would be greater still than presented if LED replacement tubes were included as part of the package.

Test Results – Uncertainty of Plug Load Energy Savings

The key benefit of such a highly instrumented test space is the capability to parse data out to a level of granularity that provides key insights into what has been happening in the space, whether it is occupancy or load variation (arising from varying patterns of use, or change in number of types of loads) but this is a luxury that is highly unlikely to be present at customer sites.

One key observation on energy use was the uncertainty of energy savings arising from plug load control. This is due to a) the variations in occupancy, b) the variations in load (i.e. what is connected when) and most importantly c) the power and energy requirements for equipment that is being controlled (mainly monitors and task lighting) relative to equipment that isn't (laptops and computers).

Our analysis showed that when all equipment is included in the energy performance assessment, our sample size was not sufficient to confidently assert that with such a sample size, the energy savings we measured would be observed – the measured savings that we observed on controlled equipment in all 3 tests (between 0 and 0.2 kWh/sqft/year) is smaller in magnitude than the potential error in measurement that would occur merely as a function of sample size – see Figure 12, Figure 13, and Figure 14 below. We are unable to confirm what the appropriate sample size beyond stating that it likely exceeds our maximum sample size of 15 cubicles.

Figure 12: Uncertainty of Energy Savings as a Function of Sample Size – Test 1

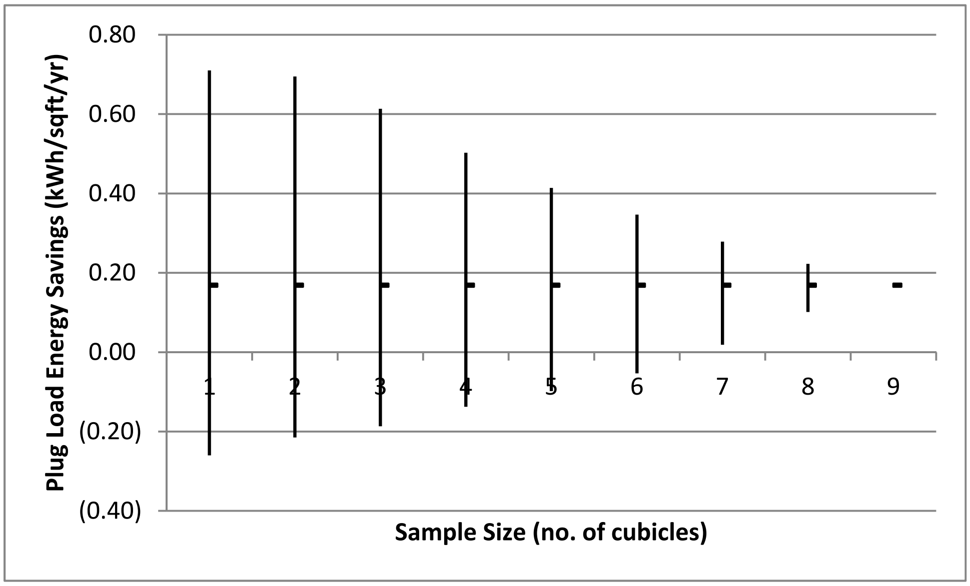


Figure 13: Uncertainty of Energy Savings as a Function of Sample Size – Test 2

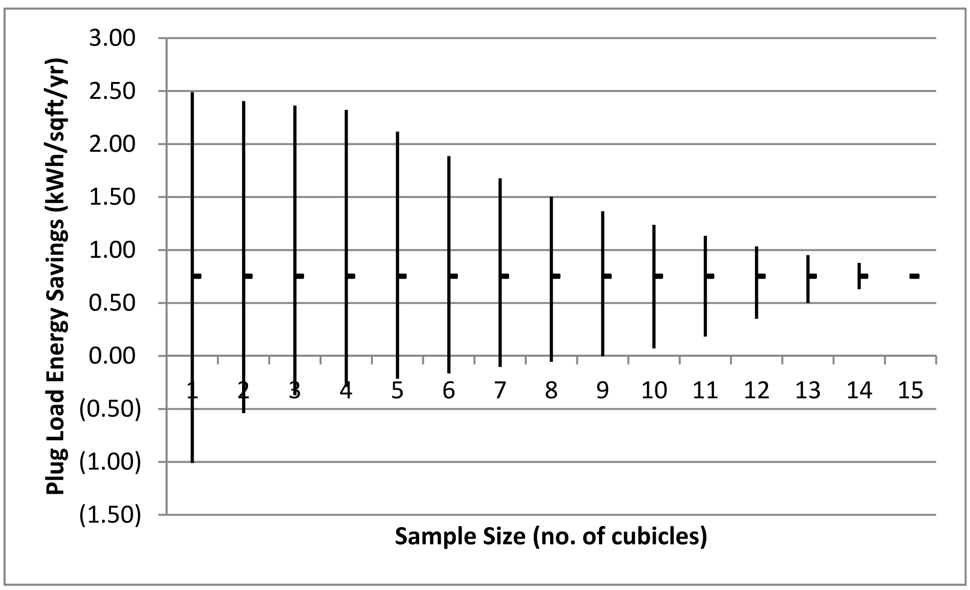
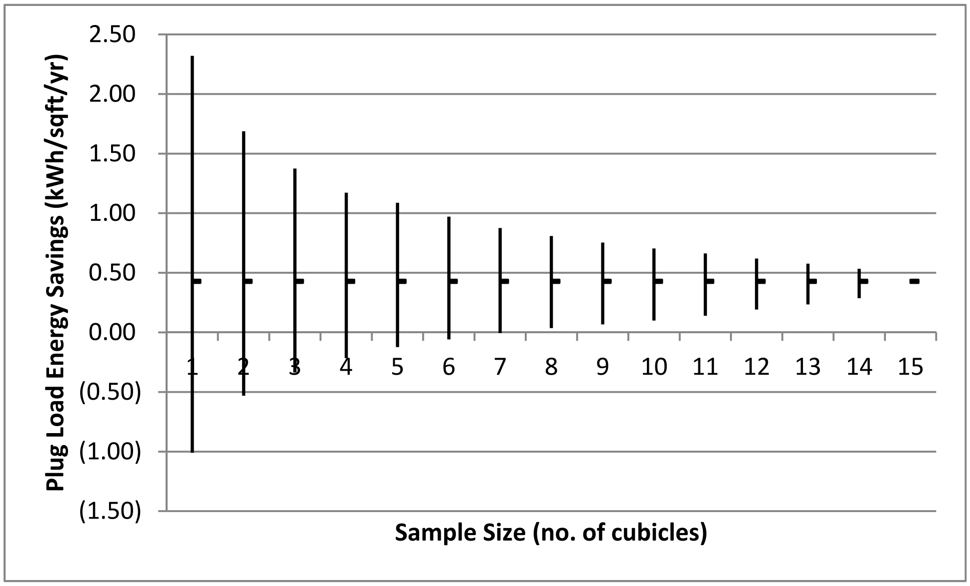


Figure 14: Uncertainty of Energy Savings as a Function of Sample Size – Test 3



Also, when including all equipment in our assessment, we also saw highly variable energy savings results from each of the tests – this likely reflects the reality of equipment use in an office environment when accounting for vacations, telecommuting, meeting schedules etc. where for numerous reasons energy use can vary from one month to the next (for example in the case of the testbed, staff running computer simulations is thought to be a key variable).

5 Technology Assessment for Customers

5.1 Methodology for Assessment

On the basis that potential customer sites generally satisfy the candidate site requirements outlined in Section 3 above, gaining insight into the potential value proposition for each of the technology packages is the next step in assessing whether to move forward with implementation.

As is implied by a base set of site requirements, energy savings from the proposed technology packages vary according to the setting into which they are installed and the operating and performance characteristics of the individual technology package.

LBNL developed a simple methodology to assist customers with completing high level site assessments, which is codified in the Excel spreadsheet that accompanies this document. The method is focused on estimating energy savings from overhead lighting only, based on an initial characterization of the site proposed for retrofit in terms of dimensions, use type, workstation density etc. plus a summary of the overhead lighting system specification and usage patterns. Once baseline conditions are defined, reference to the FLEXLAB® test results approximate predicted performance of each of the technology packages as a retrofit package for the site as defined. For the overhead lighting system, this assumes 1-for-1 light source or fixture replacement in each case.

For plug loads, although the results of testing indicated energy savings as discussed in the previous section, these are difficult to detect without a high degree of instrumentation, and vary significantly according to occupancy and due to the impact of non-controlled loads (mainly laptops and computers) on overall plug load energy (computer load is several-fold greater than non-computer loads, especially when completing work tasks for which processors are being heavily utilized). Our measured energy results, which are relatively consistent across the 3 tests, support a base assumption that the task light is used for the duration of occupied office hours, with calculations indicating that this would reduce the direct energy benefits of plug load control to zero – consistent with a conservative approach to predicting energy savings.

It should be noted that this methodology is only for assessing potential savings in the context of targeting, akin to a “back of the envelope” analysis. It does not have the level of rigor typically needed for M&V, which is discussed in the next section.

The methodology comprises the following steps:

1. Estimate area proposed for retrofit, including classification of the retrofit area into space office space types, or ‘other’ (which would not be included in the assessment of retrofit potential), and input estimated number of occupants.
2. Define office occupied hours in terms of work days and normal daily schedule.
3. Characterize the existing lighting system in terms of fixture type, fixture number, lamp type, lamp number per fixture type, rated lamp power per lamp type and type of controls present. At this point, the lighting energy baseline has been captured.
4. Determine energy savings from the three specified technology packages.
5. Enter utility rate input (average flat rate) to determine approximate energy cost savings.

5.2 FLEXLAB® testing for assessment tool development and validation (summary)

The method validation process is based on utilizing the FLEXLAB® test results as the points of reference. Variation in key inputs is what will impact results for candidate buildings with different physical and operating characteristics.

LBNL has included factors to account for variation in occupied hours and fixture density, and reviewed the results of field studies to validate the method. LBNL has also created a simulation model of the test space, and verified performance of multiple light sources of varying power densities to verify outputs of the method, and critically that these reflect a situation whereby the minimum floor plane light level of 200 lux can be met or exceeded.

6 M&V

6.1 Installation and Operation Verification Requirements

According to the International Performance Measurement and Verification Protocol (IPMVP) operational verification "consists of a set of activities that help to ensure that the ECM is installed, commissioned and performing its intended function." IPVMP states that operational verification should be included in M&V plans. IPMVP describes four approaches to operational verification: visual inspection, sample spot measurements, short-term performance testing, and data trending and control logic review.

The performance of task-ambient lighting and occupancy-based automated plug load control it's strongly dependent on appropriate equipment selection and programming and operation of controls.

For overhead lighting, Technology Package 1 depends on the appropriate light source selection to enable light levels at the floor plane to be at the appropriate level, which is assumed to be approximately 200 lux in this case. For Technology Package 2, proper commissioning of the controls is necessary to a) ensure that the 200-lux light level is achieved and b) that occupancy based control, whether implemented at the zone or cubicle level, is enabled and functioning correctly.

For both technology packages, the occupancy-based plug load control has set-up and commissioning requirements to ensure that only the appropriate loads are being controlled and that each occupancy sensor is tied to its respective controlled outlet.

Given that, we strongly recommend that operational verification utilize visual inspection, sample spot measurements, data trending and control logic review. We recommend the following at a minimum:

Overhead lighting system:

- Measure workplace illuminance at the floor. 200 lux is not the absolute minimum, but reflects the approximate performance requirement for the testing of the systems described and specified here. IES recommends that for corridors and transition spaces, 100 lux is appropriate – a more conservative recommendation was adopted for testing here.
- Where appropriate, verify occupancy control of overhead lighting via observation of lighting operations at time of initial occupancy, and post-system timeout at the end of the scheduled day, when the retrofit area has been completely vacated.
- Trend power levels and review trend data to ensure that lighting power reduction and appropriate occupancy control has been successfully implemented.
- Plug load control system:
- Observe operation of plug load control via task light as indicator – note automated-on operation of light in response to occupation of sample cubicle(s). Note automated-off operation after specified time-out period following vacating of cubicle.
- Trend equipment power on the controlled receptacles to ensure operation pattern matches observed occupancy patterns (best achieved by monitoring start-day and end-day times).
- The verification for both systems maybe done as part of routine commissioning for these systems, and may be included in the scope of work for the installer.

6.1 M&V Approaches and Metrics

6.1.1 Project M&V

The available options for measurement and verification activities for both pre- and post-retrofit scenarios are described below with the aim of providing a range of options for the DSM program. Some measurement and verification options comprise an inherently greater level of uncertainty in the energy savings than other approaches.

Using this information, a utility DSM program may decide to adjust the incentive amount to the customer to account for the uncertainty of energy performance associated with each of the measurement options described in 6.1 below. The aim of offering the menu of options is to present different M&V approaches, including traditional ones and new options that could streamline measurement and verification activities at customer sites, potentially reducing the cost of implementing these M&V strategies. Utility members may use this data and information in discussions with program evaluators with an eye towards streamlining those efforts. Feedback and engagement with program evaluators would be encouraged early on in this case, with the proposed objective being to identify the most appropriate M&V option given the circumstances of retrofits.

6.2 M&V Options

IPMVP describes four options for M&V. Below we discuss the applicability and implications for each of the options. The program could use a tiered approach - stipulate savings based on FLEXLAB results above and provide limited incentive based on discounted savings and basic operational verification. Additional incentives may be provided based on the uncertainty reduction associated with each of the M&V options described above.

Table 21: M&V Options Summary

IPMVP Option	Savings Calculation Method
Option A: Retrofit Isolation - Key Parameter Measurement Field (spot or short-term time resolved) measurements of key performance parameters that define energy use of systems affected by the energy conservation measures. Energy savings are calculated utilizing estimates for other (secondary) parameters.	Engineering calculations based on measurements taken, historical data and / or manufacturers specifications.
Option B: Retrofit Isolation - All Parameter Measurement Continuous measurement of the device or system at the appropriate monitoring points. Performance and operations metrics are measured.	Engineering calculations utilizing measured data.
Option C: Whole Facility Energy savings are determined by measuring energy use at the facility meter or sub-meter level. The baseline is determined by projecting from historical data using a range of possible methods.	Analysis of utility meter data using techniques ranging from simple before-and-after comparisons to regression analysis.
Option D: Calibrated Simulation	Software simulations model the buildings performance via

This approach uses a calibrated simulation using professional software and applies to the whole facility or sub-facility.	iterative calibration and then the calibrated model is used to determine the retrofit systems energy use.

6.3 Additional M&V Considerations

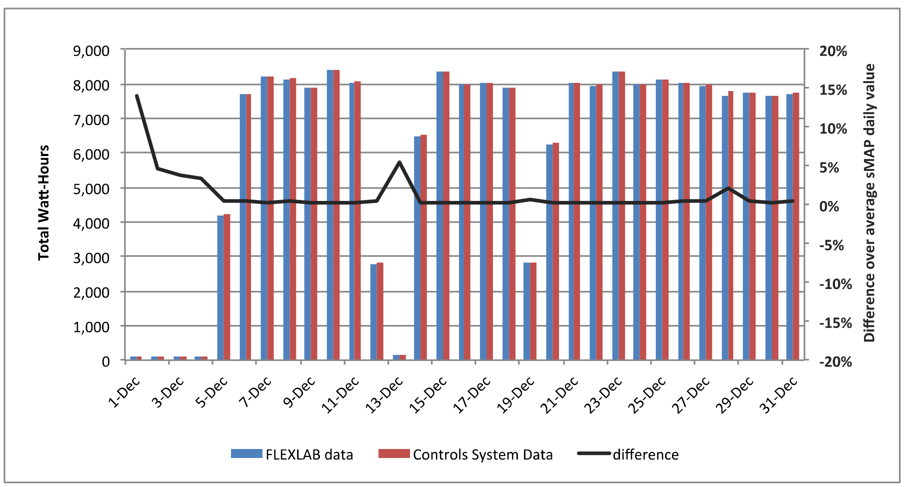
A unique advantage of the density of data available from FLEXLAB® testing is that it is possible to assess the effects on measured energy performance associated with the absence of specific data – which may reflect cases of incomplete information under a prescribed M&V approach or an M&V approach that has less site-specific intelligence or data granularity associated with it.

In this particular case, we used FLEXLAB data to assess the impact of two issues:

- Reliability of control system calculated lighting power
- Savings uncertainty with different measurement periods

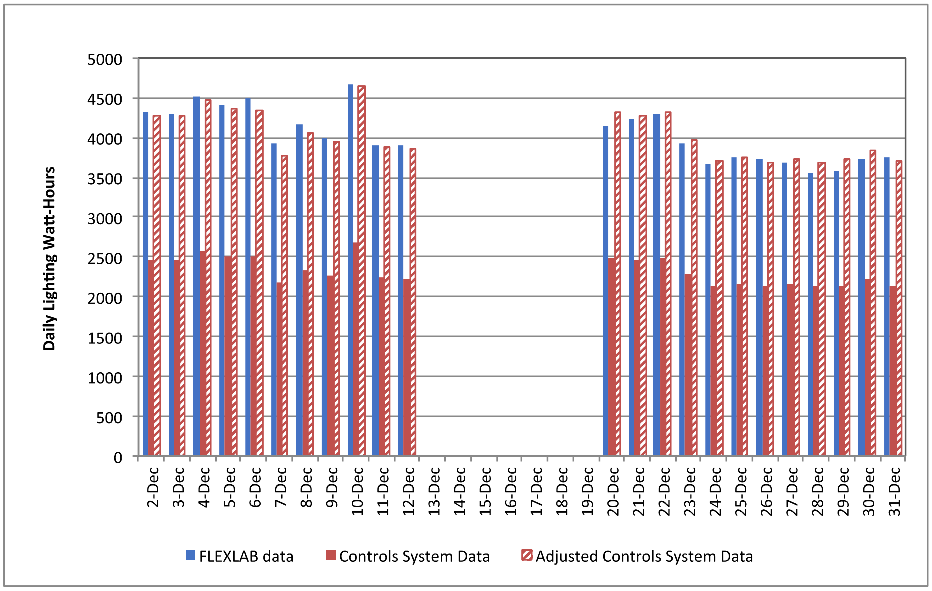
For one test which used a lighting controls system that actually measures lighting energy at the control point, the total controls-reported energy for the evaluated period was within a half % of measured energy, as shown in Figure 15.

Figure 15: Comparison of lighting energy from control system that measured actual lighting energy vs. lighting energy measured by FLEXLAB instrumentation.



For another test which used a lighting controls system that for energy reporting purposes relies on user-inputs for controlled loads (e.g. nameplate fixture wattage) and dimming behaviors (e.g. slope of dimming curve), controls-reported energy for the evaluated period was not close enough to measured energy to rely on for M&V (figure 44). Since the system did not actually measure fixture power for reports, energy reporting accuracy was entirely dependent on the load information entered during commissioning. However, detailed commissioning of the controlled loads during setup was not in the scope for the controls set up and commissioning. It is possible that with more attention to this detail the reported energy could be more accurate. This finding is not unique to the particular controls system deployed for this experiment. In fact, it was noted that the variations in watt-hours reported for the fixtures corresponded to variations in the measurements and that that the difference in the data seemed mostly due to scaling. A scaling factor derived from a regression of the data was applied to "adjust" the controls system data, and the total energy for the scaled controls dataset was within 0.03% of measured data (dashed bars in Figure 16).

Figure 16: Comparison of lighting energy from control system that calculates lighting energy vs. lighting energy measured by FLEXLAB instrumentation



The key finding is that if the control system is not measuring actual lighting energy, it should be carefully commissioned, calibrated and compared to actual measured values to ensure that the calculated values are within the bounds of desired accuracy for M&V or other purposes.

6.4 M&V Approaches and Metrics

6.4.1 M&V Approach Testing and Results

In principle, the M&V methods proposed under IPMVP are all applicable for used when assessing performance of the system technology packages outlined in this manual. In practical terms, Option D – Calibrated Simulation may be the least appropriate due to the cost of conducting analysis on a building-by-building basis – the range of possible candidate buildings is too great to foresee a cost-effective approach under this method.

Option A:

This method is likely to have a relatively high degree of uncertainty associated with it, as inherent in its nature is a mix of measured an estimated data input – which metrics are measured and what information comes from specifications or estimates will determine this. For example, where observations on occupancy patterns from a period of days are applied as 'typical' across the year, errors in prediction could be significant, or not. Therefore, when considering this option, it is critical that the key independent variables be well understood, measured as accurately as possible and for as long as possible. For inputs that are estimated, based on technical documentation or engineering expertise, the sensitivity of the result to variation of these inputs should be well understood (i.e. if you vary input X by 25%, what is the energy impact for sub-system Y and by extension the overall energy impact in percentage terms).

Option B:

This method provides the most direct measurement of savings attributable to the measure. It may be the only option if the whole building option C is not viable due to the retrofitted area being too small relative to total area. There are two components to the savings: lighting savings and plug load savings.

Lighting energy metering: Post retrofit measurement may possible from the lighting control system. Some systems measure power directly, while others calculate power based on dimming status. In the latter case, it is critical to ensure that the commissioning was done and the calculated power was verified with direct measurements (see section 6.3.1 for more information)

Pre-retrofit lighting energy use could be estimated using temporary measurements of load and the same schedule as post-retrofit. If the retrofit included a change in lamps or fixtures and the intent is to determine savings attributable only to the automated shading and dimming, the baseline can be determined from the post-retrofit peak wattage without dimming. Installing a permanent EIS that includes lighting energy use would have the dual benefit of M&V as well as continuous commissioning.

Area Sampling: Savings can vary by zone due to variations in occupancy and due to the degree and granularity to which occupancy-controls are implemented (this varies according to specifications of the different technology packages). If sampling, it is critical to ensure that the sample spaces have occupancy profiles that broadly reflect the overall retrofitted area.

Measurement period: To account for variations in savings that occur due to fluctuations in occupancy at the individual and group level (i.e. personal vacation time out of season and seasonal vacation periods respectively), it is important to a) collect data for an appropriate period of time and b) schedule data collection appropriately. The ideal period would be for at least 3 months, outside of the winter and summer holiday seasons. If that is not viable, it could be done for shorter periods e.g. a week or fortnight of each month, to achieve a total period of 3 months.

Plug load energy savings: Although the results of FLEXLAB® testing showed plug load energy savings, the means of calculating these plus the fact that the quantity of potential energy savings is dwarfed by energy use by the non-controlled plug load equipment (mainly computers and laptops) suggests that it is not therefore considered cost-effective to attempt to confirm and quantify these savings.

Option C:

The key criterion for using option C is whether the whole building savings are large enough relative to the volatility in whole building energy use due to weather and operations. While overall energy savings in the retrofitted areas are large (~13-27%) the savings at the whole building could be much lower, because the retrofitted area may only be a portion of the total building floor area. The degree to which energy savings can be detected will depend on the size of the retrofit as a proportion of the overall building and the accuracy of the model used in predicting the baseline condition.

In terms of retrofit area proportion, this is a case-by-case situation as buildings vary significantly in terms of complexity. Potential customers should refer to ASHRAE Guideline 14 for more detail on this.

For the CA POU system, the key variable is occupancy, and specifically for overhead lighting performance which accounts for the vast majority of energy savings, how patterns of office attendance (in terms of occupant numbers and first arrival and last departure time) may be shown to be consistent across baseline and retrofit cases.

As with option B, it is important to have measurements to cover 'typical' periods of occupancy outside of holiday seasons to capture accurate measurements of system operation and performance. If savings need to be extrapolated, they could refer to the same set of variables as the assessment method, but it should be noted that folding in such an approach here will bring the user closer to IPMVP Option A, in terms of methodology – the assessment method developed for here is not intended for use as a post-install M&V tool.

Option D:

Calibrated simulation could, in theory, be used. However, it takes considerable effort and essentially represents a custom approach. Also, it requires considerable expertise to correctly model automated shades and their control logic. As such, we do not think Option D is a scalable approach for this system.

7 Savings Persistence Guidelines

A study by LBNL explains efficiency measure lifetime as a function of the equipment lifetime (the average years the equipment will operate) and the measure savings persistence; "the time that an energy-consuming measure actually lasts taking into account business turnover, early retirement of installed equipment, and other reasons that measures might be removed, damaged or discontinued"11 Savings persistence from a measure like advanced lighting controls could include changes in expected energy usage resulting from changes in operating hours, space configurations, and user interactions with the system (controls overrides for example)..

The authors identify savings persistence as an issue for efficiency measures that among other things, have significant behavioral or operational variability over time and in different applications, and represent very different technologies from the baseline or standard measures they replace. Both issues are applicable to advanced lighting controls measures, which represent a significant change from basic wall switches and lighting schedules, and are deployed for particular populations and space configurations that may change over time. If the user group (for whom the controls system is commissioned) changes, lighting controls operations may not be appropriate for the next occupants, which can lead to deactivation, overrides, or misapplication of the controls from an energy savings standpoint. It has been pointed out by efficiency experts that utility experience with lighting controls measures has not always been positive, with instances of poor persistence and unreliable energy savings (not designed, installed, commissioned properly, not used properly by building operators, difficulties with reconfiguring) (Lighting System Optimization: Leveraging the New Technology Paradigm DOE SSL Technology Development Workshop November 17, 2015).

However, a strength of advanced, networked and centrally managed lighting controls, as well as fixtures with embedded programmable sensors and controls, is the flexibility of the systems to reconfiguration and recommissioning to adapt to new users and space configurations. Lighting system zoning through programmable interface and GUI, or remote control, allows advanced lighting controls to adapt to changes more easily than legacy hard-wired systems, which should improve measure persistence.

Key to realizing this benefit will be operator familiarity, facility, and engagement with use of the lighting controls hardware and interfaces so that changes can easily be effected when necessary, allowing the controls to provide expected service (and energy savings) for their useful lifetime. Often the commissioning agent that sets the system up initially is a vendor employee or technician, with all the knowledge and familiarity of interacting with the system controls. The transfer of the knowledge and skills to facility personnel is critical if the facility is going to take ownership of controls operation and keep them operating in line with expectations and user desires going forward.

Examples of space reconfiguration impacts on lighting controls operation:

- Dimmable lighting systems are typically "tuned" from full output down to a lower level that results in the desired average light level at the task plane. This tuned value needs to be customized for given spaces and adjusted when spaces change, to prevent over-lighting or under-lighting spaces.

[11] May 2015, *Energy Savings Lifetimes and Persistence: Practices, Issues and Data*, Ian M. Hoffman, Steven R. Schiller, Annika Todd, Megan A. Billingsley, Charles A. Goldman, Lisa C. Schwartz, Lawrence Berkeley National Laboratory

- Reconfiguration of space and office populations can impact lighting controls daylight dimming function, which is normally commissioned at installation by turning the lights on in a given space, in the absence of daylight. The resulting controls photosensor reading is then used as the set-point that the system controls to from that point on. During this commissioning process, the daylight sensor "sees" the intended light level, based on electric lighting system design for that space as configured at that time. The lights then dim in proportion to any "extra" light sensed by the photosensor throughout the day, at a response rate and sensitivity programmed into the controls system logic. Issues arise if the space is reconfigured - desks moved, fixtures moved, partitions added or subtracted. If the lighting system is not re-commissioned, it will continue to control to a set-point that may no longer reflect intended light levels, which could impact savings persistence.
- Occupancy sensors: savings persistence can be impacted by occupancy sensor operation as well due to space configuration changes. Lighting controls systems typically zone several fixtures to one occupancy sensor. If the space is reconfigured in the area of the sensor, it may end up controlling fixtures no longer in logical groups, either leaving unoccupied areas lit or occupied areas dark. A major benefit of the integrated sensors and controls approach is that fixtures and space can be reconfigured without necessarily detrimentally affecting lighting controls operation; each fixture can act autonomously based on the occupancy in its own zone.

Automated, plug load control, in contrast to automated lighting control and daylight dimming, is not technology building occupants are accustomed to engaging with, and as it directly impacts their immediate work environment, steps should be taken to ensure that they understand intended operating characteristics and what steps to take should they encounter equipment behavior that is at odds with this. The objective is to prevent dissatisfaction in the first instance, and in instances where operations are not as intended, this may be addressed quickly.

Recommendations:

Rigorous formalized training requirement during acquisition and installation of lighting controls and plug load controls systems, so that the facility develops the institutional knowledge and skills to not only operate the new controls as commissioned, but to periodically verify system operation and re-commission as spaces and users change through time.

Periodic (annual, bi-annual) lighting controls review:

- Measurement of light levels in representative locations within lighting zones; recommissioning of "tuned" setting and daylight dimming setpoint if out of desired range
- Check operation of lights, switches and sensors
- Solicit occupant feedback on lighting and plug load operation, concerns
- Check zoning of occupancy sensors to ensure that logical groups of fixtures respond to the right sensors in a space, and re-zoning of occupancy sensors if necessary.

Refer to Appendix B for a verification checklist process that can be periodically applied to ensure that light levels and controls operation are set to desired levels.

8 Training for Program Implementers

The following stakeholders should be considered for outreach efforts in the development and deployment of the workstation specific lighting system incentive program:

- **Program Design & Planning:** Responsible for developing and proposing programs including specification levels, evaluating cost-effectiveness, establishing incentive levels and deciding which activities the program will encompass (e.g., stakeholder education).
- **Program Management:** Oversees program delivery and provides insights for process regarding what has or hasn't worked in the past.
- **Marketing & Outreach:** Promotes programs to the public and trade allies and makes decisions regarding promotional materials, advertising placements and conducting on-line promotions.
- **Evaluation or Market Research:** Plans and oversees: market research for program planning or baseline setting, tracking and assessment of program impacts, progress towards program goals, and/or process evaluation. May also collect and analyze data in support of these efforts.
- **Regulatory Affairs:** Responsible for working with regulators on rate cases.
- **Technology & Engineering:** Qualified to evaluate the technical potential, performance, or safety of equipment under consideration for inclusion in programs.
- **Portfolio Management:** Responsible for assessing efficiency program objectives, timelines, and resources (for a sector or the total portfolio), planning a set of sector programs needed to meet requirements beyond the current program year, and maintaining a balance of sector program activities across the portfolio in order to achieve multi-year goals, among other responsibilities.
- **Government:** Has government perspective of working toward energy efficiency goals.

9 References

Moorfield, L., B. Frazer, and P. Bendt, 2008. Office Plug Load Field Monitoring Report, ECOS. [Accessed online February 20 2015, from: http://www.energy.ca.gov/2011publications/CEC-500-2011-010/CEC-500-2011-010.pdf]

Metzger, I., D. Cutler, and M. Sheppy, 2012. Plug Load Control and Behavioral Change Research in GSA Office Buildings, General Services Administration. [Accessed online February 20 2015, from: http://www.gsa.gov/portal/mediaId/197383/fileName/GPG_Plug_Load_Control_09-2012.action]

Wei, J., F. Rubinstein, J. Shackelford, and A. Robinson, 2015. Wireless Advanced Lighting Controls Retrofit Demonstration, LBNL-183791. [Accessed online January 8 2015, from: https://www.gsa.gov/portal/getMediaData?mediaId=227615]

Shackelford, J. A. Robinson, and F. Rubinstein, 2015. Retrofit Demonstration of LED Fixtures with Integrated Sensors and Controls, General Services Administration. [Accessed online January 7 2015, from: http://www.gsa.gov/portal/mediaId/240307/fileName/LED_Fixtures_with_Integrated_Controls_-_final_508.action]

Williams, A., B. Atkinson, K. Garbesi, F. Rubinstein, and E. Page, 2011. A Meta-Analysis of Energy Savings from Lighting Controls in Commercial Buildings. Technical report. Lawrence Berkeley National Laboratory. LBNL-5095E.

Appendix A: Market Segmentation Analysis

1 EXECUTIVE SUMMARY

This report presents findings from research commissioned by Lawrence Berkeley National Laboratory (LBNL) to identify energy savings potential for systems based energy efficiency in individual market segments (e.g., offices) and sub-segments (e.g., large offices owned by the tenant).

Conducted by DNV GL, this study is part of a larger “Getting beyond Widgets” research project aimed at identifying the most appropriate methods to promote systems-based energy savings in US commercial buildings via utility incentive programs.

This version of the report will refer to all three utilities and associated systems throughout the body text but for the sake of clarity and brevity, will largely only show results for the CA POU systems in tables and charts.

1.1 Study Approach

LBNL worked with three utility partners to define the systems to be considered in this study and the best building types (i.e., market segments) applicable to these systems. The systems and segments are shown in Table 1. This amended version of the report will refer to all three utilities and associated systems throughout the body text but will only report results for the CA POU systems in tables and charts.

Table 1. Study targets

Utility Partner	Segment	System Packages
California Publicly Owned Utilities throughout the state (CA POUs)	Offices	Package 1. Plug-and-play overhead lighting and automated plug load control system Package 2. Overhead lighting and / or networked controls change out and automated plug load control system
Commonwealth Edison in Illinois (ComEd)	Offices and Schools	Package 1. Automated shading (roller) with integrated lighting controls
Xcel Energy in Minnesota and Colorado (Xcel)	Offices	Package 1. Zonal HVAC controls with lighting upgrade and integrated zone-level daylighting and lighting controls Package 2. Integrated, enterprise-level networked lighting and lighting controls, daylight redirecting film, and HVAC controls

Once the systems and primary market segments were defined, DNV GL further segmented the market into sub-segments using data from the utility partners and CoreLogic, a commercial real estate database. We then estimated the technical, economic, and achievable potential for each system within the chosen market segments using both replace on burnout (ROB) and retrofit (RET) applications. We conducted expert interviews to obtain a greater understanding of the target markets, develop “adoption curves”, and to refine the estimates of achievable market potential.

Technical potential refers to the complete penetration of lighting systems in all segments deemed technically feasible from an engineering perspective.

Economic potential is that portion of the technical potential that the utility considers cost-effective when compared to supply-side alternatives.

Achievable potential is the portion of economic potential that can realistically be achieved based on customers' likelihood to adopt the systems in response to specific marketing approaches and incentive levels.

Based on this research and analysis, we identified the market segments that provide the greatest potential for cost-effective energy savings from the selected energy-efficient systems. See Section 2.2 for a more comprehensive discussion of the study approach.

1.2 Key Findings

The most notable findings of this study include the following:

- Systems tend to be cost-effective from the utility Total Resource Cost (TRC => 1.0) perspective for office building applications for the Northern and Southern California POUs and in larger office buildings for Xcel Colorado. These systems (as defined for this study) are not cost effective for Xcel Minnesota. For ComEd, these systems are cost-effective, but only for specific sub-segments and only when evaluated using incremental system costs.
- The differences in cost-effectiveness, and thus economic potential, are due more to levels of utility avoided costs[1] rather than the system costs or their savings on a per square foot basis. For example, the avoided cost stream average was $0.22 per kWh in California and $0.15 per kWh for Xcel Colorado. ComEd in Illinois and Xcel Minnesota were much lower with an average of $0.04 per kWh.
- From the customer perspective, the simple payback for these systems (depending on application and location) ranged from approximately 7 years to 35 years in the retrofit scenario and 6 years to 22 years in the replace-on-burnout scenario.
    - Some of this difference is due to the wide variation in customer energy rates. Over the analysis period of 20 years, commercial rates in California average approximately $0.20 per kWh[2]. For ComEd in Illinois, rates in the analysis averaged $0.10 per kWh. Xcel CO and MN have average rates of about $0.09 per kWh.
- DNV GL interviews of subject matter experts found sufficient general market awareness of these systems but their benefits in terms of energy savings and operational efficiency improvement are not well understood by facility managers and building owners. Since benefits in terms of energy savings, maintenance and operations savings, and building operational control are key drivers of adoption; a lack of knowledge in these areas implies that adoption will be slower than that of well-understood widget equipment.
- The adoption decisions and installation of these systems are much more involved and disruptive to building tenants than typical widget replacement projects. As a result, experts interviewed for this study asserted that, given the longer paybacks of these systems and with no program intervention, only 13% to 20% of the market would adopt

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[1] Avoided costs are the proxy used to reflect the benefits to the utility. In this study, they refer to eliminating, or significantly delaying utility expenditures for infrastructure upgrades and fuel costs due to a reduction of energy consumption by customers.

[2] California electric retail rates for POUs reflect California Energy Commission forecast averages. Avoided costs reflect costs developed for California Investor Owned Utilities.

these over the next 10 years. This is comparable to market studies of lighting widgets, in the northeast for example, that estimated approximately 13% adoption of high efficiency LED lighting and controls over 10 years.[3]

- Reducing payback times to 2-years or less, either through market driven cost reductions or utility intervention, will increase expected market saturation to between 24% and 43% over 10 years. Saturation will range from 13% to 20% over this same period if payback is greater than 2-years.

The total technical potential of energy savings for each utility partner in GWh is in Table 2.

Table 2: Technical potential (GWh savings)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	412	752	833	883
Southern California	479	876	1,028	1,028

Values are the same for packages with the same energy reduction values. There may be package differences however due to system cost, demand reduction or both.

In both the RET and ROB scenarios economic potential is from the perspective of the utility and is considered cost-effective if the TRC ratio is greater than or equal to 1.0. In service areas with TRC threshold requirements at the resource program portfolio level (rather than equipment level) a low TRC, by itself, does not preclude inclusion into the utility EE portfolio. Similarly, the utility may offer a program to "jump start" market adoption with a goal of transforming how integrated systems are marketed and priced. For these instances, exceeding a TRC threshold may not be necessary. For the most part TRC values remain the prime criterion for by which regulators judge utility programs. The TRC values for determining the economic potential of systems in RET and ROB applications are reported in Table 3 and Table 4.

Table 3: TRC values (RET average)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	1.04	1.13	1.98	1.19
Southern California	1.11	1.23	2.17	1.28

For retrofit scenarios, the calculation uses the full cost of the integrated system equipment. RET uses full cost because the customer's equipment is working. Cost of the system is the difference between installing the system and leaving the existing system as is.

For replace on burn out scenarios the TRC are higher because the equipment cost used in the test lower. ROB uses an incremental cost. Since the customer must take some action to replace failed equipment the ROB cost is the difference between the cost of an integrated system and the cost of widget based equipment.

[3] The analysis does not include any potential changes in building codes for future years.

Table 4: TRC values (ROB average)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	1.42	1.35	2.38	1.32
Southern California	1.54	1.48	2.63	1.43

The total economic potential of energy savings (as filtered by a TRC ≥ 1.0) for each utility partner is presented in Table 5 (RET) and Table 6 (ROB).

Table 5: Economic Potential for RET (GWh savings)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	412	752	883	883
Southern California	479	876	1,028	1,028

Economic potential of zero in these tables means that as defined, these lighting systems are not cost-effective from a utility program perspective. The technical potential to install them still exists, but utilities need to use other criteria to justify including them in an energy efficiency portfolio. See Supporting Information for a discussion of these programs.

Table 6: Economic Potential for ROB (GWh savings)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	412	752	883	883
Southern California	479	876	1,028	1,028

Note: (lower bound / upper bound)

An estimate of program savings can be derived once economic potential is calculated. The lower and upper bound forecast of adoption potential for the RET and ROB scenarios are presented in Table 7 and Table 8. These tables represent the minimum estimated level of savings achievable for a systems based utility programs over a 10-year period.

Table 7: Cumulative Adoption for RET (GWh savings at 10 years)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	98/136	178/250	209/294	209/294
Southern California	113/159	207/291	244/342	244/342

Note: (lower bound / upper bound)

Table 8: Cumulative Adoption for ROB (GWh savings at 10 years)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	7/9	12/17	14/20	14/20
Southern California	8/11	14/19	16/23	16/23

Note: (lower bound / upper bound)

A detailed discussion of study findings are in Chapter 4 of this report.

1.3 Conclusions

The most notable conclusions of this study are:

- Ample technical potential exists to deploy systems-based energy efficiency programs for lighting in commercial office buildings.
- Applications also exist for schools and medical facilities, but factors such as utility cost-effectiveness and customer payback thresholds limit these opportunities.
- Even though the components of these systems exist today and are "off-the-shelf", combining them into a complete system is not common practice.
- To increase uptake of the systems approach, utility programs should consider including an educational component to increase awareness among designers and contractors of lighting systems.
- The system packages in this study had energy savings reduction estimates ranging from 9% to 33% and full systems costs ranging from $1.37 to $7.70 per square foot. Similar to widget-based equipment, the relationship between system costs and the utility benefit from system savings determines economic potential. Across service areas however, differences in utility benefits (due to avoided costs differentials) rather than differences in installed system costs or savings drove the economic potential.

Section 5 of this report provides a more complete discussion of study conclusions and recommendations.

2 INTRODUCTION

2.1 Background and Objectives

With funding from the US Department of Energy (DOE), Lawrence Berkeley National Laboratory (LBNL) is currently leading a "Getting beyond Widgets" research project to advance systems-based energy efficiency measures in US commercial buildings.[4] This effort seeks to expand utility incentive programs beyond the traditional focus on individual "widgets" (i.e., components) in order to unlock deeper energy savings from energy-efficient systems such as lighting measures with advanced controls.

As part of this effort, LBNL engaged DNV GL to estimate the market potential for specific energy-efficient systems selected and defined by LBNL and three utility partners:

California Publicly Owned Utilities (CA POUs) though out the state
Commonwealth Edison in Illinois (ComEd)
Xcel Energy in Minnesota and Colorado (Xcel)

Table 9 shows the market segments and system packages selected for each utility partner.

Table 9. Study targets

Market	Segment	System Packages
CA POUs	Offices	Package 1. Plug-and-play overhead lighting and automated plug load control system Package 2. Overhead lighting and / or networked controls changeout and automated plug load control system
ComEd	Offices and Schools	Package 1. Automated shading (roller) with integrated lighting controls
Xcel	Offices	Package 1. Zonal HVAC controls with lighting upgrade and integrated zone-level daylighting and lighting controls Package 2. Integrated, enterprise-level networked lighting and lighting controls, daylight redirecting film, and HVAC controls

The objective of this study is to identify which market segments (e.g., offices, schools) and sub-segments (e.g., large offices owned by the tenant) provide the greatest potential for cost-effective energy savings from the specific systems. This information will help LBNL gain a better understanding to target systems-based programs to market segments and sub-segments.

2.2 Study Approach

To develop the market profile for these systems DNV GL conducted the following tasks as part of this study:

1. **Segment the market.** Starting with the applicable data set(s) for each utility partner (e.g., data on all Xcel Office customers), we further divided the data into sub-segments based on factors such as building

[4] See https://cbs.lbl.gov/getting-beyond-widgets-enabling-utility-incentive

size (small or large), vintage (new or old), and ownership (owned or leased). See Section 3.1 for a discussion of the methods and assumptions used in this task.

2. **Estimate the market size.** To determine the market size, we calculated the technical and economic potential for the selected systems in the applicable market segments. In this study, “technical potential” is defined as the total square footage available to install each system, and “economic potential” is defined as the amount of technically feasible square footage for which a system is economically viable from the utility’s perspective. See Section 3.2 for a discussion of the methods and assumptions used in this task; see Section 4.1 for related findings.
3. **Conduct expert interviews**. We conducted market actor interviews to further understand the target markets and assess adoption for each market segment and sub-segment. See Section 3.2 for a discussion of the methods and assumptions used in this task; see Section 4.4 for related findings.
4. **Assess the adoption (achievable) potential.** Using the results of the economic potential analysis and “adoption curves” developed with input from the expert interviews, we estimated the percent of square footage in each market segment and sub-segment likely to adopt the selected systems over a 10-year timeframe. See Section 3.2.3 for a discussion of the methods and assumptions used in this task.
5. **Prioritize the market segments.** We ranked the market segments according to their “adoption potential” and other criteria developed from the expert interviews.

A summary of study findings and recommendations is provided in Section 5, Conclusions and Recommendations. The appendices of this report include tables of findings for technical potential, economic potential, and estimated achievable potential for these systems over time under different pricing scenarios.

3 METHODS AND ASSUMPTIONS

This chapter discusses the methods and assumptions we used to:

Segment the market
Estimate technical, economic, and achievable potential for each system
Conduct the expert interviews

3.1 Market Segmentation

3.1.1 Criteria for Market Segmentation

To develop the savings potential analysis, we disaggregated the utility partners' target markets into sub-segments using the following criteria:

Building type: As defined by the utility partners
Size: Small or large is defined differently for each utility partner:

- CA POUs: the CA POUs selected one building type: offices. Offices were defined as small or large based on building square footage. Offices occupying less than 50,000 square feet were classified as small, and offices occupying 50,000 square feet or more were classified as large. This is consistent with the square footage classifications used in the California Commercial End-Use Survey (CEUS).

Ownership type: Own vs. rent
Vintage: old vs. new Vintage is defined differently for each area:

- For California we used 1978, the year Title 24 came into effect, as the delineation between old and new buildings.

Existing system configuration: multiple packages based on systems described in Table 9.
Climate and geography:

- CA POUs: We segmented California into two regions: north and south. The systems included in the study are not weather sensitive and are applicable throughout the state.

Finally, lighting systems in this study were not weather sensitive.

3.1.2 Data Sources for Market Segmentation

DNV GL segmented the data in the manner described above using three sources of data: site-level information from the utility partners, site-level information from the CoreLogic database, and micro-data from the US Energy Information Administration's 2012 Commercial Buildings Energy Consumption Survey (CBECS). A description of these data sources and their applications in this study begin in the next section.

3.1.2.1 Site-Level Information – LBNL Utility Partners

DNV GL used the following data sources to segment each of LBNL's utility partner markets:

California POUs

- The California Public Utilities Commission recently sponsored a Commercial Saturation Survey (CSS) that collected building characteristics and energy equipment data from nearly 8,000 phone surveys and 1,400 site visits of non-residential customers. These data, collected from the investor-owned utility (IOU) service territories, populate a comprehensive database that can support numerous analyses needed for the market segmentation task. As the IOU and POU territories are often adjacent (or overlapping in the case of gas), we used this data source in the current analysis to support the development of saturation estimates.

- The CA POUs and LBNL staff provided the base system energy-use intensities (EUIs) and system savings.
- The California CEUS developed estimates of square footage and EUIs for various market segments in California. This data provided a crosscheck the data purchased from CoreLogic, discussed in section 3.1.2.2 below.
- LBNL provided information on the distribution of energy consumption, by building type, for each California POU (except for Los Angeles Department of Water and Power).
- The Northern California Power Agency provided detailed information on the commercial customers served by its member utilities. Although this was not a direct input into the model, this information provided us with a better understanding of commercial customers within the POU territories, and it and was used to cross-check other data used in the analysis.

3.1.2.2 Site-Level Information – CoreLogic

The key to DNV GL's market segmentation approach was to start with a data source that could provide site-level information on the required segmentation variables: building type, size in square feet, occupancy type, and building vintage. This information, often not tracked in utility billing data systems, and the resulting sample sizes from saturation studies often do not lend themselves to further market segmentation beyond building type.

As such, we started our analysis for each utility partner using data collected and developed by CoreLogic, a company that maintains a comprehensive database of property and related financial information.[5] This database provided building square footage by ZIP code and contained fields for vintage, and limited ownership information for all identified building types. We used this information to segment the market as requested for each utility partner, and to allocate total square footage to each sub-segment.

One caveat to using the information provided by CoreLogic for market segmentation is that data quality varies from state to state and county to county. While data requested for California buildings were available with an "office" building type identifier, several counties in other states only differentiated between "Commercial," "Industrial," and "Residential" buildings. Additionally, ownership information was limited to a degree that prevented any meaningful segmentation by that category using the CoreLogic data. For these reasons, we supplemented CoreLogic with the 2012 CBECS micro-data, described below.

3.1.2.3 2012 CBECS Data

The US Energy Information Administration recently released micro-data associated with the 2012 CBECS survey. This data contains records about individual commercial buildings from all 50 states, broken into census divisions. With these data we generated segments by geographic region, principal building activity, square footage, and vintage. We used the more detailed building-level information (e.g., average ceiling height, window to wall ratio, heating and cooling delivery

[5] http://www.corelogic.com

systems, and presence of a building automation system) to cross-check the regional-level market segmentation developed using the CoreLogic and CSS/CEUS data.

3.1.3 Developing Square Footage and Consumption by Sub-Segment

One of the primary steps in the market segmentation process was developing total square footage and site numbers by building type, size category, ownership category, vintage category, and geographic/climate area for each of the key market segments defined above. Our initial attempt to calculate these numbers was based on the CoreLogic data acquired for relevant utility territories in California, Colorado, Illinois, and Minnesota; however, this data did not provide all necessary information, requiring integrating the CBECS 2012 micro-data. We used the CBECS to address three specific problems with the CoreLogic data:

- Missing ownership category
- Counties where buildings were categorized as "Commercial", instead of having a more detailed "Office" designation. This was an issue for Colorado, Illinois and Minnesota, but not for California
- Counties where a large number of buildings had square footage listed as zero

To address the first problem, we calculated the percentage of buildings owned versus rented for each market segment based on the census division containing the relevant state. We then applied these percentages to the site number and square footage values taken from the CoreLogic data.

To address the second two problems, we took the following steps:

1. We calculated average and median CoreLogic building square footage numbers by the market segmentation categories.
2. Where missing square footage, we used the CBECS data to estimate the percentage of missing buildings that should be large or small within each market segmentation category.
3. We imputed square footage for the buildings missing square footage based on the median square footage for each of the non-missing segmentation categories
4. Where county data identified buildings as "Commercial" instead of "Office," we used CBECS to estimate and allocate the percentage of "Commercial" square feet assigned to office buildings.

After allocating the sites by market segment, we then aggregated this site-level information in order to calculate square footage by market segment.

LBNL provided energy consumption information for each base system under review. DNV GL reviewed these data against CEUS and other studies of savings potential information we have developed to ensure the saturation and savings information used for this analysis was reasonable.

The systems that are the subject of this analysis are described in detail in 0.

3.2 Estimating the Technical, Economic, and Achievable Potential

To assess the achievable potential associated with system-level energy efficiency installations, DNV GL started by using a similar approach for estimating the technical and economic energy savings potential for stand-alone equipment.

However, because we consider system-level approaches as conceptual or emerging technologies, determining final achievable potential was more involved than conducting benefit/cost ratios and payback calculations. The final achievable potential developed for these systems were from data collected from interviews of subject matter experts.

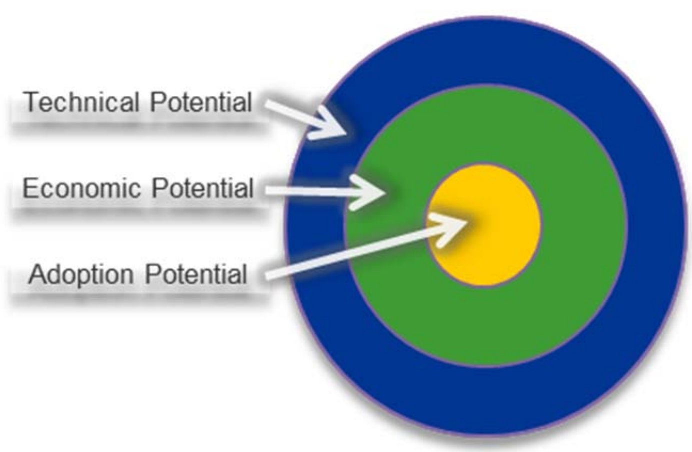
For technical and economic savings potential for each market segment and system, DNV GL used a bottom-up approach to processing building level data through our energy efficiency potential model, DSM Assyst. The analysis started with building data from CoreLogic for the targeted areas. We crosschecked these data against other publicly available data sets on commercial buildings, as described above. To determine the level of reasonableness for all regions of CoreLogic data, we analyzed the CBECS published by the US Energy Information Administration. For California we reviewed the Commercial CEUS developed by the California Energy Commission and the CSS developed by the California Public Utilities Commission.

Table 10 summarizes the types of potential we estimated, the source for each, and an overview of the relationship between these categories of potential. An illustration of this approach is in Figure 1.

Table 10. Sequence of potential categories

Category		Definition	Source
1	Technical potential	The complete penetration of all measure applications deemed technically feasible from an engineering perspective	DSM Assyst Modeling analysis
2	Economic potential	The technical potential of those energy conservation measures that are cost-effective when compared to supply-side alternatives	DSM Assyst Modeling analysis
3	Adoption potential	The amount of economic potential that could be achieved based on customers' likelihood to adopt the systems in response to specific marketing approaches and incentive levels.	Based on economic potential and results of expert interviews to determine adoption potential by system and market segment

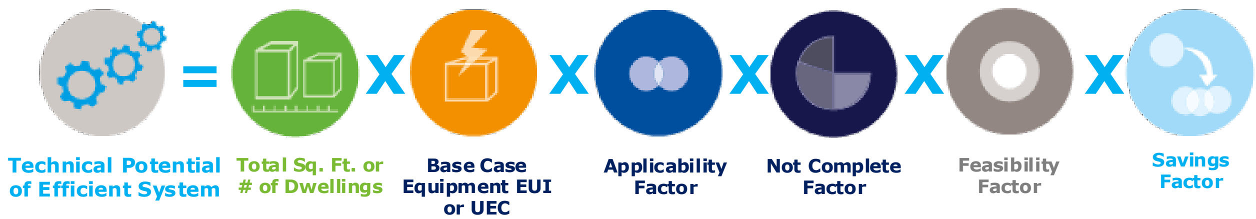
Figure 1. Relationship between economic, technical, and adoption potential



3.2.1 Technical Potential

As noted in Table 10, the analysis begins by estimating technical potential. Figure 2 shows a representation of the equation we used to estimate the technical potential for energy savings of the systems and market segments targeted in this study. Technical potential for peak demand reduction was calculated in a similar manner. Note that all elements of the equation are developed from inputs developed using the bottom-up data.

Figure 2. Technical potential estimation equation



Total square feet represent the total floor space for all buildings in the customer class.

Base-case equipment EUI (energy use intensity) or UEC (unit energy consumption) is the energy used per square foot by each base-case technology in each customer class. It is the energy consumption of the equipment being replaced, or affected by, the efficient technology.

Applicability factor is the fraction of the floor space that is applicable for the efficient technology in a given customer class.

Not complete factor is the fraction of applicable floor space not yet converted to the efficient measure. That is, one minus the fraction of floor space that already has the EE system installed.

Feasibility factor is the fraction of the applicable floor space that is technically feasible for conversion to the efficient technology from an engineering perspective.

Savings factor is the percent reduction in energy consumption resulting from application of the efficient technology. We utilize the percent savings applied to base energy use to ensure our savings estimates are correctly proportional to load.

3.2.2 Economic Potential

DNV GL estimated economic potential by identifying which measures and market segment combinations are cost effective. Cost effectiveness of energy efficiency projects is evaluated several ways. Customers evaluate investments in any capital equipment using simple or discounted payback calculations. Utilities evaluate potential programs based on their ability to generate positive values on four tests. These tests are:

Total resource cost (TRC): This compares the present value of avoided generation, transmission, and distribution against the present value costs to administer the program (excluding incentives) and the cost of the installed equipment. Equipment cost can be full or incremental to a baseline depending on the application (e.g., if the new equipment or system is replacing an active system (retrofit) or one that has failed (replace-on-burnout)).

Program administrator cost (PAC): This compares the present value of avoided generation, transmission, and distribution against the present value costs to administer the program, *including incentives*.

Participant cost (PC): This is the cost to the participant from participation in the program. Benefits are discounted bill savings and any rebates or other financial incentives. Costs are all related out of pocket expenses (equipment, disposal, additional operations and maintenance, any additional fuel costs, and customer time with program administration, if significant). This ratio very closely relates to discounted payback years.

Ratepayer impact measure (RIM): Expressed as a ratio, the RIM reflects the direction rates will change (via changes in utility revenues) due to the program. A RIM greater than 1.0 indicates that rates will go down because new utility revenues are greater than utility costs. In practical terms this ratio is net-present-value utility avoided costs divided by the sum of net-present-value customer bill savings, utility administrative costs, and utility incentives paid out.

Each utility assigns different levels of importance to these tests, but all start with the TRC. As a result, DNV GL used the TRC test to determine economic potential in the model. In other words, energy efficiency measures are cost-effective if they meet the minimum threshold set by the utility (e.g., a TRC greater than or equal to 1.0).

Using TRC as the threshold, we were able to estimate the square footage that provide the greatest potential for total savings and is cost-effective by program administrators. We use TRC instead of payback for one main reason: for utilities to claim savings for their efforts, they must demonstrate the degree to which they influenced the customer adoption decision and show that all customers benefit from the transfer of ratepayer funds to a few customers. A TRC greater than 1.0 is the first condition that needs to be satisfied. In contrast, if a project is deemed cost effective using payback measures, in theory the customer should elect to do this without intervention from a utility program. Any savings achieved by the utility might be deemed from free riders by regulators and the savings from these utility programs credit denied.

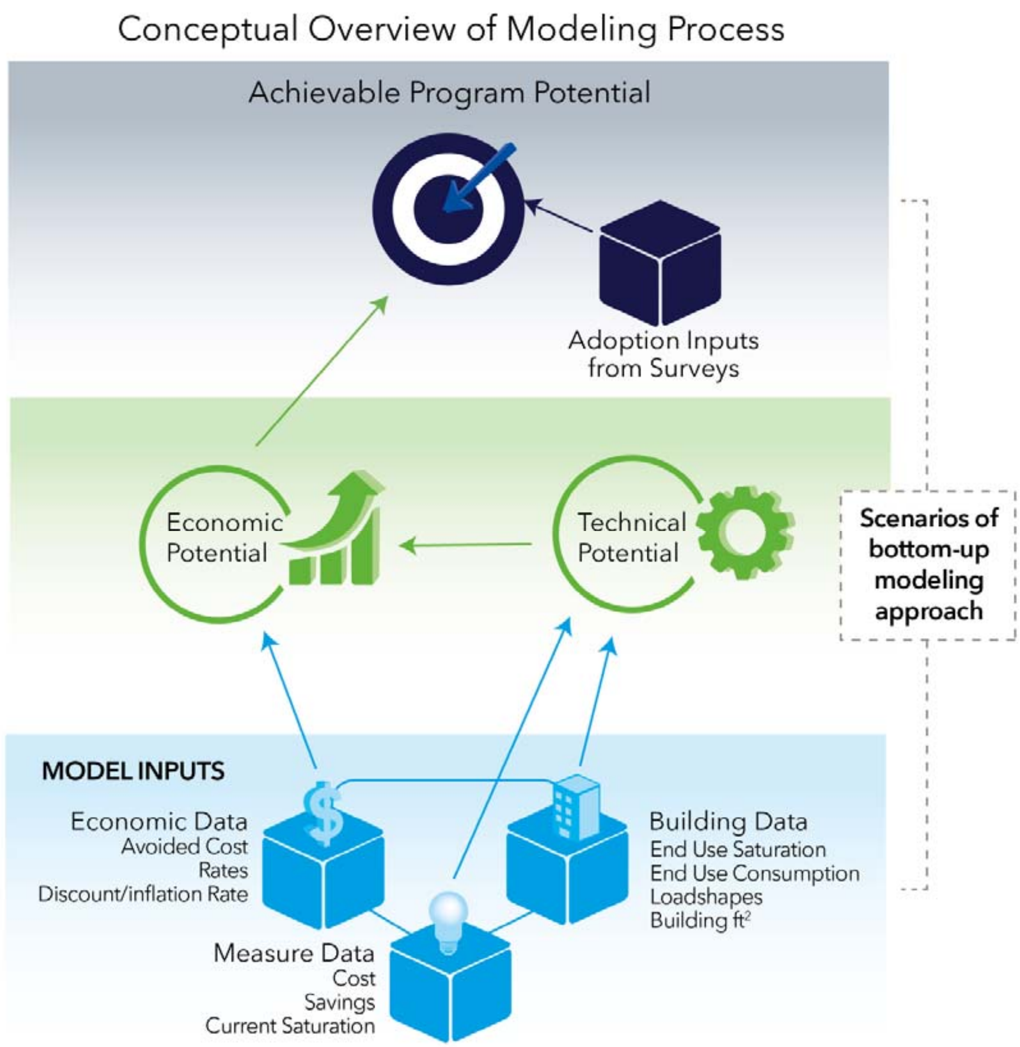
3.2.3 Achievable Potential

While the DSM Assyst model has a measure penetration module, the penetration curves in that module calibrate mainly to widget-based measures. Recalibration for system measures was not feasible due to data limitations. To compensate for this, DNV GL developed a penetration/adoption analysis that relied on expert judgment.

To develop adoption rates that vary by market segment and by program aggressiveness assumptions we used information developed from expert interviews. Programs can be used to increase customer awareness and the economic feasibility of the targeted systems two ways. They can fund awareness/education campaigns. They provide financial incentives for installations. They can do both simultaneously.

We applied the interview-derived adoption rates to the estimated economic potential to provide estimates of kW and kWh achievable potential expected under various intervention scenarios. Figure 3 provides a graphical representation of the modeling process.

Figure 3. Achievable potential overview



3.3 Interviews with Subject Matter Experts

DNV GL conducted two sets of interviews with subject matter experts to understand issues surrounding the adoption of energy-saving systems rather than individual components. As noted earlier, this information supported development of adoption curves for system-based measures; it also provided qualitative information about market opportunities and threats.

The first round of interviews included internal DNV GL experts from across the US who work with commercial customers and design lighting systems as part of program implementation. The second round targeted external experts on lighting system technologies. This included representatives from 13 market actor organizations: seven manufacturers/vendors, four solution providers, one architectural firm, and one market transformation organization. A listing of all interviewees is in 0. The interview guide is in 0.

Among the internal experts, there was no experience-based awareness of the specific systems described in the prep document. All were aware of the system concepts and had specific knowledge of advanced control systems for one end use only. For this reason, we changed the presentation of our question topic to “integrated control systems” and defined these as systems that control more than one end use with some degree of automation.

The in-depth interviews covered the following topics:

Respondent perspective: The role of the respondent, their experience in relevant fields, and their organization’s position in the marketplace were used to gauge the reliability and accuracy of their opinions.
Current status of system approaches: Respondent estimates of the existing level of awareness of system approaches, their benefits, their penetration into the marketplace, and of programs promoting them were used to determine the baseline market acceptance and to inform the analysis of barriers and opportunities.
Benefits of Systems: Promoting energy efficiency solely for its own sake has proven limiting over time. System approaches are likely to provide benefits beyond energy savings that can inform program design, especially in terms of marketing and targeting promotion efforts.
Barriers and opportunities: A thorough understanding of the barriers to adoption facing market actors is essential for estimating the adoption potential over time and for the development of effective programs that support these systems.
Numerical estimate of adoption using three simple payback scenarios (two, five, and ten years): These estimates were the basis for the development of the numerical adoption curves used to estimate the adoption potential of system approaches.
Segmentation: The experience of the respondent pool promoting or selling these systems to their clients offered insight into the market sectors most and least likely to adopt them.

The project team developed the interview guide and administered it to the internal DNV GL expert pool. Interim results of this round of interviews were presented to LBNL for discussion. The guide was revised based on findings and refined direction from LBNL. The second round of interviews captured a range of market actors, primarily in the field of advanced lighting controls. A single DNV GL senior consultant administered these interviews. Interview duration ranged from 30 minutes to roughly 90 minutes, depending on the respondent’s level of interest, knowledge, and involvement in the subject matter. The interview guide was adapted in real-time to respect respondent availability limitations and to reduce redundancy once clear trends developed for topics other than the core adoption questions.

3.3.1 Sample

The first round sample was pre-selected based on knowledge of DNV GL’s organizational capability. We developed the second round sample using input from DNV GL staff and by on-line searches for additional vendors and manufacturers based on search terms such as “advanced lighting control,” “building automation systems,” and “energy management systems.” In most cases, the survey respondents were discovered through a series of screening calls to the identified organization. Overall, we contacted thirty-eight individuals by telephone and/or electronic mail. Thirteen agreed to participate, for a response rate of approximately 34%.

3.3.2 Analysis

After the completion of the first round interviews, the DNV GL team performed a preliminary analysis and submitted the interim findings to LBNL for review.[6] We performed a second round of analysis after the completion of the second round interviews. This analysis consolidated the finding from both rounds of interviews. An overview of the processes for developing adoption curves and for analyzing, the qualitative responses, including TRC values are in the following sections.

The interview collected data points for hypothetical program years 2, 5, and 10 under three different scenarios of program effort, represented by simple project payback times of less than 1 year, less than 2 years but more than 1 year, and more than 2 years. Respondents were asked to consider the "eligible market" defined as that portion of the building stock that would undertake significant retrofits or renovations during a program year. It became clear from the responses however, that some respondents used the entire building stock as the reference point instead of the eligible market. Rather than attempting to calibrate the respondent during the interview, the DNV GL team decided to normalize the data as a separate step. The team normalized the data to both the unweighted average value (lower bound) and the analyst's estimate (upper bound based on expert opinion) of the 10-year adoption potential for the eligible market. The point estimates at years 2, 5, and 10 became the reference points to develop annual estimates that roughly mirrored the S-shaped diffusion curves used to model market penetration of typical utility energy efficiency programs that offer financial incentives.

We aggregated Responses to qualitative questions, such as the respondents' perspectives on barriers to adoption, by question and topic area and synthesized these into succinct findings. We reviewed the synthesized findings across question and topic area to check for consistency, and to identify trends in respondent answers. As the final step in the analysis for these factors, the DNV GL team distilled the salient points by topic; this information is in Section 4.4.

[6] Submitted on 8/28/15 as "FirstRoundSummary150827.docx"

4 FINDINGS

4.1 Estimated Market Size

DNV GL determined the market size for the selected systems by estimating square feet. The technical and economic potential are reported in terms of energy savings, as described in Section 3.2. This section presents the findings from the analysis. Finally, all savings are reported in kWh for consistency.[7]

4.1.1 Technical Potential

Technical potential is the total savings possible from installation of these systems. The calculation of technical potential begins by identifying the total square feet available to install these systems. This step reduces total existing square feet by the area where the system is feasible and not installed already. For this analysis, we set feasibility and availability to 100%. We did not reduce available total square footage for two reasons. First, the target area was pre-selected for its feasibility. Second, we consider these systems as emerging and rarely present in the target markets.

The total square footage for these systems that is considered applicable, feasible, and not already installed for large and small facilities is reported in Table 11. 0 provides greater detail on the square feet of sub-segments.

Table 11. Total Square Feet Physically Available by Segment

State	Region	Building Type	Building Size	Square Feet
California	North	Office	Large	115,482,555
California	North	Office	Small	57,724,036
California	South	Office	Large	138,073,257
California	South	Office	Small	63,512,746

Figure 4 presents the technical energy potential in kWh across regions for the different system packages. Technical potential for kW savings is presented in Figure 5. An important caveat is that these savings estimates are not additive. The model assumes the installation of only one system (Package 1 or Package 2) across all the available square footage in each segment. In reality, a combination of these two systems is more likely. In addition, the kWh and kW potential presented in these charts applies to both the replace-on-burnout (ROB) and retrofit early-retirement (RET) scenarios.

[7] 1.0 million kWh is equal to 1.0 GWh.

Figure 4: Technical potential in kWh

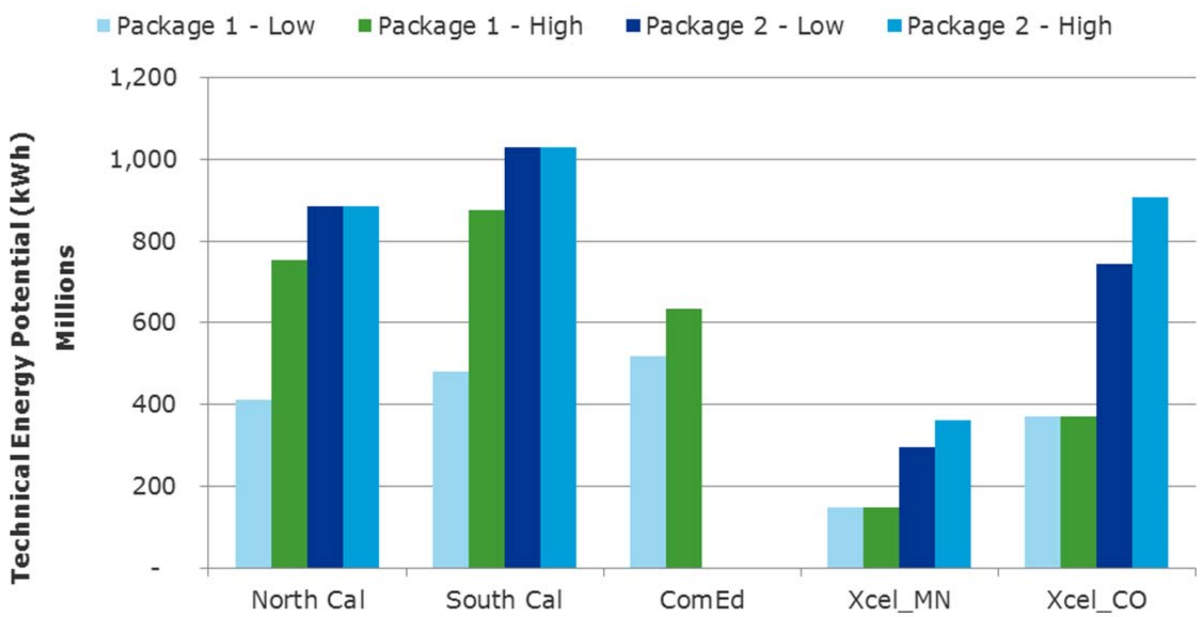
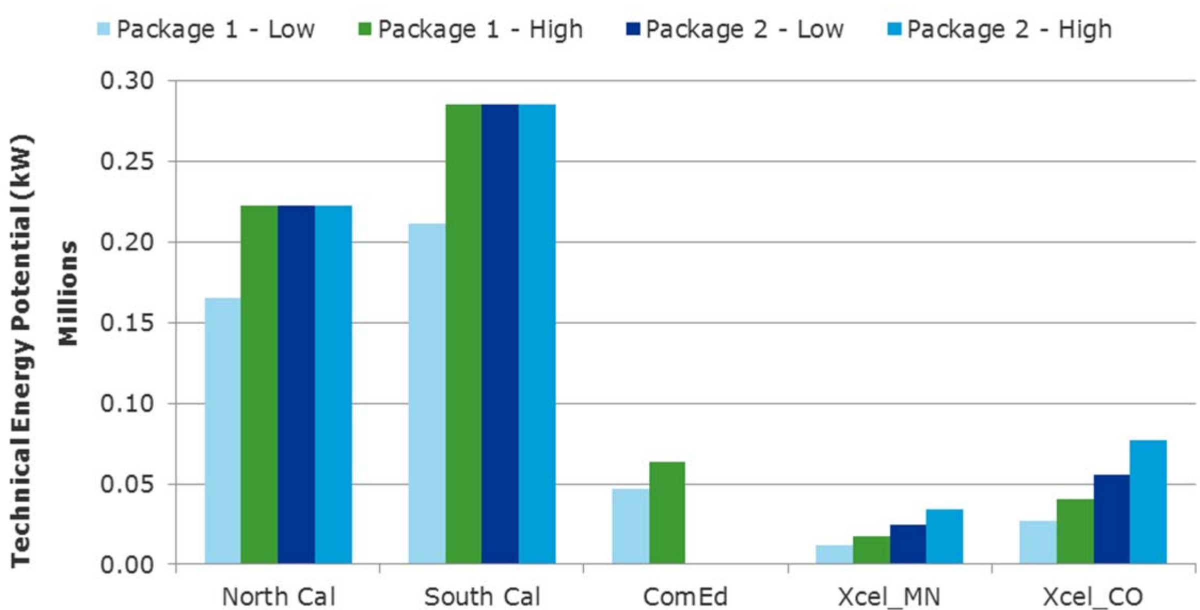


Figure 5: Technical potential in kW



The square feet available remain the same in each region and for each package. The potential kWh and kW savings represent the range of savings associated with each package. For example Package 2 for California provides the same energy savings but at two different costs. The result is that the Package 2 (High and Low cost) savings potential is the same.

As noted earlier, a critical interpretation of this savings potential graph is that Package 1 and Package 2 are not additive. Each package applies to the same physical square feet. Another way to interpret this is that Package 2 - High represents the maximum technical savings potential and Package 1 - Low represents the minimum technical savings potential for these systems.

4.1.2 Economic Potential

DNV GL estimated the amount of square footage that is economically viable from the utility's perspective using the TRC discussed earlier. When TRC for an integrated lighting system was greater than or equal to 1.0 the applicable square footage became part of the economic potential. Since market segments were narrowly defined and there are no competing technologies as part of this analysis, if a system was economically viable the economic potential was equal to the technical potential.

In both the RET and ROB scenarios economic potential is from the perspective of the utility. A system is considered cost-effective if the TRC ratio is greater than or equal to 1.0. In utility service areas with TRC threshold requirements at the resource program portfolio level (rather than equipment level) a low TRC, by itself, does not preclude inclusion into the utility EE portfolio. Similarly, the utility may offer a program to "jump start" market adoption with a goal of transforming how integrated systems are marketed and priced. For these instances, exceeding a TRC threshold may not be necessary. For the most part TRC values remain the prime criterion for by which regulators judge utility programs. The TRC values for determining the economic potential of systems in RET and ROB applications are reported in Table 3 and Table 4.

Table 12: TRC values (RET average)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	1.04	1.13	1.98	1.19
Southern California	1.11	1.23	2.17	1.28

Table 13: TRC values (ROB average)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	1.42	1.35	2.38	1.32
Southern California	1.54	1.48	2.63	1.43

When we defined Economic Potential in section 3.2.2 the definition of TRC included the costs to administer the program. For this analysis, we included a program administration cost of 10 cents per kWh.[8] This cost is a DNV GL estimate of typical program costs across the country and was held constant across all utility partners. We included an estimate of program cost to provide a more inclusive cost effectiveness value. Actual utility administrative costs for a systems based program will vary. Without streamlined assessment tools to target buildings, more efficiently these costs may be greater than widget based programs due to the complex nature of selling and incentivizing systems compared to widgets.

[8] This value can be adjusted in the Excel workbook model.

4.1.2.1 Scenarios

The next step is to identify the amount of whole building square feet where the TRC value is 1.0 or higher and where installation of integrated systems is feasible. To understand the extent and type of opportunity available the TRC calculation uses two costing scenarios. The first scenario is a retrofit situation (RET). The second scenario is a replace on burnout scenario (ROB). We noted earlier that this analysis does not include competing systems. Where TRC is equal to or greater than 1.0, economic square feet are equal to technical square feet.

Table 14. Whole Building Square Feet Available and Considered Cost Effective

State	Region	Building Type	Size	Square Feet - RET	Square Feet - ROB
California	North	Office	Large	115,482,555	115,482,555
California	North	Office	Small	57,724,036	57,724,036
California	South	Office	Large	138,073,257	138,073,257
California	South	Office	Small	63,512,746	63,512,746

Even though the available square feet may be the same, energy savings under each scenario is different. Interestingly, less available square feet does not guarantee less economic potential. A much higher economic potential could exist for ROB than RET due to the lower incremental ROB cost. As a result, the difference in economic potential could be great enough to offset the availability of the square feet.

The amount of cost effective square feet available is shown in Table 14. Economic potential (kWh savings) for RET is shown in Figure 6.The economic potential for ROB is illustrated in Figure 7.

Figure 6 presents the economic energy potential in kWh at the whole building level across segments and different system packages under a RET full cost scenario. The ROB incremental-cost scenario is shown in Figure 7. Again, these savings estimates are not additive. The assumption selection and installation will be for one system package only across all of the available square footage for each segment.

Figure 6: Economic potential kWh (RET)

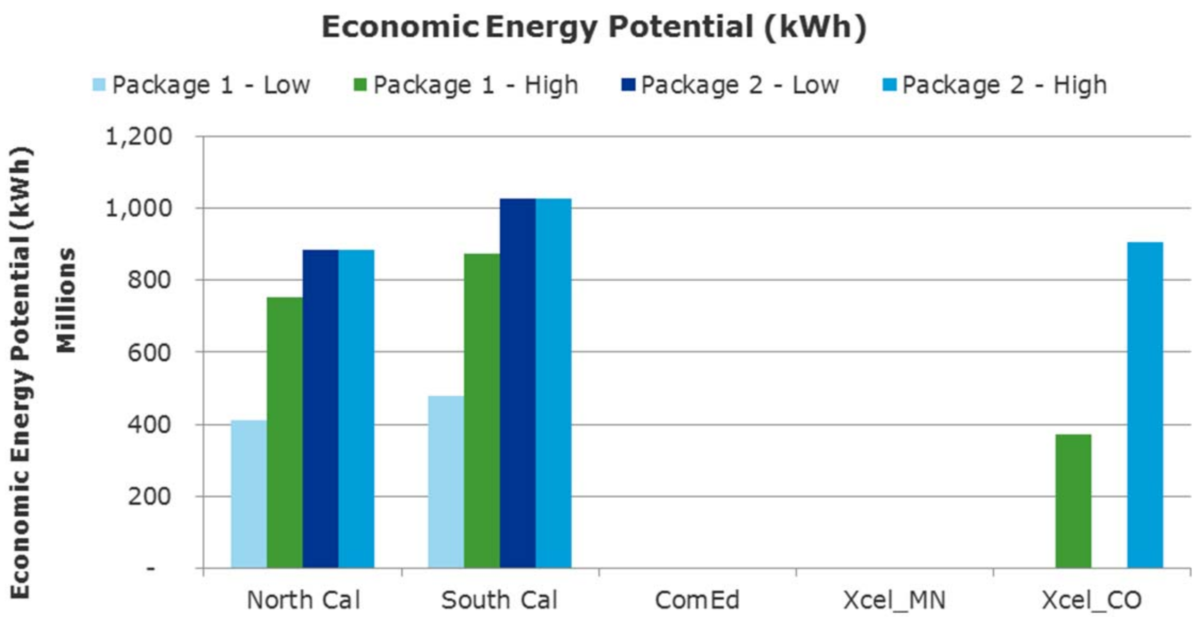
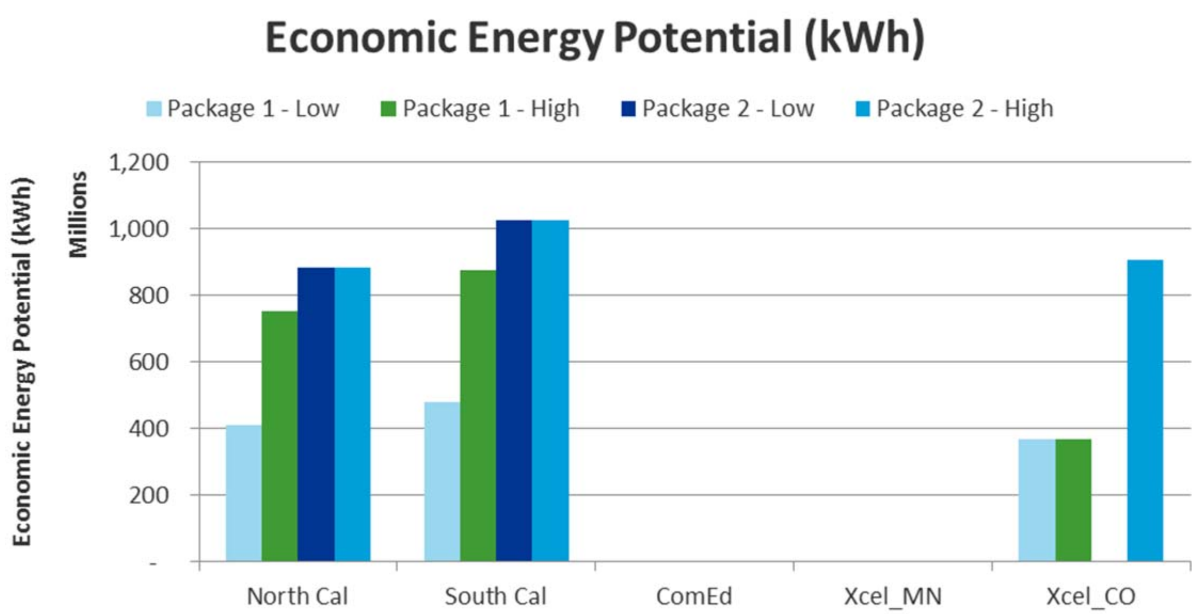


Figure 7: Economic potential kWh (ROB)



For the graphs it is easy to see that in California these systems are considered cost effective for both the RET and ROB scenarios. Similarly, Package 1 and 2 are economically viable for Xcel Colorado, but not Xcel Minnesota. The ComEd package was not cost effective for any segm7ents.

4.2 System Achievable Potential

Once technical and economic potential are identified, the next step to calculating energy savings is determining how much of the economically viable square footage would adopt these systems (vs widgets) and the period this is expected to occur. In this section, we develop the adoption curves and present the savings potential at year 10 of a program.

When estimating achievable potential, RET and ROB scenarios are treated differently. A retrofit application implies the replacement of functioning equipment. All applicable square footage is available each year since a retrofit can be performed at any time. For ROB scenarios, the equipment must fail before initiating a replacement. Failure can occur for any reason, but our assumption is that equipment is at the end of its useful life. In this analysis, we apply the estimated system life of 15 years to develop applicable square footage estimates. The implication is that in these ROB scenarios only 1/15 of the available square footage is available to install an integrated system in any given year.

In this study, we consider the systems as an "emerging technology." As used here, "emerging technology" refers to the fact that systems installations are a new way of approaching building operations and are not a common market practice. As such, there is little or no historical data to incorporate into an estimate of future adoption. To compensate for this lack of market data, criteria and thresholds for adoption were determined through interviews with experienced program implementers, lighting designers, vendors, and manufacturers with familiarity of regional and national markets. Through these interviews, DNV GL generated a set of adoption curves and applied these to the economic potential developed use the DSM Assyst model, as discussed in Section 3.2.3.

4.2.1 Adoption Curves

Adoption curves were generated using responses collected in interviews with subject matter experts. Table 15 and Table 16 show market adoption of systems under different customer simple payback scenarios. Since this estimated curve is from interviews, we provide the upper and lower bounds. A key observation is that when payback is two years or more, customer adoption drops off dramatically, reaching somewhere between 13% and 20% over a 10-year period where Y1 is the first year of program implementation and Y10 is the tenth year.

Simple payback greater than 2 years is the proxy for any payback greater than 2 years. In our interviews, we also asked respondents for estimates at 5 and 10 years. The consensus was that adoption begins to decrease as payback approaches 2 years and drops significantly for any time greater than 3 years.

Table 15. Cumulative achievable market penetration (upper bound)

Payback	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
≤ 1 yr	1%	4%	7%	10%	15%	20%	25%	31%	37%	43%
≤ 2 yr	1%	2%	4%	7%	10%	14%	18%	23%	28%	33%
> 2 yr	0%	1%	2%	4%	5%	8%	10%	13%	17%	20%

Table 16. Cumulative achievable market penetration (lower bound)

Payback	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
≤ 1 yr	1%	3%	5%	7%	10%	14%	18%	22%	26%	30%
≤ 2 yr	1%	2%	3%	5%	7%	10%	13%	16%	20%	24%
> 2 yr	0%	1%	1%	2%	4%	5%	7%	9%	11%	13%

4.3 Energy Savings Achievable Potential

Energy savings is calculated by multiplying the energy saved per square foot for each system by the square feet of interest. For example, calculating the energy savings possible from the technical potential provides an upper possible bound of potential savings, but does not necessarily provide a realistic estimate of the savings that will be achieved by a utility program or even market forces. Similarly, economic potential provides an estimate of total savings considered economically viable, but does not provide information on what is likely to be achieved.

There are no historical data to calibrate the adoption of these systems to utility programs or market activity. The systems by themselves (with no utility incentives) have a simple payback ranging from a low of 5.4 years in to a high of 22 years under a RET scenario. This range is driven by the combination of estimated bill saving and the installed equipment cost. DNV GL estimated cumulative potential annual energy savings for each system package using the middle payback estimate of greater than 1 year, but less than or equal to a two-year payback scenario. We chose the customer's simple payback instead of discounted payback as the criteria for adoption. We understand that customers that are more sophisticated or those contemplating projects requiring large capital amounts may use discounted payback as adoption criteria. Simple payback however is a common metric used by most businesses to screen and adopt capital expenditures. It also represents a more conservative view of payback and therefore will not overstate system adoption. We applied there adoption factors to the economic potential developed in the prior step.

This analysis includes multiple combinations of system savings and cost estimates (high/low), building size (small/large), vintage (old/new), ownership (rent/own) and situation (RET/ROB). DNV GL ran each of these scenarios through its DSM Assyst model. To allow LBNL to develop customized scenarios we developed an interactive scenario tool for use in future analysis[9].

In this report, we walk through two sets of output from this tool. Although we forecast savings under RET and ROB scenarios using three simple payback periods, the results reported here are from the middle period (≤ 2 years) where payback is greater than 1 year and less than or equal to 2 years. In other words, this assumes that through a combination of decreasing costs of integrated systems and utility rebates the customer's simple payback is about 2 years. The RET scenario is presented first and is followed by the ROB scenario.

4.3.1 RET

A retrofit application implies the replacement of functioning equipment. Each successive adoption year shows the cumulative total savings for that year (i.e. in year two, total adoption includes

[9] The DNV GL Potential Studies Evaluation Tool is a Microsoft Excel workbook

installed square feet from year 1 plus installed square feet from year 2). This section provides the 10-year cumulative lower achievable bound (LAB) and upper achievable bound (UAB) energy savings for each package reviewed for each utility partner. Where systems are cost effective across service territories the cumulative savings are more a function of available square feet than differences in markets at the regional level.

Achievable potential in all office buildings for Northern and Southern California is shown in Figure 8 and Figure 9 respectively. The savings for both configurations of Package 2 are the same because the high and low packages differ by cost and not by savings per square foot.

Figure 8: Northern California office RET lower and upper achievable kWh

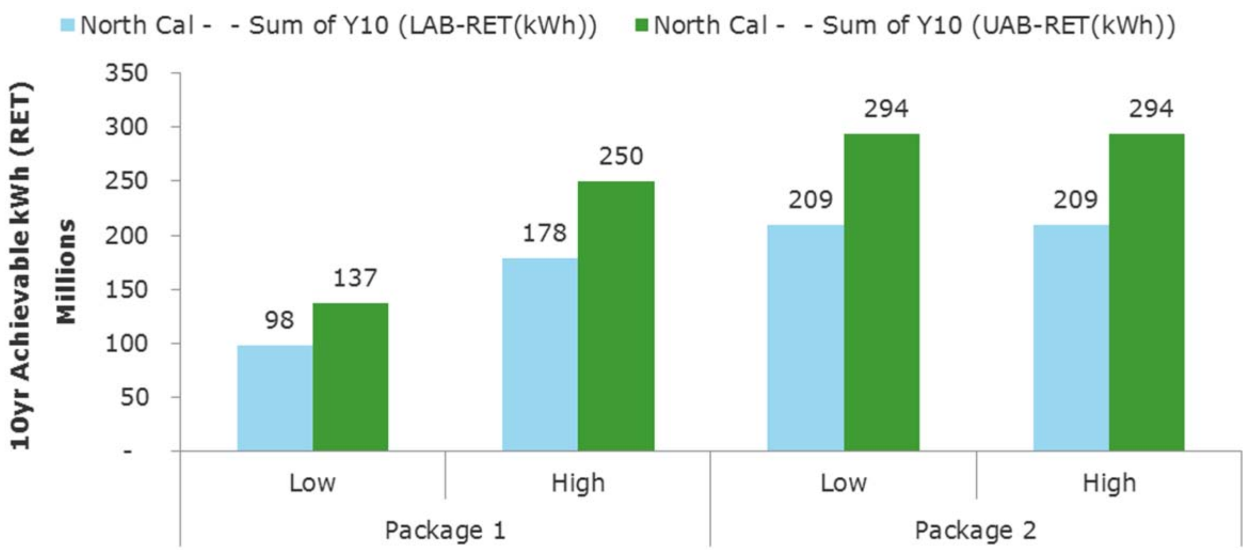
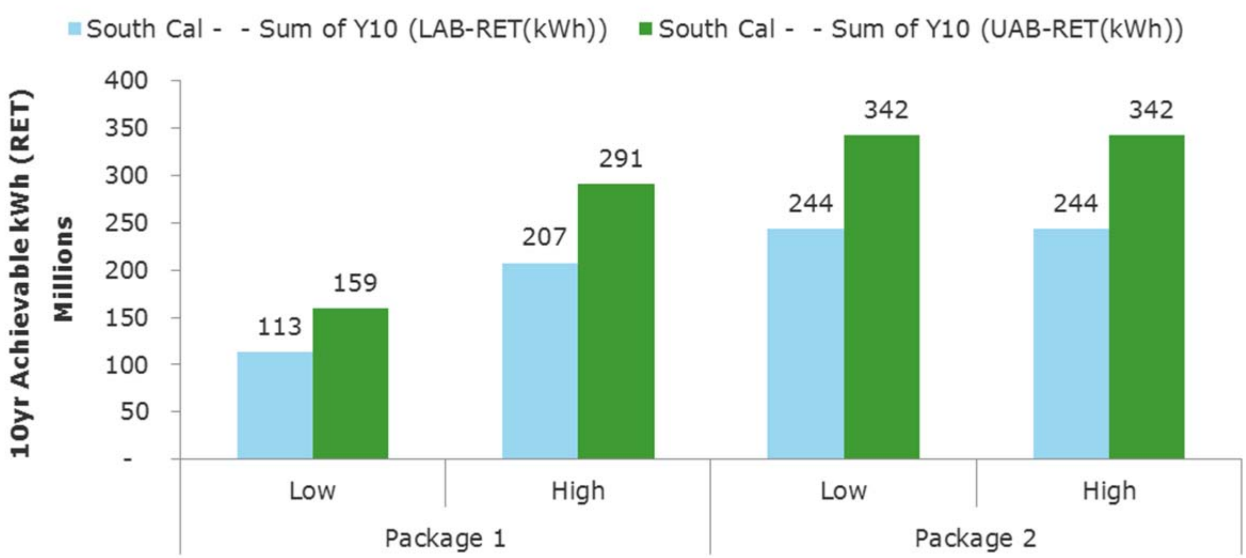


Figure 9: Southern California office RET lower and upper achievable kWh



Graphs of the adoption curves for Northern and Southern California are presented in Figure 10 and Figure 11.

Figure 10: Adoption curves for Northern California (kWh RET)

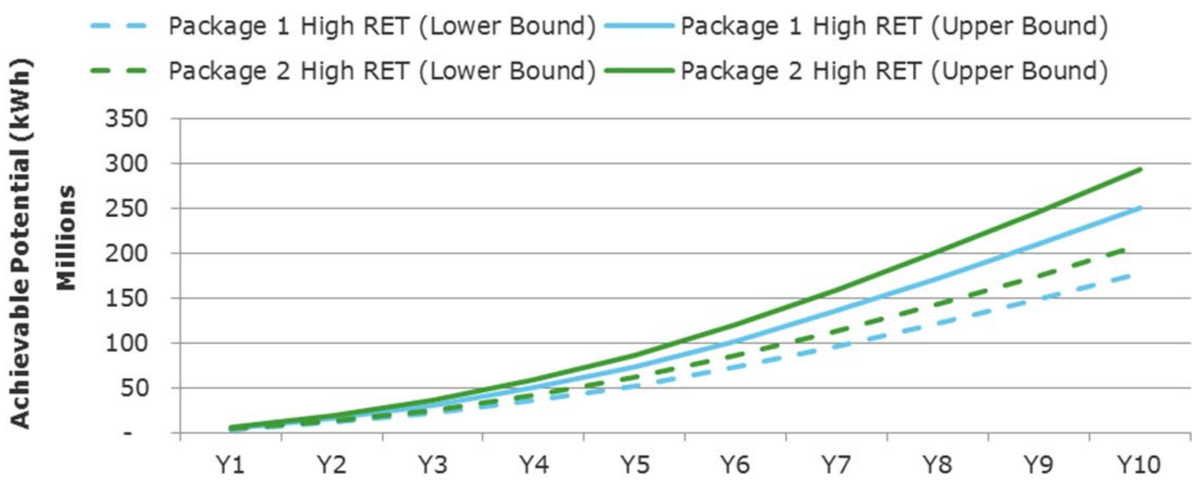
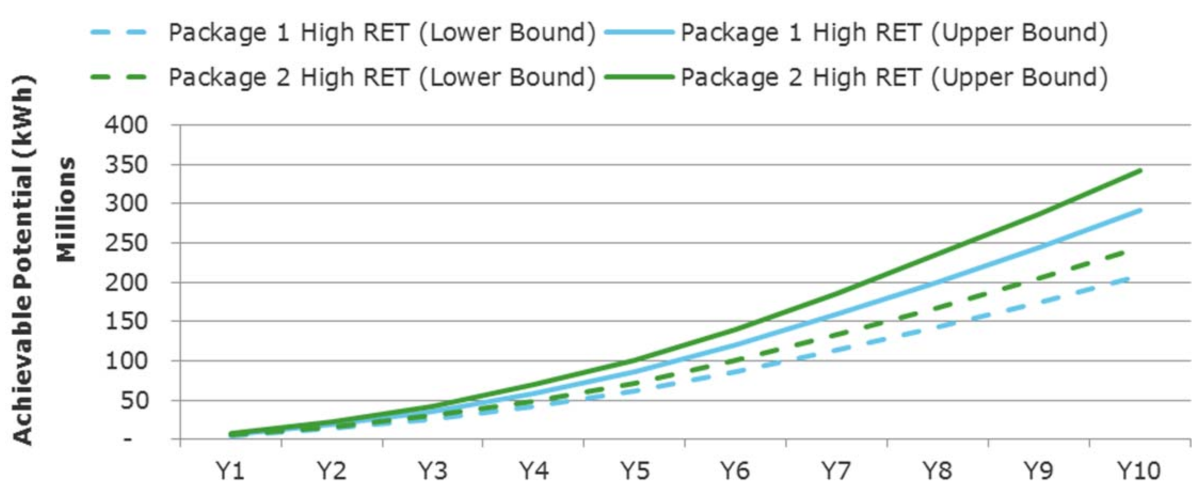


Figure 11: Adoption curves for Southern California (kWh RET)



One interesting point shown in these graphs is that the potential exists for Package 1 (at the upper achievable bound) to save more energy than Package 2 (at the lower achievable bound).

4.3.2 ROB

Energy savings potential under a ROB scenario is always lower than a retrofit scenario due to the availability of applicable square footage. For ROB, the equipment must fail before initiating replacement. Failure can be for any reason, but for purposes of forecasting the assumption is that equipment is at the end of its useful life. In this analysis we apply an estimated life for the base widgets of 15 years and use this to develop the applicable square footage estimates by year. The implication is that in these ROB scenarios only 1/15 of the available square footage comes available to install an integrated system in any given year. The reported savings represent the cumulative savings for a particular year.

While there may be less square footage available in any given year, ROB scenarios typically have higher TRC values than RET scenarios because with ROB only the incremental cost of the system over a base widget is factored into the TRC test. In RET scenarios use the full cost of the equipment because there is no requirement to install replacement equipment.

Figure 12: Northern California office ROB lower and upper achievable kWh

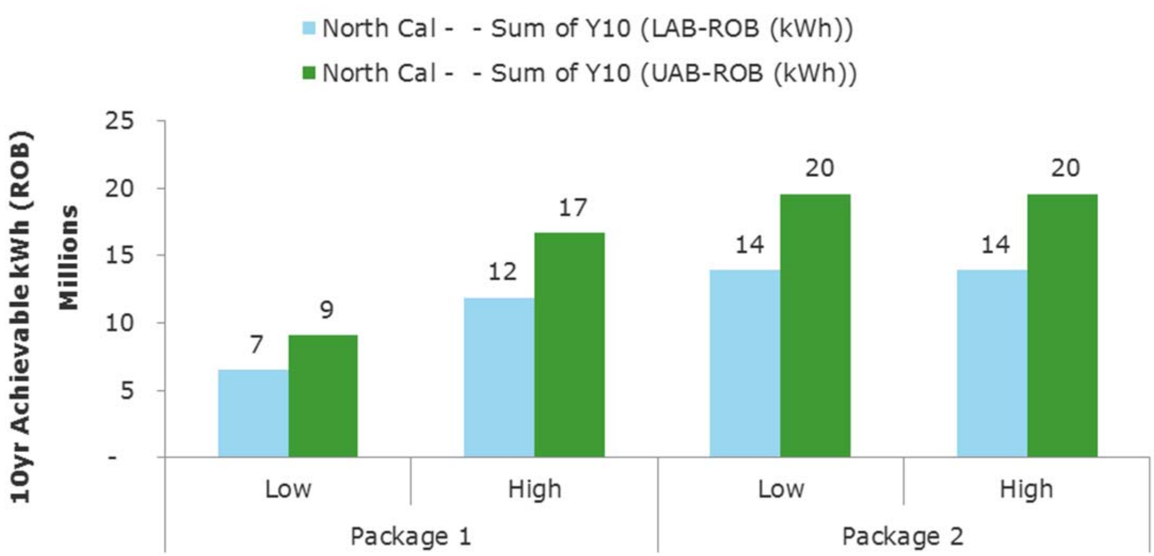
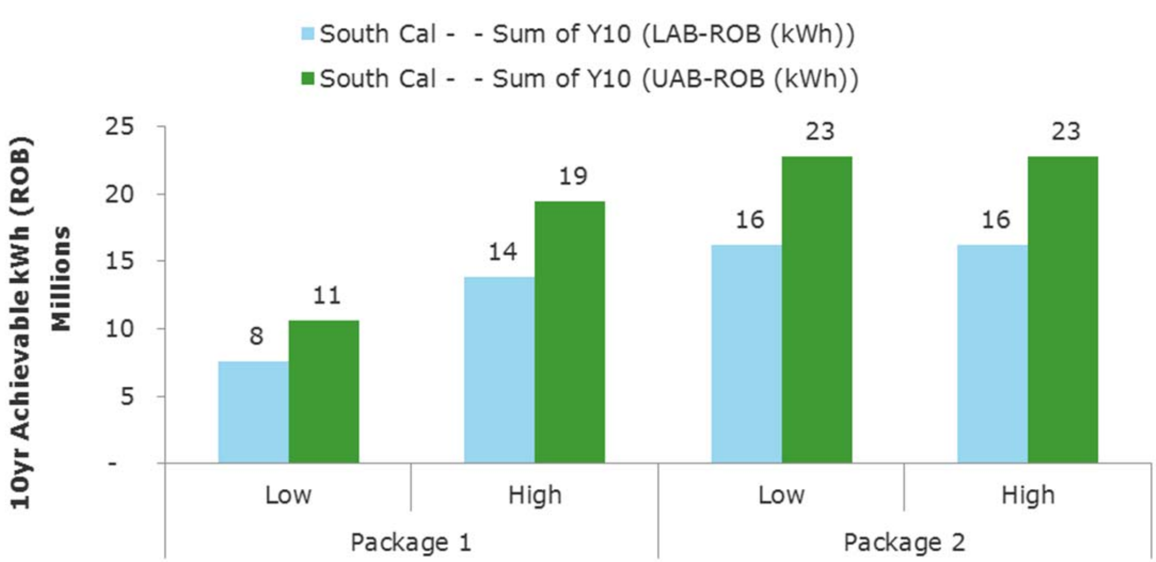


Figure 13: Southern California office ROB lower and upper achievable kWh



4.4 Market Perspectives

This section summarizes the findings of the expert interviews conducted for this study. The findings should be considered within the context of the following key points.

With a few exceptions, the promotion of systems approaches to energy efficiency is not widespread in the marketplace. Based on the first round of interviews, the research team decided to focus on “intelligent control systems,” a generic term that incorporates advanced lighting controls (ALC) and advanced building automation systems (A-BAS), as a proxy for system approaches. These technologies interact with at least one typical “widget” measure, are an essential component of systems approaches, and in general are familiar to market actors. The key difference is that A-BAS systems are more likely to be enterprise wide, while ALCs may be site specific.

In general, responses related to adoption potential, awareness, barriers, and other key indices were closely aligned, regardless of whether the expert was associated with the ALC or A-BAS space.

The most significant difference related to the payback period. Stakeholders in the A-BAS space perceived customer tolerance for a higher payback threshold (~5 years) than those in the ALC space (~2 years). This difference is attributable to the differences in complexity, cost, sophistication of potential customers, and benefits between A-BAS and ALC installations.

As the market currently operates, opportunities to install intelligent control systems, for the most part, do not exist except in new construction or in cases of substantial building alterations of the controlled measures.

4.4.1 Awareness

Most respondents differentiated between awareness of the existence of intelligent control systems, which was seen as generally high, and a solid understanding of the potential benefits of these systems, which was generally considered low.

Awareness is “horrendous - low, low. Less than 5% (of the potential end-users are) aware of true capability.”
“In general everyone is familiar … but not aware of everything they (these systems) can do.”

The respondents perceived that design professionals are aware of these systems, but are unable to present a strong value proposition in a convincing manner. They highlighted significant gaps in general market awareness regarding the benefits of these systems and of third-party validation of system performance.

4.4.2 Penetration

Respondents were asked to estimate the portion of new C&I construction and the portion of existing buildings that would have intelligent control systems installed in the next year. For new construction, the answer varied by context, with Title 24 building codes in California substantially increasing expected adoption for new construction. The continuum of what constitutes an “intelligent control system” was also an issue in this discussion.

“Maybe 20%-30% in California due to Title 24, the rest of the country 5%”
“Less than 1% of buildings built if you exclude motion sensors”

The highest estimate for installation of intelligent control systems in new construction over the next year was 30%, with low estimates in the single digits.

Respondents expected even fewer installations of these systems in existing buildings than in new construction, with a high estimate of 5% of the eligible market and a low estimate of 0.5% or less. The Design Lights Consortium (DLC) estimates that advanced lighting controls are present in less than 3% of all C&I buildings. A review undertaken by the DLC of data from four efficiency programs found advanced network controls in less than 1% of all lighting retrofit projects.

The respondent pool mentioned a few energy efficiency programs that provide incentives for the incorporation of intelligent control systems in measure- level projects (e.g., layering advanced lighting controls onto LED re-lamping projects). Multiple respondents mentioned Eversource in Massachusetts & Connecticut, AEP Ohio, and Consumers Energy of Michigan in this regard. Most respondents differentiated the following market sectors in terms of awareness and adoption:

For California, Title 24 was mentioned frequently as a driver toward intelligent controls.
Other markets in the Northeast and Northwest are moving toward intelligent controls or system approaches.
The municipal-university-school- hospital sectors, as well as geographically diverse organizations with significant space requirements (e.g., some chain stores), have higher adoption rates than many of the other sectors.
Warehouses, large industrial spaces, and parking garages have been relatively receptive to advanced lighting controls due to high savings potential and the possibility of capturing non-energy impacts.

4.4.3 Barriers

Intelligent control systems face the following barriers to adoption, according to respondents:

- Cost. These systems have a relatively high entry cost in terms of basic assets required for implementation. These assets include the processing unit, control interface, and network capability.
- Uncertainty of benefits. The benefits of these assets are not susceptible to estimation on a per-unit basis, vary greatly depending on facility and control strategy, may include a substantial portion of non-energy benefits, and are not easily calculated. The respondents actually found this to be the greatest barrier, as shown by the representative quotes below:
- "Biggest barrier is the perception that there are not savings from controls, there is not a need for intelligence. The education gap is the first biggest barrier to adoption."
- "Perception is the greatest barrier, the high level perception that controls are bells & whistles, which is an industry self-inflicted wound."
- "We can't project the savings, once you have information that intelligent control systems can develop, you can really save."
- Complexity. These systems are more complex. They require thorough and ongoing commissioning and user education. Contractors in are often not knowledgeable about them. These factors lead to less than optimal user experiences and resistance in the supply chain. In the words of one respondent, control systems "Have a stigma among contractors, they don't have familiarity with them, they add tremendous padding to the labor price on installation, which is a huge barrier to entry."
- Operational disruption. Installation of a facility-wide system may be more disruptive than the installation of widgets, especially in cases were wired networks are necessary. Wireless networked systems are significantly reducing this difference and are increasing in availability.
- Absence of unified standards. Intelligent controls system manufacturers have yet to settle on a consistent standard. There are some standards that many systems can use, such as BACnet, a data communication protocol for building automation systems. However, inter-operability, plug-and-play functionality, and the ability to swap out components based on availability or preference is still lacking.

- Perverse incentives. A decision maker driven by short-term financial considerations comparing the payback of a widget-based project (e.g., LED retrofit) with that of a system-based project (e.g., LED retrofit and intelligent control system) will see a substantially longer payback for the system, even though the total return on investment of the latter might be many times greater. Utility programs typically provide incentives favoring the short-term certainty that component replacement provides.

The first cost of intelligent control systems is undoubtedly a barrier. However, in the view of the respondents to this research effort, it is not the greatest barrier. The greatest barrier is the absence of information and education about the already-realized potential of these systems to save energy and to provide other ancillary benefits.

4.4.4 Opportunities

According to respondents, intelligent controls systems have a substantially greater return on investment than simple widget-based projects. Respondents reported energy savings of approximately 85% or greater due to the installation of advanced lighting controls. They also noted non-energy benefits from these systems, such as increased operational control, enhanced occupant satisfaction, space utilization optimization, reduced maintenance/outage costs, and real-time measurement and verification of system performance. In their opinion, the full potential of these systems has been neither fully explored nor fully documented. Below are the benefits noted by respondents:

- "The biggest thing is the quality, not so much the quantity of light, the ability to improve quality of light and improve spaces for inhabitants."
- "The short timer settings on occupancy sensors drive people nuts. Intelligent systems are controllable and rampable."
- "Maintenance reductions, less down time, less wear and tear, being proactive with facility."
- "There are tons of other benefits (of ALCs) that are hard to quantify, inter-operability with building management systems, benefits in classroom or office on productivity, hospitals (improve) circadian rhythm for better sleep, LEED points for control of light levels."
- "An entire new value stream (from A-BAS) is available when buildings become active nodes on the grid, essentially (they become) dispatchable."

Respondents suggested program interventions to overcome the barriers noted above. We grouped the suggested intervention strategies into three major categories: information, education, and appropriate support.

Information. Information developed by utilities and other independent third-party organizations would help overcome the uncertainty barrier. This information could include a comprehensive database of case studies across a wide variety of market segments, quantification of a variety of non-energy benefits, and the establishment of objective standards like the DLCs Commercial Advanced Lighting Controls Networked Lighting Controls Specification. These efforts could increase certainty and credibility.

- "Relevant industry case studies. Garner the whole value of energy savings and functional benefits."
- "Third party verified case studies would help."
- "The real market challenge is having trusted resource on the site."

Education and training. The respondents felt that education was sorely lacking across the stakeholder chain. They noted that manufacturer representatives who have intelligent controls systems in their product lines might not be aware of them, that contractors do not have sufficient knowledge to successfully install them, and that users may not preserve the knowledge necessary to operate them. This is on top of the low awareness of the full range of benefits these systems can provide. Respondents reported that the value of efficiency programs' education on these systems was on the same order as program incentives.

They also noted that the systems are getting both smarter and more user-friendly, so perhaps the education can focus more on benefits and less on operation in the near future.

- "Think of the average car with all the microprocessors, and yet my 86 year old mom can still drive the car."

Appropriate support. One respondent noted that, recently, "the whole retrofit market in California came to a screeching halt; anything that you do that could trigger Title 24 won't be incentivized." Others noted that incentives for LEDs without the requirement of advanced lighting controls might effectively postpone the acquisition of significantly greater energy savings and non-energy benefits for decades.

- "Utility incentives that push harder on advanced system. There should be dis-incentives of non-intelligent systems."
- "Great piece some utilities offer are bonus incentives for comprehensive measures."

5 CONCLUSIONS AND RECOMMENDATIONS

This section summarizes the overall findings, opportunities, and threats to programs offering systems-based incentives, along with recommendations to help any future programs operate more effectively.

Conclusion 1: Ample potential exists to deploy systems-based energy efficiency programs for lighting in commercial office buildings. As expected, segments with the largest amount of square feet produce the most savings.

Recommendation 1: Advanced lighting systems should begin to be included as part of utility energy efficiency portfolios. Additional work will need to be done before these systems can move from a custom application to a more standardized one.

Conclusion 2: Even though the components of these systems exist today and are considered "off-the-shelf," combining them into a complete system is not common practice. Utility incentives programs can be most effective in situations when current payback periods are longer than customer investment thresholds. In addition to reducing payback times using financial incentives, utility programs can increase customer awareness and educate decision makers on the benefits of system-based approaches versus widget-based change outs.

Recommendation 2: To increase uptake of the systems approach, utility programs need to include an educational component to increase awareness among designers and contractors of lighting systems.

Conclusion 3: Installation of systems tends to be related to a major event that results in a remodel and therefore creates a "replace on burnout" decision path rather than a retrofit decision path.

Conclusion 4: Systems save energy, but are sensitive to utility avoided costs. The driver of economic potential was more about differences in avoided costs than by differences in system costs or savings.

Recommendation 3 & 4: Utility program should target the ROB market and use incremental cost to determine cost effectiveness for these programs.

Supporting Information: System Detailed Descriptions

This section provides detailed descriptions of the "Beyond Widgets" projects selected for the three LBNL utility partners.

California POU Customer System Technology Specification

This section provides a summary description of the system selected for the California Publicly Owned Utilities (CA POUs)-LBNL "Beyond Widgets" project: Plug loads and lighting occupancy controls, with task and ambient lighting retrofits. This section includes the system features, technology packages, site requirements, and likely energy savings impacts. It will be used as the basis for developing detailed technology specifications, savings metrics and M&V approaches, and FLEXLAB testing plans.

The target market is currently anticipated to be commercial office space.

System Features

The following are features of the proposed systems energy efficiency program package. A suite of technology package options will be developed from these features which will be pursued for testing, validation and program implementation guidance development.

<u>Lighting and Lighting Controls</u>

Occupancy controls

- Switches on in response to occupancy at the zone level
- Controlled to background/ambient level

Daylight dimming

- Electric lighting output reduces in response to natural light availability
- Applies particularly to retrofits where Title 24 is triggered

Task lighting and ambient lighting upgrade

- Installation of schedule and occupancy-based control task lighting and desktop equipment at workstation level
- Overhead lighting relamping or light fixture replacement to achieve ambient light level condition

<u>Plug Load Controls</u>

Occupancy control

- Operates in response to occupancy at zone level (overhead lighting) or individual workstation (plug loads) level
- Occupant preferences accommodated via override and sensitivity settings

Networked Controls System

Lighting and plug load controls scheduling, occupancy and reporting functions

Occupant Feedback System

Occupant engagement and awareness strategies for persistence of energy savings

The technology packages will be developed to ensure that there is more than one equivalent commercially available product source for each package.

System Performance Specification

Ambient (Overhead) Lighting and Lighting Controls

The overhead lighting retrofit should comprise some or all of the following elements:

1. Light fixtures
2. Lamps
3. Dimming ballasts or LED drivers
4. Panel and remote mounted load control relays and dimmers
5. Power supplies
6. Routers, controllers, processors and servers
7. Analog and digital input and output modules
8. Emergency lighting control

The primary objective is to control overhead lighting output by either a) lighting power density de-rating via lamp change-out or b) tuning existing lamps for a lower lumen output. This approach is consistent with a strategy known as task / ambient lighting, where background lighting is provided by ceiling mounting fixtures and task–specific lighting is provided on-demand by personal desktop lamps. Illuminance at the workplane should be based on current IESNA recommendations and user preferences. Primary control shall be in response to occupancy.

Additional specific requirements:

1. Light fixture (or luminaire) may be either in-ceiling or surface-mounted 'troffer' (available in various dimensions) or ceiling hung 'pendant' fixture
2. Lamps for use in retrofit projects should have a minimum rated lamp life of 68,000 hours[10]
3. Minimum initial delivered lumens will vary according to number of lamps, but a rough guide should be for 1′ x 4′ to provide 1500 initial lumens, and for 2′ x 4′ to provide 3000 initial lumens. 2′ x 2′ fixtures should provide 2000 initial lumens. The minimum Luminaire Efficacy Rating (LER) should be at least 110 lm/W.
4. Where drivers are installed or replaced, efficiency rating for driver technologies should be 0.83 (digital ballasts) and >80% (LED drivers)
5. For projects that incorporate dimming elements of lighting controls, related to institutional tuning, daylight dimming and demand response, electronic ballasts or LED drivers shall be capable of providing flicker-free dimming from 100% to 5%. Step dimming from 100% to at least one present level between 70% and 10% should be an available option TO support appropriate tuning according to site

[10] L_{70} (LED) or based on 12-hour start with instant start ballast (fluorescent)

requirements / user preferences. There should be no phase-cut dimming. Communications protocols such as DALI, DMX/RDM, Zigbee and EnOcean are among the viable options

6. For systems with integrated lighting controls, this may comprise some or all of: occupancy sensors, photosensors (daylight dimming), lumen management and load shedding capability
7. Where implemented, all networked system sensors and controls shall be programmed to ensure minimal lamp cycling (and associated reduced lamp life and occupant distraction) and should be capable of easy recalibration to accommodate changes in environment/preferences. They should be calibrated to ensure that IES guidelines[11] are maintained. The control system should be capable of controlling multiple zones using the input from a single sensor, allowing separate adjustable settings for each control zone. The system should allow for variable target setpoints. The location and number of the photo sensors should be optimized by the control system supplier.

Occupancy-Based Plug Load Control, including Task Lighting

Plug load control and occupancy-based task lighting shall comprise the following elements:

1. Block of controllable electrical sockets
2. Resettable circuit breaker
3. Power-on indicator light
4. Desktop LED task light

The primary objective is to control plug loads according to usage patterns defined by a) user / building operating schedules and / or b) occupancy at individual work locations. The objective is to minimize operating hours for office plug loads, particularly desktop equipment such as computers and monitors. Provision of task lighting powered via the APS aims to meet task level illuminance requirements while allowing lower ambient lighting LPD.

Additional specific requirements:

1. The blocks of sockets should consist of at least four power outlets – this will enable management of all common desk-based plug loads (computer / laptop, monitor, task light) The instructions for installation and operation should be intuitive and simple to understand – it should be possible for someone not previously familiar with the technology to make modifications to control settings.
2. Optional - Remote access and control may be provided for controllable outlets via a web-based interface, and will allow programming of individual outlets according to user preferences, including, but limited to schedule.
3. Control options shall include one or more of the following:
   - Schedule / timer
   - Master outlet-based control
   - Remote manual switch
   - Remote occupancy sensor - this sensor could either be a) part of the APS package or b) utilize occupancy signals from the appropriate sensor that is part of the overhead lighting controls package.
4. The LED task light should have a manual on-off switch

[11] For example, for commercial offices, 30 footcandles on the workplane.

Note that the impact on HVAC systems operation will be estimated / measured, however, integration and optimization of HVAC performance with the system described above is not an objective for this project's system.

Technology Packages

The intent is to allow a range of different component technology options that meet the system features described above. The program incentives would be paid based on system performance rather than component performance or features. The technical requirements for each component are summarized below, followed by technology packages that will be selected for testing.

At least two packages are being considered, for review and feedback from the California POUs – a package that targets lower cost, minimally invasive installation, such as localized wireless or other stand-alone controls interventions, and another package that targets small cost technologies that might be slightly more involved to install, but could unlock deeper energy savings, such as networked controls and feedback.

Technology Package 1

Package 1 provides a low cost option, focusing on stand-alone controls with non-automated means of feedback and savings persistence guidance.

Technology Description

Overhead (ambient) lighting will be a lamp or fixture replacement with reduced lighting power density and lower lumen output. Local load sensing controlled power outlets, with task lighting providing required light levels at the task area.

Lighting and Lighting Controls System

The functional performance requirement is for the overhead lighting system to provide ambient / background lighting so that overall lighting energy use is minimized.

Primary control mode shall be in response (in real time) to:

Zone-level occupancy
Schedule controls

Representative technologies meeting description:

1. Overhead lights - Luxul linear LED replacement tube, recessed or pendant fixture
2. LED task lights - Tambient Boston Light

Plug Load Controls System

The functional performance requirement is plug loads to be controlled at the workstation level so that workstation plug load energy use is minimized. Control shall be implemented via schedule or occupancy sensor signal

Primary control mode shall be in response (in real time) to:

1. Cubicle-level occupancy sensor signal
2. Pre-programmed work schedules

No secondary control inputs are envisioned.

Representative technology meeting description:

Autani Smartlet

Targeted Measurements

This technology package will not automate or trend the collection of controls data. However, measurements will be taken as a result of the package features, including:

plug load use schedule
plug load energy
lighting circuit energy

Technology Package 2

This package provides a small cost option, focusing on networked controls with automated means of feedback and savings persistence guidance.

Technology Description

Overhead (ambient) lighting will be a lamp or fixture replacement with reduced lighting power density and lower lumen output. Task lighting will supplement illuminance requirements in the work area. Local occupancy sensors will control overhead lighting (zone) and controlled power outlets (cubicle), including desktop task lighting.

Lighting and Lighting Controls System

The functional performance requirement is for the overhead lighting system to provide ambient / background lighting levels so that overall lighting energy use is minimized.

Primary control mode shall be in response (in real time) to one or a combination of:

Workstation occupancy
Schedule controls

All workstation level occupancy sensors shall be configured to reflect occupancy of workstation specific areas, and installed in a semi-permanent fashion (e.g. affixed to furniture system), to discourage relocation of sensor.

Representative technologies meeting description:

Overhead lights - Philips SpaceWise
LED task lights - Tambient Boston Light

Plug Load Controls System

The functional performance requirement is for occupancy sensors to control plug loads at the workstation level so that workstation plug load energy use is minimized. Control shall be implemented via workstation specific occupancy sensor connected to workstation level plug loads. Occupants may adjust timeout, occupancy sensor sensitivity and direction of sensor viewing angle. No overrides at the occupant level are envisioned.

Primary control mode shall be in response (in real time) to:

Pre-programmed work schedules
Workstation level occupancy sensing

No secondary control inputs are envisioned. All workstation level occupancy sensors shall be configured to reflect occupancy of workstation specific areas, and installed in a semi-permanent fashion (e.g. affixed to furniture system), to discourage relocation of sensor.

Representative technology meeting description:

Telkonet EcoGuard

Targeted Measurements

This technology package will not automate or trend the collection of controls data. However, measurements will be taken as a result of the package features, including:

Workstation occupancy
Plug load use schedule
Plug load energy
Lighting circuit energy

Candidate Site Requirements

Standard set of commercial office equipment of 1990's/00's era, e.g. laptops, desktop computers, flat screen monitors, etc.
9-10ft floor-to-ceiling height with dropped ceiling/plenum
Existing overhead lighting system with T12 or T8 light fixtures, either lay-in or pendant hung
Overhead lighting system zone covers the same area as the workstations incorporating task lighting and plug load controls (i.e. the existing lighting controls don't impact adjacent spaces such as conference rooms)
Existing switch based or networked lighting controls, without daylight dimming
Network access to workstations for occupant level feedback software or network access to a common display for workstation area feedback
Average daily occupancy a minimum of 8 hours a day, 5 days a week

Energy Saving Impacts

Baseline Case

The California POUs use California's Title 24 Energy Code as their baseline for comparison for all energy efficiency Demand Side Management Programs. This presents a number of challenges for utilities in the state, since on a prescriptive and component based level it is difficult to develop technology offerings that are substantially higher energy savings over Title 24 to justify an incentive program. This systems level technology package provides a distinct advantage in this respect, as energy savings are greater at the system level.

The relevant prescriptive elements of California's Title 24 Energy Code are as follows for plug loads and lighting respectively.

Lighting and Lighting Controls

Scheduling, institutional tuning, occupancy based operation and daylight dimming to be implemented in office areas.

Plug Loads

Circuit controls for 120-volt receptacles for office workstation equipment (PCs, local printers, task lighting), which incorporate the capability to implement on-off schedules. Plug-in power strips with occupancy based control do not qualify under the current Code.

Proposed Technology Packages Energy Savings

Energy savings arising from advanced lighting controls are expected to reach approximately 38%.[12] Implementing a task ambient strategy are generally expected to surpass this, with measured energy savings of between 30-60% depending on the baseline.

Energy savings arising from load sensing (proxy occupancy control) and occupancy sensor control of power strips is indicated as being between 10-23% of connected plug loads.[13,14]

HVAC Impacts

In addition to the savings demonstrated within the plug loads and lighting systems, impacts on cooling energy reduction are also of interest. These interactive effects are less well studied in case studies and other technology reports.

References

No references were provided for this case study.

[12] http://eetd.lbl.gov/sites/all/files/a_meta-analysis_of_energy_savings_from_lighting_controls_in_commercial_buildings_lbnl-5095e.pdf

[13] http://www.gsa.gov/portal/mediaId/197383/fileName/GPG_Plug_Load_Control_09-2012.action - includes all common office equipment items, excluding kitchen area appliances.

[14] http://aceee.org/files/proceedings/2012/data/papers/0193-000277.pdf

Supporting Information: Listing of Interview Participants

Table 17 lists the DNV GL staff interviews by name and title for the internal adoption potential interviews. The external interviews (Table 18) are listed by company name and role in the market for integrated systems. One small architectural firm agreed to talk to us on the condition of anonymity. These responses represent a wide array of market actor perspectives.

Table 17. DNV GL internal respondents

Name	Title
Max Neubauer	Consultant, Policy Advisory and Research
Ryan Ollie	Engineer, Program Development and Implementation
Angela Xanders	Senior Consultant, Program Development and Implementation
Ben Huntington	Consultant, Policy Advisory and Research
Blake Herrschaft	Senior Engineer, Sustainable Buildings and Communities
Jarred Metoyer	Head of Section, Engineering West

Table 18. External subject matter experts

Company	Role
Ameresco	Solution provider
Anonymous	Architect
Design Lights Consortium	Market transformation
Digital Lumens	Manufacturer
Eaton/Cooper	Manufacturer
Encelium/Sylvania	Manufacturer
Enlighted	Advanced lighting systems
Facilitec	Solution provider
Johnson Controls	Manufacturer
Leading Edge Design Group	Solution provider
Schneider Electric	Manufacturer
Siemens	Manufacturer
Universal Devices	Solution provider

Supporting Information: Market Actor Interview Guide

Based on findings from interviews with DNV GL internal experts, the market actor interviews focused on “integrated systems”. These were defined as a system that controls more than one end-use with some degree of automation.

During the in-depth interviews, these questions serve as a guide for the discussion. The interviewer may probe certain areas more in one interview than another, or may collect responses in an order other than the one provided in the guide.

Preliminary

1. In a few words, please summarize your experience and expertise with regard to integrated control systems.
2. Does your company have/ Do you specify a proprietary systems, or do you have detailed knowledge of a specific system or technology

Awareness

3. How would you characterize the awareness of integrated control systems in the market place, for example relative to awareness of efficient lighting or heating? As a percentage of eligible customers?
4. What approach do you think programs could take to increase awareness of integrated control systems?
5. Does this differ from key measures (LED lights) for example, and if so, how?

Penetration

6. Are you aware of any energy efficiency programs that are promoting integrated control systems or comparable? If so, where and how?
7. Are there any market segments in particular that might more readily adopt integrated control systems? Any that you identify as particularly resistant? Why?

Barriers

8. What kind of barriers to adoption do integrated control systems face that are different from those facing specific end use measures, such as efficient lighting or HVAC equipment?
9. Are there any approaches to overcoming barriers that might be particularly useful for promoting integrated control systems?
10. [IF NOT PREVIOUSLY MENTIONED] – What specific barriers might efficiency programs have to overcome to increase adoption of integrated control systems in existing buildings? How might they do so?
11. What features of integrated control systems are particularly worth promoting?
12. Historically it has been relatively easy to encourage vendors to promote higher efficiency measures in their core business line. What might encourage them to promote integrated controls systems if they are not in their product line?

Decision Making

13. How does the decision making to install integrated control systems differ from the decision making to install just one of the component measures?

14. If integrated control systems can be shown to offer substantially greater benefits, including non-energy benefits, what benefits do you think would be most attractive to decision-makers? [Prompt if necessary "Substantially greater energy savings, reduced demand charges, increased productivity, increased comfort, increased sales "]

Adoption Forecast

15. What percentage of new commercial and industrial buildings will have integrated control systems installed in the next twelve months?
16. What percentage of existing commercial and industrial buildings will have integrated control systems installed in the next twelve months?
17. Assuming a comprehensive marketing effort and a simple payback of less than 2 years but more than one year less what percentage of eligible customers would install integrated control systems in the two years of the program? In the next five years? In the next 5 years? In the next 10 years?
    a. What if the payback were greater than 2 years?
    b. Less than a year?
18. Assuming that an average adoption rate can be determined for integrated control systems across all C&I market segments. Would you expect the adoption rate to be higher or lower, and by how much in terms of percentage, for the following type of decision makers:
    a. Those who own their buildings?
    b. Those that lease buildings?
    c. Small building owners?
    d. Large building owners?
    e. Old building owners?
    f. New building owners?

Next Steps

19. Now that you've heard all the questions, can you recommend anyone else we should talk with?
20. Are there any questions I haven't asked that I should have?

Conclusion

Thank you for your time. Please contact me if you think of anything about these systems you would like to add.

Supporting Information: System Assumptions Used in This Study (all values are whole building level)

Msr ID	Measure Name	Building Type	Energy Savings %	Peak Reduction %	Widget Cost ($/sqft)	System full cost ($/sqft)	System EUI (kWh/sqft)	System Life (yrs)	Widget Life (yrs)
CA POU_Package 1_Low	Plug load and lighting controls	Office pkg1	17.0%	18.0%	$0.80	$2.80	13.10	10	15
CA POU_Package 1_High	Plug load and lighting controls	Office pkg1	23.0%	18.0%	$0.80	$4.70	17.70	10	15
CA POU_Package 2_Low	Plug load and lighting controls	Office pkg2	27.0%	18.0%	$0.80	$4.50	17.70	15	15
CA POU_Package 2_High	Plug load and lighting controls	Office pkg2	27.0%	18.0%	$0.80	$7.70	17.70	15	15
ComEd_Package 1_Low1	Shading/lighting	Med Office	9.0%	2.0%	$1.81	$3.24	13.10	15	15
ComEd_Package 1_High1	Shading/lighting	Med Office	12.0%	3.0%	$2.05	$4.23	13.10	15	15
ComEd_Package 1_Low2	Shading/lighting	Large office	9.0%	10.0%	$1.22	$2.19	17.70	15	15
ComEd_Package 1_High2	Shading/lighting	Large office	12.0%	16.0%	$1.46	$2.93	17.70	15	15
ComEd13	Shading/lighting	Medical	NA	NA	NA	NA	NA	NA	NA
ComEd_Package 1_Low4	Shading/lighting	Primary School	20.0%	22.0%	$1.70	$3.06	7.46	15	15
ComEd_Package 1_High4	Shading/lighting	Primary School	23.0%	23.0%	$2.04	$4.10	7.46	15	15
ComEd_Package 1_Low5	Shading/lighting	Secondary School	13.0%	12.0%	$0.47	$1.37	12.26	15	15
ComEd_Package 1_High5	Shading/lighting	Secondary School	14.0%	13.0%	$0.66	$2.03	12.26	15	15
Xcel_Package 1_Low	Integrated lighting+HVAC controls, redirecting film	Office pkg 1	17.5%	10.0%	$0.80	$2.50	11.70	15	15
Xcel_Package 1_High	Integrated lighting+HVAC controls, redirecting film	Office pkg 1	17.5%	15.0%	$0.80	$2.50	11.70	20	15
Xcel_Package 2_Low	Integrated lighting+HVAC controls, redirecting film	Office pkg 2	27.0%	16.0%	$0.80	$6.00	15.20	15	15
Xcel_Package 2_High	Integrated lighting+HVAC controls, redirecting film	Office pkg 2	33.0%	22.0%	$0.80	$6.00	15.20	20	15

Supporting Information: Technical Potential Sub-Segments

Table 19: Technical potential for California POUs by sub-segment

Utility	Region	Bldg. Type	Bldg. Size	Vintage	Own or Rent	Square Footage
California POU	North	Office	Large	New	Rent	48,319,755
					Own	11,334,264
				Old	Rent	36,091,175
					Own	19,737,361
			Small	New	Rent	9,335,001
					Own	4,392,941
				Old	Rent	23,317,930
					Own	20,678,164
	South	Office	Large	New	Rent	65,016,080
					Own	15,250,685
				Old	Rent	37,369,853
					Own	20,436,639
			Small	New	Rent	18,036,621
					Own	8,487,821
				Old	Rent	19,603,801
					Own	17,384,503

Supporting Information: Achievable Potential kWh (Package 2)

These tables and charts provide the kWh savings for systems deployed in the CA POU service territories. For all tables the abbreviations for "Lower Achievable Bound" and "Upper Achievable Bound" are LAB and UAB respectively. The table values include the following conditions,

- package 2 - high cost, high savings
- a replace-on-burnout (ROB) situation
- a retrofit (RET) situation
- 2-year payback
- Cumulative savings in year 10

Table 20: California POU achievable kWh (Package 2)

Utility	Region	Bldg. Type	Bldg. Size	Vintage	Own or Rent	kWh – ROB LAB	kWh – ROB UAB	kWh – RET LAB	kWh – RET UAB
CA POU	North	Office	Large	New	Rent	3,891,471	5,461,713	58,372,060	81,925,699
					Own	912,814	1,281,143	13,692,212	19,217,139
				Old	Rent	2,906,632	4,079,484	43,599,481	61,192,254
					Own	1,589,564	2,230,968	23,843,466	33,464,514
			Small	New	Rent	751,802	1,055,160	11,277,028	15,827,407
					Own	353,789	496,546	5,306,837	7,448,192
				Old	Rent	1,877,928	2,635,689	28,168,926	39,535,334
					Own	1,665,333	2,337,309	24,979,991	35,059,636
	South	Office	Large	New	Rent	5,236,123	7,348,944	78,541,840	110,234,162
					Own	1,228,226	1,723,826	18,423,395	25,857,396
				Old	Rent	3,009,611	4,224,016	45,144,172	63,360,241
					Own	1,645,881	2,310,009	24,688,219	34,650,132
			Small	New	Rent	1,452,594	2,038,728	21,788,908	30,580,923
					Own	683,574	959,402	10,253,604	14,391,023
				Old	Rent	1,578,808	2,215,871	23,682,120	33,238,064
					Own	1,400,075	1,965,018	21,001,126	29,475,264

The graphs illustrate the savings between package 1 and 2 in the ROB scenario. Even though package 2 is more expensive, this package has the potential to achieve more savings than either configuration of package 1.

Figure 14: Northern California adoption curve kWh (ROB)

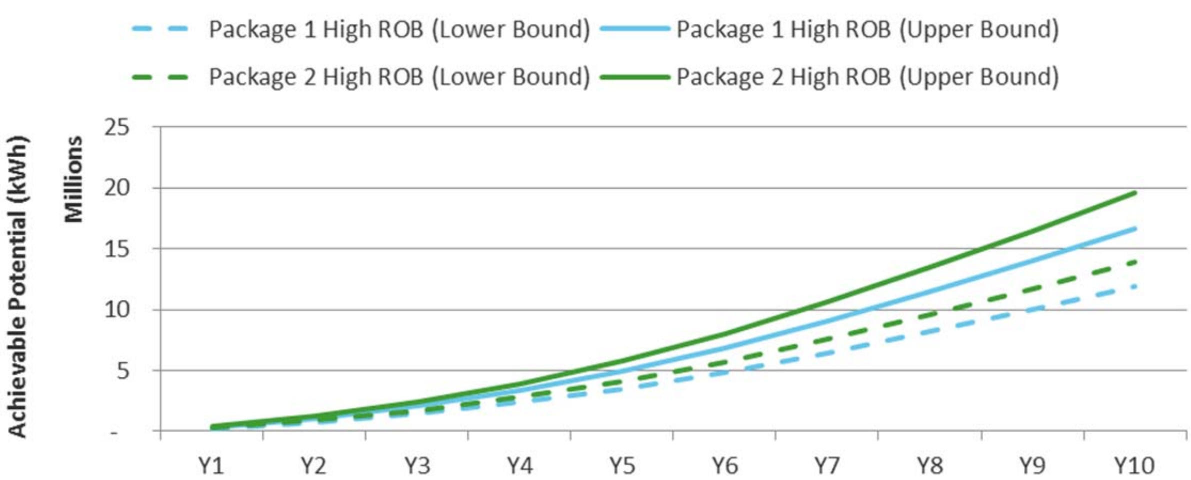
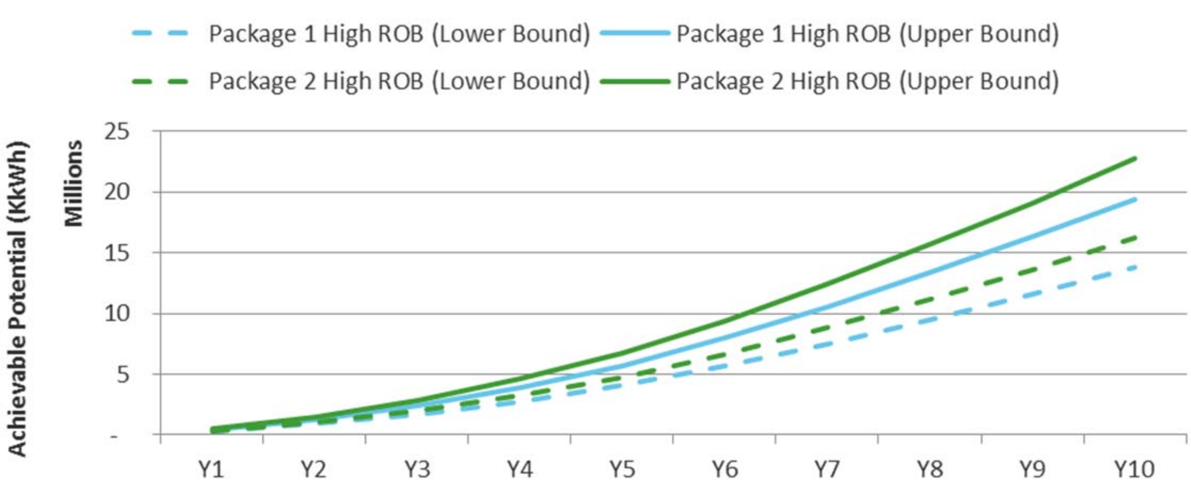


Figure 15: Southern California adoption curve kWh (ROB)



Interestingly the savings in Northern and Southern California are very similar. This result is driven by the fact that both regions of the state have very similar distributions of square feet in the office building segment. For both regions, the largest segment for savings is newer large office buildings that are leased to tenants

There is no kWh achievable potential table here for ComEd since none of the system configurations or applications passed the TRC test.

Supporting Information: Achievable Potential kW (Package 2)

Table 21 provides the kWh savings for systems deployed in the service territories of ComEd, Xcel Colorado and Xcel Minnesota. For all tables the abbreviations for "Lower Achievable Bound" and "Upper Achievable Bound" are LAB and UAB respectively. The table values include the following conditions,

- package 2 - high cost, high savings
- a replace-on-burnout (ROB) situation
- a retrofit (RET) situation
- 2-year payback
- Cumulative savings in year 10

Table 21: California POU achievable kW (Package 2)

Utility	Region	Bldg. Type	Bldg. Size	Vintage	Own or Rent	kW – ROB LAB	kW – ROB UAB	kW – RET LAB	kW – RET UAB
CA POU	North	Office	Large	New	Rent	982	1,378	2,845	3,994
					Own	230	323	1,339	1,879
				Old	Rent	733	1,029	11,001	15,440
					Own	401	563	6,016	8,444
			Small	New	Rent	190	266	2,845	3,994
					Own	89	125	1,339	1,879
				Old	Rent	474	665	7,108	9,976
					Own	420	590	6,303	8,846
	South	Office	Large	New	Rent	1,454	2,041	6,051	8,493
					Own	341	479	2,848	3,997
				Old	Rent	836	1,173	12,537	17,596
					Own	457	642	6,856	9,623
			Small	New	Rent	403	566	6,051	8,493
					Own	190	266	2,848	3,997
				Old	Rent	438	615	6,577	9,231
					Own	389	546	5,832	8,186

There is no kW achievable potential table here for ComEd since none of the system configurations or applications passed the TRC test.

Supporting Information: Achievable Potential

In Figure 16 and Figure 17, a threshold of TRC ≥1.0 is the basis for the potential shown for the California POUs and Xcel Colorado. For ComEd and Xcel MN the potential is based on a TRC ≥ 0 threshold.

Figure 16: Economic Potential RET

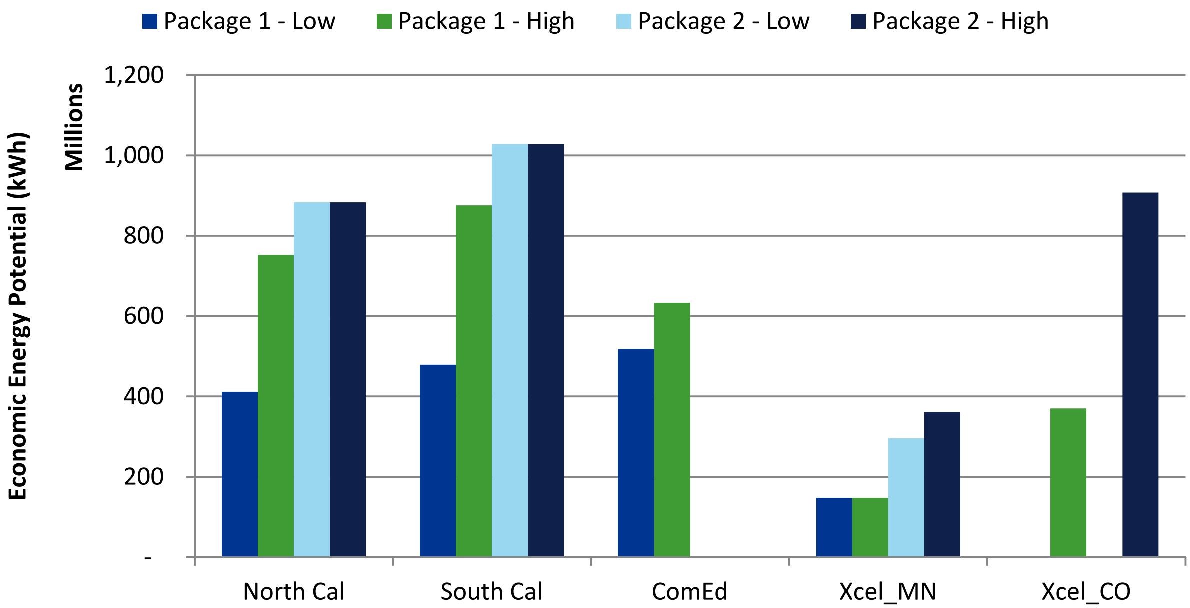
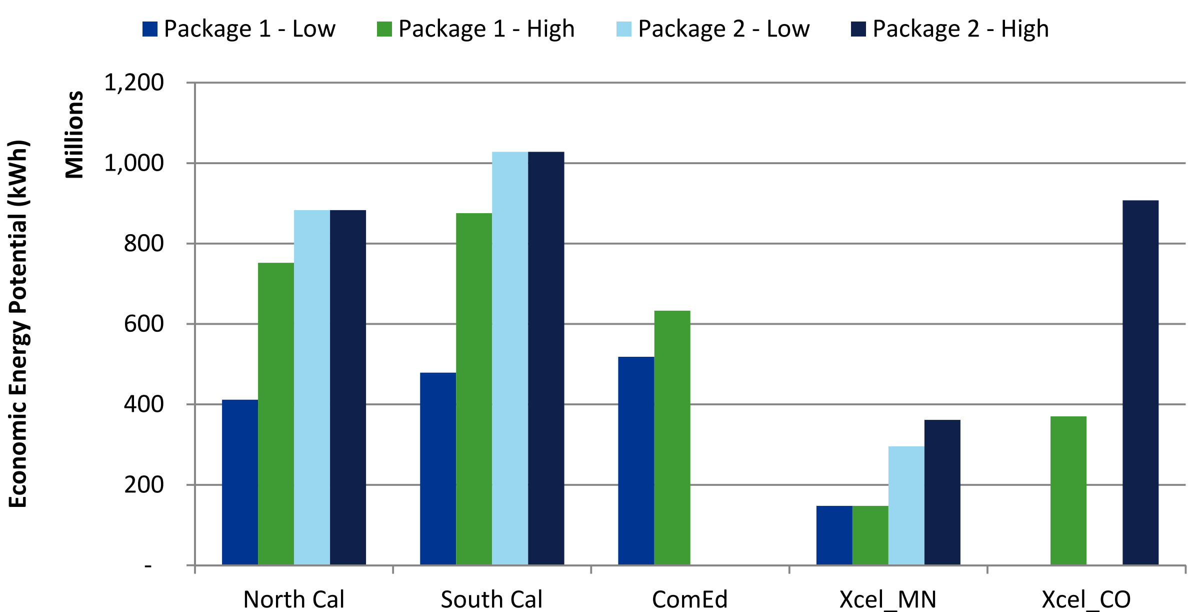


Figure 17: Economic Potential ROB



Appendix B: Assessment Methodology

The assessment methodology is attached as a separate .XLS document. Screenshots of the excel-based assessment method are included below.

All Blue Cells Entered By User

Participant Name	(enter participant name)
Building Name	(enter building name)
Building Address	(location)
Utility Rate ($/kWh)	$.15 / kWh

Area Details

Select Method from Dropdown		
Method One - Repeating Floorplate		
Method One - Repeating Floor Plate		Validation, unit
No. of Floors	1	1 to 50 floors
Floorplate area	1,728	1 to 1,000,000 square feet
Total Building Area	1,728	1 to 1,000,000 square feet
% Area to be Retrofit (office spaces or	100%	1% to 100%
Retrofit Area	1,728	1 to 1,000,000 square feet
Method Two - Whole Building		Validation, unit
Total Building Area	17,623	1 to 1,000,000 square feet
Percent Area to be Retrofit	100%	1% to 100%
Retrofit Area	17,623	1 to 1,000,000 square feet
Total Building Area	**1,728**	0 to 1,000,000 square feet
Total Retrofit Area	**1,728**	1 to 1,000,000 square feet

Space Type Details (for retrofit space only)

	Open Office	Private Office	Other*	Total	Validation, unit
Proportion of Space Type	100%	0%	0%	100%	must total to 100%
Square Feet per Space Type	1,728	0	0		square feet
Occupied Area per Space Type	80%	0%			1% to 100%
No. of Occupants	100	0			1 to 1,000,000 occupants
Occupant Density	13.824	#DIV/0!			square feet per occupant

*"Other" spacetype not considered occupied; out of retrofit scope

Schedule Details

	(enter "open" hours for facility)			
	Arrival	Departure	Hours Occupied	Validation, unit
Mon to Fri Open Hours	7:00:00 AM	7:00:00 PM	12.0	hours, 1 to 23.5
Sat Open Hours			0.0	hours, 0 to 23.5
Sun Open Hours			0.0	hours, 0 to 23.5
Holidays per year	10			days, 0 to 50
Estimated Annual Open Hours	**3,008**	*		

* normal open hours are in the 3,000 hour range

Building	(enter building name)
Total Building Area	1,728 square feet
Estimated Annual Occupied Hou	3,008 hours

Open Office Lighting Details

Area for Retrofit 1,728

Type	Quantity	Controls	Estimated Fixture Wattage	Total Connected Load (kW) per Fixture Type	Assumed Annual Operating Hours (based on "Controls")	Estimated kWh per Year per Fixture Type
1 lamp Pendant (4' sections), F54 T5HO - 4'	24	Basic Schedulers and Switches	57.4 watts	1.4 kW	3,234 hours	4,458 kWh
lamp ,	0	Basic Schedulers and Switches	.0 watts	.0 kW	3,234 hours	kWh
lamp ,	0	Basic Schedulers and Switches	.0 watts	.0 kW	3,234 hours	kWh
lamp ,	0	Basic Schedulers and Switches	.0 watts	.0 kW	3,234 hours	kWh
Total	**24**		**TOTALS**	1.4 kW	3,234 hours	4,458 kWh
					*weighted avg.	

Private Office Lighting Details

Area for Retrofit 0

Type	Quantity	Controls	Estimated Fixture Wattage	Total Connected Load (kW) per Fixture Type	Assumed Annual Operating Hours (based on "Controls")	Estimated kWh per Year per Fixture Type
lamp ,	0	Basic Schedulers and Switches	.0 watts	.0 kW	3,234 hours	kWh
lamp ,	0	Basic Schedulers and Switches	.0 watts	.0 kW	3,234 hours	kWh
lamp ,	0	Basic Schedulers and Switches	.0 watts	.0 kW	3,234 hours	kWh
lamp ,	0	Basic Schedulers and Switches	.0 watts	.0 kW	3,234 hours	kWh
Total	**0**		**TOTALS**	. kW	0 hours	kWh

Appendix C: Installation Verification Checklist

The following checklists document several of the important features of the overhead lighting system to be aware of and verified in order to help ensure the energy savings levels are realized with the system as expected. The following checklists are not meant to replace a complete commissioning set of checklists (e.g. Pre-functional and functional tests).

Spot Measurement Verification

Testing conducted at night, with minimal exterior light penetration.

Light meter used for spot measurement verification	
Manufacturer:	
Model No.:	
Accuracy:	
Last Calibration Date (attach certificate):	

Room No.	**Light Fixture Installation**		**Light Output (lux) with Setting to 100% ON**		**Light Output (lux) at Commissioned level**	
	Qty and Type Expected	**Observed**	**Expected (Lux)** (e.g. 300, 500 lux at floor)	**Measured (Lux)**	**Expected (200 Lux)**	**Measured (Lux)**

Add rows as necessary to provide an adequate sampling throughout the installation.

Trend Analysis Verification

Trend the lighting power over the course of several days and verify that the dimming profile is as expected for each row of fixtures. For example, the row closest to the window would dim more than rows further from the window.

Trend data source used for verification	
Software source:	
Trend data file names:	
Trend dates:	

Room No.	**Trend Dates**	**Performance**		**Notes**
		Expected	**Observed**	

Add rows as necessary to provide an adequate sampling throughout the installation.