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FINAL PROJECT REPORT

SAVING ENERGY IN BUILDINGS WITH ADAPTIVE LIGHTING SYSTEMS

Solutions for the Retail Sector

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PREFACE

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ABSTRACT

The retail sector, which represents 13 percent of California's lighting electricity use, has historically not embraced the use of lighting controls to save energy. California regulators have responded to retailer's concerns that lighting controls and lighting power density restrictions may have a negative impact on sales and customers. Currently, building lighting energy-efficiency standards for the retail sector are less stringent than regulations imposed on other commercial space types. As such, the use of adaptive lighting systems, which automatically adjust their output and operation based on occupancy, daylight availability and other application-specific criteria, are severely underutilized in the retail sector, costing California ratepayers millions in unnecessary electricity costs each year.

To address the slow adoption of adaptive lighting solutions in the retail sector, researchers developed and demonstrated an optimized retail lighting control strategy based on a set of control layers specifically designed to deliver maximum lighting energy savings and minimal negative impacts. The feature set incudes specific recommendations for retail lighting power density and optimized control settings. Application of this feature set in retail environments is expected to save up to 65 percent of lighting energy use as compared to systems designed to current energy standards.

Keywords: adaptive, lighting, bi-level, retail, energy, lighting control, controls, network, tuning, lighting power density, Title 24, building code

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EXECUTIVE SUMMARY

Introduction

The retail sector, which represents 13 percent of California's commercial lighting electricity use, has historically not embraced the use of lighting controls to save energy. Reasons for this are many including perceived high cost, system complexity and the potential for negative impacts on customers and sales. California regulators have responded in kind to these concerns, and building lighting energy-efficiency standards for the retail sector are currently less stringent than regulations imposed on other commercial space types. As such, the use of adaptive lighting systems, which automatically adjust their output and operation based on occupancy, daylight availability and other application-specific criteria, are severely underutilized in the retail sector, costing California ratepayers millions in unnecessary electricity costs each year.

Project Purpose

Adaptive lighting solutions for the retail sector must be easy to understand and cost-effective for business owners. Traditional retail lighting practices utilize above-average light levels and, in many cases, are not as tied to restrictive mandatory controls requirements. Because of these allowances, there exists a significant energy savings opportunity tied to increased adoption of adaptive lighting strategies that employ reduced lighting power density and advanced controls.

This project focused on development of advanced, adaptive lighting strategies targeted at reducing the unnecessary power consumption allowed by current energy code and adding controls to retails spaces that normally are unaddressed by such measures. The team sought solutions to maintain or increase amenity for business owners, while reducing their overall electricity bill. Outcomes are intended to better educate stakeholders on the potential energy savings benefits of advanced lighting and its ability to meet the needs of the retail sector in California.

Project Results

Researchers created model lighting systems designed to current building and energy code requirements, then compared the energy use of those systems to the use of systems designed to industry recommendations. Reductions between that allowed by code and that recommended in modern lighting design represent clear electricity savings for retail businesses.

In retail applications, systems designed to industry recommended standards were shown to save approximately 15 percent to 60 percent electricity as compared to 2013 Title 24 code requirements. Optimized control strategies include occupancy-based dimming, tuning and scheduling, which saved an additional 15-30 percent as compared to retail spaces that did not utilize these adaptive lighting control systems. In field demonstrations, the optimized, adaptive lighting systems achieved 53 percent energy savings as compared to the demonstration site's existing lighting system. The demonstrated systems achieved 65 percent savings in electricity over a 2013 Title 24-compliant lighting design.

Project Benefits

As LED technology becomes even more efficient and cost effective, standards must adapt to capture improvements in the technology and ensure California buildings continue to lead in energy-efficient lighting design. This work demonstrated that lighting power density reductions are possible in the retail sector and application of appropriate control strategies can save energy without negative impacts on product sales or customer interest. Application of the lighting control systems and strategies developed and demonstration as part of the research can achieve electricity savings up to 65% over systems designed to existing Title 24 lighting requirements.

CHAPTER 1:
Introduction and Background

The retail sector, which represents 13 percent of California's commercial lighting electricity use (Itron 2014 pg. 4-10), has historically not embraced the use of lighting controls to save energy. Reasons for this are many including perceived high cost, system complexity and the potential for negative impacts on customers and sales. California regulators have responded in kind to these concerns, and building lighting energy-efficiency standards for the retail sector are currently less stringent than regulations imposed on other commercial building space types. As such, the use of adaptive lighting systems, which automatically adjust their output and operation based on occupancy, daylight availability and other application-specific criteria, are severely underutilized in the retail sector, costing California ratepayers millions in unnecessary electricity costs each year.

To address the gaps between adoption of advanced lighting technology and the retail building sector, this work sought to identify the current state of lighting for the retail market, understand stakeholder perceptions of lighting systems and upgrades in the retail sector, quantify the savings potential of adopting advanced lighting solutions that exceed current building energy-efficiency regulations, identify emerging technology able to serve this market's needs, and demonstrate the most promising solutions for California retail ratepayers. Outcomes are intended to better educate stakeholders on the potential energy savings benefits of advanced lighting and its ability to meet the needs of the retail sector in California.

1.1 What is an Adaptive Lighting System?

An adaptive lighting system automatically adjusts its light output and operation to provide targeted light levels based on environmental conditions, user schedules, or other application-specific criteria. An adaptive system can also often be manually tuned, over time, in terms of light level, and in some cases, color, to provide optimal lighting conditions as designated by system operators, building owners or occupants. This feature set is accomplished by combining controllable luminaires with lighting controls and communication hardware that are able to interpret changes in the environment and adjust the luminaires accordingly.

An adaptive lighting system can include many different types of products including dimmable lamps and luminaires, occupancy sensors, photocontrols, time clocks, communication panels, and wireless communication nodes. This work focuses on evaluation and application of networked controls systems for the retail sector. Networked systems offer the most robust set of system features including lighting system monitoring, reporting, and retro-commissioning options. Networked systems can offer the most benefit to the retail market and could help advance adoption within this sector.

Adaptive lighting control strategies, enabled by a networked control system, include:

- Bi-level Adaptive Lighting – Bi-level adaptive control is the most commonly used strategy for smart corridors. This strategy utilizes an occupancy sensor to dim the luminaires after the space has been vacant for a set period of time. These sensors automatically turn lights up when an occupant is present in the sensor's field of view. This strategy can be made more complex with scheduling, allowing for different high and low levels for the lighting during open hours and closed hours.
- High End Trim – This strategy saves energy by tuning the maximum allowable light level to a lower recommended level and setting this level as the maximum output of the system.
- Daylight Harvesting – Daylight harvesting controls allow the electric lights to scale their output based on the daylight contributions into a space. The electric lights dim or turn off during the day and return to full output only when needed.
- Scheduling – Scheduling allows luminaires to automatically turn on, off, or dim based on a preset schedule.
- Demand Response (DR) – DR is enacted in cooperation with local utilities to trim energy usage during peak hours or periods of critical demand. Some utilities have automated demand response programs that automatically signals advanced control systems to reduce lighting loads to predefined levels.
- Zoning – Zoning is the grouping of luminaires into functional areas. This can be accomplished through physical wiring or digitally through a networked control system. The zone of luminaires responds identically to occupancy and daylight signals.
- Dynamic contrast – Dynamic Contrast is the increase in the ratio between an illuminance target, such as a display, as compared to the general illuminance based on occupancy triggers, which draws occupant attention to the target.
- Dimming– This is a theoretical dimming scheme based on occupant density that could be applied to general illuminance levels, such as wall washers. When more occupants are in the store, the overall illumination can slowly be brightened.

CHAPTER 2:
The Current State of Retail Lighting

Retail lighting systems are used to provide both general and task-specific illumination. Task lighting is used to accent signage and product displays to make them brighter than their surroundings, which can draw a shopper's attention to the highlighted area. General lighting provides an overall, uniform level of lighting throughout the space. Currently, the obvious energy retrofit measure for both general and task lighting is conversion to LED technology and adoption of lighting controls.

Regardless of its purpose or source technology, retail lighting is regulated in California as part of its Building Energy-Efficiency Standards. These requirements are much more lenient in terms of allowed power density and mandatory controls than other commercial space types. The following information describes the current state of retail lighting in California, regulations, and the potential energy savings that can be achieved through this sector's adoption of adaptive lighting systems that exceed current code requirements.

2.1 General Area Lighting

Most general area lighting utilizes recessed troffers, surface mounted wrap fixtures or suspended pendants. According to a recent statewide survey, linear fluorescent lamps are the most prevalent lamps utilized by these luminaires, and in retail, linear fluorescents make up 72 percent of the total lamp stock (Itron 2014 pg. 5-9) The emerging energy-efficient retrofit for this type of general lighting is conversion to LED technology. Solutions include tubular LED replacement lamps (TLEDs) and retrofit kits.

Retrofit kits provide an LED array and a driver that fit into the existing fixture. Normally the existing lamps, lamp holders, and ballasts are removed. Some retrofit kits utilize the existing lens while the others provide a new lens. Product examples are shown in Figure 1. This retrofit allows for a completely new look, energy savings and minimal installation costs. In addition, retrofit kits are often useful in spaces with asbestos where the ceiling cannot be disturbed without costly containment measures.

Figure 1: LED Troffer Retrofit Kits

Source: MaxLite and Phillips

In contrast to LED retrofit kits, TLEDs utilize the lenses and, often, lamp holders and fluorescent ballast of the existing luminaire. Three different versions of this technology are commercially available. The first utilizes the existing ballast, and the fluorescent lamp is simply replaced with an LED lamp, pictured left in Figure 2. This technology can be Underwriters Laboratories (UL) listed indicating that the product has met applicable UL safety standards. The second solution consists of TLEDs and an LED driver, pictured center in Figure 2. This product requires removal of the existing ballast and fixture rewiring. These products can receive a mark of UL classified indicating that the LED lamp replacement kit has been evaluated with respect to a limited range of hazards. The third type of lamp replacement contains an integrated LED driver and connects directly to line voltage, pictured right in Figure 2. This solution may retain existing lamp holders, use those lamp holders merely for support, or line voltage can be run directly to them where they serve as the electrical connection to the TLED. This solution can be dangerous for future maintenance workers if safety stickers are not provided to clearly warn that line voltage has been run to the lamp holders. This product is not recognized by UL. All three of these lamp replacements utilize the existing luminaire and allow the contents of the ceiling to remain untouched.

Figure 2: Linear LED Replacement Lamps

Photo Credit: Cree, Next Lighting and Seesmart

Many LED alternatives are dimmable. Products often offer 0-10V dimmable or digitally addressable lighting interface (DALI) dimming drivers. 0-10V dimming is based on a low-voltage, analogue control signal. This technology is a popular option for troffers and LED retrofits. The DALI technology facilitates dimming through a bi-directional, digital data exchange. DALI is a less prevalent, but includes more features than 0-10V dimming. DALI systems allow for zones of control down to the individual luminaire, independent of electrical circuiting. Both dimming protocols are compatible with most networked control systems.

To better understand performance of these LED technologies, several products were tested and compared to traditional fluorescent solutions. Table 1 contains the test results for a fluorescent troffer, a TLED replacement with external driver (replaces fluorescent ballast), and two different LED retrofit kits. All of the tested solutions delivered approximately 4000 lumens with comparable color rendering index (CRI) and correlated color temperature (CCT). Test products utilized the same fixture; the lens was removed in the case of the LED retrofit kit with lens.

The LED retrofit kit with lens had the highest efficacy, which included LEDs designed specifically for use with the integral lens allowing for the most efficient optical control. The

next most efficacious products were the TLED with driver and the incumbent T8. The TLED with driver is an improvement over the incumbent product as it is slightly more efficacious with a slightly higher CRI. All tested LED products have a longer lifespan than fluorescent technology. The LED retrofit kit designed to work with the incumbent lens was the least efficacious solution[1].

Table 1: Troffer Products: Fluorescent Troffers, LED Retrofit Kits and TLED Replacements

Product	Light Output (lumens)	Luminaire Input Power (Watts)	Luminaire Efficacy (lu/W)	CRI
Incumbent T8	4434	59.3	74.8	83.4
TLED with Driver	3686	48.9	75.3	83.8
LED Retrofit Kit	3783	53.1	71.2	84.1
LED Retrofit Kit With Lens	4145	38.9	106.5	83.8

Source: CLTC

2.2 Accent and Display Lighting

Track lighting is the most common type of retail, accent, and display lighting. These luminaires have a can-like housing and utilize directional lamps or contain reflectors to re-direct the light of a non-directional lamp. These sources can be adjusted to illuminate a specific target. These luminaires provide increased illuminance to draw interest to displays throughout a retail space. With respect to accent and display lighting, the most prevalent lamp types are incandescent, halogen, compact florescent (CFL), and LED. These lamps have pin or medium screw bases and they make up 20 percent of the total retail lamp stock. These lamps are often used in track and wall-mounted accent fixtures. LED replacement lamps can offer as much as 80 percent savings over incandescent and halogen accent/display lighting.

Some 1st generation LED replacement lamp models utilized in existing track housings experienced premature failure due to thermal conditions presented by the enclosed housings. Integrated LED track typically performs better as it is designed specifically for the LEDs allowing for better optical distribution and thermal management. The improved thermal management also allows for a higher steady-state efficacy due to reduced LED junction temperature.

[1] Further testing of more products is needed to make additional generalizations about the current state of LED retrofit technologies.

Color rendering is an important consideration in the retail environment. With respect to LED solutions, high color rendering often equates to reduced efficacy. This correlation can be seen in Table 2, which compares two products from the same manufacturer with a comparable wattage and CCT. The product with a higher CRI has a lower efficacy as compared to its lower CRI counterpart. However, some consumers value increased CRI over a slight increase in efficacy (Papamichael, K. 2015). The reduction in CRI would be more noticeable than a 35 percent drop in lumen output.

Table 2: Comparison of Two LED Replacement Lamps

Lamp Name	CRI	CCT	Light Output (lumens)	Power (W)	Power Factor	Lamp Efficacy (lu/W)
Product B	81.6	2896	1108	21.6	0.96	51.3
Product A	96.5	2953	725	21.1	0.97	34.4

Source: CLTC

Integrated, dimmable LED track systems may utilize one of several different dimming protocols: magnetic low voltage (MLV), electronic low voltage (ELV), DALI and 0-10V dimming. MLV dimming is based on symmetric, forward phase control and is utilized by many halogen products. MLV dimming does not work with most networked control systems. ELV dimming works through reverse phase control and is used with most types of track products. The most prevalent dimming protocol that is also compatible with most networked control systems is ELV dimming. DALI and 0-10V dimming are not very common for track lighting products, however both are compatible with most networked control systems.

2.3 Networked Lighting Control Systems

The lighting control system is the backbone of an adaptive lighting system. Controls provide the platform through which luminaires are controlled and energy saving strategies are implemented. There are many different adaptive lighting systems on the market. Table 3 includes information on multiple, commercially available products.

Most networked control systems have comparable components and functionality. Luminaires, sensors, switches and other components are able to transmit and receive data through the network. The communication protocols are normally bi-directional and information can be transmitted wired or wirelessly among connected devices. The most common network topologies are the daisy chain, a wired topology that transmits signals only between devices that are directly connected to each other, or a mesh configuration, a wireless topology in which each component can communicate with every other component in the network.

There are several different controls components available for use with a networked system including occupancy sensors, photo cells, dimming switches and scene controllers. Devices are either powered over the communication connection, such as power over Ethernet or are powered through low voltage connections. Most of the controls components are proprietary to

the system brand; however, several companies allow the use of 3rd party sensors. Additionally, some systems allow integration of accessory system components such as shades and thermostats. This feature enables the user to access many different component types from the same interface, which can reduce overall building operation complexity and improve building performance. This increases compatibility among products and provides additional options to end users.

Remote access of these systems is normally available allowing the user to control the system remotely via a network connection. This feature also allows for easier troubleshooting of system settings and operation by the manufacturer, if needed. System maintenance and energy reporting is also common with most systems.

As with individual lamps and luminaires, the networked control system may utilize a specific dimming protocol for communication. It is important to match control systems with connected devices to ensure they utilize the same dimming protocol. All solutions listed in Table 3 support 0-10V dimming, a very common protocol used with dimmable LED and fluorescent lighting. With respect to track lighting, which is very common in retail applications, ELV dimming using reverse phase control is most common, and this protocol was supported by only three of the six systems surveyed.

Table 3: Networked Control Systems

	System	Daintree	Encelium	Enlighted	Acuity nLight	Lutron Quantum	WattStopper DLM
	Network Type	Wireless	Wired	Wireless	Wired	Wired and Wireless	Wired
	Topology	Mesh	Daisy chain	Mesh	Daisy Chain	Tree	Daisy Chain
Hardware	**Sensor Types**	Occupancy, Photo, Thermostat	Occupancy and Photo sensor	All in one: Occupancy Temperature and Ambient Light	Occupancy and Photo sensors	Occupancy and Photo sensors	Occupancy and Photo sensor
Hardware	**Sensor Power Source**	Low Voltage	Low Voltage	Low Voltage	Power over Ethernet	Battery or Low Voltage	Power over Ethernet
Hardware	**Accessories**	Shades, Switches, Plug loads and HVAC integration	Switches	Switches	Switches and Touch pads	Shades, Switches	HVAC integration and Plug Loads
Hardware	**Source of Components**	3rd party	3rd party	Proprietary	Proprietary	Proprietary	Proprietary
Hardware	**Lifetime of control components**	5 year warranty	5 year warranty	3 year warranty	5 year warranty	2 year warranty	5 year warranty
Software	**Interface**	Local server - remotely accessible via internet	Local server (Polaris) - remotely accessible via internet	Local server - remotely accessible via internet	Local server - remotely accessible via internet	Local server (Green Glance) - remotely accessible via internet	Local server - remotely accessible via internet

Control Strategies	**Schedule**	Yes	Yes	Yes	Yes	Yes	Yes
	Daylight Harvesting	Yes	Yes	Yes	Yes	Yes	Yes
	Dimmable	0-10v	0-10v, forward and reverse phase	0-10v, DALI	0-10v, reverse phase	0-10v, DALI, forward & reverse phase	0-10v, forward phase
	High End Trim	Yes	Yes	Yes	Yes	Yes	Yes
	Task Tuning	Yes	Yes	Yes	Yes	Yes	Yes
	Automated Demand Response	Yes	In Development	Yes	In Development	Yes	Yes
Other	**Maintenance reporting**	Yes	No	Yes	No	yes	No
	Compatible with BMS	Yes	Yes	Yes	Yes	Yes	Yes
	Energy Monitoring	Yes	Estimated	Estimated	Current Monitoring	Estimated	Yes

Source: CLTC-information gathered from vendor product literature

2.4 Retail Lighting Energy-Efficiency Regulations

California's Building Energy Efficiency Standards (Title 24, Part 6) regulate the type of lighting systems that may be installed in commercial buildings and total power that those systems may consume. The standards provide two compliance paths for retail buildings and spaces: the area category method and the tailored method. Lighting and controls requirements also vary based on the project type, with new construction projects having more stringent requirements than building alterations.

2.4.1 Lighting Power Allowances

The area category method's allowable lighting power density (LPD) for retail sales floors is 1.2 watts per square foot (W/sf). Retail applications have additional allowable power allotments for accent/display lighting and decorative lighting of 0.2 and 0.3 W/sf, respectively. The total, allowable LPD for retail spaces is 1.7 W/sf. This is one of the largest allowable LPD's of any commercial, primary function area. Overall, retail-related primary function areas have a higher, allowable LPD compared to other applications.

The tailored method uses a general illuminance calculation and allowable LPD. The general illuminance provided for retail spaces, aligns with the recommended lighting levels of the Illuminating Engineering Society (IES) for most primary function areas. There are additional LPD's available for wall displays, task lighting and ornamental lighting. Retail has the highest wall display power at 14 W/sf of any other functional area.

2.4.2 Control Requirements

Below is a brief summary of California's mandatory requirements per 2013 Title 24 standards for lighting controls in new buildings:

a) Area controls – Each area enclosed by ceiling height partitions must be independently controlled by manual on/off switches.

b) Multi-level controls – This requirement can be met through manual dimming, lumen maintenance, tuning, automatic daylight or demand response controls. These controls will not override automatic daylighting or demand response controls.

c) Shut-off controls – The controls are compliant through the use of occupant sensing control, automatic time-switch control, or a signal from another building control system capable of automatically shutting off all of the lights when the building is typically unoccupied. Separate controls are necessary for each enclosed space and for general, display and ornamental lighting.

d) Automatic Daylighting – This is the ability to reduce the output of the area lighting in spaces where daylighting is prevalent. Skylit and primary sidelit spaces are the areas in which the luminaire are controlled by automatic daylighting controls.

e) Demand Responsive controls – These are necessary in any building larger than 10,000 square feet. This control type is capable of automatically reducing the light power to a minimum of 15 percent below the total installed light power.

For building alterations, controls requirements are less stringent. Exact requirements may be found in Table 141.0-E of the standards. These requirements are based on the percentage of luminaires altered and the percent of the allowed LPD utilized by the new systems.

Track lights have additional requirements under Title 24, which are intended to insure that the maximum allowed power is not exceeded by adding additional track heads to existing track. There are three paths to compliance. The first is to use the maximum volt–ampere rating of the branch circuit that feeds the track. This rating must be under the allowed LPD. The second is to utilize an integral current limiter installed on each section of track to insure that each section does not exceed the allowable wattage. The third method is a supplementary overcurrent protection panel. Each track branch is run into the panel to an appropriately sized protection device that limits the wattage to each section of track.

2.4.3 Lighting Energy Savings Potential – Current Code Enforcement

Full adoption of 2013 Title 24 energy-efficiency codes in California's existing buildings will provide substantial energy savings. The average, retail LPD is approximately 3 W/sf, which is based on published reports of annual lighting hours of use for retail, along with an estimate of a retail business's average size (floor area)(Navigant Consulting, 2012 and Itron, 2014). The 2013 Title 24 code allows a maximum of 1.7 W/sf. At a 100 percent adoption rate, a savings of 1.7 percent of California's electricity use is possible. This amounts to 4,600 million kWh annually. While this savings is substantial, the adoption of adaptive lighting, which reduces the average LPD and operating hours of retail lighting could save an additional 50 percent or more.

Table 4: California annual electricity savings based on the adoption of 2013 Title 24 LPD requirements in retail spaces

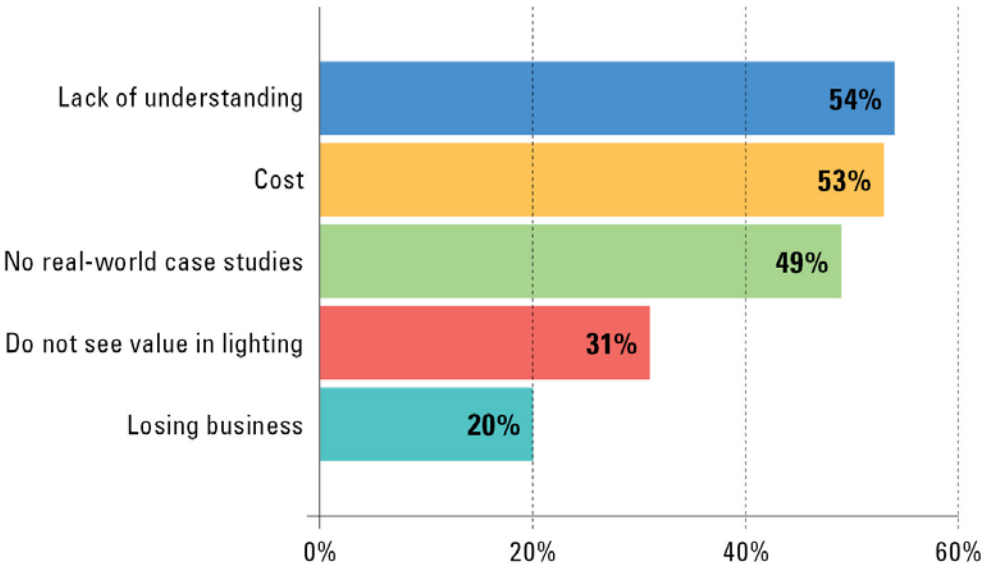
Adoption Rate in Existing Buildings (1.7 LPD)	0	5%	10%	25%	50%	75%	100%
Electricity Use (Millions of Kwh)	278,680	278,449	278,218	277,525	276,370	275,216	274,061
Savings	0.00%	0.08%	0.17%	0.41%	0.83%	1.24%	1.66%

Source: CLTC

2.5 Market Barriers

To achieve the savings potential inherent in Title 24 compliance and beyond, retailers must elect to complete lighting system upgrades. Retailers, however, remain hesitant to complete energy-efficiency projects. A retail market survey, conducted in connection with this research, identified several important factors that influence a retailer's decision of complete an energy-efficient lighting upgrade. Almost half of retailers surveyed stated they would upgrade their lighting systems if it led to increased sales (Siminovitch, 2012). Less than 20 percent of those surveyed said they would upgrade their lamps if it would only decrease their electricity cost and not increase sales. When asked why they held reservations about conducting efficiency projects, lack of understanding was cited as the number one reason. In addition, 53 percent responded that high first cost was a primary concern regarding lighting upgrades.

Figure 3: Reservations regarding lighting upgrades cited by retail business owners



Source: Consumer Preference Survey on Directional LED Replacement Lamps for Retail Application

CHAPTER 3:
Adaptive Solutions for the Retail Sector

Adaptive lighting solutions for the retail sector must be easy to understand and cost-effective for business owners. Traditionally, retail lighting practices utilize above-average light levels and, in many cases, are not as tied to restrictive mandatory controls requirements. Because of these allowances, there exists a significant energy savings opportunity tied to increased adoption of adaptive lighting strategies that employ reduced LPD and advanced controls. Research focused on advanced lighting designs targeted at reducing unnecessary power consumption as allowed by current 2013 Title 24 code and adding controls to retails spaces that normally are unaddressed by such measures. Solutions were targeted to maintain or increase amenity for business owners, while reducing their overall electricity bill.

3.1 Reducing Lighting Power Density

To better understand potential LPD reductions for the retail sector, the illuminance levels resulting from application of maximum Title 24 LPD allowances were compared with industry recommended illuminance levels. Illuminance levels for both scenarios were estimated through building simulations. Reductions between that allowed by code and that recommended in modern lighting design represent clear electricity savings for retail businesses.

Lighting simulations were conducted for a warehouse (big box) store and a department store. Several different luminaires were selected for simulation. Each luminaire was modeled in two different uniform layouts. The first layout was designed to utilize the maximum LPD allowed by 2013 Title 24's area category method and the second was designed to achieve the illuminance recommended by the IES. Simulations produced estimated horizontal illuminance at for each design.

For both space types, the 2013 Title 24 designs used more energy, and provided more light, than was necessary to reach industry recommended light levels. As LED technology becomes even more efficient and cost effective, standards must adapt to capture improvements in the technology and ensure California buildings continue lead in energy-efficient lighting design.

3.1.1 Warehouse Applications

The warehouse store model had an area of 134,000 square feet and a ceiling height of 30 ft. The model utilized high-bay luminaires, a type of luminaire designed for the extended ceiling heights where the mounting height is larger than the luminaire spacing distance. The source types used for simulation were linear fluorescent (standard T8), high intensity discharge (HID) and LED. The Title 24 design utilized more luminaires giving it a higher LPD as compared to the IES model. Designing to IES recommended light levels provides 13-43 percent savings over designs that utilize the maximum LPD allowed by 2013 Title 24 code. The savings per technology are shown in Table 5.

Table 5: Warehouse store - Electricity savings potential of a modern, retail lighting design as compared to a design using the maximum LPD allowed by Title 24

Luminaire	Potential Energy Savings
T8 High Bay	43%
HID High Bay	22%
LED High Bay	13%

Source: CLTC

3.1.2 Retail Department Stores

The department store model had a total area of 48,000 square feet and a ceiling height of 12 ft. The luminaires utilized for the design in this application were recessed troffers. Several different sources were chosen for this application; fluorescent T8, fluorescent T5 and LED. Three different styles of luminaires were also utilized: strip, parabolic and volumetric. Strip fixtures are a type of luminaire that have no baffling or reflectors. Parabolic fixtures have an inner reflector that directs the light directly out of the luminaire. The volumetric troffer has a reflector and lensing system that helps to spread the light in multiple directions, instead of directly down like the parabolic fixture. Each luminaire was used to create a layout for two design strategies: IES recommended light levels and 2013 Title 24 LPD. Once again, fewer luminaires were needed for the IES layout. Table 6 contains the energy savings results for these simulations. The IES design saved 53-60 percent over the Title 24 design.

Table 6: Department store - Electricity savings potential of a modern, retail lighting design as compared to a design using the maximum LPD allowed by Title 24

Fixture Type	Potential Energy Savings
T5 Architectural	58%
T5 Parabolic	43%
T2 Parabolic 2	41%
T5 Volumetric	53%
T5 Volumetric 2	41%
T8 Architectural	60%
T8 parabolic	58%
T8 Strip	57%
T8 Volumetric	56%
LED Architectural	57%
LED Volumetric	58%

Source: CLTC

3.2 Optimizing Controls Operation

Many factors contribute to the success of control strategies. To optimize the value of an investment in adaptive lighting solutions, systems must be optimized in terms of their operation. Optimizing control settings such as sensor time-out periods and the size of sensor coverage zones is critical to achieve maximum energy savings.

Three studies were completed to understand how changes in lighting control settings effect overall lighting energy use. Sensor density simulations were performed to determine energy savings associated with adaptive lighting strategies in retail spaces based on the effects of luminaire zone sizes and sensor timeouts. Extended height occupancy sensor testing was also performed to determine if common, commercially available occupancy sensors were suited for ceiling heights found in retail applications. In addition, electrical characterization of luminaire controllers, such as dimmers and scene controllers, was performed to determine if incompatibilities existed between standard control hardware and typical light sources used in retail applications.

3.2.1 Zone Size and Occupancy Controls

Coverage zone size has an effect on occupancy sensor performance with respect to accurate occupant detection. Accuracy translates directly to energy use. False triggers can increase lighting energy use, while failure to detect occupants can result in increased savings but at the expense of light quality and safety. To understand the relationship between sensor coverage area, coverage zone size and energy use, researchers simulated the effects of various sensor zone sizes on lighting energy use using models developed from audits of multiple department stores in Northern California.

Networked lighting control systems normally utilize one of two approaches for occupancy sensor coverage. The first is to use the minimum number of sensors needed for coverage of the desired area. With this strategy, one or more sensors are typically mounted on the ceiling to create one or more zones of control. In the second approach, one sensor is installed in each luminaire to create multiple, small zones of control, regardless of any overlap in coverage area between sensors. These strategies are independent of the number of luminaires in the space.

First, researchers create a model lighting plan and operating schedule for a typical retail department store using prototypical data collected through onsite audit of three department stores[2]. Occupancy profiles were then applied to the space. The luminaire wattages, quantities and lighting power density are listed in Table 7. For the purpose of this exercise, luminaires were dimmable and employed a bi-level dimming lighting strategy. The reflected ceiling plan from the model is shown in Figure 4. Troffers, circled in purple, indicate that they are in the walkways and luminaires circled in orange are track lights. Troffers circled in blue represent

[2] The total area of the model was approximately 144,000 sf. Luminaires simulated were 4-lamp 28W 2x4 recessed troffers for the area lighting, 1-lamp 54W T5HO recessed wall wash for the decorative lighting and sets of six (6) 13W halogen track lights for the accent, display and feature lighting.

the remaining area lighting and luminaires around the perimeter, circled in green, are wall washers. The center area without luminaires contains the department store escalator.

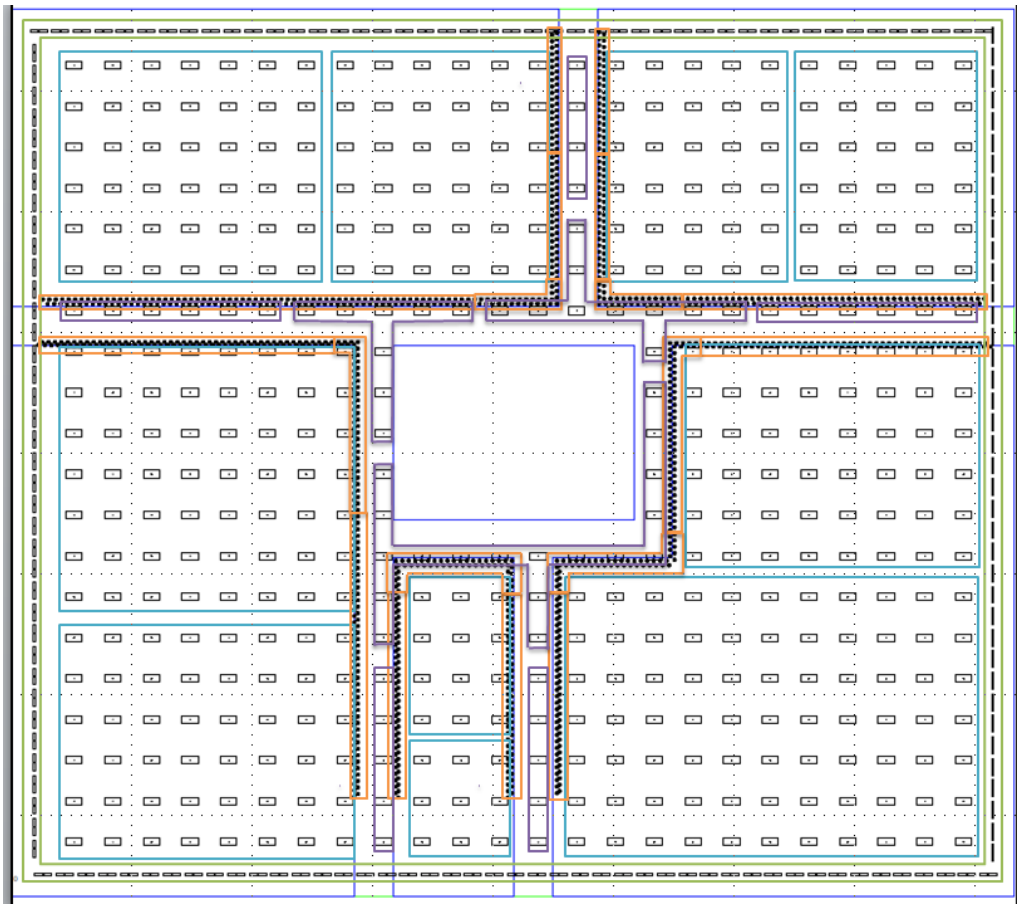
Table 7: Luminaire Specifications for Department Store Model

Luminaire	Wattage	Quantity	Total Wattage	Lighting Power Density
Wall washers	56	501	28,056	0.19
Troffers	130	1,350	175,500	1.22
Track Lights	13	3,420	44,460	0.31

Source: CLTC

Luminaires were grouped together into zones under four unique scenarios to simulate the effects of detected occupancy and zone size on lighting energy use. The first zoning scenario utilized individual luminaire zones, where each luminaire acts autonomously based on occupancy signals from a sensor installed it the fixture. The *Small Zone* grouping includes walkway troffers and track controlled in groups of three luminaires, and the area troffers controlled in groups of six. The *Medium Zone* grouping includes walkway troffers, area lighting and track subdivided into approximately 10 zones. The *Large Zone* grouping combine all of the walk way lighting into one functional zone and subdivides the remainder of the lighting into four zones or quadrants, creating a total of five control zones. In all scenarios, wall wash lighting is not controlled by occupancy sensors. All luminaires within a zone act identically based on the occupancy stimuli provided to the zone's occupancy sensor.

Figure 4: Zones for department store model



Source: CLTC

Throughout the day, light levels change to accommodate different events within the store. The daily lighting schedule is shown in Table 8. During standard business hours, troffers, walkway lighting and track lighting is dimmed to 20 percent when no store occupants are detected. Lighting is also reduced before and after standard business hours when employees are restocking or doing other maintenance tasks. During this time, the wall washers remain off and the track lights turn on when triggered by occupants. During cleaning hours, 10 p.m. to 6 a.m., the wall washers and track remain off and the troffer output is reduced to 50 percent during occupied periods and 20 percent during unoccupied periods.

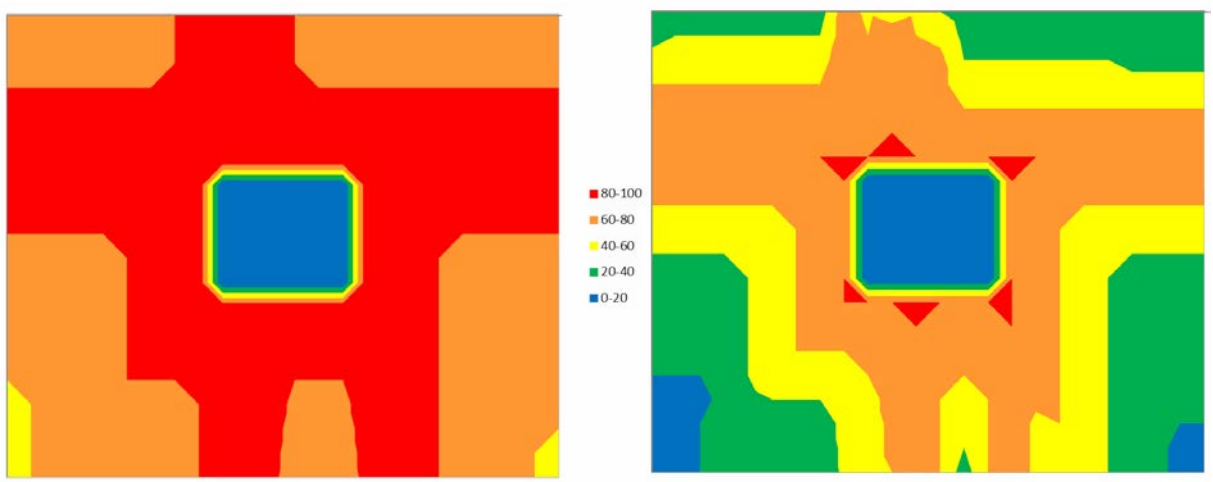
Table 8: Bi-level Light Level Outputs for Various Store Hours

	Standard Business Hours (9 am to 9 pm)		Cleaning/Closed (10 pm to 6 am)		After Hours: Employees Only (9 pm to 10 pm)	
Luminaire Types	Low	High	Low	High	Low	High
Wall washers	100%	100%	OFF	OFF	OFF	OFF
Troffers	20%	100%	20%	50%	20%	100%
Walkway Troffers	20%	100%	20%	50%	20%	100%
Track Lights	30%	100%	0	0	0	100%

Source: CLTC

For each time period, a high and low occupancy map was applied to each zoning scenario, shown in Figure 5. The highest occupancy areas follow the main paths within the store (red and orange). When a zone had two or more occupancy levels within its borders, the higher occupancy rate was utilized for the entire zone. This is called absolute occupancy and it indicates highest level of activity for the lights in the zone.

Figure 5: Occupancy Occurrences for High and Low Volumes of Occupants



Source: CLTC

The use of large occupancy control zones equated to increased lighting energy use. Average annual savings ranged from 13 percent and 23 percent depending on the control zone size as compared to the same store without occupancy controls. Control zone size did not significantly impact savings when zone size increased beyond approximately 500 square feet.

Table 9: Control Zone Size and Energy Savings

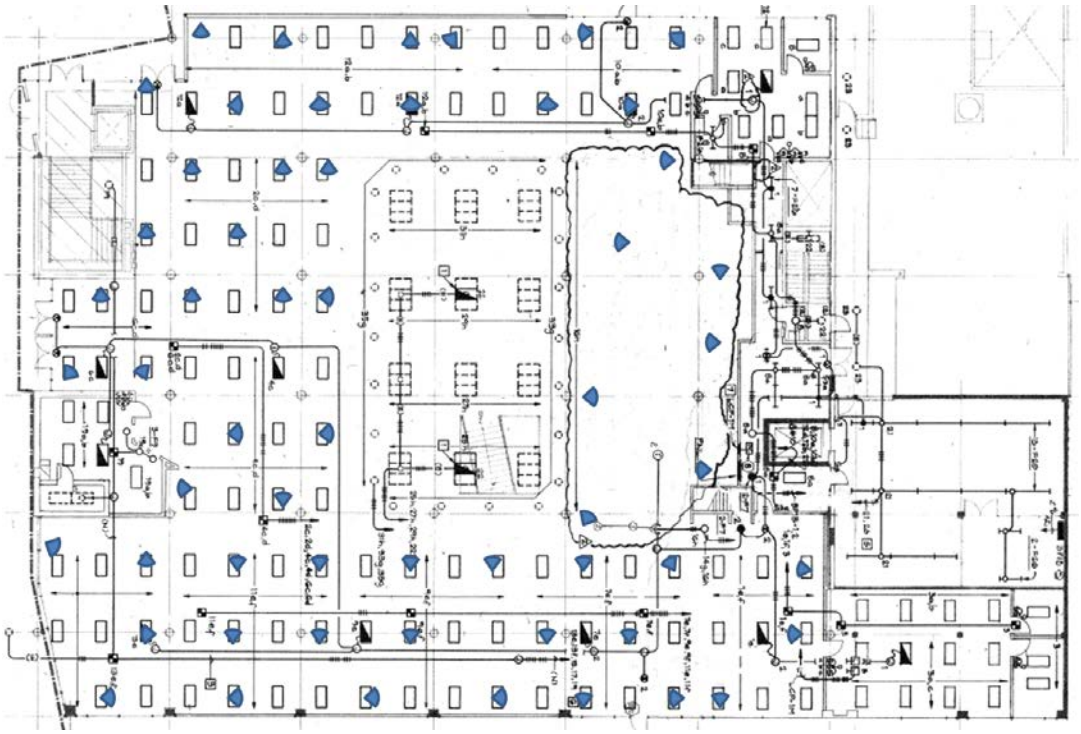
	Zone Size (square feet)	Average Savings
Individual Luminaire	0-250	23%
Small Control Zone	250-500	19%
Medium Control Zone	500-5,000	13%
Large Control Zone	5,000-10,000	13%

3.2.2 Occupancy Timeout and Zoning

Most occupancy sensors allow users to select a timeout period, usually between 0 and 30 minutes, which controls how quickly luminaires are extinguished after the sensor no longer detects occupants in the space. The length of the timeout period has a direct influence on the energy use of a lighting system. Systems controlled by occupancy sensors with a long timeout period use more energy than those controlled by sensors with short timeout periods. The challenge in a retail environment, however, is to reduce frequent switching, which can negatively impact customers and sales. This is achieved by lengthening the timeout period at the expense of energy savings. To better understand the tradeoffs associated with the use of occupancy sensors in retail spaces, researchers recorded the occupancy patterns in a typical retail space and applied varied occupancy timeout profiles to the data, resulting in a spectrum of energy use correlated to occupancy sensor timeout period.

Researchers installed more than 50 light and occupancy data loggers in a retail bookstore to gather information on occupancy as compared to lighting system use. These loggers were set to record occupancy and light-level status in 1 min increments for a period of 30 days. The loggers are denoted as blue wedges on Figure 6.

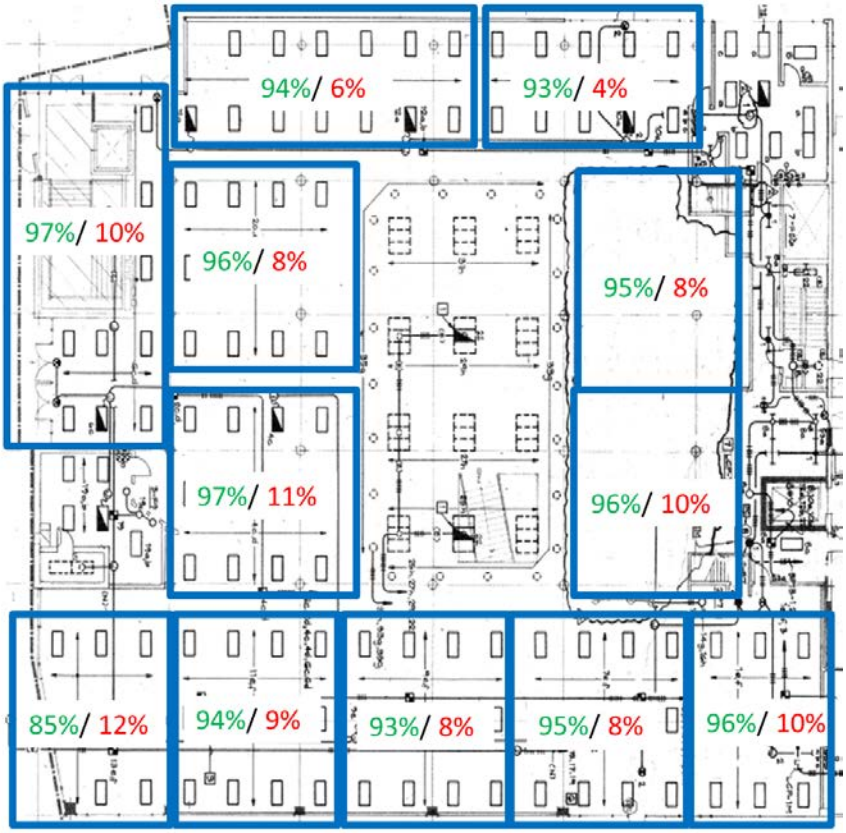
Figure 6: Floor plan showing location of occupancy/light loggers utilized in the retail occupancy study



Source: CLTC

The book store sales floor was broken into twelve zones. Recorded occupancy for business and non-business hours is shown in Figure 8. Within each zone, researchers selected one data logger to represent the zone's "occupancy sensor". Researchers compared the data from all other sensors in the zone to the "occupancy sensor" in order to determine the difference in actual occupancy and lighting energy as compared to that sensed by the "occupancy sensor". This data was used to calculate the percent of "on" hours.

Figure 7: Absolute occupancy for business (green) and non-business (red) hours with a five minute timeout

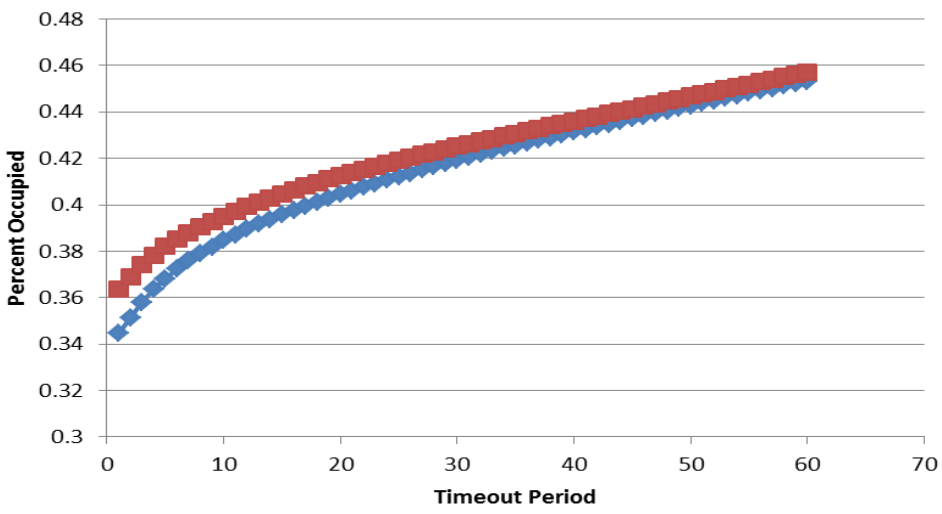


Source:CLTC

This calculation was repeated, applying increasing timeout periods to the "occupancy sensor" in order to map the relationship between timeout period and lighting energy use. Results of this study are shown in Figure 8. Blue data points indicate occupancy as compared to timeout period for individual, local sensors (generally, one at each luminaire). Red data points indicate occupancy as compared to timeout period for the zonal "occupancy sensor".

As the timeout period increased, so did the percent of ON hours for the lighting system. For both the absolute occupancy (that sensed by the zonal "occupancy sensor") and the local occupancy, increases in the timeout period increased lighting energy use by up to 30 percent. In California, occupancy sensor timeout settings cannot exceed 30 minutes. Savings between a 30 minute timeout period and a 1 minute timeout period, using a zoned control approach, was found to be approximately 17 percent.

Figure 8: Effects of timeout on lighting zones and local occupancy



Blue data points indicate occupancy as compared to timeout period for individual, local sensors (generally, one at each luminaire). Red data points indicate occupancy as compared to timeout period for the zonal "occupancy sensor".

Source:CLTC

3.2.2.1 Extended Height Applications

Retail ceiling heights often exceed 10 feet. Most manufactures currently provide sensor coverage patterns for occupancy sensors mounted between 8 and 10 feet only. To better understand occupancy sensor performance in applications that exceed the 10′ threshold, researchers performed extended height testing for a cross-section of commercially available sensors. Researchers created a flexible grid system for luminaires with a mounting height of 12 ft. Testing followed the National Electrical Manufacturers Association (NEMA) WD 7-2000 Occupancy Motion Sensors Test Procedure.

Researchers tested dual technology sensors, which contain both passive infrared (PIR) and ultrasonic (US) sensing capabilities. For the purposes of this testing, only the PIR coverage pattern was evaluated. Researchers utilized two sensors from different manufacturers. Due to the large coverage patterns and the limited space of the flexible grid, 26x28.5ft, only half of the sensors coverage pattern was tested. For testing purposes, half the Fresnel lens was taped off following the symmetric patterns in the lens.

Both the major and minor motion NEMA test procedures were followed to fully characterize the coverage pattern of each occupancy sensor. A 3 ft. by 3 ft. grid was centered underneath the flexible grid system, Figure 9. The occupancy sensor was also centered and leveled at the back edge of the 3ft by 3ft grid. This will allow the 180 degree view of the occupancy sensor to have the maximum amount of space for coverage pattern testing. The NEMA operating conditions were met for each test; test environment, test subject specifications and setup procedures.

Figure 9: Occupancy sensor coverage pattern testing

Photo credit: CLTC

Results of major and minor motion testing are shown in Table 10. Both of the sensors tested either reached or had a further range than reported in product specifications. Sensor 1 had a larger range of detectable minor motion than Sensor 2. Sensor 1 also had a further major motion coverage. Both of these sensors coverage patterns were deemed appropriate for retail applications.

Table 10: Results of major and minor motion testing

	Sensor 1		**Sensor 2**	
	Minor	Major	Minor	Major
Specified	12 ft.	20 ft.	7 ft.	11 ft.
Tested	12 ft.	24+ ft.	15 ft.	21 ft.

Source: CLTC

3.2.3 Control System Feature Set – Retail Applications

Based on controls and operational evaluations of existing commercial systems and retail applications, researchers developed an optimized, retail, control system feature set. Additional control layers, such as daylighting or occupancy-based control for accent lighting may be appropriate based on the individual retail space.

General Illumination:

1. Lighting power density: 0.85 to 1.25 W/sf
2. Systems shall be fully dimmable
3. Zonal occupancy sensing resulting in a multi-level lighting design:
    a. Occupancy sensor with timeout period between five and 10 minutes.
    b. Occuppied: full light output
    c. Unoccuppied: 30 percent – 50 percent of full output
    d. Control zones shall should be less than 500 sf to maximize savings. If this is not feasible, control zone size will not likely impact occupancy savings, and zone size should be based on product guidelines or other stated project requirements.
4. Tuning: based on system design, high-end trim should be utilized to reduce full output by 10 percent to 30 percent.
    a. Systems should be evaluated at the end of 5 years to adjust high-end trim to account for lumen depreciation, or use systems that include automatic lumen maintenance adjustments.

Task and Accent Lighting:

1. All systems shall be automatically switched OFF after business hours

Chapter 4: Technology Demonstration

Researchers utilized results from controls development and testing as part of a demonstration project conducted to assess the in-situ performance of systems operating with an optimized control system feature set identified for retail spaces.

4.1 Retail Demonstration Space

The demonstration space was composed of approximately 4,300 square feet of retail space in a multi-tenant light commercial building. The space contained a large open retail area, an adjacent bike repair area, as well as several support spaces such as storage, offices and restrooms. The retailer utilized area lights for the general merchandise and track lights along the perimeter to add extra illuminance to the vertical displays, Figure 11. The technology demonstration addressed application of adaptive control solutions for the general lighting in the main retail and bike repair area.

Figure 6: Retail demonstration space - preretrofit

Photo credit: CLTC

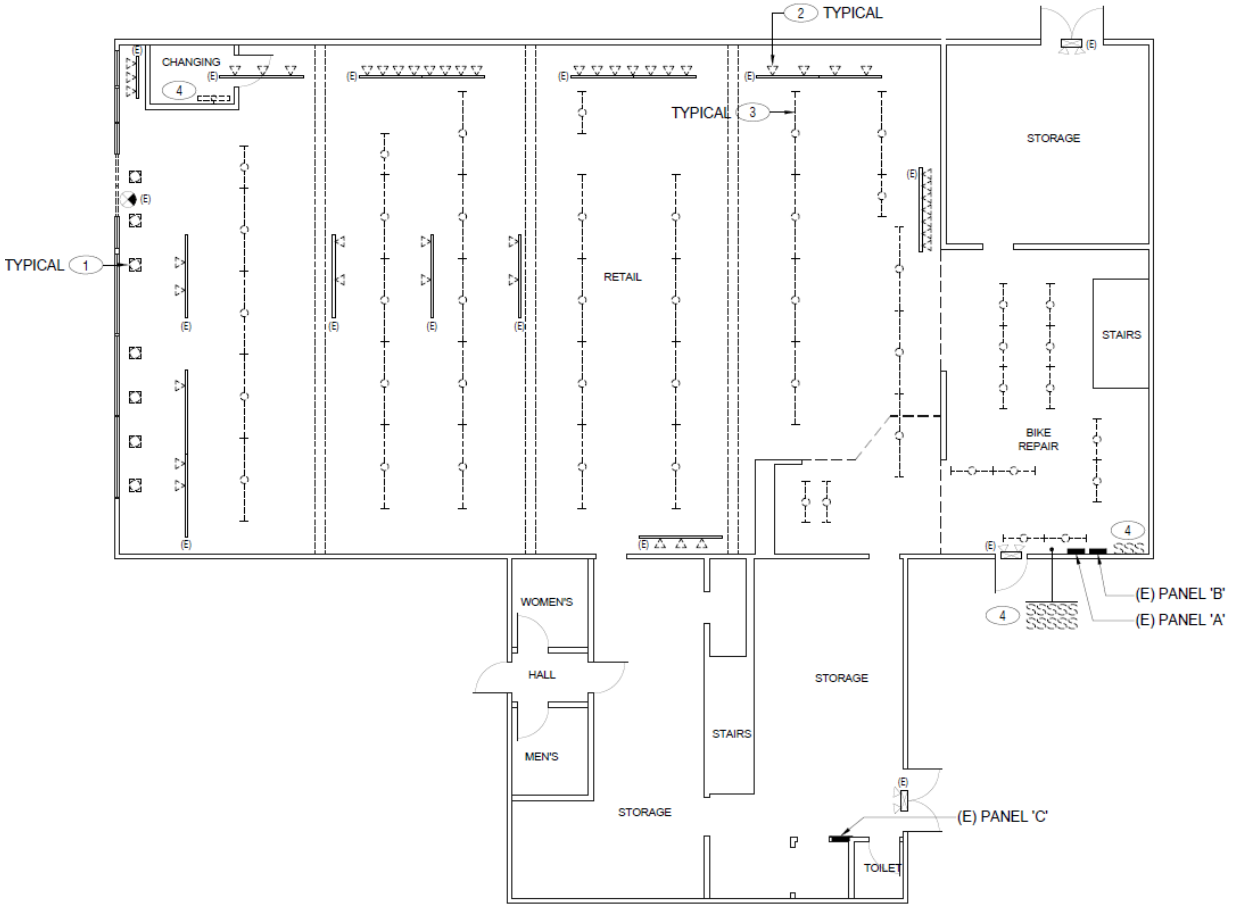
4.1.1 Incumbent Technology

General lighting was provided by surface mounted, linear fluorescent luminaries operating with standard 4′ or 8′ T8 lamps. In addition, the main retail area contained recessed down lights near the front of the store. Track lighting was also used, mainly around the sales floor perimeter, and it consisted of mixed stock track heads with incandescent PAR-30 or GU-12

lamps. Lighting was controlled by manual toggle switches. A lighting plan is shown in Figure 11.

The store's business hours are Monday through Friday, 9 a.m. to 8 p.m., Saturday 9 a.m. to 7 p.m. and Sunday 12 p.m. to 5 p.m. Lighting in the main retail area was ON only during business hours. Lighting in the bike repair area was used for an extended period of time, both before opening and after closing; allowing employees extended work time in the space.

Figure 7: Luminaire Layout



Source: Edge Electrical Consulting

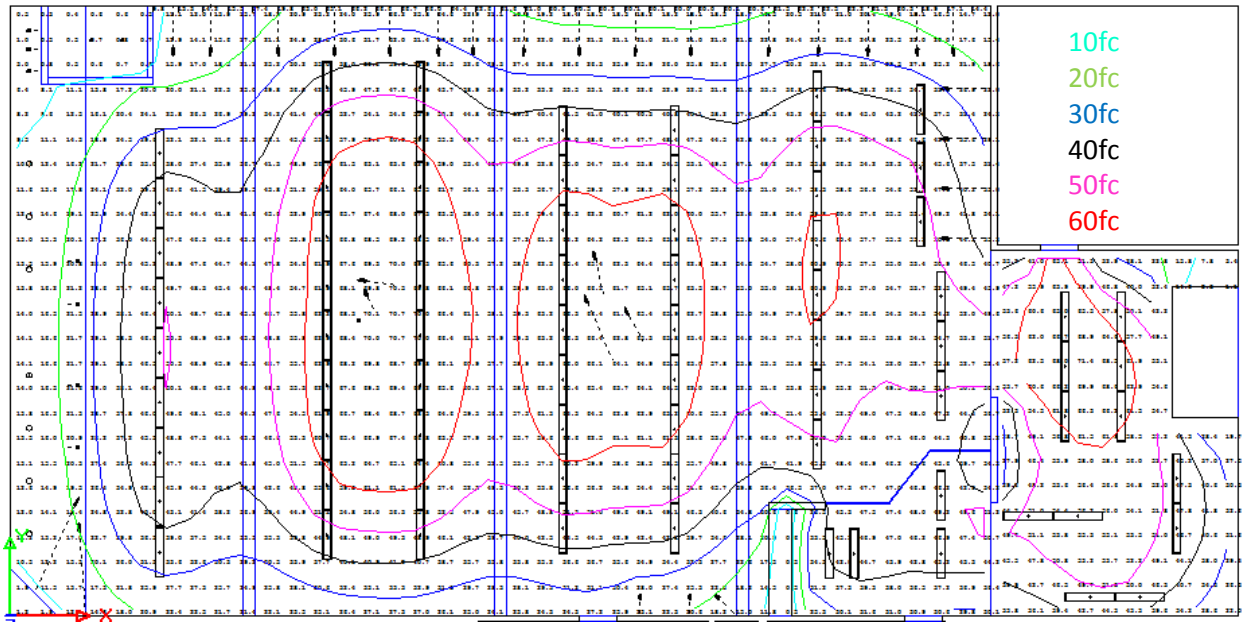
4.1.2 Adaptive Lighting – Demonstrated Systems

The lighting demonstration package included LED area lights and a networked lighting control system. The system was designed and specified such that its performance achieved IES recommended light levels for retail applications. Existing luminaire mounting locations were maintained in most areas of the store.

For general retail areas, IES recommends horizontal illuminance of 40 fc at 2.5 ft. from the finished floor. Existing fluorescent luminaires were retrofit with dimmable, LED alternatives, which were expected to deliver light levels exceeding IES recommendations (42 fc estimated).

IES recommended light levels for general service areas is 50 fc. New luminaires for this area were expected to deliver light levels exceeding this value for much of their useful life (67 fc estimated).

Figure 8: Lighting layout for demonstration space



Source: CLTC

Designs were verified for compliance with LPD and controls requirements contained in California's 2013 Building Energy Efficiency Standards (Title 24, Part 6). As of the time of this demonstration, the allowed LPD for the main retail area and the bike repair area are 1.7 W/ft^2 and 0.9 W/ft^2 respectively[3]. Total allowed lighting power was 6913 W. Total power of the new systems was 3320 watts, approximately 52 percent less than that allowed by code.

Alterations also required area controls, multi-level lighting controls and shut-off controls to meet code requirements. Controls requirements were met through inclusion of a digital lighting management control system. Area and multi-level controls were achieved through use of two separate dimming switches, one for the retail space and another for the shop area. Additionally, manual dimming did not override other controls measures such as daylighting and high-end tuning; however, switches did override scheduled dimming or OFF periods for up to two hours. Automatic shutoff off control was achieved through the use of zonal occupancy sensor and a scheduling feature included with the digital control system. Daylighting controls were also included, however, the measure was not required by code for this alteration.

[3] Based on the Area category method. Includes an additional 0.3 W/sf allowance for accents/displays and an additional 0.2 W/sf for decorative lighting in retail spaces as allowed by code.

Occupancy sensors were used to provide bi-level dimming during vacant hours. The dimming schedule is shown in Table 11. During open hours the bike repair area lighting was trimmed to 70 percent at full output. During unoccupied periods, lighting dimmed to 20 percent of full output. The reduction was set to occur after a 20 minute timeout period. For non-business hours, the occupied light level remained at 70 percent; however, lighting was fully extinguished during vacant periods after only a five minute timeout. For the retail sales floor, maximum light output during occupied business hours was trimmed to 65 percent. During vacant business hours, lighting was reduced to 35 percent of full output, a higher level than the repair area, so that the store remained visually inviting when viewed from outside. For nonbusiness hours, security lighting was left ON at 65 percent; while the rest of the lighting was dimmed down to 35 percent while occupied and OFF otherwise.

Table 11: Adaptive light levels for business and non-business hours

	Business Hours		Non-business hours	
	High	**Low**	**High**	**Low**
Bike Shop	70%	20%	70%	Off
Retail Area	65%	35%	35%	Off
Retail Security	65%	35%	65%	55%

Source: CLTC

4.1.3 System Performance

Researchers evaluated system performance along three vectors: energy, light level and building occupancy. Data was collected for both pre and post retrofit conditions. Energy savings are presented for both a 2013 Title24-compliant design as compared to the demonstrated, adaptive lighting system and the actual site baseline as compared to the new system.

4.1.3.1 Lighting Use and Area Occupancy

To confirm occupancy and lighting use, researchers utilized a single data logger capable of recording both measurements. The loggers were installed strategically around the retail sales floor and bike repair area to capture a majority of the space. Loggers were set with a 5-minute timeout period to align with the occupancy sensor timeout period planned for the new control system. Researchers collected three months of preretrofit data.

The results of the light and occupancy logging can be found in Table 12. Logging confirmed that the lighting systems were used continuously during business hours. Data suggests that new adaptive lighting systems, controlled by occupancy sensors set to a five minute timeout period, should achieve a 15 percent reduction during business hours in the main sales area for the occupancy control measure, and negligible reduction in the bike repair area. Additional planned control measures, such as daylighting and tuning can provide additional savings.

Table 12: Occupancy rates and lighting system operation at retail demonstration site

	Logger ID#	Total Time On	Total Occupancy	Average Occupancy Rate	Occupancy – Business Hours	Occupancy – Non-business hours
Bike Repair	6	54%	38%	48%	98%	13%
	7	97%	0%			
	67	19%	24%			
Main Area	20	28%	5%	41%	85%	10%
	23	49%	24%			
	49	6%	25%			
	56	24%	6%			
	59	20%	9%			
	71	34%	6%			
	73	54%	7%			
	75	38%	21%			
	86	22%	6%			
	94	63%	3%			

Occupancy rate for timeout period set at 5 minutes

Source: CLTC

4.1.3.2 Light Levels

Researchers collected light level readings for both pre and post-retrofit conditions. Horizontal illuminance measurements were taken at the task level, 2.5 ft. Measurements were taken along an 8 ft. by 8 ft. grid, throughout the store. The grid was aligned such that measurement locations alternated between a point directly under a luminaire and a point between two adjacent luminaires. Results are shown in Table 13. New systems delivered improved uniformity and light levels that exceeded recommendations.

Table 13: Illuminance – retail demonstration site

	Horizontal Illuminance		Vertical Illuminance - Perimeter	
	Average (fc)	Maximum/Average Uniformity Ratio	Average (fc)	Maximum/Average Uniformity Ratio
IES Standard	40	3:1	75	4.1
Preretrofit	43.5	1.5:1	35	1.8:1
Post retrofit	45+	Pending	35+	Pending

4.1.3.3 Lighting System Electricity Use and Cost Savings

Energy use of the new system was monitored in phases in order to attribute energy savings to each of the control layers applied to the space. During phase 1 only tuning, scheduling and occupancy control were enabled. Data was collected for two weeks under these control

conditions. In the second phase, task specific tuning was added. The new luminaires, excluding application of control measures, saved 52 percent annually as compared to a Title 24 compliant lighting system, Table 14. The addition of bi-level, occupancy based control per the schedule listed in Table 11 results in an additional 10 percent energy savings, or 62 percent total savings annually. Application of a 20 percent high-end trim to tune the system to deliver light levels consist with industry recommendations resulted in a final system savings of approximately 65 percent.

Table 14: Annual energy savings - retail demonstration site

Technology	LPD (W/sf)	Lighting system power (W)	Annual Energy Consumption (kWh)[4]		
			No Controls	Bi-level occupancy control	Add Tuning
Title 24-compliant Baseline	1.6[5]	6,900	25,116	-	-
Demonstration site - baseline	1.2	5,175	18,837	-	-
New System	0.77	3,320	12,084	10,875	8,700
Savings – demonstrated	36%	36%	36%	42%	53%
Savings compared to Title 24 baseline	52%	52%	52%	57%	65%

4.1.4 Conclusion

Many commercially available advanced lighting control systems (ALCS) contain functions and features that may be appropriate for use in retail environments. While control strategies will differ among retail sites, at a minimum, strategies should utilize scheduling, high-end trim and occupancy-based dimming. Control zones and control device settings should follow the guidelines developed through this project. Demonstration showed that these recommendations can result in significant energy savings as compared to 2013 Title 24 building energy-efficiency standards.

[4] Based on 3,640 annual hours of use (actual business operating hours).

[5] Weighted average of 1.7 W/sf in main retail space and 0.9 W/sf in bike repair area.

GLOSSARY

Term	Definition
ALCS	Advanced lighting control system
CCT	Correlated color temperature
CFL	Compact Fluorescent Lamp
CRI	Color rendering index
CT	Current transducer
DALI	Digitally Addressable Lighting Interface
DR	Demand Response
ELV	Electronic Low Voltage
fc	Foot-candle
HID	High Intensity Discharge
IES	Illuminating Engineering Society
LED	Light emitting diode
LPD	Lighting power density
lu	lumens
MLV	Magnetic Low Voltage
NEMA	National Electrical Manufacturer's Association
PIR	Passive infrared
TLED	Tubular Light Emitting Diode
UL	Underwriter's Laboratory
US	Ultrasonic
W/sf	Watts per square foot

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