Xcel Energy – LBNL ‘Beyond Widgets’ Project

LEDs with Advanced Lighting Controls and Occupancy Sensor-based Demand Control Ventilation

System Program Manual

December 2022

Executive Summary

This manual was developed by Lawrence Berkeley National Laboratory (LBNL), in collaboration with Xcel Energy (Colorado and Minnesota) 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 Xcel, in both target service territories. It may also be used by other utilities to help develop similar programs.

The structure and content of the document reflects the anticipated requirements of utility teams in the development of a program to implement the system package, and will be utilized by Xcel staff for developing related documents such as the Technical Resource Manual (TRM) and other filings pertaining to the roll-out of programmatic energy systems-based rebate incentives.

Xcel staff worked with LBNL to develop a package including LED lighting with luminaire-level controls (occupancy and daylight dimming) and paired with occupancy sensor-based demand-controlled ventilation, or DCV, applied as an integrated system package retrofit for medium and large commercial offices, in the Xcel service territories in Colorado and Minnesota. Integrated system packages present opportunities for deep energy savings; however, by nature these systems have additional levels of complexity and effort required for their design and energy savings assessment, which creates barriers for utility incentive programs to easily evaluate and capture these savings.

Previous studies indicate significant annual lighting energy savings of 28-63%, with an average of 47% (Wei et al., 2012) for LED lighting systems with advanced controls, due to reduced lighting power density compared with fluorescents and more efficient controls strategies like occupancy based switching and daylight dimming. DCV is a well understood but somewhat underutilized method of ventilation control. Energy savings arising from DCV implementation depend heavily on the application; for the best results it should be implemented in spaces with highly variable occupancy. Results from building simulation studies estimate the range of HVAC energy savings of between 9-33% (Zheng et al., 2020).

The design and operating principle of this system package is that via installation of LED light fixtures with onboard sensors and controls (luminaire-level lighting controls, or LLLCs), the heating, ventilation, and air conditioning (HVAC) system zones may also be configured to appropriately regulate the volume of ventilation supply air, relying on the lighting controls occupancy sensor data in each zone. In doing so this will save electric lighting energy by providing lighting only when and where it is needed, and ventilation supply air will similarly be provided in response to need.

The system package was selected for analysis and development following a rigorous process of energy modeling and cost effectiveness analysis conducted by LBNL. This included a literature review and building simulation modeling, supporting evaluation of individual energy efficiency measures (EEMs) in terms of energy performance and cost-effectiveness. Multiple EEMs identified as being cost effective were considered for inclusion in the final measure package for deployment in the large commercial office target market.

Market analysis was developed for large commercial office buildings in Xcel's Colorado and Minnesota service territories, indicating a market adoption potential for 30-90 gigawatt-hours (GWh) and 10-32 GWh of energy savings potential for Colorado and Minnesota respectively. Market potential was evaluated for two installation scenarios:

Normal Replacement (NR) - the existing systems have come to the End of Useful Lifetime (EUL), and are replaced. Cost effectiveness is calculated based on the cost difference between the like-for-like replacement and that of the proposed system package (incremental cost).

Early Replacement (ER) - replacement of the existing package occurs prior to the EUL. The full cost of the system package is included in the cost-effectiveness analysis.

Total Resource Cost (TRC) is the metric by which cost-effectiveness is evaluated, with values of 1 or greater indicating an acceptable return on investment from the utility program perspective. TRC values for the package measure vary by location, and range from 0.42 to 0.59, and 0.37 to 0.52 for an Early Replacement case, and 1.25 to 1.52 and 1.15 to 1.42 for a Normal Replacement strategy for Colorado and Minnesota respectively. These results indicate good economic potential for deployment of this system in the Normal Replacement case in both territories, while further investigation of customer-side benefits and valuation of non-energy benefits might be required to incentivize customers to proceed with Early Replacements. It should be noted that the cost of avoided energy in both markets may be low ($0.07/kWh for Minnesota, $0.08/kWh for Colorado) relative to other utility territories, and these TRC values would not be representative of deployment potential in other markets with higher utility rates. In addition, installation costs used for these systems may decrease with time, further enhancing their return on investment.

Model simulations for the proposed measure package indicate annual whole-building energy savings of approximately 13% for Colorado (assuming ASHRAE climate zone 5B) and 12% for Minnesota (ASHRAE climate zone 6A). Energy savings from LEDs and lighting controls (occupancy and daylight dimming), are estimated at 68% versus the base case lighting system (fluorescent lighting on scheduled controls). HVAC energy performance is impacted by the thermal effects of the lighting retrofit, whereby more natural gas heating is required to offset the reduction in heat gain due to the more efficient new lighting system. For the Colorado climate this impact translates into a net HVAC energy penalty (-3% savings), even though energy savings associated with ventilation and cooling are approximately 8%. For Minnesota, including the heating penalty due to more efficient lighting, heating energy savings are estimated at approximately 2%, with approximately 7% energy savings in ventilation and cooling.

The system package was configured and tested in LBNL's FLEXLAB™ (flexlab.lbl.gov) under a range of seasonal and ambient conditions, to evaluate the energy performance benefits and indoor environmental quality implications of the proposed measure package, compared to an existing building base case. The FLEXLAB testing demonstrated strong lighting energy savings against the baseline case of a T-8 zonal lighting configuration typical for Xcel's office market, with 79% average lighting energy savings during the test periods. Energy savings from DCV operations depended on the season and the prevailing climate conditions. During winter season tests, daily heating energy impacts ranged from a 22% energy penalty to a 40% energy saving, and for cooling, daily energy impacts ranged from a 12% penalty to 100% energy saving. In the spring season, daily energy impacts ranged from 11% to 80% heating energy savings, and 8% to 22% cooling energy savings.

The energy modeling simulation results are a more realistic reflection of energy performance at the whole building level for a number of reasons. First, the simulation results are for an entire year of system performance through all seasons and operating conditions, modeled in the specific climate zones of Xcel service territories. Also, the lab test environment is a much smaller building with relatively higher exterior surface area to interior conditioned volume, and much less thermal mass, than the approximately 500,000 ft^2 simulated office building. The impact of infiltration is also significantly greater in the smaller lab building compared with the large simulated building.

From an indoor environmental quality (IEQ) point of view, the retrofit case met the benchmark performance standards in terms of visual and thermal comfort. For visual comfort, illuminance levels were maintained above 300 lux in all locations of the test space during occupied hours. Performance of the LED system with controls did result in a reduction in task illuminance relative to the base case, which can be considered to be an over-lit environment, especially within the perimeter zone (a distance equivalent to 2 times the window height away from the window) where daylight was abundant. Thermal comfort was maintained at very similar performance levels between the base and test cases, under both Predicted Percentage Dissatisfied (PPD) and Predicted Mean Vote (PMV) indices.

Implementation guidance included here is intended to assist utility program managers in the design of an incentive program and educate customers on key aspects of the system to focus on in commissioning and operations to ensure that lighting savings are realized. These include aspects such as a requirement for appropriate programming and commissioning of the HVAC system that provides ventilation air according to occupancy needs. It also includes a requirement for a commissioned lighting system that supports desired illuminance levels at the workplane, including when daylight dimming controls features are enabled. Overall, LED lighting with luminaire-level lighting controls and occupancy-based demand-controlled ventilation present a strong potential for cost effective whole building energy savings in Normal Replacement scenarios, as demonstrated by the modeling simulation results and previous case studies.

1. Introduction

This program manual contains detailed technical information for implementing an incentive program for LED lighting with luminaire-level controls (occupancy and daylight dimming) and paired with occupancy sensor-based demand controlled ventilation, or DCV. This manual was developed by Lawrence Berkeley National Laboratory, in collaboration with Xcel Energy for the Minnesota and Colorado service territories, as partners in the ‘Beyond Widgets’ program funded by the U.S. Department of Energy Building Technologies Office. The target audience for this manual is the program staff for Xcel.

It is anticipated that the content of this manual be utilized by the utility partner 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 for the LED Lighting, Lighting Controls and Occupancy-based Demand Controlled Ventilation package.

This document contains the following sections:

> **Section 2** describes the process for selection of the energy efficiency technologies and features that are packaged into the measure.
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> **Section 3** contains a description of the proposed system technology package, key features, and key factors in determining energy savings and demand reduction.
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> **Section 4** contains a description of the base case technology, and specified the base case requirements for implementation of the proposed system package.
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> **Section 5** outlines the assumptions around Code requirements, and the implications these have for energy performance of the proposed system package.
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> **Section 6** specifies the normalizing unit for energy performance measurement of the system package.
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> **Section 7** on program requirements describes the program eligibility for implementation of the proposed system package, and the method by which the proposed system package should be assessed. It includes considerations around how the energy baseline is defined, the related cost basis for the system package, and documentation requirements. It also categorizes the program delivery methods appropriate for the proposed system package.
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> **Section 8** specifies program exclusions; rules or restrictions that limit or prevent implementation of the proposed system package.
>
> **Section 9** explains how energy savings were determined, and describes the methodology, assumptions and other processes relevant to these estimates for the proposed system package.

Section 10 outlines the requirements for data collection for the purposes of conducting measurement and verification of the system package performance. It also includes a summary of sensitivity analyses appropriate for identifying variables that are key drivers of measure impacts and / or cost effectiveness of the system package.

Section 11 describes details of the appropriate baseline for any given set of circumstances at a facility implementing a retrofit.

Section 12 describes the market channel(s) to which program services are targeted and how program objectives will be achieved.

Section 13 summarizes the cost of implementing the proposed system package, including cost breakdowns for equipment to the major component level, and labor costs for all major tasks.

Section 14 lists the works referenced in this manual.

Appendix A provides measurement and verification protocols and options for implementation of the technology system package measure.

Appendix B discusses FLEXLAB validation of the retrofit system package, including performance validation and energy savings from the lighting retrofit and the system package as a whole as determined from laboratory tests, and provides a comparison of those results to the whole building energy modeling approach discussed in Section 9.

Appendix C provides details on the retrofit lighting system cost estimates.

Appendix D is the Market Deployment Potential Analysis report. For the energy efficiency Measure package, this report provides analysis of the prospective market opportunities in the territory of Xcel Energy in Minnesota and Colorado. This report addresses the package deployment potential and determines the total technical and market potential within the territory service areas. The results from this analysis can be utilized in combination with the savings and cost metrics of the validated system calculated by LBNL to characterize energy savings potential in the utility service territory.

2. Summary of Systems Selection and Markets

Market studies show that there is significant energy savings potential for retrofits in commercial buildings. A variety of energy efficiency retrofit technologies and strategies are available, including efficient lighting and advanced lighting controls, efficient heating, ventilation, and air conditioning (HVAC) equipment and controls, and plug load controls. To develop retrofit system packages, a set of applicable efficiency measures were identified. Measure selection started with preparation of a list of relevant commercially available technologies. Measures were then prioritized based on track record in commercial buildings, utility program support, and total resource cost. Measures were screened based on ability to logically pair them in a complementary retrofit scope, grouping measures into a retrofit package. The package concept is based on research showing that integrated retrofits that encompass several end uses have higher energy savings potential than component-based approaches.

A variety of sources were reviewed to assemble the list of potential package measures - 71 measures with significant savings potential were originally evaluated. Utility partners then ranked the measures based on savings potential, program priorities, likelihood of adoption, and potential interest from customers. Thirteen individual measures were finally selected based on the utility partner ranking, and were combined into packages, applying several considerations:

- Measures that could all be implemented by a single trade in order to leverage the fixed costs of contracting and mobilization of that workforce on site.
- Measures that leveraged the capabilities of other measures, whether interactive or integrated (e.g., the use of occupancy sensors in light fixtures to inform demand-controlled ventilation).
- Measure combination based on scope of construction.
- Combinations of measures that were more applicable to retrofits.

In total, 34 packages of retrofit measures were developed and analyzed. The range of packages went from lower complexity and cost to higher. Whole building energy simulations were then conducted in order to estimate energy savings per package against a standardized baseline, also evaluating first-order cost effectiveness. Energy savings and cost outputs from modeling helped to down-select package options and arrive at the LED Lighting, Lighting Controls and Occupancy-based Demand Controlled Ventilation package.

3. Measure Case Description

This Measure is a technology system package consisting of LED lighting with advanced lighting controls integrated with occupancy sensor-based demand control ventilation. The design and operating principle of this system package is that via installation of LED light fixtures with onboard sensors and controls (luminaire-level lighting controls, or LLLCs), the HVAC system zones may also be configured to appropriately regulate the volume of ventilation supply air, relying on the lighting controls occupancy sensor data in each zone. In doing so this will save electric lighting energy by providing lighting only when and where it is needed, and ventilation supply air will similarly be provided in response to need.

Table 1. Measure description

Measure ID	Measure Description
A	LED Lighting with Advanced Lighting Controls & HVAC Demand Control Ventilation

Core Elements

- LED fixtures shall include luminaire-level controls (occupancy and daylight dimming) to be paired with occupancy sensor-based demand controlled ventilation.
- LED fixtures shall be listed on the Design Lights Consortium (DLC) Qualified Products List (https://qpl.designlights.org/solid-state-lighting)
- Lighting controls shall be of the type networked lighting controls (NLC), defined as consisting of “an intelligent network of individually addressable luminaires and control devices, allowing for application of multiple control strategies, programmability, building- or enterprise-level control, zoning and rezoning using software, and measuring and monitoring.” Design Lights Consortium Network Lighting Controls Requirements. https://www.designlights.org/workplan/networked-lighting-controls-specification/.
- The Advanced Lighting Control system shall be listed on the DLC Networked Lighting Controls Qualified Product List (https://qpl.designlights.org/networked-lighting-controls)
- Lighting controls shall be able to integrate with the existing building management system.
    - Compatibility with existing BAS (via BACNet interface, other BMS protocol, or API): The networked lighting controls (NLC) system with luminaire-level occupancy sensing must be able to communicate with other systems. Data from NLC components, such as luminaires, sensors, and controllers, shall be made available through an Application Programming Interface (API) that can be utilized by other building systems to improve operational efficiencies. Accessing the NLC component data using the API allows integration with other building systems. Adapted from Interoperability for Networked Lighting Controls. DesignLights

Consortium.
https://www.designlights.org/lighting-controls/reports-tools-resources/interoperability-for-networked-lighting-controls/report/

- The DCV control shall be added to an existing HVAC system with a functioning economizer. CO_2 sensors may be added in the return duct of the HVAC systems or in the zones.
- The existing building management system shall be capable of adding the additional data points for advanced lighting controls and DCV controls.

Key Factors Determining Energy Savings and Demand Reduction

Table 2 below identifies and describes some of the factors that influence the potential for energy savings and demand reduction associated with the proposed system.

Table 2. Building factors affecting retrofit package savings potential

Building Vintage	Age of the building will be reflected in thermal performance of its shell, and envelope, as well as being a factor in HVAC system type and efficiency.
Envelope / Glazing Area:	Building window size influences access to natural light, and degree of thermal energy loss from the building to the outdoor environment. Daylight supplements electric lighting at certain times of the day in perimeter areas of the building, with daylight dimming of the lighting system reducing electricity consumption. Depending on the climate, heating or cooling requirements increase with window size. Large windows are a less effective thermal barrier than solid walls.
Occupancy / Operating hours:	Defines the period within which normal building operations - including lighting and ventilation - take place, and has a strong correlation to energy consumption. The time of day during which operating hours occur will impact demand conditions due to ambient climate and weather conditions.
Occupant numbers / density:	A factor in lighting design and light power density (LPD) necessary to support safe working conditions. Occupancy numbers influence design air supply volume per zone as there is a per-person

	ventilation requirement. The number of occupants directly impacts cooling load in a space due to body heat radiation.
Mix of space types:	Occupancy patterns and occupancy load are often a reflection of space type. Example: In open office locations, occupant sensors integrated into individual light fixtures support more granular response to vacancy. For HVAC, the same occupancy sensors provide the capability for modulation of ventilation supply air according to the number of occupants detected. In private offices and conference rooms, single occupant sensors typically do not count people, indicating occupied or vacant only, and normally control to binary on-off modes.

4. Base Case Description

The base case description describes the base case scenario that is appropriate for implementation of the measure package.

Table 3. Measure base case

Measure ID	Base Case Description
A	Existing linear fluorescent lighting fixtures, incandescent or compact fluorescent (CFL) fixtures that are either manually controlled or are controlled by wall or ceiling mounted occupancy sensors. No Demand Control Ventilation in the HVAC zones.

The target market segment identified by the partner utilities for this system package: medium and large commercial office.

Core Elements:

- The existing lighting fixtures should be linear fluorescent, incandescent or CFLs that are either manually controlled or are controlled by wall or ceiling mounted occupancy sensors. These could be either troffers or pendants.
- The current HVAC system should have functioning economizers.
- The existing zone ventilation should be provided by variable air volume (VAV) boxes that are direct digital controls (DDC) controlled.
- The existing system must ventilate continuously during occupied hours and may not have any other device previously installed that is intended to perform DCV such as an occupancy sensor that controls ventilation rate.

5. Code Requirements

Standards and regulations can impact the assumptions and inputs of the energy savings and demand reduction calculations.

This section identifies and describes all federal and/or state regulations that pertain to the minimum energy use requirements of the proposed Measure, and identifies the appropriate baseline condition used for the calculation of measure impacts.

Core Element:

For program eligibility, the utility partner should refer to any state code or Industry Standard Practice for advanced lighting controls, LED fixtures, economizer control, general ventilation and DCV requirements.

Light Fixtures and Controls

The existing building condition is assumed for this purpose, which will vary on a case-by-case basis. There is currently no code applicable for performance evaluation of lighting and lighting controls.

HVAC Controls

The guidance below relates specifically to the implementation of Demand Control Ventilation under the proposed system package.

For requirements on ventilation and indoor air quality, refer to Section 6 of Ventilation for Acceptable Indoor Air Quality, ASHRAE Standard 62.1-2016. Occupied spaces served by mechanical ventilation are required to meet outdoor air requirements according to both the design number of occupants and the serviced floor area.

- For outdoor air dedicated to the floor area fraction, Table 6.1 (ASHRAE Standard 62.1-2022) stipulates that 0.06 cubic feet per minute per square foot (cfm/ft^2) is required for occupied office space. Breakrooms have higher requirements of 0.12 cfm/ft^2.
- For outdoor air dedicated to meeting the occupant fraction, Table 6.1 (ASHRAE Standard 62.1-2022) stipulates that 5 cfm is required per occupant throughout the building.
- Building zones that are suitable for occupied-standby mode (i.e., open office areas) may include a zero-flow setting during vacancy, if normal operations are resumed once occupancy is detected (section 6.2.6.1.4 and Table 6.1, ASHRAE Standard 62.1, 2022)
- For Demand Control Ventilation, Table 6.2.2.1 (ASHRAE Standard 62.1-2022) stipulates that the minimum outdoor air rate for DCV shall be no lower than the sum of the per area and per occupant fractions as outlined above, in cfm/ft^2 (0.06 cfm/ft^2 + ((5 cfm/occupant)/ft^2 per occupant)).

For requirements on economizer operations, refer to Section 6.5.1 of ASHRAE Energy Standards in Buildings ASHRAE Standard 90.1-2013. The economizer high limit will be determined by the control device that is utilized - the assumed accuracy of each sensor type is stipulated in Section 6.5.1.1.6.

6. Normalizing Unit

Savings and costs are expressed by a unit of measure referred to as the Normalizing Unit. Savings and cost here are normalized by floor area, in terms of square feet.

a. Costs of implementation for the system package are expressed in dollars per square foot of treated floor area ($\$/ft^2$)
b. Energy savings derived from the system package are expressed as an annual figure in kilowatt-hours per square foot of treated floor area ($kWh/ft^2/yr$)
c. Demand savings derived from the system package are expressed as an annual figure in kilowatts per square foot of treated floor area ($kW/ft^2/yr$)
d. Energy cost savings estimates are derived from application of appropriate energy unit prices according to the appropriate time-of-use tariff structure, to energy savings calculated in (b), and are expressed as an annual figure in dollars per treated floor area. ($\$/ft^2/yr$)
e. Demand cost savings estimates are derived from application of appropriate demand reduction unit prices according to the appropriate tariff structure, to demand savings calculated in (d), and are expressed as an annual figure in dollars per treated floor area ($\$/ft^2/yr$)

7. **Program Requirements**

Program requirements include all eligibility requirements for implementation of the Measure.

Core Elements:

- **Measure Implementation Eligibility**: Designates the measure application type, delivery type, and sector combinations for which measure packages have been developed.

Measure application type is a categorization based on the circumstances and timing of the measure installation; each measure application type is distinguished by its baseline determination, cost basis, eligibility, and documentation requirements. If the equipment has useful life left (e.g. ability to continue to render service), then the measure will qualify as an early replacement (ER), sometimes also known simply as a retrofit, but if the equipment has exceeded its useful life then it will qualify as normal replacement (NR), often also called replace on burnout. If any control is being added to an existing piece of equipment to improve its performance, then the measure qualifies as a retrofit add-on (RAO).

Categorization of the measure application type is a critical element in understanding cost effectiveness. This reflects a) the appropriate cost basis for installation, and b) the energy baseline against which system package energy performance is evaluated, and its duration. There are three categories of equipment replacement and controls implementation as described in Table 4 below.

Table 4. Cost effectiveness inputs

Measure Application Type	**Description**	**Cost Basis**	**Duration of Benefits**	**Energy Benefits**
Normal Replacement (NR)	Equipment or controls replaced with appropriate equivalent technology, at Expected Useful Lifetime (EUL) or later	Incremental cost above Code minimum option	EUL of replacement	Above prevailing Code energy savings only
Early Replacement (ER)	Equipment or infrastructure, including controls, replaced prior to EUL.	Full cost	EUL of replacement	Relative to existing baseline

Measure Application Type	Description	Cost Basis	Duration of Benefits	Energy Benefits
Retrofit Add-on (RAO)	Addition of equipment or controls items not originally present.	Full cost	Remaining Useful Lifetime (RUL) of current baseline	Relative to existing baseline

LED Lighting and Controls

Option 1 Example: The fluorescent lighting fixtures currently in a building were installed in 2012. Considering the EUL of a fluorescent lamp is 15 years, there are still 5 years of operation left as of 2022. If the customer were to replace the existing lighting fixtures with LED lighting fixtures, this upgrade would fall under the ER category, because the equipment still has useful life remaining. If the customer were to include advanced lighting controls as part of the LED fixture installation, the controls will fall under the RAO category.

Option 2: The fluorescent lighting fixtures currently in a building were installed in 2003. As they are past their assumed EUL, replacing them now would fall under the NR category. If the customer were to include advanced lighting controls as part of the LED fixture installation, the controls will fall under the ROA category.

Demand Controlled Ventilation

Option 1: There is currently no demand-based ventilation control in the building. If the customer were to implement the controls upgrade, and install the necessary supplementary CO2 sensors in each zone, the installation would come under the RAO equipment category.

Due to the multiple elements that make up the Measure package described, the overall system package application type inevitably combines multiple measure application types. However, as the DCV element always falls into the RAO type, the applicable baseline will defer to whichever measure application type applies to the LED lighting and controls - both ER and NR are evaluated over their Expected Useful Lifetime, the difference being that they are assessed against different baselines. Table 5 outlines how measure application type impacts system application type, and the implications for which is an appropriate energy and carbon emissions baseline.

Table 5. Relationship between measure and system application type

Measure Application Type - Lighting	Measure Application Type - Lighting Controls	Measure Application Type - DCV	Overall System Application Type	Duration of Benefits	Benefits
ER	RAO	RAO	ER	EUL of Replacement Lighting	Relative to existing baseline
NR	RAO	RAO	NR	EUL of Lighting and Controls	Above code savings only

Delivery type is the broad categorization of the delivery channel through which the market intervention strategy (financial incentives or other services) is targeted. In many areas, there are three delivery types that can be employed; deemed (express) and custom, but other types exist, including pilot and emerging technology (ET) measures, hybrid, and normalized metered energy consumption (NMEC).

The Measure package described here is intended for inclusion in a rebate incentive program that would necessarily require calculations to support reporting of energy savings, at least in the near-term, prior to data being available on performance of the Measure package, when installed.

The International Performance Measurement and Verification Protocol (IPMVP) provides guidance on operational verification, which “consists of a set of activities that help to ensure that the energy conservation measure (ECM) is installed, commissioned and performing its intended function.” There are several available options for calculating energy savings as would be required here. These are described in Table 6 below.

Using this information, a utility demand-side management (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. The aim of offering the menu of options is to present different measurement and verification (M&V) approaches, including traditional ones and new options that could streamline M&V 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.

Table 6. Measurement and Verification options

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

The utility and its customers are best placed to identify which of the options above is the best fit at a) the facility and b) the program portfolio level. For more detail on M&V, refer to Appendix A.

For example: If the utility has a rebate program where the energy savings are based on a per fixture, per control point, or per building square feet basis (per unit basis of measure), then the measure will qualify as an express measure. The savings for express measures are either based on workpapers or regional technical resource manuals. However, if the utility requires calculations to report energy savings then the measure will likely qualify as a custom measure. The savings for custom measures are calculated either from whole building energy simulations, excel spreadsheet calculations, or meter-based measurement.

Market Sector
This system is being considered for medium and large commercial office buildings only.

Table 7. System application type

System Application Type	Delivery Type	Sector
Early Replacement	Custom → Express	Commercial
Normal Replacement	Custom → Express	Commercial

Eligible Products

Detailed Lighting and Lighting Controls Requirements

The system package shall include the following:

- Selection of appropriate fixtures (power, light output) to deliver lighting for required ambient conditions, per prevailing lighting design criteria
    - LED fixtures with luminaire-level controls (occupancy and daylight dimming) to be paired with occupancy sensor-based demand controlled ventilation.. Selected equipment must meet DesignLights Consortium (DLC) Solid-State Lighting Technical Requirements and be listed on the DLC SSL Qualified Products List, https://www.designlights.org/search/)
        - LED fixtures
          OR
        - LED replacement kits
- Selection of appropriate lighting controls system to deliver advanced controls features required for this package, meeting DLC Networked Lighting Controls Technical Requirements and listed on DLC's qualified products list, https://qpl.designlights.org/networked-lighting-controls.

    - Lighting controls shall be "an intelligent network of individually addressable luminaires and control devices, allowing for application of multiple control strategies, programmability, building- or enterprise-level control, zoning and rezoning using software, and measuring and monitoring." DesignLights Consortium Network Lighting Controls Technical Requirements. https://www.designlights.org/our-work/networked-lighting-controls/technical-requirements/nlc5/

- o The Advanced Lighting Control system shall be listed on the DLC Networked Lighting Controls Qualified Product List (https://qpl.designlights.org/networked-lighting-controls)
- o Lighting controls shall be compatible with the existing building management system (via BACNet interface, other BMS protocol, or API): Data from NLC components, such as luminaires, sensors, and controllers, shall be made available through an Application Programming Interface (API) that can be utilized by other building systems to improve operational efficiencies. Accessing the NLC component data using the API allows integration with other building systems. Adapted from Interoperability for Networked Lighting Controls. DesignLights Consortium. https://www.designlights.org/lighting-controls/reports-tools-resources/interoperability-for-networked-lighting-controls/report/
- o Required controls features
    - ▪ Occupancy controls
        - ● Switches on in response to occupancy at either zone or cubicle level
        - ● Switches off in response to vacancy, with appropriate timeout.
        - ● Dims to specified (background/ambient) level in vacant areas / cubicles of zone
    - ▪ Required (in perimeter zones): Daylight dimming
        - ● Dimming at zone or cubicle level in response to available natural light
    - ▪ Schedule controls: Sweep / time clock-based auto-off for after-hours / weekend periods
- o Optional controls features
    - ▪ Manual operation via switching
    - ▪ Occupant dimming / task-tuning controls

Energy savings are derived from several elements of the new equipment and infrastructure:

- Reduction in installed lighting power per unit area (W/ft^2) that reflects increased efficacy of the light source technology and delivered lumens equivalent to the base case condition
- On-off operation of individual light fixtures according to fixture integrated occupancy sensor signal
- Daylight dimming of individual light fixtures in building perimeter zones during occupancy
- Sharing of occupancy sensor data with HVAC system for demand controlled ventilation purposes, reducing conditioning energy needed for outside air when lower demand allows.

<u>Detailed Demand Controlled Ventilation Requirements</u>

- Normal system ventilation control shall occur per relevant standard, e.g. ASHRAE 62.1-2016, during periods of maximum occupancy at the zone and air handler levels.

- Ventilation flow rates shall be adjusted at the zone and air handler levels to account for lower occupancy levels as indicated by utilizing lighting occupancy sensor readings at the fixture level to make adjustments based on occupancy. Ventilation rates are expected to span several conditions:
    - Ventilation at maximum levels to meet full design occupancy
    - Ventilation reduces to relevant minimums according to unoccupied zone sensing
    - Ventilation at intermediate occupancy levels implemented based on occupant counts at the zone level, for multiple zones
    - CO_2 sensor as back-up / safety alarm as required by local code, standards or preference. Location of the CO_2 sensor shall be at a centralized return air location, or as required by relevant ventilation standard or code (i.e., one per air handler return).

Eligible Building Types and Vintages: The target market sector for this system package is medium and large commercial office buildings of all vintages so long as lighting and HVAC systems meet requirements for base case equipment and Measure package implementation.

8. Program Exclusions

The system package described here is for implementation in commercial office buildings only - the descriptions, inputs, assumptions and analysis herein should not be applied to other building types, and similarly the case for implementation in other building types does not apply.

9. Energy Savings

Simulation results

Whole building and end-use energy usage were modeled with EnergyPlus-based simulations for the relevant climate zone. EnergyPlus provides assessments of integrated building designs and solutions, and is a free, open-source platform that enables hourly time step energy outputs, which are needed to assess energy costs with various utility rate structures including demand charges.

Whole building energy use was simulated under baseline conditions and with the retrofit package implemented in the EnergyPlus model to derive package savings as the difference between the baseline model and the retrofit model. The large office building model used in simulations is approximately 500,000 ft^2 with 12 floors, an aspect ratio of 1.5 (length-to-width), and a window-to-wall ratio of 0.4. The detailed zoning version of the DOE reference model for commercial office ("Commercial Reference Buildings," n.d.) was used, as this model entails more detailed and realistic thermal zones than the standard reference models. The detailed zoning version, illustrated in Figure 1 below, has 26 zones per floor. Detailed zoning was important for the package analysis because the package involves HVAC zone level controls that account for diversity in zone conditions (e.g. occupancy).

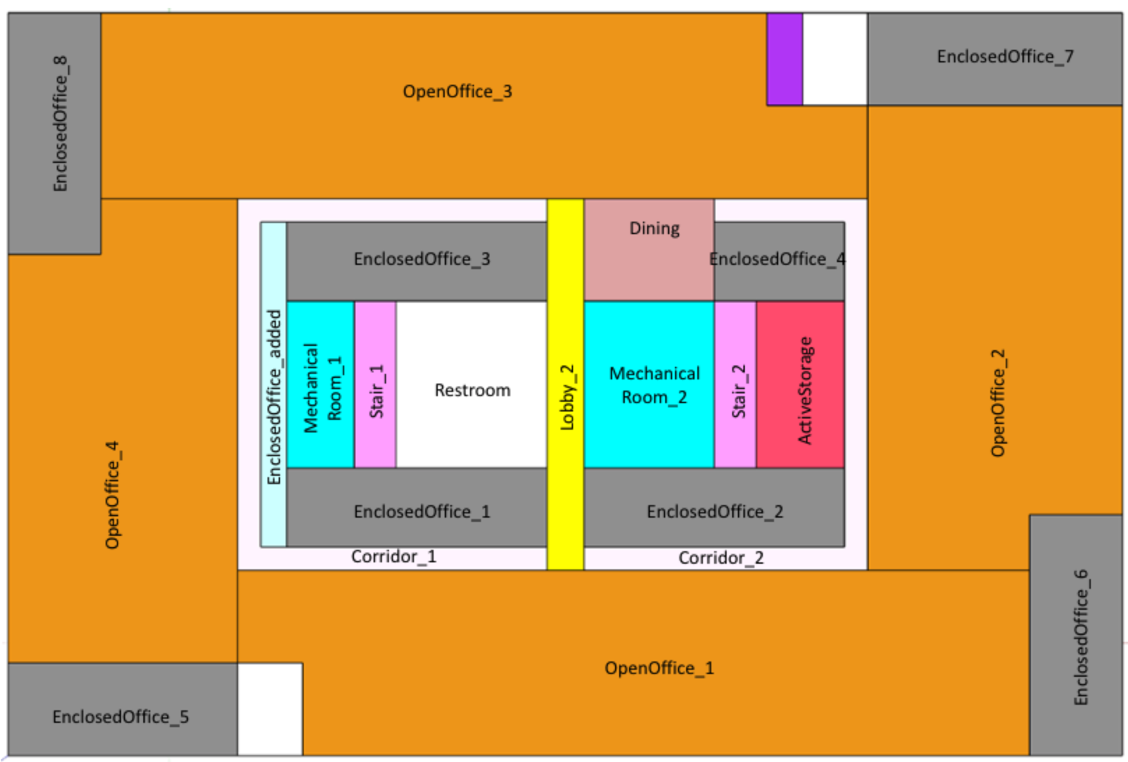

Figure 1. Floor plan showing thermal zones in the detailed zoning version of the commercial building prototype model used for the analysis

For an existing building baseline, the post-1980 vintage model was used. As most existing buildings will have lighting systems that have been retrofitted from T12 fluorescent lamps consistent with earlier reference model lighting power densities, the lighting system assumptions for the existing building baseline were updated to the lighting power density (LPD) levels of ASHRAE 90.1 2010, consistent with 3-lamp T8 fluorescent fixtures: LPD of 0.98 (open office). Figures 2 and 3 show the breakdown of end-use energy in the existing building baseline for Colorado and Minnesota; both electrical and gas energy, expressed in units of kWh/year.

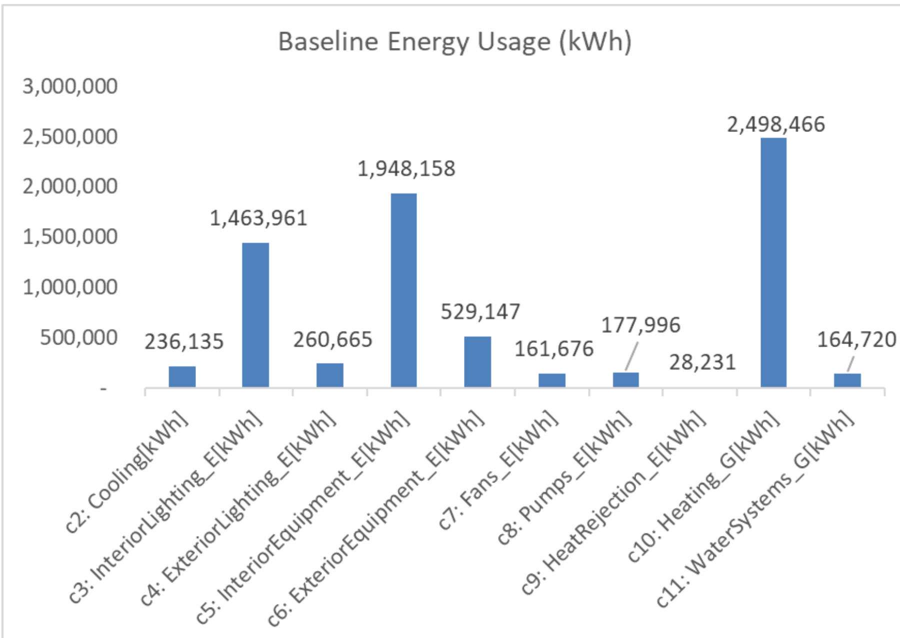

Figure 2. Simulation-based annual energy usage for existing building baseline – Colorado

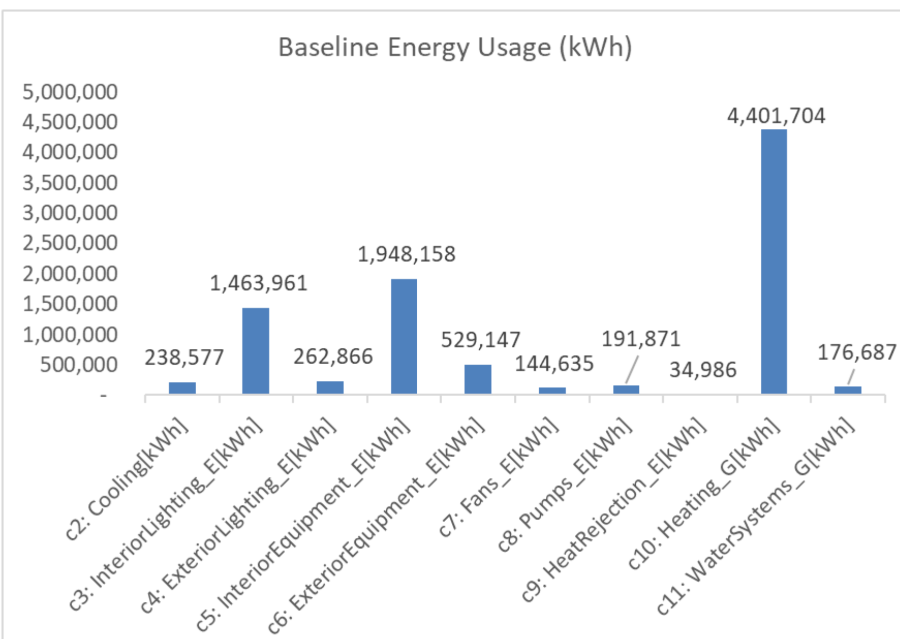

Figure 3. Simulation-based annual energy usage for existing building baseline - Minnesota

Simulation savings

Based on annual energy simulations, the measure savings were derived for the LED lighting with advanced controls and DCV package. Savings results from the existing building baseline are tabulated in Table 8 below in relative terms (%) and in floor area-normalized terms of annual energy usage intensity and peak demand intensity. Figures 4 and 5 illustrate relative savings (%) for Colorado and Minnesota for whole building energy, peak electric demand, and as well as energy at the level of lighting and HVAC systems, and natural gas energy.

Table 8. Simulation-based annual energy savings for measure in relative (%) and normalized energy and demand terms

	Whole Building Energy Savings		**Lighting Electricity Savings**		**HVAC Electric Savings**		**Gas Energy Savings**		**Peak Demand Savings**	
	EUI savings (kWh/ft^2/yr)	% savings	EUI savings (kWh/ft^2/yr)	% savings	EUI savings (kWh/ft^2/yr)	% savings	EUI savings (kWh/ft^2/yr)	% savings	W/ft^2 savings	% savings
Existing Building - Colorado	**1.94**	**13%**	**2.00**	**68%**	**0.10**	**8%**	**(0.15)**	**-3%**	**0.92**	**31%**
Existing Building - Minnesota	**2.28**	**12%**	**2.00**	**68%**	**0.08**	**7%**	**0.21**	**2%**	**0.83**	**26%**

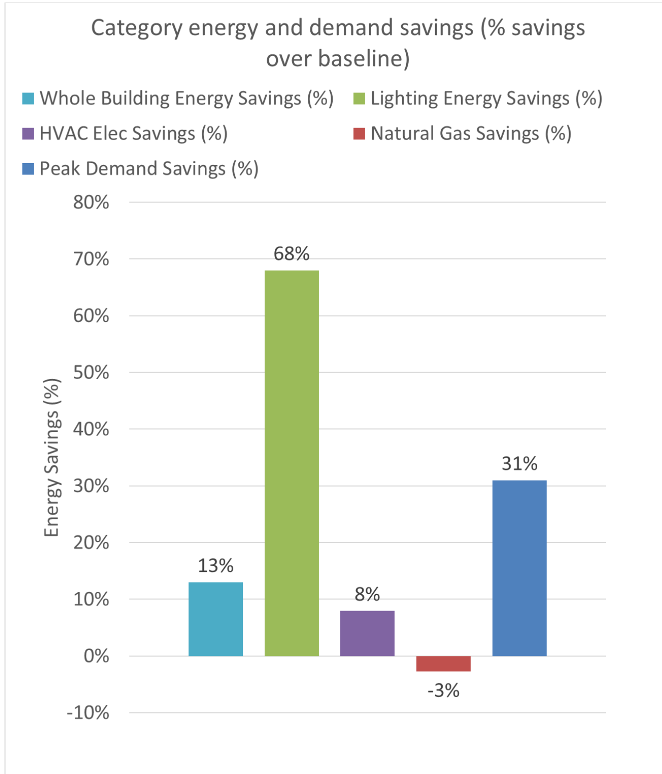

Figure 4. Simulation-based annual energy savings for existing building baseline - Colorado

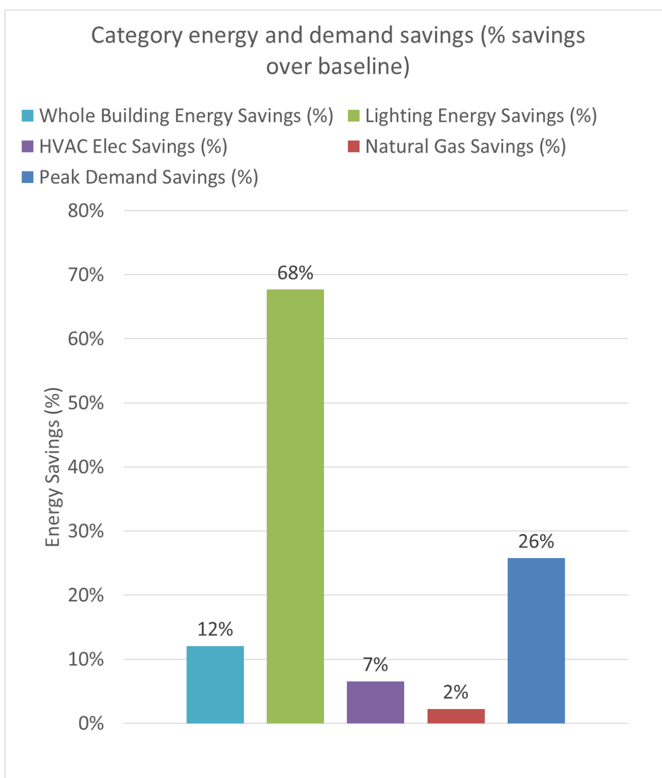

Figure 5. Simulation-based annual energy savings for existing building baseline - Minnesota

Laboratory validation

In addition to whole building annual energy simulations, the systems package was tested at FLEXLAB®, LBNL's comprehensive integrated building technologies test facility (FLEXLAB.lbl.gov). The main objectives of the testing for this system were to validate performance of and lighting and HVAC energy savings from the LED Lighting, Lighting Controls and Occupancy-based Demand Controlled Ventilation package, and to evaluate visual and thermal comfort parameters.

The retrofit case (the systems package) and the base case (i.e., baseline T8 fluorescent lighting system without advanced controls, and no demand controlled ventilation) were tested over the dates shown in Table 9. The baseline and retrofit systems were tested at the same time under identical conditions using the two parallel test cells in the FLEXLAB rotating testbed, pictured below in Figure 6.

Table 9. FLEXLAB test days per season

Winter	**Spring**	**Summer**
10 days	23 days	13 days

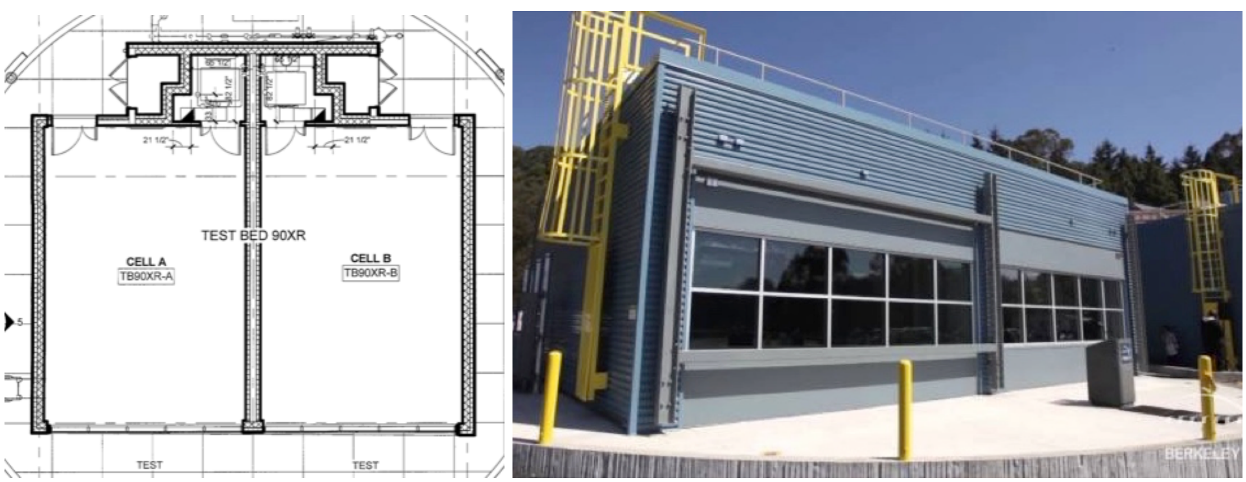

Figure 6. FLEXLAB testbed layout (left) and image of south-facing facade of testbed (right)

Generally FLEXLAB testing validated the viability of the retrofit package, demonstrating continuous and reliable operation of HVAC and lighting systems with retrofit measures implemented and maintaining HVAC and lighting setpoints and schedules throughout each test day. Lab results showed significant lighting energy savings (79%) in line with though greater than simulation predictions (68%), and additional savings in HVAC thermal load. For HVAC thermal load results from lab tests, it is important to recognize that they are for a relatively small number of days of operation in a specific location and building; HVAC thermal load savings from lab tests are not annualized, whereas the whole-building simulations do provide annual results.

Lab tests also validated that indoor environmental comfort parameters were maintained within acceptable levels; levels equivalent to or better than baseline performance, including task illuminance and thermal comfort values (Predicted Mean Vote and Predicted Percentage Dissatisfied). More details on FLEXLAB testing and validation, including comparison of lab and simulation results, are provided in Appendix B.

Net-to-Gross (NTG)

(The net-to-gross (NTG) ratio represents the portion of gross impacts that are determined to be directly attributed to a specific program intervention. For this measure the NTG, usually higher when a new measure is launched and decreasing over time when the market saturates, shall be determined by utility partner).

The measure NTG may be based on lighting and advanced controls measure and HVAC measure NTGs, but consideration should be made for the very low market penetration to-date of energy efficiency packages that integrate lighting and HVAC controls.

The appropriate NTG ratio will be determined by the utility.

Effective Useful Life (EUL)

EUL is an estimate of the median number of years that a measure installed through a program is still in place and operable. The Measure package is assumed to have an EUL of 10 years. Table 10 below details measure savings over the 10 year assumed EUL.

Table 10. Estimated EUL energy savings in relative (%) and normalized energy terms

	Whole Building Energy Savings	**Lighting Electricity Savings**	**HVAC Electric Savings**	**Gas Energy Savings**
	10-yr EUI savings (kWh/ft^2)	10-yr EUI savings (kWh/ft^2)	10-yr EUI savings (kWh/ft^2)	10-yr EUI savings (kWh/ft^2)
Existing Building - Colorado	**19.4**	**20**	**1**	**(1.5)**
Existing Building - Minnesota	**22.8**	**20**	**0.8**	**2.1**

Core Element:

- The utility partners should refer to their energy efficiency (EE) measure database to determine the proper eligibility of the retrofit package since it is a combination of lighting, advanced lighting controls, and HVAC controls measures.

10. Data Collection Requirements

Collection of data for projects that have implemented the measure package is an essential part of documenting appropriate installation and implementation. In particular, the list below indicates data requirements for detailed estimates of measure energy and demand impacts and for M&V of effective measure implementation, and will complement whichever M&V option is most appropriate for the project or the program.

Core Elements:

The list below identifies the necessary information required for verification of measure installation and is complementary to the operational verification process described in the IPMVP literature. Factors that drive measure impact and cost effectiveness and impact performance of the baseline and / or the Measure package are identified as key analysis factors.

General

- Building type
  - Vintage
    - Key analysis factors: thermal performance of shell / envelope assembly, HVAC system efficiency
  - Geometry and orientation
    - Key analysis factors: glazing area as a proportion of envelope (availability of natural light and daylight dimming)
  - Floor area
    - Key analysis factors: floor area per zone
  - Tenant type
    - Key analysis factors: occupant density (cooling and heating load per unit area)
  - Occupancy schedule
    - Key analysis factors: occupant density per zone (average and peak ventilation supply requirements)

Lighting

- Lighting system audit, for applicable floor area where lighting will be retrofitted:
  - Reflected ceiling plan (RCP) showing fixture location per zone, floor
  - Count of actual fixture quantities per zone, floor, etc. (may vary from RCP)
    - Key analysis factors: as-built fixture quantity and location
  - Fixture baseline types, wattages, per fixture
    - Key analysis factors: fixture density, lighting power density
  - Fixture retrofit type, wattages, per fixture
  - Baseline system controls type per space, zone, floor etc.
    - Switch and sensor locations
    - On/off schedules, if automated

        - Key analysis factors: equivalent full load operating hours/yr
    - Retrofit system advanced lighting control capabilities (shut-off, continuous dimming, daylighting, task tuning, occupancy sensing)

<u>HVAC</u>

- HVAC system type and age
    - Key analysis factors: overall system efficiency
- Nominal cooling capacity (tons)
- As-found minimum ventilation position (>0% open)
- As-found occupied fan operation (Continuous/ON)
- As-left minimum ventilation position
- Sensor location (zones or return ducts)
- CO2 concentration high limit (ppm)
- Monitoring data from the Building Management System to verify proper control operation (for DCV, ALCS and VAV controls)

11. Measure Application Type

This section briefly describes the process by which the utility should classify an energy efficiency retrofit activity and the appropriate baseline treatment.

Table 11. Measure application definitions and baselines

Measure Application Type	First Baseline
Normal Replacement (NR), Early Replacement (ER), and Retrofit Add-on (RAO)	Existing Condition with Prior Lighting Upgrade (from T12 to T8)[1]

Core Elements:

- If the project is doing early replacement (ER) or Retrofit Add-On (RAO) then the utility partner should collect the preponderance of evidence (POE) to show program influence in the customer's decision.
- If the project uses a normal replacement (NR) approach then the customer should adhere to the state codes for lighting, controls, and ventilation. The utility partner should refer to their other EE programs for deciding on if/how to cap the incentives for this project (since the incremental measure cost will be so low).
- The utility should refer to their other EE programs to determine the appropriate measure effective useful life, and how this is applied as it relates to the ER, NR and RAO cases described. These definitions will be a determining factor in the methodology selected for cost calculation.

[1] Assuming ASHRAE 2010, whereby 3-lamp T8 fixtures constitute the in-place lighting equipment. It is assumed that there are no networked controls, and that scheduled operation is from 8am - 6pm.

12. Measure Delivery Type

This section identifies the Delivery Type options, which refer to the market channel to which program services should be targeted, and reflect the equipment elements and characteristics in the measure package.

Table 12. Measure delivery channels

Possible Measure Delivery Types	
Upstream	Targets manufacturers and importers
Midstream	Targets distributors
Downstream	**Targets the customer through an implementer**
Custom	**Mostly targets customers through implementers**
Rebate	**Targets customers after purchase**

In many utility programs, the incentive is paid either directly to the consumer or to the implementer (contractor) who has done the work for the customer. These are known as downstream measures. Another common approach is to encourage the distribution of the product by offering discounts on specific products that are some at the distributor level. These are midstream measures.

It is possible to have a program that is implemented through multiple channels to maximize the opportunity for program success. As underscored in Table 12 above, the measure package here is intended for delivery via the downstream channel and direct to customers via rebate delivery - the performance evaluation of the package herein reflects this intention. There may also be customers for whom the custom channel is most appropriate. The utility should review its existing delivery channels and programs and determine which is the best fit.

13. Measure Cost

Measure Case Material and Labor Costs

Costs were estimated for the Measure package using a variety of sources: a construction industry cost estimate database ("RSMeans Online," n.d.), prior experience with equipment installation for other projects, market intelligence from industry experts, and discussions with lighting and HVAC manufacturers and suppliers. This database allows for regionalization of costs according to local equipment pricing and labor rates.

Material cost estimates (before scale markdowns, contractor markups, overhead, and taxes) are around $180 per LED fixture and $20 for on-board controls per fixture, with base labor costs per fixture of $60 to $90 depending on region (before markups, including 3rd shift premium). Installation cost estimates are calculated from the estimated number of units installed, built up from project floor area and density of units per area, and estimated cost per unit (materials and installation labor). For LEDs with integrated and networked occupancy and daylighting controls, a lighting fixture density of just over 80 sf per fixture is assumed, and approximately 450,000 ft^2 of floor space are applicable. Final lighting and controls system costs include equipment markup, project overhead, material taxes, and costs for network commissioning, including luminaire mapping and zoning in the controls network, and total around $1.8 million for CO and $2.0 million for MN.

Retrofit costs for early replacement were based on the estimated total cost of equipment and labor whereas normal replacement (replace on burnout) costs were based only on the incremental cost of the measure option compared to a 'standard' option (e.g., for lighting, basic LED or fluorescent fixtures without integrated sensors and controls), with estimated totals of $481,000 (CO) to $490,000 (MN).

For zonal demand-controlled ventilation (DCV) via occupancy-sensing, costs are estimated per zone controlled, with 90 applicable zones, at 3,600 sf per zone and approximately 325,000 ft^2 of applicable floor area. Implementation costs of $720 to $1,060 per zone is assumed, at a labor rate of $90 to $132/hour. The estimated installed cost with markups for DCV implementation is $78,000 (CO) to $119,000 (MN) or $0.17 to $0.26/$ft^2$ of applicable area. This is the assumed cost as a retrofit add-on, and is the same whether the project is early replacement or normal replacement for the lighting system, since the DCV implementation is an add-on to existing HVAC rather than replacing a system.

The total estimated cost for the Measure, including the lighting system and DCV costs, for the approximately 500,000 ft^2 office model is $1.9 million (CO) to $2.1 million (MN) for early replacement and $560,000 (CO) to $608,000 (MN) for normal replacement. Final cost for implementation in the reference building according to the descriptions above, and normalizing the costs of the various elements to the gross useful floor area of the entire building.

Table 13. System implementation cost estimates - Colorado

	LED Retrofit with	LED Replace on Burnout

	Advanced Controls	with Advanced Controls
Lighting Equipment and Controls ($)	$1,831,000	$480,000
Demand Control Ventilation ($/ft^2)	$78,000	$78,000
Total ($/ft^2)	**$3.83**	**1.12**
Total ($)	**$1,909,000**	**$559,000**

Table 14. System implementation cost estimates - Minnesota

	LED Retrofit with Advanced Controls	LED Replace on Burnout with Advanced Controls
Lighting Equipment and Controls ($)	$2,017,000	$490,000
Demand Control Ventilation ($/ft^2)	$119,000	$119,000
Total ($/ft^2)	**$4.28**	**$1.22**
Total ($)	**$2,136,000**	**$608,000**

14. References

ANSI/ASHRAE/IES Standard 90.1-2019 -- Energy Standard for Buildings Except Low-Rise Residential Buildings. https://www.ashrae.org/technical-resources/bookstore/standard-90-1-document-history

ASHRAE Standard 62.1-2016. Ventilation for Acceptable Indoor Air Quality. https://www.ashrae.org/technical-resources/bookstore/standards-62-1-62-2

DLC. Design Lights Consortium Network Lighting Controls NLC5 Technical Requirements. 2020. https://www.designlights.org/our-work/networked-lighting-controls/technical-requirements/nlc5/

DLC. Networked Lighting Controls Qualified Product List. https://qpl.designlights.org/networked-lighting-controls

DLC. Interoperability for Networked Lighting Controls. DesignLights Consortium. Yao-Jung Wen, Teddy Kisch, and Dan Hannigan, Energy Solutions. May 2020. https://www.designlights.org/lighting-controls/reports-tools-resources/interoperability-for-networked-lighting-controls/report/

DOE. U.S. Department of Energy Commercial Reference Buildings. https://www.energy.gov/eere/buildings/commercial-reference-buildings

EnergyPlus whole building energy simulation program. https://energyplus.net/

International Performance Measurement and Verification Protocol (IPMVP) Concepts and Options for Determining Energy Savings. Efficiency Valuation Organization (EVO®). https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp

RSMeans Data from Gordian ® https://www.rsmeans.com/products/online

Wei, J., A. Enscoe, F. Rubinstein. 2012. Responsive Lighting Solutions. GSA Green Proving Ground. https://www.gsa.gov/cdnstatic/GPG_Occupant_Responsive_Lighting_09-2012.pdf

Zheng D. O'Neill, Yanfei Li, Hwakong C. Cheng, Xiaohui Zhou & Steven T. Taylor. 2020. Energy savings and ventilation performance from CO2-based demand controlled ventilation: Simulation results from ASHRAE RP-1747, Science and Technology for the Built Environment, 26:2, 257-281, DOI: 10.1080/23744731.2019.1620575

Appendix A - Measurement and Verification

Operation Verification

According to the International Performance Measurement and Verification Protocol (IPMVP) operational verification “consists of a set of activities that help to ensure that the energy conservation measure (the retrofit package in this case) is installed, commissioned and performing its intended function.”

As a precursor to the four detailed M&V options, IPVMP states that the task of operational verification should be included in M&V plans, “...as a low-cost initial step for assessing savings potential and verifying performance over time…”.

IPMVP describes the four approaches to operational verification, summarized in the table below.

Table A-1. IPMVP operation verification approaches

Operational Verification Approach	Activities
Visual Inspection	View and verify the physical installation of the EEM.
Sample Spot Measurements	Measure single or multiple parameters that reflect EEM performance for a representative sample of EEM installations
Short-term Performance Testing	Test for functionality and control of EEM, and measure key parameters. May include tests that highlight performance over full range of function / capacity,
Data Trending and Control-Logic Review	Set up trends and review data or control logic. Test period can range significantly from hours to weeks depending on the objective.

For the lighting system operation, verification may include:

- Verify that at 100% dimming that the light fixture actually produces no light output. It has been observed that some lighting control systems have a preprogrammed lower limit on their dimming controls so that the lights do not actually turn off at full dimming.
- Verify the light output (lux) of the fixture at 100% (on) corresponds to the intended illuminance level at the workplane. Measurement should be done in the absence of any other light source that could affect readings.
- Trend lighting power over the course of several days and verify that the dimming profile is as expected for all fixtures and zones. For example, those closest to daylight sources such as windows and skylights should dim more than those further from daylight. If lighting power is not available, dimming status may be used as a proxy.

For demand controlled ventilation, verification may include:

- Confirm data communication from light fixture occupancy sensors to BAS, and routing to HVAC control modules.
- Verify minimum ventilation flow rates according to occupancy and treated floor area volume flow rate requirements
- Verify minimum and maximum outdoor air damper position
- Verify supply air fan speed against occupancy-sensor data to confirm appropriate mapping

Verification for both systems may be done as part of routine commissioning for these systems, and may be included in the scope of work for the installer.

- **M&V Options**

IPMVP describes four options for M&V. Included in the table below is a summary of the applicability and implications for each of the options.

Table A-2. IPMVP M&V options

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	Analysis of utility meter data using techniques ranging from simple before-and-after

determined by projecting from historical data using a range of possible methods.	comparisons to regression analysis.
Option D: Calibrated Simulation This approach uses a calibrated simulation using professional software and applies to the whole facility or sub-facility.	Software simulations model the buildings performance via iterative calibration and then the calibrated model is used to determine the retrofit systems energy use.

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.

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 HVAC savings.

Lighting energy metering: Post retrofit measurement may be 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 calculated power has been verified with direct measurements.

Pre-retrofit lighting energy use could be estimated using temporary measurements of load and the same schedule as post-retrofit. 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 orientation due to different solar and external conditions. If sampling, it is critical to ensure that the sample spaces cover the range of orientations and external conditions as well as internal occupancy conditions.

Measurement period: Due to seasonal variations in savings from daylight dimming, it is important to have measurements cover a range of seasonal conditions. The ideal period would be from solstice to solstice. If that is not viable, it could be done for shorter periods e.g. a week each month.

HVAC metering for demand controlled ventilation savings:

Outdoor air flow rates can be sampled via in-duct airflow sensors, and compared with occupancy levels - data that should be accessible from the BAS via the advanced lighting controls system. This is by far the simplest exercise to determine the relationship between outdoor air airflow and occupancy. To determine accurate operations of the DCV design, this data may also be cross-referenced with that from several other control points.

Monitoring of Supply Air Fan Speed and Outside Air Damper Position: The programming and commissioning process should comprise mapping and recording of supply air fan speed and outdoor air damper position according to various occupancy levels. Comparison of air flow rates to mapping data will confirm whether this has been executed correctly.

Sampling of CO2 levels in critical zone: The system package does not include provision of a CO2 sensor as a means of ensuring that recommended concentrations that would satisfy the substantial majority of occupants (700 ppm)[2] are not exceeded. Installation would be at the discretion of the building owner, with the recommendation that sensors should be placed in the return air duct for priority zones.

Option C:

The key criterion for using option C is whether the whole building savings (the signal) is large enough relative to the volatility in whole building energy use (the noise) due to operational variability. While the lighting savings in the impacted area will likely be large, the savings at the whole building level are much lower, because of the many energy end-uses in the building in addition to lighting. As with option B, it is important to have measurements cover a range of seasonal conditions due to significant seasonal variations in savings. If savings need to be extrapolated, they could use the same set of variables as the assessment method.

Option D:

Calibrated energy simulations can be used, with site-custom building models, which takes considerable effort to perform and essentially represents a custom approach.

[2] ASHRAE Standard 62.1, 2016, Appendix D

Appendix B - FLEXLAB Validation

Lab test overview

The retrofit systems package was tested at FLEXLAB®, LBNL's comprehensive integrated building technologies test facility (FLEXLAB.lbl.gov). The main objectives of the testing for this system were to validate performance of the LED Lighting, Lighting Controls and Occupancy-based Demand Controlled Ventilation package and validate lighting and HVAC energy savings as well as evaluating visual and thermal comfort parameters. The test case (the systems package) and the base case (i.e. baseline T8 fluorescent lighting system without advanced controls, and no demand controlled ventilation) were tested at the same time under identical conditions using the two parallel test cells. The photographs in Figure 7 show the workstations and open office configuration for the FLEXLAB tests. Each test cell is approximately 20' wide and 30' deep. The cells were configured in an open office plan with six workstations per 600 ft^2 of area. Each test cell includes a 20' wide south-facing window wall, which can be seen in the photos. Occupant thermal generators at each workstation represent the internal heat gains from office occupants and each desk is also equipped with programmable plug loads representing internal heat gains from office computers and other electrical equipment.

Figure 7. Photos of the workstation setup and open office configuration in the lab test cells

The baseline lighting system is shown in the photo on the left in Figure 8 below, comprising standard 3-lamp T8 fluorescent troffers laid out in an 8' by 10' on-center grid, with basic on/off scheduling controls for the entire open office zone. The retrofit package lighting system is shown in the photo on the right and includes high efficacy LED troffers in the same layout as the baseline lighting system; the LED troffers include luminaire-level networked lighting controls, with occupancy based on/off switching and daylight dimming capabilities. For the retrofit package, demand controlled ventilation operation was based on lighting system occupied/unoccupied status per office cubicle.

Figure 8. Photos showing the baseline fluorescent lighting system (left) and retrofit LED lighting system (right)

Lab test schedule

The system package was tested against three different baselines (Existing Building, ASHRAE 90.1 2013, and California Title 24 2016) during three different test seasons (Winter, Spring, Summer). Dates for each test period are given in the following table. Test dates for the Existing Building baseline configuration are relevant for the purposes of this program manual.

Table B-1. Lab test dates per season

Baseline Configuration	Winter	Spring	Summer
ASHRAE 90.1 2013	Jan 20 - 25	April 12 - 20	July 14 - 19
CA T.24 2016	n/a (test issues)	March 31-Apr 7	July 21-July 27
Existing Building	Jan 28 - 30, Feb 3	March 23 - 28	n/a (test issues)

Open-office occupancy emulation

Occupancy-based lighting controls and demand controlled ventilation (DCV) are both energy saving strategies that depend on variable occupancy in a space, so variable occupancy representative of a commercial office space was an important feature to implement for laboratory validation. Plausible occupancy schedules were developed for each emulated occupant, such that the summed zonal occupancy for all workstations in the test cell through each day matched closely with the DOE prototype model hourly assumptions for occupant presence and loads. Variable occupancy at the individual level allowed for testing of lighting controls and DCV with the diversity of individual occupancies from workstation to workstation. Programmable plug loads were also located at each workstation with on/off schedules programmed to coincide with workstation occupancy (plug loads were typically not turned off during periods of intermittent vacancy in the workday). The recurring occupant and plug load patterns for the six workstations are shown in the Figure 9 plots below.

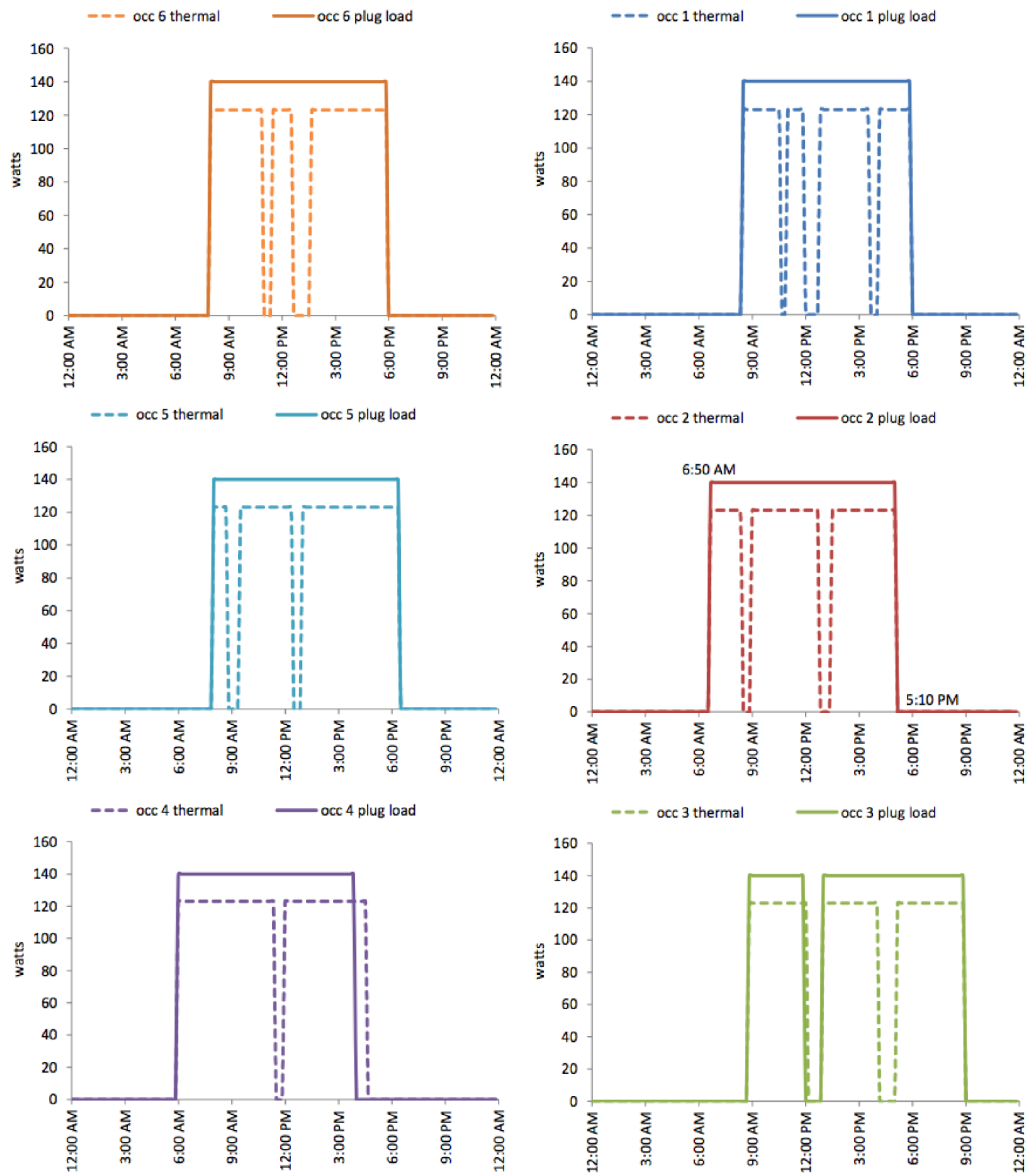

Figure 9. Occupancy and plug load profiles for each of the six workstations in the test cells

For the zone total occupancy and plug load wattages, the sums of occupant and plug load wattage for all workstations are plotted in Figure 10, along with the DOE reference model hourly occupant and plug load profiles. Total daily internal loads in the lab test and in the DOE reference model is nearly identical.

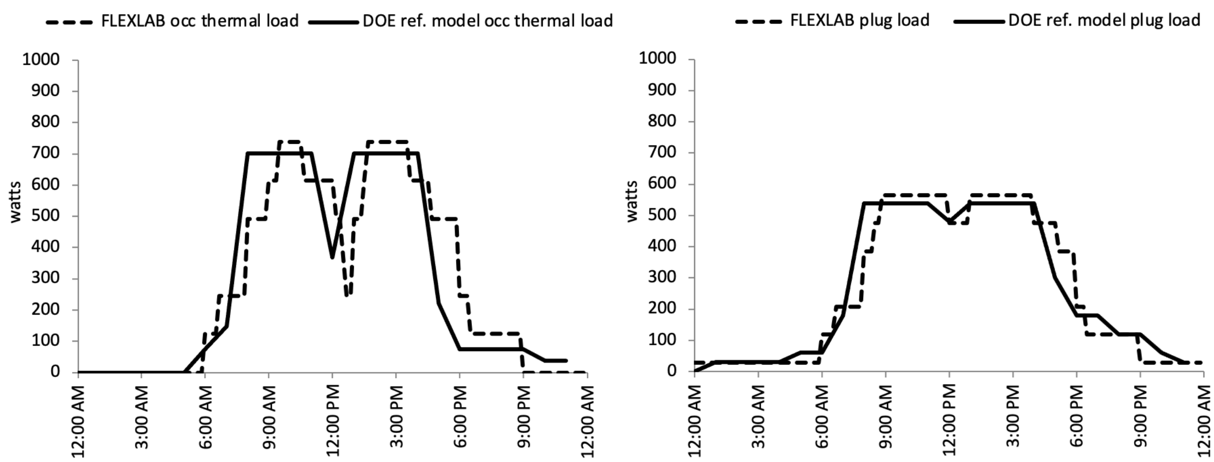

Figure 10. Daily zonal thermal load profiles for occupants (left) and plug loads (right) compared to DOE reference model load profiles

FLEXLAB savings

Lighting energy savings

Test results showed significant lighting energy savings resulting from a combination of reduced lighting power density due to the source-change from fluorescent to LED lighting, as well as occupancy-based switching and daylight dimming. The average daily lighting load over time for the fluorescent and LED systems is plotted in Figure 11.

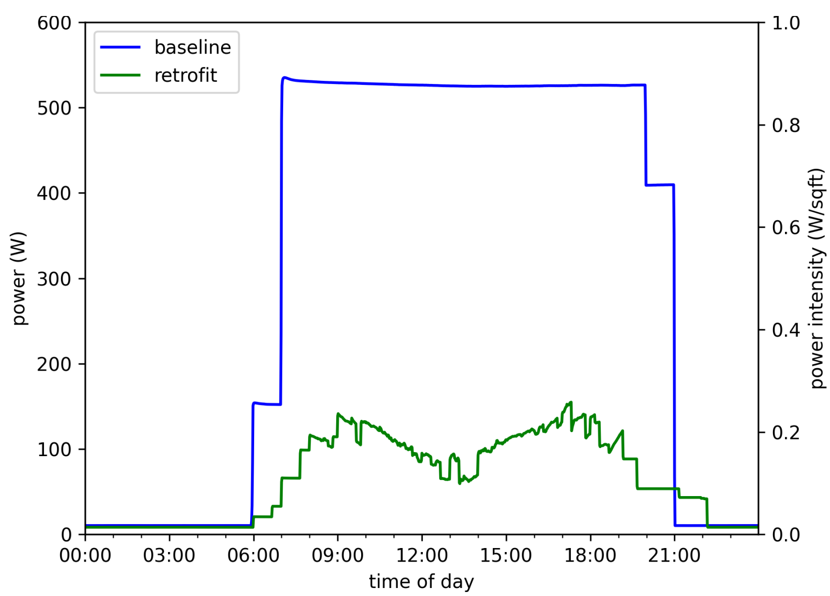

Figure 11. Average daily baseline and retrofit lighting power profiles from lab test

Comparing baseline and retrofit lighting energy in Figure 12 below, including all of the winter and spring test days with the Existing Building baseline configuration, average daily lighting energy savings of 79% were found.

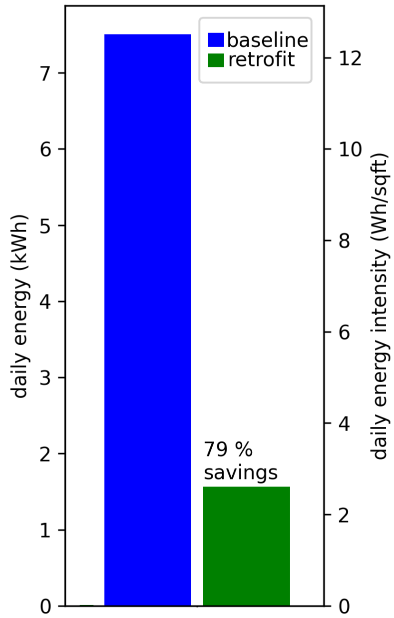

Figure 12. Average daily baseline and retrofit lighting energy from lab test

HVAC Energy Savings

Depending on the season of testing, lab tests found some heating energy penalty (winter period) due to the efficient lighting retrofit measure, which reduces internal thermal load and requires some extra HVAC heating energy, or significant heating energy savings, net of the heating penalty from efficient lighting, due to demand controlled ventilation effects. Figure 13 presents a bar graph of daily heating and cooling load totals for the baseline and retrofit cells in the winter and spring test periods. Minimum, median, and maximum thermal load savings (heating and cooling) for the test days in each season are presented in Table C-2 below. Note that total mechanical thermal load is measured in the lab; in other words the thermal load due to internal and external gains and losses that the HVAC system services in order to maintain thermal setpoints. This is not the same as the energy that the HVAC system uses to meet this load; HVAC plant energy to meet load will depend on plant-level heating and cooling efficiencies, which vary based on building mechanical systems and equipment.

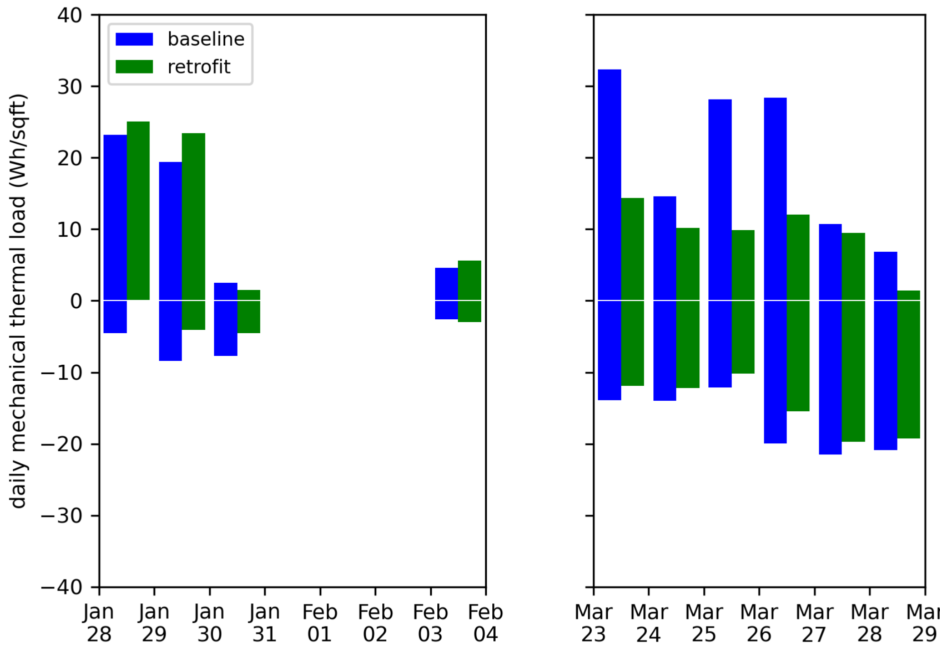

Figure 13. Daily baseline and retrofit heating load (positive values, above x-axis) and cooling load (negative values, below x-axis) for winter and spring test periods

Table B-2. Daily thermal heating and cooling savings from winter and spring lab tests

Winter Test Period

Lab Test Date	Heating savings %	Cooling savings %
1/28/21	-8%	100%
1/29/21	-21%	52%
1/30/21	40%	41%
2/3/21	-22%	-12%
Min	-22%	-12%
Median	**-14%**	**46%**
Max	40%	100%

Spring Test Period

Lab Test Date	Heating savings %	Cooling savings %
3/23/21	56%	14%
3/24/21	30%	13%
3/25/21	65%	16%
3/26/21	58%	22%
3/27/21	11%	8%
3/28/21	80%	8%
Min	11%	8%
Median	**57%**	**14%**
Max	80%	22%

Validation of lab energy savings results with building simulation results

Baseline and system retrofit package performance was modeled through whole-building energy simulations, as described in *9. Energy Savings: Simulation Results*. The whole building simulations are for an entire year of operation of the reference large office model and relied on typical meteorological year (TMY) data for CO and MN locations. Lab tests run for a smaller number of days at the specific location of FLEXLAB in Berkeley, CA but provide data and results that can be complementary to simulation results and provide additional insight into operation of and energy savings from the retrofit package.

Outputs from the computer model can include zone-level results as well as whole-building results. While the lab environment is configured to resemble and operate as a commercial office space, it is a small-scale model with different geometry and physical attributes than an actual commercial building equivalent to that in the computer model. As such, the lab and simulation results are not entirely comparable, but it is still helpful to evaluate whether operating characteristics and energy savings from the lab and the model are directionally in agreement, so after lab testing, a comparison of results was carried out. To compare lab findings to simulation results, a multi-step process was implemented.

1. First, heating degree hours and cooling degree hours from a base of 65^{o}F were calculated for every day of the meteorological data from one of the computer simulations (location: Denver CO). Then the same was done for each lab test day, based on hourly outside air temperature measured on site. Model and lab daily degree hour totals were compared so that comparable meteorological days could be found. Hourly outside air temperature profiles were also compared for selected simulation days and lab test days to find days with the most similar diurnal temperature patterns.
2. For the selected days of simulation data meteorologically comparable to lab days, hourly thermal heating load per zone and cooling load per zone was summed per day in the baseline and retrofit model. Two zones from the large office model were selected for comparison with the lab results; an open-office zone on the top floor of the multi-story office on the south perimeter, and an enclosed office zone on the top floor, on the southwest perimeter. The open office zone results are discussed here. Comparing zonal simulation results to the lab results was preferred over whole-building simulation results, since the individual zones more closely resemble the geometry and configuration of the lab test space, a 600 ft^2 test cell with south-facing perimeter and configured in an open office plan.
3. For the selected simulation days, baseline and retrofit daily total zonal thermal energy for heating and for cooling were compared, and daily heating and cooling energy savings were calculated.

4. Zonal heating and cooling savings for the simulation days were then compared to heating and cooling savings from the equivalent lab test meteorological days.

To illustrate the daily thermal heating and cooling load analysis for meteorologically equivalent days, two plots of total loads for the simulated baseline and retrofit zone are shown in Figure 14, with a winter day on the left, and a spring day on the right.

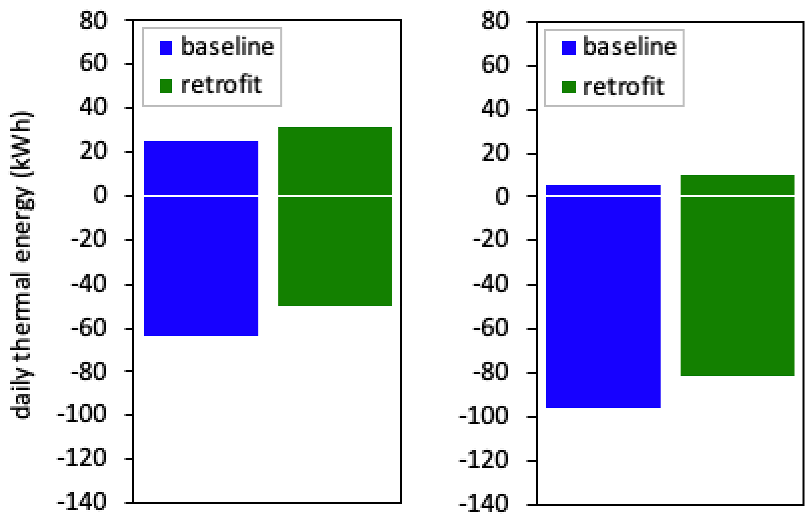

Figure 14. Plots of daily baseline and retrofit heating thermal energy (positive values, above x-axis) and cooling thermal energy (negative values, below x-axis) for two sample days from simulation results; single top floor open office zone

Comparing the lab thermal energy results with those of the single open office zone in the simulation results for equivalent meteorological days, it was found that relative savings in terms of cooling thermal energy agreed well in the spring season, where median cooling thermal savings were almost identical (14% vs. 15%, respectively). For the winter season of testing, day-to-day cooling savings varied considerably (-12% to 100%), while in the model the wintertime range was more consistent (20% to 40%). Tables C-3 and C-4 below show the comparative results from the lab and simulation tests, for the winter and spring periods respectively.

For heating thermal energy results, it was found that the operation of the lab space and the simulated space differed too significantly for meaningful comparisons. This is believed to be due to a variety of factors generally leading to higher relative heating thermal demand in the lab space, likely due to differences in geometry and building physical characteristics relative to the single open office zone in the building simulation. Confounding factors may include:

- Exterior walls on north, south, and west (baseline cell) or east (retrofit cell) side of lab space, whereas the simulated zone is a perimeter area with conditioned floor area on all sides except the south facade.

- The floor of the lab space is insulated slab on-grade, whereas the simulated zone has a dozen conditioned floors below it.
- The relative effects of infiltration and exfiltration are much greater in the lab space (includes door to exterior, much smaller overall floor area, greater surface area-to-volume ratio), compared to the top-floor open office zone of the large multi-story building (no exterior doorway, larger floor area, surrounded by conditioned floor space)

Table B-3. Winter lab test period results compared to equivalent days from simulation data

Lab Results			Model Results (equivalent meteorologic days, top floor open office zone)	
Lab Test Date	Heating savings %	Cooling savings %	Heating savings %	Cooling savings %
Min	-22%	-12%	-97%	21%
Median	**-14%**	**46%**	**-44%**	**30%**
Max	40%	100%	-27%	40%

Table C-4. Spring lab test period results compared to equivalent days from simulation data

Lab Results			Model Results (equivalent meteorologic days, top floor open office zone)	
Lab Test Date	Heating savings %	Cooling savings %	Heating savings %	Cooling savings %
Min	11%	8%	-121%	14%
Median	**57%**	**14%**	**-64%**	**15%**
Max	80%	22%	35%	20%

Flexlab test results, visual and thermal comfort

As illustrated in Figure 15, task illuminance in the retrofit package for occupied time periods remained above the setpoint of 300 lux in all areas of the office space for nearly all of the test periods. Illuminance levels in the retrofit case are lower than in the base case, which would be considered an over-illuminated environment relative to the task illuminance setpoint, common in older fluorescent lighting systems.

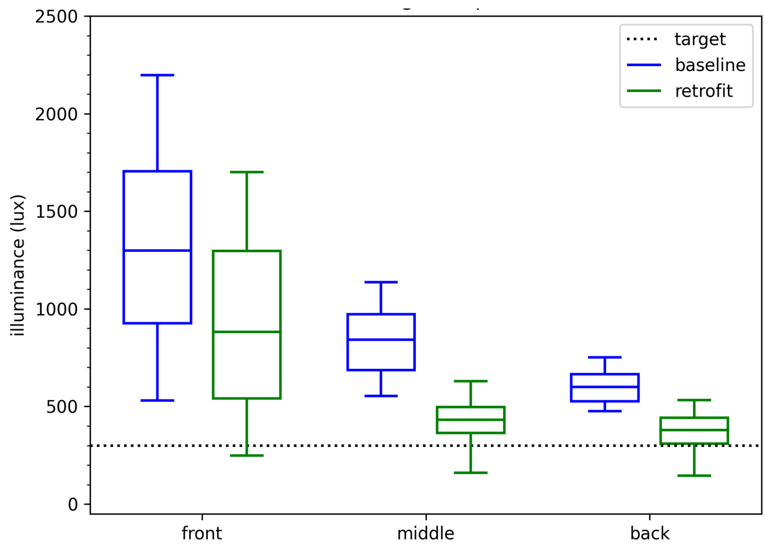

Figure 15. Box and whisker plots showing 5%, 25%, median, 75% and 95% illuminance values from data for all test days; front, middle, and rear workstations (two each), occupied periods only. Setpoint target of at least 300 lux is also shown.

Figures 16 and 17 show thermal comfort results for the front and back half of the test cells; thermal parameters were measured for both due to the potential difference in thermal comfort nearer to the window wall (front) and farther away (back). Thermal comfort data show very similar results in the basecase and retrofit case, confirming that retrofit operation did not negatively impact thermal comfort parameters, at least in PPD and PMV terms.

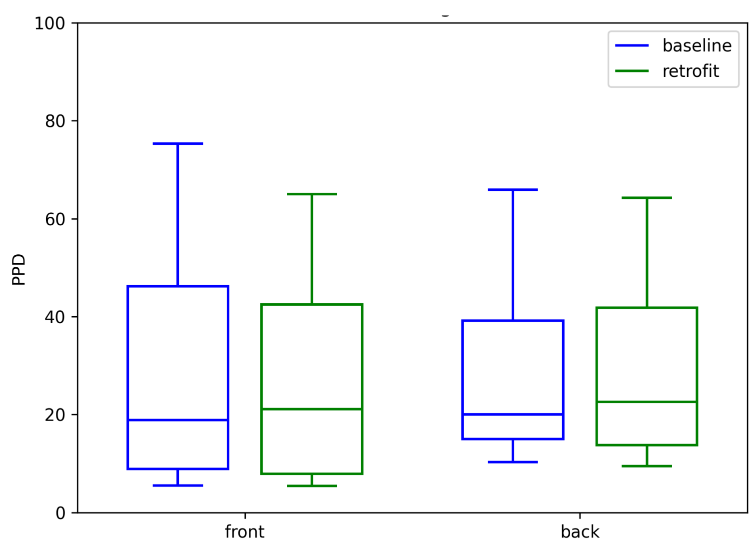

Figure 16. Box and whisker plots showing 5%, 25%, median, 75% and 95% PPD values from data for all test days; front and back half of baseline and retrofit test cells, occupied periods only

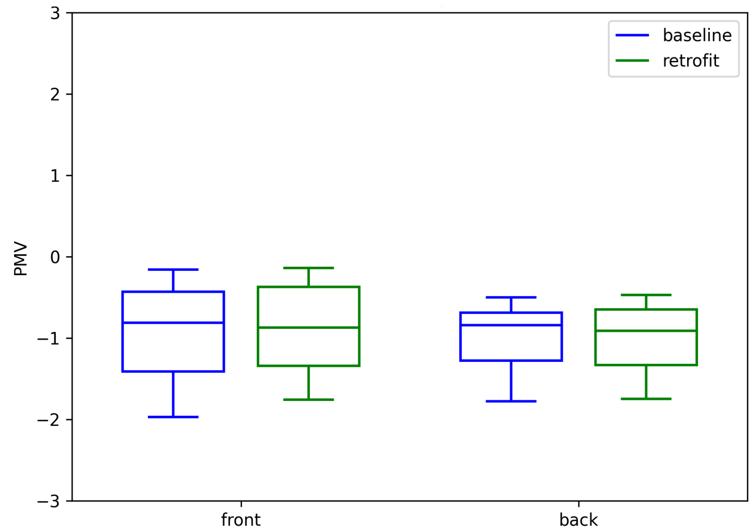

Figure 17. Box and whisker plots showing 5%, 25%, median, 75% and 95% PMV values from data for all test days; front and back half of baseline and retrofit test cells, occupied periods only

Appendix C - Lighting Costs

Table C-1: Lighting system base cost estimates (overhead, taxes, markups included)

	Colorado		Minnesota	
	Early Replacement	Normal Replacement	Early Replacement	Normal Replacement
Fixtures and Controls	$259.28	$84.37	$260.49	$84.76
Labor	$72.28	$2.78	$104.67	$4.03
Total	$331.56	$87.15	$365.16	$88.79
Ft^2 Per Fixture	82	82	82	82
Cost per Ft^2	$4.04	$1.06	$4.45	$1.08

Appendix D - Market Deployment Potential Analysis

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October 4th, 2022

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1 Executive Summary

The Lawrence Berkeley National Lab (LBNL) is developing an energy efficiency package of measures for large office buildings that includes advanced lighting (LED), lighting controls, and HVAC controls measures. This report supports this effort with analysis of the prospective market opportunity for these measures in the territory of the Xcel Energy in Minnesota, and Xcel Energy in Colorado. This report studies the deployment potential for each measure package and determines the total technical and market potential within these territory service areas.

The results from this analysis can be utilized in combination with the savings and cost metrics of the validated systems calculated by LBNL to characterize energy savings potential in each of the projects' utility partner's service territory for each specified measure package.

Measure Package Description

There are four measures that are included in this project for analysis, combined into two measure packages, so they are not being evaluated independently. The four measures are:

- LED lighting retrofit – retrofit existing linear fluorescent lighting equipment LED retrofit kit trays or replace the existing luminaire with a new LED luminaire.
- Lighting controls retrofit/improvement – retrofit or install lighting controls in conjunction with the LED retrofit to implement a network lighting control (NLC) system that can leverage different factors within the building to maximize energy savings.
- HVAC demand control ventilation (DCV) installation or reprogramming – within a suitable HVAC system, leverage the lighting control system occupancy sensors to provide information on the occupancy state of HVAC zones so that the HVAC supply air can be reduced during unoccupied periods or completely eliminated during normally unoccupied times.

There are is one two measure package included in this evaluation:

- **Measure Package #1** – LED Lighting – Lighting Controls – HVAC DCV

This measure package has been modelled through the energy efficiency modelling and the basis for the predictions of technical potential and other potential savings opportunities that might be possible in the respective market areas through program intervention.

Target Market Suitability and Potential

Figure 1 shows a summary of the total building area suitable for each retrofit measure, or combination of measures, by utility territory.

Figure 1. Market Suitability Summary, Total Large Office Building Area (million square feet)

Column	Xcel CO (Million Sq. Ft.)	Xcel MN (Million Sq. Ft.)
DCV Measures	156	45
Lighting and Controls	216	99
Combined Ltg + DCV (Measure Package)	104	31

Total Resource Cost (TRC) Calculations

TRC created four options of cost effectiveness for each utility partner based on their market potential, retail rates, current incentive offerings and measure implementation costs in their region. The program savings values will fall within one or more options described below.

- **Option 1 –** The energy savings are based on the energy modelling results for the prototype building as provided by LBNL and the market size information developed thorough the variety of sources as detailed in Chapter 3. The measure cost of implementation is the full measure cost. The program will target 1% of the total market in any given year. The incentives will be $0.15/ kWh for Lighting and DCV measure package.

- **Option 2 –** For this option we applied a 20% increase in the energy savings from Option 1. This is done to account for older building vintages that might exist in the utility service territory. Target market potential is same as Option 1. The incentives for this option are increased to make the measure packages attractive to the target customers. The incentives are $0.25/ kWh for Lighting and DCV measure package. By increasing the incentives, the utility partners can expect higher program participation.

- **Option 3 –** For this option, the energy savings are the same as Option 1. The measure implementation cost for this option is reduced by a factor of 20% to account for more aggressive measure pricing. The target market potential is the same as Option 1. The incentives for this option are $0.25/ kWh for the Lighting and DCV measure package.

- **Option 4 –** This option is a combination of Option 2 and Option 3 above. Energy savings are increased by 20% to account for projects with deeper energy savings and measure implementation cost is reduced by 20% to account for more aggressive measure pricing.

Early Retirement (ER)

For the lighting and DCV measure, the TRC values are not cost-effective in any option. This is due to lower energy savings and higher measure costs for this measure.

Replace on Burnout (ROB)

For the lighting and DCV measure, the TRC values are cost-effective in all the options for Xcel Colorado and Xcel Minnesota utility region.

Figure 2 provides the TRC values calculated for the measure package within the context of these four options.

Figure 2. TRC Test Values for Measure Package #1: Lighting + DCV, Based on Utility Region

Utility Partner	Option 1 ER/ROB	Option 2 ER/ROB	Option 3 ER/ROB	Option 4 ER/ROB
Xcel Colorado	0.42/1.25	0.47/1.30	0.49/1.34	0.58/1.52
Xcel Minnesota	0.37/1.15	0.42/1.21	0.44/1.24	0.52/1.42

2 Introduction

The project objective is to facilitate uptake in energy-efficient system retrofits in US commercial buildings via expanding utility incentive programs' reach beyond the component/widget level and towards a systems-based approach. This will be accomplished through the development of tested and validated specific building system packages and creating related deliverables that support their deployment in utility incentive programs. The current project is working with Xcel Energy (MN and CO) as utility partners in selecting and developing these system packages for deployment.

The objective for this research paper scope of work is to study the deployment potential for each selected system in specific market segments to which these systems-based, incentive programs would be targeted, creating metrics around their potential market size and energy savings, and an assessment of their related utility program cost effectiveness using developed metrics such as Total Resource Cost and other metrics as appropriate.

The results from this analysis can be utilized in combination with the savings and cost metrics of the validated systems to characterize energy savings potential in each of the projects' utility partner's service territory for each specified measure package.

2.1 Description of Measures

There are four measures that are included in this project for analysis, but these are combined into two measure packages, so they are not being evaluated independently. The four measures include:

- LED lighting retrofit – retrofit existing linear fluorescent lighting equipment LED retrofit kit trays or replace the existing luminaire with a new LED luminaire.
- Lighting controls retrofit/improvement – retrofit or install lighting controls in conjunction with the LED retrofit to implement a network lighting control (NLC) system that can leverage different factors within the building to maximize energy savings.
- HVAC demand control ventilation (DCV) installation or reprogramming – within a suitable HVAC system, leverage the lighting control system occupancy sensors to provide information on the occupancy state of HVAC zones so that the HVAC supply air can be reduced during unoccupied periods or completely eliminated during normally unoccupied times.

These measures can be evaluated independently but since this project is focused on promoting packages of measures, this will be done only as a step towards the combined measure package savings opportunity. Additionally, the LED retrofit and the lighting controls measures are almost always done together because the work to perform one of the measures makes the inclusion of the other measure more cost effective and there are deeper energy savings possible through a combination of these measures, so these are treated as a single measure in the following calculations.

As a result of the package approach, there is one measure package included in this evaluation:

- LED Lighting – Lighting Controls – HVAC DCV

This measure package has been modelled through the energy efficiency modelling and the basis for the predictions of technical potential and other potential savings opportunities that might be possible in the respective market areas through program intervention.

2.2 Project Approach

This section describes the high-level approach that TRC has used to develop the information, results, and conclusions that are presented in the following chapters.

2.2.1 Description of Target Market Segments

This task is to describe the target market in the four utility coverage areas in a manner that provides a contextual groundwork for energy savings calculations that follow in the next task below. This task involves collecting information from a variety of sources to develop a comprehensive description of the market for the measure packages within the large office building type.

This work includes a variety of factors that must be established for each region, including:

- The estimated square footage of large office buildings
- The vintage profile of the buildings
- The lighting, lighting controls, and the HVAC technology used in the buildings.
- The suitability of lighting, lighting controls, and HVAC retrofit or retro-commissioning measures for the buildings in the territory
- The percentage of large office building space that has suitable conditions for retrofit to occur.
- The percent of building square footage that has been retrofitted to modern technology recently
- The current energy use intensity (EUI) of the buildings in the territory

These questions must be answered for each utility territory despite the fact that there is very little consistent sources of information on the building stock that is applicable across the four regions, and additionally that the data is not only inconsistent from region to region, but the vintage of the information presents the need to make projections on some of the statistics to account for the changes due to the real estate market growth and the ever-changing march of technology improvement that is found in the market share of building systems.

This task compiles the disparate sources of information, makes best engineering estimates in situations where the information is unavailable or obsolete, projects the data to the present day when appropriate, and compiles the final results into a consistent format that can then be presented for all four utility territories.

2.2.2 Energy Savings and Demand Reduction Potential

With the market characterization complete, the energy savings and demand reduction calculations are developed by incorporating the modelled energy savings results from the LBNL prototype building calculations into the market characterization results.

This is done by considering the percentage of energy savings that are accomplished in the modelling and scaling the results of the prototype building calculations to the larger building stock results that were developed in the previous task. Since the task developed several different values for the building square footage in each utility territory, the specific details of the measure package savings are dependent on several factors, presented below:

- The technical potential savings – this represents the largest *technically possible* savings impact within the region, but it in no way represents the feasible opportunity for measure package impact because other variables will have an influence to reduce the overall potential in the territory.
- The economic potential savings – this represents the limit of the retrofit that that meets a certain level of return judged to be viable without program intervention.

The market characterization and the energy savings calculations are based on the top-level savings values, the technical potential square footage. Cost effectiveness metrics discussed below delves into the program influences on the possible market impact and builds on the energy savings potential calculated in this section.

2.2.3 Utility Cost Effectiveness Metrics

The third portion of analysis is focused on the cost effectiveness metrics that the utilities may use to determine the size and scope of an efficiency program focused on leveraging the measure packages in the market. This analysis employs a set of inputs that are collected from the specific utilities to ensure that the results are reasonable for the conditions within each utility territory. Some of the inputs needed include:

- Program design strategy (measure packages or individual widgets)
- Scale of the program (#units/kW/Kwh/therms)
- Utility avoided electricity cost ($/kWh)
- Utility avoided capacity cost ($/kW)
- Utility avoided gas cost ($/therm)
- Customer avoided electricity cost (Retail $/kWh)
- Customer avoided capacity cost (Retail $/kW)

- Customer avoided gas cost (Retail $/therm)
- Adders or discounts applied by the utility towards their cost effectiveness calculations
- Current incentive offerings for these individual measures

This analysis includes some of the market characterization results and the energy savings calculation results to develop the boundaries of an efficiency program that will be viable and produce the results that are desired by the utility for meeting the constraints of cost effectiveness and other regulatory requirements. Utilities evaluate potential programs based on their ability to generate positive values on four tests. These tests are – Total Resource Cost (TRC), Program Administrator Cost (PAC), Participant Cost (PC) and Ratepayer Impact Measure (RIM). Each utility assigns different levels of importance to these tests, but all start with the TRC test. As a result, we used the TRC test to determine cost effectiveness of the measure packages (i.e., a TRC greater than or equal to 1.0).

Within this context, there are several levels of program savings that are calculated for the measure packages. These are dependent on multiple variables in the utility program models, some of which have been listed above. The potential program savings is broken into three values, which represents a range of savings opportunity that are viable within the constraints of program cost effectiveness metrics. These are:

- Achievable program savings – this represents the savings feasible through a cost-effective program during a 'typical' program cycle (three years) using differing incentive levels and target customer size as described below.
  - Minimum viable program savings– this represents the likely size of the market for a program that has a level of intervention to make the measure packages attractive to the target customers. This is limited by the possible program budget, and the portion of market that will be interested in performing the efficiency measures based on their cost-benefit.
  - Likely program savings – this represents the likely size of the program based on optimizing the program savings and expenses constrained by utility budgets and desired market penetration of the program. Typical programs will target no more than 1%-5% of the total market in any given year.
  - The maximum achievable program savings – this represents cost-effective program potential achievable without the constraints of program budgetary limitations.

Model Calculations and Baselines

The models used for the calculations must contain a context to be relevant for the sake of developing the proper comparisons. These calculations include three different performance savings calculations that are employed to calculate the TRC. These levels of performance are described below:

- **Baseline Building** – This calculation is based on the performance of an existing building before any retrofit activity occurs and is presumed to be operating in a typical level of upkeep. It does not represent the performance level of a specific code baseline, but it is segmented into the target markets based on the utility territories, so local climate differences are included in the baseline energy performance.

- **Early Replacement (ER)** – This represents the savings and costs that are present when the building systems are not at end of life (EOL) and the retirement represents a proactive intervention to reduce energy consumption through a proactive effort. In this circumstance, the costs are the full cost of the retrofit because the system does not require the intervention.

- **Normal Replacement (NR)** – This represents the savings and costs for a retrofit where the existing systems are considered at or beyond EOL. They may still be fully functional, but there is no amortized value operational value left in the system. In this case, the costs are only the incremental cost above a code-minimum retrofit.

There is an additional potential baseline that uses a combination of the existing baseline for some circumstances and one of the other baselines and is called a hybrid baseline. This approach is used in some locations for some measures depending on the conditions of the facility and the measure (commonly applied to lighting measures).

Total Resource Cost (TRC) Calculations

TRC created four options of cost effectiveness based on market potential, retail rates, current incentive offerings and measure implementation costs in their region. The program savings values described above will fall within one or more options described below.

- **Option 1 –** The energy savings are based on the energy modelling results for the prototype building as provided by LBNL and the market size information developed thorough the variety of sources as detailed in Chapter 3. The measure cost of implementation is the full measure cost. The program will target 1% (total for both measure packages) of the total market in any given year. The incentives will be $0.15/ kWh for Lighting and DCV measure package.

- **Option 2 –** For this option we applied a 20% increase in the energy savings from Option 1. This is done to account for older building vintages that might exist in the utility service territory. This option reflects the potentially higher savings opportunity that may be achieved in typically older, poorer performing buildings where there is the potential for higher savings, but it only will be directly applicable in situations where the utility can apply all of the savings towards the program rather than just the savings that are beyond the code baseline. However, it does reflect the actual savings that can be achieved, and this calculation is valuable to consider the savings that might be present (and reflective in the participant's utility bills) but unclaimable for the utility. The target market potential is same as Option 1. The incentives for this option are increased to make the measure packages attractive to the target customers. The incentives are $0.25/ kWh for Lighting and DCV measure package. By increasing the incentives, the utility partners can expect higher program participation.

- **Option 3 –** For this option, the energy savings are the same as Option 1. The measure implementation cost for this option is reduced by a factor of 20% to account for more aggressive measure pricing. The target market potential is the same as Option 1. The incentives for this option are $0.25/ kWh for the Lighting and DCV measure package.

- **Option 4 –** This option is a combination of Option 2 and Option 3 above. Energy savings are increased by 20% to account for projects with deeper energy savings and measure implementation cost is reduced by 20% to account for more aggressive measure pricing.

Figure 3 provides the TRC values calculated for these two measure packages within the context of these four options.

Figure 3. TRC Test Values for Measure Package 1: Lighting + DCV, Based on Utility Region

Utility Partner	Option 1 ER/ROB	Option 2 ER/ROB	Option 3 ER/ROB	Option 4 ER/ROB
Xcel Colorado	0.42/1.25	0.47/1.30	0.49/1.34	0.58/1.52
Xcel Minnesota	0.37/1.15	0.42/1.21	0.44/1.24	0.52/1.42

We have run the cost effectiveness for each measure package in different configurations (measure cost, incentives, admin cost, etc.) for each utility partner to come up with a range of TRC test.

3 Description of Target Market Segments – Task 1

This task required TRC to develop assessments of the existing building stock applicable to the target market segment(s) for each system within each of the four utility service territories. This market suitability data will inform estimates of energy savings and demand reduction potential, as well as cost effectiveness metrics in subsequent tasks.

TRC leveraged a combination of publicly available national datasets, such as the Commercial Buildings Energy Consumption Survey (CBECS), and local and utility market potential and market data sources. Sources vary by each utility, and the specific datasets TRC referenced are detailed in the sections below.

By nature, this analysis is speculative since it does not involve any primary data collection. However, TRC is confident that the information presented along with each of the utilities own databases of customers will provide enough actionable information for LBNL's purposes under this project.

3.1 Methodology for Market Segmentation Analysis

Within this task, there are a variety of sources of information that may be collected to help create a picture of the individual market spaces in each utility territory. The following is a generalized explanation of the process employed for each partner utility without specifically addressing all the specific details that occurred in each region. The process for establishing the technical potential square footage of suitable building stock within each utility territory is as follows:

- Establish the regional building performance for characteristics for a variety of operational metrics within the available dataset (CBECS), including:
  - Typical building size for the stock within the 50,000+ sf size bin
  - Percent of building stock in the "Office" category that falls into the 50,000+ sf size bin
  - Average kWh and BTU consumed per year, per SF
  - Vintage of the building stock
- Collect data from available reports for each region to provide more specific information on several factors, including:
  - Percentage of building stock (of total SF of stock) that falls into the "Office" and "Large Office" categories
  - Similarly, information on the "Education", "Health Care", and other similar building types that are likely to have substantial portions of their building stock meet the general requirements to perform as a "Large Office" building despite their categorization
  - Building vintage information
  - Individual building size information
  - The penetration of building technologies in the existing building stock
  - The breakdown of existing building technologies for lighting and HVAC
  - The adoption of existing (current) efficiency measures in the existing building stock

- Reconcile the building stock of the "Large Office" category by combining available "Office" category information and other similar building stock and filtering the data to remove buildings smaller than 50,000 sf.

- Evaluate the building stock square footage based on the individual measure applicability within the respective spaces by reducing the potential stock through space suitability for the measure and further by eliminating spaces that either do not include suitable existing technology or have been recently retrofitted with modern technology. Do this for each measure individually (with the lighting and lighting controls combined).

- Produce a composite square footage that combines the individual measures into a single combined measure through ratio reduction of the total square footage by each measure percentage reduction.

In some circumstances, information was not available in the units needed (square footage of existing stock) but estimates for the total within each partner utility territory, the information available to make the necessary modifications may not be directly available. In those circumstances, three approaches were employed, depending on the specific information that is unavailable. These three approaches are:

- Employ regional or national data if it is available.

- Apply information collected from another utility region and make modifications to the data if there is compelling information to expect that the two regions are different in a quantifiable manner.

- Make a best engineering estimate based on the experience that TRC has gained in the past with the building technology or market aspect in question.

3.2 Summary Results

Figure 4 shows a summary of the total building area suitable for each retrofit measure, or combination of measures, by utility territory.

Figure 4. Market Suitability Summary, Total Large Office Building Area (million square feet)

Column	Xcel CO (Million Sq. Ft.)	Xcel MN (Million Sq. Ft.)
DCV Measures	156	45
Lighting and Controls	216	99
Combined Ltg + DCV	104	31

The process for determining each of market suitability values is discussed in more detail in the following sections.

3.3 Xcel Energy – Colorado

3.3.1 Data Sources

TRC consulted the following sources to develop the market segmentation for large office buildings in Xcel Colorado territory:

- CBECS, 2012 Data
- Colorado DSM Market Potential 2010 (Xcel Energy, 2010)

  Calculated 2020 estimates based on average growth per year compounded annually from 2010 to 2020
- Update to the Colorado DSM Market Potential 2013 (Xcel Energy, 2013)
- Xcel Energy Colorado Lighting Efficiency Evaluation 2019 (Xcel Energy, 2019)
- Colorado Lighting Market Study 2016 (Xcel Energy, 2016)

3.3.2 Analysis

To estimate the overall market potential for the proposed technologies, TRC first collected data on electricity end use market saturation, energy use intensity, and total electricity use by end use from the Colorado DSM Market Potential study, as illustrated in Figure 5.

Figure 5. Commercial Baseline Electricity Consumption Factors, Colorado DSM Market Potential study 2010

Office End-Use	Saturation	EUI (kWh/ft^2)	GWh	MW
Indoor Lighting	100%	6.75	2,040	337
Outdoor Lighting	89%	1.06	319	3.9
Chillers	31%	0.56	168	126
DX Packaged Systems	55%	1.70	515	385
Ventilation	95%	1.68	509	160
Refrigeration	12%	0.02	5.20	0.6
Office Equipment	100%	1.35	409	50.5
Servers / Data Centers	1%	1.46	440	54.3

Vending Machines	39%	0.33	99.3	12.9
Cooking	8%	0.17	52,3	7
Heating	37%	0.55	165	10
Miscellaneous	100%	1.29	389	50.2
TOTALS		**16.9**	**5,110**	**1,200**

TRC also collected estimated office area and energy use from the Colorado DSM Market Potential study. Since this data was reported in 2010, TRC used an average annual growth rate of 1.5% to estimate the size of the office market in 2020. In addition, TRC calculated an estimate of the large office market based on the proportion of large office buildings in the overall office market as reported in CBECS, as illustrated in Figure 6. TRC also estimated total large office energy use based on these estimated 2020 market size values, multiplied by the office EUI reported above in Figure 5.

Figure 6. Office Market Size and Energy Use Estimates for 2020, calculated based on Colorado DSM Market Potential study 2010

	2010 Data	Average Annual Growth Rate	2020 Estimate
Office Area Estimate (Million Sq. Ft.)	302	1.5%	351
Large Office Area Estimate (Millions Sq. Ft.) *			325
Total Office Energy Use (GWh)	5,110		5,500
Total Office Peak Demand (MW)	1,200		1,290
*Large office estimated for 2020 assuming 92.6% of area in buildings over 50,000 square feet, per CBECS 2012			

To determine market suitability for lighting retrofit measures, TRC reviewed both the Colorado Lighting Market Study and the Xcel Energy Colorado Lighting Efficiency Evaluation. The Colorado Lighting Market Study reported zero market penetration for LED in interior lighting in 2015. However, a number of other factors indicate that LED penetration has a achieved a more substantial market share to date:

- LED market penetration in the Xcel Energy Minnesota territory in 2019 was 15%
- Xcel Colorado has been offering several Upstream and Midstream LED incentives in recent years

Based on these factors, TRC estimates that LED may have achieves as much as 30% market share in the large office sector. This results in a conservative estimate of overall LED retrofit market potential of 70%.

In addition, the Xcel Energy Colorado Lighting Efficiency Evaluation found relatively low uptake of advanced lighting controls in the utility territory as of publication in 2019. As a result, TRC assumes less than 5% of the large office market currently has advanced controls.

3.3.3 Results

Based on the above analysis, TRC estimated the overall market suitability for the proposed measures in the Xcel Colorado territory.

Based on the estimated penetration of lighting technologies in the Xcel Colorado territory, and assuming a uniform distribution of technologies, TRC estimates that 67% of the large office market is suitable for a LED lighting and advanced controls retrofits, as shown in Figure 7.

Figure 7. Estimated Market Share Potential for Lighting Measures, Xcel Colorado

Measure	Percent Area Potential
Total Lighting Potential	70%
Total Controls Potential	95%
Total L+C Potential	**67%**

Based on the estimated size of the large office market as described above in Figure 6, this estimate results in roughly 216 million square feet of large office space suitable for lighting and controls retrofits in the Xcel Colorado territory, as shown in Figure 8

Figure 8. Market Suitability of Lighting and Controls Retrofits, Xcel Colorado

Total Building Area (Million Sq. Ft.)	Annual Electricity Use (TWh)	Annual Gas Use (MMDtherms)
216	3.65	9.06

Due to limited available information on existing HVAC systems in the Xcel Colorado territory, TRC estimated the proportion of buildings suitable for HVAC measures based on data from the neighboring utility, ComEd, assuming that the building stock and systems in the two utility territories is relatively similar, and then applied those proportions to the total size of the building type markets based on the area calculations described above. TRC then applied a “space suitability factor”, assuming roughly 80% of spaces in a large office building would be suitable for DCV. By combining all these factors, TRC determined an estimated proportion of each building type where DCV would be suitable and applied those proportions to the overall market size to determine the building square footage and energy savings for the DCV retrofits as illustrated in Figure 9

Figure 9. Estimated Market Share Potential for DCV Retrofits, Xcel Colorado

	Percent Area Suitable

DCV Hardware Vintage Suitability	60%
DCV Space Suitability	80%
Total DCV Suitability	**48%**

Based on these estimates and the estimated size of the large office market, TRC estimates almost 156 million square feet of large office space are suitable for DCV retrofits, as shown in Figure 10.

Figure 10. Market Suitability of Demand Control Ventilation Measures, Xcel Colorado

Total Building Area (Million Sq. FT.)	Annual Electricity Use (TWh)	Annual Gas Use (MMDtherms)
156	2.63	6.54

TRC also estimated the overall market suitability for combined HVAC and lighting measures. Assuming a roughly uniform distribution of system and technology types across the large office market, TRC estimated the suitability of the combined measures by multiplying the market suitability of each of the HVAC measures by the market suitability of the combined lighting and controls measures, as shown in Figure 11.

Figure 11. Market Suitability of Combined Lighting and DCV Measures, Xcel Colorado

Total Building Area (Million Sq. Ft.)	Annual Electricity Use (TWh)	Annual Gas Use (MMDtherms)
104	1.75	4.35

3.4 Xcel Energy – Minnesota

3.4.1 Data Sources

TRC consulted the following sources to develop the market segmentation for large office buildings in Xcel Minnesota territory:

- CBECS 2012
- Minnesota PG Study 2019 Appendix K – Commercial Large Buildings (MNCEE, 2018)
- MNcee.org website tool (MNCEE, 2020)
- Minnesota TRM Manual v 2.2 (MN Commerce Department, 2018)

3.4.2 Analysis

To estimate the market suitability for the proposed measure packages in the Xcel Minnesota territory, TRC first started with the CBECS information for the census division to collect some broader market performance for the area. This was then enhanced with collected information for various existing building technology penetration as documented in the Minnesota PG Study Appendix K. Existing light source technologies are shown below in Figure 12.

Figure 12. Existing Light Source Technology Share, Minnesota PG Study Appendix K

Light Source Technology	Office Buildings	Health Care	Education
LED	15%	19%	24%
Linear Fluorescent	76%	66%	69%
CFL	7%	15%	5%
HID	0%	0%	2%
Incandescent	2%	0%	0%

Existing lighting controls technologies are shown below in Figure 13.

Figure 13. Existing Lighting Controls Technology Share, Minnesota PG Study Appendix K

Lighting Controls	Office Buildings	Health Care	Education
Occupancy Controls	19%	11%	39%
Timeclock and BAS	6%	26%	15%
Dimmer	4%	2%	0%

Existing HVAC system information is shown below in Figure 14.

Figure 14. Existing HVAC Systems, Minnesota PG Study Appendix K

HVAC Characteristics	Office Buildings	Health Care	Education
Central air handler	30%	100%	80%
Constant volume system (any)	20%	20%	30%
Number of zones	109	412	55
Area per zone (sf)	2,520	775	3,200
Average area per building	274,000	319,000	176,000

To determine the total market area for the large office, healthcare, and education sectors in the Xcel Minnesota territory, TRC used 2020 measure energy savings potential data and the technical resource manual for the state of Minnesota to extrapolate estimated total building area. These calculations are summarized in Figure 15 below.

Figure 15. Total Square Footage Estimates by Building Category

	Large Office	Healthcare	Education
Tube LED Replacement			
Number of fixtures in the 2020 Potential	29,600	105,000	51,000
Adjust for updated lighting market reduction	39,000	160,000	74,000
Total number of fixtures in Xcel territory (Thousands)	790	3,240	1,500
Estimated area (Million Sq. Ft.)	66.3	272	126
LED Troffer Replacement			
Number of fixtures in the 2020 Potential	3,500	12,500	6,000
Total number of fixtures in Xcel territory	39,500	141,000	67,700
Estimated area (Million Sq. Ft.)	3.32	11.9	5.69
LED Troffer			
Number of fixtures in the 2020 Potential	2,970	10,900	4,950
Total number of fixtures in Xcel territory	33,600	123,000	55,900
Estimated area (Million Sq. Ft.)	2.82	10.3	4,70
Estimated Total Area (Million Sq. Ft.)	**72.5**	**294**	**136**

3.4.3 Results

Due to limited available information on existing HVAC systems in the Xcel Minnesota territory, TRC estimated the proportion of buildings suitable for HVAC measures based on data from the neighboring utility, ComEd, assuming that the building stock and systems in the two utility territories is relatively similar, and then applied those proportions to the total size of the building type markets based on the area calculations described above. Again, the suitability estimates include all large office buildings, as well as portion of both healthcare and education under the assumption that both building types include a proportion that are functionally large office buildings.

Figure 16 shows the estimated market suitability for Demand Control Ventilation measures in the Xcel Minnesota territory.

Figure 16. Market Suitability of Demand Control Ventilation Measures, Xcel Minnesota

	Office	Health	Education	TOTAL
Estimated Total Area, (Million Sq. Ft.) (from Figure 15, above)	72.5	294	136	
DCV – Remaining Market Potential	100%	100%	94%	
DCV – Suitability, HVAC System	58%	10%	69%	
DCV – Space Suitability in Building	80%	80%	80%	
DCV COMBINED %	46%	8%	52%	
DCV Total Suitable Area (Million Sq. Ft.)	**33.6**	**4.71**	**7.06**	**45.4**

For the suitability of lighting measures, TRC used the estimates of existing fluorescent lighting market penetration documented in the Minnesota PG Study, Appendix K, combined with an assumed low penetration of advanced lighting controls, like the estimate for the Xcel Colorado territory. TRC also applied a space suitability factor for the lighting measures, assuming 95% of spaces would be suitable for lighting and controls retrofits. TRC then combined all these factors together to determine the overall market suitability for lighting and controls retrofits for each building type, as shown in Figure 17.

Figure 17. Market Suitability of Lighting and Controls Retrofits, Xcel Minnesota

	Office	Health	Education	TOTAL
Estimated Total Area, (Million Sq. Ft.) *(from Figure 14, above)*	72.5	294	136	
L+C – Remaining Market Potential Lighting	76%	76%	76%	
L+C – Remaining Market Potential Controls	95%	95%	95%	
L+C – Space Suitability in Building	95%	95%	95%	
L+C COMBINED %	69%	69%	69%	
Lighting Total Suitable Area (Million Sq. Ft.)	**49.7**	**40.4**	**9.33**	**99.4**

TRC also estimated the overall market suitability for combined HVAC and lighting measures. Assuming a roughly uniform distribution of system and technology types across the large office market, TRC estimated the suitability of the combined measures by multiplying the market suitability of each of the HVAC measures by the market suitability of the combined lighting and controls measures, as shown in Figure 18 and Figure 19.

Figure 18. Market Suitability of Combined HVAC and Lighting Measures, Xcel Minnesota

	Office	Health	Education
Lighting + DCV COMBINED	32%	5%	36%

Figure 19. Total Suitable Area of Combined HVAC and Lighting Measures, Xcel Minnesota

	Office	Health	Education	TOTAL
Lighting + DCV Total Suitable Area (Million Sq. Ft.)	23.0	3.23	4.88	31.1

Based on these estimates and the estimated size of the large office market, TRC estimates almost 45.4 million square feet of large office space are suitable for DCV retrofits, as shown in Figure 20.

Figure 20. Market Suitability of Demand Control Ventilation Measures, Xcel Minnesota

Total Building Area (Million Sq. FT.)	Annual Electricity Use (TWh)	Annual Gas Use (MMDtherms)
45.4	0.77	8.92

TRC also estimated the overall market suitability for combined HVAC and lighting measures. Assuming a roughly uniform distribution of system and technology types across the large office market, TRC estimated the suitability of the combined measures by multiplying the market suitability of each of the HVAC measures by the market suitability of the combined lighting and controls measures, as shown in Figure 21.

Figure 21. Market Suitability of Combined Lighting and DCV Measures, Xcel Minnesota

Total Building Area (Million Sq. Ft.)	Annual Electricity Use (TWh)	Annual Gas Use (MMDtherms)
31.1	0.53	6.12

4 Energy Savings and Demand Reduction Potential for Target Market Segments – Task 2

4.1 Summary

The energy savings and demand reduction potential for each target market has been calculated and the results are summarized below. These results are based on the energy modelling results for the prototype building as provided by LBNL and the market size information developed thorough the variety of sources as detailed above in Chapter 3.

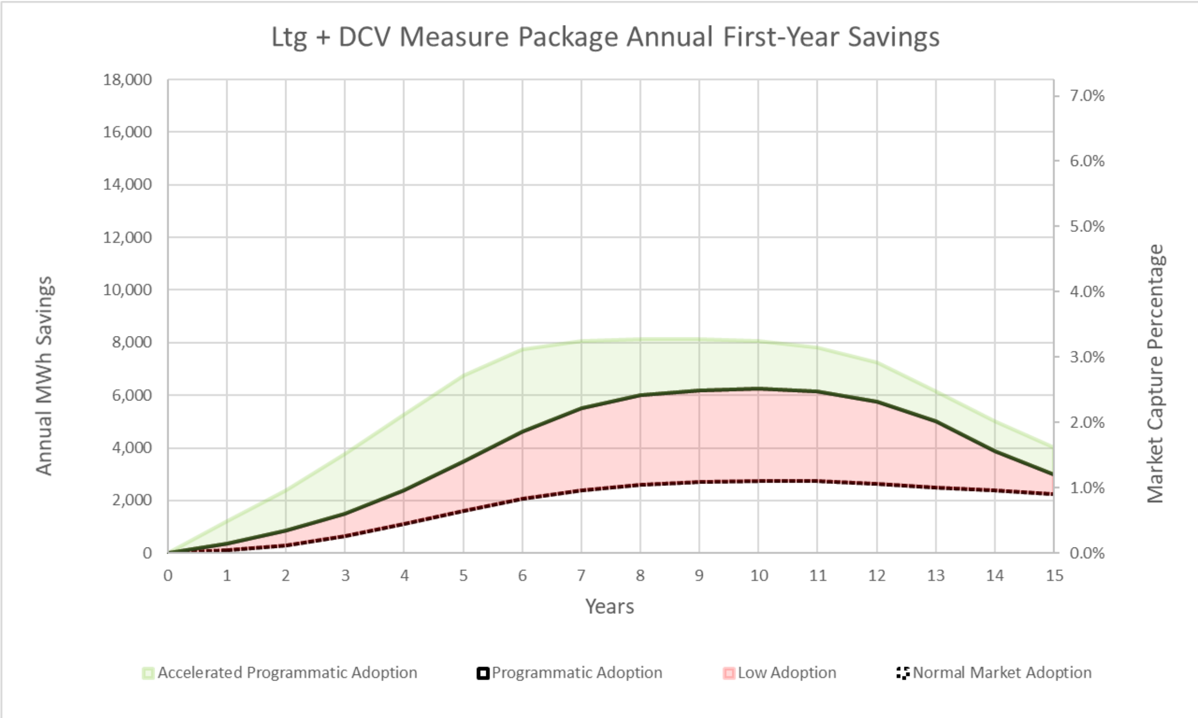
4.2 Program Savings Potential Model

The project team developed a simplified model for the possible savings that a program designed to achieve 2.5% of market potential capture year-to-year may occur. The discussion on this follows.

4.2.1 Measure and Program Lifecycle

A program is designed to accelerate the normal market adoption (NOMAD) of a measure or package of measures to encourage energy savings to increase more rapidly than might occur without the market intervention. The technology or approach that creates the measure will have a life cycle that goes through a normal progression from pre-adoption (lab research and field emerging technology studies) through early adoption (pilot programs), to mid- and late- adoption (main program measures), and into the end cycle (implementation into codes). Figure 22 below shows how a typical program may impact the market over a natural lifecycle.

Figure 22. Possible Measure and Program Lifecycle



Through this cycle, the NOMAD will occur to establish a floor to the possible influence that the program might have on the market. NOMAD is the source of net to gross calculations in program evaluations, as a certain number of customers who participated in a measure may be deemed as free riders because they were essentially not influenced by the program activities to adopt the measure. This NOMAD curve is shown at the bottom.

Above that, the program activities will encourage customers to adopt the measure, and the range of the values will vary depending on the program goals and budget. The earliest years on this graph (years 1 and two, possibly) are likely to be a pilot program to test the market acceptance and learn the effort needed to achieve program success. After those years, a larger program may be adopted that markets on a larger scale and to a wider customer base. However, since the measure is still somewhat emerging, the success of the measure will take time to develop. This is reflected in the continuing ramp-up of first year savings in the program, even though the same amount of marketing effort and incentives may be applied.

Later, the measure begins to reach a saturation point where many of the customers inclined to adopt the measure will have done so and the remaining customers become more difficult to convince to adopt the measure. This shows the decline in the later years of the program influence drops down toward the NOMAD. Note that the NOMAD may also decline for the same reason, as is shown in this model.

The program influence is especially important in moving customers to adopt earlier, and with some measures, taking a more aggressive approach to program size and goals can have a particularly large impact in the early years because the market is still not fully aware of the technology. This is shown in the first six to seven years on this graph in how the aggressive program adoption has higher impact at the beginning, but then it may decline a bit more quickly as well, closing the gap toward NOMAD more rapidly near the end.

At some point, the measure may become part of the local energy code. When this happens, it normally can no longer be a viable program, and will likely have an abrupt end.

Note that this model and all the subsequent models in this document are demonstrative of possible program influence. Measure adoption and influence in the market share, adoption and decline rates, and measure duration are all substantially variable and the specifics of mapping these possible influences involves market surveys and technological evaluation of market readiness that is outside the scope of this work. These projection models should not be considered as more than one possible outcome for the program influence out of many possible outcomes.

4.3 Xcel Energy – Colorado

4.3.1 Energy and Demand Savings Potential

For the lighting and DCV measure the electricity savings potential is 269 TWh and there is a gas savings penalty of 19 TWh. The combined lighting and DCV measure full market savings potential is 250 TWh of annual energy savings. The total potential peak demand savings for this combined measure package is 118 MW. These results are detailed in Figure 23 below.

Figure 23. Total Potential Market Savings for Xcel-Colorado Territory

Package Description	Elect. Savings (GWh)	Gas Savings (GWh)	Whole Building Elect. Savings (%)	Whole Building Gas Savings (%)	Peak Demand Savings (MW)	Peak Demand Savings (%)
Lighting & DCV	269	(19)	22%	-3%	118	31%

These measures do overlap on potential square footage that could have the measures implemented, so the total potential savings for the territory is not the addition of these two measures.

4.3.2 Energy Cost Savings Potential

For the Lighting and DCV combined measure, the Xcel Colorado territory has the potential for approximately $7.8 million in electricity savings and an additional $13.3 million in demand savings for electricity use per year. There is a reduction in gas consumption that will result in approximately $6 million in savings. The results are shown in Figure 24 below.

Figure 24. Total Potential Cost Savings for Xcel-Colorado Territory

Package Description	Electrical Energy Cost Savings (Million $/Yr)	Gas Cost Savings (Million $/Yr)	Electrical Demand Cost Savings (Million $/Yr)	Total Cost Savings (Million $/Yr)

Lighting & DCV	$7.8	$(0.85)	$13.3	$20.2

These measures do overlap on potential square footage, so the total combined savings potential for both measure packages cannot be combined.

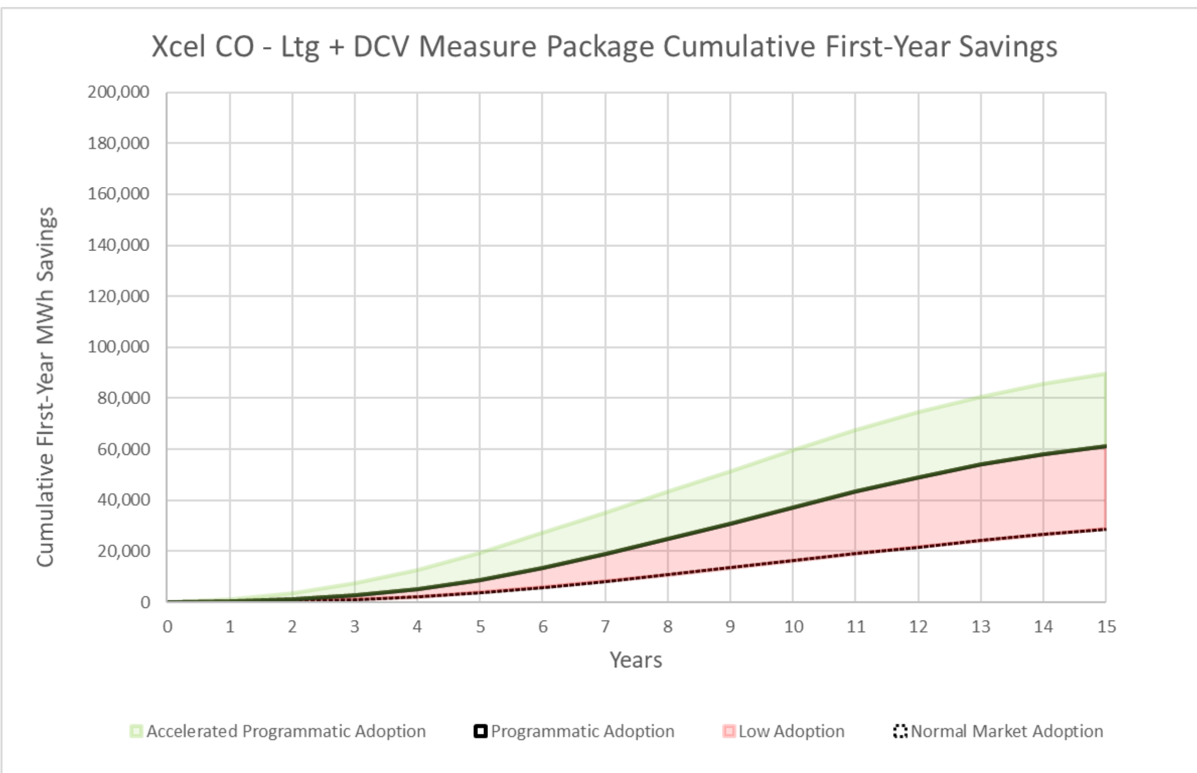
The cost savings are calculated based on approximately $0.029 per kWh for electricity and $115. per kW for annual electrical demand. The gas savings is calculated based on $0.045 per kWh of gas consumption.

4.3.3 Program Energy Savings Potential

Modelling an energy savings potential for a program that is targeting 2.5% of the total market potential per year will produce an estimate of the energy savings potential for each year. The following graphs provides a possible curve of adoption for each measure package in a yearly basis. Refer to Section 4.2.1 above for more information on the modelling built into these graphs.

Figure 25 below shows the possible program first-year energy savings for the lighting and DCV measure package given the market size and a possible 2.5% target program influence. It also shows the NOMAD of approximately 1.1% per year, and a potential high program influence of 3.2% per year in the peak years.

Figure 25. Xcel CO Lighting + DCV Measure Package Cumulative First-Year Savings Model



4.4 Xcel Energy – Minnesota

4.4.1 Energy Savings Potential

For the lighting and DCV measure the electricity savings potential is 80 TWh and gas savings potential is 8 TWh. The combined lighting and DCV measure full market savings potential is 88 TWh of annual energy savings. The total potential peak demand savings for this combined measure package is 32 MW. These results are detailed in Figure 26 below.

Figure 26. Total Potential Market Savings for Xcel - Minnesota Territory

Package Description	Elect. Savings (GWh)	Gas Savings (GWh)	Whole Building Elect. Savings (%)	Whole Building Gas Savings (%)	Peak Demand Savings (MW)	Peak Demand Savings (%)
Lighting & DCV	80	8	21%	2%	32	26%

These measures do overlap on potential square footage that could have the measures implemented, so the total potential savings for the territory is not the addition of these two measures.

4.4.2 Energy Cost Savings Potential

For the Lighting and DCV combined measure, the Xcel Minnesota territory has the potential for approximately $6.3 million in electricity savings and an additional $4.5 million in demand savings for electricity use per year. There is a decrease in gas consumption that will result in approximately $231 thousand in savings. The results are shown in Figure 27 below.

Figure 27. Total Potential Cost Savings for Xcel-Minnesota Territory

Package Description	Electrical Energy Cost Savings (Million $/Yr)	Gas Cost Savings (Million $/Yr)	Electrical Demand Cost Savings (Million $/Yr)	Total Cost Savings (Million $/Yr)
Lighting & DCV	$6.3	$0.23	$4.5	$11.1

These measures do overlap on potential square footage, so the total combined savings potential for both measure packages cannot be combined.

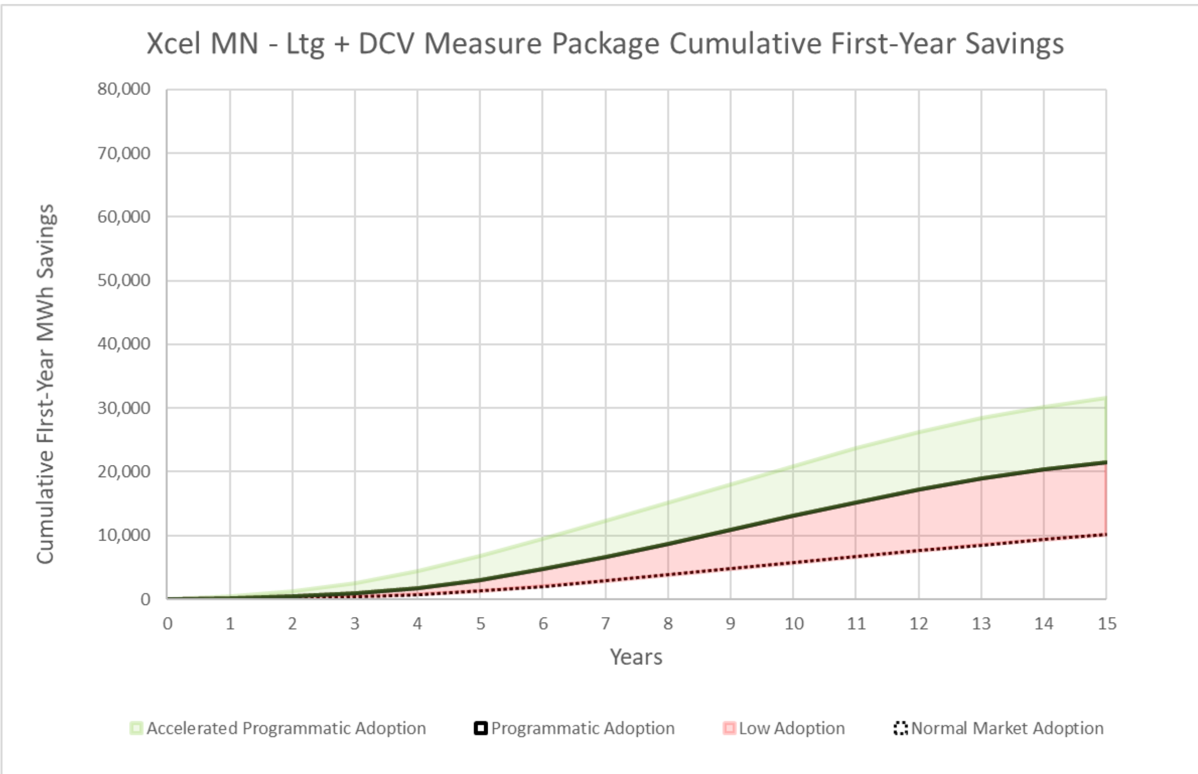
The cost savings are calculated based on approximately $0.079 per kWh for electricity and $150. per kW for annual electrical demand. The gas savings is calculated based on $0.028 per kWh of gas consumption.

4.4.3 Program Energy Savings Potential

Modelling an energy savings potential for a program that is targeting 2.5% of the total market potential per year will produce an estimate of the energy savings potential for each year. The following graphs provides a possible curve of adoption for each measure package in a yearly basis. Refer to Section 4.2.1 above for more information on the modelling built into these graphs.

Figure 28 below shows the possible program first-year energy savings for the lighting and DCV measure package given the market size and a possible 2.5% target program influence. It also shows the NOMAD of approximately 1.1% per year, and a potential high program influence of 3.2% per year in the peak years.

Figure 28. Xcel MN Lighting + DCV Measure Package Cumulative First-Year Savings Model



5 Utility Program Cost Effectiveness Metrics – Task 3

5.1 Summary and Methodology

Cost effectiveness of energy efficiency projects is evaluated in several ways. Customers evaluate investments in any project using simple or discounted payback calculations. Utilities evaluate potential programs based on their ability to generate positive value on the Total Resource Cost (TRC) test.

Total resource cost (TRC): The Total Resource Cost test measures the net costs of a demand-side management program as a resource option based on the total costs of the program, including both the participants' and the utility's costs. The results of the TRC Test are expressed as a benefit-cost ratio. The benefits calculated in the TRC Test are the avoided supply costs, the reduction in transmission, distribution, generation, and capacity costs valued at marginal cost for the periods when there is a load reduction. The costs in this test are the program costs paid by both the utility and the participants plus the increase in supply costs for the periods in which load is increased. 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 (early retirement) or one that has failed (replace-on-burnout)).

Utilities also look at three other tests while designing potential programs – Participant Cost Test (PCT), Ratepayer Impact Measure (RIM) test and Program Administrator Cost (PAC) which is also known as Utility Cost Test (UCT). Each utility assigns different levels of importance to these tests, but the most important test is the TRC. As a result, we used the TRC test to determine the cost effectiveness of these measure packages. In other words, energy efficiency measure packages are cost-effective if they meet the minimum threshold set by the utility (e.g., a TRC greater than or equal to 1.0).

We looked at the total market potential (square feet) for each utility and using TRC as a threshold, we were able to estimate the square footage that provide the greatest potential for total savings. TRC used the ModelMaster tool to calculate the technical and economic savings potential for each measure package and utility. TRC worked with LBNL to get the costs data from the Utility Partner (see the list below) and referred to the energy savings and demand reduction potential calculated as part of the market potential study (see Chapter 3).

Data points that are entered in the ModelMaster tool as inputs are as follows.

- Utility Avoided Electricity Cost ($/kWh)
- Utility Avoided Capacity Cost ($/kW)
- Utility Avoided Gas Cost ($/therms)
- Customer Avoided Electricity Cost (Retail $/kWh)
- Customer Avoided Capacity Cost (Retail $/kW)
- Customer Avoided Gas Cost (Retail $/therms)
- Annual Energy Savings (kWh/sf)
- Annual Demand Reduction (kW/sf)
- Annual Gas Savings (Therms/sf)
- Measure Life (EUL)
- Net-To-Gross (NTG)
- Measure Cost ($)
- Incentive Budget ($)
- Non-Incentive Budget ($)

TRC used the ModelMaster tool to simulate several iterations and "what-if" scenarios for comparison and sensitivity analysis. For each utility partner, four options were tested based on the savings and cost combinations (see section 2.2.3 above).

5.2 Report Data Assumptions

This section descries the methods and assumptions we used to estimate some of the data points listed above.

5.2.1 Global Assumed Data

The following items are assumed values based on reasonable industry expectations for each specific item as detailed below.

Inflation Rate and Discount Rate

TRC test calculates the net present value of program impacts over the lifecycle of those impacts. To calculate the net present value for Xcel Colorado and Xcel Minnesota, we used an inflation rate of 2.4% and discount rate of 7.74% for each year over the life of the measure package

Net-To-Gross (NTG)

Another input for the TRC test is the Net-To-Gross (NTG) ratio. NTG is the ratio or percentage of net program impacts divided by gross or total impacts. NTG ratios are used to estimate and describe the free ridership that may be occurring among energy efficiency program participant. All the utility partners agreed to use an NTG of 0.90 for these measure packages. The reason for this selection is because these measures have not been offered before in this combination for this target market (large office buildings).

Effective Useful Life (EUL)

An estimate of the median number of years that the measures installed under the program are still in place and operable. TRC estimated an EUL of 15 years for these measure packages.

Figure 29 below provides the assumed values for each of these respective variables corresponding to the respective utilities.

Figure 29. Assumed Global Variables for ModelMaster TRC Calculations

Data Point	Xcel CO	Xcel MN
NTG	0.90	0.90
EUL	15 years	15 years
Inflation Rate	2.4%	2.4%
Discount Rate	7.4%	7.4%

5.2.2 Utility-Specific Data

Utility Avoided Energy Costs and Customer Avoided Retail Costs

To calculate the TRC of the measure packages, we worked with LBNL to get the utility avoided energy costs and customer avoided retail costs for each utility partner. For Xcel, TRC estimated these costs by researching a combination of DSM market potential studies, electric resource plan, advice letter filings, utility website (for retail rates), rate schedules, avoided costs spreadsheets, etc.

Figure 30 below provides the avoided costs of energy and customer retail rates corresponding to the respective utility territory.

Figure 30. Assumed Global Variables for ModelMaster TRC Calculations

TRC Calculations Data Point	Xcel CO	Xcel MN
Utility Avoided Electricity Costs ($/kWh)	$0.07	$0.07
Utility Avoided Gas Costs ($/Therm)	$0.28	$0.28

Customer Avoided Retail Electricity Cost ($/kWh)	$0.11	$0.11
Customer Avoided Retail Gas Cost ($/kWh)	$0.74	$0.74

Notes:

1. *The above costs are either estimated or provided by the utility partner for only a year.*
2. *For Xcel Colorado and Xcel Minnesota, a discount rate of 7.4% and an inflation rate of 2.4% is applied to calculate the Net Present Value (NPV) of these costs over 15 years EUL of the measure packages. These values have been obtained from the DSM Market Potential Study for the Colorado region.*
3. *The values in red in above figure are based on market research and assumptions and are not utility-supplied values.*

5.3 Xcel Energy – Colorado

5.3.1 Assumed Data Values

- Utility Avoided Electricity Costs ($/kWh) was taken from the 'Update to the Colorado DSM Market Potential 2013' document.
- Customer Avoided Retail Costs ($/kWh) was taken from the 'Update to the Colorado DSM Market Potential 2013' document.
- Utility Avoided Gas Costs ($/therm) was taken from the DSM-Plan 2019-2020
- Customer Avoided Gas Costs ($/therm) was taken from the DSM-Plan 2019-2020
- *Discount rate of 7.4% and an inflation rate of 2.4% is applied to calculate the Net Present Value (NPV) of the above costs over 15 years EUL of the measure packages*

The four options have been described in detail in section 2.2.3 above.

Figure 31. Option 1 TRC Test Results – Xcel Energy Colorado

Option 1	Incentive ($/kWh)	TRC ER/ROB
DCV + Ltg Controls	$0.15	0.42/1.25

Figure 32. Option 2 TRC Test Results – Xcel Energy Colorado

Option 2	Incentive ($/kWh)	TRC ER/ROB
DCV + Ltg Controls	$0.25	0.47/1.30

Figure 33. Option 3 TRC Test Results – Xcel Energy Colorado

Option 3	Incentive ($/kWh)	TRC ER/ROB
DCV + Ltg Controls	$0.25	0.49/1.34

Figure 34. Option 4 TRC Test Results – Xcel Energy Colorado

Option 4	Incentive ($/kWh)	TRC ER/ROB
DCV + Ltg Controls	$0.25	0.58/1.52

5.4 Xcel Energy – Minnesota

5.4.1 Assumed Data Values

- Utility Avoided Electricity Costs ($/kWh) was taken from the 'Update to the Colorado DSM Market Potential 2013' document.
- Customer Avoided Retail Costs ($/kWh) was taken from the 'Update to the Colorado DSM Market Potential 2013' document.
- Utility Avoided Gas Costs ($/therm) was taken from the DSM-Plan 2019-2020
- Customer Avoided Gas Costs ($/therm) was taken from the DSM-Plan 2019-2020
- *Discount rate of 7.4% and an inflation rate of 2.4% is applied to calculate the Net Present Value (NPV) of the above costs over 15 years EUL of the measure packages*

The four options have been described in detail in section 2.2.3 above.

Figure 35. Option 1 TRC Test Results – Xcel Energy Minnesota

Option 1	Incentive ($/kWh)	TRC ER/ROB
DCV + Ltg Controls	$0.15	0.37/1.15

Figure 36. Option 1 TRC Test Results – Xcel Energy Minnesota

Option 2	Incentive ($/kWh)	TRC ER/ROB

DCV + Ltg Controls	$0.25	0.42/1.21

Figure 37. Option 3 TRC Test Results – Xcel Energy Minnesota

Option 3	Incentive ($/kWh)	TRC ER/ROB
DCV + Ltg Controls	$0.25	0.44/1.24

Figure 38. Option 4 TRC Test Results – Xcel Energy Minnesota

Option 4	Incentive ($/kWh)	TRC ER/ROB
DCV + Ltg Controls	$0.25	0.52/1.42

5.5 Conclusions

The following results and conclusions are based on the calculations results as generated through the ModelMaster tool to produce cost effectiveness of the programs and the LBNL energy modelling for prediction of the energy savings per unit area for each utility territory.

There exists ample technical potential to implement systems-based energy efficiency programs for lighting and HVAC controls in commercial office buildings. The most notable conclusions of the cost effectiveness analysis for each utility partner are:

5.5.1 Xcel Colorado Territory

Findings

- Energy savings (from the model results) for lighting and DCV controls is 2.41 kWh/sf. The customer retail rates are $0.06/ kWh and 0.74/ therm.

Conclusion

- For early retirement (ER), the measure package is not cost effective in all four options due to lower market potential for this measure combination and lower utility rates.
- For replace on burnout (ROB), the measure packages are cost effective in all four options due to relatively low installation cost.

5.5.2 Xcel Minnesota Territory

Findings

- The Utility Partner was not able to provide the customer retail rates and the utility avoided energy costs. Therefore, for the cost effectiveness analysis we assumed the same utility avoided energy costs and customer retail costs as Xcel Colorado.
- Energy savings (from the model results) for lighting and DCV controls is 2.82 kWh/sf.

Conclusion

- For early retirement (ER), the measure package is not cost effective in all four options due to lower market potential for this measure combination and lower utility rates.
- For replace on burnout (ROB), the measure packages are cost effective in all four options due to relatively low installation cost.

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