Title

The Value Proposition for Cost-Effective, Demand Responsive-Enabling, Nonresidential Lighting System Retrofits in California Buildings

Authors

Schwartz, Peter
Gerke, Brian
Potter, Jennifer
et al.

Publication Date

2019-04-01

Peer reviewed

Energy Research and Development Division

FINAL PROJECT REPORT

The Value Proposition for Cost-Effective, Demand Responsive-Enabling, Nonresidential Lighting System Retrofits in California Buildings

California Energy Commission

Gavin Newsom, Governor

April 2019 | CEC-500-2019-041

PREPARED BY:

Primary Authors:

Lawrence Berkeley National Laboratory

Peter Schwartz (PI)
Jennifer Potter
Brian Gerke
Alastair Robinson

Energy Solutions

David Jagger
Jasmine Shepard
Kelly Sanders
Teddy Kisch
Yao-Jung Wen

Electronics, Lighting and Networks Group
Building Technology and Urban Systems Division
Energy Technologies Area
Lawrence Berkeley National Laboratory
1 Cyclotron Road MS 90R2000
Berkeley CA 94720
(510) 486-6926

Contract Number: EPC-15-051

PREPARED FOR:
California Energy Commission

Adel Suleiman
Project Manager

Virginia Lew
Office Manager
ENERGY EFFICIENCY RESEARCH OFFICE

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Drew Bohan
Executive Director

ACKNOWLEDGEMENTS

The authors acknowledge the partners Technical Advisory Committee members who made this project possible, demonstrating the vision and commitment necessary to bring it to successful completion:

- Teren Abear, Emerging Products Technical Lead, SCE
- Rick Aslin, Manager, PG&E
- Gary Barsley, Manager of Customer Self-Generation, SCE
- Albert Chiu, Expert Product Manager, DR Technology and Solutions Team, PG&E
- Kelly Cunningham, Senior Program Manager, Energy Efficiency Codes and Standards, PG&E
- John Goodin, Regulatory Policy Manager, Market and Infrastructure Policy, CAISO
- David Hungerford, Senior Scientist, Research and Development Division, CEC
- Mike Jaske, Senior Policy Analyst, Energy Assessments Division, CEC
- Mark Jewell, President, Selling Energy
- Tarun Kapoor, Expert Product Manager, Emerging Technologies, PG&E
- Charles Knuffke, Western Regions Sales Manager, Watt Stopper
- Vireak Ly, Manager of Technology Test Centers, SCE
- Angela McDonald, Senior Lighting Program Coordinator, PG&E
- Carol Manson, Sr. Policy Advisor, Customer Programs, SDG&E
- Mark Martinez, Manager of Emerging Markets and Technology, SCE
- Dr. Robert T. Nachtrieb, Lead Scientist, Lutron Electronics Co.
- Neda Oreizy, Expert Strategic Analyst, PG&E
- Evan Petridis, Chief System Architect, Enlighted, Inc.
- Sam Piell, Demand Response Emerging Technologies, PG&E
- Edwin (Chip) Poland, Director of Utility Programs, Enlighted, Inc.
- Kevin Powell, Director of Research, Green Proving Ground Program, GSA
- Jill Powers, Infrastructure and Regulatory Policy Manager, CAISO
- Pauravi Shah, Commercial Product Manager, PG&E
- Mona Tierney Lloyd, Senior Director, Western Regulatory Affairs, EnerNOC
- Greg Wikler, Managing Director, Energy Practice, Navigant
- Gil Wong, Principal Strategic Analyst, PG&E

California Energy Commission

The California Energy Commission provided primary funding to make this project possible, and we would like to thank the following staff for providing their kind support and strategic project stewardship:

- Simon Lee, Electrical Engineer, Energy Efficiency Division
- Thao Chau, Electrical Engineer, Energy Efficiency Division
- Gabriel Taylor, Mechanical Engineer, Energy Efficiency Division
- Peter Strait, Supervisor, Building Standards Development, Energy Efficiency Division
- Brad Williams, Mechanical Engineer, Energy Research and Development Division
- Adel Suleiman, Senior Electrical Engineer, Energy Research and Development Division

PREFACE

The California Energy Commission's Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solution, foster regional innovation and bring ideas from the lab to the marketplace. The California Energy Commission and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The Energy Commission is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

The Value Proposition for Cost-Effective, Demand Responsive-Enabling, Nonresidential Lighting System Retrofits in California Buildings is the final project report for Grant Number EPC-15-051 conducted by Lawrence Berkeley National Laboratory and Energy Solutions. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

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

ABSTRACT

Commercial lighting represents a significant potential source of demand response (DR) for the electrical grid, via traditional load shedding and rapid-dispatch (fast-DR) ancillary services when DR is enabled by networked lighting controls (NLCs). However, despite the significant opportunity and a regulatory push, DR-enabled lighting is installed in relatively few buildings because most building owners do not recognize its strong value proposition. Although NLCs can reduce energy bills, optimize facilities, and increase revenue, these co-benefits are not well quantified. This project analyzed lighting DR resources and energy-related co-benefits for commercial buildings in California. Using more than 100,000 individual hourly load profiles, the team forecasted the potential DR resources likely available from commercial lighting in 2025 and estimated revenues available from participation of these DR resources in energy markets. Combining these results with field-study estimates for NLC installation costs and energy savings provided a detailed accounting of site-level cost and energy-related co-benefits by building type from NLC's DR enablement. In many cases, energy savings alone can deliver significant net value, justifying NLC DR-enabled adoption. Additionally, the study considers the sometimes-larger non-energy benefits (NEBs).

This report summarizes the team's development of a framework to capture the high customer values from NLC non-energy benefits to drive DR adoption. More than 130 NLC case studies were reviewed to quantify NEBs and develop a benefits value intensity (BVI) model, which captures the NEB values for energy, building, people, and revenue. Generally, values in higher BVI categories can be several orders of magnitude higher than energy and demand management values alone. Armed with the quantitative NEB information and the high-influence market barriers and opportunities, the team designed a sample logic model and conceptualized five intervention strategies as part of the market transformation theory for achieving large-scale commercial lighting DR adoption.

Keywords: networked lighting controls, non-energy benefits, commercial lighting, demand response, lighting controls value proposition

Please use the following citation for this report:

Schwartz, Peter, Brian Gerke, Jennifer Potter, Alastair Robinson, David Jagger, Kelly Sanders, Yao-Jung Wen, Jasmine Shepard, Teddy Kisch. 2019. Lawrence Berkeley National Laboratory. *The Value Proposition for Cost-Effective, DR-Enabling, Nonresidential Lighting System Retrofits in California Buildings*. California Energy Commission. Publication Number: CEC-500-2019-041.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

EXECUTIVE SUMMARY

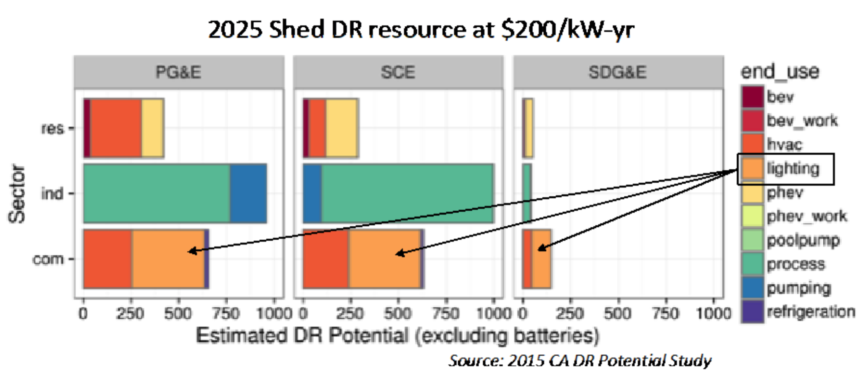
Introduction

California's Clean Energy & Pollution Reduction Act (Senate Bill 350, de León, Chapter 547, Statutes of 2015) requires the state's energy-efficiency savings to double by 2030. One strategy to help meet that goal is to use new technologies that can maintain or improve building comfort-conditioning or process systems and end-uses performance while reducing the electricity needed to operate the building. Because commercial buildings account for more than a third of the energy used in California, innovative wireless communications, embedded sensors, data analytics, and controls offer substantial opportunities to optimize building systems in real time to reduce energy use.

Commercial buildings with networked lighting controls that enable demand response (the ability to reduce or increase electricity demand to better match available supplies) can, when aggregated, provide a distributed energy resource that rivals the annual production capability of California's peaker power plants (which are typically costly, fossil-fueled plants that are generally operated only when there is high demand). The costs for demand response-enabled networked lighting controls plus LED lighting fixture retrofits can be recovered either through energy savings alone, or in some circumstances through savings associated with additional networked lighting functionality. Costs can also be recovered through the value provided by non-energy benefits that, if quantified, could be ten times greater than energy savings alone. The ability to recover these costs depends on the building type, building size, its location and utility rate structure, but activating this resource would provide great benefits to the state of California.

Among the technologies shown in Figure ES-1, lighting in commercial buildings represents an important but underused demand response resource. To effectively tap this resource, owners need to invest in advanced, networked lighting controls combined with new LED sources, which not only facilitate significant energy savings but also enable dispatchable, responsive building loads for providing electricity grid services. Networked lighting controls or advanced lighting systems are a key responsive building load that represents in aggregate, an important DER that can address grid needs.

Figure ES-1: Estimated Shed Demand Response Resource Potential by Building Sector



Since 2013, California Title 24 building code mandates demand response-capable lighting for most new commercial facilities. Despite the significant opportunity and regulatory push, few building owners have installed demand response-capable lighting systems because they do not see the value. Networked lighting controls can enable effective demand response and deliver value to customers in the form of reduced energy bills, optimized facilities, and increase revenues, among other non-energy, co-benefits. However, because lighting technologies can serve the dual purpose of providing energy savings and demand response, it has become more difficult to fully quantify their demand response value in California's Building Energy Efficiency Standards (Title 24). Up to now, systematic analysis of those benefits has been incomplete.

Project Purpose

This project sought to quantify the value of the energy and non-energy benefits and costs of networked lighting controls, including their demand response and energy-efficiency benefits, and to integrate this value into a broader advanced lighting control value proposition framework (that is, how to demonstrate the value of a technology or service to the consumer). In turn, this framework can provide a tool to better quantify in real terms, the value associated with networked lighting controls for different building types. The analysis and framework will help program implementers promote this technology by:

- Supporting next-generation energy code enhancements.
- Providing a means to fully quantify networked lighting control benefits from a customer's or building operator's perspective, in a marketplace where energy savings benefits potentially are outweighed by non-energy benefits when consumers are deciding what to buy.

This study summarizes the framework development that captures the high customer values from the non-energy benefits of networked lighting controls to help increase demand response adoption.

Project Goals

This project sought to:

- Promote wider technology adoption within California to support the state's net-zero energy, sustainability, and electric grid reliability policy goals.
- Identify cost-effective conditions for customer investments.
- Characterize and quantify the electricity grid value of networked lighting controls including operational and infrastructure benefits.
- Quantify the value proposition for implementing code-compliant, demand response-enabling lighting controls in retrofits, including:
- Identifying key non-energy benefits from automated demand response-enabled networked lighting control systems.
- Determining the costs and energy savings of automated demand response-enabled, networked lighting control systems.

- Design a networked lighting control system value proposition framework.
- Evaluate how adoption of non-energy benefits can lead to greater demand response.

Project Approach

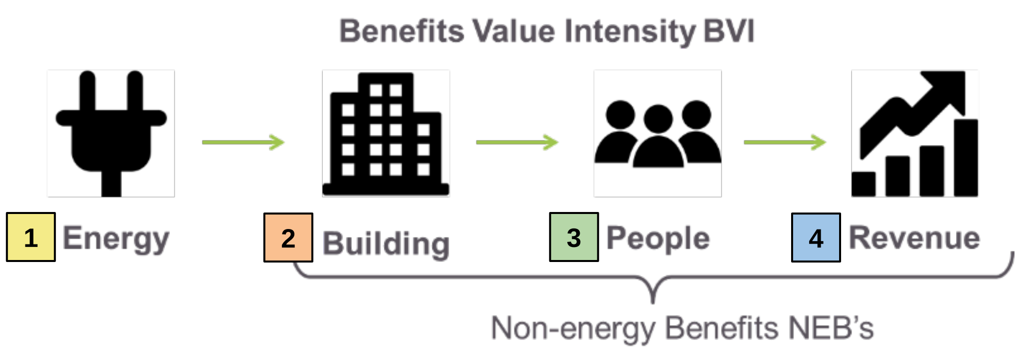
To accomplish the project goals, the research team conducted three major activities. First, the team evaluated the statewide potential at the individual building level for lighting demand response and, based on that information, identified strategies that could overcome market barriers to expanding demand response by better matching load-reduction opportunities with system needs to better inform California's policy makers.

Next, the team quantified the value proposition of implementing code-compliant, demand response-enabling lighting controls for retrofitting multiple nonresidential building types, in an effort to help building owners and contractors better understand all the benefits of using lighting to participate in demand response programs offered by California's investor-owned utilities.

Finally, based on the results of these activities, the team designed a framework for a value proposition for lighting controls, and how adoption of non-energy benefits could enable greater use of demand response. Incorporated in that was an analysis of what needs to occur for that to happen.

The team reviewed more than 130 networked lighting control case studies to quantify the non-energy benefits and develop a benefits value intensity model that captures the energy and non-energy benefits related to building, people and revenue (Figure ES-2).

Figure ES-2: "3:30:300:3000" Rule of Thumb Benefits Value Intensity Framework Categories



Source: Lawrence Berkeley National Laboratory

This approach was built upon the "3:30:300:3000" rule of thumb, which signifies the relative dollar per square foot value associated with building energy, rent, and occupant salary costs, in addition to the potential revenue generated by the people within a building (Table ES-1). Generally, values in the higher benefits value intensity categories (Levels 2 – 4) can be several orders of magnitude higher than energy and demand management (Level 1) values alone.

Table ES-1: Benefits Intensity Value Index

BVI Level	Organization Category	Definition	Example
1	**Energy (Ave. cost = $3/ft^2)**	The lowest BVI category. Describes the energy benefits that may accompany a NEB.	Reduced energy consumption achieved by reducing unused space
2	**Building (Ave. cost = $30/ft^2)**	Generalized "costs of rent" to capture all values a NEB can create on a building's operation	Avoided costs by not adding new space since current space is more efficiently used
3	**People (Ave. cost = $300/ft^2)**	Captures a NEB's impact on people or activities they perform in a building	Employees can find spaces to work and conduct meetings. More efficient use of their time increases satisfaction with their space.
4	**Revenue (Ave. = $3,000/ft^{2*})**	The highest BVI category. Capturing additional revenue generated from business activities performed in the building as a result of a NEB.	Increased revenue generated by additional employees added to use the same workspace; increased revenue from using retail wayfinding to increase customer sales

*** Revenue represents a very rough estimate, since this metric requires significant exploration. NEB is non-energy benefit.**

Source: Lawrence Berkeley National Laboratory

Using quantitative non-energy benefits information and high-influence market barriers and opportunities, the team designed a sample logic model and conceptualized five intervention strategies as part of the market transformation theory for achieving large-scale commercial lighting DR adoption:

1. Lack of user value: Research and normalize non-energy benefit narratives and metrics to standardize their quantification.
2. Perceived impact (user, trade ally): Define demand response strategy best practice, demonstrate, and publish results proving that lighting demand response implementation does not adversely affect performance.
3. Lack of standardization: Develop capability performance specifications for inclusion in programs and by specifiers.
4. Lack of best practices and commissioning: Develop configuration template and commission guides.
5. Lack of integrated program support: Bundled program design linking energy efficiency, demand response, non-energy benefits, and persistence.

Analytical Strategy for Office and Retail Buildings

For office and retail buildings, the study employed the "bottom-up" modeling framework for demand response capabilities and availability that was developed in demand response potential study conducted for the California Public Utilities Commission (Alstone et al. 2017). The framework leverages large customer-level electricity use and demographic datasets provided by each California investor-owned utility to estimate the potential resource for different demand response service types by sector, building type, site size, and end use in 2025. The first step for estimating resource availability is to group customers in similar cohorts, or "clusters." Each cluster represents aggregated real customer consumption and demographic information. Each cluster's consumption time series is disaggregated into its constituent end uses, and these end-use baseline load shapes are forecasted to the study year of 2025.

Commercial lighting load was explicitly disaggregated for clusters representing office and retail buildings. The clustering further subdivided these building types into small, medium, or large site sizes that is consistent with utility practices for assigning rates and demand charges as illustrated in Table ES-2.

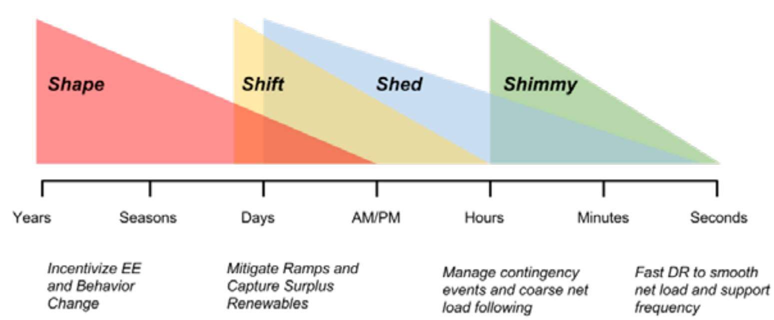
Table ES-2: Peak Demand Thresholds for Categorizing Small, Medium, and Large Commercial Customers

Demand Categories	Small Commercial	Medium Commercial	Large Commercial
Peak demand threshold	< 50 kW	50–200 kW	> 200 kW

Modeling Framework

The 2025 California demand response potential study introduced a new broad demand response type categorization that represented a new demand response taxonomy (Figure ES-3).

Figure ES-3: 2025 California Demand Response Potential Study Demand Response Taxonomy



Source: Lawrence Berkeley National Laboratory

- This study focused on shape, shed, and shimmy regimes when evaluating networked lighting controls demand response value for offices and retail buildings. "Shape" refers to demand that permanently reshapes customer load profiles. "Shed" refers to traditional demand response and loads that can be reduced or restricted to provide peak capacity and support the electric system. "Shimmy" is an emerging service that involves using loads to address short-run ramps and disturbances including frequency or voltage regulation.

The team forecasted load shapes to the year 2025, using California's investor-owned utility smart meter data. The analysis includes the following modeling assumptions regarding networked lighting control benefits:

- Networked lighting control upgraded lighting energy savings:
  - LED upgrades yield up to a 50 percent static reduction in lighting energy intensity as a result of from improved system efficiency and modern illumination level practices.
  - Networked lighting controls yield an additional 40 percent to 60 percent energy savings from active control (2017 DLC).
- The present value of energy savings is calculated based on investor-owned utility commercial time-of-use rates.
- Revenue from demand response participation in energy markets is based on the California Independent System Operator's price forecasts.

Project Results and Benefits to California

This research found that networked lighting controls are likely to become a more important distributed energy resource because of the increased efficiency they bring to lighting systems, their flexible control and rapid-response capabilities, and their ease of load aggregation. Adoption of these technologies is expected to grow rapidly as more facilities recognize the non-energy benefits of networked lighting control systems, market adoption increases, technology prices fall, and the electricity market becomes more volatile.

Project costs were found to be generally consistent across building types, though small retail is slightly higher due to a higher fixture density. As expected, project costs decrease significantly as project size increases.

Table ES-3 displays the net revenue associated with site-level levelized costs and energy-related benefits from installing a demand response-enabled lighting system in six different building categories (small, medium and large for both office and retail) within each California investor-owned utility service territory. Values in red indicate negative value from energy-related benefits and costs.

Office and Retail Site-level Costs and Energy Benefits

Figure ES-4 displays the site-level levelized costs and energy-related benefits from installing a demand response-enabled lighting system in three different retail building categories within Southern California Edison's and Pacific Gas & Electric Company's service territories.

The cost and benefit results are presented as waterfall diagrams, displaying:

- Costs as positive red bars that incrementally build up the total cost.
- Benefits are shown as negative green bars that subtract from the aggregated cost to yield a total "energy-only" (that is, exclusive of non-energy benefits) net cost or net benefit.

Table ES-3: Levelized Annual Costs and Savings, in Dollars per Year

Utility	Building Type	Building Size	Net Revenue
PG&E	Office	Large	$182,769
		Medium	$17,315
		Small	$1,015
	Retail	Large	$173,610
		Medium	$27,780
		Small	$2,095
SCE	Office	Large	$3,951
		Medium	$58
		Small	$44
	Retail	Large	$3,037
		Medium	$415
		Small	$535
SDG&E	Office	Large	$73,374
		Medium	$3,189
		Small	$286
	Retail	Large	$41,510
		Medium	$4,800
		Small	$496

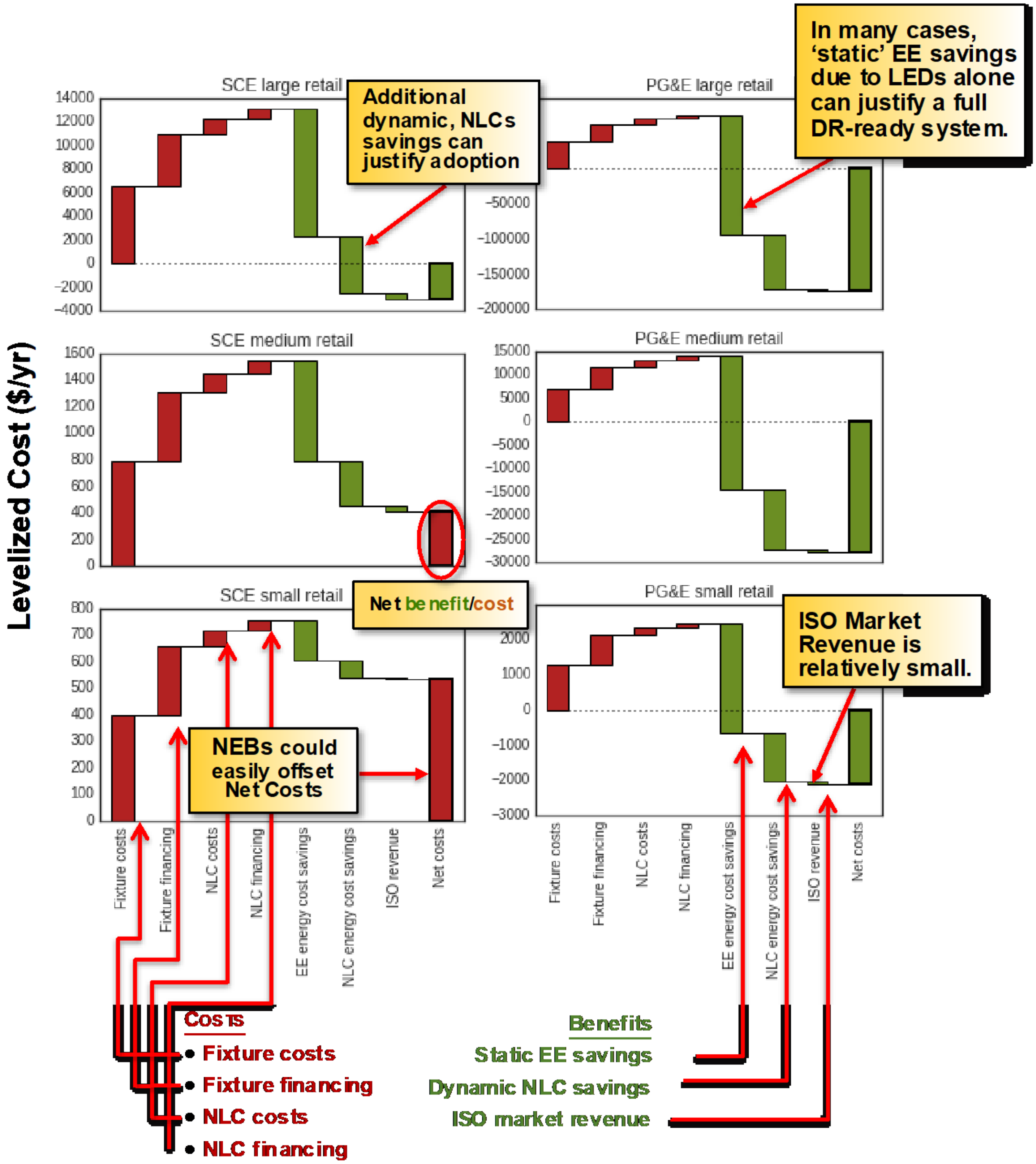
Corresponding partially to the values plotted in Figure ES-4.

Source: Lawrence Berkeley National Laboratory

The figure shows that the energy-only cost-effectiveness of demand response-enabled lighting systems varies substantially depending on building size and service territory. In general, such systems are more cost-effective for larger buildings than for smaller ones, and for offices than for retail sites, across all service territories. In Pacific Gas & Electric Company's service territory, where commercial retail electricity rates are relatively high (especially on peak), there is a substantial net benefit across all building sizes and types, and demand-response-enabled systems can generally be justified based on the static energy efficiency savings alone. The site-level value proposition in this case is straightforward. In contrast, in Southern California Edison's service territory where electricity rates are lower, the cost-effectiveness depends strongly on the building size, with a net benefit for large buildings only. In this case, the value proposition for small and medium buildings would likely need to rest on the non-energy benefits, rather than on the energy-related benefits. The results for the San Diego Gas & Electric Company's service territory are somewhere between these two cases.

Notably, the available revenue from independent system operator markets is always small relative to the system costs and overall energy cost savings. This suggests that the primary value proposition for demand response-enabled networked lighting controls comes from the site-level energy savings that will be realized with or without demand response participation. It may therefore be important to develop additional strategies to encourage participation in demand response programs once these technologies are adopted.

Figure ES-4: Levelized System Installation Annual Costs and Energy-Related Benefits in Southern California Edison and Pacific Gas & Electric Service Territories



Far Right Total: GREEN **indicates Positive value;** RED **is Negative**

Source: Lawrence Berkeley National Laboratory

Comparing the available networked lighting controls energy savings in gigawatt-hours per year (GWh/yr) in Table ES-4 clearly indicates that the aggregate potential 5,091 GWh/yr resource exceeds the annual 4,425 GWh/yr peaker power output for 2015 reported to the Energy Commission. In fact, the available resource represents about 4-percent of the total 126,919 GWh/year of state natural gas generation.

Table ES-4: Potential Shed and Shimmy Demand Response Resources and Networked Lighting Controls Energy Savings

	Available Average* Shed Resource (MW)	Available Average Shimmy Regulation Resource (MW)	Available Average Shimmy Load-Following Resource (MW)	Available NLC Energy Savings (GWh/yr)
Total	**1,026.6**	**824.2**	**1,033.6**	**5,090.7**

Note: These are values that would be achievable by universal installation of networked lighting controls in California office and retail buildings.

*** The average demand response resource refers to the average load that would be expected to be available for times when the demand response needs to be dispatched.**

Source: California Energy Commission QFER CEC-1304 Power Plant Data Reporting

Demand Response Adoption Framework Summary

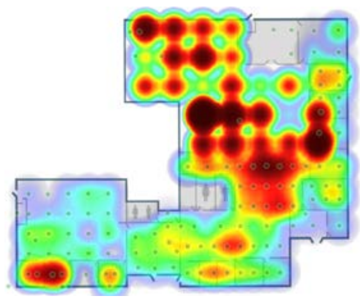
Networked lighting controls hold the promise of unlocking significant new value by capturing detailed environmental and device level sensory information. They can also implement control strategies to reduce energy consumption and manage building lighting load without affecting lighting characteristics, such as dim level or color, so precisely that user comfort is unaffected. However, these technologies still face adoption barriers, particularly for enabling features such as demand response. The project team developed a framework by which non-energy benefits can be leveraged to enable and support market adoption of energy benefits such as demand response. This adoption framework was used to clarify which cost-effective intervention strategies will increase demand response adoption (enablement and use). The framework leverages four components:

1. Benefits value intensity, which identifies and values non-energy benefits by building and space type.
2. Smart device maturity lifecycle, which explores how system capabilities support identified non-energy benefits while also supporting required demand response functionality and use.
3. Logic model and market transformation theory, to clarify and scope needed market intervention strategies including various activities, outputs and outcomes to remove specific barriers or leverage opportunities.
4. Program design, which evaluates all three elements above to select the most impactful program type to support market transformation.

Benefits Value Intensity

The Benefits Value Intensity model helps categorize the magnitude of the impact of non-energy benefits on businesses' energy costs, building costs, employee productivity, or company revenue, typically in terms of a financial value such as dollars per square foot where such quantification is possible. Actual documented values are highly specific to organizations and industries. For example, "increased facility control" by monitoring and optimizing humidity levels in a manufacturing facility might increase revenue by reducing the number of defective products. A warehouse might increase facility control by using occupancy-sensing heatmaps (Figure ES-5) to optimize stocking practices and boost employee productivity. In both cases, the benefits value intensity framework helps categorize and define value for non-energy benefits that are typically concurrent with demand response enablement.

Figure ES-5: Example Occupancy Visualization



Source: Garcia (2015)

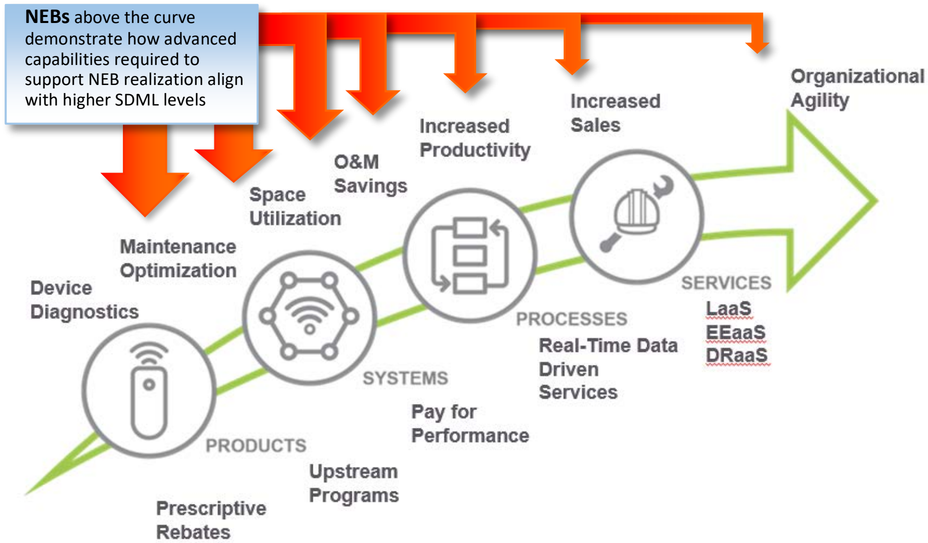
Importantly, the average Level 2 Benefits Value Intensity non-energy benefit savings in dollars/square foot/year is comparable to the overall Level 1 realized energy savings resulting from energy-efficiency improvements. This suggests that enabling networked lighting controls to decrease operations and maintenance costs in some cases through employing better operational data capture for things like asset utilization, could achieve equivalent dollar value benefits as energy savings associated with operating the networked lighting controls system for purely lighting alone.

Smart Devices Maturity Lifecycle

While the Benefits Value Intensity focuses on defining business value from networked lighting controls capabilities, the technology and its capabilities are evolving over time to create new and emerging business value. Smart devices typically follow a maturity cycle as they evolve and become increasingly connected and intelligent, and the smart devices maturity lifecycle focuses on this evolution to anticipate future capabilities that may unlock additional value.

The smart devices maturity lifecycle identifies four maturity levels: (1) products, (2) systems, (3) processes, and (4) services as shown in Figure ES-6. As activities move from nascent products (left) to services (right), then the benefits value intensity multiplier increases by factors of 10 described earlier in the 3:30:300:3000 rule of thumb.

Figure ES-6: Smart Device Maturity Lifecycle with Utility Programs and Non-energy Benefits Alignment



Note: LaaS = Lighting as a Service; EEaaS = Energy Efficiency as a Service; DRaaS = Demand Response as a Service

Source: Lawrence Berkeley National Laboratory

Market Transformation

Market transformation theory for demand response-enabled networked lighting controls reflects that consumer interest in non-energy benefits can be used to support grid beneficial capabilities but may have limited customer interest. Utility program support and incentives for networked lighting control demand response-enablement provides a win-win, allowing customers to adopt innovative new systems to obtain the non-energy benefits and utilities to have a persistent measurable supply of energy resources like energy efficiency and demand response. Additionally, this approach can influence actions that in turn will begin to prepare the building stock for more advanced energy benefits such as fast-demand response, for which networked lighting controlled, solid-state lighting is ideally suited.

The market transformation theory statement for networked lighting controls demand response-enablement is as follows:

- By clearly communicating the value proposition for each instrumental stakeholder and demonstrating the appropriate risk/reward, demand response adoption and use will be sought to co-fund initial networked lighting controls system costs and pave the way to significant non-energy benefits.

The market transformation theory statement leverages perception of value, the need to quantify value, the need to identify implicated stakeholders, the need to resolve perceived or real barriers to adoption, the connection between the value of non-energy benefits and the value of energy, and the conclusion of a behavioral change. In this context, each phrase within the statement has specific elements or goals.

- “Clear communication of value” includes defining and quantifying the value in clear terms, such as “dollars saved per square foot”, through efforts such as the Benefits Value Intensity, so that market actors understand the networked lighting control proposition in the context of their own business model lists “Instrumental stakeholders” included in the process of non-energy benefits/energy benefits realization (non-energy benefit-specific).
- “Demonstrating appropriate risk/reward” refers to assessing possible impacts to each stakeholder (through demonstrations, surveys, etc.), and capturing the full list of rewards (or value) they may receive from the solution. In addition, this element must address perceived adverse impacts such as DR events that affect lighting quality.
- “Adoption and use” refers to configuring the DR capability included in most current NLC systems on the market, installing any remaining hardware/software, commissioning the proper application, receiving commitments to ongoing use through DR program enrollment, and verifying use.
- “Sought to co-fund” implies the knowledge and desire of the building owner or operator to seek the value proposition of NLCs and include utility incentives, in a bundled energy efficiency/DR package, leveraging “clear communication of value” to finance initial system costs to an acceptable level.
- “Initial system costs” include the full system implementation costs to provide all capabilities required to produce the targeted NEB(s) and the DR functionality.
- “Pave the way to significant non-energy benefits” refers to the higher levels of the BVI, including buildings, people, and revenue value generation. Quantification, to a “significant” level, is from the perspective of the targeted stakeholder.

Market actors include: building owners, property/facility managers, occupants, trade allies, specifiers, manufacturers and utilities, all residing at different intervention points along the building and smart devices maturity lifecycles. This necessitates innovative program design approaches to eliminate or mitigate any market barriers to technology adoption.

Program Design – New Business Models

As an outgrowth of this study, the project identified that new business models are required to fully implement deployment of demand response-enabling networked lighting controls. Such models include developing pay-for-performance programs that bundle energy and non-energy benefits to support new services-oriented business models. Concepts like lighting as a service fall into this category. By default, this requires defining a new frame of reference rather than using historical energy efficiency/demand response program regulatory boundary conditions because the value of networked lighting controls goes beyond purely energy efficiency benefits to now include non-energy benefits.

Conclusion

The project team found networked lighting controls have great potential to provide both energy savings and demand flexibility. Importantly, these technologies enable demand response capability within buildings that represents a significant distributed energy resource that in aggregate can more than offset peaker power plant production. Further research is required to unlock this potential to create a clearer site level, value proposition.

In many cases, energy savings alone can easily justify adoption of this technology, but in other cases, additional incentives or accounting of non-energy benefits may be necessary to justify investment. A long-term vision is to automate the quantification of non-energy benefits. Doing so would rely heavily on standardized networked lighting control commissioning using uniform nomenclature to ensure a syntactically and semantically meaningful data collection. Leveraging various Internet of Things (IoT) features, such as device data reporting, machine learning, data analytics, and so on, could make it possible to continue expanding and updating the non-energy benefits dictionary to keep up with technology advances and discover new non-energy benefits.

In general, the project team found values in higher benefits value intensity categories (Levels 2-4) could be several orders of magnitude larger than values in energy and demand management alone (Level 1). Using the quantitative information on non-energy benefits and high-influence market barriers and opportunities, the project team designed a sample logic model and conceptualized five intervention strategies as part of the market transformation theory for achieving large-scale commercial lighting demand response adoption.

In addition, the team concluded that where networked lighting controls are installed, additional incentives might be needed to encourage participation in utility demand response programs because typical revenue from bidding lighting demand response into energy markets is comparatively tiny (Figure ES-4).

This research sets the stage for California’s investor-owned utilities to offer new pay-for-performance programs to support lighting technologies that create responsive buildings that become viable distributed energy resources able to provide grid services. Further, the research identifies which class of office or retail building can provide significant resource in different investor-owned utility load aggregation points.

More effort is necessary on several market transformation fronts to achieve success in deploying networked lighting controls effectively to create responsive, demand response-enabled buildings in California. This study is an initial effort, and indicates the need for further research and utility program support.

CHAPTER 1: Value Proposition for Nonresidential Building Lighting Retrofits and Demand Response

Research Objective

Advanced lighting controls are among the many rapidly evolving technologies that use wireless communications, embedded sensors, data analytics, and controls to optimize building systems in real time as discussed in more detail in Chapter 2. These technologies provide increased insight and controllability of building systems and offer not only energy savings, but also opportunities to develop dispatchable building electrical loads for providing electricity grid services, for example frequency regulation, ramping, and so on. This new functionality, combined with dense sensor networks that capture large datasets, is causing a shift in the lighting controls market such that energy benefits are becoming a smaller piece of the technology's overall value proposition (how one conveys the value of the technology to potential customers). In fact, several lighting controls manufacturers have evolved their business models to become sensor platform companies in recognition of the non-energy value streams and Internet of Things (IoT) market trends. These companies recognized that instead of tying their sensors and controls just to the lighting system, by adding enhanced sensor functionality like temperature and humidity, and so on into individual fixtures they could create the equivalent of a building central nervous system that multiple building end use systems could tap into to optimize their operation. This establishes a highly granular and dense sensor network that provides high quality, real-time data. What once was a simple analysis is now increasingly complex in terms of promoting the benefits of lighting controls as specified in energy codes, including requirements to provide demand response (DR) capability.[1]

To date, no one has systematically quantified the DR value proposition for lighting controls in California's Title 24 Building Energy Efficiency Standards fully. This project sought to quantify the energy and non-energy benefits and costs (value) of DR-enabling, networked lighting control systems (NLCs) in addition to their energy-efficiency (EE) benefits, and to integrate this DR value into a broader advanced value proposition framework for lighting controls that can be used in the future. The intent of performing this analysis and developing this framework was to help program implementers promote the technology by supporting next-generation, energy code enhancements. In addition, the research will provide a tool to quantify NLC benefits in a marketplace where non-energy benefits (NEB) could outweigh energy savings benefits when consumers are considering what to buy.

[1] Demand response is a change in an electric utility customer's power consumption to better match the demand for power with the supply available to the electricity grid.

Study Scope

This project promotes wider adoption of cost-effective DR-enabling technologies within California, in support of the state's policy goals for net-zero energy, sustainability, and electric grid reliability, by refining the value proposition for lighting controls' value proposition, including their DR benefits. The research project works to achieve this by:

- Determining the statewide potential for lighting DR and identifying strategies for overcoming market barriers to expanding DR in all sectors by improving the matching of load-reduction opportunities with system needs, which will better inform California's policy makers.
- Quantifying the value proposition of implementing code-compliant, DR-enabling lighting controls for retrofitting various nonresidential building types, which helps building owners and contractors better understand the benefits of using lighting to participate in DR. This includes:
    - Identifying key NEBs from automated demand response (ADR)-enabled NLC systems.
    - Determining ADR-enabled NLC systems' costs and energy savings.
- Designing a framework for a value proposition for lighting controls, and how NEB adoption can lead to DR-enablement and use (and what needs to occur for this to happen).

Report Organization

- Chapter 2 presents the statewide DR potential report.
- Chapter 3 outlines the cost and energy savings of ADR-enabled networked lighting controls systems.
- Chapter 4 identifies the non-energy benefits that can accrue from the use of DR-enabled lighting control systems.
- Chapter 5 discusses the adoption of non-energy benefits and DR enablement including the findings and drivers that affect DR enablement, as well as next steps.
- Chapter 6 summarizes the overall project material.

CHAPTER 2:
Statewide Demand Response Potential Report

Advanced lighting controls are among the rapidly evolving technologies that use wireless communications, embedded sensors, data analytics, and controls to optimize building systems in real time. Lighting controls' energy benefits are becoming a smaller piece of the technology overall value proposition. This project task sought to quantify the DR value (energy and non-energy benefits/costs) for networked lighting systems in addition to their energy-efficiency benefits, and to integrate this DR value into a broader advanced lighting controls value proposition framework that can be employed as a tool moving forward.

This research project's purpose is to identify, quantify and evaluate the incremental costs and benefits of demand-responsive (DR) networked lighting controls (NLC) system requirements in the California Title 24 Building Energy Efficiency Standards (Figure 1) across California's existing, nonresidential building stock. The project focuses on the incremental costs and benefits associated with adding the functionality necessary to enhance general lighting upgrades in these existing, nonresidential buildings, to enable them to act as DR resources.

Figure 1: 2013/2016 California Title 24 Mandatory Lighting Control Demand Response Requirements

California Title 24, Part 6

SECTION 130.1 – MANDATORY INDOOR LIGHTING CONTROLS

Nonresidential, high-rise residential and hotel/motel buildings shall comply with the applicable requirements of Sections 130.1(a) through 130.1(e).

2013 Building Energy Efficiency Standards for Residential and Nonresidential Buildings

Section 130.1(e) Demand Responsive Controls.

Lighting power in buildings larger than 10,000 square feet shall be capable of being automatically reduced in response to a Demand Response Signal; so that the building's total lighting power can be lowered by a minimum of 15 percent below the total installed lighting power. Lighting shall be reduced in a manner consistent with uniform level of illumination requirements in TABLE 130.1-A.

Spaces that are non-habitable shall not be used to comply with this requirement, and spaces with a lighting power density of less than 0.5 watts per square foot shall not be counted toward the building's total lighting power.

2016 Building Energy Efficiency Standards for Residential and Nonresidential Buildings

Section 130.1(e**) Demand Responsive Controls.**

1. Buildings larger than 10,000 square feet, excluding spaces with a lighting power density of 0.5 watts per square foot or less, shall be capable of automatically reducing lighting power in response to a Demand Response Signal; so that the total lighting power of non-excluded spaces can be lowered by a minimum of 15 percent below the total installed lighting power when a Demand Response Signal is received. Lighting shall be reduced in a manner consistent with uniform level of illumination requirements in TABLE 130.1-A.

   EXCEPTION to Section 130.1(e): Lighting not permitted by a health or life safety statute, ordinance, or regulation to be reduced shall not be counted toward the total lighting power.

2. Demand responsive controls and equipment shall be capable of receiving and automatically responding to at least one standards-based messaging protocol by enabling demand response after receiving a demand response signal.

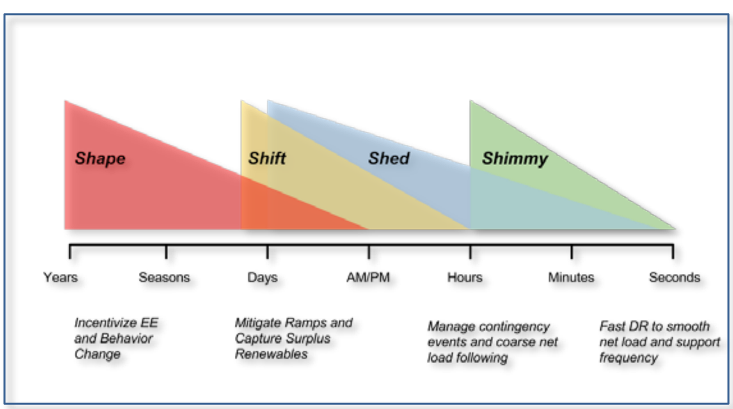
Demand Response Service Types

Based on future grid needs, the research team defined two key "service types" for which there may be significant lighting end-use DR potential: shed and shimmy.

- "Shed" describes loads that occasionally can be curtailed to provide peak capacity and support the system in emergency or contingency events—at the statewide level, in local high load areas, and on the distribution system, with a range in dispatch advance notice times. Shed technology pathways examples are:
  - Interruptible processes
  - Advanced lighting controls
  - Air-conditioner cycling
  - Behind-the-meter storage
- "Shimmy" involves using loads to dynamically adjust demand on the system to alleviate short-run ramps and disturbances at timescales ranging from seconds up to an hour. Examples of shimmy technology pathways are advanced lighting, fast-response motor control, and electric vehicle (EV) charging.

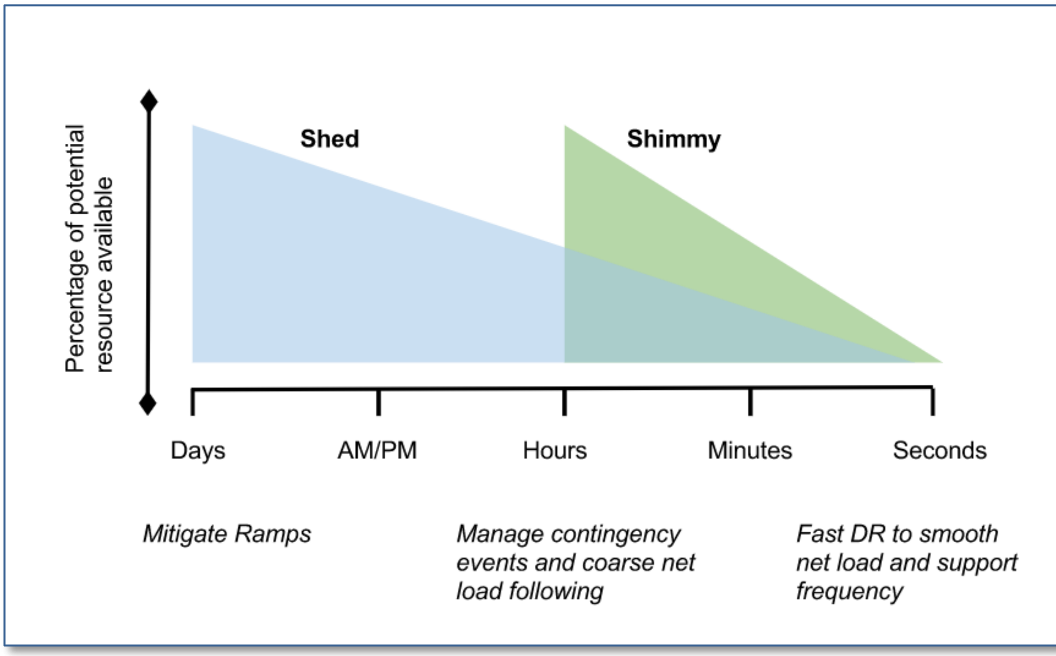
Alstone et al. (2016) also considered a DR service type called "shift" to capture the potential for energy-neutral, dispatchable load-shifting as a means of balancing varying generation capacity throughout the day. However, the lighting end use typically has little to no time flexibility (with the possible exception of industrial-scale, agricultural process loads not considered in this study), so it is unlikely to be a significant source of shift. These service types or resources span a range of possible California electrical grid needs, and these are mapped conceptually onto a time line in Figure 2. They range from days (addressed by shed) to seconds (met by shimmy and some shed resources). Previous studies for energy efficiency or distributed generation often treat the resources as "static" decentralized energy investments with deterministic outcomes, but DR investment outcomes are more probabilistic and depend on continued customer engagement for a durable resource. Furthermore, the value created by DR depends on the specific timescale of the response.

Figure 2: 2025 California Demand Response Potential Study Demand Response Taxonomy



Source: Lawrence Berkeley National Laboratory

Figure 3: DR Service Types Presented over a Timescale for Grid Service Dispatch Frequency and/or Response



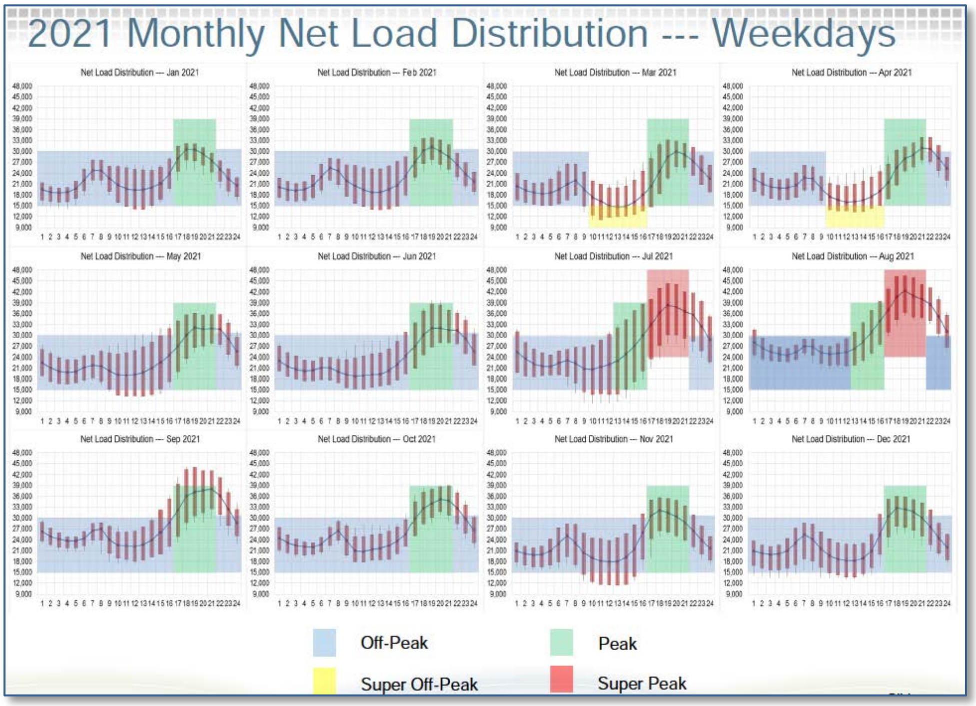
Source: Lawrence Berkeley National Laboratory

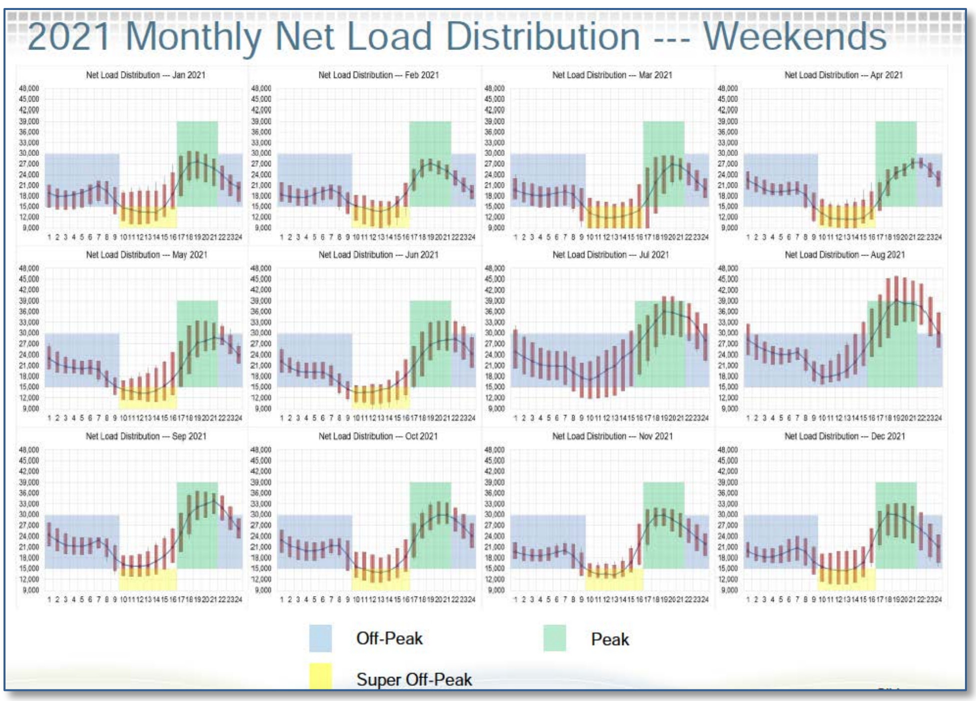
In this study, the team modeled shed resources that include and go beyond conventional DR, which is often dispatched many hours or a day ahead to manage forecasted, system-level peaks (see Figure 4 below where green indicates a system net peak load; red indicates a system net super-peak load; yellow indicates a system net super off-peak load; and blue indicates an off-peak load (Rothleder 2016). Figure 4 clearly shows that the traditional midday peak has completely shifted to late afternoon-early evening peaks and weekday super-peak loads due to the increasing renewable energy deployments.

Lighting can play a key resource role as a fast-shedding resource that can meet local capacity needs or distribution system needs, and that respond in the event of contingency and emergency conditions.

The team defines Fast-DR that can follow sub-hourly to seconds-level signals as shimmy resources. The need for shimmy is bounded based on net load variability, but has high value for maintaining stability. In addition to the existing variability from a diverse set of loads from the quick-paced, Internet of Things (IoT) devices evolution, the growing solar and wind power generator fleet introduces new kinds of shimmy-scale variations that pose enormous cost implications at the California Independent System Operator (CAISO) to handle both grid regulation and “jagged” ramping up and down renewable generation (see Figure 5, Figure 6 and Figure 7).

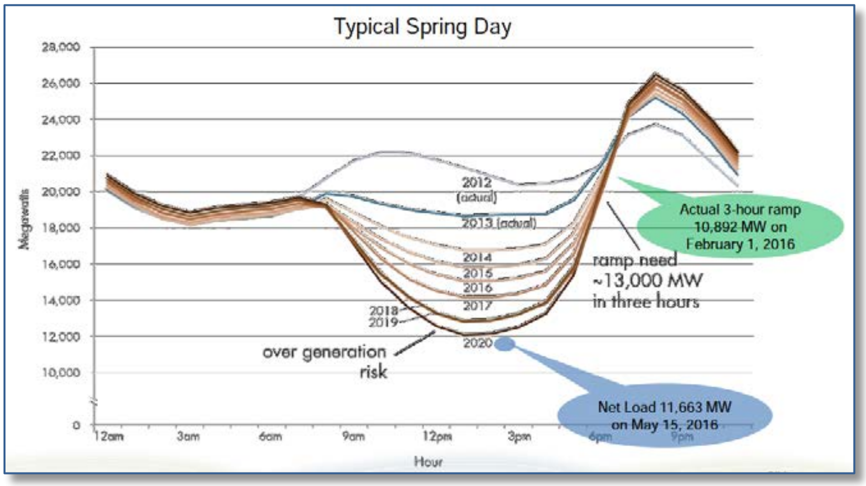
Figure 4: California Independent System Operator Projected 2021 Net Load Weekday and Weekend Peaks





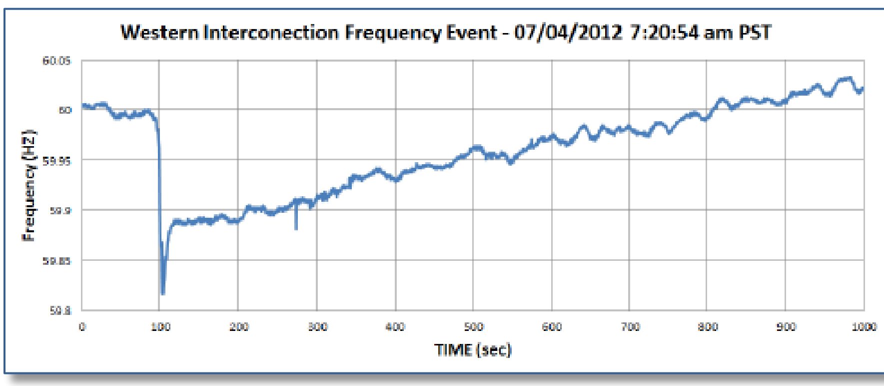
Source: Rothleder (2016)

Figure 5: California Independent System Operator "Duck Chart"



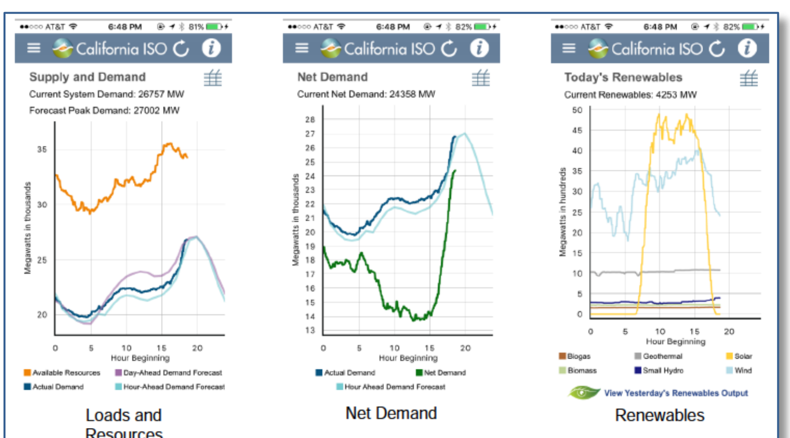
Source: Rothleder (2016)

Figure 6: Over-frequency Event Example



Source: Loutan et al. (2016)

Figure 7: Real-time View of Supply and Demand, Renewable Energy Production, Emergency Notifications and Requests for Energy Conservation



Sources: Rothleder (2016) and www.caiso.com/Pages/ISOToday.aspx

These DR service products provide value to the grid, and are framed and valued differently in various balancing authority areas. In California, there are ranges of existing and emerging products for DR participation in CAISO markets, resources adequacy (RA) procurement, and at the retail or load-modifying level. Figure 8 illustrates CAISO's control room market monitoring and dispatch system wherein each desk monitors and manages a separate CAISO market while the large wall-mounted monitors track different aspects of the entire western grid.

Figure 8: CAISO Control Room Tracking Renewable Profiles

Source: Rothleder (2016)

The team mapped these California DR markets to the shed and shimmy framework in Table 1. The choice to reframe market products into the more generic services framework was a conscious one, designed to ensure the study's results are broadly applicable for future market structures that may not match current-day approaches. The service types' mathematical formulations closely match CAISO and other requirements when possible (for example, with conventional shed).

Another benefit the team uncovered in the study's course is the usefulness of a shorthand lexicon for DR in having technical exchanges of ideas about future policy and market operations. The short names (shape, shed, shift, shimmy) trade specific details for broader and more accessible concepts in grid management, and facilitate discussions between building scientists, policy analysts, and power systems experts without necessarily requiring specific and esoteric knowledge of California market processes.

Table 1: Demand Response Service Types Mapped to California's Conventional Wholesale and Retail Market Products

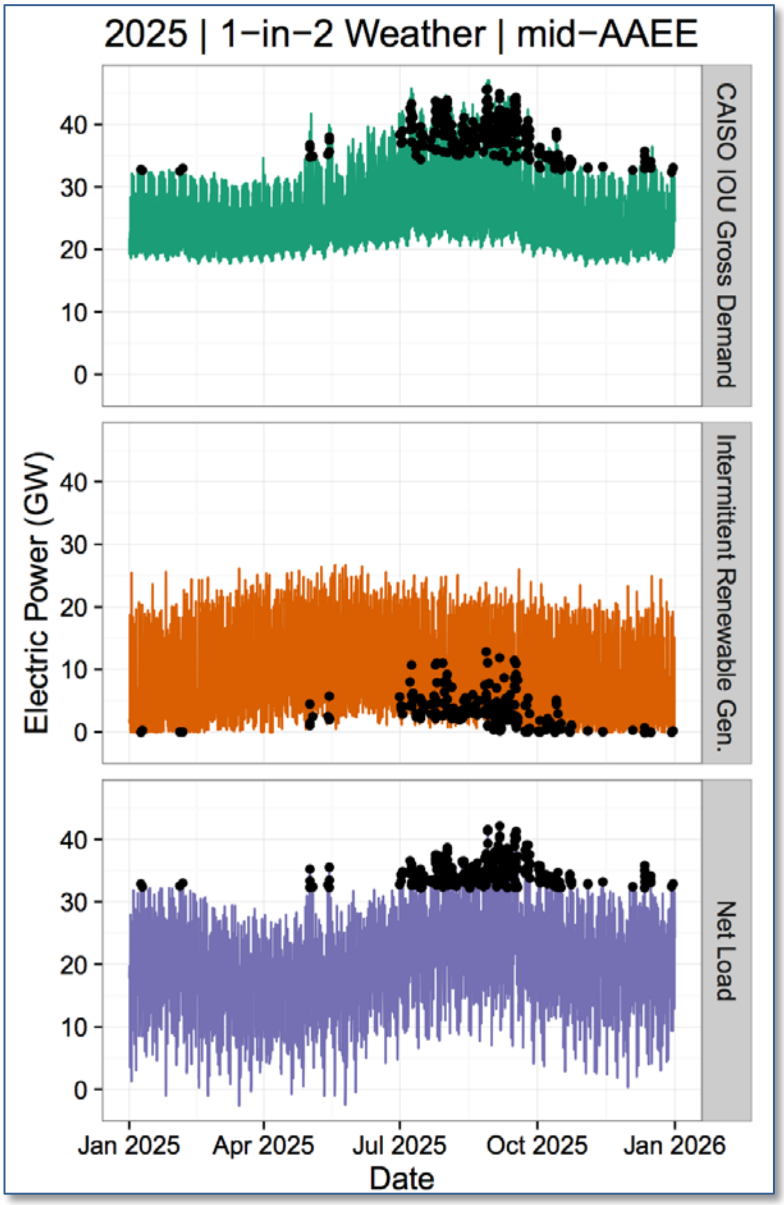
	DR Service Product	California Market	Description / Notes
Shed	Peak Capacity	System and Local RA Credit	Resource Adequacy planning capacity. Requires participation as an economic DR resource and a four-hour continuous response capability requirement.
Shed	Economic DR	Economic DR/Proxy Demand Resource	Resources in the energy market. (Proxy Demand Resource [PDR]). Reliability Demand Response Resources (RDRR) also can bid economically in energy markets.
Shed	Contingency Reserve Capacity	Ancillary Services (AS) – spinning reserves	Dispatched within 10 minutes in response to system contingency events. Spinning reserves must also be frequency responsive. CAISO currently has no established method for allowing DR to provide this.
Shed	Contingency Reserve Capacity	AS – non-spinning reserves	Able to respond within 10 minutes and run for at least 30 minutes. The sum of spinning and non-spinning reserves should equal the largest single system contingency.
Shed	Emergency DR	Emergency DR/ Reliability DR Resource	This resource can only be called when the system is in dire condition with limited dispatch. This is not always in CAISO markets, however, resources in these programs must register as RDRR in CAISO to access the wholesale energy market.
Shed	DR for Distribution System	Distribution	Used to manage targeted issues. California is not currently deploying this type of DR, but it is the subject of study in the Demand Response Provider (DRP). The capacity value is related to investment deferral in the distribution system.
Shimmy	Load Following	Flexible Ramping Product (similar)	"Load Following" is modeled in RESOLVE as a symmetric flexibility product on a five-minute dispatch. The CAISO Flexible Ramping Product is capacity that is awarded in the real-time market, for either increasing or decreasing load but without symmetric dispatch. The resources ramp in five minutes.
Shimmy	Regulating Reserve Capacity	AS – Regulation	Capacity that follows (in both the positive and negative direction) a four-second ISO power signal. It requires one hour of continuous response. Capacity is limited by the resource's five-minute ramp.

Source: Lawrence Berkeley National Laboratory

Shed Service Type Description

Shed describes loads that can occasionally be curtailed to avoid system upgrades and generation facilities related to peak capacity—at the statewide level, in local load pockets, and on the distribution system, with a range in dispatch advance notice times. Shed is measured and estimated in terms of equivalence to a peak power generator that is available during the top 250 hours of the year, a heuristic the team verified based on a parallel analysis of DR's estimated load-carrying capacity. Figure 9 presents the 2025 system load summary for gross, renewable, and net loads. The black dots indicate the top 250 hours used in the project's shed service type analysis.

Figure 9: 2025 System Load Summaries, in a 1-in-2-Weather Year



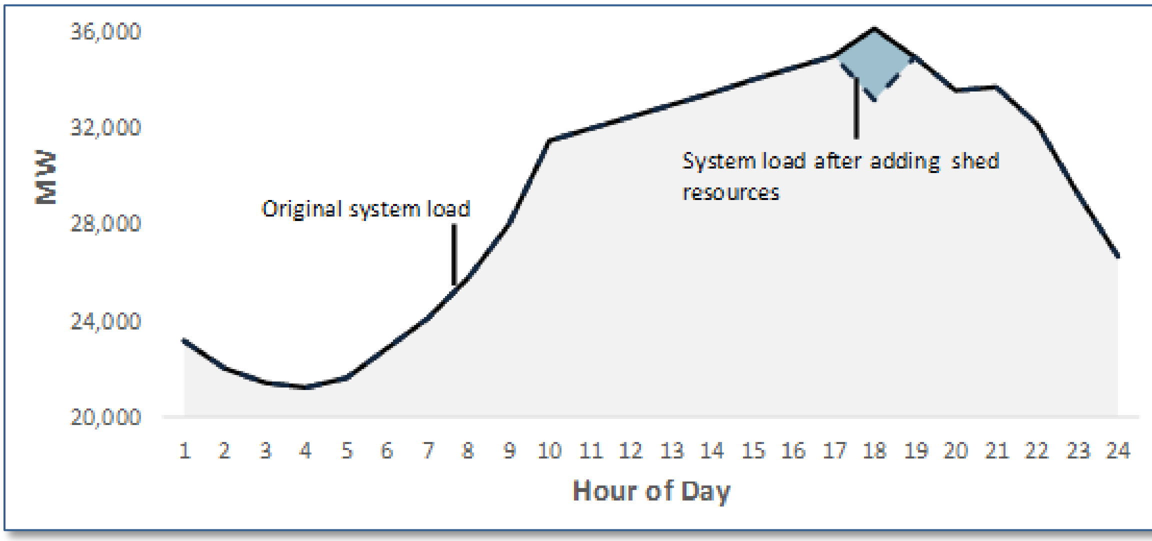
Black points indicate the top 250 hours of the year.

Source: Lawrence Berkeley National Laboratory

The shed service type represents DR that is called to reduce customer load demand during peak net load hours and represents traditional "hot summer day" DR. Shed service supports the grid by reducing the peak capacity required by the grid, and therefore improves reliability and reduces the need for expensive peaking generation units. Service interruption is the most common type of conventional DR, falling under the shed service type category.

Figure 10 shows shed resources, also known as "conventional demand response." Dispatching shed resources can potentially avoid the costs associated with building and running marginal gas peaker plants.

Figure 10: Illustrative Shed Resource



Source: Lawrence Berkeley National Laboratory

Shimmy Service Type Description

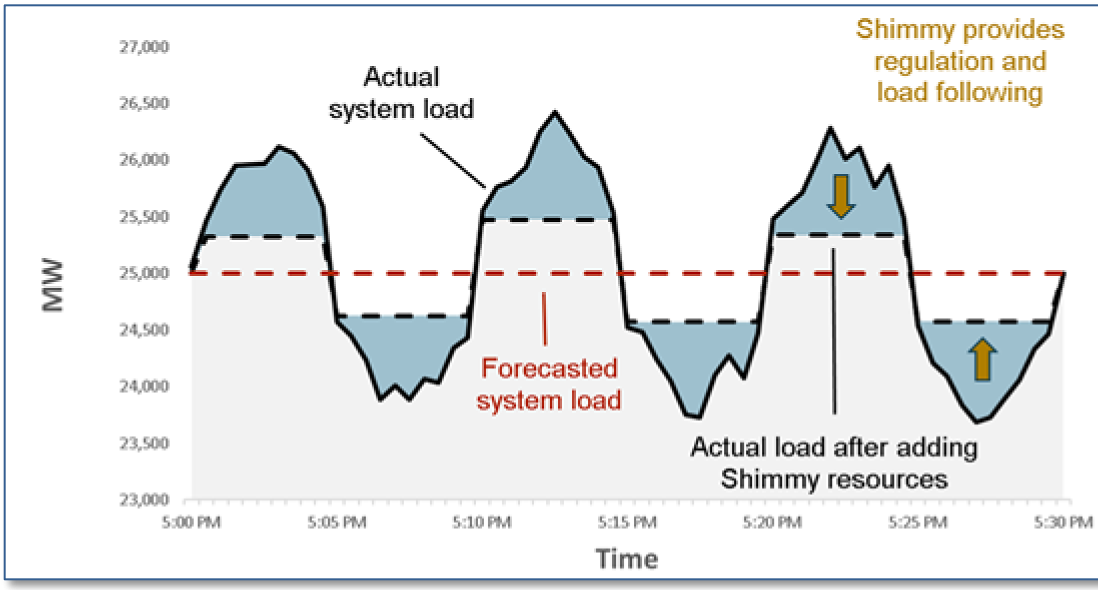
Shimmy involves using loads to adjust demand on the system dynamically, to alleviate ramps and disturbances at timescales ranging from seconds up to an hour. Estimates for shimmy are based on the annual weighted average availability of appropriately fast resources, with emphasis on hours when the price in the ancillary services regulating reserves markets is highest.

The shimmy service type represents "Fast" DR and includes what is often referred to as ancillary services (AS), which support the continuous flow of energy through the grid to meet demand. In other words, this service corrects the real-time, continual gap between predicted (and therefore dispatched) demand and actual demand. This gap can be from either too much or too little predicted demand, and therefore, shimmy resources must be able to both take and shed load on a short timescale. The team estimated DR potential for two shimmy service types:

- Load following, where the resource follows a five-minute dispatch signal, and regulation, where the resource follows a four-second-dispatch signal.
- Shimmy DR supports the grid by reducing the need for generation units to provide this service.

Figure 11 shows the DR's shimmy function. This reduces the need for other resources (for example, storage or thermal generators) to provide these functions, leaving them more available to provide other value, such as freeing up batteries to charge during periods of over-generation to reduce curtailment.

Figure 11: Illustrative Shimmy Resource



Source: Lawrence Berkeley National Laboratory

Categorization of Demand Response-Enabling Lighting Technologies that Can Provide Bulk Power System Services

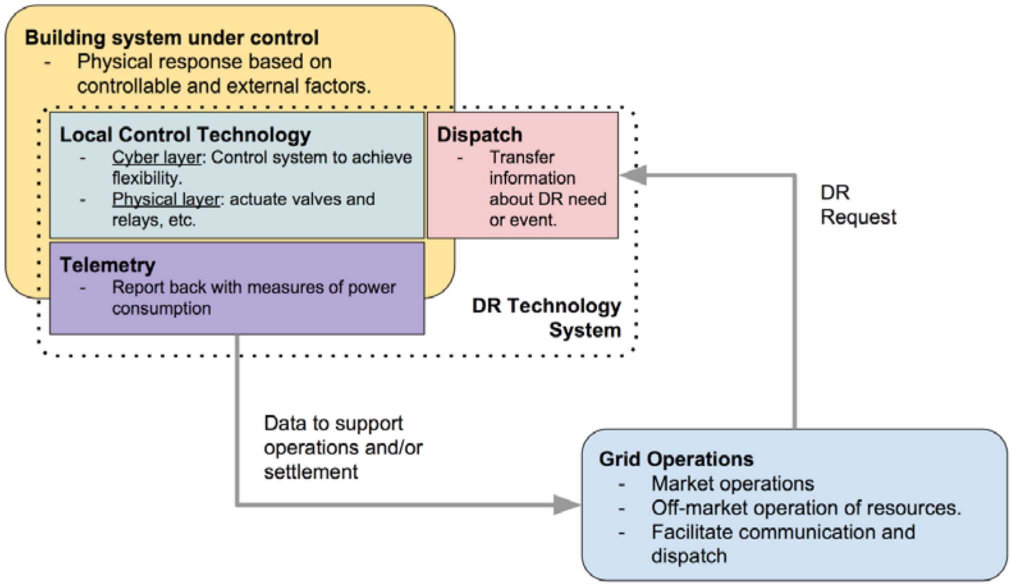
To determine which DR-enabling lighting technologies and end-use combinations can provide each service type to the bulk power system, the team defined each enabling technology in terms of three key attributes:

1. Local control technology
2. Dispatch communication
3. Telemetry requirements

Figure 12 describes the role each attribute plays in facilitating interaction between a DR technology system, a building system, and the bulk power system grid. The team compared each DR technology system's capabilities to specific grid services' needs and requirements (that is, participation as resource for shed and shimmy). Thus, the team determined whether each technology system meets the response characteristics necessary to provide each candidate grid service.

Within this assessment framework, each end-use/technology combination has a set of characteristics (that is, communication resource, telemetry, local control) that define the ability for the end-use to respond to a DR dispatch signal. The team defines a set of filters, described in Table 2, that the team use to determine whether a particular end-use/technology pair matches the response characteristics required to provide each specific grid service type.

Figure 12: Interactions between the Demand Response Technology System, Grid Operations and the Building Systems under Control



Source: Alstone et al. (2017)

Table 2: Description of Filters Used to Determine which Enabling Technologies Meet the Response Characteristics Required to Provide Specific Grid Services

Filter	Units	Description
Regulation-quality telemetry and dispatch required	True or False	Does the product categorically require dispatch and telemetry technology performance on the order of seconds (four-sec)?
Expected dispatches per year	Number of days	This filter can disqualify technologies that are extremely dispatch-limited (e.g., Design Lights Consortium (DLC) programs that are called no more than 10 times/year).
Maximum dispatch delay allowed	Seconds	Maximum time between when a dispatch request is made and the start of local response (the delay to start of local response).
Maximum ramp allowed	Seconds	Maximum additional time allowed for ramping. The total response delay including the ramp should be less than the sum of the maximum dispatch delay and ramp allowed.
Maximum resolution for control signal	Time, as specified (e.g., minutes or hours)	The maximum time between control signal steps (the “local control resolution”). For example, a load that can change its operation every 10 minutes has a “10-minute” local control resolution.
Minimum bid duration	Time, as specified (e.g., minutes or hours)	The minimum continuous time that a load must be able to participate when dispatched.
Maximum telemetry delay	Time, as specified (e.g., minutes or hours)	The maximum delay between DR response and telemetry signals back to the system operator (or if there is no active telemetry, the settlement signal).
Maximum telemetry resolution	Time, as specified (e.g., minutes or hours)	The maximum time step resolution on telemetry.

Adapted from Alstone et al. (2017)

Methodology

Analytical Strategy by Building Occupancy Type

Office and Retail Building Occupancy Types

For the office and retail building occupancy types, this study employed the “bottom-up” modeling framework for DR capabilities and availability that was developed in the *2025 California Demand Response Potential Study* (Alstone et al. 2017). This framework leverages large customer-level electricity use and demographic datasets provided by each of California’s investor-owned utilities (IOUs) to estimate the potential resource for different DR service types by sector, building type, site size and end use in 2025. The first step for estimating DR resource availability is to group customers in similar cohorts, or “clusters.” Each cluster represents aggregated real customer consumption and demographic information. Each cluster’s consumption time series is disaggregated into its constituent end uses, and these end-use baseline load shapes are forecasted to the study year of 2025.

The DR futures model is divided into two core analytical capabilities:

1. LBNL-Load: This is an end-use, load-forecasting approach that capitalizes on IOU-provided demographic data for the full set of more than 11 million utility customers and hourly load data for 220,000 customers across the three IOUs. Using these data, the team developed approximately 2,700 representative customer clusters characterized by a typical demographic profile, location, and hourly end-use load estimates. Table 3 provides details on the number of customers and clusters by sector for each of the IOU service territories. See Alstone et al. (2017) for documentation, intermediate results, and discussion of this model.

2. DR-PATH: This is a DR capability analysis model that estimates the potential hourly DR contributions to support system reliability across a diverse set of future pathways. The possible pathways consider the predicted end-use load (from LBNL-Load), technology capabilities, market design parameters, and expected participation rates derived from the demographic variables. It includes an economic analysis framework that estimates the effective capacity available at a range of levelized cost ceilings to establish supply availability curves. See Alstone et al. (2017) for documentation, intermediate results, and discussion of this model.

Table 3: Commercial Customer Clusters for Each IOU Service Territory by Customer Sector

Utility	Cluster Quantity	Average Customer Number Per Cluster
Pacific Gas and Electric	641	843
Southern California Edison	481	1,125
San Diego Gas & Electric	70	1,866

Source: Lawrence Berkeley National Laboratory

The team used LBNL-Load and DR-PATH as an integrated package to simulate self-consistent, energy futures cases with coincident and time-synchronized weather, loads, prices, renewable generation, and distributed technology scenarios.

Commercial lighting load was explicitly disaggregated for clusters representing office and retail buildings. The clustering further subdivided these building types into small, medium, or large site sizes as characterized in Table 4.

Table 4: Peak Demand Thresholds for Categorizing Small, Medium, and Large Commercial Customers

	Small Commercial	Medium Commercial	Large Commercial
Peak demand threshold	< 50 kW	50–200 kW	> 200 kW

Source: Lawrence Berkeley National Laboratory

Other Occupancy Types

The project team was unable to address other building occupancies using a similar methodology described above since the original project concept was based on using expected data generated by the *2025 California Demand Response Potential Study* model (See Alstone et al. [2017] for documentation) for examining the Title 24 occupancy list. However, that study used a more limited approach than initially envisioned by the project team in 2014-2015. The study focuses only on office and retail occupancies versus the ones comprising California Title 24 as shown in Table 5 below.

Table 5: California Title 24 Occupancy Categories

Occupancy	
Primary/secondary schools	Retail
Groceries	Hotels/hospitality sector
Hospitals/healthcare	Small offices (< 30,000 SF)
Large offices (> 30,000 SF)	Restaurants
Warehouses	Refrigerated warehouses
Industrial	Miscellaneous
Post-high school education	

Source: Lawrence Berkeley National Laboratory

Itron's *California Commercial Saturation Survey* (CSS) and *California Commercial Market Share Tracking Study* (Itron 2014a,b) were two large on-site data collection efforts performed under contract with the California Public Utilities Commission (CPUC). These studies were undertaken by the CPUC to develop a better understanding of the current baseline of new purchases and existing equipment in the commercial sector in the service territories of Pacific Gas and Electric (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E).

- The Commercial Saturation Survey (CSS) study collected on-site data from 1,439 commercial buildings in California. The data describes saturation, age, condition, and efficiency levels of electric consuming measures in select business types in the electric service territories of Pacific Gas and Electric, Southern California Edison, and San Diego Gas & Electric, along with information regarding building characteristics and relevant firmographic data (sets of characteristics to segment prospect organizations).

- The Commercial Market Share Tracking Study (CMST) describes the nonresidential recent purchase market for linear fluorescents, televisions, and small packaged heating, ventilation, and air conditioning (HVAC) units in the service territories of Pacific Gas and Electric Company, Southern California Edison, and San Diego Gas & Electric Company. The market for these measures was analyzed using recent purchase information collected on-site from businesses purchasing equipment and through telephone surveys with lighting and HVAC contractors.

Table 6: California Commercial Saturation Survey Occupancies and Mean Energy Intensity

CSS Business Type	Disaggregated Business Type	Mean Energy Intensity (kWh/ft^2-yr)
Food/Liquor	Convenience Store	55.8
	Large Grocery	44.0
	Small Grocery	30.2
Health/Medical - Clinic	Medical/Dental	11.7
	Rehabilitative Services	15.5
Miscellaneous	Assembly	6.8
	Laboratory	48.9
	Multi-Family	15.9
	General Miscellaneous	10.7
	Services	7.2
Office	Office	13.2
Restaurant	Fast Food Restaurant	60.6
	Table Restaurant	33.0
	Other Food	33.1
Retail	Auto Sales	19.5
	Retail	7.7
	Variety/Warehouse	14.2
School	School	6.1
Warehouse	Conditioned Warehouse	4.9
	Unconditioned Warehouse	2.3
	Storage	0.9
	Refrigerated Warehouse	14.5

Note: kWh/ft^2/yr is kilowatt-hours per square foot per year; CSS is Commercial Saturation Survey.

Source: Itron (2014a,b)

The project team used the 2014 CSS and CMST (tempered by 2006 California Commercial End Use Study [CEUS] data) to help calibrate the effective percent DR load shed for each occupancy, based on assumptions for offices and retail buildings to establish baseline lighting electricity consumption (kWh/year), electricity intensity (kWh/ft^2-year), demand (kW), and demand intensity or lighting power density (W/ft^2).

Developing the Lighting Load Profiles

To determine the load and eligible load for DR control technology in the office and retail building occupancies, the team used the cluster load profile forecasts by end use that were developed during the *2015 California Demand Response Potential Study* (Alstone et al. 2017). The researchers generated these load profiles by disaggregating actual customer hourly load data from 2014, and then forecasting the growth of each end use to 2025, under the "mid" assumptions for additional achievable energy efficiency (MidAAEE) estimated in the California Energy Demand Forecast (CEC 2014). The lighting load profiles in particular were disaggregated based on the CEUS load-profile dataset from 2006 (CEC 2006).

In this study, the team further refined the CEUS load profiles to reflect the expected lighting load in the 2014 customer data by decreasing the CEUS lighting profiles by 20-percent, to capture the impact of statewide lighting retrofit programs that targeted T12 florescent fixtures. The team assumed that the vast majority of businesses throughout the state installed T8 fixtures between 2006 and 2014, which resulted in decreased energy intensity for lighting in commercial office and retail buildings, relative to the CEUS estimates. This is supported by the 2014 CSS data).

The research team's DR lighting load forecasts in 2025 further assume that any future DR lighting system installation will be combined with an upgrade to light-emitting diode (LED) lighting, as well as, adhering to contemporary standards for lighting levels, which are lower than those used in past fluorescent installations. Such savings were not considered as part of the MidAAEE forecasts used in this study, so the team adjusted the forecast lighting load shapes downward to account for these savings. Together, the team assumes that these upgrades will yield a further 50-percent reduction of energy intensity for lighting in 2025, relative to 2014.

Table 7: Excerpted Table from 2014 Commercial Saturation Survey

Table 5-29: 2014 CSS and 2006 CEUS Linear Fluorescent Lamp Efficiency Distribution by Business Type – Indoor Lighting

2014 CSS	Food/ Liquor	Health/ Medical – Clinic	Miscel-laneous	Office	Restau-rant	Retail	School	Ware-house
4-foot T12	4.5%	27%	14%	9%	30%	8%	8%	17%
4-foot T8 Unknown Efficiency	4.1%	1.5%	5%	4.2%	3.3%	10%	2.6%	4.0%
4-foot T8 Base Efficiency	70%	56%	60%	76%	52%	47%	71%	36%
4-foot T8 High Efficiency	21%	16%	18%	10%	14%	28%	17%	29%
4-foot T5	0.5%	0.3%	2.8%	1.4%	0.5%	8%	1.1%	13%
4-foot Other	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
4-foot LED	0.4%	<0.1%	0.1%	<0.1%	<0.1%	0.1%	<0.1%	<0.1%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

2006 CEUS	Food/ Liquor	Health/ Medical – Includes Hospitals	Miscel-laneous	Office – Large & Small	Restau-rant	Retail	School	Ware-house – Ref & Other
4-foot T12	22%	26%	44%	29%	62%	21%	22%	40%
4-foot T8	78%	74%	56%	71%	38%	79%	78%	60%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

* **The CSSS results presented above have been weighted by site weight.** The CEUS results are kWh-weighted.

Note: This table compares market movement away from four-foot T12 fluorescent lamps since 2006 California Commercial End Use Study (CEUS).

For the CSS/CEUS comparison results presented in Table 5-29, the CSS T8 technologies have been grouped into T8s with Unknown Efficiency, Base Efficiency T8s, and High Efficiency T8s. For this comparison, Base Efficiency T8s are 700- and 800-Series T8s, while High Efficiency T8s are High Performance and Reduced Wattage T8s. The CEUS-collected data was not subject to the make and model lookups that enable the T8 lighting efficiency distributions developed in the CSS. The CEUS, however, did collect information on Linear lighting wattage whenever possible. The CEUS wattage data indicates that nearly all T8s installed at the time of the CEUS were 700-Series, or Base Efficiency, T8s.

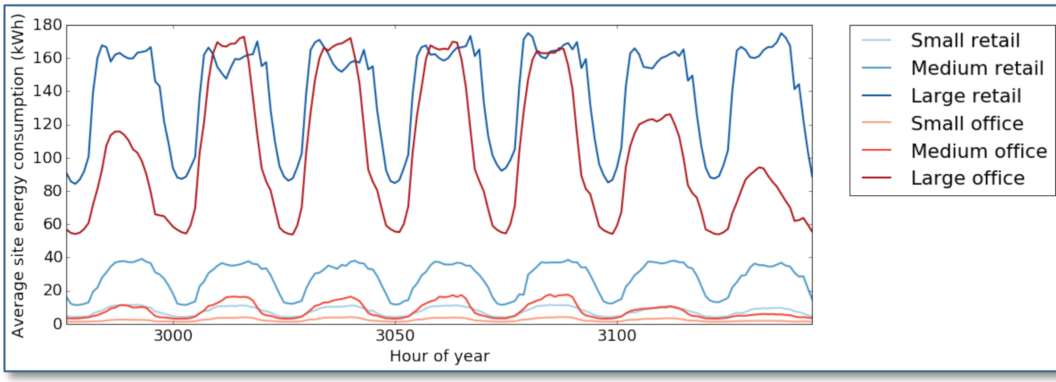
The data in Table 5-29 indicate that the share of T12 Linear lamps has fallen substantially for most business types. For Offices, the business type with the largest number of linear technologies (see Figure 5-2 in CEUS), the share of linear lamps that are T12s has fallen from 29-percent in the CEUS to 9-percent in the CSS, a reduction of 20-percentage points. The share of Restaurant T12s has fallen from 62-percent in the CEUS to 30-percent in the CSS; Miscellaneous business type T12s have fallen from 44-percent to 14-percent; and Warehouse T12s have declined from 40-percent to 17-percent. Health/Medical Clinics in the CSS have 27-percent T12s, while Health/Medical Clinics plus Hospitals in the CEUS have 26-percent T12s. The appearance of a 1-percentage point increase in the share of T12s in Health-related businesses is deceiving because the CEUS Health businesses include Hospitals.

Hospitals are typically Large-sized businesses, which have a substantially smaller share of T12s than Small and Very Small businesses (see Table 5-19). The CSS Health/Medical Clinics likely have a higher share of T12s than the CEUS Health/Medical Clinics plus Hospitals due to the lack of Large-sized Hospitals in the CSS study (Itron 2014a, 5-43 Lighting).

Source: 2014 Commercial Saturation Survey

Figure 13 shows example average site-level lighting load profiles for a selected set of clusters, forecasted to 2025 (prior to applying the LED efficacy corrections), for the various building occupancy types and site sizes modeled in this study.

Figure 13: Example Forecasted 2025 Site-level Lighting Load Profiles



The lighting load profiles are for each building occupancy that is modeled explicitly in the DR-Futures framework for this study. The curves show one week of lighting load for a selected set of clusters drawn from the model.

Source: Lawrence Berkeley National Laboratory

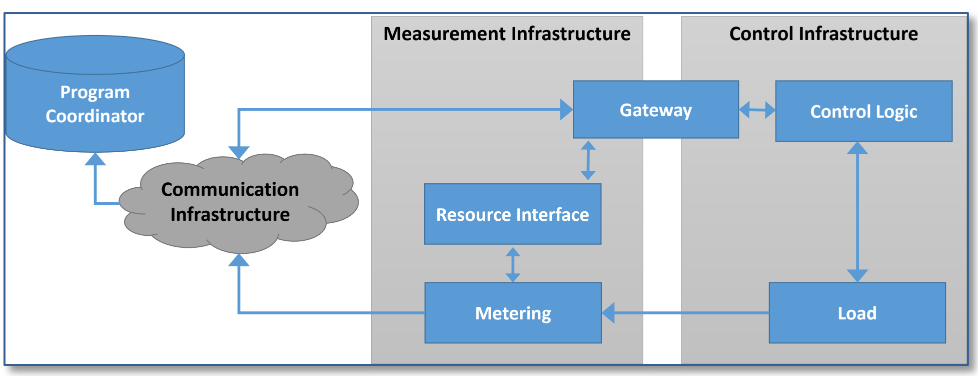
Demand Response-Enabling Technologies: Assumptions and Inputs

DR-enabling technology is the mix of load control and communications hardware and software that make it possible to change the energy consumption patterns of end uses. For this analysis, the team defined cost and performance inputs specific to distinct technologies, as well as distinct customer/building types (for example, small office or large retail). The team made these distinctions because similar technologies may perform differently in different types of buildings. The team drew upon research conducted during the *2025 California Demand Response Potential Study* and primary research conducted for this project by Energy Solutions.

To develop cost and performance estimates for advanced lighting controls, the team evaluated the components that are required to provide the shed and shimmy service types. DR-enabling technology can be categorized into three general components (Figure 14):

- Control infrastructure
- Communication infrastructure
- Measurement infrastructure

Figure 14: Demand Response-enabling Technology Component Categories



Source: Adapted from Piette et al. (2015)

Each component is required for operating lighting DR-enabling technologies and to measure system performance. For each of the infrastructure components, various options are available for enabling a site to provide shimmy and shed services. The infrastructure component types deployed at each premise/site define the system costs and determine the bulk power system services that the lighting system can provide. Within this study, the team evaluated the lighting control technologies with the various measurement and communications infrastructure components described below. To determine the DR potential and costs for enablement, each lighting control technology was paired with several combinations of telemetry and communications hardware and software. The sections below describe each of the categories and their specific elements, as well as, background on communication and measurement infrastructure, telemetry, communication resource interfaces, and gateways associated with DR-enabling technologies, to educate the reader on the full breadth of system componentry that may be required to activate these building types as DER resources.

Lighting Demand Response Control Infrastructure

For commercial lighting control infrastructure, the team focused on three advanced lighting systems:

- Digitally addressable luminaire lighting systems, which are highly granular control systems including individually addressable luminaires with integral occupancy and photosensors.
- Zone-based digital lighting systems, which are zonally controlled luminaires.
- Standard practice lighting systems, which are consistent with meeting the 2016 California Title 24 Energy Code baseline.

In the zonal control system, a centralized panel controls each channel (or circuit) in unison. The addressable luminaire lighting system is similar in design to that of a centralized control panel, but with more granular control capabilities due to individual luminaire-based sensors and control. Zonal- and luminaire-level lighting systems are enabled with ADR technologies and are capable of providing shed and shimmy services. Standard lighting controls with ADR technology can only provide shed type services to the bulk power system, since the controls are not sophisticated enough to permit dimming and daylighting sensing (Wei et al. 2015).

Existing requirements in Title 24, including Section 131(d) automatic shutoff control, are assumed to require a centralized network connection to a time clock or a control panel with built in time-clock functionality. There are some exceptions to this assumption; for example, in scenarios when each space is connected to occupancy sensors, which meets the requirements for automatic shutoff control without the need for a time clock. These exceptions are most similar to the zone-based lighting system, as both systems use network adapters to enable each room to be monitored and controlled for demand response.

For each advanced lighting system, the team estimates the load reduction that can be obtained from each control technology for each service type. These estimates, which the team refers to as performance filters, were initially developed for the *2025 California Demand Response Potential Study*. As discussed in the previous section, the team assumed that all DR-capable lighting installations will include an upgrade to LED lighting technologies. These lighting upgrades ultimately reduce the absolute amount of DR that can be obtained from lighting systems due to static efficiency improvements; however, incentivizing upgrades to LED systems with NLCs would result in more DR-capable lighting systems throughout California, in compliance with Title 24 standards. Historically there is low penetration of DR-enabling lighting control systems associated with existing fluorescent systems.

Demand Response Performance Filters

The shed service type of lighting DR resources can respond to DR event signals ranging from a day to minutes in advance. The available DR from lighting is defined as the baseline load in each hour times a fraction of sheddability available over a continuous DR event window that lasts as long as the minimum bid duration. For this study's purpose, the assumed bid duration is four hours.

The shimmy service type of lighting DR resources can increase or curtail load intra-hour in response to a CAISO five-minute (load-following) or four-second (regulation) signal. Load-following capabilities (five-minute dispatch) enable loads to be in the real-time energy market and spin. Regulating reserves (four-second dispatch) enable loads to participate in regulation markets.

Both shimmy services are defined in terms of bandwidth (how much capacity to go up or down, a fraction of the baseline). The load-following and regulation capacity performance filters are shown in lighting load percentages that can be controlled and respond to four-second and five-minute CAISO dispatch signals.

The performance filters for shed and shimmy service types are provided as percentages of the total site-level lighting load in Table 8 below. These filters are applied after accounting for the load reductions arising from adoption of LED lighting technology, which the team assumes will accompany the installation of DR-enabled lighting systems.

Table 8: Demand Response Performance Filters for Lighting Control Technologies

Lighting Control Technology	Shed DR Performance Filters (%)	Shimmy Load Following DR Performance Filters (%)	Shimmy Regulation DR Performance Filters (%)
Digitally addressable luminaire lighting systems	65	65	65
Zone-based digital lighting systems	35	35	35
Standard practice lighting systems	20	0	0

Source: Lawrence Berkeley National Laboratory

Communications Infrastructure

Communications in DR technology solutions refer to the components that receive signals and submit information back to a head-end DR platform (two-way communication). There are three primary solutions used to send a dispatch signal to end uses or to the energy management control systems at the customer premise. These include:

- Wi-Fi or broadband communication solutions
- Cellular communication solutions
- Advanced metering infrastructure (AMI) network communication solutions

Measurement Infrastructure

The second DR automation system component group encompasses the electric meter or other telemetry data source, the communication resource interface, and the "gateway" communication of measured data back to the program coordinator. For ADR applications, the typical telemetry architecture includes several components. At the site level, a data collection mechanism measures the premise and end-use loads and delivers those data to a resource interface that packages and delivers the data to send to a gateway. The gateway packages and encrypts the data using protocols such as DNP3-L2, PKI or ICCP[2] and sends the data to a bulk power system operator or aggregator.

For lighting end uses to deliver advanced DR services, specific telemetry and dispatch configurations must be met so they can participate in shimmy services. While the specific requirements may vary, telemetry and communication system upgrades for advanced DR, beyond those required for the conventional demand response resources, are required. These could include special metering, a resource interface, a gateway, or another component.

Telemetry

The study identified several candidate technologies for energy measurement. Energy measurement captures, consolidates, and delivers energy measurement data to a head end meter data management system (MDMS) or a communication resource interface. The team considered options to enable DR with the four options described by Alstone et al. (2017):

- Typical AMI meters
- Advanced AMI meters
- Revenue quality meters
- Power quality meters

It should be noted that DR resources that provide shimmy services have much greater technical requirements to comply with market rules necessitating investment in advanced DR-enabling technologies. For example, such resources must provide a faster response to a dispatch signal, with regulation up or regulation down market participation requiring the fastest response time, two-seconds (IRC 2016). To accommodate such rigorous aggregator/program administrator or

[2] Distributed Network Protocol (DNP3) is a set of communications protocols mainly used by electric utilities between process automation systems' components. The public key infrastructure (PKI) represents the roles, policies, and procedures needed to create, manage, distribute, use, store and revoke digital certificates and manage public-key encryption. The Inter-Control Center Communications Protocol (ICCP or IEC 60870-6/TASE.2) is specified by utilities worldwide to provide data exchange over wide area networks (WANs) between utility control centers, utilities, power pools, regional control centers and Non-Utility Generators.

CAISO measurement and communications requirements, it is necessary to install advanced telemetry technologies (such as revenue or power quality meters) to capture granular energy data and transmit it back in near real-time. Such technologies are more costly than more typical AMI technologies and affect a customer's desire to install DR-enabling lighting technologies for the DR capability alone. These aspects are discussed in more detail later in the report.

Communication Resource Interface

A communication resource interface, typically comprised of stand-alone hardware and software, are required for DR participation in supplemental reserves, regulation reserves, and imbalance energy bulk power system services. The communication resource interface is the mechanism for receiving data from the meter, or some alternative energy measurement data source, and packaging it to enable the next step to a gateway connected to the wholesale market operator systems. Telemetry from the data source must be packaged and made available to the gateway within the time restrictions for each bulk power system service, as specified by CAISO. For example, to support one-minute data samples, the resource interface must be able to query for the data from the meter or data source at no less than one-minute frequencies, and then push those samples to the gateway for aggregation with the streams from other meters at the premises (Potter and Cappers 2017). In this study, the team considered the following communication resource interface options, which are described in detail by Alstone et al. (2017):

- KYZ Modules
- Zigbee radio
- Network Interface Card (NIC)

Gateways

Gateways are logical interface hardware systems that interconnect and exchange energy information between the customer facility and one or more energy service providers (ESPs). Gateways are also known as energy service interfaces (ESI), and are used in residential homes or commercial customer facilities to connect two incompatible networks (networks with different protocols) They facilitate bidirectional communications by translating messages passed between the two networks. Gateways provide other features such as data logging and control and monitoring of device response.

With the interoperability enabled between the systems, customer facilities can receive pricing and DR signals to dispatch and/or manage the operation of customer systems and devices, including HVAC and lighting systems. A gateway typically interconnects to both the AMI meter and to an ESP's management system. Depending on the system architecture, the AMI system may be the only system that a gateway interconnects to for DR signals. A gateway can collect data from the meter's NIC, KYZ module, or Zigbee radio interface, and relay it to the cloud or to ESP's system for monitoring or reporting (for example, transmittal to CAISO). The gateway can also be used to aggregate multiple data streams from other meters at a customer facility.

Note that gateways are generally used for more complex DR applications where more than one device in a customer facility is receiving price, energy, or DR signals from an ESP's EMDS.

Gateways are not required for conventional DR, but in advanced DR applications that are providing shimmy or fast-response shed services to the bulk power system, a gateway would be required to transmit data to the head end systems that are managing the DR events (Potter and Cappers 2017).

Demand Response Potential Scenarios

The *2015 California Demand Response Potential Study* (Alstone et al. 2017) defined three feasible DR market and technology trajectory scenarios: business-as-usual (BAU), medium, and high. These each represent a DR cost and performance improvement trajectory over time, relative to the "base" scenario—the DR market and technology characteristics circa 2014–2015 when that study framed and developed its methodology. The BAU scenario represents the steady incremental progress that has unfolded during the past decade toward improving technology performance and finding new ways to market and administer DR programs. The medium and high scenarios show what is possible with moderate and more aggressive market transformations, respectively.

For the purpose of this study, the team reports all findings in the "medium DR" scenario, which the team believes is achievable with continued progress in policy, markets, and technology. The *2025 California Demand Response Potential Study* also considered different weather scenarios, but these have no effect on the lighting load forecasts, so the team ignored those scenarios here. The scenario defines multipliers on the DR costs, performance, and consumer uptake in 2025, relative to a 2014 baseline (see Alstone et al. 2017, for details). The team notes that rational caps on performance are enforced (so that, for example, a site cannot shed more load than what is under control, regardless of the performance multiplier). Also, in this study the team estimated the total potential lighting DR resource, irrespective of consumer participation rates, so the multipliers on consumer uptake are not relevant here.

Economic Valuation of Lighting Demand Response Potential

Cost Perspective

When defining DR technology system costs to derive a baseline site-level value proposition for DR-enabled lighting, the team presented the costs and benefits from the perspective of enabling a single premise/site with DR technology. From this perspective, the associated costs included the costs of installing DR-capable lighting fixtures and controls, including both device and labor costs; the costs of site-level DR-enabling hardware for communications and telemetry; and any associated financing costs. The team did not include costs that would accrue to the utility or aggregator, such as paying for incentives, program administration, or marketing, since these would be used as tools to strengthen the value proposition developed herein, so their proper amounts should be informed by this study's results. As a result of enablement at the premise, the benefits included a revenue stream from wholesale energy-market participation, as well as energy-savings co-benefits arising from the more efficient lighting system. Throughout, the costs and benefits are presented in "levelized" terms—that is, as the expected average annual value. To clarify the split between initial price and financing costs, the team report these costs separately, with the levelized purchase price being simply the price divided by the system lifetime, while the levelized financing costs represent the present value of interest payments on the initial cost, amortized over the technology lifetime using a 7-percent weighted average cost of capital.

Demand Response Lighting System Costs

For each of the lighting control systems, the team estimated the initial up-front enablement costs for a customer site, based on customer sector and size. The costs include lighting fixtures, control technologies, and installation costs, and are provided as (1) an aggregate cost for enabling a site with communications and telemetry for DR participation (in $/customer site), and/or (2) calculated by enablement costs per kW of load enabled to provide DR (in $/kW).

To compute the average enablement costs per kW, the team made the following calculations:

- First, the team estimated the average premise size (ft2) for each building occupancy type. Then, the team determined the average cost per square foot ($/ft2) for each lighting control system and building occupancy type. These values were developed from primary research conducted by Energy Solutions.
- Second, the team derived the average load shed per site by multiplying CEUS estimates of noncoincident peak lighting load by the average premise size (ft2), and the percent load shed for each lighting DR control technology. The percent load shed for the systems are: 32.5-percent for digitally addressable systems, 17.5-percent for zonally controlled systems, and 10-percent for standard systems consistent with meeting California Title 24 Energy Code baseline.
- Third, the team derived the average load shed per square foot (kW/ft2) by dividing the average load shed per site by the average premise size (ft2).
- Finally, the team divided each of the lighting systems' cost per square foot ($/ft2) by the average load shed per square foot (kW/ft2) to determine the DR-enabling technology cost per kW of load shed per lighting system technology case ($/kW).

In the commercial and industrial sectors, enablement costs were estimated for each kW of load that is enabled to provide DR services: shed or shimmy. The cost estimates reflect the maximum predicted load impact from installed controls for each end use or premise. The team borrowed this accounting framework for the costs of enabling technology from Piette et al. (2015), in which the cost categories, described below, are used to develop comparable and scalable estimates and averages for unit enablement costs in $/kW.

A description of each cost category is as follows:

- The fixed initial communication and hardware costs for achieving controllability "per site" for the given end use or customer premise. Costs included in this category are telemetry, communication resource interface, and installation costs. The site-level communication and control cost reflects the added communication and telemetry costs to enable shimmy DR, above what would be required for shed DR. These are reported in $ per site.

- The variable initial control technology costs for achieving controllability “per kW” (for example, HVAC and retail lighting controls). These are reported as $ per kW enabled for DR services.

It is important to note that most lighting controls are sold as complete systems, where the ballast or fixture includes the DR controls, and the entire system is controlled via an energy management control system or similar platform. Luminaire-level (in offices, this typically refers to workstation-specific lighting) and zonal lighting control systems can provide shed and shimmy services, but providing shimmy requires an additional communication and telemetry expense, as described earlier.

Demand Response Sources of Revenue

DR services can receive revenue by participating in CAISO wholesale markets, as shown in Table 9. In this study, shed services participated in the energy market and received RA capacity payments, while shimmy services participated in the AS market. Participation in other markets (including markets that do not yet exist) is possible but was not quantified in this study. Such markets could include flexible ramping capacity payments. Hourly prices for the energy and ancillary services markets quantified in this study were obtained from a PLEXOS simulation run by CAISO based on the 2014 long-term procurement plan scenario (CPUC 2013).

Table 9: CAISO markets considered for three DR service types. Checkmarks (✔) represent market revenue calculated in this study.

Service Type	Ancillary Services Market	Energy Market	Capacity & RA Payments
Shed		✔	✔
Shimmy	✔		

Source: Lawrence Berkeley National Laboratory

Results for this study are aggregated to annual values, and therefore, assumptions must be made for the dispatch frequency and timing of DR resources. Methods used to calculate annual revenue are directly tied to those used to aggregate hourly DR availability into annual values. Therefore, shed DR energy market revenue is calculated as the total revenue earned in the top 250 net load hours of the year, where each hour of revenue is the amount of DR available times the market price.

The team assumes that shimmy services, by contrast, are needed during all hours of the year. Participants in the relevant AS markets receive a market price per MW for making capacity available, whether or not it is dispatched, along with an additional “mileage” payment related to their cumulative response to dispatch signals. In this study, the team estimated the maximum possible market payment that a DR-enabled site would receive, as follows. The team assumed that the site participates in the relevant shimmy market whenever its forecast market price is nonzero. At those times, the potential market payment to the site is equal to the total load that can provide shimmy service, multiplied by the market price. Summing this product over the full year yields maximum annual CAISO market revenue for participating in shimmy markets. Because the mileage payments received are random and unpredictable, the team excludes them in this study, so the ISO revenues computed represent a conservative available market revenue estimate.

Co-Benefits of Demand Response Lighting Technologies

For certain end uses, the same technologies or device upgrades that enable DR (for example, smart thermostats, building energy management systems, or lighting controls) produces other cost benefits by allowing a building to operate more efficiently (Goldman et al. 2010). These economic benefits are referred to in this study as "co-benefits," and were modeled as a percentage of enabling technology costs by which the upfront cost attributed to DR would be reduced. In practice, co-benefits could be realized through customer bill savings that come from DR-device-induced efficiency that help buy down the upfront cost of DR.

In our study, the team calculated the co-benefits for lighting (standard code, luminaire-level, and zonal) controls typically installed to receive energy savings benefits. The team briefly discusses the methodology for calculating these co-benefits below.

Energy Cost Savings from Efficiency and from Demand Response-enabling Networked Lighting Controls

The cost savings associated with reduced energy consumption in the commercial sector depend strongly on the hourly load profile of the reduced end use, since most commercial customers in California pay time-of-use (TOU) rates that may have a high discrepancy between peak and off-peak periods. Thus, to estimate the energy cost savings associated with DR-enabled lighting systems, the team first developed an hourly average commercial electricity rate for each of the California IOUs, based on current 2017 rate schedules, accounting for the daily TOU variations, as well as seasonal changes and differences between weekday and weekend/holiday rates. Multiplying this hourly electricity rate by the forecast site-level lighting load profile for each cluster, and summing over all hours, yielded a baseline annual site-level cost for lighting energy consumption, prior to any savings arising from adoption of LED or NLC technologies. To this annual cost, the team then applied an adjustment to account for an annual increase in electricity rates, which the team assumes to be 3-percent in inflation-adjusted terms. This escalation applies in each year from 2017 through 2025, and then accrues over a 15-year technology lifetime to yield an average annual electricity cost for installed systems in 2025.

The team was then able to apply a series of multipliers to this baseline energy consumption to compute the estimated site level energy savings in each cluster. As discussed previously, the team assumes that adoption of LED lighting would yield a 50-percent reduction in lighting energy intensity, relative to the baseline forecast, so the team takes the site-level energy savings from LED adoption in each cluster to be 50-percent of the calculated baseline energy costs. On top of this savings, a recent study of NLC performance by the DesignLights Consortium estimates that NLCs yield energy savings of 44-percent and 63-percent in retail and office buildings, respectively (see Appendix A for further discussion of these savings estimates). To calculate the site-level energy cost savings from NLCs in each cluster, then, the team applied the appropriate building-type-specific multiplier to each cluster's remaining energy costs, after subtracting the savings from LED adoption.

Non-Energy Benefits from DR Lighting Systems

The following is a brief discussion of non-energy benefits (NEBs); see Chapter 5 for the main discussion of NEBs.

While identifying significant energy savings associated with LED lighting and NLC systems, the team also recognized that exist significant NEBs that represent additional value to customers and building owners. These benefits can easily outweigh energy efficiency and DR benefits in their relative scale.

Defining Energy and Non-Energy Benefits

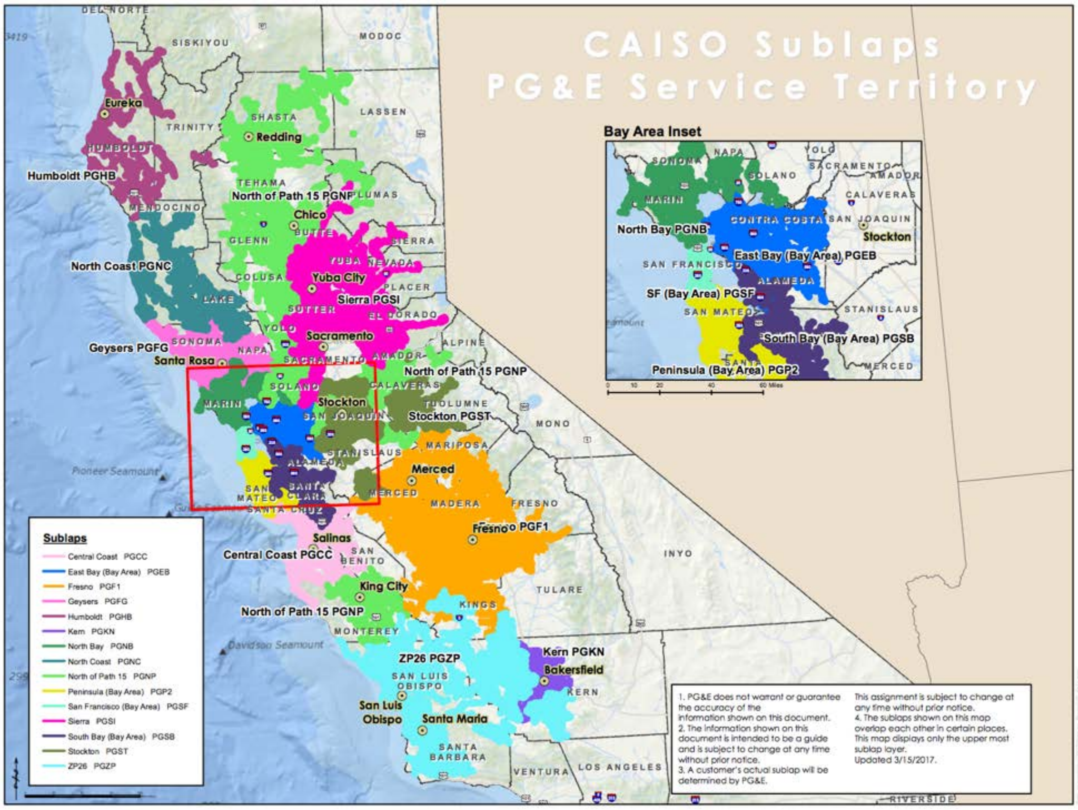
For the purposes of this report, energy benefits are defined as:

- Energy efficiency: The reduction on a utility bill from reduced energy consumption over the billing period due to the implementation of NLC system. This includes both energy use and demand charges.
- DR: Compensation received by the customer for participating in a traditional DR program and curtailing load when called upon, typically during peak-day periods on the ten hottest days of the year.
- Distributed energy resources: Compensation received by the customer for participating in demand management programs and in the CAISO market, such as capacity or ancillary services markets. These markets do not fully exist presently or are in pilot phase, such as the current Demand Response Auction Mechanism (DRAM) and Excess Supply Pilot.

Results and Findings

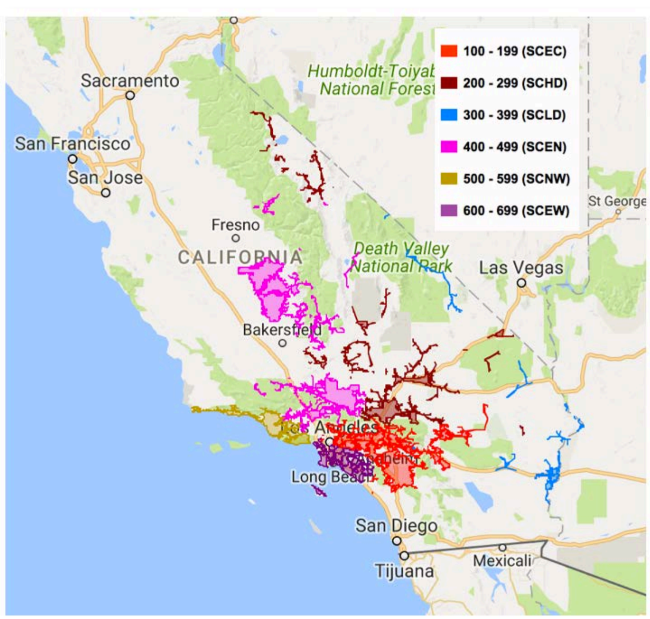
The team presents this study's results by occupancy type, sub-load aggregation point (SubLAP), and DR service type. With the exception of the office and retail occupancy types, estimates for shed and shimmy DR potential were developed from engineering estimates. The team presents the DR potential in tables for each building type and SubLAP, and provides a waterfall graphic to present the upfront and operational costs alongside the revenues and energy savings. The three following figures display the individual IOU SubLAPs used in the analysis.

Figure 15: Pacific Gas & Electric Company SubLAPs Circa 2017



Source: Pacific Gas and Electric Company

Figure 16: Southern California Edison SubLAPs circa March 2017



Source: Southern California Edison, https://www.sce.openadr.com/dr.website/scepr-event-blockview.jsf;jsessionid=36221C595D0142AE494BE83B9FFE9612.aku-sf-sce-app1

Figure 17: San Diego Gas & Electric Company Service Territory SubLAP

San Diego Gas & Electric Company is itself a single SubLAP: SDG1.

Source: San Diego Gas & Electric Company

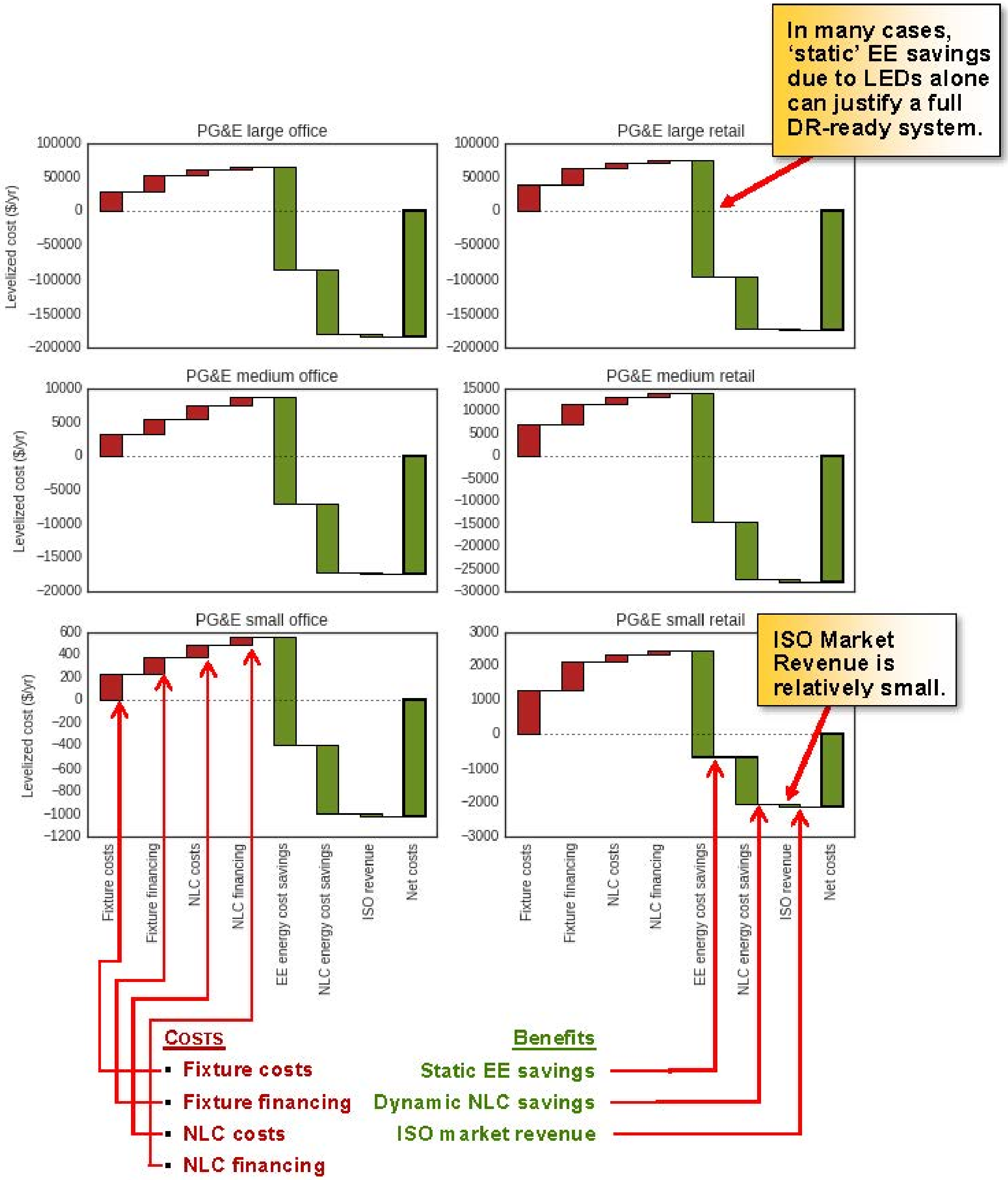
Office and Retail

The modeling described in the methodology section earlier in this chapter identified, for each commercial office and retail cluster, their site level costs and benefits considered by the model. To produce final aggregated results by building type, utility, and SubLAP, the team computed average costs and benefits, weighted by the number of customers in each cluster, for all clusters in a particular segment of interest (for example, all office buildings in a particular SubLAP, or medium retail buildings in a particular IOU service territory). To compute the total potential DR resource and incremental energy savings, the team summed the available DR and total cluster energy savings across the customer segment of interest. These aggregated results are presented in the following subsections.

Site-level Costs and Energy Benefits

Figure 18, Figure 19 and Figure 20 display the site-level levelized costs and energy-related benefits from installing a DR-enabled lighting system in six different building categories (small, medium and large for both office and retail) within each California IOU service territory. The cost and benefit results are presented as waterfall diagrams, displaying costs as positive red bars that incrementally build up the total cost, while benefits are shown as negative green bars that subtract from the aggregated cost to yield a total "energy-only" (that is, exclusive of NEBs) net cost or net benefit. Costs include the up-front costs of purchasing and installing new lighting fixtures and NLCs, as well as the levelized costs of financing the installation (assuming a 7 percent cost of capital), as described in the methodology section. The benefits in this analysis are limited to the readily quantifiable, energy-related installation benefits, whose calculation is also described in the methodology section. These include the annual reduction in energy expenditures arising from static, energy-efficiency savings (that is, LED savings over a fluorescent lamp baseline) and from NLC operation, as well as the maximum available revenue from participating in ISO markets (which always happens to come from load-following shimmy, although the available resulting revenue is relatively small in all cases). Comparing these energy benefits to the NEBs, which are more difficult to quantify, is discussed in the next section. The costs and benefit data displayed in these three figures are also tabulated in Table 10.

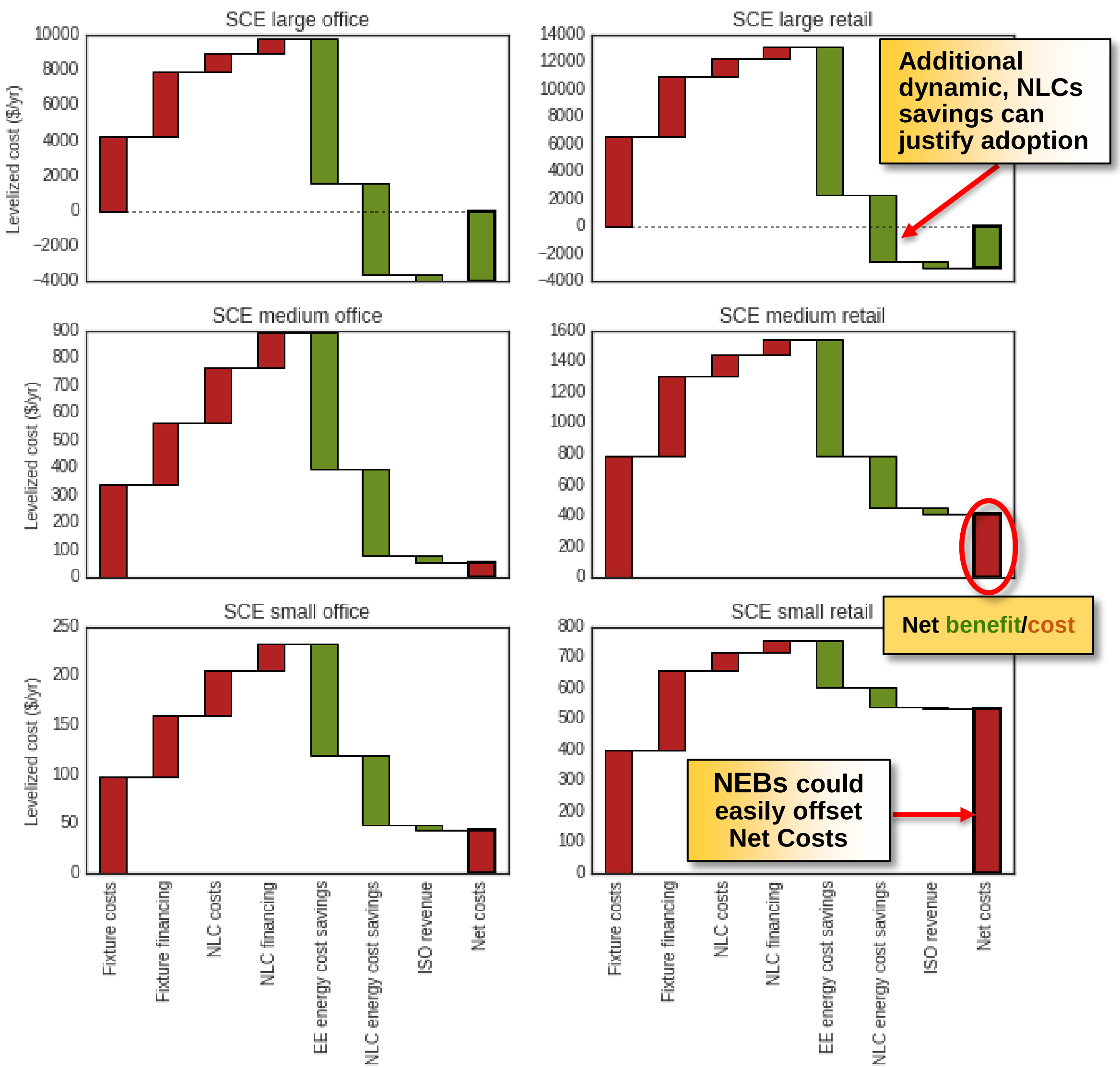
Figure 18: Levelized Annual Costs and Energy-Related Benefits of Demand Response-Enabled Lighting Systems in Different Office and Retail Building Categories in Pacific Gas & Electric Company's Service Territory



Far Right Total: GREEN indicates Positive value; RED is Negative

Source: Lawrence Berkeley National Laboratory

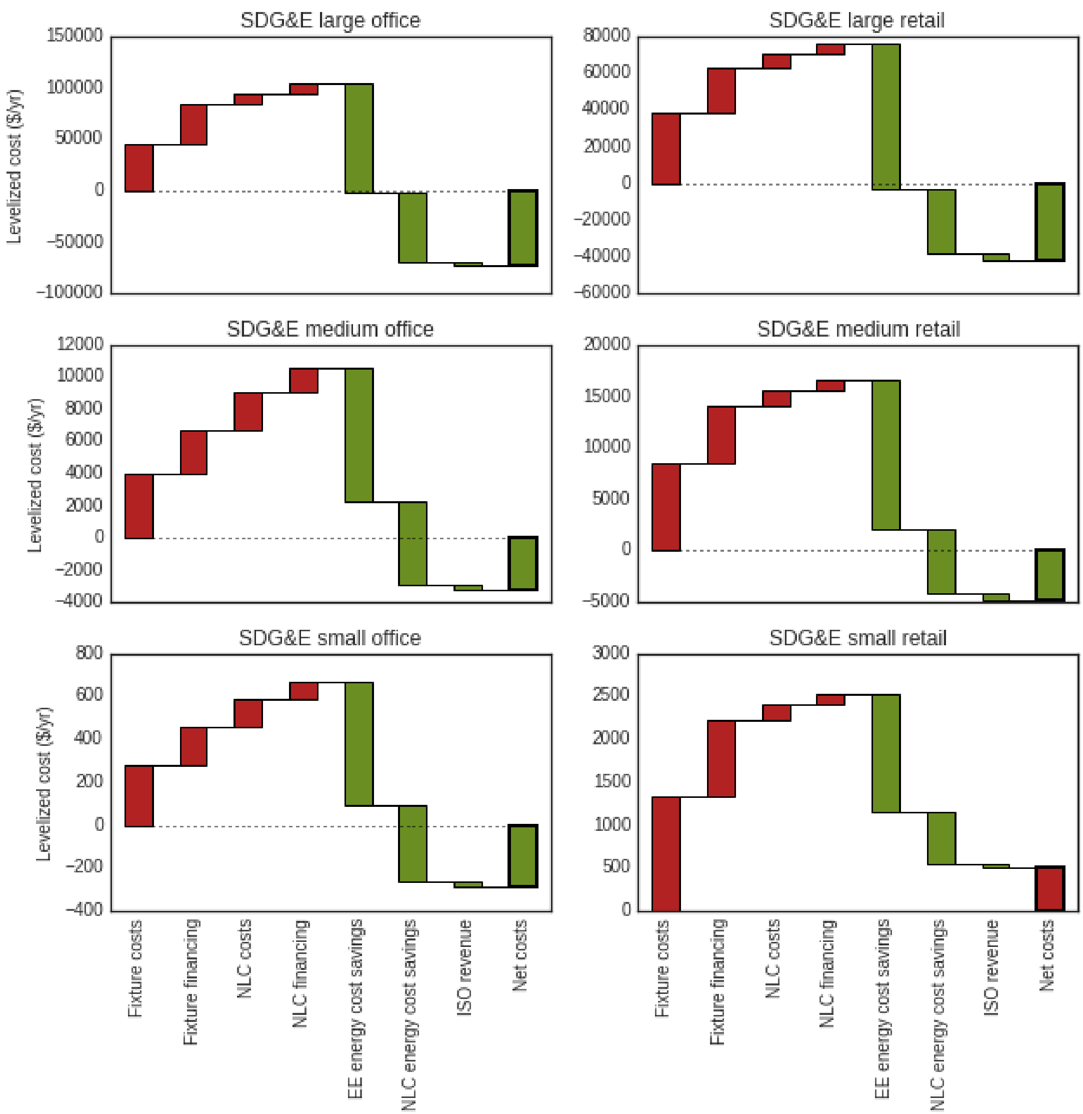
Figure 19: Levelized Annual Costs and Energy-Related Benefits of Demand Response-Enabled Lighting Systems in Different Office and Retail Building Categories in Southern California Edison's Service Territory



Far Right Total: GREEN indicates Positive value; RED is Negative

Source: Lawrence Berkeley National Laboratory

Figure 20: Levelized Annual Costs and Energy-Related Benefits of Demand Response-Enabled Lighting Systems in Different Office and Retail Building Categories in San Diego Gas & Electric Company's Service Territory



Far Right Total: GREEN indicates Positive value; RED is Negative

Source: Lawrence Berkeley National Laboratory

Table 10: Levelized Annual Costs and Savings, in Dollars per Year

Utility	Building Type	Building Size	Fixture Costs	Fixture Financing	NLC Costs	NLC Financing	EE Energy Cost Savings	NLC Energy Cost Savings	ISO Revenue	Net Costs
PG&E	Office	Large	$28,595	$25,388	$6,561	$5,825	$151,288	$95,311	$2,538	$182,769
		Medium	$3,356	$2,171	$1,977	$1,279	$15,849	$9,985	$264	$17,315
		Small	$233	$151	$105	$68	$955	$602	$16	$1,015
	Retail	Large	$38,280	$24,764	$7,733	$5,002	$170,899	$75,195	$3,296	$173,610
		Medium	$7,143	$4,621	$1,353	$875	$28,625	$12,595	$552	$27,780
		Small	$1,309	$847	$186	$120	$3,124	$1,374	$59	$2,095
SCE	Office	Large	$4,219	$3,746	$968	$859	$8,209	$5,171	$364	$3,951
		Medium	$342	$221	$201	$130	$501	$315	$21	$58
		Small	$98	$63	$44	$28	$113	$71	$5	$44
	Retail	Large	$6,644	$4,298	$1,342	$868	$10,863	$4,780	$546	$3,037
		Medium	$791	$512	$150	$97	$763	$336	$36	$415
		Small	$401	$259	$57	$37	$147	$65	$7	$535
SDG&E	Office	Large	$44,871	$39,839	$10,295	$9,141	$106,596	$67,156	$3,768	$73,374
		Medium	$4,047	$2,618	$2,383	$1,542	$8,268	$5,209	$301	$3,189
		Small	$280	$181	$126	$82	$574	$361	$20	$286
	Retail	Large	$38,319	$24,789	$7,741	$5,008	$79,229	$34,861	$3,277	$41,510
		Medium	$8,503	$5,501	$1,611	$1,042	$14,481	$6,372	$603	$4,800
		Small	$1,346	$871	$191	$124	$1,374	$604	$57	$496

Corresponding to values plotted in Figures 18, 19, and 20. Net Costs in red ($) indicate positive revenue.

Source: Lawrence Berkeley National Laboratory

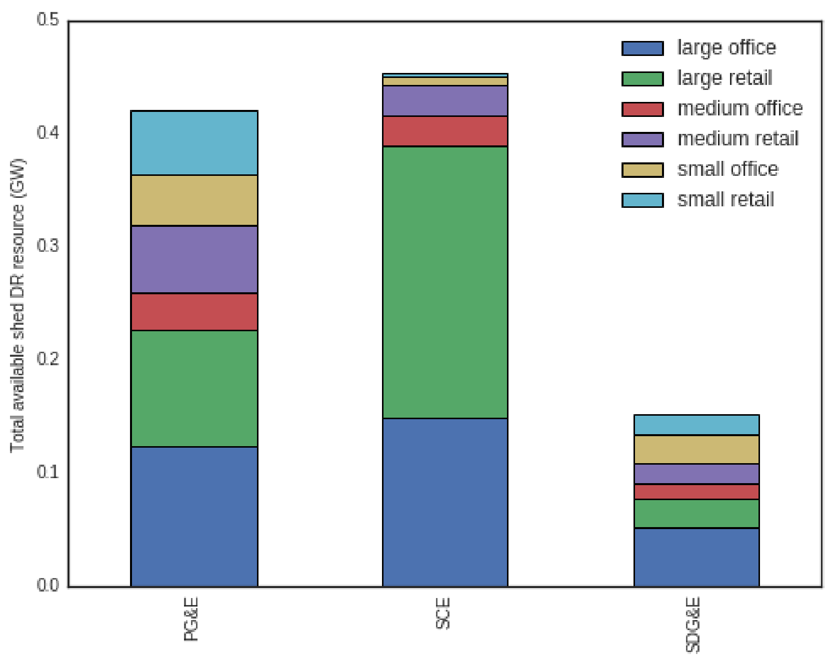
The figures show that the DR-enabled lighting systems' energy-only, cost-effectiveness varies substantially depending on building size and service territory. In general, such systems are more cost-effective for larger buildings than for smaller ones, and for offices than for retail sites, across all service territories. In PG&E's service territory, where commercial retail electricity rates are relatively high (especially on peak), there is a substantial net benefit across all building sizes and types, and DR-enabled systems can generally be justified based on the static energy efficiency savings alone. The site-level value proposition in this case is straightforward. In SCE's service territory, by contrast, where electricity rates are lower, the cost-effectiveness of DR lighting systems depends strongly on the building size, with a net benefit for large buildings only. In this case, the value proposition for small and medium buildings would likely need to rest on the NEBs, rather than the energy-related benefits. The results for the SDG&E service territory are intermediate between these two cases.

Notably, the available revenue from ISO markets is always small relative to the system costs and the energy cost savings. This suggests that the primary value proposition for DR-enabled lighting systems comes from the site-level energy savings that will be realized with or without DR participation. It may therefore be important to develop additional strategies to encourage participation in DR programs once DR-enabled technologies are adopted.

Energy Savings and Demand Response Potential

Using the DR-Futures model, the team estimated the total shed and shimmy resources that can be provided by DR-enabled NLC systems in California office and retail buildings. Figure 21 shows the total potential shed-type resource that could be enabled by installing NLCs in all such buildings, broken down by IOU service territory and building size. The breakdown is similar for the shimmy-type products, although the absolute size of these resources is somewhat different, since they have different dispatch profiles. The potential for each DR product type is broken out in detail in Table 11.

Figure 21: Total Shed-Type Demand Response Resource (Gigawatts) Enabled During Typical Shed Demand Response Event if Networked Lighting Controls were Installed Universally in California Office and Retail Buildings, by Utility Service Territory and Building Size



Source: Lawrence Berkeley National Laboratory

The resource shown in Figure 21 assumes all buildings have been upgraded to solid-state lighting, which reduces the overall load that is available to participate in DR. The breakdown by IOU and building type is similar for shimmy-type DR resources; these are tabulated in Table 12.

In DR lighting savings ($\$/ft^2$) from the 2013 Codes and Standards Enhancement (CASE) Initiative indicate that for other occupancies, there may be substantial energy savings and DR potential. This statement needs to be tempered until a more comprehensive analysis can be performed using this study's methodology and once data associated with occupancies other than office and retail are incorporated into future California DR potential studies.

Table 11: Demand Response Lighting Savings by Climate Zone & Building Occupancy ($/ft²)

Occupancy	CZ1 ($/ft²)	CZ2 ($/ft²)	CZ3 ($/ft²)	CZ4 ($/ft²)	CZ5 ($/ft²)	CZ6 ($/ft²)	CZ7 ($/ft²)	CZ8 ($/ft²)	CZ9 ($/ft²)	CZ10 ($/ft²)	CZ11 ($/ft²)	CZ12 ($/ft²)	CZ13 ($/ft²)	CZ14 ($/ft²)	CZ15 ($/ft²)	CZ16 ($/ft²)	Average Savings Weighted Across Climate Zones ($/ft²)
Office	$0.11	$0.15	$0.15	$0.14	$0.11	$0.16	$0.15	$0.13	$0.18	$0.15	$0.16	$0.15	$0.12	$0.11	$0.11	$0.15	**$0.14**
Retail	$0.19	$0.26	$0.26	$0.24	$0.19	$0.27	$0.24	$0.21	$0.29	$0.26	$0.28	$0.24	$0.20	$0.19	$0.18	$0.25	**$0.23**
Grocery Store	$0.19	$0.26	$0.26	$0.24	$0.19	$0.27	$0.24	$0.21	$0.29	$0.26	$0.28	$0.24	$0.20	$0.19	$0.18	$0.25	**$0.23**
Hotel	$0.21	$0.29	$0.29	$0.27	$0.21	$0.31	$0.27	$0.23	$0.33	$0.29	$0.31	$0.27	$0.23	$0.21	$0.20	$0.28	**$0.26**
Restaurant	$0.16	$0.22	$0.23	$0.21	$0.17	$0.24	$0.21	$0.18	$0.26	$0.23	$0.24	$0.21	$0.18	$0.17	$0.16	$0.22	**$0.20**
Refrigerated Warehouse	$0.10	$0.13	$0.13	$0.12	$0.10	$0.14	$0.12	$0.11	$0.15	$0.13	$0.14	$0.12	$0.10	$0.10	$0.09	$0.13	**$0.12**
Schools	$0.14	$0.19	$0.19	$0.18	$0.14	$0.20	$0.18	$0.16	$0.22	$0.19	$0.21	$0.18	$0.15	$0.14	$0.13	$0.19	**$0.17**
Warehouse	$0.09	$0.12	$0.13	$0.12	$0.09	$0.13	$0.12	$0.10	$0.14	$0.13	$0.13	$0.12	$0.10	$0.09	$0.09	$0.12	**$0.11**
Average Savings Weighted Across Building Types ($/sf)	**$0.14**	**$0.19**	**$0.20**	**$0.18**	**$0.14**	**$0.21**	**$0.18**	**$0.16**	**$0.22**	**$0.19**	**$0.21**	**$0.18**	**$0.15**	**$0.14**	**$0.13**	**$0.19**	**$0.18**

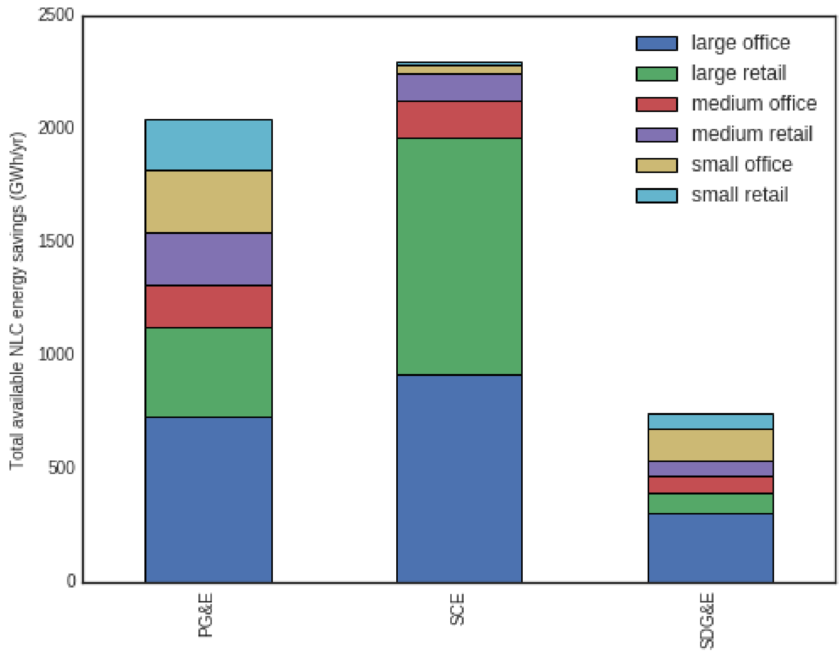
Source: 2013 CASE Report – DR Lighting

As discussed in the earlier section on methodology, the team can also use the model to estimate the total energy savings that installation of NLC systems can provide. Figure 18 shows this savings potential, broken down by building type and service territory; the values shown are also presented in Table 12. It is worth noting that large buildings are the dominant source of DR potential and energy savings. As discussed earlier in this section, these are the buildings that have the clearest value proposition for NLCs. Large commercial buildings have also historically had a much higher rate of DR participation than smaller buildings, so these buildings may represent an attractive target for future lighting DR efforts (see Appendix F of Alstone et al. 2016 for more discussion of DR participation propensities).

The bottom-up structure of the DR-Futures model, which constructs estimates of DR and energy savings potential from clustered customer load profiles, allows us to disaggregate our results to a much finer level of regionalization than the IOU service territories. Table 13 presents the potential DR resources from lighting, as well as the NLC-enabled energy savings, for office and retail buildings, broken out by SubLAP. As with the other results presented here, the values shown are the maximum potential resources that would be available under universal installation of NLCs in these buildings. The available resources vary dramatically by region: perhaps unsurprisingly, the largest resources are available in more urbanized SubLAP, with more rural SubLAP having much smaller potential. For instance, comparing in PG&E's service territory the East Bay region (PGEB) to Humboldt County (PGHB), we can see this disparity in the available NLC energy savings (for example, for office: PGEB 243.9 GWh/yr vs. PGHB 4.9 GWh/yr; for retail: PGEB 147.2 GWh/yr vs. PGHB 6.6 GWh/yr).

In Figure 22, the savings shown are additional dynamic savings available from NLC operation, assuming that all buildings have already been upgraded to solid-state (LED) lighting.

Figure 22: Total Energy Savings (GWh/yr) Achievable by Installing Networked Lighting Controls Universally in California Commercial Office and Retail Buildings, by Utility Service Territory and Building Size



Source: Lawrence Berkeley National Laboratory

Table 13 displays the available, average shed (MW), shimmy-regulation (MW), shimmy-load following (MW), and energy savings (GWhy/yr) resources in each of the California IOUs' SubLAPs. The data represents SubLAP-level disaggregation of the potential resources that would be enabled under universal installation of NLCs in California office and retail buildings. SCEW (located around Long Beach) showed the greatest potential; PGP2 (located on the peninsula south of San Francisco) showed moderate potential; and PGNC (located on the Mendocino Coast north of San Francisco) showed the least potential.

Table 12: Potential Shed and Shimmy Demand Response Resources and Networked Lighting Control Energy Savings Achievable by Universal Installation in California Office and Retail Buildings by Building Type and Utility Service Territory

Utility	Building Type	Building Size	Available Average* Shed Resource (MW)	Available Average Shimmy Regulation Resource (MW)	Available Average Shimmy Load-Following Resource (MW)	Available NLC Energy Savings (GWh/yr)
PG&E	Office	Large	123.6	97.0	121.6	729.8
		Medium	32.4	25.2	31.6	185.6
		Small	45.1	36.2	45.4	271.6
	Retail	Large	103.4	78.6	98.5	400.9
		Medium	60.0	46.1	57.8	231.6
		Small	56.6	44.7	56.1	227.0
SCE	Office	Large	148.8	124.0	155.5	919.7
		Medium	26.8	21.9	27.5	164.2
		Small	6.8	5.4	6.8	41.5
	Retail	Large	240.9	204.9	257.0	1,041.3
		Medium	27.2	23.6	29.6	119.2
		Small	2.9	2.6	3.2	13.0
SDG&E	Office	Large	52.2	40.2	50.4	303.6
		Medium	14.2	10.2	12.8	75.2
		Small	26.1	19.3	24.2	145.6
	Retail	Large	24.9	18.9	23.7	94.7
		Medium	17.2	12.5	15.7	62.0
		Small	17.5	12.9	16.2	64.2
		Total	**1,026.6**	**824.2**	**1,033.6**	**5,090.7**

*** The average DR resource refers to the average load that would be expected to be available for times when the DR needs to be dispatched.**

Source: Lawrence Berkeley National Laboratory

Table 13: Available Average Shed (MW), Shimmy (MW) and Energy Savings (GWh/yr) Resources by Utility SubLAP for Office and Retail Buildings

SubLAP	Available Average Shed Resource (MW)		Available Average Shimmy Regulation Resource (MW)		Available Average Shimmy Load-Following Resource (MW)		Available NLC Energy Savings (GWh/yr)	
	Office	Retail	Office	Retail	Office	Retail	Office	Retail
PGCC	5.5	12.5	4.6	9.3	5.8	11.7	34.3	46.7
PGEB	43.2	38.6	32.4	28.8	40.6	36.2	243.9	147.2
PGF1	15.4	27.2	13.0	22.8	16.3	28.6	97.4	115.9
PGFG	3.2	9.2	2.7	6.7	3.4	8.4	20.1	33.6
PGHB	0.7	1.6	0.7	1.3	0.9	1.6	4.9	6.6
PGLP	7.3	22.7	6.1	18.6	7.6	23.3	45.2	94.8
PGNB	5.9	10.2	5.0	7.6	6.3	9.5	37.1	38.4
PGNC	0.5	1.4	0.5	1.2	0.6	1.5	3.6	6.1
PGNV	2.4	5.6	1.9	4.6	2.4	5.8	14.2	23.5
PGP2	18.3	15.5	13.7	11.0	17.2	13.8	102.1	55.2
PGSA	7.6	16.1	5.8	12.4	7.2	15.6	43.9	63.5
PGSB	43.8	35.9	35.6	25.7	44.6	32.2	266.5	130.7
PGSF	45.7	18.4	34.7	14.1	43.4	17.7	261.2	71.6
PGSI	3.0	4.2	2.5	3.6	3.1	4.5	18.7	18.2
PGSN	0.2	0.2	0.1	0.1	0.2	0.2	0.9	0.7
PGST	3.4	15.6	3.1	13.1	3.9	16.4	23.4	66.2
Total PG&E	**206.1**	**234.9**	**162.4**	**180.9**	**203.5**	**227.0**	**1,217.4**	**918.9**
SCEC	34.2	56.9	27.8	51.8	34.8	65.0	204.8	267.8
SCEN	5.7	12.6	4.6	11.5	5.8	14.5	33.9	59.0
SCEW	118.2	142.4	98.5	118.9	123.4	149.2	733.5	597.1
SCHD	1.7	9.0	1.4	8.0	1.8	10.1	10.6	41.3
SCLD	1.8	8.5	1.5	8.0	1.9	10.0	11.4	41.1
SCNW	16.0	26.8	13.6	21.2	17.0	26.6	100.9	107.9
Total SCE	**177.6**	**256.2**	**147.4**	**219.4**	**184.7**	**275.4**	**1,095.1**	**1,114.2**
SDG1	92.5	59.7	69.8	44.3	87.4	55.6	524.3	220.8
Total SDG&E	**92.5**	**59.7**	**69.8**	**44.3**	**87.4**	**55.6**	**524.3**	**220.8**
Total all IOUs	**476.2**	**550.8**	**379.6**	**444.6**	**475.6**	**558.0**	**2,836.8**	**2,253.9**

Colors indicate relative resource intensity: GREEN (lower), YELLOW (moderate) and RED (high). The average DR resource (average shed resource) refers to the average load that would be expected to be available at times when the DR needs to be dispatched.

Source: Lawrence Berkeley National Laboratory

CHAPTER 3: Cost and Energy Savings of Automated Demand Response-Enabled Networked Lighting Control Systems

Purpose and Scope

Section Summary

Networked lighting control (NLC) systems offer intelligent energy savings solutions for commercial and industrial lighting applications. In 2016, connected lighting systems represented less than 1 percent of the installed luminaire base in the United States. However, the United States Department of Energy (USDOE) expects these systems to achieve 33-percent penetration by 2035 (DOE, 2016) (DOE, 2017) due to both their energy savings potential and significant non-energy benefits. Improved control strategies, sensor interoperability, and economies of scale have all aided in improving energy savings and IoT applications while decreasing costs as the market for NLCs has grown. Capturing and understanding the current energy savings potential and system costs is an important first step to encouraging cost-effective NLC adoption.

To estimate NLC energy savings and associated controls costs, the team reviewed recent literature and conducted outreach to manufacturers and other market actors to estimate NLC project costs for various prototype buildings. The team then synthesized this information into ubiquitous metric of dollars per square foot ($\$/ft^2$) metrics, which was then integrated into the Lawrence Berkeley National Laboratory (LBNL) DR Potential model to evaluate DR-enabled, NLC system cost-effectiveness.

Overview of Networked Lighting Controls

Networked lighting control systems consist of intelligently networked luminaires, sensors, and control devices that enable multiple control strategies, programmability, building- or enterprise-level control, interactive software, and commonly, usage measuring and monitoring (DLC, 2017). While NLC system architecture varies by manufacturer, a system typically consists of the following components:

- Sensors, which have the capability to measure occupancy, light levels, temperature, humidity, and other device or space characteristics. A sensor can be a stand-alone external device or embedded in a luminaire.
- Network connectivity, or interoperability between individual luminaires and controls devices, which enables digital data exchange between other luminaires and control devices on the system.

- Processing software, firmware, and associated hardware that incorporate inputs from the networked sensors with programmed information (such as scheduling, occupancy timeouts, etc.).
- Web or app-based, graphical user interface (GUI) that allows the user to control settings, reviewing energy monitoring reports, and remotely control fixtures (DLC, 2017).

There is increasing utility interest in developing incentive programs to support NLC adoption. The Design Lights Consortium (DLC) established the first qualified products list (QPL) for NLC systems in April 2016, which includes the technical requirements listed in Figure 23. The presence of a broadly accepted QPL is a critical element to support utility NLC programs. Since this initial release, the technical requirements have been updated to require reporting of a number of system capabilities, including load shedding/demand response. It is expected that the number of capabilities on this list will include more NEB capabilities over time.

Figure 23: DLC NLC Technical Specification 2.0

"Required" Interior System Capabilities

- Luminaire & Device Networking
- Occupancy Sensing
- Daylight Harvesting/Photocell Control
- High-End Trim (Institutional Tuning)
- Zoning
- Luminaire & Device Addressability
- Continuous Dimming

“Reported” Interior System Capabilities

- Control Persistence
- Scheduling
- Energy Monitoring
- Device Monitoring/Remote Diagnostics
- Type of User Interface
- Luminaire-Level Lighting Control (LLLC, integrated)
- Personal Control
- Load Shedding (DR)
- Miscellaneous Electric (Plug) Loads Control
- External Systems Integration (e.g., BMS, EMS, HVAC, Lighting, API)
- Emergency Lighting
- Security
- Color Changing/Tuning
- Start-Up & Configuration Party
- Scene Control

BMS = building management system; EMS = energy management system; API = application programming interface.

Source: DLC 2017

Generally, NLC systems can be informally categorized as either “clever” or “smart.” A clever system is defined as an NLC system that meets basic DLC QPL requirements (high-end trim, dimming, occupancy sensors, and photocells) and consists of “plug and play” fixtures that require little to no commissioning upon installation. A smart system includes all “clever” capabilities, but it can also analyze and communicate energy and non-energy data to inform decisions for a wide variety of IoT use cases and analytics above standard requirements, such as space use, heating, ventilating, and air conditioning (HVAC) optimization, and retail (or other) asset tracking.

While virtually all smart systems have DR enablement as a standard feature, not all clever systems have this capability. As such, all systems that lacked DR-enablement were excluded from this analysis.

Networked lighting controls are expected to play an increasingly prominent role in reducing building energy consumption and demand management. In 2016, connected lighting systems currently represented less than 1-percent of the installed luminaire base in the United States. As stated earlier, DOE expects these systems to achieve 33-percent penetration by 2035 (DOE, 2016) (DOE, 2017). Due to their connectivity, controllability, and ease of configuration, NLCs provide a wide variety of potential benefits to both customers and the grid, including the following (summarized in Table 14 below):

- Energy savings from lighting due to increased control. NLCs leverage control strategies (that is, institutional tuning, occupancy sensing, daylight harvesting, high-end trim, and continuous dimming) to achieve additional energy savings beyond a basic LED retrofit. Energy savings attributed to controls are site-specific, based on implementation strategies and facility attributes, but typically exceed 80-percent or more (DLC, 2017).
- Energy savings from HVAC integration. Occupancy and temperature sensing data from NLCs can integrate with other building system components such as HVAC to inform its operating patterns and modify HVAC usage based on actual building occupancy and temperature information. This can create additional energy savings beyond lighting.
- Increased demand management. NLCs provide increased demand management, which can support essential grid functions such as load balancing, an increasingly important strategy to manage the increasing grid penetration of renewables. However, these markets do not yet exist, and therefore provide minimal customer benefit at present.
- Non-energy benefits that support business optimization. Sensing data from NLCs inform a wide range of business processes and operations, including improving how spaces are used and how equipment is serviced and maintained.
- Streamlined code compliance. Title 24 requires buildings to meet stringent power allowances, control requirements, and demand response enablement requirements. NLCs can help meet these mandates and facilitate compliance in a turnkey system, minimizing compliance efforts for building owners and managers.

Table 14: Overview of NLC Benefits and the Beneficiary

	Customer Benefits	Grid Benefits
Lighting energy savings from increased control	X	X
Streamlined code compliance	X	
Energy savings from HVAC integration	X	X
Demand management		X
Non-energy benefits	X	

Source: Lawrence Berkeley National Laboratory

Currently the primary market driver of NLCs is the energy savings, although streamlined Title 24 compliance is another significant benefit that NLC systems offer. This is chiefly because the other three benefits have significant potential value, but their value is currently not well defined or they lack existing markets in which customers can participate.

Defining Non-Energy Benefits

NEBs are highly specific to how organizations use the information collected from NLC systems to create business value. For example, humidity sensor readings may have little or no value to commercial office owners, but may be important to hospitals and healthcare facilities. The potential benefits can be simplified as three levels of business value beyond energy:

- Facilities and maintenance-related
- Productivity-related
- Revenue-related

Overview of Title 24 Demand Response-Enabled Lighting Requirements

As of 2008, Title 24 Part 6 began requiring DR capability in all buildings with an area of 50,000 ft^2 or greater that do not meet specific exemption requirements. The updated 2013 Title 24 codes expanded DR lighting control requirements to all nonresidential buildings over 10,000 ft^2.

In Title 24, DR capability is defined as the capability to receive a signal from the local utility, Independent System Operator (ISO), or designated curtailment service provider or aggregator. This signal must indicate to a customer a price or request to modify electricity consumption for a limited time period.[3] Under current regulations, buildings are not required to actively participate in DR programs, only that they have the capability to receive a demand response

[3] Cited from the California Statewide Codes and Standard's education program "Energy Code Ace" https://energycodeace.com/site/custom/public/reference-ace 2013/index.html#!Documents/gloss_demandresponsesignal.htm.

signal. Title 24 code requirements allow buildings to forego the DR requirements if the buildings have a lighting power density (LPD) of less than 0.5 watts per square foot.[4]

Networked Lighting Control Energy Savings from Demand Response-Capable Systems

Estimating Energy Savings from Networked Lighting Control Systems

A recent study published by DLC served to further inform this study's building-level energy savings analysis because the DLC used pre-existing NLC installation building energy data and conducted a thorough review. The DLC study analyzed hourly fixture- and zone-level energy monitoring data in 114 commercial buildings for an average duration of 60 days to identify energy savings attributed to NLC systems (DLC, 2017). These data were then compared to an inferred baseline[5] to develop the observed energy savings by the NLC system. In the DLC study, overall savings by building type had a significant range of results. The wide variation indicates that DR-enabled NLC systems have the potential to achieve significant energy savings but depend heavily on proper implementation and configuration to maximize savings.

While the study had a number of caveats and significant variability in NLC savings achieved across buildings, this study is likely the best available representation of real-world NLC installations, control strategy measures, and energy savings.[6]

In Figure 24, each circle in represents an individual building, and the whiskers extend to the minimum and maximum values. The solid horizontal line is the average (mean), while the dashed line is the median (DLC, 2017).

As described in Chapter 2, the project team ultimately used the percent lighting savings and applied it to the LBNL-Load forecast. This also included the 20-percent downward adjustment in the CEUS estimates in our model to account for market changes documented in the CSS.

The average energy saving was found to be 47-percent across all building types,[7] suggesting that there are significant additional energy savings beyond basic LED retrofits.[8] The highest average energy savings was found in warehouses, and the wide variation across building types

---

[4] Based on Table 140-C in the building code, this "85-100 LPD allowance" is an option for complying with the prescriptive approach that exempts alterations with an LPD that is 85-percent or less of the maximum LPD from most of the mandatory lighting controls requirements, including DR capability (CEC 2015). It is estimated that of all code-compliant lighting alterations projects, 37-percent of alterations use the "85 to 100-percent LPD allowance."

[5] The baseline condition for each zone was assumed to have the same occupied hours as the post-NLC data but operate at its rated power. An occupancy threshold was established at 10-percent of the zone's maximum power draw to differentiate between hours where the lighting in the inferred baseline is expected to be in use (space is occupied), and thus registers at the rated power output versus the space being unoccupied where it is assumed the power draw to be the same. For further detail, please refer to the referenced DLC study.

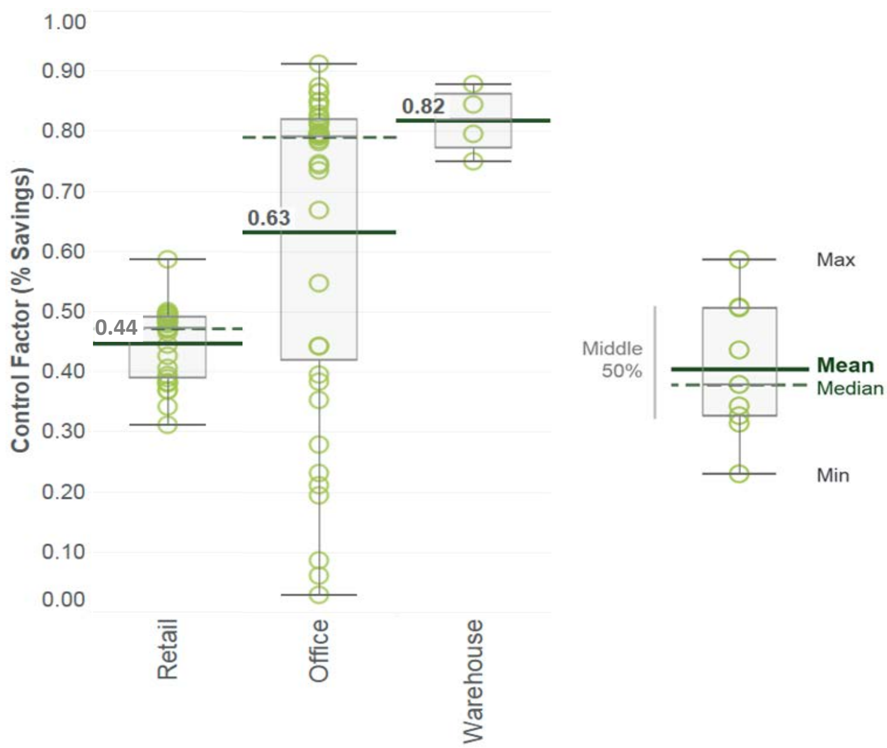
[6] Previous controls studies had significantly smaller sample sizes or were conducted prior to LEDs achieving widespread adoption (DLC, 2017).

[7] Building types reviewed in this report included assemblies, schools, manufacturing facilities, retail, restaurants, offices, and warehouses.

[8] In addition to the retail, office, and warehouse building types shown, the DLC report reviewed 42 buildings' data across assembly, school, manufacturing, and restaurant building types.

is due to differences in occupancy patterns and NLC implementation practices across each building, such as high-end trim levels and occupancy settings.[9]

Figure 24: Box and Whisker Plot of Retail, Office and Warehouse Energy Savings Against an Inferred Baseline



Source: Lawrence Berkeley National Laboratory

Table 15: Summary of Inferred NLC Savings by Building Type Results (DLC, 2017)

Building Type	Total Buildings	Unique Manufacturers	Control Factor (% savings)	
			Average	25th–75th Percentile
Retail	29	1	0.44	0.39–0.49
Office	39	3	0.63	0.43–0.82
Warehouse	4	2	0.82	0.78–0.85

Source: Lawrence Berkeley National Laboratory

Interoperability Savings

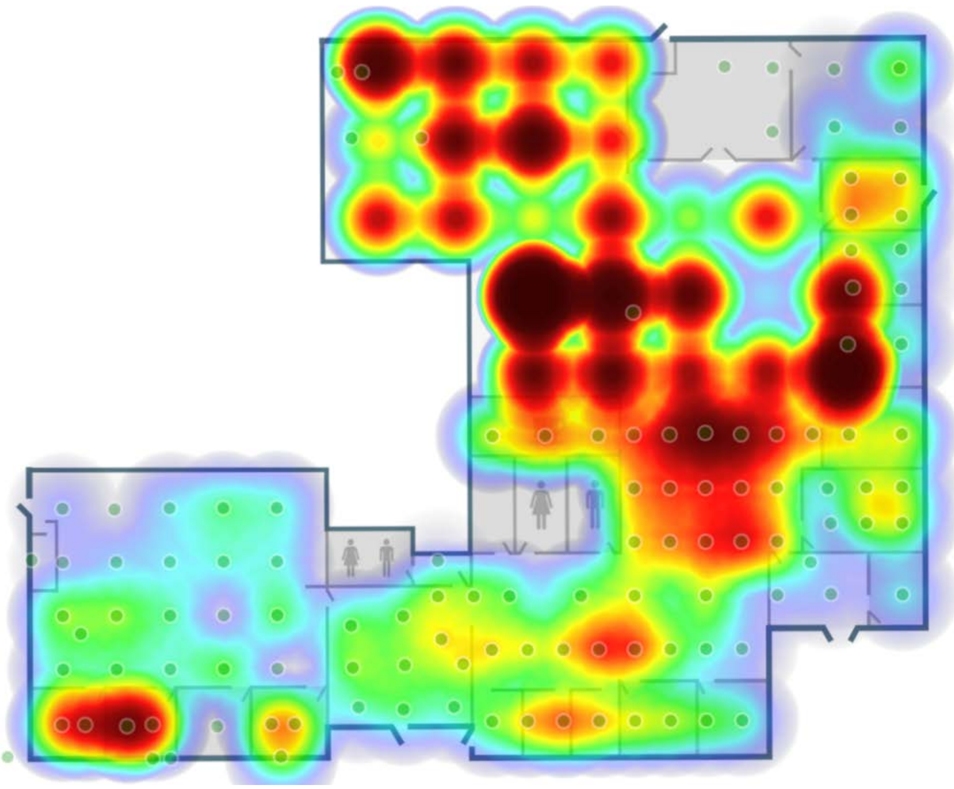
In addition to achieving lighting energy savings, some NLC systems combine temperature sensors with occupancy and photometric sensors to improve building operations in other high-

[9] In addition to the DLC study, the team reviewed a wide number of studies that provided supplemental data on energy savings by space and building type. While these studies did not provide direct inputs to the LBNL statistical model, they are helpful to understand broader savings opportunities by building and space types. A summary of this detailed information is provided in Appendix A.

energy consumption end uses like HVAC. For example, temperature sensors, when used in conjunction with natural light sensors, can provide highly granular data that helps to identify additional heat sources near windows (due to the sun) to influence local heating and cooling needs. Similarly, occupancy sensors can be used to create occupancy heat maps (Figure 25) and identify enclosed spaces that are unoccupied. If they are predicted to remain unoccupied, HVAC settings can be adjusted to exclude them and provide further savings.

While HVAC energy savings represent significant potential to improve the value proposition of NLCs in the future, their savings were not integrated into this study's analysis due to the limited data available. As this feature gains traction, it may be quantitatively included in future NLC analyses. However, for the purposes of this study, the team identified existing case studies to identify how it might affect the NLC value proposition in the near future.

Figure 25: Example Occupancy Visualization



Source: Garcia (2015)

Despite the apparent ability of NLC systems to reduce HVAC energy consumption, to date there are limited existing data to quantify the potential impact of such a strategy. In a literature review, the team identified a single case study from an NLC manufacturer, Enlighted, of a roughly 500,000 ft^2 installation at an office park consisting of office, laboratory and warehouse spaces. The retrofit included replacing fluorescent lights with new LED fixtures with NLCs that contained embedded sensors capable of measuring ambient light levels, temperature, and occupancy. Each of these sensors was mapped to a zone that was controlled by a given thermostat, and the information they provided was integrated into the controls of the HVAC system.

The energy savings potential highlighted by this case study directly relates to the demand response potential of interoperability. Because HVAC units often operate during peak periods, the ability to leverage information collected by the lighting system can provide deeper and more precise demand response measures while limiting tenant impact to sustainable levels. Examples of the HVAC optimization now possible due to the system integration include adjusting HVAC down and reducing airflow when occupancy is reduced, as well as using micro-zone temperature data to fine-tune thermostat setpoints.

The manufacturer case study reported 15-percent HVAC energy savings by making the occupancy and temperature data available to the HVAC controller. These savings are highly significant because HVAC energy consumption is typically 2.4 times the energy of lighting in office buildings[10] (U.S. Energy Information Administration, 2016), which is equivalent to a 36-percent decrease in the lighting system's energy use. In some cases, the HVAC energy savings may be equal to or greater than the lighting savings achieved by NLCs, creating significant additional value for the system.

Beyond the savings attributed to direct interoperability action, the facility realized an additional 10-percent savings due to reduced cooling needs by replacing the existing fluorescent fixture, as well as an additional 5-percent savings due to improved scheduling. While HVAC integration has a significant opportunity to create additional customer value streams for NLCs, it requires further study to better quantify its potential.

Network Lighting Control System Costs

Demand Response-Enabled Networked Lighting Controls Cost Methodology and Key Assumptions

The project team used two approaches to estimate NLC project cost data: (1) modeling NLC project costs based on a set of standard building prototypes, and (2) comparing these estimates with internal project invoice data from completed NLC projects.

Modeling Networked Lighting Controls Costs Based on Building Prototypes

The team conducted outreach to three manufacturers and two manufacturer representatives to obtain cost estimates for eight distinct NLC system products. For each system, the team asked each participant to provide a complete cost estimate for all components required to install a code-compliant NLC system (Table 16).

[10] According to the United States Energy Information Administration, Table E5 for electricity consumption by end use in 2012. In offices, heating, ventilation, and air conditioning consumes 103 billion kWh while lighting uses 43 billion kWh.

Table 16: Networked Lighting Controls Installation Components

Hardware Components	Labor
• Fixtures • Stand-alone devices (occupancy/photo sensors, switches) • Energy management device • DR enabling components (e.g., ADR box)	• Installation • Commissioning

Source: Lawrence Berkeley National Laboratory

To standardize across each manufacturer's product offering, each estimate was based on sample Energy Commission prototypes across the office, retail and warehouse building types with pre-specified floor areas and fixture densities[11] (Table 17). Fixture density and typical area size can vary across building sectors; this provides a realistic project description for accuracy in determining costs.

Table 17: Building Assumptions

Building Prototype	Floor Area	Fixture Density (Floor Area per Fixture, ft^2)
Small Office	5,502	85*
Medium Office	53,628	85
Large Office	298,589	85
Large Retail	240,000	Fine Retail: 64 Big Box: 240
Small Retail	24,563	Fine Retail: 64 Big Box: 240
Warehouse	49,495	100

Source: Lawrence Berkeley National Laboratory 2015

Analyzing Networked Lighting Controls Costs Based on Project Invoice Data

In addition to developing NLC project estimates based on prototype buildings, the team analyzed internal project invoice data from 23 NLC projects completed from 2014 to 1017, separating costs into fixture-based costs and controls-based costs.

Fixture material costs include lamps, retrofit kits, luminaires, drivers, pre-retrofit fixture disposal fees, and any wiring connected to lighting components. For fixtures with integrated controls, the incremental cost between a basic fixture and the integrated fixture was subtracted out and incorporated into control costs.

[11] Fixture density is a key component in determining fixtures and control costs. NLCs that use gateways for connectivity are dependent on number of devices connected. Office fixture density was based on a recent NLC demonstration study by the General Services Administration (LBNL 2015). The team based fixture density for retail and warehouse building types primarily on field observation and invoice data, with some modifications to ensure that resulting LPDs did not exceed 2016 Title 24 requirements.

Controls material costs include the NLC system's occupancy sensors, photo sensors, gateways, power over Ethernet (PoE) switches (if applicable), wall switches/dimmers, software, and any licensing fees for connectivity or monitoring. Control labor includes installation of sensors, switches, gateways, as well as any programming of devices or commissioning necessary. All other labor is assumed to be included in fixture installation.

Results: Demand Response-Enabled Networked Lighting Control Implementation Costs

Table 18, Table 19, and Table 20 show the average costs per square foot of an NLC system for office, warehouse, and retail building types, broken out by materials and labor for both fixtures and controls.

As the results indicate, NLC project costs are generally consistent across building types, though small retail is slightly higher due to a higher fixture density. As expected, project costs decrease significantly as project size increases. The main drivers of costs are fixture density, building area, and necessary peripherals (for example, gateways, photo sensors, occupancy sensors).

Table 18: Office Average Fixture and Control Costs (dollars per square foot)

Building Size	Average Fixture Material Costs ($\$/ft^2$)	Average Fixture Labor Costs ($\$/ft^2$)	Average Controls Materials Costs ($\$/ft^2$)	Average Controls Labor Costs ($\$/ft^2$)
<10,000	2.07	1.26	0.68	0.31
10,000–100,000	1.83	0.96	0.34	0.40
>100,000	1.81	0.77	0.29	0.23

Source: Lawrence Berkeley National Laboratory

Table 19: Warehouse Average Fixture and Control Costs (dollars per square foot)

Building Size	Average Fixture Material Costs ($\$/ft^2$)	Average Fixture Labor Costs ($\$/ft^2$)	Average Controls Materials Costs ($\$/ft^2$)	Average Controls Labor Costs ($\$/ft^2$)
<10,000	2.01	1.47	0.70	0.26
10,000–100,000	1.85	1.13	0.23	0.27
>100,000	0.96	0.45	0.23	0.15

Source: Lawrence Berkeley National Laboratory

Table 20: Retail Average Fixture and Control Costs (dollars per square foot)

Building Size	Average Fixture Material Costs ($/ft²)	Average Fixture Labor Costs ($/ft²)	Average Controls Materials Costs ($/ft²)	Average Controls Labor Costs ($/ft²)
<10,000	2.87	1.59	0.40	0.23
10,000–100,000	1.50	1.07	0.35	0.19
>100,000	1.46	0.71	0.21	0.10

Source: Lawrence Berkeley National Laboratory

In addition to project cost, the team calculated the relative incremental cost associated with installing controls on top of an LED retrofit. Overall, the NLC system incremental cost was between 12 to 26-percent greater than a standard LED system (Table 21). This incremental cost is important to consider when comparing the relative increase in benefits and value that an NLC system brings beyond a standard LED retrofit.

Table 21: Percentage of Installation Costs Attributed to Controls

Building Type	<10,000 sq. ft. (%)	10,000–100,000 sq. ft. (%)	>100,000 sq. ft. (%)
Office	26	26	20
Warehouse	24	16	19
Retail	12	20	16

Source: Lawrence Berkeley National Laboratory

This is particularly important given the long lifetime of LEDs and that once an LED system without controls is installed, it is not economically viable (based on NLC energy savings alone) to install an NLC system later on. This creates an issue where LED systems without controls may become legacy technologies in five years, preventing organizations from achieving the additional value associated with connected lighting and non-energy benefits.

Joining the building-level cost information developed in Table 18, Table 19 and Table 20 with the building-level energy savings potential in Table 21[12] provides insight into the cost-effectiveness of DR-enabled NLC systems when only considering the energy savings potential of the lighting controls. This comparison suggests that NLCs can achieve paybacks ranging from 0.67 to 3 years times the annual energy savings potential when completed at the same time as an LED retrofit, although this is dependent on each building's energy savings. However, this finding underscores that even without NEBs, NLCs can provide significant incremental value on top of basic LED retrofits (see Figure 18, Figure 19 and Figure 20), and adding the impacts of NEBs makes an even stronger value proposition. The team recommend further study to refine NLC cost estimates as the technology matures compared to the value generated from both energy and non-energy benefits.

[12] Assuming an average electricity rate of $0.1773/kWh, which was the California commercial building average in August 2017 according to the United States Energy Information Administration.

CHAPTER 4:
Identifying Non-Energy Benefits from Demand Response-Enabled Lighting Control Systems

Non-Energy Benefits Overview

Section Summary

Using the connectivity and data collecting capabilities of NLCs, NEBs have the potential to accelerate NLC adoption by creating alternative, higher business value levels than simply saving energy (kilowatt-hours), including streamlining facility operations, improving employee productivity, and increasing revenue through enhanced features. Navigant Research estimates that global market revenue for IoT lighting will grow from $651 million in 2017 to $4.5 billion in 2026 (Navigant, 2017). However, many of the emerging benefits responsible for its expected growth are still not well quantified. As part of a literature review, the team reviewed 108 case studies across five Unites States-based NLC manufacturers that cited facility-specific energy and non-energy benefits from completed projects. Among the 108 case studies, 57 case studies mentioned NEBs, including maintenance benefits, improved productivity, and increased security. Only 16 case studies quantified NEB cost savings values, and the vast majority of these were quantifying maintenance cost savings. Data from existing case studies suggest that cost savings from streamlined facility maintenance and operations were 11 times greater than energy savings, and cost savings from space optimization were 67 times greater than energy savings. While there are limited data to date and the NEB question requires further study to draw more definitive conclusions across building types or between NEBs, the existing data strongly suggests that in many cases, the value from NEBs is equal to or greater than the cost savings derived from energy savings alone, significantly increasing the value of NLCs to business operations.

Non-energy Benefits Market Overview

While energy savings and DR capabilities are currently important NLC system characteristics, as NLC products mature, an emerging suite of IoT use cases for future networked lighting controls increasingly will be driven by their sophisticated sensing and processing capabilities. These capabilities create NEBs by providing insight into how buildings are used and operated, which can generally be categorized into two overarching types of value:

- Increased insight into facility operation that can result in reduced maintenance costs.
- Those that can help to optimize building operations, improve employee productivity, and increase revenue and business efficiency.

Organizational Costs

Non-energy benefits can have widely varying business and magnitude values, depending on the organization type. A common rule of thumb for organizational costs and value is the "3-30-300" rule,[13] which characterizes an organization's occupancy costs per square foot as levels of magnitude: $3 per square foot for energy, $30 per square foot for rent, and $300 per square foot for employee costs, including salaries, benefits, etc. (Terrapin Bright Green 2012).[14] Thus, NEBs that streamline facility operations and reduce space needed to operate could create a revenue impact ten times that of simply saving energy. Similarly, NEBs that facilitate improvements in human productivity could potentially generate savings on the order of one hundred times the typical energy savings from NLCs.

There is even the concept put forth that the team should embrace the "3-30-300-3000" rule, which purports that the team should include potential revenue enhancement (at $3000 per square foot) in addition to energy-rent-employee costs. Currently, the "3-30-300-3000" rule is significantly harder to document due to numerous different revenue models associated with the vast variety of business types occupying buildings. It is still important to note that, once captured and quantified, this value would obviously dwarf any energy benefit.

The DOE estimates that the majority of remaining energy savings will come from connected lighting, and that the major driver of these savings will be due to a businesses' desire to gain non-energy insights from the devices (IoT/Big Data aspects), rather than the energy savings themselves (DOE, 2016).[15] Although these emerging use cases highlight significant benefits beyond lighting, in many cases they currently lack quantified evidence on the magnitude of their potential impact. Increasing customer and utility awareness and confidence in the value of these use cases is imperative to capturing the full value proposition of NLCs and accelerating their adoption.

Figure 26 provides an overview of sample use cases for NLC monitoring data (both energy and non-energy) as a function of NLC product maturity. Emerging product offerings such as conference room scheduling, space use, asset tracking, and indoor positioning are expected to become more standard offerings as NLC products evolve.

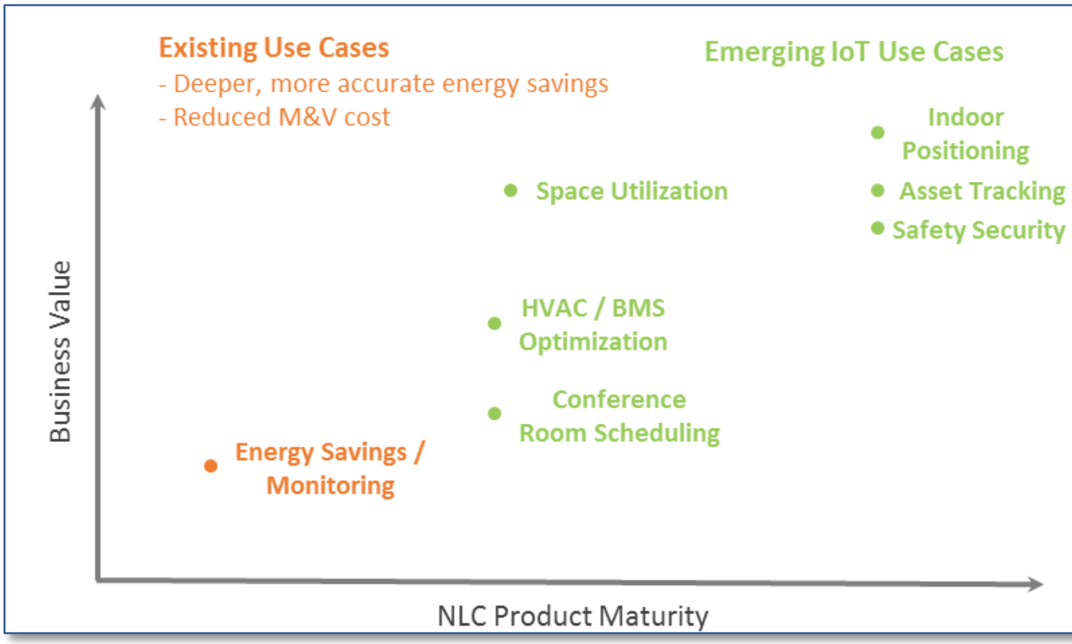
---

[13] Green + Productive™ Workplace. 2014. Jones Lang LaSalle IP, Inc. http://www.us.jll.com/united-states/en-us/Documents/Workplace/green-productive-overview.pdf.

[14] A recent addition to the rule of thumb, promulgated at a recent DLC stakeholder meeting by Acuity Brands Lighting, is modifying it to reflect 3-30-300-3000, where revenue can be considered to generate an estimated $3,000 of revenue per square foot (Do, 2017). While organizational revenue varies significantly across companies and sectors, devices that can increase revenue have an order of magnitude greater impact on organizational finances than those simply reducing energy costs.

[15] The United States Department of Energy estimates that non-connected lighting controls will have minimal growth in the future, and the vast majority of growth will come from connected systems (DOE, 2016).

Figure 26: Overview of Sample Networked Lighting Controls Use Cases and Value Propositions



Note: As NLCs mature (move right along the x-axis), they continue to incorporate new features.

Source: DLC (2017)

How Leveraging Non-energy Benefits supports Demand Response-enablement and Use

While DR-enablement is part of California Title 24 Building Standards Code requirements, the vast majority of systems are capable of receiving a signal, yet they do not actively use their demand management capability, for a variety of reasons:

- There is an additional cost to implement demand management capability so that buildings can participate in programs.
- Very few small and medium commercial facilities participate in demand management programs because there is no clear value or business priority.
- Because newer LED lighting systems consume far less energy than traditional fluorescent systems and their loads represent a much smaller percentage of overall building energy consumption, therefore, they make the demand reduction potential smaller and less attractive to participate in traditional event-based DR programs on an individual building basis (depending upon size and controls sophistication).

While traditional event-based programs may have limited benefits, more frequent fast-DR events may provide value to both customers and the grid, and thus it is in the utility and grid operator’s interest to increase penetration of NLC systems that have the capability to participate in fast-DR.

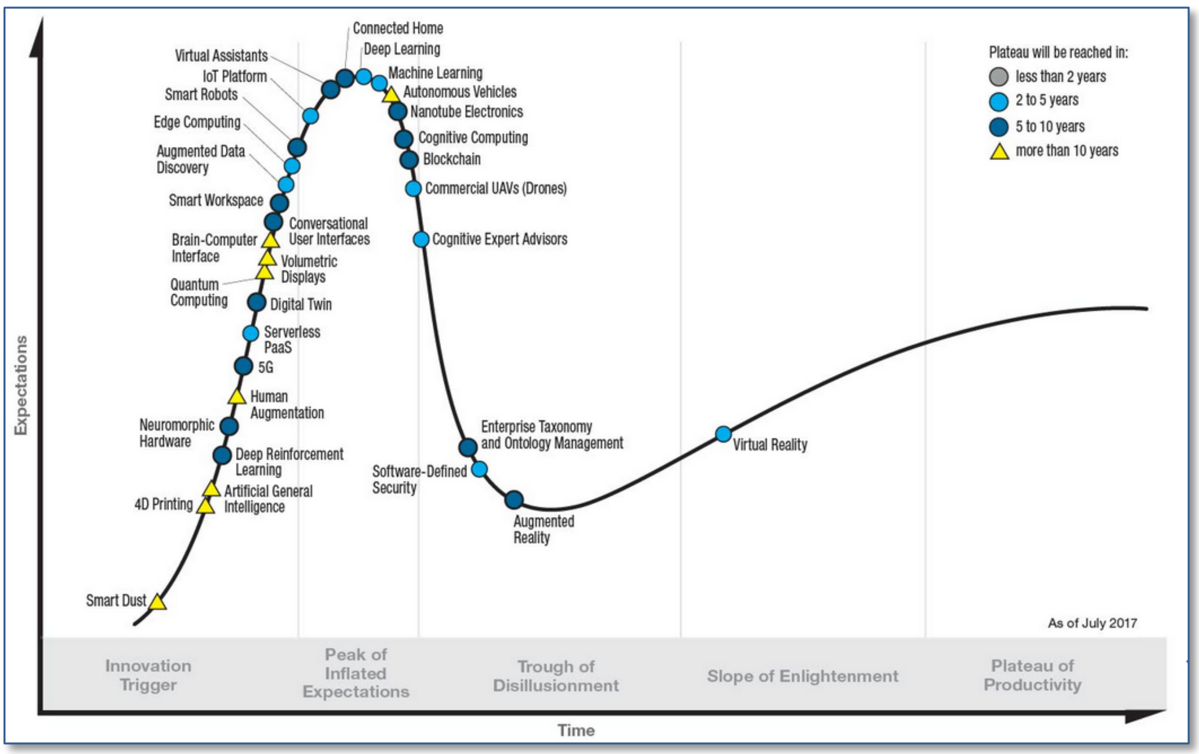
Non-energy benefits that are linked or co-mingled with DR-enablement offer the best opportunity for increasing deployment, because these benefits have a stronger value proposition than DR-enablement itself. Quantifying NEBs and promoting their adoption through NLC DR capabilities can encourage facilities to enable demand response.

DR-enablement is not likely to grow to the levels required to support California's demand management needs without a major catalyst that creates business value for customers and encourages DR-enablement. While emerging NEBs have significant potential to provide business value and spur adoption of NLC systems that can provide DR-enablement, in many cases, they are often insufficiently quantified to be incorporated into business decision-making.

Existing State of Non-Energy Benefits Acceptance in the Networked Lighting Controls Market

Generally, as product capabilities grow and gain traction, they tend to follow a product maturity and acceptance cycle where the value proposition (and its quantification) becomes increasingly well defined as products mature (Figure 27).[16]

Figure 27: Gartner Hype Cycle for Emerging Technologies, 2017



Source: Panetta (2017)

For example, LED lighting went through a similar market adoption expansion in the mid-2000s, where the value and specific benefits (such as product lifetime and lumen output) were not well quantified. Consumer confidence in the product's value and benefit claims increased as the products evaluation metrics matured and features became better quantified.

---

[16] This is a general pattern for technologies, often referred to as the *Gartner Hype cycle* or *similar maturity pattern.*

This type of technology maturity is found across many industries, particularly in information technology products, which tend to follow a pattern known as the Gartner Hype Cycle.[17] This pattern suggests that new technologies go through a period of overinflated expectations relative to their capabilities and achieve a "plateau of productivity" over time develop improved quantification of the product's actual value.

Networked lighting controls have a wide-range of potential capabilities, but very few of those capabilities are quantitatively defined. Table 22 provides a high-level overview of how NLC benefits may be quantified as they mature.

Table 22: Quantification of Value and NEB Maturity

NEB Maturity Stage	Quantification of Value
Initial mention by NLC manufacturers or others	Limited detail or case studies
Few projects, limited documentation or case studies	Increasing reference in product literature, benefits may or may not be quantified. Only early adopter organizations will consider this into decision making
Increasing product acceptance	Increasing standard practice, energy savings are quantified (but not always in a standard method). A limited number of organizations may consider this
General Acceptance	Standard practice or product option, value is quantified, and decision makers incorporate into their business decisions

Source: Lawrence Berkeley National Laboratory

Non-Energy Benefits Identification and Prioritization

Literature Review of Non-Energy Benefits

To understand the NEB landscape, the team performed a broad literature review of existing academic publications, industry reports, and marketing content from NLC manufacturers. The existing literature on NEBs (generalized and not exclusive to NLCs) can generally be classified into the three categories outlined in Table 23.

[17] Top Trends in the Gartner Hype Cycle for Emerging Technologies. 2017. www.gartner.com/smarterwithgartner/top-trends-in-the-gartner-hype-cycle-for-emerging-technologies-2017/.

Table 23: Non-energy Benefits Category Details

Category	Definition	Example	Primary Audience
Public NEBs	Benefits at the highest level, affecting society as a whole	Increased safety from better distribution patterns and color rendering of LED street lights	Society at large, users of public services
Sector-Wide NEBs	General benefits quantified at the level of an entire building and business sector	Improved air quality from reduced power plant emissions	Policymakers
Facility-Specific NEBs	Benefits created by the business type, operations, and other localized parameters	Occupancy generated heat maps helping a retail store optimize product locations	Influences owner, operators, and people conducting business within a specific facility

Source: Lawrence Berkeley National Laboratory

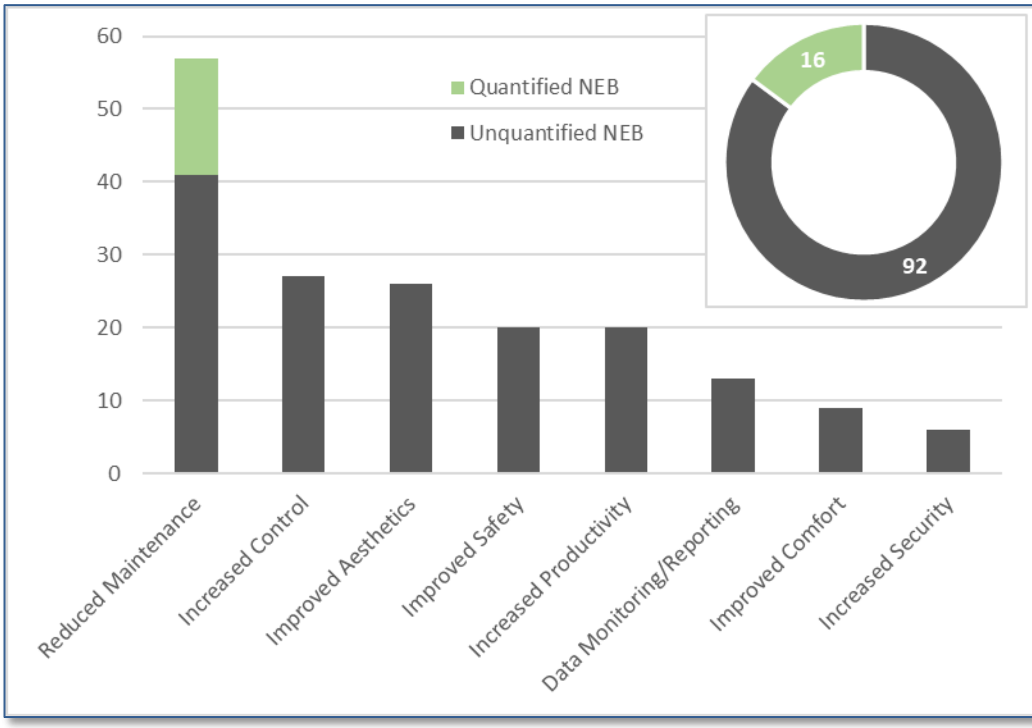
Existing papers and reports primarily focus on public NEBs and sector-wide NEBs, and some quantification methods have been established to quantify NEBs to support regulatory policy development[18] (Bicknell and Skumatz 2004; Skumatz et. al. 2000; Skumatz 2016; Pearson and Skumatz 2002; Bement and Skumatz 2007; Mills and Rosenfeld 1996). While public and sector-wide approaches are important for policy-making, this report focuses on facility-specific NEBs because they have a direct impact on customers' NLC purchasing decisions, and therefore the ability to accelerate lighting DR adoption. As part of this effort, the team conducted a literature review of facility-specific NEBs to identify: (1) which facility-specific NLC NEBs are most prominent, and (2) the degree to which these NEBs are quantified.

The team reviewed 108 case studies across five United States-based NLC manufacturers that cited facility-specific energy and non-energy benefits from completed projects.[19] Among the 108 case studies, manufacturers advertised energy savings as the primary benefit, with 88 case studies explicitly mentioning them. Fifty-seven case studies mentioned maintenance benefits, such as reduced lamp replacement costs and reduced operating hours. Only 16 case studies, roughly 15-percent, included quantified values and, in all 16 cases, the quantified NEB was maintenance cost savings.

[18] The NEBs discussed in the literature for these two categories are related to public policies and programs, and are not specific to NLCs.

[19] A reference list for all reviewed case studies is provided at the end of this report.

Figure 28: Non-energy Benefits Mentioned in 108 Manufacturer Case Studies Reviewed



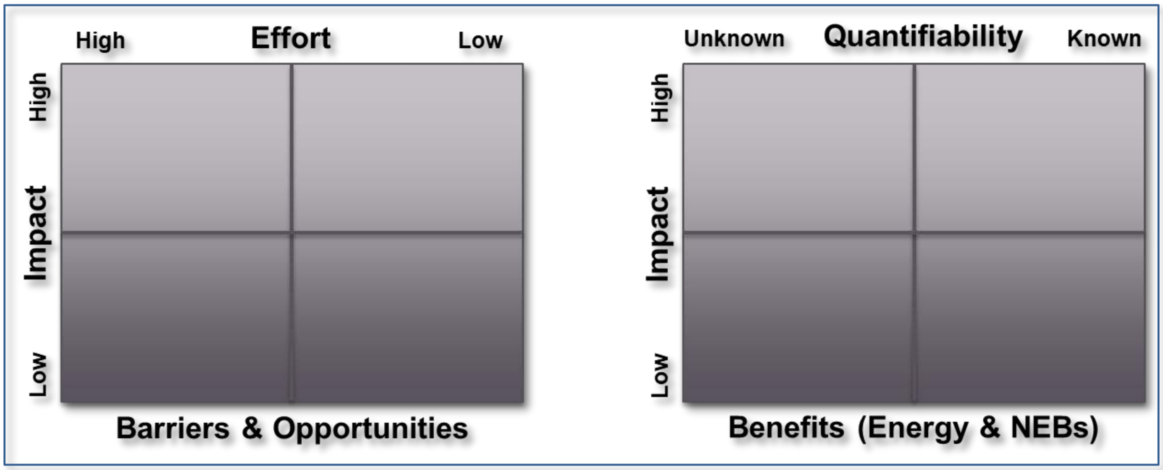
Source: Lawrence Berkeley National Laboratory

This broad literature review confirms that while NEBs are cited as appealing features that can result from NLCs, at this stage in their product maturity most of these NEBs are still discussed qualitatively, not quantitatively. This is largely because energy and maintenance savings metrics and values are widely accepted and understood, while the emerging value propositions, when mentioned, often lack metrics to easily communicate value to building owners and facility managers. In addition, the case studies cite different NEBs across use cases, which suggest that a specific NEB can have various levels of impact depending on building types and business functions. For example, space optimization might have a widely different impact improving stocking patterns in a warehouse than improving how hospitals track equipment. There are many potential non-energy benefits from NLCs, and their diverse values and use cases require further stratification and prioritization to identify the most promising value propositions, as well as which NEBs have the greatest potential to support DR adoption.

Non-Energy Benefits Stratification and Prioritization

To explore the potential of how specific NEBs could support DR-enablement, the team performed two exercises to stratify and prioritize NEB quantification. The goal of this exercise was to prioritize NEBs, barriers, and opportunities with the highest level of impact and potential to influence lighting DR adoption compared to the relative effort necessary to overcome its barriers. Eight project team members with diverse expertise in lighting control systems and demand response identified NEBs and their associated barriers and opportunities, based on the viewpoints of wide range of NLC stakeholders, including manufacturer, building owner/operator, building tenant/user, utility/regulator, and verifiers. Each NEB and the corresponding barriers and opportunities were categorized in a matrix based on relative impact and the effort or degree of quantifiability. The two matrices are shown in Figure 29 below, which display the quadrants used in the quantification prioritization.

Figure 29: NEBs, Barriers, and Opportunities Stratification and Prioritization Exercise Graphs



Source: Lawrence Berkeley National Laboratory

Non-Energy Benefits Identification

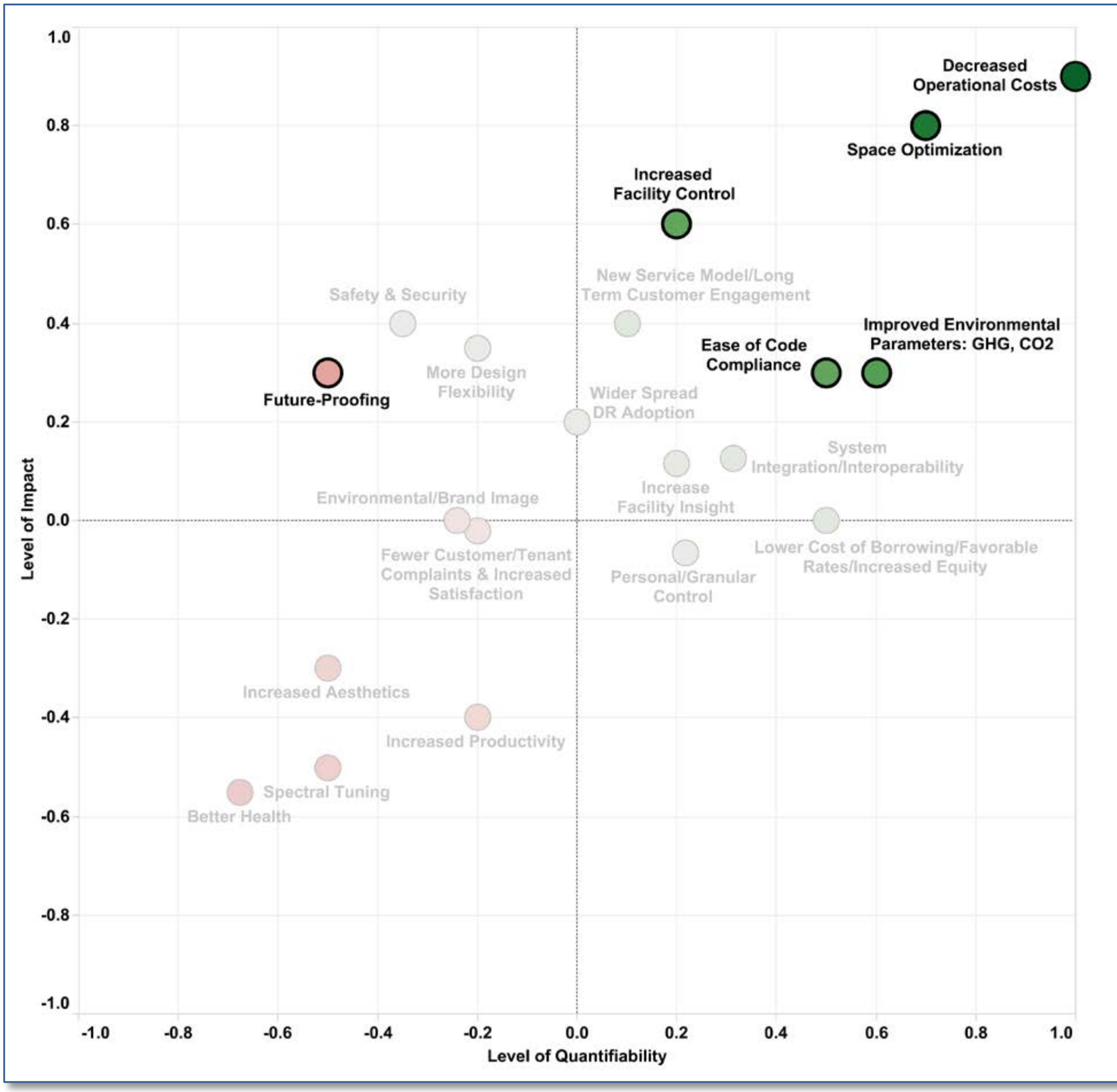
In the first exercise, the team identified NEBs by their perceived level of impact on lighting DR adoption against their level of quantifiability. The goal of this exercise was to identify specific NEBs that can have a greater impact on lighting DR adoption would allow us to prioritize our quantification efforts to the most impactful NEBs.

Building on the NEBs identified in our initial literature review, the team identified 20 possible NEBs and ranked them in the four-quadrant matrix to characterize their potential impact on DR adoption and ease of quantification. In Figure 30, the vertical axis represents a NEB's expected impact on DR adoption, and the horizontal axis qualifies the efforts required to quantify the NEB. Of the 20 NEBs, the team identified the top five that had both the greatest potential impact on DR adoption and ease of quantification. These included the following:

1. Decreased operating and maintenance (O&M) cost
2. Space optimization
3. Increased facility control
4. Improved environmental parameters, such as reduced greenhouse gas emissions
5. Ease of code compliance

While not one of the top five NEBs, the team included "future proofing" due to its potentially high impact on lighting DR adoption, despite the fact that it was difficult to quantify.

Figure 30: NEBs' Impact on Lighting DR Adoption versus Ease of Quantification, with Prioritized NEBs Highlighted



NEBs are highly specific to industries, and so "space optimization" may have a very different meanings in commercial office compared to a warehouse. Thus, the NEBs included are intentionally high-level, so as to capture this variation under a single term. Future work can assess the specific value of each NEB across industries.

Source: Lawrence Berkeley National Laboratory

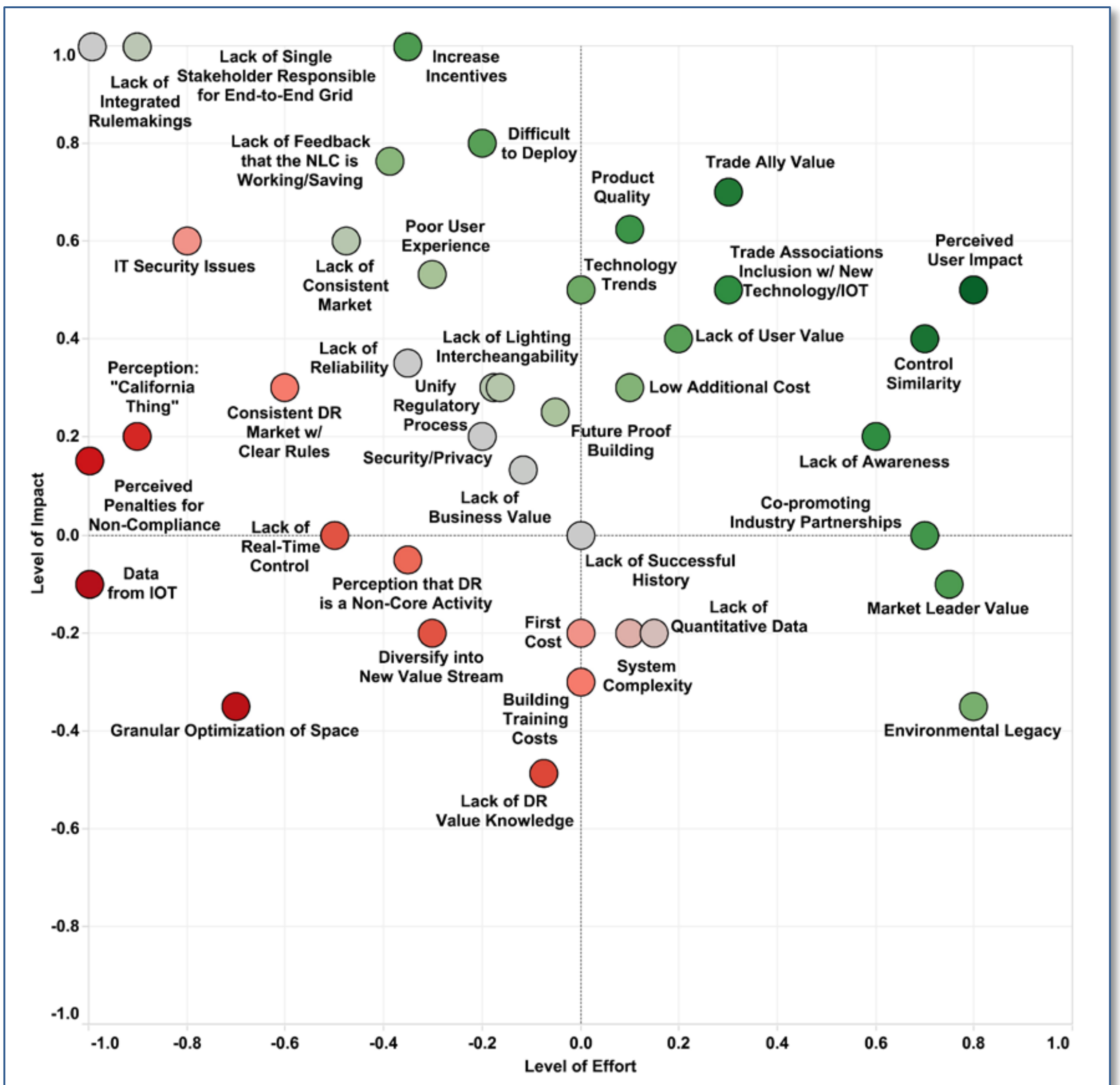
Identification of Barriers and Opportunities for Demand Response-enablement

The project team completed a second exercise to identify barriers and opportunities for lighting DR adoption. This provides the basis for leveraging NEBs to transform the market by addressing the barriers and opportunities identified that have the highest impact on lighting DR adoption.

Based on an extensive literature review and outreach, the team identified and ranked 40 distinct barriers and opportunities (Figure 31) based on their potential impact on DR adoption if addressed (y-axis) and the level of effort required to address them (x-axis). These perceived value and user impact of DR lighting can be broken down primarily into the following three categories:

1. Perceived impact of DR on light quality
2. Technology maturity, such as interoperability capabilities and the ability to verify energy savings
3. Market readiness/maturity, such as improving trade association collaboration and installer training

Figure 31: Demand Response Adoption Impacts and Effort Required to Address Various Market Barriers and Opportunities



Source: Lawrence Berkeley National Laboratory

These three groups represent barriers and opportunities that are addressable by the prioritized NEBs and are based on the technology required to enable the NEBs. A detailed explanation of how the NEBs can address these barriers and support adoption is addressed in the logic model in Chapter 5.

Barriers and opportunities in the upper right quadrant in Figure 31 have the highest impact on lighting DR adoption, with the lowest effort required to address them.

Non-Energy Benefits Quantification and Consolidation

While the "3-30-300" rule of thumb helps characterize organizational costs (in $/ft^2) and target savings opportunities, the real-world value of NEBs depends on the actual cost savings they deliver. The team developed the benefits value intensity (BVI) framework to capture and organize the prioritized NEBs and to streamline their quantification effort. This new framework allows us to compare the four BVI levels of energy, rent, employees and revenue to determine how the actual values vary depending on the building, business types and use cases. Following the "3-30-300-3000" rule of thumb, the BVI framework is comprised of four categories: energy, building, people and revenue as shown in Table 24 and Figure 32 below.

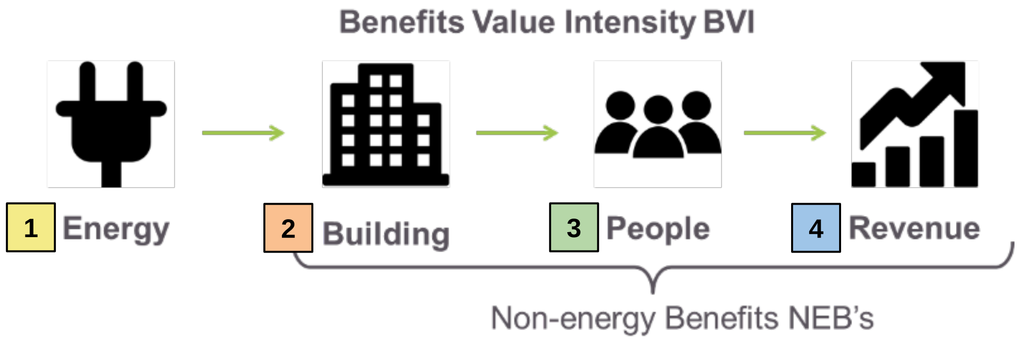
Table 24: Benefits Value Intensity Category Summary

BVI Level	Organization Category	Definition	Example
1	**Energy (Ave. cost = $3/ft^2)**	The lowest BVI category. Describes the energy benefits that may accompany a NEB.	Reduced energy consumption achieved by reducing unused space
2	**Building (Ave. cost = $30/ft^2)**	Generalized "costs of rent" to capture all values a NEB can create on a building's operation	Avoided costs by not adding new space since current space is more efficiently used
3	**People (Ave. cost = $300/ft^2)**	Captures a NEB's impact on people or activities they perform in a building	Employees can find spaces to work and conduct meetings. More efficient use of their time increases satisfaction with their space.
4	**Revenue (Ave. = $3,000/ft^{2*})**	The highest BVI category. Capturing additional revenue generated from business activities performed in the building as a result of a NEB.	Increased revenue generated by additional employees added to use the same workspace; increased revenue from using retail wayfinding to increase customer sales

*** Revenue represents a very rough estimate, since this metric requires significant exploration.**

Source: Lawrence Berkeley Laboratory

Figure 32: Benefits Value Intensity Framework



The key BVI framework concept is that the more value a NEB can add to the upper-level BVI categories, the higher and closer the impact is to the building owner's core business and thus, the more likely that an organization will consider it when considering NLCs.

Source: Lawrence Berkeley Laboratory

A single NEB may have multiple value types: for example, space optimization in a retail store may both improve retail workers' stocking efficiency while also increasing sales revenue. The key BVI framework concept is that the more value a NEB can add to the upper-levels 2 – 4 (i.e., 30:300:3000) BVI categories, the higher and closer the impact is to the building owners' core business and thus, the more likely that an organization will consider it.

In performing Non-Energy Benefits Identification, the team identified and distilled 35 distinct NLC use cases that could be quantified across the office, retail, and warehouse building types (Table 25).[20] These quantified values were focused primarily in the office sector at the lower BVI levels, with the biggest focus on decreased O&M costs. Reduced energy usage through decreased O&M costs is the most common qualitative talking point across manufacturer literature, and explains why, among all NEBs, these values are most frequently quantified. The higher BVI values have the highest potential impact magnitude but are more difficult to define and delineate quantitatively. Identifying the specific BVI, building type, and NEB intersections that lack quantification may encourage subsequent research to quantitatively define these intersection points.

[20] To determine specific use cases and relevant narratives, the team subsequently performed a targeted literature review and manufacture outreach. The team contacted and reviewed literature from all NLC manufacturers and contractors it could identify, and reviewed relevant publications from the academic research community. In addition, the team discussed narratives with a technical advisory committee to verify their relevance and applicability. Additional use cases and building types were synthesized, and those are detailed in the companion Excel spreadsheet detailing use cases and quantified values by building type. Forty-five use cases were identified across office, retail, and warehouse building types but 10 required more context, such as detailed building or baseline energy usage information, to effectively quantify.

Table 25: Non-energy Benefits Quantified Value Distribution

	Office				Retail				Warehouse			
BVI Level	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
NEB	**Energy**	**Building**	**People**	**Revenue**	**Energy**	**Building**	**People**	**Revenue**	**Energy**	**Building**	**People**	**Revenue**
Decreased O&M Costs	11	3			2	1			2	1		
Space Optimization	1	1	1	0	0	0	0	2	0	0	0	0
Increased Facility Control	1	2	0	1	0	0	1	1	0	0	0	0
Improved Environmental Parameters	0	0	1		2	0	0		0	0	0	
Ease of Code Compliance	1	0			0	0			0	0		
Future Proofing	0	0	0	0	0	0	0	0	0	0	0	0

Source: Lawrence Berkeley Laboratory

Results

Detailed results for all building types, BVI levels, and NEBs can be found in the accompanying NEB quantification MS Excel spreadsheet in the Non-Energy Benefit Quantification Case Study References, focusing on the primary building types of office, retail and warehouse displayed in Appendix B.

For offices (Table 26), the Level 1 BVI was $0.26/ft^2 savings, while Level 2 BVI increased by $5.61/ft^2.

Table 26: Energy and Building Benefits Value Intensity Categories for the "Decreased Operation and Maintenance Costs" Non-energy Benefit in Offices

Energy				Building	
Median* (kWh/ft^2/year)	**Range** (kWh/ft^2/year)	**Median*** ** ($/ft^2)	**Range**** ($/ft^2)	**Median*** ($/ft^2)	**Range** ($/ft^2)
1.49	0.13–14.84	0.26	0.02–2.63	5.61	0.54–8.87

***Due to the limited number of the quantified data set and its widespread nature, the median would be more representative than the average, which is prone to be skewed by extreme values.**

**** According to the U.S. Energy Information Administration, California commercial buildings in August 2017 had an electricity rate of $0.1773/kWh.**

Source: Lawrence Berkeley Laboratory

However, individual case impacts can range greatly. In some cases, the energy level BVI could be greater than the Level 2 BVI. It is important to note that the data cited in this study were primarily derived from manufacturer case studies, which are likely to highlight the most successful instances of leveraging NLC NEBs. Thus, the ranges should not be interpreted as definite bounds, but as what is possible. These values and ranges will gain more certainty as NLCs' capabilities and case studies are increasingly quantified.

It is important to note that the average NEB $/ft²/year savings at Level 1 BVI is comparable to the overall Level 2 energy savings realized in Table 27. This suggests that, in some cases, enabling NLCs to decrease operations and maintenance costs could achieve equivalent dollar value benefits as operating the NLC system in a purely lighting operations capacity.

To look at the "people" BVI Level 3, the team examined quantification findings for space optimization. This was based on a single case study in which NLCs were used to identify commercial office usage and how to most effectively optimize existing office space. Using the NLC system, the organization leveraged occupancy data to identify that new employees could be added without the need to increase office size: 1,000 new employees were added, reducing per employee space from 12.6m² to 7.6m² per person, while still maintaining an effective work environment. In this case, the relative value for people (Level 3) was 167 times the value of energy savings (Level 1), and the avoided facility cost (the building BVI Level 2) was 67 times the value of energy (Table 27 below).

Table 27: Office Space Optimization Non-energy Benefits Quantified Results Summary

BVI	Energy	Building	People
Use Case Narrative	Reduced energy consumption and equivalent dollar value by reducing unused space	Avoided costs by not adding new space through more efficient current space use	Lowered overhead costs on employee-specific supplies, equipment and spaces
Savings ($/ft²)	0.16	10.54	26.4
Benefit Multiplier (normalized to energy)	1	67	167

Source: Lawrence Berkeley Laboratory

While there are limited data to date on the value of NEBs and the value must be further studied before drawing definitive conclusions across building types or between NEBs, the existing data strongly suggests that the value from NEBs is in many cases equal to or greater than cost savings derived from energy savings alone. An important caveat is that while NLC systems certainly have the potential to yield cost savings beyond energy, it is uncertain what fraction of building owners or facility managers actually use the systems to their full potential to capture this value. However, the team expects that NLC analytics usage will become increasingly common as organizations adopt data-driven approaches to organizational decision-making. Over time, more examples will improve confidence in these estimates as the number of quantified use cases continues to grow. Thus, continued documentation should be a priority for both utilities and the NLC industry.

CHAPTER 5: Adoption of Non-Energy Benefits and Demand Response-Enablement

Demand Response Adoption Framework Summary

This chapter discusses how NEB adoption can lead to DR-enablement and use (and what needs to occur for this to happen). While there is significant value from widespread adoption of NLCs to both customers and utilities, the technology still faces significant adoption barriers, particularly with regard to enabling its DR capability. To address this, the project team developed a market transformation theory approach to identify the necessary outcomes leading to successful adoption, as well as a logic model highlighting specific intervention strategies, activities, and outputs necessary to achieve these outcomes. Key initial intervention strategies include the following:

- Research and normalize NEB narratives and metrics to standardize their quantification.
- Define DR strategy best practice, demonstrate, and publish results proving that lighting DR implementation does not adversely impact performance.
- Develop capability performance specifications for inclusion in programs and by specifiers.
- Develop configuration templates and commissioning guides.
- Bundled program design linking energy efficiency + DR + NEBs + persistence.

Demand Response Adoption Framework Overview

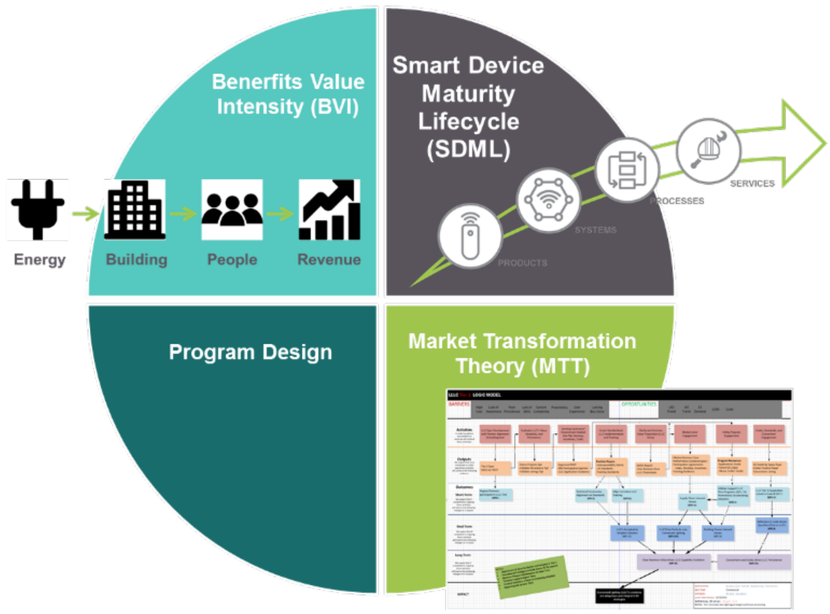
Networked lighting controls systems hold the promise of unlocking significant new value by capturing detailed environmental and device level sensory information. They can also implement control strategies to reduce energy consumption and manage building lighting load without affecting lighting characteristics, such as dim level or color, so precisely that user comfort is not affected. However, NLCs still face adoption barriers, particularly for enabling features such as demand response. This section identifies a framework by which NEBs can be leveraged to enable and support market adoption of energy benefits such as demand response.

This DR Adoption Framework is used to clarify which cost-effective intervention strategies will increase DR adoption (enablement and use). As shown in Figure 33, the framework leverages four components:

1. Benefits value intensity, which identifies and values non-energy benefits by building and space type.
2. Smart device maturity cycle (SDML), which explores how system capabilities support identified NEBs while also supporting required DR functionality and use.

3. Logic model and market transformation theory, to clarify and scope needed market intervention strategies including various activities, outputs, and outcomes to remove specific barriers or leverage opportunities.
4. Program design, which evaluates all three elements above to select the most impactful program type to support market transformation.

Figure 33: Snapshot of the Smart Devices Maturity Lifecycle



Source: Lawrence Berkeley Laboratory

Benefits Value Intensity

As described in Chapter 4, the BVI model helps categorize the magnitude of impact that a NEB could have on the business' energy costs, building costs, employee productivity, or company revenue, typically in terms of a financial value such as dollars per square foot where such quantification is possible. Actual documented values are highly specific to organizations and industries: for example, "increased facility control" by monitoring and optimizing humidity levels in a manufacturing facility may increase revenue by reducing the number of defective products. A warehouse may increase facility control by using occupancy-sensing heatmaps to optimize stocking practices and boost employee productivity. In both cases, the BVI framework helps categorize and define value for NEBs that are typically concurrent with DR-enablement.

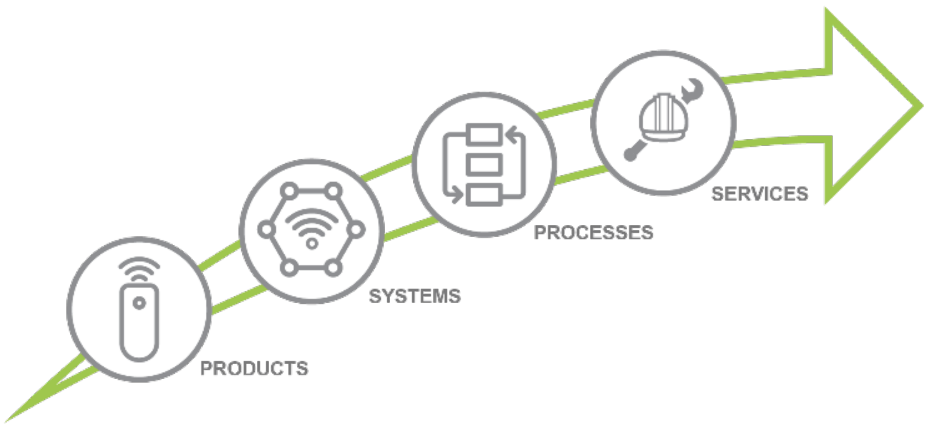
The Smart Devices Maturity Lifecycle

While the BVI focuses on defining business value from NLC capabilities, NLC technology and the capabilities themselves are evolving over time to create new and emerging business value.[21] Smart devices typically follow a maturity cycle as they evolve and become increasingly

[21] An example is how the insurance industry might leverage NLC data to make inferences about building spaces and offer discounted premiums to incent specific behaviors and/or maintenance requirements. While there are not yet case studies on this capability, there are active discussions about this opportunity and its potential.

connected and intelligent, and the SDML focuses on this evolution to anticipate future capabilities that may unlock additional value. The SDML identifies four maturity levels: (1) products, (2) systems, (3) processes, and (4) services. These maturity levels are based on historic observations in the information technology industry to identify and anticipate how product and system capabilities evolve as devices become more intelligent and connected. Figure 34 shows the SDML's progression of technology evolution and as capabilities mature, the opportunities grow to optimize business processes, create new services, and unlock new business value for building owner/operators and utilities.

Figure 34: Smart Device Maturity Lifecycle



Source: Lawrence Berkeley Laboratory

In the initial "Products" stage, technology companies primarily focus on the device itself and how its core "feature set" can be a differentiating factor. An example of this for NLCs may be continuous dimming or control strategy capabilities, which can drive both energy and NEBs.

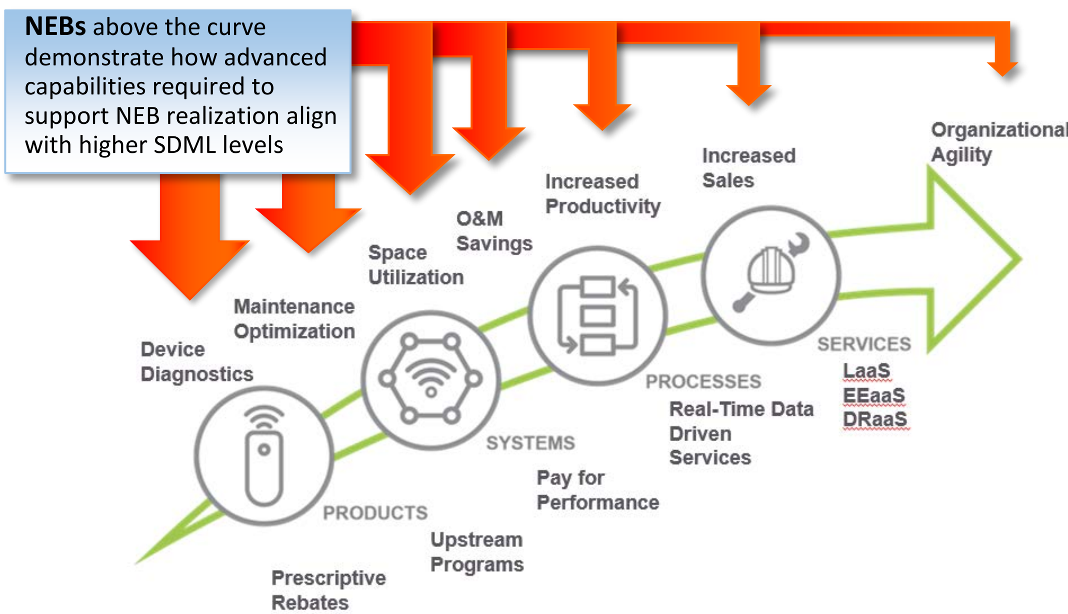
As the technology matures, it enters the "Systems" stage, which focuses on how the product can function within the broader building ecosystem and on how groupings of devices can communicate with each other to create more value and efficiency across an entire building system. For example, for NLCs this may involve integration with the HVAC or security systems. This type of networking capability is mandatory for DR implementation, as well as many NEBs, such as maintenance optimization. Value at this stage requires breaking silos, integrating with other enterprise systems, and reengineering business processes.

In the "Processes" stage, information from the device is integrated (through the interoperability capability) and changes businesses processes. For example, commercial building space use may leverage edge sensors to communicate occupancy status to a building management system, which then pushes that information into a space-scheduling solution (for example, a Microsoft Exchange server). This full business integration is a significant evolution beyond an NLC identifying if a space is occupied to simply save energy.

Smart devices achieve the "Services" stage when near real-time data are collected and, through standardization and integration, are processed effectively across enterprise systems to create entirely new services. At this level of maturity, organizations have the opportunity to outsource services, with defined service-level agreements (SLAs), and suppliers can begin offering innovative new energy services. For example, a service contracts company can leverage the information coming from a building's NLC system to provide preventative maintenance so that lighting is optimized and replacements are located and replaced prior to needing them.

Utilities have traditionally spent much of their time and incentive programs on the Products stage, focusing on the installation of more efficient products to capture energy savings. Figure 35 shows how utility programs can align and evolve with the SDML approach to capture increasingly high-value stages of the device lifecycle as connected devices become more prevalent. For example, as the real-time flow to data is available (the Processes level), utilities can choose to leverage the data for confirmation of system persistence and DR usage.

Figure 35: Smart Device Maturity Lifecycle with Utility Programs and Non-energy Benefits Alignment



LaaS = Lighting as a Service; EEaaS = Energy Efficiency as a Service; DRaaS = Demand Response as a Service

Source: Lawrence Berkeley Laboratory

In Figure 35, representative NEBs are located above the curve to demonstrate how advanced capabilities that are required to support NEB realization align with higher SDML levels. To achieve the goal of scaled DR adoption, utilities can assess which NLC capabilities[22] are required for DR-enablement and how those capabilities support NEBs that have significant customer value. Common capabilities that support energy benefits are continuous dimming, occupancy sensing, daylight sensing, networking, energy monitoring, scene strategies,[23] and a graphical

[22] For a list of capabilities that meet DLC's NLC product qualification requirements, see https://www.designlights.org/lighting-controls/qualify-a-system/technical-requirements/ (site accessed 2/1/19) and https://www.designlights.org/lighting-controls/download-the-qpl/(site accessed 2/1/19).

[23] Scene strategies ensure that control is executed in a way to ensure that a specific action occurs (that is, that DR, dimming, occupancy, etc. occurs without affecting occupant satisfaction).

user interface (GUI) to roll up energy information into a usable reporting format. The ability to create lighting scenes (a grouping of actions that leverage system capabilities for an intended result) is critical to fully realizing NLCs' benefits to create energy and non-energy benefits.

Non-Energy Benefits Capability Formulas

Benefits capability formulas are a useful way to understand what capability combinations make up different benefits (energy and non-energy). By comparing one set of capabilities (that is, demand response) to another set (that is, space optimization) one can begin to identify important capabilities that may be missing. If the benefits capability formula exposes the required capabilities to fulfill one or more desired NEBs, and additionally the required capabilities to implement DR, then any lacking capability(ies) can be addressed (via intervention strategies and program design) to influence its inclusion in the system design, commissioning, training, etc.

For example, the capabilities combination set identified below—which is required to support a facility's interest in increased facility control, streamlined code compliance, and improved facility insight—shares many capabilities with ADR-enablement. The only major additional item is the ability to receive an OpenADR 2.0 signal. This creates an opportunity where utilities can provide incentives for NLCs provided they participate in DR programs and achieve HVAC integration. This creates a win-win situation in which the customer receives NLCs for a reduced cost while utilities ensure that the building integrates DR capability and leverages both lighting and larger HVAC loads for demand management.

Example of Non-Energy Benefits Capability Formulas

- Increased Facility Control = Networking + Dimming + Occupancy + Scene Strategies + GUI
- Ease of Code Compliance = Networking + Energy Monitoring + GUI
- Improved Facility Use Insight = Networking + GUI + Energy Monitoring

Example Energy Benefits Capability Formulas

- Lighting DR = Networking + Dimming + Occupancy + Scene Strategies + OpenADR2.0
- Lighting DR-V (verified) = DR capabilities (above) + Energy Monitoring

Market Transformation Theory and Logic Model for Demand Response Adoption

Introduction to Market Transformation Theory and logic models

Market transformation theory (MTT) is the process of developing a course of action(s), supported by a set of intervention strategies which influence market actor behaviors, including their processes, products, and services, by overcoming barriers and leveraging opportunities to move the market to a "new normal" or new level of standard practice. Taking a market transformation approach is useful in influencing networked lighting controls DR adoption because it crystalizes a vision, or future market state, that guides actions outside of existing programs and paradigms. This approach is particularly valuable for DR-enabled lighting because existing participation of lighting in DR programs is low and not expected to change dramatically in the near future without intervention.

A logic model supports MTT by providing the pathway to accomplish that market transformation goal. It includes detailed barrier and opportunity identification, intervention strategies to address them, and expected outcome descriptions with metrics to measure the transformation's success. Intervention strategies within a logic model concept are used in coordination to influence the market. Strategies to address lack of value, perceived user impact, lack of standardization, lack of best practices/commissioning, and lack of integrated program support are defined. Logic models are useful in complex markets when multiple barriers, opportunities, activities, and outcomes must be understood and addressed to successfully intervene in the market. Many times, intervention strategies (activity threads) are synchronized to maximize market impact, and the model provides a formalized way to capture the market transformation approach in one document. A logic model assumes that there is a limited set of intervention strategies, which if applied correctly in the marketplace, will remove barriers and influence the accelerated adoption of the intended result.

Market Transformation in the Context of Demand Response Enablement of Networked Lighting Controls

The market transformation theory for DR-enabled NLCs reflects that consumer interest in NEBs can be used to support capabilities like DR-enablement that are beneficial to the grid but may have limited interest from customers. Utility program support and incentives for DR-enablement in NLC provides a win-win, allowing customers to adopt innovative new NLC systems (to obtain the NEBs) and utilities to have a persistent measurable supply of energy resources (energy efficiency and DR). Additionally, this approach can influence actions which begins to prepare the building stock for more advanced energy benefits such as Fast-DR, which NLC controlled solid-state lighting (SSL) is ideally suited for. The MTT statement for the DR-enablement of NLCs is as follows:

- "By clearly communicating the value proposition for each instrumental stakeholder and demonstrating the appropriate risk/reward, demand response adoption and use will be sought to co-fund initial NLC system costs and pave the way to significant non-energy benefits."

The MTT statement leverages perception of value, the need to quantify value, the need to identify implicated stakeholders, the need to resolve perceived or real barriers to adoption, the connection between value of NEBs and value of energy, and the conclusion of a behavioral change. In this context, each phrase within the statement has specific elements or goals:

- "Clear communication of value" includes defining and quantifying the value (through efforts such as the BVI) in clear terms, such as "dollars saved per square foot" through efforts such as the BVI, so that market actors (see Table 28) understand the NLC proposition in the context of their own business model lists "Instrumental stakeholders" included in the process of NEB/Energy benefits realization (NEB-specific).

Table 28: Networked Lighting Controls Benefits from the Perspective of All Project Stakeholders

Stakeholder	Description	NLC Benefits
Building Owners	Financial owners of the building	Increased revenue, savings, future proofing their lighting investments
Property/Facility Managers	Hired to manage the building and/or run its operations	Increased facility control, savings, revenue
Occupants	Inhabit the space	Increased productivity, satisfaction
Trade Allies (TAs)	Installer, Maintainer	Increased revenue, customer satisfaction
Specifiers	Stipulate system requirements	Increased customer satisfaction, reputation
Manufacturers	Design/Build the solution	Increased revenue, product performance persistence
Utilities	Local electric utility	Increased savings, customer satisfaction, control, future energy benefits (Fast-DR)

Source: Lawrence Berkeley Laboratory

- "Demonstrating appropriate risk/reward" refers to assessing possible impacts to each stakeholder (through demonstrations, surveys, etc.), and capturing the full list of rewards (or value) they may receive from the solution. In addition, this element must address perceived adverse impacts such as DR events that affect lighting quality.
- "Adoption and use" refers to configuring the DR capability included in most current NLC systems on the market, installing any remaining hardware/software, commissioning the proper application, receiving commitments to ongoing use through DR program enrollment, and verifying use.
- "Sought to co-fund" implies the knowledge and desire of the building owner or operator to seek the value proposition of NLCs and include utility incentives, in a bundled energy efficiency/DR package, leveraging "clear communication of value" to finance initial system costs to an acceptable level.
- "Initial system costs" include the full system implementation costs to provide all capabilities required to produce the targeted NEB(s) and the DR functionality.
- "Pave the way to significant non-energy benefits" refers to the higher levels of the BVI, including buildings, people, and revenue value generation. Quantification, to a "significant" level, is from the perspective of the targeted stakeholder.

Demand Response Enablement Logic Model

The project team developed a logic model to organize the themes of the MTT into a limited number of activities and intervention strategies required to increase adoption and use of the NLC DR functionality. Some elements of the logic model are use case and building type specific, however, and some intervention strategies may not be applicable to all market sectors. At the highest level, the logic model consolidates barriers and opportunities, activities, and outputs (deliverables) for how DR adoption can be increased into four distinct categories:

- Value and impact of energy and non-energy benefits
- Technology maturity and identification of synergistic DR and NEB capabilities
- Market readiness, including identifying barriers and opportunities
- Business model of how DR-enablement and NEBs value drive market adoption

The DR Adoption Framework Logic Model (Table 29) identifies five intervention strategy threads that can be used to remove barriers or leverage opportunities to accelerate DR-enablement and use.[24]

Table 29: Barriers and Opportunities Selected for Strategies

Barrier / Opportunity	Description	Intervention Strategy	Intended Outcome
Lack of User Value	Unclear or missing quantified value proposition for the building owner, operator, or occupant	Research and normalize NEB narratives and metrics to standardize their quantification	Utilities and specifiers reference NEB dictionary
Perceived Impact (User, Trade Ally)	Concerns that the NLC DR-enabled strategy may affect user satisfaction and therefore trade ally profitability from callbacks	Define DR strategy best practice, demonstrate, and publish results proving that lighting DR implementation does not adversely affect performance	Case studies used to address concerns in alignment with NEBs
Lack of Standardization	Manufacturers of NLCs develop proprietary capabilities, limiting consistency of NEB value	Develop capability performance specifications for inclusion in programs and by specifiers	DR capabilities specification used by manufacturers to fulfill program requirements
Lack of Best Practices and Commissioning	Difficulty implementing the DR strategy in NLCs is a deterrent to trade allies	Develop configuration template and commission guides	Utilities and specifiers use guides to support DR use and persistence
Lack of Integrated Program Support	The perceived value of DR potential from lighting is small and is not persuasive	Bundled program design linking EE + DR + NEBs + persistence	TA's and users leverage to cover significant first costs

Source: Lawrence Berkeley Laboratory

The DR adoption logic model (LM) in shows several strategies that are staged in a way to increase the model's effectiveness. They should be reviewed in context and program activities should be aligned to support their success. There are several important connection points in the logic model:

[24] Note that several important barriers pertaining to non-NEB topics are not within the scope of this project and do not have associated intervention strategies.

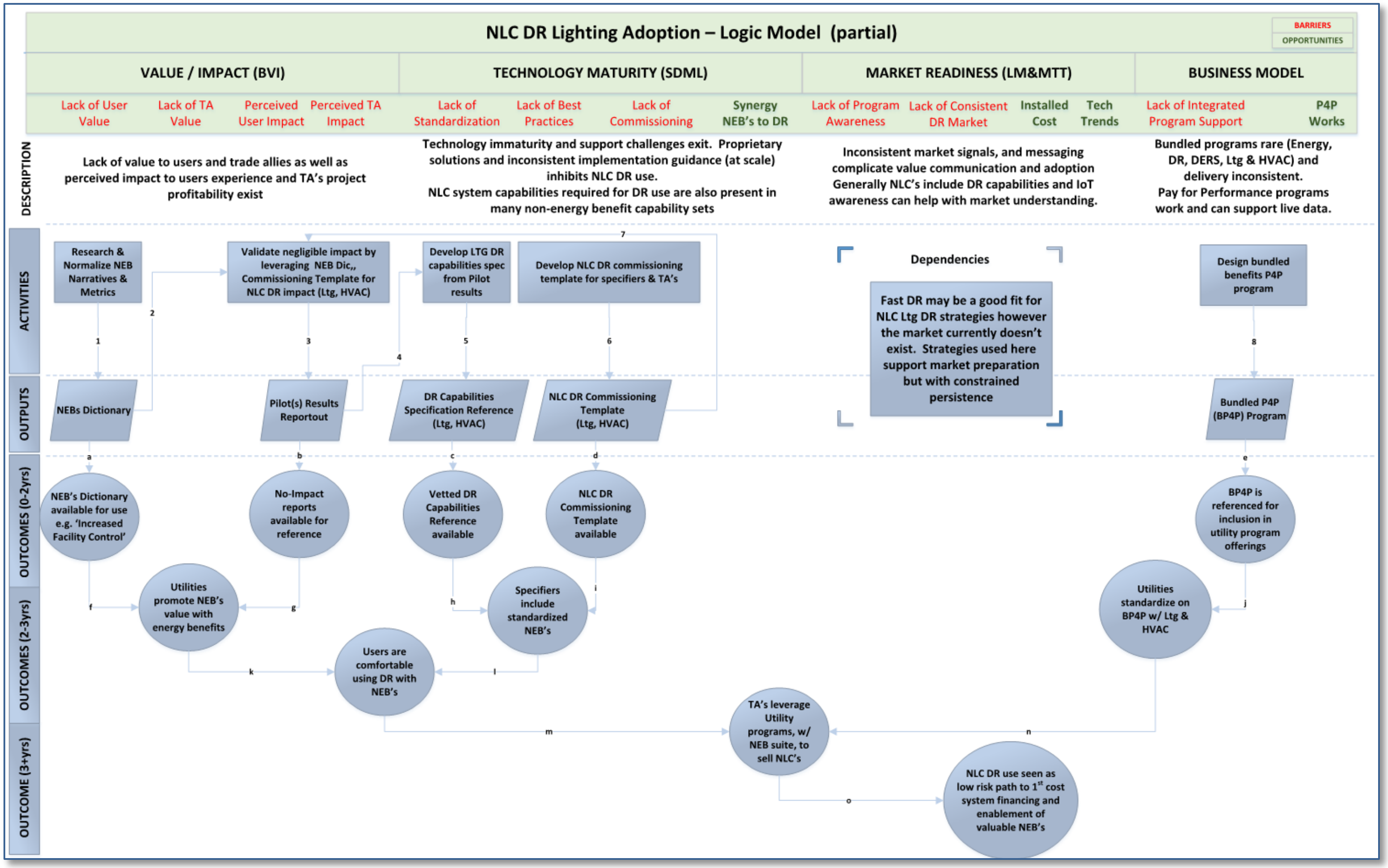
- Creation of a NEB dictionary to normalize use case narratives and metrics that feed pilot design promoting levelized results.
- A unifying commissioning template is integrated into the pilot design, promoting levelized results.
- Levelized pilot results feed the development of standardized capability specifications, leading to more uniform solution feature sets
- Bundled pay-for-performance (P4P) programs, focused on integrated lighting and HVAC energy benefits that reduces installation costs, enabling higher-level non-energy benefits.
- Best practices, user comfort, standardized capabilities and commissioning, and promoted bundled P4P programs influence the market to broad acceptance of NLC-enabled DR. Persistent DR use in NLCs may require a DR marketplace to be created that provides remuneration for desired behavior.

Intended outcomes from the targeted intervention strategies are publicly available work products that support product development, specification, system design, project implementation and commissioning, performance measurement, and utility program support. Other outcomes include the routine use of these work products, by utilities, specifiers, users, manufacturers, and trade allies to fulfill corporate goals and program requirements.

Individual intervention strategies may address multiple market barriers. As an example, the NEB "increased facility control" can enable energy efficient benefits as well as non-energy benefits, supported by its NLC system. If an intervention strategy is designed to increase interoperability (the Technology Maturity category) for an existing HVAC system, the results also could be leveraged in another strategy (for example, to quantify savings - Value/Impact). Such is the case in this logic model, where certain strategies create results that support other strategies. This approach can build upon successes in early threads and amplify results in later threads.

Expected results of implementing the DR Adoption Framework's logic model include intervention strategies likely to influence: increased use of networked lighting control DR in the short term (2–3 years), important industry collaboration opportunities driven by utility efforts supporting greater energy value, and a long-term (3-plus years) path to market transformation where DR-enablement and use are considered important financial and operational options to fulfill corporate goals.

Figure 36: Demand Response Adoption Framework Logic Model



Source: Lawrence Berkeley Laboratory

While the logic model helps to consolidate and align many intervention strategies needed to remove barriers and leverage opportunities to accelerate DR use in networked lighting controls, the process itself has constraints.

- The logic model process starts with the “ideal” end in mind. This is the desired outcome, years in the future, with all intervention strategies being successfully implemented. Many circumstances may prevent an ideal realization of the vision; however, intervention strategies will influence the market directionally.
- The structured process to consider market barriers and opportunities individually, then within the context of alignment to efficiently deploy resources, provides comprehensive insights that are leveraged (later) in the market transformation theory. Barriers may be existing (known) or anticipated, and limited market tests are necessary to refine activity and output designs.
- Working backward from the long-term outcome (final desired state) to create logical mid- and short-term outcomes helps stakeholders to understand the progression and breadth of change needed to support the transformation. This may dictate that a combination or even revisions to activities are required to continue to realize the outcomes envisioned.
- Finally, the choices around scoping and prioritizing activities and how to influence market changes through “leveraged” activities (those activities controlled by external groups, but triggered through LM activities) are critical to transformation success. Again, limited approach testing is required.

It is clear, through the creation of this LM, that customers who see value in general benefits of NLCs will consider energy as part of those benefits. They may also be apprehensive of externally controlled strategies (such as lighting DR) until proven otherwise, and skeptical of non-energy benefits due to lack of standardization and quantification.

Applications of the Market Transformation Theory and Logic Model to Influence Program Design

The MTT and LM are used in conjunction with the other DR Adoption Framework components, to provide a full view of the vision (outcomes), benefits, activities, influence points, technical synergies, and timeliness of details leading to appropriate program design. The following steps may be used to guide program design development:

- Identify the use cases and building types most relevant for the program.
- Create a vision for what the transformed market would look like for utilities and customers.
- Identify what benefits (energy and non-energy) would be valuable to customers and the host utility.
- Quantify benefits for all stakeholders included in the adoption process.
- Perform a gap analysis of system capabilities required for each targeted NEB and energy benefit.

- Create costs/risks/benefits for each stakeholder.
- Identify marketplace barriers and opportunities that would prevent adoption.
- Create, value, and test intervention strategies.
- Refine MTT and LM with the minimal set of required intervention strategies.
- Identify model externalities and resolve them.
- Value market potential for energy benefits.
- Support cost effectiveness calculations.
- Acquire program design approval, funding and internal and external champions.

These are the high-level steps to use when leveraging the NLC DR Adoption Framework, in support of creating a transformational program design. Many incremental steps (subtasks) may be required, based on specific organizational processes of the implementer(s). To achieve success, market transformation theory also requires a long-term view and commitment (funding, resources, priority) to support all activities.

Market Transformation Theory and Logic Model Summary

Based on the LM, the project team identified five key activities (outlined in Table 1 above) that can substantially facilitate and support DR enablement and use in buildings with NLCs:

- Research and normalize NEB narratives and metrics to standardize their quantification.
- Define DR strategy best practices, and demonstrate and publish results proving that DR lighting implementation does not adversely impact performance.
- Develop DR lighting functionality performance specifications for inclusion in IOU energy efficiency/DR programs and for use by specifiers designing new or retrofit projects.
- Develop a configuration template (that is, a pattern guide) and commissioning guides mainly for design-build projects that typically lack specialized contractors and specifiers.
- Bundle program design linking energy efficiency, DR, NEBs, and persistence benefits.

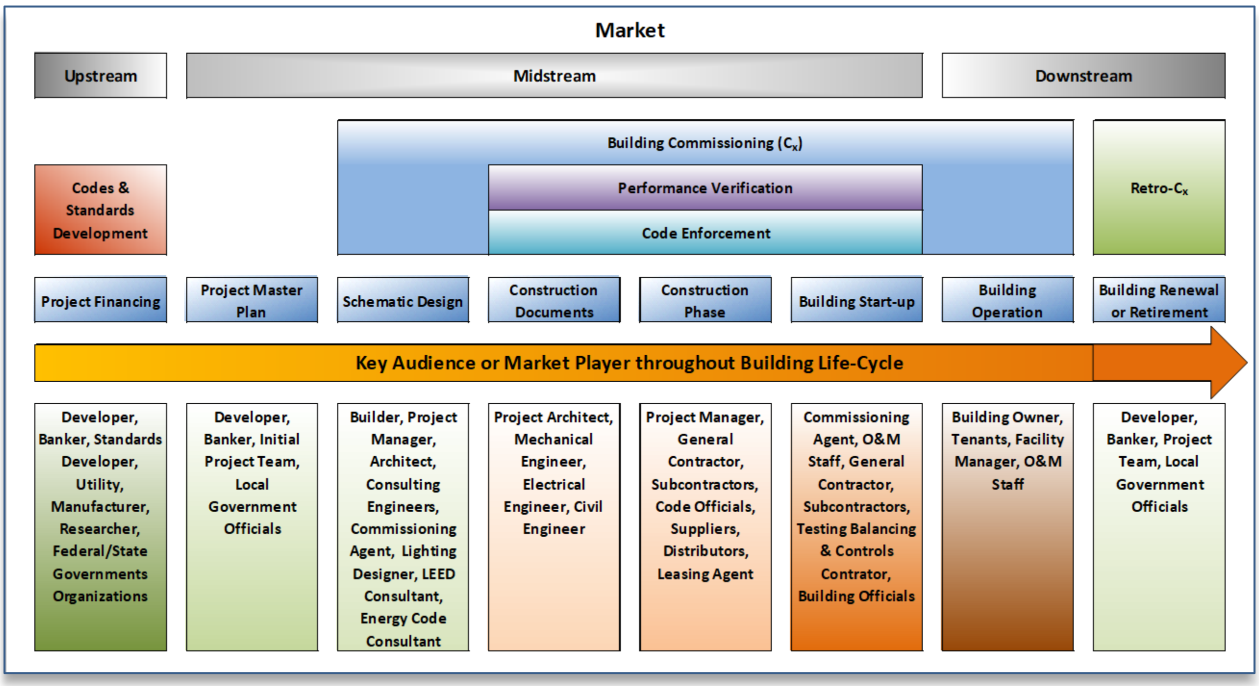
Transformation theory is only successful through sustained efforts and committed support, as business processes, models, and infrastructure can often be slow to change. The framework activities need to address multiple barriers, aligned in a way to collapse timeframes while collaborating with multiple stakeholder groups. The speed of NEBs' change (tied to IoT) in the marketplace exceeds that of typical utility business cycles.

As next steps, the project team recommends that utility programs consider research efforts that support these intervention strategies and their eventual integration into programs. As adoption grows, the strategies will help set the stage for successful programs that can maximize the benefits of NLCs to both the customers and the grid.

Summary of Findings, Drivers Influencing Demand Response-Enablement, and Next Steps

As indicated in the previous discussion, a number of barriers and opportunities to DR-enabling, NLCs market adoption exist, including: (1) a lack of quantifiable NEBs end user value, (2) perception that these systems may adversely impact user or trade ally profitability, (3) a lack of NLC standardization between the various manufacturers product lines and technology solutions that poses significant system integration challenges, (4) a market lack of widely accepted best practices and commissioning guides, and importantly, (5) a lack of integrated energy efficiency/DR program support to instigate meaningful market transformation.

Figure 37: Key Stakeholders & Intervention Points throughout the Building Lifecycle

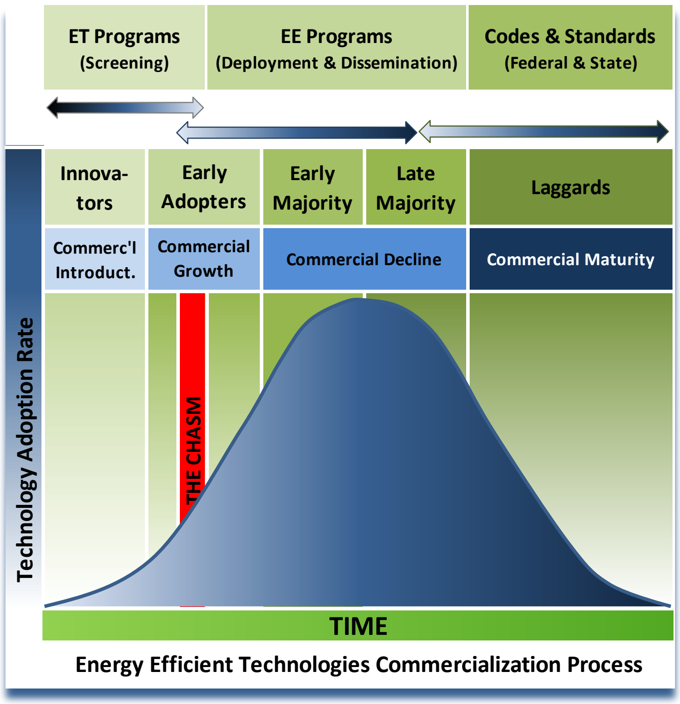


Source: Lawrence Berkeley Laboratory

To accelerate early adopter projects and quickly mainstream DR-enabling, NLCs, the goal is to educate the key market stakeholders as described in Figure 37 above, with regards to the technology solutions for the various customer segments and applications so that implementers and manufacturers can quickly bridge the crest of the market adoption curve and drive greater technology adoption and price reduction (see Figure 38).

Not so obvious, is the need to pre-condition the market by reaching out early, and by supporting with intensive education efforts to contractors, specifiers, distributors, lighting manufacturer reps, building officials, customer groups, etc., to overcome this asymmetric knowledge gap. Where this is most evident is in early projects before the previously listed stakeholders become comfortable with the various innovative technology solutions. The challenge to this new technology approach is how they try to integrate it with a 'business-as-usual' costing, bidding, installing and commissioning process structured around a static-efficiency approach. The usual result from what is perceived as something new and risky is significantly increased price markups on either hardware or labor (depending upon the party).

Figure 38: Energy Efficiency Technology Market Adoption Curve



Source: Lawrence Berkeley Laboratory

At each stakeholder boundary in Figure 37, is a possible intervention point wherein there is an opportunity to influence the key stakeholders representing different business interests.

Non-Energy Benefits Value Proposition to Lighting and Other Demand Response-enablement

- This section elaborates on other possible intervention strategies to enable DR-enablement and use including tapping supply chain, trade ally, and facility management influence points.

One of the key areas for intervention is the NLC supply chain. In the past, as an example, one can look at the market transformation related to moving the HVAC industry from analog to direct-digital controls (DDC), wherein there was great support from the industry and the utilities vis-à-vis training, education, sales-support tools around the technology benefits, and significant financial incentives over a lengthy period of years. This included incentives to overcome numerous supply chain barriers that included: upstream manufacturer incentives to produce more efficient and capable equipment and systems, midstream distribution channel incentives to improve equipment stocking practices to reduce product lead times, and design incentives to support the specifier community in incorporating perceived higher risk, new technology into their projects, and downstream incentives to offset initial costs to contractors and building owners. Additionally, it was supported by working with lenders and insurance companies to provide preferred rates to building owners in recognition of the new technology's risk reduction features some of which pertained to non-energy benefits around fire and life safety.

Promoting DR-enabling, NLCs require similar treatment, but to date the market has lacked a cohesive, persistent market transformation effort from the traditional players (mainly the IOUs and third-party program implementers). This market gap can be addressed by getting the key industry stakeholders in line to support the common goal of promulgating this T24 Code-compliant technology that serves to precondition California ratepayers' buildings for a rapidly changing omnidirectional electricity market moving toward time-of-use (TOU) rates, critical peak pricing (CPP), and ultimately, real-time pricing (RTP).

Opportunities for Further Quantification of Non-Energy Benefits

In this study, the project team developed a DR adoption framework for realizing large-scale DR lighting adoption. The central idea is to leverage technological synergies between DR capability and NEB activation in NLCs to enable customer access to NEBs high business values while allowing utilities to reap persistent energy value. The framework consists of a benefits value intensity (BVI) model that provides a systematic approach for capturing NEBs and organizing their values, and a market transformation theory that uses a logic model to form intervention strategies to influence program design and market activities/outputs that lead to DR lighting adoption.

While BVI is discussed in the context of DR throughout this report, it may be applicable to a broader set of applications. In any case, a lot more quantification efforts are needed to establish pertinent NEB valuation. The challenge lies in not only assigning a value to a NEB but also characterizing it in a proper category (that is, energy, building, people, and/or revenue, etc.) and using a standardized narrative and metric for the applicable building type(s).

As vendors' NLC value propositions shift towards NEBs, and as organizations focus more and more on work efficiency, productivity and well-being, NEBs will eventually make energy savings less of a factor in decision making from a corporate spending perspective. It is crucial to plan ahead and start thinking about NEBs within the energy proposition as a program lever that can be employed to sustain demand-side grid operation and to grow customer relationships.

The first and foremost action is to promote industry-wide adoption of the "NEBs dictionary", a library composed of normalized narratives and the corresponding metrics for quantitatively characterizing NEBs in each BVI category and building type. This will be the key enabler for confidently and clearly communicating the business value of NEBs to stakeholders.

To keep the energy proposition relevant, the second action is to assess the correlation between ramping in a particular NEB and the energy benefit it drives. Recognizing that realizing energy benefits and NEBs requires most of the same NLC capabilities, this essentially ranks NEBs' impacts with respect to an energy-related measure. For example, if a utility would like to drive fast-DR, what NEB should it promote for achieving the optimal program effectiveness?

A long-term vision is to automate NEBs quantification. This would rely heavily on standardized NLC commissioning using uniform nomenclature to ensure a syntactically and semantically meaningful data collection. Leveraging various IoT features, such as device data reporting, machine learning, data analytics, and so on, it could be possible to continue expanding and updating the NEBs dictionary to keep up with technology advances and discover new NEBs.

Comparison to Non-Energy Benefits

Ideally, significant next step efforts would include funding NEB research and analysis such that the value for quantifiable NEBs would be generated and produce a companion table to Table 10. This information could then be added to the waterfall diagrams of NLC costs and revenue in Chapter 2 and populate the empty column in Table 30 below.

Table 30: Comparison of Relative Net Costs to Quantifiable Non-Energy Benefits

Utility	Building Type	Building Size	Net Costs	Quantified NEBs	Difference
PG&E	Office	Large	$182,769		$182,769
		Medium	$17,315		$17,315
		Small	$1,015		$1,015
	Retail	Large	$173,610		$173,610
		Medium	$27,780		$27,780
		Small	$2,095		$2,095
SCE	Office	Large	$3,951		$3,951
		Medium	$58		$58
		Small	$44		$44
	Retail	Large	$3,037		$3,037
		Medium	$415		$415
		Small	$535		$535
SDG&E	Office	Large	$73,374		$73,374
		Medium	$3,189		$3,189
		Small	$286		$286
	Retail	Large	$41,510		$41,510
		Medium	$4,800		$4,800
		Small	$496		$496

Source: Lawrence Berkeley Laboratory

CHAPTER 6: Technology Transfer

Overview

Transferring and disseminating technology and concepts from the project to a wider audience of stakeholders was a foundational goal of this project. At the outset, a technology transfer plan was drafted, outlining strategies and tactics to be implemented in support of knowledge transfer from the project's achievements to the stakeholders and entities addressing the large, nonresidential customer segment, and to help promote the vision and potential of energy savings through demand-responsive, networked lighting controls technologies for California's electricity ratepayers.

The team employed technology transfer activities including: formal and informal outreach, meetings, and conversations at academic, research, and industry events and conferences, as well as presentation of papers, findings and research outcomes at various symposia. Project team members maintained contacts and communications with stakeholders, industry groups, and a broad audience of beneficiaries.

Outreach

Presentations

- Presentation on some of this project's research efforts to the Design Lights Consortium.
- 2017 Emerging Technology Coordinating Council (ETCC) in Anaheim, CA.
- Submitted course proposal to LightFair 2018, "Will all lighting become connected?"
    - Course Summary: Advanced, networked lighting controls have considerable DR value both to the customer and grid. It's been very challenging promoting these technologies do to an inability in quantifying their non-energy benefits (NEBs). This seminar presents their true value proposition. Networked lighting controls have considerable DR value both to the customer and grid.
- Presentation on project's research efforts to leading networked lighting controls company Enlighted; including to Tanuj Mohan, CTO; Evan Petridis, Chief System Architect; and Chip Poland, Director of Utility Programs.
- Informal outreach at Lightfair 2017 and 2018 to support the project including meetings with industry stakeholders and suppliers (no official public presentations at these).
- Outreach at Strategies in Light conference and tradeshow, including a March 2016 presentation. This event is second only to the annual LightFair conference in attendance.
- Conducted briefings on this project and its relevance to promoting wider DR participation and foundational grid modernization impacts for the following parties:
    - California State Senator Stern in September 2017

- o LA County in January 2018
- o David Nemtzow, Director, Building Technology Office, EERE, U.S. DOE in June 2017
- o Amy Jiron, Lead Energy Technology Program Specialist for High Impact Technology Catalyst, Building Technology Office, EERE, U.S. DOE
- o Marina Sofos, Program Manager ARPA-E, Building Technology Office, EERE, U.S. DOE
- o Monica Neukomm, Senior Policy Advisor, Building Technology Office, EERE, U.S. DOE
- o Karma R. Sawyer, Program Manager, Emerging Technologies Program, Building Energy Research & Development, Building Technologies Office, EERE, U.S. DOE in January 2018

- Provided monthly briefings during DOE's Advanced Lighting Controls stakeholder call.

2018 ACEEE Summer Study Papers

- Driving Adoption of Demand-Responsive Commercial Lighting with a Clarified Value Proposition: Non-Energy Benefits Framework (Kelly Sanders, Yao-Jung Wen, David Jagger, Teddy Kisch, Jasmine Shepard and Willie Calvin, Energy Solutions, Peter Schwartz, Lawrence Berkeley National Laboratory, Adel Suleiman, California Energy Commission

  Abstract: Commercial lighting represents a significant potential source of demand response (DR) for the electrical grid when DR is enabled by networked lighting controls (NLCs). Since 2013, California Title 24 building code mandates DR-capable lighting for most new commercial facilities. Despite the significant opportunity and regulatory push, DR-capable lighting is installed and enabled in a relatively small number of buildings because most building owners do not see a strong value proposition from DR-enabled lighting. NLC capabilities that enable effective DR, deliver value to customers in the form of reduced energy bills, optimized facilities, and increase revenue cost, among other co-benefits. Unfortunately, these co-benefits are currently not well quantified. This paper summarizes our endeavor to develop a framework that captures the high customer values from NLC non-energy benefits (NEBs) to drive DR adoption. We reviewed over 130 NLC case studies in an attempt to quantify NEBs and develop a Benefits Value Intensity (BVI) model, which captures the NEBs value in four categories: energy, building, people, and revenue. In general, we found values in higher BVI categories can be several orders of magnitude higher than values in energy and demand management alone. Armed with the quantitative NEBs information and the high-influence market barriers and opportunities, we designed a sample logic model and conceptualized five intervention strategies as part of the market transformation theory for achieving large-scale commercial lighting DR adoption.

- Driving Adoption of Demand-Responsive Commercial Lighting With a Clarified Value Proposition: Site Level Energy Savings and Cost-Benefit Analysis (Brian F. Gerke, Jennifer Potter25, Peter Schwartz, Alastair Robinson, Lawrence Berkeley National Laboratory, David Jagger, Jasmine Shepard, Teddy Kisch, Energy Solutions, Adel Suleiman, California Energy Commission

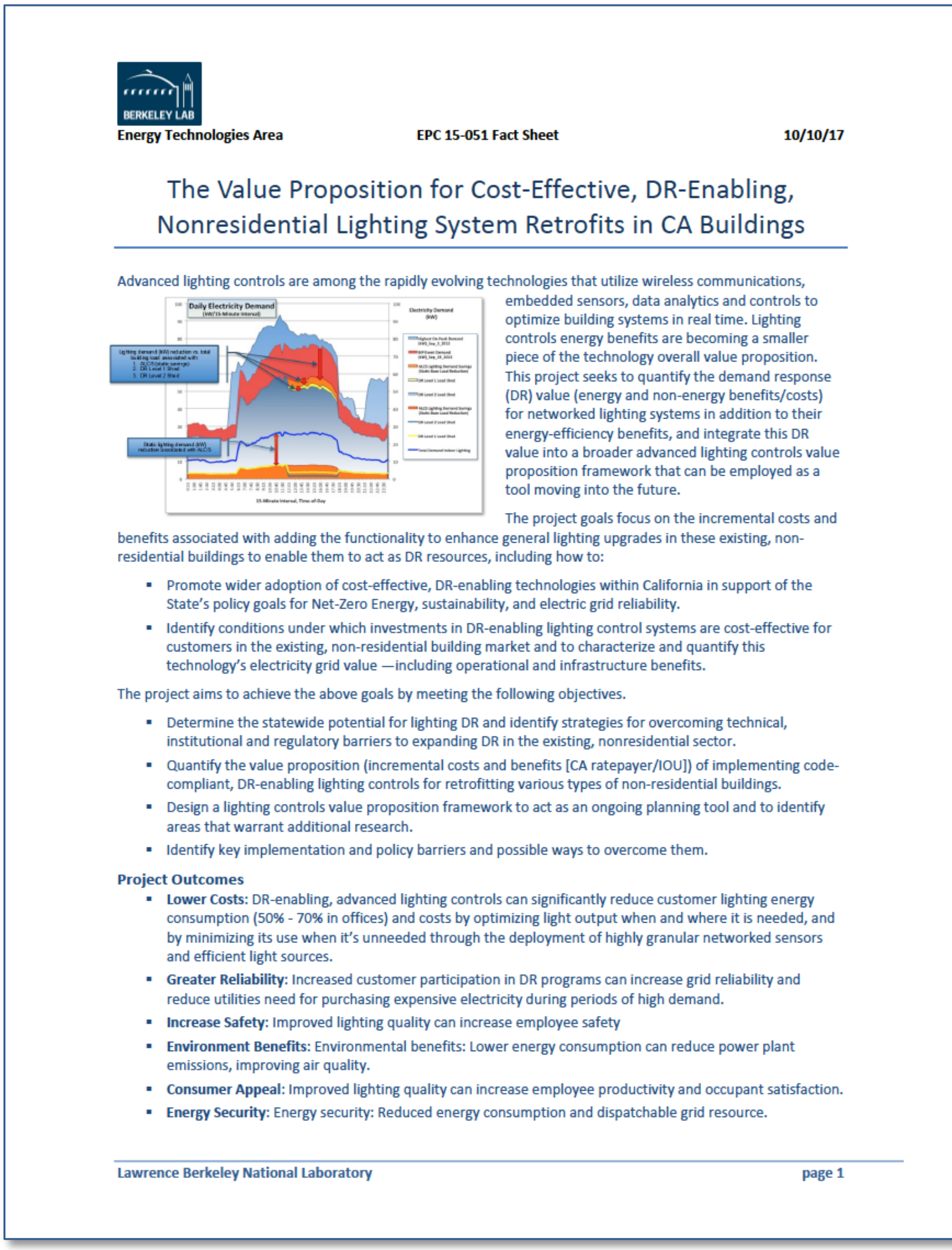
  Abstract: Commercial lighting represents a significant potential source of demand response (DR) for the electrical grid, via traditional load shedding and also via rapid-dispatch ("fast-DR") ancillary services when DR is enabled by networked lighting controls (NLCs). Since 2013, California Title 24 building code mandates DR-capable lighting in certain circumstances. Despite the significant opportunity and regulatory push, DR-enabled lighting is installed and enabled in a relatively small number of buildings because most building owners do not see a strong value proposition from DR-enabled lighting. While NLCs can support DR enablement by providing additional capabilities that deliver value to the customer such as reduced energy bills, optimized space utilization, and increased revenue, these co-benefits from NLCs are not well quantified. This paper undertakes a detailed analysis of lighting DR resources and energy-related co-benefits for commercial buildings in California. Using over 100,000 individual hourly load profiles, we forecast the potential DR resources that could be available from commercial lighting in 2025. We also estimate the revenues available from participation of these DR resources in energy markets. Combining these results with field-study estimates for NLC installation costs and energy savings, we perform a detailed accounting, by building type, of the site-level costs and energy-related co-benefits arising from DR enablement with NLCs. In many cases, the energy savings alone can deliver significant net value to the site, strongly justifying the adoption of NLC-enabled DR. A companion paper considers the additional non-energy benefits, which can be even larger than the energy benefits.

Project Fact Sheet

See Figure 39.

[25] Current affiliation: Hawaii Public Utilities Commission

Figure 39: EPIC Project Fact Sheet



BERKELEY LAB

Energy Technologies Area | EPC 15-051 Fact Sheet | 10/10/17

The Value Proposition for Cost-Effective, DR-Enabling, Nonresidential Lighting System Retrofits in CA Buildings

Advanced lighting controls are among the rapidly evolving technologies that utilize wireless communications, embedded sensors, data analytics and controls to optimize building systems in real time. Lighting controls energy benefits are becoming a smaller piece of the technology overall value proposition. This project seeks to quantify the demand response (DR) value (energy and non-energy benefits/costs) for networked lighting systems in addition to their energy-efficiency benefits, and integrate this DR value into a broader advanced lighting controls value proposition framework that can be employed as a tool moving into the future.

The project goals focus on the incremental costs and benefits associated with adding the functionality to enhance general lighting upgrades in these existing, non-residential buildings to enable them to act as DR resources, including how to:

- Promote wider adoption of cost-effective, DR-enabling technologies within California in support of the State's policy goals for Net-Zero Energy, sustainability, and electric grid reliability.
- Identify conditions under which investments in DR-enabling lighting control systems are cost-effective for customers in the existing, non-residential building market and to characterize and quantify this technology's electricity grid value —including operational and infrastructure benefits.

The project aims to achieve the above goals by meeting the following objectives.

- Determine the statewide potential for lighting DR and identify strategies for overcoming technical, institutional and regulatory barriers to expanding DR in the existing, nonresidential sector.
- Quantify the value proposition (incremental costs and benefits [CA ratepayer/IOU]) of implementing code-compliant, DR-enabling lighting controls for retrofitting various types of non-residential buildings.
- Design a lighting controls value proposition framework to act as an ongoing planning tool and to identify areas that warrant additional research.
- Identify key implementation and policy barriers and possible ways to overcome them.

Project Outcomes

- **Lower Costs:** DR-enabling, advanced lighting controls can significantly reduce customer lighting energy consumption (50% - 70% in offices) and costs by optimizing light output when and where it is needed, and by minimizing its use when it's unneeded through the deployment of highly granular networked sensors and efficient light sources.
- **Greater Reliability:** Increased customer participation in DR programs can increase grid reliability and reduce utilities need for purchasing expensive electricity during periods of high demand.
- **Increase Safety:** Improved lighting quality can increase employee safety
- **Environment Benefits:** Environmental benefits: Lower energy consumption can reduce power plant emissions, improving air quality.
- **Consumer Appeal:** Improved lighting quality can increase employee productivity and occupant satisfaction.
- **Energy Security:** Energy security: Reduced energy consumption and dispatchable grid resource.

Lawrence Berkeley National Laboratory | page 1

Technical Advisory Committee

In October 2017, the research team engaged industry stakeholders for the project Value Proposition for DR-Enabled Lighting Potential Study Technical Advisory Committee (TAC) Meeting. During this meeting, the team both informed and solicited feedback from the people listed below:

Industry Stakeholders

- Teren Abear, Emerging Products Technical Lead, SCE

- Rick Aslin, Manager, PG&E
- Gary Barsley, Manager of Customer Self-Generation, SCE
- Albert Chiu, Expert Product Manager, DR Technology and Solutions Team, PG&E
- Kelly Cunningham, Senior Program Manager, Energy Efficiency Codes and Standards, PG&E
- John Goodin, Regulatory Policy Manager, Market and Infrastructure Policy, CAISO
- David Hungerford, Senior Scientist, Research and Development Division, CEC
- Mike Jaske, Senior Policy Analyst, Energy Assessments Division, CEC
- Mark Jewell, President, Selling Energy
- Tarun Kapoor, Expert Product Manager, Emerging Technologies, PG&E
- Charles Knuffke, Western Regions Sales Manager, Watt Stopper
- Vireak Ly, Manager of Technology Test Centers, SCE
- Angela McDonald, Senior Lighting Program Coordinator, PG&E
- Carol Manson, Sr. Policy Advisor, Customer Programs, SDG&E
- Mark Martinez, Manager of Emerging Markets and Technology, SCE
- Dr. Robert T. Nachtrieb, Lead Scientist, Lutron Electronics Co.
- Neda Oreizy, Expert Strategic Analyst, PG&E
- Evan Petridis, Chief System Architect, Enlighted, Inc.
- Sam Piell, Demand Response Emerging Technologies, PG&E
- Edwin (Chip) Poland, Director of Utility Programs, Enlighted, Inc.
- Kevin Powell, Director of Research, Green Proving Ground Program, GSA
- Jill Powers, Infrastructure and Regulatory Policy Manager, CAISO
- Pauravi Shah, Commercial Product Manager, PG&E
- Mona Tierney Lloyd, Senior Director, Western Regulatory Affairs, EnerNOC
- Greg Wikler, Managing Director, Energy Practice, Navigant
- Gil Wong, Principal Strategic Analyst, PG&E

California Energy Commission

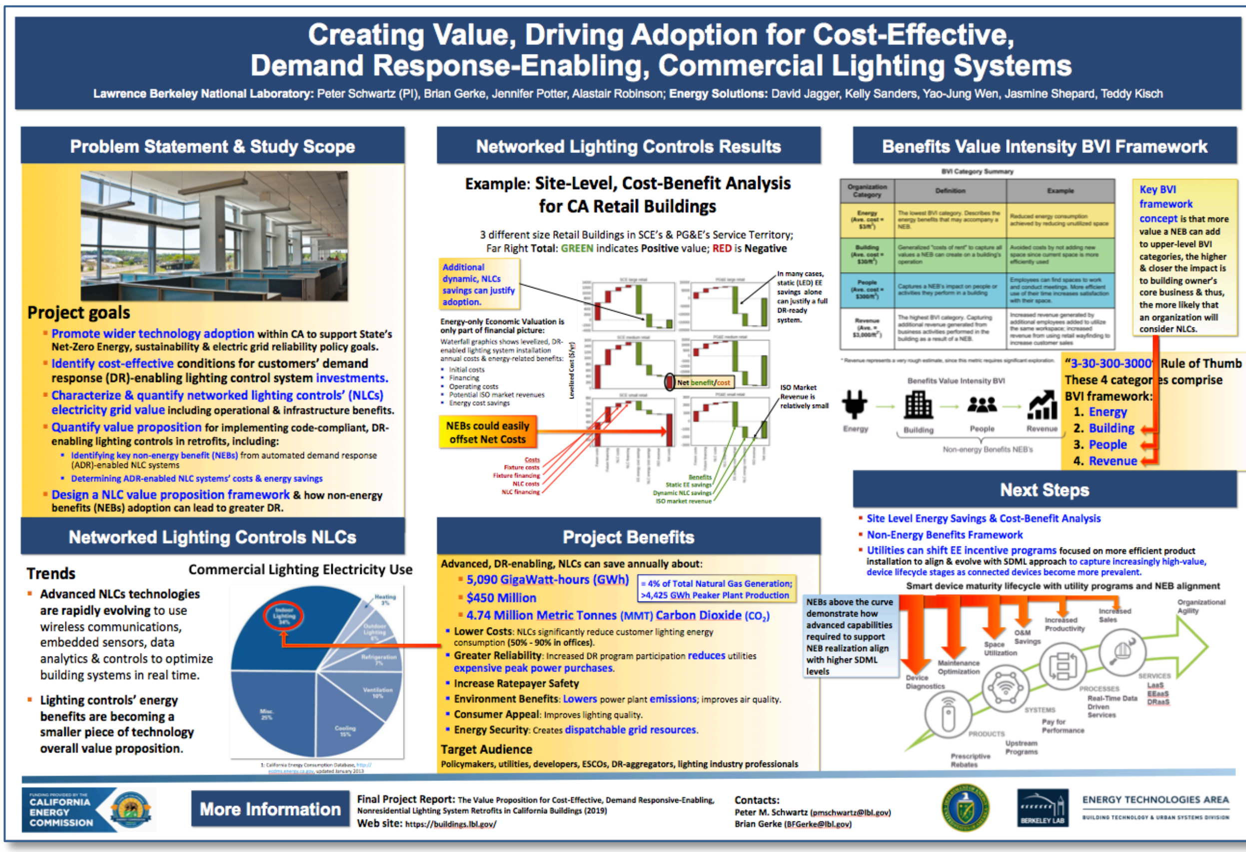
- Simon Lee, Electrical Engineer, Energy Efficiency Division
- Thao Chau, Electrical Engineer, Energy Efficiency Division
- Gabriel Taylor, Mechanical Engineer, Energy Efficiency Division
- Peter Strait, Supervisor, Building Standards Development, Energy Efficiency Division
- Brad Williams, Mechanical Engineer, Energy Research and Development Division
- Adel Suleiman, Senior Electrical Engineer, Energy Research and Development Division

The outgrowth of the meeting resulted in number of the attending organizations restructuring their market approaches in response to the leveraging impacts of non-energy benefits. Additionally, the traditional utility energy-efficiency program managers are reconsidering their cost-effectiveness criteria in response to the significant NEB values in helping promote this technology.

Poster

The project had a poster at the 2019 EPIC Symposium. The 2019 poster is shown in Figure 40 below.

Figure 40: EPIC 2019 Symposium Poster



Source: Lawrence Berkeley National Laboratory

CHAPTER 7: Summary and Benefits to California

An important aspect to remember from this research is that NLCs will become an ever more important distributed energy resource—not only in the face of lighting system source efficiency improvements due to LEDs, organic LEDs, or future plasma or laser technologies, but also because of lighting's ability to be flexibly controlled combined with rapid-response capabilities and ease of load aggregation. The resource will grow rapidly as more facilities recognize NLCs' non-energy benefits, market adoption increases, technology prices fall, and the electricity market become more volatile.

As discussed in Chapter 2, DR-enabled lighting systems' energy-only, cost-effectiveness varies substantially depending on building size and service territory. We found that generally, such systems are more cost-effective for larger buildings than for smaller ones, and for offices than for retail sites, across all service territories. Additionally, the project team found where:

1) Commercial retail electricity rates are relatively high like for PG&E (especially on peak), there is a substantial net benefit across all building sizes and types, and DR-enabled systems can generally be justified based on the static energy efficiency savings alone. The site-level value proposition in this case is straightforward.
2) Electricity rates are lower as in SCE's service territory; the DR lighting systems' cost-effectiveness depends strongly on the building size, with a net benefit for large buildings only. In this case, the value proposition for small and medium buildings would likely need to rest on the NEBs, rather than the energy-related benefits.
3) Moderate electricity rates exist as in SDG&E's service territory, the results are intermediate between the two previous cases.

The current available ISO market revenue is always small relative to the system costs and the energy cost savings. This points to DR-enabled lighting systems' primary value proposition comes from the site-level energy savings that will be realized with or without DR participation. It may therefore be important to develop additional strategies to encourage participation in DR programs once DR-enabled technologies are adopted.

Also, as discussed in Chapter 2, the shape of electricity system loads are in flux as the market moves from traditional central generation plants to high renewable penetration. What we do not know at this juncture is what the net system load shape will look like with an omnidirectional electricity grid with a growing population of DERs comprised of highly variable renewable sources, electric vehicles (including autonomous vehicles), increased storage (for example, electrochemical, compressed air, hydro, thermal, hydrogen), responsive loads (for example, buildings' HVAC, lighting, industrial process, miscellaneous electric loads), fuel cells, and end-use electrification. Further, evolving electricity rates and tariff structures moving to TOU and real-time, dynamic pricing ("pay as you go" per demand) will also significantly influence net system load shapes and DER response, which adds to the uncertainty.

The project team found NLCs have great potential to provide both energy savings and demand flexibility. Importantly, NLCs enable DR capability within buildings that represents a significant distributed energy resource (5,090.7 GWh annually) that can more than offset peaker power plant production (4,425 GWh annually (2015)). Further research is required to unlock this potential to create a clearer site level, value proposition.

What is clear is that the electricity grid will require significantly more flexible assets to address increasing generation and load variability and to maintain the grid's reliability and resiliency, while responding to whole new electricity market paradigms—both from large infrastructure and consumer perspectives and from new business models perspectives. IoT players will continue to take hold to rapidly reshape the marketplace.

What else remains clear is that lighting integrated with networked lighting controls and dense sensor networks represents the most responsive building load, acting as a viable DER to address the grid's current and future needs. Lighting can play a key resource role as a fast-shedding resource that can meet local capacity needs or distribution system needs, and that respond in the event of contingency and emergency conditions.

Chapter 3 discussed ADR-enabled NLC systems' cost and energy savings and found in many cases, energy savings alone can easily justify NLC adoption, but in other cases, additional incentives or NEBs accounting may be necessary to justify investment in installing NLCs. A long-term vision is to automate NEBs quantification. This would rely heavily on standardized NLC commissioning using uniform nomenclature to ensure a syntactically and semantically meaningful data collection. Leveraging various IoT features, such as device data reporting, machine learning, data analytics, and so on, it could be possible to continue expanding and updating the NEBs dictionary to keep up with technology advances and discover new NEBs.

In Chapter 4, energy and non-energy benefits (NEBs) from DR-enabled networked lighting control (NLC) systems were identified and ranked into two sets of quadrants first, for benefits, from unknown to known quantifiability, and from high to low impacts; and second, for barriers and opportunities, from high to low effort, and from high to low impacts.

In general, the project team found values in higher BVI categories could be several orders of magnitude higher than values in energy and demand management alone (that is, the 3:30:300:300 rule of thumb). Armed with the quantitative NEBs information and the high-influence market barriers and opportunities, the project team designed a sample logic model and conceptualized five intervention strategies as part of the market transformation theory for achieving large-scale commercial lighting DR adoption.

Finally, Chapter 5 examined NEB adoption and DR-enablement issues wherein, the project team concluded that where NLCs are installed, additional incentives may be needed to encourage IOU DR program participation because typical revenue from bidding lighting DR into energy markets is comparatively tiny (see Figure 18).

With regards to the NEBs framework and future research requirements, this research sets the stage for California's IOUs to offer new P4P programs in support of deploying DR-enabling

NLCs that create responsive buildings that become viable DERs capable of providing grid services. Further, the research identifies which class of office or retail building can provide significant resource in different IOU SubLAPs, which can aid utilities and the CPUC in specifically targeting program implementation for the greatest impact.

More effort is necessary on several market transformation fronts to achieve success in deploying NLCs effectively to create responsive, DR-enabled buildings in California. This study represents an initial effort to analyze DR-enabling, NLCs potential and highlight a BVI framework that folds in NEBs value, and has suggested areas for further research and utility program support.

LIST OF ACRONYNMS

Acronym	Definition
ADR	Automated demand response
ARCs	Aggregators of retail customers
AS	Ancillary services
BEV	Battery electric vehicle
BVI	Benefits value intensity
CAISO	California Independent System Operator
CEUS	California Commercial End Use Survey
CPUC	California Public Utilities Commission
CSS	Commercial Saturation Survey
DER	Distributed energy resource
DLC	Direct load control
USDOE	United States Department of Energy
DR	Demand response
DRP	Demand response provider
EE	Energy efficiency
FERC	Federal Energy Regulatory Commission
GUI	Graphical User Interface
HVAC	Heating, ventilation and air conditioning
IoT	Internet of Things
ISO	Independent System Operator (grid management agency)
IOU	Investor-owned utilities
LED	Light-emitting diode
LPD	Lighting power density
NEBs	Non-energy benefits
NERC	North American Electric Reliability Corporation

Acronym	Definition
NLCs	Networked lighting controls
PDR	Proxy demand resource
PG&E	Pacific Gas & Electric Company
PHEV	Plug-in hybrid electric vehicle
RA	Resource adequacy
RDRR	Reliability demand response resources
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric Company
SDML	Smart devices maturity lifecycle
TA	Trade allies
TOU	Time-of-use

GLOSSARY

Aggregator: An intermediary between an energy supplier and its customers, providing the utility with demand response by spreading the request among multiple consumers. Also referred to as Aggregators of Retail Customers (ARCs).

Ancillary Services: Those services that are necessary to support the transmission of capacity and energy from resources to loads while maintaining reliable operation of the Transmission Service Provider's transmission system in accordance with good utility practice. (From FERC order 888-A.)

Automated Demand Response (ADR): Demand response programs where a third party (for example, utility or aggregator) is able to control a customer's load for DR purposes. ADR involves installation of advanced control and communication programs where an automated signal from the dispatcher (for example, utility) triggers a pre-defined response from the customer's end use.

Behind-the-Meter (BTM) Storage: Energy storage devices such as batteries that are on the customer's premise and metered electrical system. These devices are owned and operated by the customer or a third party that has been contracted by the customer. This is in contrast to utility- or grid-scale storage that is owned and operated by a utility provider.

Capacity: A power rating for generation or DR. Often the maximum amount of power able to be supplied by the electric grid at any time. Other usages include: to describe peak net load, that is, the maximum need for generation from dispatchable energy resources; to describe a service that reduces the maximum generation ability needed (for example, "DR has the potential to provide capacity").

Configurable DR Opportunities: Programs that provide a utility or ARC with the ability to control the electricity consumption of one or more customer devices for a specified period of time, but where the customer can configure the control technology to override the DR signals that are received under certain conditions.

Controllable DR Opportunities: Programs that provide a utility or ARC with the opportunity to directly control (via radio, Internet, telemetry, or other remote means) various customers' electricity consuming end uses (for example, electric water heaters, pool pumps) or some portions of their load which could be increased, decreased, or even physically disconnected from the grid with little to no notice.

Critical Peak Pricing (CPP): Rates that institute a single or variable predetermined price for electricity during a narrowly defined period (for example, summer weekday between 4 PM and 7 PM) that is only applied during specific system operating or market conditions and generally limited in the number of times it can be dispatched (for example, twelve times per year).

Distributed Energy Resources (DERs): From FERC's definition of DERs in Docket Nos. RM-16-23-000, "A DER is a source or sink of power that is located on the distribution system, any subsystem thereof, or behind a customer meter. These resources may include, but are not limited to, electric storage resources, distributed generation, thermal storage, and electric vehicles and their supply equipment."

Demand Response: A mechanism through which an end-use's load profile is changed (by the user, a third party, or a utility) in response to system needs, often in return for economic compensation (for example, payments or a different rate structure).

Enabling Technology: A set of on-site hardware and software that enables a particular end use or set of end uses to provide DR service across one or more products.

End Use: A service performed using energy (for example, lighting, refrigeration) or a type of energy-using device (for example, refrigerators, pool pumps). These end use and their demand for electricity make up customer load.

EPIC (Electric Program Investment Charge): The Electric Program Investment Charge, created by the California Public Utilities Commission in December 2011, supports investments in clean energy technologies that benefit electricity ratepayers of Pacific Gas and Electric Company, Southern California Edison Company, and San Diego Gas & Electric Company.

Flexible Loads: End-use load that is able to change its demand profile for DR purposes. This may refer to the total load of the given end use or some fraction of the total load that can be modified. For example, only half of a customer's HVAC load may be "flexible," as the portion providing the ventilation services may be required to stay on at all times.

Investor-Owned Utility (IOU): A business organization providing utility service(s) that is managed as a private enterprise rather than a function of government or a utility cooperative.

Internet of Things (IoT): The inter-networking of physical devices, vehicles (also referred to as "connected devices" and "smart devices"), buildings, and other items embedded with electronics, software, sensors, actuators, and network connectivity which enable these objects to collect and exchange data over a network without requiring human-to-human or human-to-computer interaction.

Open Automated Demand Response (OpenADR): An open and interoperable information exchange model and communication standard. OpenADR standardizes the message format used for ADR controls, gateways, and energy management systems to enable standardized communication of price and DR signals between customer facilities and utilities, Independent System Operators (ISOs), or Energy Service Providers.

Regulating Reserves: An amount of reserve responsive to Automatic Generation Control, which is sufficient to provide normal regulating margin.

Sector: A market or population segment sharing common characteristics. For the purposes of this study, the relevant sectors are: residential, commercial, and industrial (which includes agriculture).

Smart Grid: Smart grid is the thoughtful integration of intelligent technologies and innovative services that produce a more efficient, sustainable, economic, and secure electrical supply for California communities.

Telemetry: An automated communications process by which measurements are made and other data collected at remote or inaccessible points and transmitted to receiving equipment for monitoring.

Variable Peak Pricing (VPP): A hybrid of time-of-use and real-time pricing where the different periods for pricing are defined in advance (for example, on-peak = four hours for summer weekday afternoon; off-peak = all other hours in the summer months), but the effective price for the on-peak period varies by market conditions and prices.

REFERENCES

Alstone, P., Potter, J., Piette, M. A., Schwartz, P., Berger, M. A., Dunn, L. N., Smith, S. J., Sohn, M. D., Aghajanzadeh, A., Stensson, S. and Szinai, J. (2016) *Interim Report on Phase 1 Results - 2015 California Demand Response Potential Study: Charting California's Demand Response Future*. Prepared for California Public Utilities Commission. April, 2016.

Alstone, P., Potter, J., Piette, M. A., Schwartz, P., Berger, M. A., Dunn, L. N., Smith, S. J., Sohn, M. D., Aghajanzadeh, A., Stensson, S., Szinai, J., Walter, T., McKenzie, L., Lavin, L., Schneiderman, B., Mileva, A., Cutter, E., Olson, A., Bode, J., Ciccone, A. and Jain, A. (2017) *2025 California Demand Response Potential Study, Final Report and Appendices on Phase 2 Results: Charting California's Demand Response Future*. Lawrence Berkeley National Laboratory. Prepared for California Public Utilities Commission. April, 2017.

Bement, D., and Skumatz, L. A. (2007). *New Non-Energy Benefits (NEBs) results in the commercial/industrial sectors: Findings from incentive, retrofit, and technical assistance / new construction programs*. ACEEE 2007 Summer Study. pp. 1551-1559.

Bicknell, C. and Skumatz, L. A. (2004). *Non-Energy Benefits (NEBs) in the Commercial Sector: Results from Hundreds of Buildings*. Skumatz Economic Research Associates, Inc.

California Energy Commission. *California Commercial End Use Survey*. Prepared by Itron, Inc., March, 2006.

California Energy Commission. *California Energy Demand 2014-2024 Forecast*, January, 2014.

DLC. (2017). https://www.designlights.org/news-events/news/dlc-releases-networked-lighting-controls-technical-requirements-v2-0/networked-lighting-controls-technical-requirements-v2-0/ and https://www.designlights.org/news-events/news/dlc-releases-technical-requirements-v4-2/

Fagen, S. (2016) *Assessment of Technologies Available to Meet California Independent Systems Operator (Caiso) Telemetry Requirements for Pdr – Final Report*. S. Piell. Prepared for Pacific Gas and Electric Company. May 2016.

Goldman, C., Reid, M., Levy, R. and Silverstein, A. (2010) *Coordination of Energy Efficiency and Demand Response*. January 2010. 74 pages. LBNL-3044E.

IRC (2016) *2015 North American Demand Response Characteristics Comparison*. ISO/RTO Council. April.

Itron. 2014a California Commercial Saturation Survey. http://capabilities.itron.com/wo024/Docs/California%20Commercial%20Saturation%20Study_Report_Final.pdf

Itron. 2014b. California Commercial Market Share Tracking Study. http://capabilities.itron.com/wo024/Docs/California%20Commercial%20Market%20Share%20Tracking%20Study_Report.pdf

Loutan, C. and Gevorgian, V., P. Klauer, S. Chowdhury, S. Hall, M. Morjaria, V. Chadliev, N. Milam, C. Milan (2016). Using Renewables to Operate a Low-Carbon Grid: Demonstration of Advanced Reliability Services from a Utility-Scale Solar PV Plant. CAISO, NREL, First Solar. p.11 and p.65

Mills, E., and Rosenfeld, A. (1996). *Consumer Non-Energy Benefits as a Motivation for Making Energy-Efficiency Improvements*. Lawrence Berkeley National Laboratory.

Pearson, D., and Skumatz, L. A. (2002). *Non-Energy Benefits Including Productivity, Liability, Tenant Satisfaction, and Others: What Participant Surveys Tell Us about Designing and Marketing Commercial Programs*. Proceedings from the 2002 ACEEE Summer Study on Energy Efficiency in Buildings.

Piette, M. A., Schetrit, O., Kiliccote, S., Cheung, H. Y. I. and Li, B. (2015) *Costs to Automate Demand Response – Taxonomy and Results from Field Studies and Programs*. Lawrence Berkeley National Laboratory, Berkeley, CA. November. LBNL-1003924.

Potter, J. and Cappers, P. (2017) *Demand Response Advanced Controls Framework and Assessment of Enabling Technology Costs*.

Potter, J. M., George, S. S. and Jimenez, L. R. (2014) *Smartpricing Options Final Evaluation. Sacramento Municipal Utility District*. Prepared for U.S. Department of Energy, September 2014.

Regnier, C., P. Mathew, A. Robinson, P. Schwartz, J. Shackelford, T. Walter (2018). *Beyond Widgets: Validated Systems Energy Savings and Utility Custom Incentive Program Systems Trends*, Lawrence Berkeley National Laboratory, Proceedings from the 2018 ACEEE Summer Study on Energy Efficiency in Buildings (Paper No. 4-0194_0286_000050).

Rothleder, M. (2016) *Information Technology and Energy Industry*, California ISO, July 12, 2016 from https://www.eia.gov/conference/2016/pdf/presentations/rothleder.pdf.

Skumatz, L. A., C. A. Dickerson, and Coates, B. (2000). *Non-Energy Benefits in the Residential and Non-Residential Sectors - Innovative Measurements and Results for Participant Benefits*. Proceedings from the 2000 ACEEE Summer Study on Energy Efficiency in Buildings.

Skumatz, L. A. (2016). *Non-Energy Benefits / NEBs - Winning at Cost-Effectiveness Dominos: State Progress and TRMs*. Proceedings from the 2016 ACEE Summer Study on Energy Efficiency in Buildings.

Solid State Instruments. (2011). *What Are Kyz Pulses?* Retrieved October 5, 2016. 2016, from http://solidstateinstruments.com/newsletters/kyz-pulses.php.

Terrapin Bright Green. (2012). *The Economics of Biophilia*. Terrapin Bridge Green LLC. New York.

Non-Energy Benefit Quantification Case Study References

Acuity Brands. (n.d.). *16500 Offices in San Francisco.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/16500#

Acuity Brands. (2014). *Day Kimball Case Study.* Retrieved August 11, 2017, from https://www.acuitybrands.com/-/media/Files/Acuity/Solutions/Inspire-Me/Case-Studies/DayKimball_Case%20Study_WEB.pdf?la=en

Acuity Brands. (2014). *Tishman Speyer Case Study.* Retrieved August 11, 2017, from https://www.acuitybrands.com/-/media/Files/Acuity/Solutions/Inspire-Me/Case-Studies/TishmanSpeyer_WEB.pdf?la=en

Acuity Brands. (2015). *Acuity Brands Lighting and Controls Help El Paso Reach Sustainability Goals, Reduce Operating Costs by 67 Percent.* Retrieved August 11, 2017, from https://www.acuitybrands.com/-/media/Files/Acuity/Solutions/Inspire-Me/Case-Studies/El%20Paso%20Case%20Study.pdf

Acuity Brands. (2015). *Acuity Brands Provides LED Solutions to Meet the Bay Bridge Tunnel's Rigorous Demands.* Retrieved August 11, 2017, from https://www.acuitybrands.com/-/media/37F3E4CBEE2F439686AC47A9BF4327CC.pdf

Acuity Brands. (2015). *Elk Grove Retrofits HPS with American Electric Lighting® LED System for 60 to 70 Percent Energy Savings.* Retrieved August 11, 2017, from http://www.acuitybrands.com/-/media/C10F8D4B9C6E4786B5EB5584F7574379.pdf?la=en

Acuity Brands. (2015). *Shellworth Chevrolet Case Study.* Retrieved August 11, 2017, from https://www.acuitybrands.com/-/media/Files/Acuity/Solutions/Inspire-Me/Case-Studies/Shellworth%20Chevrolet%20Case%20Study.pdf?la=en

Acuity Brands. (2015). *Small-Town Power Plant Recognized for Big Lighting Upgrades.* Retrieved August 11, 2017, from http://www.acuitybrands.com/-/media/Files/Acuity/Solutions/Inspire-Me/Case-Studies/TVA%20Magnolia%20Power%20Plant%20Case%20Study.pdf?la=en

Acuity Brands. (2015). *WV DOH Upgrades Interstate Lighting to Holophane High Mast LED to Cut Operating Costs, Improve Safety.* Retrieved August 11, 2017, from http://www.acuitybrands.com/-/media/E4D7009ADA2E447F85861D7CD90E8BBE.pdf?la=en

Acuity Brands. (2016). *Enjoying great French fries? Thank Preferred Freezer Services and LED lighting from Acuity Brands.* Retrieved August 11, 2017, from https://www.acuitybrands.com/-/media/Files/Acuity/Solutions/Inspire-Me/Case-Studies/AB_2521_Preferred%20Freezer_Case_Study%20pdf.pdf?la=en

Acuity Brands. (2016). *HMAO LED II Luminaires Allow City of Canton to Improve Driver Safety while Significantly Reducing Operating Costs.* Retrieved August 11, 2017, from https://www.acuitybrands.com/-/media/Files/Acuity/Solutions/Inspire-Me/Case-Studies/City%20of%20Canton%20Case%20Study%20pdf.pdf

Acuity Brands. (2016). *Humility of Mary Health Partners Benefit from D-Series Outdoor LED Lighting.* Retrieved August 11, 2017, from http://www.acuitybrands.com/-/media/Files/Acuity/Solutions/Inspire-Me/Case-Studies/St%20Elizabeth%20Case%20Study%20pdf.pdf?la=en

Acuity Brands. (2016). *Kent State University Saves 76% in Energy Costs with the D-Series Area Lighting and Controls.* Retrieved August 11, 2017, from https://du1ux2871uqvu.cloudfront.net/sites/default/files/file/KSU_EnergyCostSaivngs AcuityCaseStudy01-2016.pdf

Acuity Brands. (2016). *Lighting Upgrade To Acuity Brands® LED Luminaires Creates Safe, Inviting Exterior at 38 Dignity Health Hospitals, Cuts Costs.* Retrieved August 11, 2017, from https://www.acuitybrands.com/-/media/Files/Acuity/Solutions/Featured-Spaces/Healthcare/Case%20Study/AB_3196_Dignity%20Healthcare%20Case%20Study_0516%20pdf.pdf

Acuity Brands. (2016). *Sacramento International Airport Raises Security, Lands SMUD Funding with HMAO™ Led II Lighting System.* Retrieved August 11, 2017, from https://www.acuitybrands.com/-/media/Files/Acuity/Solutions/Inspire-Me/Case-Studies/Sacramento%20Airport%20Case%20Study%20pdf.pdf?la=en

Acuity Brands. (2016). *Wabash Valley Correctional Facility Improves Security, Cuts Costs 55% with LED Lighting.* Retrieved August 11, 2017, from https://www.acuitybrands.com/-/media/Files/Acuity/Solutions/Inspire-Me/Case-Studies/Wabash%20Valley%20Correctional%20Facility%20Case%20Study%20pdf.pdf

Acuity Brands. (2016). *Wisconsin Health System Reduces Energy Footprint with Outdoor LED Luminaires.* Retrieved August 11, 2017, from https://www.acuitybrands.com/-/media/Files/Acuity/Solutions/Inspire-Me/Case-Studies/ThedaCare%20Health%20Systems%20Case%20Study%20pdf.pdf?la=en

Acuity Brands. (2017). *Award-Winning Open Office Lighting Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/ontario-canada

Acuity Brands. (2017). *Circuit of the Americas Lighting Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/circuit-of-the-americas

Acuity Brands. (2017). *City of Hercules.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/hercules-california

Acuity Brands. (2017). *DPR Construction Smart Lighting Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/dpr-construction

Acuity Brands. (2017). *Las Vegas Convention Center Lighting Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/las-vegas-convention-center

Acuity Brands. (2017). *Mall of American Parking Garage Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/mall-of-america

Acuity Brands. (2017). *Plymouth Public School District.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/plymouth-public-school-district

Acuity Brands. (2017). *Rockdale County Public Schools.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/rockdale-county-public-schools

Acuity Brands. (2017). *Semiconductor Manufacturer.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/oregon

Acuity Brands. (2017). *University of Akron.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/university-of-akron

Acuity Brands. (2017). *Wilshire High Rise Luxury Condominiums.* Retrieved August 11, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/wilshire-high-rise-luxury-condominiums

Acuity Brands. (n.d.). *Anderson University Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/anderson-university

Acuity Brands. (n.d.). *Aurora Lighting Design and OLED Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/aurora

Acuity Brands. (n.d.). *Bend Oregon Parking Plaza LED Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/oregon-parking-plaza

Acuity Brands. (n.d.). *Bird's Eye Foods Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/birds-eye-food

Acuity Brands. (n.d.). *Cammisa + Wifp Consulting Engineers OLED Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/cammisa-wipf

Acuity Brands. (n.d.). *Care-A-Lot Pet Supply LED Lighting Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/care-alot-pet-supply

Acuity Brands. (n.d.). *Chicago School District 59 LED Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/district-59

Acuity Brands. (n.d.). *Chula Vista CA Roadway Lighting Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/chula-vista-ca

Acuity Brands. (n.d.). *Comal School District Smart Lighting Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/comal-school-district

Acuity Brands. (n.d.). *Dell Children's Medical Center LEED Certification.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/dell-childrens-medical-center

Acuity Brands. (n.d.). *Detroit Renovation LED Luminaires Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/detroit-renovation

Acuity Brands. (n.d.). *Dobson Elementary School Gymnasium Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/dobson-elementary

Acuity Brands. (n.d.). *Fountain City Hall.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/fountain-city-hall

Acuity Brands. (n.d.). *Gateway Commerce Center Reno NV.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/gateway-commerce-ctr

Acuity Brands. (n.d.). *Grays Bridge MN LED Luminaires Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/grays-bridge-mn

Acuity Brands. (n.d.). *Grocery Retailer LED Lighting Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/grocery-retailer

Acuity Brands. (n.d.). *Gulf Power Highway 98 Infrastructure Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/gulf-power-highway-98

Acuity Brands. (n.d.). *Gwinnett County Public Schools.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/gwinnett-county-public-schools

Acuity Brands. (n.d.). *Hartsfield-Jackson International Terminal Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/hartsfield-jackson-international-airport-terminal

Acuity Brands. (n.d.). *Henry County Hospital LED Lighting Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/henry-county-hospital

Acuity Brands. (n.d.). *Hibbing Memorial Building Arena Hibbing, MN.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/hibbing-memorial-building-arena-hibbing-mn

Acuity Brands. (n.d.). *Iowa Public Employees Retirement System.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/iowa-public-employees-retirement-system

Acuity Brands. (n.d.). *KSA Lighting OLED Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/ksa-lighting

Acuity Brands. (n.d.). *Lakeland Community College.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/lakeland-community-college

Acuity Brands. (n.d.). *MaineDOT I-295.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/maine-dot

Acuity Brands. (n.d.). *Massachusetts Institute of Technology's Great Dome.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/mit-library

Acuity Brands. (n.d.). *Medical Mutual Lighting Retrofit Solution.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/cleveland-ohio

Acuity Brands. (n.d.). *Meissner Filtration Products.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/meissner-filtration

Acuity Brands. (n.d.). *Monsanto Grinnell IA.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/monsanto-grinnell-ia

Acuity Brands. (n.d.). *Pittsfield MA Holophane Lighting Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/pittsfield-massachusetts

Acuity Brands. (n.d.). *PNC Bank.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/pnc-bank

Acuity Brands. (n.d.). *Rothschild WI.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/rothschild-wi

Acuity Brands. (n.d.). *San Diego State University.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/san-diego-state-university

Acuity Brands. (n.d.). *Shelor Motor Mile.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/shelor-motor-mile

Acuity Brands. (n.d.). *Southland Christian Church.* Retrieved August 11, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/southland-christian-church

Acuity Brands. (n.d.). *Star Market.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/star-market

Acuity Brands. (n.d.). *Tampa General Medical Group Family Care Clinic.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/tampa-general-healthcare

Acuity Brands. (n.d.). *The Castle Museum Outdoor LED Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/castle-museum

Acuity Brands. (n.d.). *Tri-State Generation and Transmission Association, Inc.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/tri-state

Acuity Brands. (n.d.). *U.S. Embassy OLED Lighting Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/us-embassy

Acuity Brands. (n.d.). *University of Minnesota.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/university-of-minnesota-twin-cities

Acuity Brands. (n.d.). *US Highway 101 LED Lighting Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/us-highway-101

Acuity Brands. (n.d.). *Walgreens LED Lighting Case Study.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/walgreens

Acuity Brands. (n.d.). *West Richland WA.* Retrieved August 11, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/west-richland-wa

Acuity Brands. (n.d.). *Yountville CA.* Retrieved August 1, 2017, from http://www.acuitybrands.com/solutions/inspire-me/case-studies/yountville-ca

Advantus Capital. (2013). *Private Placement Bonds: Shedding Light on a Valuable Alternative.* Advantus Capital. Retrieved from https://www.advantuscapital.com/public/acm/Private%20Placement%20Bonds-A%20Valuable%20Alternative.pdf

Bernard, J. (2014). ACEEE Conference Lessons Learned. *ACEEE Financing Forum.*

Building Energy Exchange. (2015). *MechoSystems HQ Renovation Pioneering daylighting provides the foundation for this comprehensive repurposing of MechoSystems' former factory into a modern, LEED Gold corporate headquarters.* Retrieved October 10, 2017, from http://be-exchange.org/media/MechoSystems_Case_Study_copy.pdf

CEC. (2006). *California Commercial End-Use Survey (CEUS).*

CEC. (2015). *2016 Building Energy Efficiency Standards for residential and nonresidential buildings.*

Choi Granade, H., Creyts, J., Derkach, A., Farese, P., Nyquist, S., & Ostrowski, K. (2009). *Unlocking Energy Efficiency in the U.S. Economy.* McKinsey & Company.

Daintree Networks. (2012). *Wholesaler Converts, Controls and Customizes Office Lighting for Dramatic Savings.* Retrieved August 11, 2017

Daintree Networks. (2014). *Case Study – Multi-site Distributor.* Retrieved August 11, 2017

Daintree Networks. (2014). *Large Telecom Provider Invests in Wireless Controls to Optimize Lighting Energy Management for Multi-Facility Operations.* Retrieved August 11, 2017

Daintree Networks. (2014). *LifeWay's Quest for Energy Efficiency.* Retrieved November 30, 2017, from https://hub.currentbyge.com/customer-success-stories/lifeway-s-quest-for-energy-efficiency-daintree-solution-delivers-substantial-lighting-energy-savings

Daintree Networks. (2014). *Mack Technologies Achieves Unprecedented Wireless Control With LED Light in New England.* Retrieved November 30, 2017, from https://hub.currentbyge.com/customer-success-stories/mack-technologies

Daintree Networks. (2015). *Innovative Multi-Application Control Boosts Employee Comfort & Energy Efficiency.* Retrieved August 11, 2017

Daintree Networks. (2015). *National Bank of Arizona Achieves Huge Energy Savings.* Retrieved November 30, 2017, from https://hub.currentbyge.com/customer-success-stories/national-bank-of-arizona-drives-significant-energy-efficiency-and-savings

Daintree Networks. (2016). *OHL Enjoys Improved Productivity, Safety & Comfort.* Retrieved November 30, 2017, from https://hub.currentbyge.com/customer-success-stories/ohl-enjoys-improved-facilities-management-productivity-and-safety

Daintree Networks. (2016). *Salk Institute Achieves Tremendous Energy Savings.* Retrieved November 30, 2017, from https://hub.currentbyge.com/customer-success-stories/smart-science-gives-the-salk-institute-more-lighting-control

Daintree Networks. (n.d.). *Light is control 2020K Street Washington, DC.* Retrieved August 11, 2017, from https://assets.osram-americas.com/assets/Documents/2020KStreet.17b7ea74-4d25-406c-aa51-508e749d86c5.pdf

DesignLights Constrium. (2017). *DLC Advanced Lighting Technology Demonstration: Digital Lumens.* Retrieved October 18, 2017, from https://www.designlights.org/default/assets/File/Lighting%20Controls/DLC_Advanced-Lighting-Fact-Sheet_Digital-Lumens.pdf

Digital Lumens. (2013). *Stone Brewing Co. Deploys Intelligent LEDs in New Addition, Saving 86% in Annual Energy Costs Over T8 Fluorescent Alternatives.* Retrieved August 11, 2017, from https://www.digitallumens.com/resources/case-study/stone-brewing/

Digital Lumens. (2014). *SnoTemp Gains Better, Higher Quality Lighting with 50% Fewer Fixtures and Massive Energy Savings.* Retrieved August 11, 2017, from https://www.digitallumens.com/resources/case-study/snotemp/

Digital Lumens. (2014). *Swire Cold Storage's Search for Maximum Lighting Efficiency Leads to Intelligent LED Upgrade.* Retrieved August 11, 2017, from https://www.digitallumens.com/resources/case-study/swire/

Digital Lumens. (2015). *Ace Hardware Upgrades Retail Support Center to Intelligent LEDs and Saves on Lighting Energy Costs.* Retrieved August 11, 2017, from https://www.digitallumens.com/resources/case-study/ace-hardware/

Digital Lumens. (2015). *Ashland Foundry & Machine Works Saves 85% with Digital Lumens Intelligent LED Lighting.* Retrieved August 11, 2017, from https://www.digitallumens.com/resources/case-study/ashland-foundry-machine-works-saves-85-with-intelligent-led-lighting/

Digital Lumens. (2015). *Dartmouth Tackles Challenging Lighting Retrofit at Leverone Field House.* Retrieved August 11, 2017, from https://www.digitallumens.com/resources/case-study/dartmouth/

Digital Lumens. (2015). *Dassault Falcon Jet Taps Intelligent LED Lighting Solutions.* Retrieved August 11, 2017, from https://www.digitallumens.com/resources/case-study/dassault-falcon-jet/

Digital Lumens. (2015). *Intelligent LED Retrofit Enables Kenwal Steel to Dramatically Improve Lighting Quality While Saving 93% in Lighting Energy Costs Annually.* Retrieved August 11, 2017, from https://www.digitallumens.com/resources/case-study/kenwal/

Digital Lumens. (2015). *QBP Chooses Intelligent LED Lighting for New East Coast Distribution Center, Saving 85% Over Lighting Alternatives.* Retrieved August 11, 2017, from https://www.digitallumens.com/resources/case-study/quality-bicycle-products-chooses-intelligent-lighting-for-new-east-coast-distribution-center/

Digital Lumens. (2016). *AGS Achieves Productivity Gains Upgrading to LightRules ® Power from Digital Lumens.* Retrieved August 11, 2017, from https://www.digitallumens.com/resources/case-study/ags-saves-75-boosts-productivity-with-lightrules-power/

Digital Lumens. (2017). *Gelson's Chooses Intelligent Lighting Backed with Advanced Controls, Analytics, & Reporting for Santa Fe Springs Distribution Center.* Retrieved August 11, 2017, from https://www.digitallumens.com/resources/case-study/gelsons/

Digital Lumens. (2017). *Kienle + Spiess Replace Legacy Lighting with Digital Lumens Intelligent LEDs, Reduce Energy Costs by More Than 80%.* Retrieved August 11, 2017, from https://www.digitallumens.com/resources/case-study/kienle-spiess/

DLC. (2017). *Energy Savings from Networked Lighting Controls (NLC) Systems.*

DLC. (2017, June 1). *Networked Lighting Control System Technical Requirements V2.* Retrieved from Designlights: https://www.designlights.org/lighting-controls/qualify-a-system/technical-requirements/

DLC. (2017). *Networked Lighting Controls Specifications.* Retrieved from Designlights: https://www.designlights.org/workplan/networked-lighting-controls-specification/

DLC, DOE, PNNL. (2017). *Lighting Controls Case Studies.* Retrieved from Designlights: https://www.designlights.org/lighting-controls/case-studies/

DLC, DOE, PNNL. (2017). *Lighting Controls Case Studies.* Retrieved from www.Designlights.org: https://www.designlights.org/lighting-controls/case-studies/

Do, A. (2017). Expanding Lighting Benefits to Organization Mission Objectives. *DesignLights Consortium Stakeholder Meeting.* https://www.designlights.org/news-events/events/2017-dlc-stakeholder-meeting/.

DOE. (2016). *Energy Savings Forecast of Solid-State Lighting in General Illumination Applications.*

DOE. (2017). *Adoption of LIght-Emitting Diodes in Common Lighting Applications.*

EGIA. (2014, March 3). *EGIA's GEOSmart Sustainable Financing Solutions Surpasses $1 Billion in Funded Energy Efficiency and Solar Loans.* Retrieved from EGIA: http://www.egia.org/downloads/pressRelease/EGIA_PressRelease20140227.pdf

Enlighted. (2012). *San Jose City Hall.* Retrieved August 11, 2017, from https://www.enlightedinc.com/wp-content/uploads/2016/05/City-of-San-Jose-Case-Study.pdf

Enlighted. (2013). *JDSU: Implementing People-Responsive Real Estate.* Retrieved August 11, 2017, from http://info.enlightedinc.com/rs/000-IKN-871/images/Case-Study_JDSU.pdf

Enlighted. (2015). *AT&T utilizes Enlighted Advanced Sensors to produce millions of dollars in energy savings —every year.* Retrieved August 11, 2017, from http://info.enlightedinc.com/rs/000-IKN-871/images/Case-Study_ATT.pdf

Enlighted. (2015). *California State University Teams With Enlighted to Significantly Reduce Energy Consumption.* Retrieved August 11, 2017, from http://info.enlightedinc.com/rs/000-IKN-871/images/CASE-STUDY-CSUDH.pdf

Enlighted. (n.d.). *Agilent Technologies: Lighting the Path to Energy Efficiency.* Retrieved August 11, 2017, from http://info.enlightedinc.com/rs/000-IKN-871/images/Agilent%20Technologies.pdf

Enlighted. (n.d.). *Enlighted Inc Resources, Case Studies.* Retrieved from Enlighted Inc: http://www.enlightedinc.com/wp-content/uploads/2016/05/Menlo-Business-Park-Case-Study.pdf

Enlighted. (n.d.). *Interface Global, Inc.* Retrieved August 11, 2017, from http://info.enlightedinc.com/rs/000-IKN-871/images/Interface-Global-Case-Study.pdf

Enlighted. (n.d.). *Menlo Business Park.* Retrieved August 11, 2017, from http://www.enlightedinc.com/wp-content/uploads/2016/05/Menlo-Business-Park-Case-Study.pdf

Enlighted. (n.d.). *Menlo Business Park Case Study.* Retrieved November 2017, from http://www.enlightedinc.com/wp-content/uploads/2016/05/Menlo-Business-Park-Case-Study.pdf

Enlighted. (n.d.). *MERCY.* Retrieved August 1, 2017, from http://www.enlightedinc.com/customer-success-stories/?q=mercy

Enlighted. (n.d.). *SCHIEVER*. Retrieved August 1, 2017, from http://www.enlightedinc.com/customer-success-stories/?q=schiever

Fuller, M., Kunkel, C., Zimring, M., Hoffman, I., Lindgren Soroye, K., & Goldman, C. (2010). *Driving Demand for Home Energy Improvements.* Lawrence Berkeley National Lab. Retrieved from http://drivingdemand.lbl.gov/reports/lbnl-3960e-print.pdf

Fulton, M., & Brandenburg, M. (2012). *United States Building Energy Efficiency Retrofits: Market Sizing and Financing Models.* The Rockefeller Foundation and DB Climate Change Advisors.

Garcia, E. (2015, December 15). *In LEDs, Some see an Intelligence to Rival Smartphones.* Retrieved from Enlighted Inc: http://www.enlightedinc.com/news-coverage/in-leds-some-see-an-intelligence-to-rival-smartphones/

Green Building Research Center. (2014). *Best Practices Case Studies 2014: UC Santa Cruz Laboratory Lighting Conversion Project.* Berkeley: University of California, Berkeley.

Harvard Technology. (n.d.). *Leading high street blue chip retailer.* Retrieved October 11, 2017, from http://www.harvardtechnology.com/files/6514/9338/8071/Case_Study_-_Blue_Chip_Retailer_New.pdf

Harvard Technology. (n.d.). *Oxford Brookes University - United Kingdom.* Retrieved October 11, 2017, from http://www.harvardtechnology.com/files/4914/7757/8520/Case_Study_V4_-_OBU_-_4pp_web_FINAL.pdf

Harvard Technology. (n.d.). *The White Company - United Kingdom.* Retrieved October 11, 2017, from http://www.harvardtechnology.com/files/5814/9008/9581/Case_Study_-_White_Co.-_Upload6.pdf

Henderson, P. (2014, December 22). Senior Financial Policy Specialist, Natural Resources Defense Council (NRDC).

Hubbell. (2015). *CreateChange: Retrofit Lighting & Control Solutions - Commercial Buildings.* Retrieved October 4, 2017, from http://www.hubbelllighting.com/content/solutions/retrofit/downloads/CCComm_22.pdf

KNN Public Finance. (2012). *Financing Feasibility Analysis for Property Assessed Clean Energy (PACE) Programs.* KNN Public Finance. Retrieved from http://www.drivecms.com/uploads/sonomacountyenergy.org/Municipal%20Resources/Document%20Library/Feasibility%20Studies/FeasibilityAnalysis_SecondStagePACEFinancings.pdf

Lacey, S. (2014, May 14). Creating Investor-Ready Efficiency. *Green Tech Media*. Retrieved from http://www.greentechmedia.com/articles/read/ensuri-investor-ready-efficiency-the-industry-cant-just-be-a-bunch-of-cowbo

LBNL. (2015). *Retrofit Demonstration of LED Fixtures with Integrated Sensors and Controls.* Retrieved from https://www.gsa.gov/cdnstatic/LED_Fixtures_with_Integrated_Controls_-_final_508.pdf

Lux Review. (2017). *Connected lighting boosts sales at Guess.* Retrieved October 2, 2017, from http://luxreview.com/article/2017/09/connected-lighting-boosts-sales-at-guess

Lux Review. (2017). *Indoor positioning increases basket values by 10 per cent.* Retrieved October 2, 2017, from http://luxreview.com/article/2017/03/indoor-positioning-increases-store-basket-values-by-10-percent-

Massachusetts Treasury. (2013). *Mass Green Bonds: Quarterly Investor Impact Report.* Massachusetts Treasury. Retrieved from http://www.massbondholder.com/sites/default/files/files/QE%20August%202014%20Green%20Report(1).pdf

Milford, L., Saha, D., Muro, M., Sanders, R., & Rittner, T. (2014). *Clean Energy Finance Through the Bond Market: A New Option for Progress.* Brookings-Rockefeller Project on State and Metropolitan Innovation.

Navigant. (2017, December). *IoT for Lighting*. Retrieved from Navigant Research: https://www.navigantresearch.com/research/iot-for-lighting

Nexant, Inc. (2017). *Advanced Lighting Controls at Blue Diamond Growers.* Customer Advanced Technologies Program Project Evaluation Report. Retrieved August 11, 2017

Osram. (2017). *OSRAM Lighting Solutions supports "Healthy Offices-Research".* Retrieved October 4, 2017, from https://www.osram.com/ls/projects/cbre/index.jsp

Panetta, K. (2017, November). *Top Trends in the Gartner Hype Cycle for Emerging Technologies*. Retrieved from Gartner: https://www.gartner.com/smarterwithgartner/top-trends-in-the-gartner-hype-cycle-for-emerging-technologies-2017/

Philips Lighting. (2013). *Carrefour Hypermarket.* Retrieved September 21, 2017, from http://images.philips.com/is/content/PhilipsConsumer/PDFDownloads/Global/CALI20160620-001-UPD-en_AA-Case_study_Carrefour_Hypermarket_Spain.pdf

Philips Lighting. (2017). *Driving sales by guiding shoppers with lighting.* Retrieved September 21, 2017, from http://images.philips.com/is/content/PhilipsConsumer/PDFDownloads/Global/ODLI20170713_001_UPD_fr_CA_140388_CASE_STUDY_Globus_A4_LR4.pdf

Philips Lighting. (2017). *Introducing the Future of Offices: Philips connected office lighting with Cisco technology.* Retrieved September 21, 2017, from http://images.philips.com/is/content/PhilipsConsumer/PDFDownloads/United%20States/ODLI20171026%5F001%5FUPD%5Fen%5FUS%5FPLt%2D1638CS%5FToronto%5FCisco%5FAlliance%5Fcase%5Fstudy%5FJune2017.pdf

Philips Lighting. (2017). *Philips helps create a comfortable, productive and sustainable environment at The Edge.* Retrieved September 21, 2017, from http://images.philips.com/is/content/PhilipsConsumer/PDFDownloads/Global/PDFs/CSLI20170206_001-UPD-en_AA-The-Edge-Amsterdam-Connected-Lighting-Case-Study.pdf

Phillips, G. (2013). Distributed Lending as a Model for Energy Efficiency Financing . *ACEEE National Conference on Energy Efficiency as a Resource.* Denver: ACEEE. Retrieved from http://aceee.org/files/pdf/conferences/eer/2013/6A-phillips.pdf

Phillips, G. (2014, September 25). AESP Making Dollars and Sense of Energy Efficiency Financing.

Pitkin, J. (2014, February 14).

Pitkin, J. (2014). Green Jobs Green New York Program. *Institute for Energy Economics and Financial Analysis .* Retrieved from http://policyintegrity.org/documents/PITKINPanel7B_2014.pdf

SEE Action Financing Solutions Working Group. (2013). *Using Financing to Scale Up Energy Efficiency.* Retrieved from https://www4.eere.energy.gov/seeaction/system/files/documents/financing_workplan_recommendations.pdf

SEE Action Financing Solutions Working Group. (2014). *Financing Energy Improvements on Utility Bills: Market Updates and Key Program Design Considerations for Policymakers and Administrators.* SEE Action.

Sensity. (2015). *Simon Property Group: Brea Mall - Retail Parking Improved with LEDs and Light Sensory Network.* Retrieved August 11, 2017, from https://static1.squarespace.com/static/53d2cdffe4b069e965155fc8/t/5638ffbbe4b051e44e7b422a/1446576059531/SimonMall_Brea_CS_20150826.pdf

Seventhwave. (2015). *Adjusting Lighting Levels in Commerical Buildings.* Minnesota.

SIFMA. (2014, October 6). *Statistics.* Retrieved from http://www.sifma.org/research/statistics.aspx

Smithwood, B., & Hodum, R. (2013). *Power Factor: Institutional Investors' Policy Priorities Can Bring Energy Efficiency to Scale.* Ceres. Retrieved from http://www.ceres.org/resources/reports/power-factor-institutional-investors2019-policy-priorities-can-bring-energy-efficiency-to-scale

State of Connecticut. (2014, October 6). *Connecticut Statewide Energy Efficiency Dashboard.* Retrieved from http://www.ctenergydashboard.com/Public/PublicRESLoanFinancing.aspx

Team, T. 2. (2017). *2019 T24 CASE Report Indoor Controls.*

U.S. Department of Energy. (2014). *Guest Room Lighting at the Hilton Columbus Downtown.* Retrieved October 10, 2017, from https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/guest-room-lighting-at-the-hilton-columbus-dowtown-case-study.pdf

U.S. Energy Information Administration. (2016, May). *Table E5. Electricity consumption (kWh) by end use, 2012*. Retrieved from EIA.Gov: https://www.eia.gov/consumption/commercial/data/2012/c&e/pdf/e5.pdf

Veitch, J. A., Newsham, G. R., Zhang, M., Galasiu, A. D., Handerson, I. S., & Thompson, A. J. (2017). *Improving Organizational Productivity with Building Automation Systems.* Continental Automated Buildings Association. Retrieved October 6, 2017, from http://www.caba.org/documents/reports/CABA-IOPBAS-2017-Report.pdf

Wei, J. e. (2015). *Wireless Advanced Lighting Controls Retrofit Demonstration.*

Wei, J., Rubinstein, F., Shackelford, J., & Robinson, A. (2015). *Wireless Advanced Lighting Controls Retrofit Demonstration.* Retrieved October 18, 2017, from https://laincubator.org/wp-content/uploads/Daintree-3.-GPG-Full-Report-Advanced-Lighting-Controls-Retrofit-Demo.pdf

West-Lite Supply. (n.d.). *Case Studies: Fry's Electronics.* Retrieved October 11, 2017, from http://www.west-lite.com/contentonly.aspx?file=pdf/CaseStudies.pdf

Williams, A. A. (2011). *A Meta-Analysis of Energy Savings from Lighting Controls in Commercial Buildings.* Retrieved from Lawrence Berkeley National Labs: https://eta.lbl.gov/publications/meta-analysis-energy-savings-lighting

Williams, A. e. (2012). *Quantifying National Energy Savings Potential of Lighting Controls in Commercial Buildings.* LBNL.

APPENDIX A:
Building Energy Savings Insights

Methodologies

Spatial Applications

The energy savings potential of DR-Enabled NLC systems vary by specific space types, for example, private offices, retail sales floor, and hallways. Different space types require different light levels and controls to encourage detailed work,[26] relaxation, safety, and comfort. This fact is highlighted in the California Title 24 Building Code Standards, as different space types have different lighting power density (LPD)[27] and control requirements.[28]

As part of the DLC NLC report (DLC, 2017), space type savings were identified, reported, and aggregated, as data were available. There is no standardized nomenclature for space types within NLC systems, which limited the data available for this exercise. For example, a private office may be labeled "office 1" or "zone 1" in different buildings, limiting the amount of reliably comparable data available through the NLC system reports. Accounting for this hurdle, the DLC report analyzed the relevant data and produced results reporting average savings in common space types by building type.

Control Strategies

A 2012 Lawrence Berkeley National Lab study that reviewed relevant research and case studies showed that occupancy sensors, daylight harvesting, and task-tuning have the potential to save 24-percent, 28-percent, and 36-percent, respectively, and independent of one another (Williams A. e., 2012). When combining multiple control strategies this savings potential dropped to 38-percent due to the interconnected nature of the strategies. Implementing multiple control strategies is increasingly common, as it is mandated for many space types by Title 24, and revisiting the energy savings potential of strategies that are, and are not, mandated by building standards, can offer guidance to their degree of importance in future code development and building implementation.

In partnership with the U.S. Department of Energy (DOE), the DLC, and DLC member utilities, a number of NLC technologies were recently installed with the purpose of capturing and synthesizing data to better understand the performance of the system and installation practices (DLC, DOE, PNNL, 2017). To date, four case studies have been published by Pacific Northwest National Laboratory (PNNL). These studies capture energy savings by control

---

26 The IESNA lighting handbook recommends lighting levels for specific space types and tasks.

27 In the area category compliance method, this is noted on Table 140.6-C in the 2016 California Title 24 Building Standards Code manual.

28 Generally outlined in Section 130.1 Mandatory Indoor Lighting Controls and section 140.6 – Prescriptive requirements for indoor lighting of the 2016 Title 24 Building Standards Code manual.

strategies among different building types and NLC systems, which aids in understanding the range of savings potential based on application. The results of these case studies, in addition to relevant case studies conducted by Green Proving Ground (Wei J. e., 2015), offer an excellent example of continued and current research that captures the energy savings potential of individual control strategies.

Additionally, the Minnesota Department of Commerce conducted a meta-study that focused specifically on the energy savings potential of task tuning in 10 office, public assembly, and education buildings (Seventhwave, 2015). This study identified energy savings opportunities based on current light levels in the spaces and compared that with the Illuminating Engineering Society of North American (IENSA) recommendation, along with tenant feedback, on appropriate light levels. They tuned the spaces accordingly and measured the energy savings reductions. This study takes a different approach than the PNNL and Green Proving Ground case studies, and was thus kept separate in its analysis.[29] From the 10 buildings, seven spaces ranging from an open office, bar, and classrooms, in seven of the different buildings were analyzed.[30]

From a regulatory standpoint, it is important to note that the current (2016) Title 24 building standards consider occupancy, continuous dimming, and daylighting mandatory in the majority of retrofit applications. However, there are exceptions based on space type, lighting power density, and compliance methodology that would allow these control strategies to be considered in excess of the current Title 24.[31]

Reviewing these case studies and Title 24 building code requirements allows us to understand the savings potential of Title 24 code required NLC system components and those that go above and beyond code but enable effective and sustainable demand response.

Results

Energy Savings by Space Type

The DLC report parsed through the NLC zone-naming conventions to arrive at comparable space types across office, warehouse, and retail building types. The lack of nomenclature standardization across buildings resulted in some data being concentrated with specific technology types from a single manufacturer or from similar sub-building types, for example, retail stores under the same ownership.

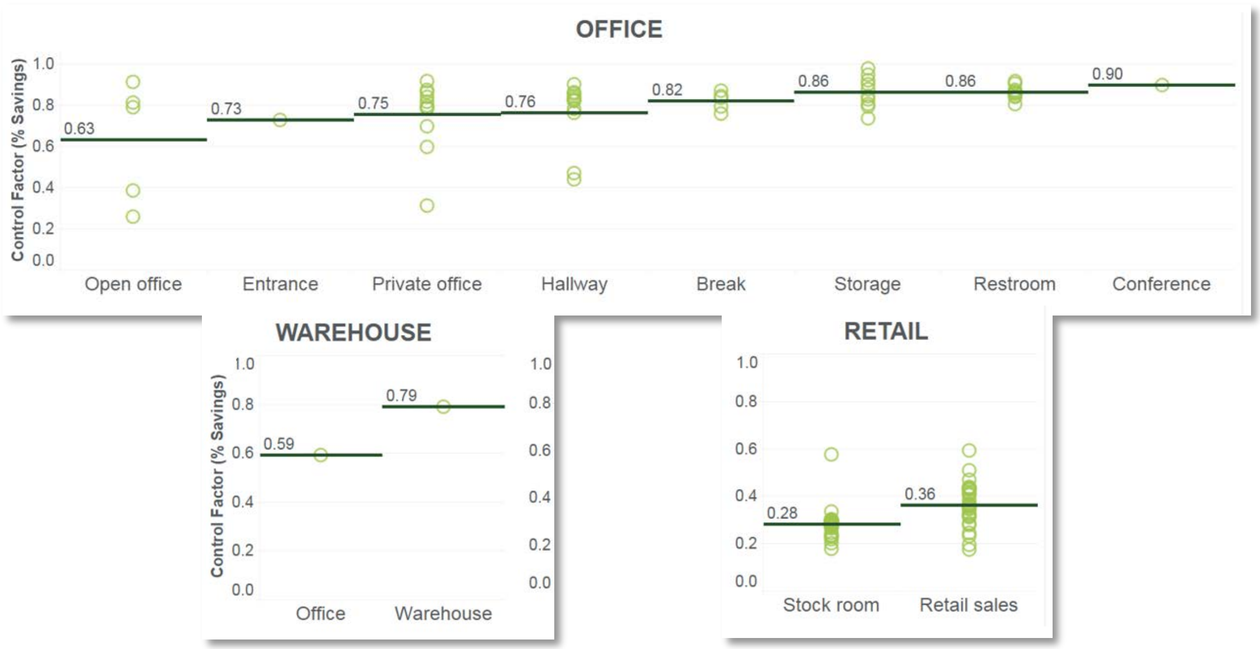
29 The DOE and LBNL case studies installed and implemented multiple control strategies as part of normal building commissioning and operation. The Minnesota DOC study was specifically tailored to task tuning and excluded full facility retrofits.

30 Due to data acquisition error at three of the buildings only seven of the 10 buildings were analyzed

31 For example, in general, continuous dimming, automatic daylighting controls and occupancy sensors are not required for a space types when their lighting power density (LPD) is below 85-percent the required LPD stated by the area category method of compliance. In addition, by complying with Title 24 through the performance approach vs. prescriptive, you can avoid the requirements to install these controls provided your energy balance is still below the performance requirements.

An important trend highlighted by the DLC report and Figure A-1 is that across the majority of building types observed, areas with lower occupancy, such as restrooms and storage, had higher energy savings. This is sensible, as occupancy controls will have the greatest impact where occupancy is most variable. Only the retail dataset runs contrary to this trend where the retail sales floor has a higher energy savings compared to the stock rooms. This could be due, in part, to the retail space type dataset being from a single set of retail buildings with relatively homogenous data and building characteristics.

Figure A-1: Energy Savings by Space Type Relative to an Inferred Baseline



Source: DLC, 2017

For further results, please refer to the DLC study (DLC. "Energy Savings from Networked Lighting Controls (NLC) Systems." 2017.) cited in the references.

Energy Savings by Control Strategy

Compared with the potential energy savings highlighted in the 2011 LBNL study, the field study tests show lower energy savings potential by control strategy, but an overall higher energy savings when operating in combination. This can be explained, at least in part, by the level of intelligence and specific application of individual control strategies. As control strategies, and the data that informs them, have matured, the individual measures have decreased their negative impact on complementary control strategies and achieve deeper energy savings applicable to specific controls. This is a noteworthy stride forward, as California Title 24 often mandates that multiple control strategies be enacted in a single space.

When compiling the results, it also becomes clear that the effectiveness of a control strategy strongly depends on the specific use case and implementation strategies. Three specific outliers from the case studies help tell the story:

- *Warehouse Task Tuning*: This facility was reported as being under-lit in advance of the retrofit, so task tuning was limited and only applied to a few fixtures.
- *Office Occupancy Sensors*: The baseline performance already included some occupancy sensors in enclosed offices and restrooms. The new embedded occupancy sensors were set to "automatic-on" and gradually dim off after the space was unoccupied for 25 minutes. This is contrary to typical operation of sensors, which automatically turn lights off when unoccupied and require manual intervention to turn lights on.
- *Grocery Daylight Harvesting*: There were few windows and skylights in this facility, resulting in low daylight harvesting savings.

The energy savings percentage is attributed after the LED retrofit in all case studies.

Table A-1: Energy Savings by Control Strategy Case Studies Summary

	Building Details			Energy Savings				
Case Study Source	**Building Type**	**Lighting Control Technology**	**Square Feet**	**LED Savings (%)**	**Task Tuning (%)**	**Occupancy Sensors (%)**	**Daylight Harvesting (%)**	**Combined Control Strategies (%)**
DOE, DLC, PNNL, et al.	Medical Office	Cree Smartcast	30,500	29	34	34	12	80
	Warehouse	Digital Lumens	103,000	50	0.20	19	13	32
	Office	Philips SpaceWise	19,400	64	12	-5	16	23
	Grocery Store	Daintree ControlScope	73,000	3	47	4	~0	51
Green Proving Ground	Office	Wireless Advanced Lighting Controls	6,800	55	10	22	7	39
			Average:	**40**	**21**	**15**	**12**	**47**
			Range:	**3 to 55**	**0.2 to 47**	**-5 to 34**	**~0 to 16**	**23 to 80**
			LBNL 2011		36	24	28	38

Sources: (DLC, DOE, PNNL, 2017), (Wei J. e., 2015), (Williams A. e., 2012)

The meta-study conducted by the Minnesota Department of Commerce found very similar task-tuning energy savings results—22-percent (Seventhwave, 2015), further strengthening the average results shown.

APPENDIX B: Non-Energy Benefit Quantification Matrix for Different Building Types, Benefit Value Intensity Levels, and Non-Energy Benefits

Offices	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Energy					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x			Decreasing energy usage with decreased lighting operation	kWh saved/ft²/year *base case is no controls	0.13 - 14.84	[022] 19,100 kWh annual savings compared to original 0.56W/ft² design (17,000 ft²)	1.12	kWh/ft²/yr
								[034] a $12,000 savings over initial three-month period (43,000 ft²)	14.84	kWh/ft²/yr
								[075] Annual savings: 986,100 kWh/ $155,000 (~3500 fixtures)	3.31	kWh/ft²/yr
								[099] 8kW peak demand reduction & > 100,000 kWh annual savings (50,000 ft²)	2.00	kWh/ft²/yr
								[101] 50 MWh/ $6,000 estimated energy savings; $1,200 HVAC interactive effect savings (250,000 ft²)	0.13	kWh/ft²/yr
								[105] 15% additional HVAC savings by making the per-lighting fixture occupancy and temperature data available to the HVAC control (500,000 ft², 60% lighting savgins, 30% HVAC savings, 2.7M kWh savings, $400k total savings)	2.45	kWh/ft²/yr
								[108] €100,000 predicted annual energy cost savings (40,000 m², 6,500 fixtures)	1.41	kWh/ft²/yr
								[109] 177,000kWh/ $45,000 annual savings; 50% energy savings over traditional fluorescent lighting. Up to 80% with the additional energy savings from analyzing the data and optimizing space usage. (1,400 fixtures)	1.49	kWh/ft²/yr
								[H001] Annual energy savings 435,712 kWh (150,000 ft², space rental: $19.5/ft², pre-retrofit NOI: $11.5/ft², 8% cap rate, $0.11/kWh electric rate)	2.90	kWh/ft²/yr
								[R003] Lighting consumption reduced from 3.7 kWh/sf/yr to 2.3 kWh/sf/yr, a 37.8% savings	1.40	kWh/ft²/yr
								[R004] Appraisers building EUI decreased from 2.3 kWh/ft² to 1.6 kWh/ft² for controls only or 0.7 kWh/ft² for controls + LED (6800 ft²); Moss building EUI decreased from 2.18 kWh/ft²/yr to 1.46 kWh/ft²/yr for controls only (24,989 ft²)	0.72	kWh/ft²/yr
Space Optimization	x	x	x	x	Negawatts by reducing unused space	kWh saved/ft²/year * base case is the same controls	0.89	[109] 177,000kWh/ $45,000 annual savings; 50% energy savings over traditional fluorescent lighting. Up to 80% with the additional energy savings from analyzing the data and optimizing space usage. (1,400 fixtures)	0.89	kWh/ft²/yr
Increase Facility Control	x	x	x	x	More insight allows for energy efficiency changes in building operation	kWh saved/ft²/year due to increased system integration (i.e. savings beyond LEDs and direct lighting controls)	1.47	[105] 15% additional HVAC savings by making the per-lighting fixture occupancy and temperature data available to the HVAC control (500,000 ft², 60% lighting savings, 30% HVAC savings, 2.7M kWh savings, $400k total savings) The lighting controls reduce heat and produce an additional 10% HVAC savings throughout the year	1.47	kWh/ft²/yr
Improved Environmental Parameters	x	x	x		Reducing GHG requires reducing energy usage.	kWh saved/ft²/year resulting from reduced GHG				
Ease of Code Compliance	x	x			T24 building code results in energy saved	Average annual operational LPD lower than code LPD allowance discounted by mandated controls	0.61	[082] 92,100 kWh energy savings. Over 34% Energy Reduction. The project also delivered automated plug load and exterior signage control and allowed the music leader to comply with California's Title 24 requirements. (150,000 ft²) * This is not necessarily consistent with the defined performance metric	0.61	kWh/ft²/yr
Future Proofing	x	x	x	x	Savings by installed advanced monitoring and control	kWh/ft²/yr reduced beyond code				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Building					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x			Increased building value through improved operating income from lowered energy and maintenance costs.	Building value increase per ft²	0.54 - 8.87	[075] Annual maintenance cost savings: $20,000 (~3500 fixtures)	8.87	$/ft²
								[099] 5% expected maintenance cost savings (50,000 ft²)		
								[101] $1,800 operational savings (250,000 ft²)	0.54	$/ft²
								[H001] Annual savings of $88,875 translates to the equivalent of $1,110,938 in asset value improvement (150,000 ft²) ->	7.41	$/ft²
Space Optimization	x	x	x	x	Avoided costs: not adding new space since current space is more efficiently used.	Space costs ($) saved/ft²/year	10.54	[108] €1.5M space utilization cost savings; reduce space required per employee from 12.6 m² to 7.6 m² (40,000 m²)	10.54	$/ft²
Increase Facility Control	x	x	x	x	Increased building value through improved operating income from lowered energy and maintenance costs due to increased control.	Building value increase per ft²	3.29 - 8.78	[105] 15% additional HVAC savings by making the per-lighting fixture occupancy and temperature data available to the HVAC control (500,000 ft², 60% lighting savings, 30% HVAC savings, 2.7M kWh savings, $400k total savings) Only the 15% HVAC energy savings considered	3.29	$/ft²
								[105] 15% additional HVAC savings by making the per-lighting fixture occupancy and temperature data available to the HVAC control (500,000 ft², 60% lighting savings, 30% HVAC savings, 2.7M kWh savings, $400k total savings) All savings considered	8.78	$/ft²
Improved Environmental Parameters	x	x	x		Buildings with low environmental impacts have higher appraised values and boost business image; therefore resulting in higher rent values. LEED certification.	% rent increased * Higher impact with additional technology improvements in addition to lighting				
Ease of Code Compliance	x	x			Operates as code intended. Additional codes to consider: fire safety where visualization and remote control allows for remote emergency light testing. Saves time of reoccurring inspections by limiting corrections and speed of any necessary changes. It also saves time in periodic (monthly) testing.	1. Cost saved on adhering to code				
Future Proofing	x	x	x	x	Increased building value, improved facility operations, incorporate staffing changes, building model changes, ease about future code or building changes	Cost (time and labor) of re-commissioning * base case is non-NLC				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					People					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Lowered overhead costs on employee-specific supplies, equipment and spaces.	Individual workspace: Reduced overhead \$/employee/year -> \$/ft²/year	26.4	[108] Reduce space required per employee from 12.6 m^2 to 7.6 m^2; added 1,000 employees to office space in 20 months; lower annual cost > €1,800/employee (40,000 m^2)	26.40	\$/ft²
Increase Facility Control	x	x	x	x	Decrease tenants/employees needed for operational analysis, data already collected on occupancy, energy usage, O&M scheduling	% decrease of time to resolution -> \$ saved on man hours for trouble shooting		[O003] Perceived performance improvement of 18%. 71% felt more energized, 78% felt happier, and 78% felt healthier. Overall 12 % increase in accuracy and 10 % difference in productivity. ***[Too difficult to distill to a value from the given information]***		
Improved Environmental Parameters	x	x	x		Buildings with lower environmental impacts often adopt human-centric design to create superior working environment	% decrease in worker sick leaves compared to like-kind buildings designed to traditional environmental parameters	25	[R001] Benchmarks: 2-15 day/yr sick leaves; Better Buildings (incl. Green Buildings): 0.4-1.5 day/yr sick leaves From the description above, worst case would be 25% (2->1.5 day/yr), and best case would be 97% (15->0.4 day/yr) decrease in sick leaves	25	%
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	More effective use of time, less complaints associated with building changes	% Reduction in facility tickets per change				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Revenue					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Increased revenue generated by additional employees added to use the same workspace.	% revenue increase/year*				
Increase Facility Control	x	x	x	x	Personalized control and/or more control versatility (e.g. Task-tuning) to increase outputs (productivity) in different areas	% increase in productivity		[O003] Perceived performance improvement of 18%. 71% felt more energized, 78% felt happier, and 78% felt healthier. Overall 12 % increase in accuracy and 10 % difference in productivity.	10%	%
Improved Environmental Parameters	x	x	x							
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	From a building owner's perspective: the flexibility of tenants, housing warehouse, office, and retail with design flexibility and code compliance. Tools that can leverage/optimize each space.	Building owner's NOI (net operating income) increased beyond market rent increase rate * not applicable to triple net leases				

NEB	Benefits Value Intensity (BVI): Energy	Building	People	Revenue	Value Impact Story & Performance Metric — Energy: Narrative	Performance Metric	Existing Literature (Manufacturer Case Studies): Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x			Decreasing energy usage with decreased lighting operation	kWh saved/ft²/year *base case is no controls	3.18 - 21.37	[009] $5,000 estimated annual savings compared to HID (20,000 ft²)	3.18	kWh/ft²/yr
								[113] >60% energy saves compared with standard lighting solutions. (7,500 m²) [Too difficult to distill to a value from the given information]		
								[Ha001] 34% energy savings through wirelessly controlled LED lighting alone ***[Too difficult to distill to a value from the given information]***		
								[Ha002] 75% savings during non-trading and stocking hours by dim lights to 25% of lumen output (129 fixtures) ***[Too difficult to distill to a value from the given information]***		
								[Z001] 1,068,579 kWh/$160,288 energy savings (avg. per store), 35,263,107 kWh/$5,289,504 savings (33 stores) (50,000-180,000 ft² per store)	5.94 - 21.37	kWh/ft²/yr
Space Optimization	x	x	x	x	Through space optimization, future store designs are improved, which consume less energy.	kWh saved/ft²/year *baseline is the existing store				
Increase Facility Control	x	x	x	x	More insight allows for energy efficiency changes in building operation	kWh saved/ft²/year due to increased system integration (i.e. savings beyond LEDs and direct lighting controls)		[Ha001] Additional 20% savings when factoring in the integrated Micro BeMS ***[Too difficult to distill to a value from the given information]***		
Improved Environmental Parameters	x	x	x		Reducing GHG leads to reducing energy usage	kWh saved/ft²/year resulting from reduced GHG	1.60–21.37	[113] Expected to reduce GHG by an 96	1.60	kWh/ft²/yr
								[Z001] 767.24 MT (avg. per store), 25,319 MT (33 stores) CO2 reduction (50,000-180,000 ft² per store)	5.94–21.37	kWh/ft²/yr
Ease of Code Compliance	x	x			T24 building code results in energy saved	Avg. annual operational LPD lower than code LPD allowance discounted by mandated controls				
Future Proofing	x	x	x	x	Savings by installed advanced monitoring and control	kWh/ft²/yr reduced beyond code				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Building					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x			Increased building value through improved operating income from lowered energy and maintenance costs.	Building value increase per ft²	3.32	[009] $5,000 estimated annual savings compared to HID (20,000 ft²). Assuming 7.54% cap rate (all metro, all class average for retail buildings)	3.32	$/ft²
Space Optimization	x	x	x	x	Through space optimization, future store designs are improved, which reduce O&M costs.	O&M costs ($) saved/ft²/year *baseline is the existing store				
Increase Facility Control	x	x	x	x	Increased building value through improved operating income from lowered energy and maintenance costs due to increased control.	Building value increase per ft²				
Improved Environmental Parameters	x	x	x		Buildings with low environmental impacts have higher appraised values and boost brand image/identity; therefore resulting in higher rent values. LEED certification.	% rent increased * Higher impact with additional technology improvements in addition to				
Ease of Code Compliance	x	x			Operates as code intended. Additional codes to consider: fire safety where visualization and remote control allows for remote emergency light testing. Saves time of reoccurring inspections by limiting corrections and speed of any necessary changes. It also saves time in periodic (monthly) testing.	Cost saved on adhering to code and losses avoided on delays in obtaining certificate of occupancy				
Future Proofing	x	x	x	x	ncreased building value, improved facility operations, incorporate staffing changes, building model changes, ease about future code or building changes	Cost (time and labor) of re-commissioning * base case is non-NLC				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					People					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Indoor positioning-based business intelligence systems purchases	% decrease in product				
Increase Facility Control	x	x	x	x	Targeted lighting strategies increase the appeal of featured products	% increase in foot traffic	15	[110] 15% more people enter the promotional area compared to uniform lighting; 6% sales increase (180m² promotional area)	15	%
Improved Environmental Parameters	x	x	x		Eco-friendly building designs attract more customers	% foot traffic increase compared to traditional store design				
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	More effective use of time, less complaints associated with building changes	Reduction in facility tickets per change can increase the efficiency of purchase cycle time				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Revenue					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Indoor positioning-based business intelligence enables a more effective product placement leading to increased revenue, based on customer shopping patterns.	% increase in sales	10	[O001] Shoppers have spent over 10% more since the installation of the indoor-positioning technology	10.00	%
								[O002] average value of purchases made by customers rise by 10%	10.00	%
Increase Facility Control	x	x	x	x	Targeted lighting strategies boosts the sales of featured products	% sales increase of featured products	6	[110] 15% more people enter the promotional area compared to uniform lighting; 6% sales increase (180m² promotional area)	6	%
Improved Environmental Parameters	x	x	x							
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	From a building owner's perspective: the flexibility of tenants, housing warehouse, office, retail...with design flexibility and code compliance. Tools that can leverage/optimize each space.	Building owner's NOI (net operating income) increased beyond market rent increase rate * not applicable to triple net leases				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Energy					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x			Decreasing energy usage with decreased lighting operation	kWh saved/ft²/year *base case is no controls	4.70 - 8.43	[087] 81% avg energy savings; LPD reduced by 39.56% (1,000,000 ft²) [Too difficult to distill to a value from the given information]		
								[091] 547,868 kWh/ $53,691 annual savings (65,000 ft²)	8.43	kWh/ft²/yr
								[094] 120,000 kWh savings (first 6 months) ***[Too difficult to distill to a value from the given information]***		
								[095] 573,994 kWh savings over fluorescent; 401,650 kWh over plain LED (122,000 ft²)	4.70	kWh/ft²/yr
Space Optimization	x	x	x	x	Negawatts by reducing unused space	kWh saved/ft²/year * base case is the same controls				
Increase Facility Control	x	x	x	x	More insight allows for energy efficiency changes in building operation.	kWh saved/ft²/year due to increased system integration (i.e. savings beyond LEDs and direct lighting controls)				
Improved Environmental Parameters	x	x	x		Reducing GHG requires reducing energy usage.	kWh saved/ft²/year resulting from reduced GHG				
Ease of Code Compliance	x	x			T24 building code results in energy saved.	Average annual operational LPD lower than code LPD allowance discounted by mandated controls				
Future Proofing	x	x	x	x	Savings by installed advanced monitoring and control.	kWh/ft²/yr reduced beyond code				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Building					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x			Increased building value through improved operating income from lowered energy and maintenance costs.	Building value increase per ft²	14.39	[091] $9,251 annual maintenance cost savings (65,000 ft²)	14.39	$/ft²
								[094] >€6,000 annual savings ***[Too difficult to distill to a value from the given information]***		
								[095] Reduce fixture count by 30% (122,000 ft²) [Too difficult to distill to a value from the given information]		
Space Optimization	x	x	x	x	Avoided costs: not adding new space since current space is more efficiently used.	O&M costs ($) saved/ft²/year				
Increase Facility Control	x	x	x	x	Increased building value through improved operating income from lowered energy and maintenance costs due to increased control.	Building value increase per ft²				
Improved Environmental Parameters	x	x	x		Buildings with low environmental impacts have higher appraised values and boost business image; resulting in higher rent values. LEED certification.	% rent increased * Higher impact with additional technology improvements in addition to lighting				
Ease of Code Compliance	x	x			Operates as code intended. Additional codes to consider: fire safety where visualization and remote control allows for remote emergency light testing. Saves time of reoccurring inspections by limiting corrections and speed of any necessary changes. It also saves time in periodic (monthly) testing.	1. Cost saved on adhering to code 2. Losses avoided on delays in obtaining				
Future Proofing	x	x	x	x	Increased building value, improved facility operations, incorporate staffing changes, building model changes, and ease about future code or building changes.	Cost (time and labor) of re-commissioning * base case is non-NLC				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					People					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Reduced time to find desired products based on optimized product locations	Avg. minutes/item retrieved decrease				
Increase Facility Control	x	x	x	x	Decrease tenants/employees needed for operational analysis, data already collected on occupancy/location, energy usage, O&M scheduling.	% decrease of time to resolution -> $ saved on people hours for trouble shooting				
Improved Environmental Parameters	x	x	x		Buildings with lower environmental impacts often adopt human-centric design to create superior working environment.	% decrease in worker sick leaves compared to like-kind buildings designed to traditional environmental parameters				
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	More effective use of time, less complaints associated with building changes.	% Reduction in facility tickets per change				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Revenue					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Warehouse more efficient stock arrangement for high-trafficked products	% increase of items processed per hour				
Increase Facility Control	x	x	x	x	Task-tuning to increase outputs (productivity) in different task areas	% increase in productivity				
Improved Environmental Parameters	x	x	x							
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	Ability to change processes based on technology changes.	% NOI (net operating income) increase versus projected baseline				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric						
					Energy						
							Existing Literature (Manufacturer Case Studies)				
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x			Decreasing energy usage with decreased lighting operation	kWh saved/ft²/year *base case is no controls	2.01	[096] 1,000,000+ kWh annual savings in lighting-related energy usage (~148,000+280,000+70,000 ft²)	2.01	kWh/ft²/yr
Space Optimization	x	x	x	x	Negawatts by reducing unused space	kWh saved/ft²/year * base case is the same controls				
Increase Facility Control	x	x	x	x	More insight allows for energy efficiency changes in building operation.	kWh saved/ft²/year due to increased system integration (i.e. savings beyond LEDs and direct lighting controls)	1.00	[096] >500,000 kWh annual reduction in heat-related loads on refrigeration systems loads (~148,000+280,000+70,000 ft²)	1.00	kWh/ft²/yr
Improved Environmental Parameters	x	x	x		Reducing GHG requires reducing energy usage.	kWh saved/ft²/year resulting from reduced GHG				
Ease of Code Compliance	x	x			T24 building code results in energy saved.	Average annual operational LPD lower than code LPD allowance discounted by mandated controls				
Future Proofing	x	x	x	x	Savings by installed advanced monitoring and control.	kWh/ft²/yr reduced beyond code				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Building					
							Existing Literature (Manufacturer Case Studies)			
NEB	**Energy**	**Building**	**People**	**Revenue**	**Narrative**	**Performance Metric**	**Value Range**	**Value(s) Cited**	**Distilled Value(s)**	**Unit**
Decreased O&M Costs	x	x			Increased building value through improved operating income from lowered energy and maintenance costs.	Building value increase per ft²	3.00	[096] $12,000 annual maintenance cost savings (~148,000+280,000+70,000 ft²); 55% fixture count reduction (280,000 ft²)	3.00	$/ft²
Space Optimization	x	x	x	x	Avoided costs: not adding new space since current space is more efficiently used.	O&M costs ($) saved/ft²/year				
Increase Facility Control	x	x	x	x	Increased building value through improved operating income from lowered energy and maintenance costs due to increased control.	Building value increase per ft²	1.32	[096] >500,000 kWh annual reduction in heat-related loads on refrigeration systems loads (~148,000+280,000+70,000 ft²)	1.32	$/ft²
Improved Environmental Parameters	x	x	x		Buildings with low environmental impacts have higher appraised values and boost business image; resulting in higher rent values. LEED certification.	% rent increased * Higher impact with additional technology improvements in addition to lighting				
Ease of Code Compliance	x	x			Operates as code intended. Additional codes to consider: fire safety where visualization and remote control allows for remote emergency light testing. Saves time of reoccurring inspections by limiting corrections and speed of any necessary changes. It also saves time in periodic (monthly) testing.	1. Cost saved on adhering to code				
Future Proofing	x	x	x	x	Increased building value, improved facility operations, incorporate staffing changes, building model changes, and ease about future code or building changes.	Cost (time and labor) of re-commissioning * base case is non-NLC				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					People					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Reduced time to find desired products based on optimized product locations	Avg. minutes/item retrieved decrease				
Increase Facility Control	x	x	x	x	Decrease tenants/employees needed for operational analysis, data already collected on occupancy, energy usage, O&M scheduling.	% decrease of time to resolution -> $ saved on people hours for trouble shooting				
Improved Environmental Parameters	x	x	x		Buildings with lower environmental impacts often adopt human-centric design to create superior working environment.	% decrease in worker sick leaves compared to like-kind buildings designed to traditional environmental parameters				
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	More effective use of time, less complaints associated with building changes.	% Reduction in facility tickets per change				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Revenue					
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Existing Literature (Manufacturer Case Studies)			
							Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Warehouse more efficient stock arrangement for high-trafficked products	% increase of items processed per hour				
Increase Facility Control	x	x	x	x	Task-tuning to increase outputs (productivity) in different task areas	% increase in productivity				
Improved Environmental Parameters	x	x	x							
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	Ability to change processes based on technology changes.	% NOI (net operating income) increase versus projected baseline				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric				
					Energy				
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Existing Literature (Manufacturer Case Studies)		
							Value Range	Value(s) Cited	Distilled Value(s)
Decreased O&M Costs	x	x			Decreasing energy usage with decreased lighting operation	kWh saved/ft²/year *base case is no controls	0.36	[R002] 145,236 kWh/ $10,167 in energy costs annual savings relative to the code power allowance ($0.07/kWh, 3,500 annual operating hours, 532 guest rooms & suites ~403,000 ft²)	0.36
Space Optimization	x	x	x	x	Negawatts by reducing unused space	kWh saved/ft²/year * base case is the same controls			
Increase Facility Control	x	x	x	x	More insight allows for energy efficiency changes in building operation.	kWh saved/ft²/year due to increased system integration (i.e. savings beyond LEDs and direct lighting controls)			
Improved Environmental Parameters	x	x	x		Reducing GHG requires reducing energy usage.	kWh saved/ft²/year resulting from reduced GHG			
Ease of Code Compliance	x	x			T24 building code results in energy saved.	Average annual operational LPD lower than code LPD allowance discounted by mandated controls			
Future Proofing	x	x	x	x	Savings by installed advanced monitoring and control.	kWh/ft²/yr reduced beyond code			

	Benefits Value Intensity (BVI)					Value Impact Story & Performance Metric					
						Building					
								Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Unit	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x			kWh/ft²/yr	Increased building value through improved operating income from lowered energy and maintenance costs.	Building value increase per ft²				
Space Optimization	x	x	x	x		Through space optimization, future hotel layout designs are improved, which reduce O&M costs.	O&M costs ($) saved/ft²/year				
Increase Facility Control	x	x	x	x		Increased building value through improved operating income from lowered energy and maintenance costs due to increased control.	Building value increase per ft²				
Improved Environmental Parameters	x	x	x			Buildings with low environmental impacts have higher appraised values and boost business image; resulting in higher rent values. LEED certification.	% rent increased * Higher impact with additional technology improvements in addition to lighting				
Ease of Code Compliance	x	x				Operates as code intended. Additional codes to consider: fire safety where visualization and remote control allows for remote emergency light testing. Saves time of reoccurring inspections by limiting corrections and speed of any necessary changes. It also saves time in periodic (monthly) testing.	1. Cost saved on adhering to code 2. Losses avoided on delays in				
Future Proofing	x	x	x	x		Increased building value, improved facility operations, incorporate staffing changes, building model changes, and ease about future code or building changes.	Cost (time and labor) of re-commissioning * base case is non-NLC				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					People					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Lowered overhead costs on employee-specific supplies, equipment and spaces.	Individual workspace: Reduced overhead \$/employee/year -> \$/ft²/year				
Increase Facility Control	x	x	x	x	Decrease employees needed for operational analysis, data already collected on occupancy, energy usage, O&M scheduling.	% decrease of time to resolution -> \$ saved on people hours for trouble shooting				
Improved Environmental Parameters	x	x	x		Brands with eco-friendly image (building designs) attract more customers.	% occupancy increase compared to traditional design				
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	More effective use of time, less complaints associated with building changes.	Reduction in facility tickets per change				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Revenue					
							Existing Literature (Manufacturer Case Studies)			
NEB	**Energy**	**Building**	**People**	**Revenue**	**Narrative**	**Performance Metric**	**Value Range**	**Value(s) Cited**	**Distilled Value(s)**	**Unit**
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Increased revenue generated by additional employees added to use the same workspace.	% revenue increase/year* * % makes more sense than $ since different business has different scale of revenue				
Increase Facility Control	x	x	x	x	Task-tuning to increase outputs (productivity) in different task areas.	% increase in productivity				
Improved Environmental Parameters	x	x	x							
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	Ability to change processes based on technology changes.	% NOI (net operating income) increase versus projected baseline				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Energy					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x			Decreasing energy usage with decreased lighting operation	kWh saved/ft²/year *base case is no controls	0.93 - 3.07	[081] Saved over $50,000 annually (108,000 ft²)	2.72	kWh/ft²/yr
								[088] 85%/$85,652 annual kWh savings (215,000 ft²)	3.07	kWh/ft²/yr
								[093] 93%annual energy savings. (110,000 ft²) [Too difficult to distill to a value from the given information]		
								[094] 120,000 kWh savings (first 6 months) ***[Too difficult to distill to a value from the given information]***		
								[DL001] 95,339 kWh/ $13,800 annual savings (103,000 ft²)	0.93	kWh/ft²/yr
Space Optimization	x	x	x	x	Negawatts by reducing unused space	kWh saved/ft²/year * base case is the same controls				
Increase Facility Control	x	x	x	x	More insight allows for energy efficiency changes in building operation.	kWh saved/ft²/year due to increased system integration (i.e. savings beyond LEDs and direct lighting controls)				
Improved Environmental Parameters	x	x	x		Reducing GHG requires reducing energy usage.	kWh saved/ft²/year resulting from reduced GHG				
Ease of Code Compliance	x	x			T24 building code results in energy saved.	Average annual operational LPD lower than code LPD allowance discounted by mandated controls				
Future Proofing	x	x	x	x	Savings by installed advanced monitoring and control.	kWh/ft²/yr reduced beyond code				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Building					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x			Increased building value through improved operating income from lowered energy and maintenance costs.	Building value increase per ft²	6.09	[088] $2,408 annual service savings (215,000 ft²)	6.09	$/ft²
								[093] Reduce 60% fixture count ***[Too difficult to distill to a value from the given information]***		
								[094] >€6,000 annual savings ***[Too difficult to distill to a value from the given information]***		
Space Optimization	x	x	x	x	Avoided costs: not adding new space since current space is more efficently used.	O&M costs ($) saved/ft²/year				
Increase Facility Control	x	x	x	x	Increased building value through improved operating income from lowered energy and maintenance costs due to increased control.	Building value increase per ft²				
Improved Environmental Parameters	x	x	x		Buildings with low environmental impacts have higher appraised values and boost business image; resulting in higher rent values. LEED certification.	% rent increased * Higher impact with additional technology improvements in addition to lighting				
Ease of Code Compliance	x	x			Operates as code intended. Additional codes to consider: fire safety where visualization and remote control allows for remote emergency light testing. Saves time of reoccurring inspections by limiting corrections and speed of any necessary changes. It also saves time in periodic (monthly) testing.	1. Cost saved on adhering to code Losses avoided				
Future Proofing	x	x	x	x	Increased building value, improved facility operations, incorporate staffing changes, building model changes, and ease about future code or building changes.	Cost (time and labor) of re-commissioning * base case is non-NLC				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					People					
							Existing Literature (Manufacturer Case Studies)			
NEB	**Energy**	**Building**	**People**	**Revenue**	**Narrative**	**Performance Metric**	**Value Range**	**Value(s) Cited**	**Distilled Value(s)**	**Unit**
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Time saved due to facility operations spacing. Reorganizing assembly line based occupancy patterns	Individual workspace: Reduced overhead \$/employee/year -> \$/ft²/year				
Increase Facility Control	x	x	x	x	Decrease tenants/employees needed for operational analysis, data already collected on occupancy/location, energy usage, downtime, O&M facility equipment scheduling.	% decrease of time to resolution -> \$ saved on people hours for trouble shooting	6 - 20	[089] line productivity increased by 20%, avoiding purchase of a \$250,000 piece of CNC equipment.	20	%
								[DL001] Workers satisfaction rose from pre-retrofit 87% (w/ 2 complaints on conditions being too bright or dim) to post-retrofit 93% (w/ 1 complaint on conditions being too bright or dim).	6	%
Improved Environmental Parameters	x	x	x		Buildings with lower environmental impacts often adopt human-centric design to create superior working environment. Less polluting and cleaner work environment.	% decrease in worker sick leaves compared to like-kind buildings designed to traditional environmental parameters				
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	More effective use of time, less complaints associated with facility changes.	% Reduction in facility tickets per change				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Revenue					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Increased revenue generated by improved processing. Identifying spaces of lag and implementing changes to allow for improvements.	% revenue increase/year* * % makes more sense than $ since different business has different scale of revenue				
Increase Facility Control	x	x	x	x	Task-tuning to increase outputs (productivity) in different task areas	% increase in productivity				
Improved Environmental Parameters	x	x	x							
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	Ability to change processes based on technology changes and/or market fluctuations.	% NOI (net operating income) increase versus projected baseline				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Energy					
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Existing Literature (Manufacturer Case Studies)			
							Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x			Decreasing energy usage with decreased lighting operation	kWh saved/ft²/year *base case is no controls	7.05	[010] 40% reduction in wattage used ***[Too difficult to distill to a value from the given information]***		
								[015] ~$54,000 energy savings similar facilities (87,300 ft²)	7.05	kWh/ft²/yr
Space Optimization	x	x	x	x	Negawatts by reducing unused space	kWh saved/ft²/year * base case is the same controls				
Increase Facility Control	x	x	x	x	More insight allows for energy efficiency changes in building operation.	kWh saved/ft²/year due to increased system integration (i.e. savings beyond LEDs and direct lighting controls)				
Improved Environmental Parameters	x	x	x		Reducing GHG requires reducing energy usage.	kWh saved/ft²/year resulting from reduced GHG				
Ease of Code Compliance	x	x			T24 building code results in energy saved.	Average annual operational LPD lower than code LPD allowance discounted by mandated controls				
Future Proofing	x	x	x	x	Savings by installed advanced monitoring and control.	kWh/ft²/yr reduced beyond code				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Building					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x			Increased building value through improved operating income from lowered energy and maintenance costs.	Building value increase per ft²				
Space Optimization	x	x	x	x	Avoided costs: not adding new space since current space is more efficiently used.	O&M costs ($) saved/ft²/year				
Increase Facility Control	x	x	x	x	Increased building value through improved operating income from lowered energy and maintenance costs due to increased control.	Building value increase per ft²				
Improved Environmental Parameters	x	x	x		Buildings with low environmental impacts have higher appraised values and boost business image; resulting in higher rent values. LEED certification.	% rent increased * Higher impact with additional technology improvements in addition to lighting				
Ease of Code Compliance	x	x			Operates as code intended. Additional codes to consider: fire safety where visualization and remote control allows for remote emergency light testing. Saves time of reoccurring inspections by limiting corrections and speed of any necessary changes. It also saves time in periodic (monthly) testing.	1. Cost saved on adhering to code 2. Losses avoided on				
Future Proofing	x	x	x	x	Increased building value, improved facility operations, incorporate staffing changes, building model changes, and ease about future code or building changes.	Cost (time and labor) of re-commissioning * base case is non-NLC				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					People					
							Existing Literature (Manufacturer Case Studies)			
NEB	**Energy**	**Building**	**People**	**Revenue**	**Narrative**	**Performance Metric**	**Value Range**	**Value(s) Cited**	**Distilled Value(s)**	**Unit**
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Lowered overhead costs on employee-specific supplies, equipment and spaces.	Individual workspace: Reduced overhead \$/employee/year -> \$/ft^2/year				
Increase Facility Control	x	x	x	x	Decrease employees needed for operational analysis, data already collected on occupancy, energy usage, O&M scheduling, and employee scheduling.	% decrease of time to resolution -> \$ saved on people hours for trouble shooting				
Improved Environmental Parameters	x	x	x		Campus with lower environmental impacts often adopt human-centric design to create superior learning environment.	% decrease in student sick absence compared to like-kind campus designed to traditional environmental parameters				
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	More effective use of time, less complaints associated with building changes. Ability to adapt to technological changes.	% Reduction in facility tickets per change				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Revenue					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Private institutions: Increased revenue generated by additional employees added to use the same workspace.	% revenue increase/year* * % makes more sense than $ since different business has different scale of revenue				
Increase Facility Control	x	x	x	x	Private institutions: Personalized control and/or more control versatility (e.g. task-tuning) to increase outputs (productivity) in different areas.	% increase in productivity				
Improved Environmental Parameters	x	x	x							
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	Ability to change building setup and operation based on attendance, school season, year-over-year adjustments.	% decrease in costs from attendance changeover vs. previous years				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Energy					
							Existing Literature (Manufacturer Case Studies)			
NEB	**Energy**	**Building**	**People**	**Revenue**	**Narrative**	**Performance Metric**	**Value Range**	**Value(s) Cited**	**Distilled Value(s)**	**Unit**
Decreased O&M Costs	x	x			Decreasing energy usage with decreased lighting operation	kWh saved/ft²/year *base case is no controls	1.83 - 4.64	[066] Annual energy savings of 379,392 kWh/>$30,000 annual savings (961 fixtures)	4.64	kWh/ft²/yr
								[077] Annual Energy and Cost Savings 255,700 kWh, 36 kW peak demand reduction (140,000 ft²)	1.83	kWh/ft²/yr
								[080] Over 34% Energy Savings In first year ***[Too difficult to distill to a value from the given information]***		
								[102] 201,436 kWh/ $26,289 annual savings ***[Too difficult to distill to a value from the given information]***		
								[Ha003] 48%/£13,000 annual savings (82 standard & 31 emergency fixtures)	0.00	kWh/ft²/yr
Space Optimization	x	x	x	x	Negawatts by reducing unused space	kWh saved/ft²/year * base case is the same controls				
Increase Facility Control	x	x	x	x	More insight allows for energy efficiency changes in building operation.	kWh saved/ft²/year due to increased system integration (i.e. savings beyond LEDs and direct lighting controls)				
Improved Environmental Parameters	x	x	x		Reducing GHG requires reducing energy usage.	kWh saved/ft²/year resulting from reduced GHG				
Ease of Code Compliance	x	x			T24 building code results in energy saved.	Average annual operational LPD lower than code LPD allowance discounted by mandated controls				
Future Proofing	x	x	x	x	Savings by installed advanced monitoring and control.	kWh/ft²/yr reduced beyond code				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Building					
							Existing Literature (Manufacturer Case Studies)			
NEB	**Energy**	**Building**	**People**	**Revenue**	**Narrative**	**Performance Metric**	**Value Range**	**Value(s) Cited**	**Distilled Value(s)**	**Unit**
Decreased O&M Costs	x	x			Increased building value through improved operating income from lowered energy and maintenance costs.	Building value increase per ft²				
Space Optimization	x	x	x	x	Avoided costs: not adding new space since current space is more efficiently used.	O&M costs ($) saved/ft²/year				
Increase Facility Control	x	x	x	x	Increased building value through improved operating income from lowered energy and maintenance costs due to increased control.	Building value increase per ft²				
Improved Environmental Parameters	x	x	x		Buildings with low environmental impacts have higher appraised values and boost business image; resulting in higher rent values. LEED certification.	% rent increased * Higher impact with additional technology improvements in addition to lighting				
Ease of Code Compliance	x	x			Operates as code intended. Additional codes to consider: fire safety where visualization and remote control allows for remote emergency light testing. Saves time of reoccurring inspections by limiting corrections and speed of any necessary changes. It also saves time in periodic (monthly) testing.	1. Cost saved on adhering to code 2. Losses avoided on delays in obtaining certificate of	28.68	[Ha003] Monthly emergency tests and inspections costs reduced from £28.98 to £7.25 (2 hrs to 0.5 hrs @ £14.49 per hour) per month (31 emergency fixtures)	28.6836	$/month
Future Proofing	x	x	x	x	Increased building value, improved facility operations, incorporate staffing changes, building model changes, and ease about future code or building changes.	Cost (time and labor) of re-commissioning * base case is non-NLC				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					People					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Lowered overhead costs on employee-specific supplies, equipment and spaces.	Individual workspace: Reduced overhead $/employee/year -> $/ft²/year				
Increase Facility Control	x	x	x	x	Decrease employees needed for operational analysis, data already collected on occupancy, energy usage, O&M scheduling, and employee scheduling.	% decrease of time to resolution -> $ saved on people hours for trouble shooting				
Improved Environmental Parameters	x	x	x		Campus with lower environmental impacts often adopt human-centric design to create superior learning environment.	% decrease in student sick absence compared to like-kind campus designed to traditional environmental parameters				
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	More effective use of time, less complaints associated with building changes. Ability to adapt to technological changes and research/funding requirements.	% Reduction in facility tickets per change				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Revenue					
							Existing Literature (Manufacturer Case Studies)			
NEB	**Energy**	**Building**	**People**	**Revenue**	**Narrative**	**Performance Metric**	**Value Range**	**Value(s) Cited**	**Distilled Value(s)**	**Unit**
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Private institutions: Increased revenue generated by additional employees added to use the same workspace.	% revenue increase/year* * % makes more sense than $ since different business has different scale of revenue				
Increase Facility Control	x	x	x	x	Private institutions: Personalized control and/or more control versatility (e.g. task-tuning) to increase outputs (productivity) in different areas.	% increase in productivity				
Improved Environmental Parameters	x	x	x							
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	Ability to change building setup and operation based on attendance, school season, year-over-year adjustments.	% decrease in costs from attendance changeover vs. previous years				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Energy					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x			Decreasing energy usage with decreased lighting operation	kWh saved/ft²/year *base case is no controls				
Space Optimization	x	x	x	x	Through space optimization, future store designs are improved, which consume less energy.	kWh saved/ft²/year *baseline is the existing store				
Increase Facility Control	x	x	x	x	More insight allows for energy efficiency changes in building operation.	kWh saved/ft²/year due to increased system integration (i.e. savings beyond LEDs and direct lighting controls)				
Improved Environmental Parameters	x	x	x		Reducing GHG requires reducing energy usage.	kWh saved/ft²/year resulting from reduced GHG				
Ease of Code Compliance	x	x			T24 building code results in energy saved.	Average annual operational LPD lower than code LPD allowance discounted by mandated controls				
Future Proofing	x	x	x	x	Savings by installed advanced monitoring and control.	kWh/ft²/yr reduced beyond code				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Building					
							Existing Literature (Manufacturer Case Studies)			
NEB	**Energy**	**Building**	**People**	**Revenue**	**Narrative**	**Performance Metric**	**Value Range**	**Value(s) Cited**	**Distilled Value(s)**	**Unit**
Decreased O&M Costs	x	x			Increased building value through improved operating income from lowered energy and maintenance costs.	Building value increase per ft^2				
Space Optimization	x	x	x	x	Through space optimization, future store designs are improved, which reduce O&M costs.	O&M costs ($) saved/$ft^2$/year *baseline is the existing store				
Increase Facility Control	x	x	x	x	Increased building value through improved operating income from lowered energy and maintenance costs due to increased control.	Building value increase per ft^2				
Improved Environmental Parameters	x	x	x		Buildings with low environmental impacts have higher appraised values and boost business image; resulting in higher rent values. LEED certification.	% rent increased * Higher impact with additional technology improvements in addition to lighting				
Ease of Code Compliance	x	x			Operates as code intended. Additional codes to consider: fire safety where visualization and remote control allows for remote emergency light testing. Saves time of reoccurring inspections by limiting corrections and speed of any necessary changes. It also saves time in periodic (monthly) testing.	1. Cost saved on adhering to code 2. Losses avoided on delays in obtaining				
Future Proofing	x	x	x	x	Increased building value, improved facility operations, incorporate staffing changes, building model changes, and ease about future code or building changes.	Cost (time and labor) of re-commissioning * base case is non-NLC				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					People					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Indoor positioning-based business intelligence systems can increase the efficiency of purchases.	% decrease in product purchase cycle time				
Increase Facility Control	x	x	x	x	Targeted lighting strategies to increase the appeal of featured products.	% increase in foot traffic				
Improved Environmental Parameters	x	x	x		Eco-friendly building designs attract more customers.	% foot traffic increase compared to traditional store design				
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	More effective use of time, less complaints associated with building changes.	Reduction in facility tickets per change				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Revenue					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Indoor positioning-based business intelligence enables a more effective product placement leading to increased revenue, based on customer shopping patterns.	% increase in sales				
Increase Facility Control	x	x	x	x	Targeted lighting strategies boosts the sales of featured products.	% sales increase of featured products				
Improved Environmental Parameters	x	x	x							
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	Ability to change building setup and operation based sales strategy (E.g., highlight seasonal vegetables, holiday offerings, and new products).	% increase in revenue from changeover				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Energy					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x			Decreasing energy usage with decreased lighting operation	kWh saved/ft²/year *base case is no controls	2.82 - 11.33	[018] 180,000 kWh savings between May/13 and Feb/14 (85,000 ft²)	2.82	kWh/ft²/yr
								[106] 1,926,733 kWh/ $138,725 annual savings (2,000 fixtures)	11.33	kWh/ft²/yr
Space Optimization	x	x	x	x	Negawatts by reducing unused space	kWh saved/ft²/year *baseline is the existing store				
Increase Facility Control	x	x	x	x	More insight allows for energy efficiency changes in building operation.	kWh saved/ft²/year due to increased system integration (i.e. savings beyond LEDs and direct lighting controls)				
Improved Environmental Parameters	x	x	x		Reducing GHG requires reducing energy usage.	kWh saved/ft²/year resulting from reduced GHG				
Ease of Code Compliance	x	x			T24 building code results in energy saved.	Average annual operational LPD lower than code LPD allowance discounted by mandated controls				
Future Proofing	x	x	x	x	Savings by installed advanced monitoring and control.	kWh/ft²/yr reduced beyond code				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Building					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x			Increased building value through improved operating income from lowered energy and maintenance costs.	Building value increase per ft^2				
Space Optimization	x	x	x	x	Through space optimization, future facility designs are improved, which reduce O&M costs. Including the ability to track expensive medical equipment.	O&M costs ($) saved/$ft^2$/year *baseline is the existing store				
Increase Facility Control	x	x	x	x	Increased building value through improved operating income from lowered energy and maintenance costs due to increased control.	Building value increase per ft^2				
Improved Environmental Parameters	x	x	x		Buildings with low environmental impacts have higher appraised values and boost business image; resulting in higher rent values. LEED certification.	% rent increased * Higher impact with additional technology improvements in addition to lighting				
Ease of Code Compliance	x	x			Operates as code intended. Additional codes to consider: fire safety where visualization and remote control allows for remote emergency light testing. Saves time of reoccurring inspections by limiting corrections and speed of any necessary changes. It also saves time in periodic (monthly) testing.	1. Cost saved on adhering to code 2. Losses				
Future Proofing	x	x	x	x	Increased building value, improved facility operations, incorporate staffing changes, building model changes, and ease about future code or building changes.	Cost (time and labor) of re-commissioning * base case is non-NLC				

NEB	Benefits Value Intensity (BVI): Energy	Building	People	Revenue	Value Impact Story & Performance Metric — People: Narrative	Performance Metric	Existing Literature (Manufacturer Case Studies): Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Lowered overhead costs on employee-specific supplies, equipment and spaces.	Individual workspace: Reduced overhead $/employee/year -> $/ft²/year				
Increase Facility Control	x	x	x	x	Decrease tenants/employees needed for operational analysis, data already collected on occupancy, energy usage, O&M scheduling.	% decrease of time to resolution -> $ saved on people hours for trouble shooting				
Improved Environmental Parameters	x	x	x		Facilities with lower environmental impacts often adopt human-centric design to create superior healing environment.	% decrease in length of a single stay compared to like-kind facility designed to traditional environmental parameters				
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	More effective use of time, less complaints associated with building changes.	% Reduction in facility tickets per change				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Revenue					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Increased revenue generated by additional employees and patients added to use the same workspace.	% revenue increase/year* * % makes more sense than $ since different business has different scale of revenue				
Increase Facility Control	x	x	x	x	Personalized control and/or more control versatility (e.g. task-tuning) to increase outputs (productivity) in different areas.	% increase in productivity				
Improved Environmental Parameters	x	x	x							
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	Ability to change building setup and operations based strategy on external changes (E.g., insurance changes to highlight different services, new technology, and improved patient processing).	% increase in revenue from changeover				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Energy					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x			Decreasing energy usage with decreased lighting operation	kWh saved/ft²/year *base case is no controls				
Space Optimization	x	x	x	x	Negawatts by reducing unused space	kWh saved/ft²/year *baseline is the existing store				
Increase Facility Control	x	x	x	x	More insight allows for energy efficiency changes in building operation.	kWh saved/ft²/year due to increased system integration (i.e. savings beyond LEDs and direct lighting controls)				
Improved Environmental Parameters	x	x	x		Reducing GHG requires reducing energy usage.	kWh saved/ft²/year resulting from reduced GHG				
Ease of Code Compliance	x	x			T24 building code results in energy saved.	Average annual operational LPD lower than code LPD allowance discounted by mandated controls				
Future Proofing	x	x	x	x	Savings by installed advanced monitoring and control.	kWh/ft²/yr reduced beyond code				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Building					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x			Increased building value through improved operating income from lowered energy and maintenance costs.	Building value increase per ft²				
Space Optimization	x	x	x	x	Through space optimization, future restaurant designs are improved, which reduce O&M costs.	O&M costs ($) saved/ft²/year *baseline is the existing store				
Increase Facility Control	x	x	x	x	Increased building value through improved operating income from lowered energy and maintenance costs due to increased control.	Building value increase per ft²				
Improved Environmental Parameters	x	x	x		Buildings with low environmental impacts have higher appraised values and boost business image; resulting in higher rent values. LEED certification.	% rent increased * Higher impact with additional technology improvements in addition to lighting				
Ease of Code Compliance	x	x			Operates as code intended. Additional codes to consider: fire safety where visualization and remote control allows for remote emergency light testing. Saves time of reoccurring inspections by limiting corrections and speed of any necessary changes. It also saves time in periodic (monthly) testing.	1. Cost saved on adhering to code 2. Losses avoided on				
Future Proofing	x	x	x	x	Increased building value, improved facility operations, incorporate staffing changes, building model changes, and ease about future code or building changes.	Cost (time and labor) of re-commissioning * base case is non-NLC				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					People					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Indoor positioning-based business intelligence systems can increase the efficiency of purchases.	% decrease in product purchase cycle time				
Increase Facility Control	x	x	x	x	Targeted lighting strategies to increase the appeal of featured products.	% increase in foot traffic				
Improved Environmental Parameters	x	x	x		Eco-friendly building designs improves brand image and attract more customers.	% foot traffic increase compared to traditional restaurant design				
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	More effective use of time, less complaints associated with building changes.	Reduction in facility tickets per change				

	Benefits Value Intensity (BVI)				Value Impact Story & Performance Metric					
					Revenue					
							Existing Literature (Manufacturer Case Studies)			
NEB	Energy	Building	People	Revenue	Narrative	Performance Metric	Value Range	Value(s) Cited	Distilled Value(s)	Unit
Decreased O&M Costs	x	x								
Space Optimization	x	x	x	x	Indoor positioning-based business intelligence enables a more effective product placement leading to increased revenue, based on	% increase in sales				
Increase Facility Control	x	x	x	x	Task-tuning to increase outputs (productivity) in different task areas (E.g., preparation stations, host stand, and cooking)	% increase in productivity				
Improved Environmental Parameters	x	x	x							
Ease of Code Compliance	x	x								
Future Proofing	x	x	x	x	Ability to change building setup and operation based restaurant strategy (E.g., open kitchen, relocate to increase seating, and open areas for easier service)	% increase in revenue from changeover				