2015

LIGHTING TECHNOLOGY OVERVIEW

DEVELOPED BY THE CALIFORNIA LIGHTING TECHNOLOGY CENTER, UC DAVIS

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PHOTO: HONDA SMART HOME US, AMERICAN HONDA MOTOR CO.

1 INTRODUCTION

This document provides overviews of commercial and residential lighting technologies and strategies with the potential to significantly reduce California's lighting energy use. Each overview represents a product or practice that may warrant new or continued market transformation support from the state's investor-owned utilities (IOUs). Some of these technologies and strategies may require a higher initial investment by consumers when compared to standard lighting retrofit solutions, but they deliver high energy, peak demand, and CO_2 savings over their lifetimes. With adequate support and utility incentives to reduce the initial purchase price, where applicable, consumer uptake is expected to increase and product costs to drop.

The original Lighting Technology Overview (LTO) was developed during a December 2008 lighting roundtable organized by the California Public Utilities Commission's (CPUC) Energy Division. Attendees consisted of utility representatives, researchers, manufacturers, sustainability professionals, policy makers, public sector stakeholders, and lighting industry leaders. Participants identified the energy-efficient lighting solutions most relevant to their respective industries. Identified lighting solutions were included in the first LTO prepared in 2009. Similar roundtable meetings were organized in 2010 and 2013 to review the LTO and suggest updates. In 2010, the LTO was revised and expanded to include an analysis of lighting best practices. In 2013, roundtable participants expressed a need to update the LTO with new technologies. This document includes the results of this update.

Each LTO summary includes a brief technology description, a general estimate of its energy savings potential, a sample of available products and a list of relevant case studies. Note, some products featured in past iterations of the LTO remain since they continue to offer significant energy savings, but have not succeeded in receiving the market transformation support necessary to make them mainstream.

The 2015 LTO focuses on solid-state lighting (SSL) products and lighting control systems. SSL continues to see exponential growth in commercially available products and light-emitting diode (LED) efficacy. In particular, certain categories of LED products have improved in their demonstrated ability to reduce energy use in specific applications at a cost-effective price. For example, LED high bay luminaires can now provide the luminous intensity and distribution needed for lighting large warehouses, making them a viable alternative to replace metal halide (MH) or fluorescent luminaires in these applications. When the first LTO was compiled, there were few LED products serving this market and concerns about LED light output compared to incumbent technology. The product category is evolving and more products are now available for warehouse and high bay lighting applications.

The LTO directly supports California as it works to meet its energy-efficiency and environmental policy goals. As an example, California is implementing the Lighting Action Plan (LAP). The 2013–2015 LAP is designed to help achieve the goals described in the California Long Term Energy Efficiency Strategic Plan, which the CPUC adopted in 2008 and expanded in 2010 to include a lighting chapter.[1, 2, 3] The four integrated sections of the LAP focus on achieving the following vision:

> *By 2020, advanced products and best practices will transform the California lighting market to deliver a 60 to 80% reduction in statewide electrical lighting energy consumption from 2010 levels.*

Stakeholders may use the 2015 LTO to encourage the adoption of its recommended technologies. Demonstrations through emerging technology programs or inclusion in utility incentive programs will help accelerate each technology's adoption rate and help achieve LAP savings goals.

PHOTO: CLTC, UC DAVIS

LED LAMPS & LUMINAIRES

INTRODUCTION TO LEDS

The development and engineering of LEDs goes back more than a half century, with the first practical application of LEDs coming in 1962. LEDs for general illumination building applications emerged in the early 2000s. LEDs produce light by different physical processes than conventional lighting sources. LEDs do not utilize electrical filaments, electrodes or gaseous discharge processes to produce light. Instead, LEDs emit light through a process called solid-state electroluminescence. Electroluminescence is an optical and electrical phenomenon in which a material emits light in response to the passage of an electric current or to a strong electric field. White light is achieved by mixing colored light from multiple, single color LEDs or adding phosphor coatings to the LEDs, which absorb one color light and emit multiple colors that appear white when combined.

LEDs are highly directional, spot sources. Light is emitted from a very small surface area on the LED chip so the output must be diffused using secondary methods such as lenses or reflective optics.

The efficacy of LEDs is rapidly improving, with some commercial products delivering 170 lumens per watt (lm/W).[4] Product life also continues to increase, with current rated life in the range of 25,000 to 100,000 hours.

Correlated color temperature (CCT) can be provided for almost any range, but CCT outside a typical range of 2,500 to 5,000K for most applications is usually not desirable. Lower CCT LEDs are available down to 1,900K but efficacy suffers. Lower CCT generally means lower efficacy. A 1,900K LED may have an efficacy of 20 lm/W and low color rendering index (CRI). A high CRI is important for applications where color rendering is valued. To achieve the right light for the application, efficacy, CCT and CRI should be evaluated with the site-specific needs in mind.

There are many advantages to using LED technology as compared to traditional incandescent, fluorescent or high-intensity (HID) sources.

1. The lifetime of an LED product is significantly longer than most alternatives, which reduces product replacement, maintenance and recycling costs.
2. LEDs are fully dimmable, last longer when dimmed, and are not affected by ON-OFF cycling, which makes them well suited for use with lighting controls solutions.
3. LEDs are good for certain applications in cold environments, since efficacy and life both increase with lower operating temperature.

FACTORS TO CONSIDER WHEN COMPARING PRODUCTS

LED lighting solutions should deliver similar, if not better, photometric and electrical performance compared to the products they claim to replace. Near-term market acceptance will be driven by the products' initial performance and their ability to meet or exceed user expectations for characteristics such as initial light output, color, and dimming. Long-term market acceptance will be driven by the products' longevity and their electrical and photometric performance throughout its life. Consider the following when selecting LED lamps and luminaires:

- **LED light engines or modules:** LED technology is still new, and not all LEDs or components are created equal. Consult with a lighting professional about the vintage of the LEDs or components used in the specific product to ensure benefits are reaped from the most recent technology advancements.
- **Heat management:** Operating temperature directly affects the lifespan of the LED, so effective heat management is critical to achieving the rated performance. Heat management occurs at the luminaire level in the housing and heat sink, which moves heat away from critical components and dissipates it into the environment. Look for precision machining, visible heat sink fins, and luminaires with a large surface area for dissipating heat to indicate that heat management has been addressed. Check with a lighting professional about the thermal characteristics of the application and the most appropriate luminaires.
- **Optics and housing materials suitable for environment:** Environmental factors such as dust and humidity are important to consider with long-life products. The cumulative effect of environmental factors over years and even decades can cause any luminaire to fail. In order to achieve the rated lifespan of an LED solution, it should be installed and operated under conditions that closely match those recommended by the manufacturer.
- **Light output and distribution:** For retrofit projects, model how the light will be delivered to the space before assuming a one-for-one retrofit from existing technologies to LEDs. LED luminaires may not provide the same illuminance levels on task surfaces even if they have a similar distribution pattern to predecessor technologies. Evaluate photometric data and modeling of the existing layout with new LED products to help determine if a new lighting design is needed.
- **Dimming:** When reviewing LED product choices, opt for dimmable lamps and luminaires. Dimming can save energy, extend the life of an LED product, and allow for customized control of illumination levels. For projects that must comply with California's Building Efficiency Standards (Title 24, Part 6), when specifying LED luminaires, it may be required that the luminaire can dim between 10 and 100% power.

The California Lighting Technology Center (CLTC) at the University of California, Davis is currently engaged in research and testing of many types of LED products. Research includes examination of LED product performance and longevity under a variety of real-world operating conditions. For example, CLTC is currently conducting LED replacement lamp life testing. The end of life for an LED product is the time at which its light output drops below 70% of their initial rated output. In the field, the lifespan of LED lamps and luminaires are limited by the various components and materials of the complete luminaire assembly rather than specifically by the LED source. In particular, the LED driver or any other electronic components are likely to fail or require maintenance long before the LED source because of the relatively short lifespan of electrolytic capacitors. A capacitor, which can be found in most electronics, is a basic electric component that stores electrical energy. It is important to consider the lifetime of system components, and not just the lifetime of the LED source.

Other quality issues surrounding LED products are also currently under investigation at CLTC. These include visible flicker, color consistency, color rendering and power factor.

PHOTO: ACUITY BRANDS

INTERIOR LED LAMPS & LUMINAIRES

LED replacement lamps and dedicated LED luminaires are a primary growth area in the lighting industry as LED technology and designs continue to advance. LED manufacturers frequently update their product offerings, and new manufacturers are entering the field. Currently, there are LED lamps for medium screw-base and bi-pin applications with products available to replace traditional omni-directional (A19), directional (reflector) and tubular (linear) light sources. There is a plethora of dedicated LED luminaires on the market including products for applications such as task lighting, downlighting, general ambient illumination, landscape lighting and outdoor general area lighting.

- **Omnidirectional (A19) Lamps**
- **Recessed Downlights**
- **Directional Lamps**
- **Troffers & Surface Mounts**
- **Linear LED Retrofit Solutions**
- **High-Bay & Low-Bay Lighting**
- **Track Lighting**
- **Parking Garage Luminaires**

Omnidirectional (A19) Lamps

A variety of LED A19 alternatives are now available to replace traditional products. For example, the DesignLights Consortium (DLC) Qualified Products List includes multiple LED A19 lamps ranging from 6 to 23W with a luminous efficacy range of 52 to 100 lm/W.[5] LED A19 availability has significantly increased since 2010, according to the U.S. Department of Energy (DOE)'s CALiPER (Commercially Available LED Product Evaluation and Reporting) program. Results from the CALiPER program show that the cost per lumen of A19 LED lamps dropped by 50% between August 2010 and November 2011.[6] In addition, LED replacement lamps have longer lifetimes than incandescent and compact fluorescents lamps (CFLs), with rated lifetimes ranging from 10,000 hours to 50,000 hours.

Information on LED A19 performance is available from a variety of sources. For example, CLTC hosts an online product database that provides access to LED replacement lamp performance data for statistical analysis and comparative evaluation. The database is accessible through a web-based interface (**ledperformancedatabase.org**). It includes data from multiple sources, including CLTC test labs, other research programs, certified laboratories and lighting manufacturers.

EXPECTED ENERGY SAVINGS

The California residential lighting market is still largely untransformed with respect to this product category. A 2012 survey of California IOU residential customers determined there were 32 incandescent lamps used per household on average (Operating at 54.6W each for 1.2 hours each day). With more than 12.5 million California households as of 2013, traditional incandescent lighting consumed nearly 10,000 gigawatt-hours (GWh) of electricity each year.[7]

LED A19 lamps also offer opportunities for energy use reductions in many non-residential applications. Restaurant and retail applications typically include track lighting, chandeliers, pendants and wall sconces, which often utilize incandescent lamps. The hospitality market also represents a significant opportunity. For example, in the Southern California Edison (SCE) service territory, there are approximately 110,000 hotel rooms and many use portable desk lamps or torchieres with A19 lamps.[8] The long lifetimes for LEDs make the switch from incandescent or CFL to LED attractive to these business operators.

With the exception of the retail sector, less than 5% of commercial pin and medium screw base lamps utilized LED technology, according to the California Commercial Saturation Survey (CSS) published in 2014.[9] In the retail sector, 13% of these lamps used LED sources, according to the same study.

FACTORS TO CONSIDER WHEN COMPARING PRODUCTS

As a result of the rapid growth in the commercial LED market, it is important to consider the most recent market surveys, publically available test reports and off-the-shelf availability for any retrofit project or program. Note, market surveys do not represent all products currently available and should be viewed as a snapshot of the overall LED market at the time of the survey's publication. To better understand product performance, third-party testing, funded by agencies such as DOE, California Energy Commission and California IOUs, should be consulted to verify manufacturer claims of equivalency to the traditional light sources they are marketed to replace. Consumers should consider verified product performance as opposed to claimed product performance.

For example, **ledperformancedatabase.org** includes 33 products marked as replacements for a traditional 60W incandescent. The average power consumption of these LED replacements is 12W, an 80% savings over incandescent if used at full output.

LED Performance Database
ledperformancedatabase.org

The LED Performance Database houses all raw and derived data obtained from comprehensive testing of a representative sample of commercially available LED replacement lamps.

Additional savings can be achieved if the LED lamp is paired with a dimmer. However, to deliver suitable performance, it is important that the lamp and dimmer be compatible. Compatibility information is typically included with product packaging. Additional LED lamp and and controls testing results are available from groups such as Pacific Gas and Electric Company (PG&E), CLTC and Pacific Northwest National Lab.[10]

In California, it is also important to consider LED lamp performance with respect to state building and appliance standards. Applicable LED replacement lamp performance standards include ENERGY STAR®,[11] Title 24,[12] California Appliance Efficiency Regulations (Title 20),[13] and the Voluntary California Quality LED Lamp Specification (CQS).[14] The CQS is a statewide quality standard for LED replacement lamps that exceeds ENERGY STAR® qualifications. Many California utilities only incentivize LED replacement lamps that meet the CQS requirements. A summary of the current ENERGY STAR® and CQS specifications are provided in Table 1. A full comparison may be found at **ledperformancedatabase.org/pages/standards**.

Table 1. Specification Comparison

Metric	Energy Star®	Voluntary California LED Lamp Specifications
Correlated Color Temperature (CCT)	2,700 K, 3,000 K, 3,500 K, 4,000/4,100 K, 5,000 K, 6,500 K*	2,700 K, 3,000 K**
Efficacy for Omnidirectional Lamps: <15 / >15 Watts (lumens / Watt)	55/65	N/A
Efficacy for Omnidirectional Lamps: <20 / >20 Watts (lumens / Watt)	40/50	N/A
Luminous Intensity Distributions (Omnidirectional)	Lamp shall vary by no more than 25% from average of all measured values (no less than 5% total flux shall be emitted in 135°–180° zone)	Per Energy Star V. 1 Draft 2
Color Rendering Index (CRI)	(Ra) ≥80; R9 > 0	(Ra) ≥90; R9 > 50
Rated Life (Years)	Decorative lamps ≥ 15,000 hours; All other lamps ≥ 25,000 hours, All lamps operational at 3,000 hours, 90% operational at 6,000 hours	Per Energy Star requirements
Flicker	Lamp average light output periodic frequency, highest percent flicker, and highest flicker index shall be reported	Lamps shall be free of flicker over full range of operation from 10%-100% light output
Warranty	< 15,000 lamp life, 2 year minimum warranty; ≥ 15,000 lamp life, 3 year minimum warranty	Minimum 5 year warranty

* Within 7-step MacAdam Ellipse from designated CCT
** Within 4-step MacAdam Ellipse from designated CCT

EXAMPLE PRODUCTS

Cree TW A19

cree.com/Lighting/Products/Indoor/Consumer/Standard-AType-Bulbs

- 800 lumens with 13.5W power usage
- 59lm/W efficacy
- 93 CRI and CCT of 2,700K
- Dimmable
- 25,000 hour rated life

Feit A19

feit.com/led-lamps/Enhance_LED_A-Bulbs

- 820 lumens with 13.5W power usage
- 60lm/W efficacy
- 93 CRI and CCT of 2,700K
- Dimmable
- 25,000 hour rated life

GreenCreative A19

gc-lighting.com/products/a19-9w-dim/

- 800 lumens with 9W power usage
- 89lm/W efficacy
- 92 CRI and CCT of 2,700K
- Dimmable
- 25,000 hour rated life

CASE STUDIES

Restaurant Lighting Retrofit, Sunnyvale, CA

▸ ecoact.org

Under PG&E's Silicon Valley Energy Watch program, Ecology Action retrofitted the lighting in a large sit-down restaurant. One hundred nine 60W incandescent lamps illuminated the main dining hall. They were replaced one-for-one with 11W Philips LED A-lamps, saving 49W per lamp. The project achieved 27,345 kilowatt-hours (kWh) and 5.04 kilowatts (kW) of total savings.

Fry's Electronics Store, San Jose, CA

▸ etcc-ca.com/sites/default/files/reports/ET12PGE1481%20Retail%20LED%20updated%2003132014.pdf

At a Fry's Electronics store, Philips Endura A19 lamps replaced the 60W incandescent lamps and 19W CFLs in 27 checkout chandeliers. Replacing the 135 lamps with LEDs saved 3,274kWh or about $458 in annual energy costs.

Mirage Hotel and Casino, Las Vegas, NV

▸ usa.lighting.philips.com/projects/mirage.wpd

The Mirage Hotel and Casino's convention complex, The Mirage Events Center, replaced 4,000 incandescent lamps used in sconces and chandeliers with Philips EnduraLED A19 lamps. The new lamps consumed only 7W, providing energy cost savings of about $60,000 per year compared to the 18W and 42W incandescents. The longer LED lamp life helped the facility meet its goals to reduce maintenance costs and re-lamping in busy areas.

Directional Lamps

Directional lamps use internal reflectors to provide various light distribution patterns. Products range from narrow-beam-angle spotlights to wide-beam-angle floodlights. As of 2010, approximately 94% of all installed directional/reflector lamps in the U.S. used incandescent or halogen sources.[15] Many directional lamps can be replaced with LED equivalents. Some of the most common are:

- **Parabolic aluminized reflector (PAR) lamps:** Often used in downlights and track lighting, PAR lamps have a wider bulb diameter than A19 lamps. Incandescent PAR lamps consume 65 to 80 W on average,[16] with an efficacy of 5 to 15 lm/W.[17] LED products have higher efficacies, from 42 to 100 lm/W,[18] and thus are available in lower wattages, 5 to 23 W.
- **Bulged reflector (BR) lamps:** BR lamps are similar to PAR lamps, with the distinction that the top of the lamp is convex with respect to the lamp base. PAR lamps have a flat form factor. Incandescent BR lamps range in wattage from 65 to 80 W,[19] have an efficacy of 5 to 15 lm/W.[20] LED BR replacement lamps have efficacies of 54 to 97 lm/W and wattages of 7 to 22 W.[21]
- **Multifaceted reflector (MR) lamps:** MR lamps are pin-based and available in a variety of sizes, including MR16 and MR11. Halogen MR lamps, the most common source for this lamp size, range in power between 20 and 100 W,[22] and an efficacy of 8 to 20 lm/W.[23] LED MR lamps range in efficacy from 30 to 84 lm/W and from 2 to 12 W.[24]

EXPECTED ENERGY SAVINGS

The potential energy savings for directional LED lamp replacements varies depending on the legacy source being replaced. Replacing incandescent or halogen directional lamps with LED alternatives can produce energy savings between 50 to 90%.[25, 26, 27, 28, 29, 30]

According to DOE, approximately 80% of reflector lamps in use in United States residential applications were incandescent or halogen light sources as of 2010.[31] This same lamp type consumed a total of 16% of total residential energy usage.[32] In interior residential applications, which compose 14,230 GWh of California's annual energy use, switching to LED sources offer potential statewide savings of 509 GWh when replacing pin-base halogen lamps (6% of current interior lighting).[33] For exterior residential lighting in California, replacing halogen flood medium screw-base lighting with LED lamps offers 294 GWh of potential annual energy savings and replacing incandescent flood medium screw-base lighting with LED lamps offers 812 GWh of potential annual energy savings.[34]

FACTORS TO CONSIDER WHEN COMPARING PRODUCTS

Light distribution and installation location are primary attributes to consider before product selection and installation. As with any directional lighting application, proper lighting distribution is vital to properly illuminate points of interest. LEDs are highly directional sources. Directional LED lamps can often achieve better focused and higher illumination on intended targets compared to traditional sources. Consumers should consider the amount of light reaching their intended target and not just the total light produced by the lamp. At first glance, a traditional source may appear to deliver more light, but a closer investigation may reveal that the LED product delivers more light where it is actually needed. Such considerations may allow selection of a product with much lower energy consumption and equivalent or better light output at the point of interest.

A second consideration is the installation location and ventilation. LED lamps require good ventilation and thermal management for optimal performance. In directional applications, the fixture may often be recessed in the ceiling or wall. This can limit airflow to the LED lamp. Consumers should compare installation location features such as lamp base orientation and Insulation Contact (IC)-rating of the fixture housing against the operating conditions used to determine the performance characteristics listed on LED product packaging. When the two differ, LED products may not deliver the performance claimed.

Some other factors to consider include using product ratings such as Energy Star to help evaluate product performance, the manufacturers' longevity in the marketplace, and warranty information.

Visual flicker can also be an issue for LED lamps. To avoid visible flicker in a LED MR16 system, for example, research shows that LED lamps paired with a driver designed for compatibility with a basic electronic transformer or electronic transformers designed specifically for LED lamps will deliver the least amount of visual flicker. In addition, avoid dimming this product except in conjunction with a manufacturer recommended or reverse-phase dimmer.[35]

EXAMPLE PRODUCTS

OSRAM SYLVANIA ULTRA LED PAR38

sylvania.com/en-us/products/new-products/Pages/ultra-par-family.aspx

- 640 to 1,300 lumens with 10 W to 20 W power usage
- 65 lm/W efficacy
- 95 CRI and CCT of 2,700 K or 3,000 K
- Dimmable to 10%
- Up to 50,000 hour lifetime

Soraa Vivid MR16

soraa.com/products/MR16-GU5.3

- 460 to 480 lumens with 12 W power usage
- 38 to 40 lm/W efficacy
- 95 CRI and CCT of 2,700 K or 3,000 K
- Dimmable to 20%
- 35,000 hour average life

Cree LBR BR30 LED Lamp

cree.com/Lighting/Products/Indoor/Lamps/LBR-Series

- 600 lumens with 12 W power usage
- 50 lm/W efficacy
- 94 CRI and CCT of 2,700 K
- Dimmable to 20%
- At least 25,000 hour lifetime

PHOTO: CLTC, UC DAVIS

PG&E Emerging Technologies Program Report: Directional LED Lamps — Laboratory Testing Program

LED replacement lamps have the potential to significantly reduce lighting energy use in the retail sector, where halogen PAR and MR lamps are among the most common choices. The Directional LED Lamps — Laboratory Testing Program was designed to verify manufacturers' product claims about life, lumen maintenance, and color maintenance of directional LED replacement lamps, based on a market cross-section of lamps commonly used in retail applications.

Read the final report at **cltc.ucdavis.edu/publication/directional-led-lamps-laboratory-testing-program**.

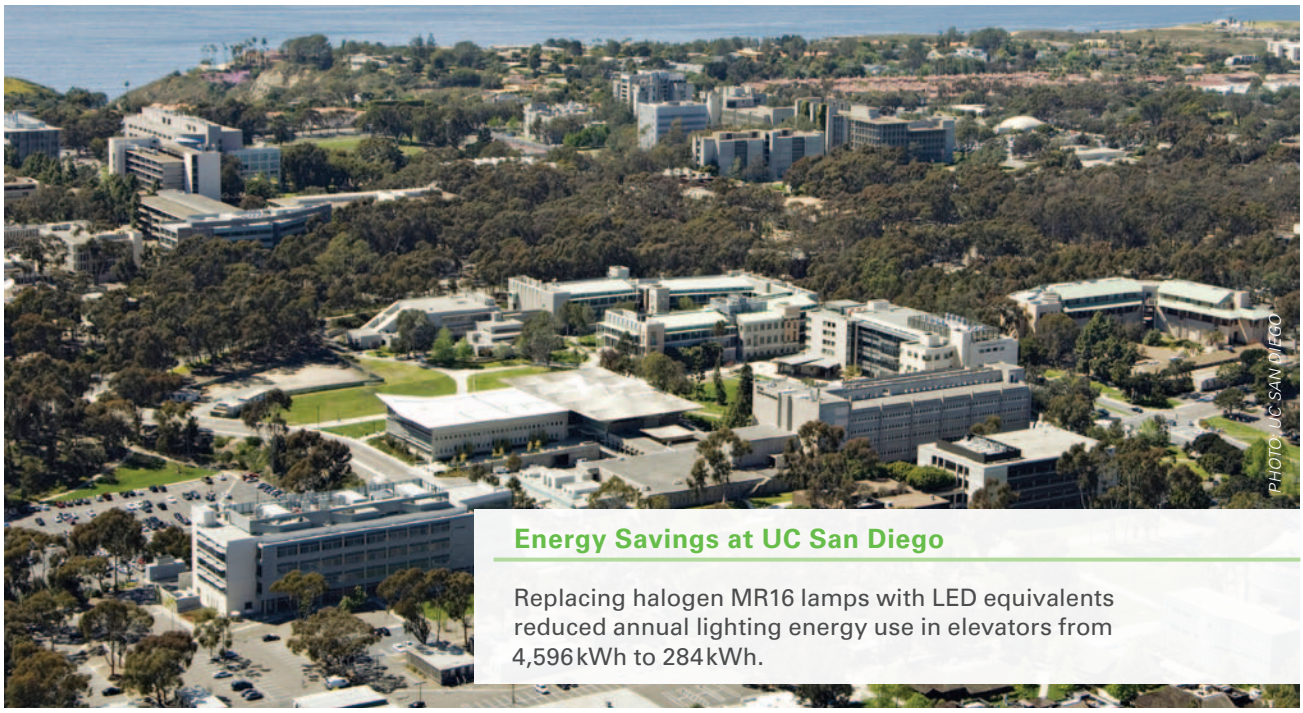


PHOTO: UC SAN DIEGO

Energy Savings at UC San Diego

Replacing halogen MR16 lamps with LED equivalents reduced annual lighting energy use in elevators from 4,596 kWh to 284 kWh.

CASE STUDIES

University of California, San Diego, CA

- etcc-ca.com/sites/default/files/reports/Bi-level%20LED%20Elevator%20Cab%20Lighting%20Demo%20Showcase.pdf

The elevator lighting at UC San Diego utilized halogen MR16, fluorescent and CFLs. As part of an LED demonstration project, nine 58.3 W halogen MR16 lamps were replaced with nine 3.6 W LED lamps. Annual energy use declined from 4,596 kWh to 284 kWh with LEDs, a decrease of 94%.

J. Paul Getty Museum, Malibu, CA

- apps1.eere.energy.gov/buildings/publications/pdfs/ssl/getty_museum_gateway_final.pdf

The J. Paul Getty Museum installed an exhibit featuring photographic prints using albumen, which is egg white. A major concern during this installation was the photographs' sensitivity to ultraviolet/infrared radiation. In an effort to minimize damage from light, the museum staff retrofitted 60W PAR38 halogen lamps with 34 Cree 12W PAR38 LED lamps. The annual energy savings was 4,490 kWh. The first year energy consumption cost savings was $539.

Linear LED Retrofit Solutions

Linear LED retrofit solutions are available to replace common linear fluorescent light sources such as 2-foot and 4-ft T8 lamps. Linear LED retrofits solutions utilize an array of LEDs distributed along the length of the lamp tube to deliver light from the same form factor as a linear fluorescent lamp. Linear LED retrofits solutions are often marketed as a one-to-one replacement for fluorescent lamps, but a large majority require a different electrical system.

New electrical components and rewiring are often necessary to make the existing fixture compatible with the new lamps. Based on the particular LED replacement lamp being considered, a linear LED retrofits solutions retrofit will typically require changing the electrical wiring, replacing the ballast with an LED driver, or altering the existing lamp holders (or "tombstones") to accommodate the new lamp.

"Drop-in" tubular LED replacement lamps incorporate a driver into the lamp. This allows the tubular LED to utilize existing fluorescent ballasts with no additional rewiring required. With these products, the tubular LED bi-pins connect directly to the existing G13 lamp holders. The thermal performance of the technology must be evaluated while installed in situ to ensure lamp life will not be compromised with the driver components exposed to higher temperatures.

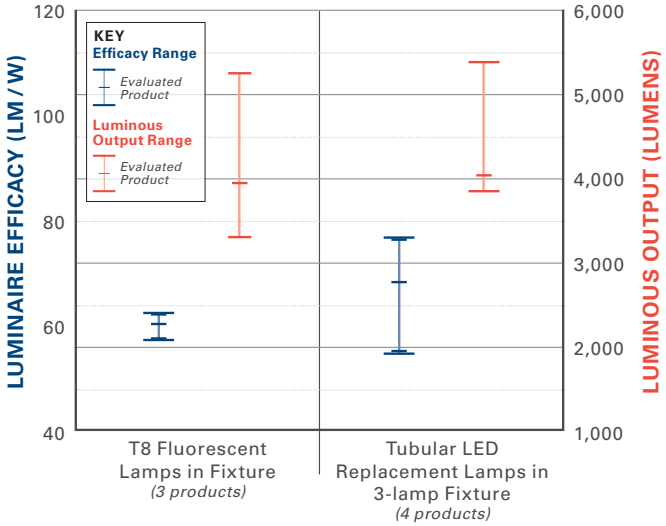
The majority of LED replacement lamps with internal or integrated drivers require line voltage be supplied directly to the lamp holders, bypassing the fluorescent ballast. Internal driver LED lamps may be either single- or double-ended, with power running to one or both ends. LED replacement lamps with external or remote drivers differ still, and require their driver be connected to either the existing tombstone, or directly to the lamp, while using the tombstone merely for stability.

Linear LED retrofit solutions that do not require wiring alterations may be considered a repair and do not trigger the Title 24 code compliance process. An existing linear fluorescent luminaire with TLED lamps is not recognized as an LED lighting system for compliance purposes.

EXPECTED ENERGY SAVINGS

Assuming any system compatibility issues are addressed, linear LED retrofit solutions can deliver significant energy savings compared to linear fluorescent lamps. Linear lamps account for 83% of installed commercial lamps in the state, according to the CSS report. The top three market sectors using linears are commercial offices (30%), schools (16%) and retail establishments (14%). Less than 0.5% of installed linears utilize LED technology.[36] Across most of the commercial sector, existing fluorescent lamps are primarily standard performing products (700–800 series T8 lamps with approximately 80 to 90 lm/W or T12 technology), according the same report. Equivalent linear LED retrofits solutions are available, which are 10 to 50% more efficacious. A recent search of the Lighting Facts website revealed three products with lamp efficacy greater than 140 lm/W and light output equivalent to a standard T8 lamp.[37] For indoor commercial lighting, which accounts for approximately 26,000 GWh annually according to a 2014 Energy Commission study,[38] conversion of linear fluorescent technology to LED can save at least 2,600 GWh each year, assuming just a 10% improvement in efficacy between incumbent technology and linear LED retrofit solutions. Savings could be much greater and are contingent on the specific product installed.

Figure 1. Luminaire efficacy and luminous output by product category



CALiPER Exploratory Study: Recessed Troffer Lighting, Prepared for DOE by the Pacific Northwest National Laboratory, 2013.

FACTORS TO CONSIDER WHEN COMPARING PRODUCTS

Replacing existing linear fluorescent lamps with linear LED retrofit solutions requires minimal new hardware, but this strategy also presents some unique challenges that should be understood thoroughly before purchase or installation.

The electrical incompatibilities between linear fluorescent and linear LED lamps constitute the most important safety issue facing linear LED retrofit solutions. Proper documentation and labeling of linear LED retrofit solutions is crucial to avoid electric hazards and protect the safety of maintenance staff and end users after the retrofit.

Another electrical wiring point of interest is whether the lamp holder is shunted for instant start fluorescent ballasts or un-shunted for rapid start ballasts. Generally, linear LED retrofit solutions that receive electricity through the lamp holder require un-shunted lamp-holders to operate as intended by the manufacturer.

Light distribution patterns may change when replacing fluorescents with linear LED retrofit solutions. Linear LED retrofit solutions incorporate multiple, directional light sources into a linear form factor through varied optical design strategies. As a result, linear LED retrofit solutions and linear fluorescent lamps installed in the same troffer can produce different light distribution patterns. With some products, initial illumination levels may not be equivalent to fluorescent predecessors so spaces are often overlit compared to recommended values. Consumers should consider how much light is recommended for the application and then match that with appropriate linear LED retrofit solutions.

EXAMPLE PRODUCTS

GE Lighting Solutions Batten LED

catalog.gelighting.com/apac/luminaire/led-indoor/led-fixture/f=t8-batten/d=0/?l=en&r=apac

- 2,840 lumens with 32 W power usage
- Up to 88.75 lm/W at source level
- 83 CRI and color temperature of 4,000 K
- Dimmable
- 30,000 hour rated life

Delviro Energy ZEN Linear

delviroledlighting.ca/project/zen-linear-led-fixture/

- 2,484 to 6,900 lumens with 20 to 60 W power usage
- Up to 130 lm/W at source level
- 84 CRI and color temperature of 3,000 K to 5,000 K
- 40,000 hour rated life
- 0 to 10 V dimming
- 200,000 hour rated life

Cree UR Series

cree.com/Lighting/Products/Indoor/Upgrade-Solutions/UR-Series

- 3,600 or 4,500 lumens with 36 or 44 W power usage
- Up to 102 lm/W at source level
- 80 CRI and color temperature of 3,500 K or 4,000 K
- Dimmable, step level to 50% or 0 to 10 V dimming to 5%
- 50,000 hour rated life

CASE STUDIES

Parking Garages, Louisville, KY

▸ energyfocusinc.com/?s=louisville+parking

The City of Louisville wanted to reduce the annual energy costs for its 12 parking garages, increase overall safety, and reduce maintenance. Energy Focus Vapor Tight Series LED housings with TLEDs were chosen to replace 2,260 high-pressure sodium 150W canopy lights and 1,420 fluorescent 175W canopy lights. The retrofit achieved a 145W reduction per fixture for a total annual energy savings of $410,239. Outfitting the fixtures with motion control occupancy sensors increased the energy savings since lighting was utilized only when needed and there was no wasted light when the garage was empty.

Scappoose City Hall, Scappoose, OR

▸ bpa.gov/EE/Sectors/Commercial/Documents/scappoose_cityhall_casestudy.pdf

The Scappoose City Hall wanted a more energy-efficient solution for the facility, which housed spaces including a courtroom, administration offices, and the police station. About 300 existing T12 lamps (40W each) were replaced with new TLEDs (18W each) from Creative Lighting Solutions, Inc. Occupants feel the facility is now much brighter and the expected energy savings from the project is 61%.

Penn Manor Middle School, Lancaster, PA

▸ energyfocusinc.com/lighting-resources/case-studies/municipal-university-schools-hospitals/penn-manor-school-district/

Penn Manor Middle School replaced fluorescent fixtures with Energy Focus Series 100 lamps. With more than 3,700 TLED lamps installed, the school improved its classroom lighting , reduced its lighting maintenance needs, and reduced lighting energy consumption by 50%, or $32,122 per year.

PHOTO: CLTC, UC DAVIS

Significant Energy Savings

Assuming safety and performance considerations are addressed, TLEDs can deliver significant energy savings compared to existing linear fluorescent lamps.

Track Lighting

Track lighting is typically used in general retail spaces, restaurants, galleries, museums and some residential spaces. For sensitive applications, LEDs can reduce damage to organic materials and historic artifacts caused by ultraviolet radiation, which is more prevalent with incandescent and halogen sources. In all applications, LED systems require less maintenance, which translates directly to cost savings.

Traditional track lighting typically uses incandescent or halogen pin or screw-base lamps (with and without reflectors) in combination with track heads and an energized track. LED retrofit options for track lighting include LED lamp replacements and a full retrofit of track heads with dedicated LED units. Dedicated LED track heads that fully replace the existing track head are designed with components (drivers, diode arrays, housings, heat sinks, and optics) built to function together as a unit. Dedicated LED track heads can often be installed on the same track used by traditional pin and screw-base lamps. LED track heads are available from a variety of manufacturers to replace existing systems.

EXPECTED ENERGY SAVINGS

Lamps used in track lighting are predominantly incandescent, halogen or metal halide (MH), so switching to LEDs can reap deep energy savings. Four studies looking at replacements of halogen lamps with LEDs or existing halogen systems with new LED track systems produced energy savings from 60 to 80%.[39, 40, 41, 42] PG&E estimates that within its service territory, conversion of existing MR16 lamps, which are the most utilized directional light source (for track and other applications) to dedicated LED units could save 77%, with associated annual savings of approximately 420 GWh. Most dedicated LED track heads range in efficacy between 40 to 90 lm/W[43] and savings estimates are similar to those stated in the directional lamp section. The total amount of installed track and associated energy use of lamps installed in this specific mounting type is unknown.


PHOTO: GE LIGHTING

FACTORS TO CONSIDER WHEN COMPARING PRODUCTS

With LED lamp replacements, consumers should consider coupling the retrofit with current limiting devices for the track. In this way, the retrofit will deliver persistent savings, that otherwise could be negated if additional track heads and/or non-LED sources can be added back to the system. When combined with a current limiting device, the track itself cannot deliver enough current to allow for a significant increase in the number or wattage of lamps used. As with any one-to-one LED lamp replacement, consumers should understand performance with respect to thermal management, current regulation, and controls compatibility.

Consumers should consider component compatibility prior to product selection. Dedicated LED track heads are rated for use only with specific models of track. Dimmable, dedicated LED track heads are expensive, but non-dimmable units are available for less than $100 each.

EXAMPLE PRODUCTS

Juno Conix II
LED Trac Lighting
junolightinggroup.com/search-results.aspx?Search=conix%20II

- 1,000 to 4,300 lumens with 19W to 64W power usage
- 53 to 67 lm/W efficacy
- 90 CRI and CCT of 2,700K, 3,000K, 3,500K or 4,000K
- Dimmable
- 50,000 hour rated life

ERCO Light
Board Spotlight
erco.com/products/indoor/swf-3circuit/spotlights-floodlights-and-wallwashers-14/en/

- 1,140 lumens with 12W power usage
- 95 lm/W efficacy
- 90 CRI and CCT of 3,000K
- Dimmable
- 50,000 hour rated life

Bruck Chroma
Magnum II Track Spot
brucklighting.com/products/lights/chroma

- 1,000 lumens with 12.7W power usage
- 79 lm/W efficacy
- 80 to 95 CRI and CCT of 2,700K, 3,000K, 3,500K or 4,000K
- Dimmable
- 50,000 hour rated life

CASE STUDIES

Safeway, San Francisco Bay Area, CA

▸ etcc-ca.com/sites/default/files/reports/ET12PGE3351_12_28_2012.pdf

A Safeway retrofitted low-voltage halogen track lighting with LED luminaires. Sixty-two 50W halogen MR16 lamps and fixtures were replaced with 45 15W Amerlux Hornet integrated LEDs. On a storewide basis, the retrofit produced a 77% reduction in peak demand, energy usage and costs. The LED longevity and the elimination of halogen relamping could provide a projected maintenance savings of 35%.

San Diego Zoo, San Diego, CA

▸ etcc-ca.com/sites/default/files/reports/San%20Diego%20Zoo%20Gift%20Shop%20LED%20Lighting.pdf

The San Diego Zoo replaced existing halogen track lighting in the zoo gift shop with LED alternatives. Two hundred fifty-four 54.5W halogen MR16 lamps were replaced with 11W LED PAR20 lamps and track heads, producing energy savings of 80%. The annual energy cost savings was $10,163.

Nordstrom Stores Lighting Retrofit

▸ bpa.gov/EE/Sectors/Commercial/Documents/Nordstrom_casestudy.pdf

Spotlights using 50W incandescent halogen were the standard for Nordstrom stores. Two years into a three-year project to convert to ceramic metal halide (CMH), Philips recommended installing LED spotlights to save energy. They also offered a longer lamp life and lower maintenance costs. Nordstrom switched to Lytespan LED track and spotlighting systems at some locations in Oregon and Washington. The installed CMH products would be used and relamped until they reached the payback period. The energy savings from the LED retrofit was 15 to 20%. Nordstrom planned to move forward with LED retrofits for the spotlights in other stores.

Recessed Downlights

Downlights (also commonly referred to as recessed lights or can lights) can be found in both residential and commercial sectors. Downlights may use incandescent, HID, CFL or LED light sources. The luminaire housing typically ranges from 4 to 12 inches in diameter. For certain retrofit situations, an LED module may use the existing screw base as a power source for the lamp and clip into the existing housing. Sometimes a trim kit is added. In other retrofit applications, the existing downlight lamp and housing are fully removed and the retrofit unit is installed in the same location. In new construction applications, LED product installation varies little from traditional downlights.

As one of the first general illumination LED applications, LED downlight technology has matured over the past decade. Best-in-class products, such as winners of the Next Generation Luminaires™ SSL Design Contest, have demonstrated efficacy improvements in this product category of 20 to 30 lm/W, in just five years.[44] LED downlights offer longer lifetimes and reduced maintenance costs compared to existing fluorescent or incandescent sources.

LED downlights are now available for high-ceiling applications (ceiling height of 20 ft or more). This application has previously been overlooked for lighting retrofits since LED products were unable to provide the light output and efficacy of CFL or CMH counterparts. Products, such as the CS Series by Meteor Lighting, can deliver up to 20,000 lm at 110 lm/W.[45]

PHOTO: CLTC, UC DAVIS

EXPECTED ENERGY SAVINGS

Replacing existing incandescent downlights with dedicated LED downlights or retrofit kits delivers energy savings of approximately 80%.[46, 47] Replacing fluorescent downlights with LED options can reduce lighting energy use by 50%.[48, 49] Conversion of existing residential recessed downlights to LED alternatives could save 4,950 GWh annually.[50] In California's commercial sector, where incandescent and CFLs predominate in pin and screw-base applications at approximately 90% or more utilization, savings from conversion to LED alternatives could be significant. Approximately 85% of all California commercial businesses utilize some form of pin or screw-base lamp.[51] Nationwide, total potential savings could be as high as 48,000 GWh, according to a 2008 DOE study.

FACTORS TO CONSIDER WHEN COMPARING PRODUCTS

In addition to typical considerations surrounding light output, color and controls compatibility, consumers should consider product serviceability. Downlights that allow for tool-less, below-ceiling maintenance to both the module and driver are preferred over traditional downlight styles, which require maintenance from above, in the ceiling plenum. This feature reduces maintenance costs over the life of the product. In addition, many products are available with "module" systems where a component of the downlight may be exchanged for another when needed instead of replacing the entire unit. This concept may apply to the LED light module, LED driver or system optics. Downlights that allow easy exchange of the LED light module, in particular, are extremely valuable. As LED efficacy improves, consumers may swap an existing LED light module for a higher performing module with little effort or installation cost. System energy-efficiency can continue to improve in line with LED technology.

EXAMPLE PRODUCTS

CREE TW CR6

cree.com/lighting/products/indoor/downlights-us/cr-series

- 575 to 800 lumens with 9.5 to 12.5W power usage
- 61 to 64lm/W efficacy
- 90 CRI and CCT of 2,700K, 3,000K, 3,500K or 4,000K
- Dimmable to 5%
- 50,000 hour rated life

Cooper Lighting Halo ML56 LED Downlighting System

cooperindustries.com/content/public/en/lighting/products/recessed_general_purpose_downlighting.html

- 900 lumens with 13.5W power usage
- 67 lm/W efficacy
- 90 CRI and CCT of 2,700K, 3,000K, 3,500K or 4,000K
- Dimmable
- 50,000 hour rated life

Amerlux Evoke 2.9" Round Adjustable Gen 2 LED

amerlux.com/products/interior/recessed-downlights

- 555 to 634 lumens with 12W power usage
- 46 to 53lm/W efficacy
- 90 CRI and CCT of 3000K
- Dimmable
- 50,000 hour rated life

CASE STUDIES

Abbey Espresso Bar & Café, Belleville, IL

▸ cooperindustries.com/content/public/en/lighting/resources/LightingStories/The-Abbey-Espresso-Bar-and-Cafe

The Abbey Espresso Bar & Café is more than a coffee shop. It also serves as a live music venue, restaurant, gelato bar, and retail store. The space needed a flexible lighting design that served all these purposes efficiently, effectively and attractively. The dimmable Halo ML56 13.5W LED recessed downlight from Eaton's Cooper Lighting business provides a warm color temperature and 900 lumens. The project saved more than $2,000 in yearly electricity costs over more traditional 75W PAR30 lamps.

Southland Christian Church, Lexington, KY

▸ acuitybrands.com/old-solutions/inspire-me/case-studies/southland-christian-church

Southland Christian Church transformed an abandoned mall into a multi-use project with classrooms, open spaces, administrative functions, and a 2,800-seat auditorium. The church needed a fixture that could be both pendant-mounted and recessed since the auditorium had varying ceiling heights that ranged from 12' to 40'. The Gotham Incito downlights accommodated this need and also offered a compact 6-inch aperture. In addition, the facility expects reduced cooling (HVAC) needs due to the lower heat output of the new LED luminaires.

Whole Foods Market, Los Angeles, CA

▸ Contact Chad Clark (chad@regreencorp.com) or Neda Farzan (neda@noralighting.com) for more information

Whole Foods Market partnered with ReGreen to upgrade the lighting in its store in Los Angeles' Fairfax District. The goal was to save energy costs, reduce maintenance, enhance the presentation of products, and improve the visual experience for customers and staff. ReGreen chose the 8-inch Sapphire from NSpec for the project. The retrofit reduced lighting energy consumption by more than 40%, produced annual energy savings of more than $28,000, and cut maintenance costs of more than $5,000 a year.

Troffers & Surface Mounts

Linear fluorescent troffers and surface mount luminaires are ubiquitous to many applications, including commercial offices and classrooms, which in California, account for 30% and 16% of all installed linear fluorescent technology, respectively.[52] Troffers comprise a major part of the lighting in commercial spaces nationwide and represent more than 50% of the luminaires currently in use in the United States.[53]

Implementing LED technology as part of a luminaire retrofit can be done in two ways. One option is installing an LED retrofit kit. These kits have the light source replacement, related electrical components, lenses and in some cases, reflectors in a single package. Since necessary electrical components are included, the kit will work as long as it is the right size for the existing troffer or fixture. Luminaires with atypical dimensions may not support all retrofit kits so test samples with the existing fixture and/or space to ensure compatibility and a successful retrofit.

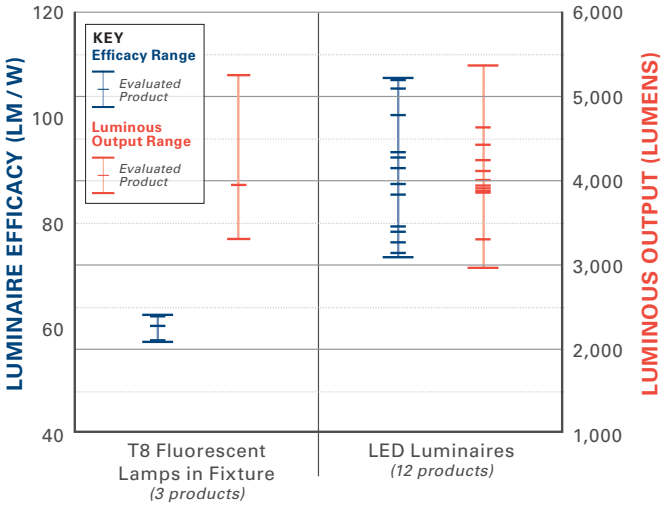
The second option is replacing the existing luminaire with a dedicated LED luminaire. This provides the opportunity to incorporate on-board sensors into the new luminaires if wireless or external controls are not being used. LED luminaires offer a simple electrical installation since the entire luminaire is being replaced. They also typically offer a higher efficacy than lamp replacements or retrofit kits and reduce installation complications. LED fixtures typically have an external driver, which makes it simpler to replace in the event of a failure. A single LED fixture may be offered with a variety of current, color and control options.

In some cases, replacing or modifying a luminaire triggers Title 24 compliance. But, the standards do not specify what technology must be used to fulfill requirements. There is ample opportunity for savings in many commercial applications, regardless of lighting power density (LPD) and controls requirements contained in the current standards. Open office applications offer a significant savings opportunity by pairing high performing LED troffers with occupancy controls. The standards do not have requirements for occupancy-based control of large zones in this application. Programs designed to support increased adoption of LED troffers and surface mounted luminaires, which achieve better than 0.8 watts per square foot (W/ft^2) and include occupancy controls is one opportunity for statewide energy savings.

San Diego State University Lighting Retrofit

Energy consumption decreased by 50% in classrooms where LED troffers replaced fluorescent fixtures.

Figure 2. Luminaire efficacy and luminous output by product category



Source: CALiPER Exploratory Study: Recessed Troffer Lighting, Prepared for DOE by the Pacific Northwest National Laboratory, 2013.

EXPECTED ENERGY SAVINGS

The energy savings from LED troffer retrofits vary. LED retrofit kits are more efficacious than fluorescent luminaires by approximately 10%, an increase from an average of 60 to 66 lm/W.[54] LED luminaires offer higher efficacies, an average of 89 lm/W, a 44% increase over fluorescent troffers.[55]

The DLC Qualified Products List includes luminaires and retrofit kits from 70 to 138 lm/W.[56]

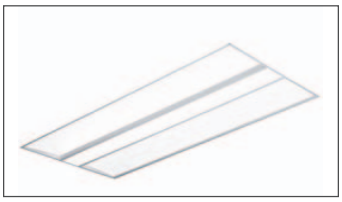
FACTORS TO CONSIDER WHEN COMPARING PRODUCTS

Currently available LED retrofit troffers compete with existing fluorescents in terms of efficacy, glare, light distribution and color quality.[57] Keep light distribution needs in mind when selecting an LED retrofit for fluorescent troffers. Retrofit kits that use arrays of bare LEDs may provide unusual striping, unwanted additional glare and other visual issues inconsistent with the performance of existing fluorescent systems. Many retrofit products also come equipped (standard) with a dimming driver, which may not be compatible with existing dimming controls. These incompatibilities can result in flicker when dimming and a nonlinear dimming curve that may cut-off (zero light output) at low dimming levels. Consumers should consider testing any retrofit products in the existing fixture with existing controls before selecting a product for widespread retrofits.

Installation is a second factor to consider. A DOE CALiPER report confirms that retrofit kits are often incompatible with existing recessed or surface mount fixtures. Additional installation time is often necessary to modify fixtures, add wiring and perform unplanned tasks necessary to make new retrofit products work with existing fixtures.

The DLC includes retrofit kits and dedicated LED luminaires on their qualified products list and consumers should strive to select products vetted by such an organization. Safety labels should also be considered, such as whether a retrofit kit is Listed, Classified or Recognized by Underwriters Laboratories / Canadian Standards Association standards since these designations have different testing requirements.

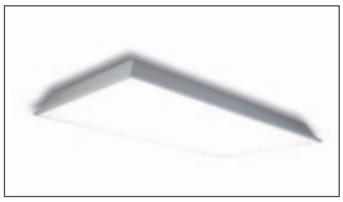
EXAMPLE PRODUCTS: TROFFERS



Finelite High Performance Recessed LED (HPR-LED): 2x4

finelite.com/products/serieshprled-2x4-overview

- 4,018 to 7,291 lumens with 35.2 W to 74.1 W power usage
- 98 to 114 lm/W efficacy
- 83 to 87 CRI and CCT of 3,000 K, 3,500 K or 4,000 K
- Dimmable to 10%
- 68,000 hour rated life



GE Lumination LED Luminaire BT14 Series

gelighting.com/LightingWeb/na/solutions/indoor-lighting/recessed

- 3,800 or 4,100 lumens with 43 W power usage
- 88 to 95 lm/W efficacy
- 80 CRI and CCT of 3,500 K or 4,000 K
- Non-dimmable
- 50,000 hour rated life

Lithonia Lighting 2RTLED Volumetric LED Luminaire

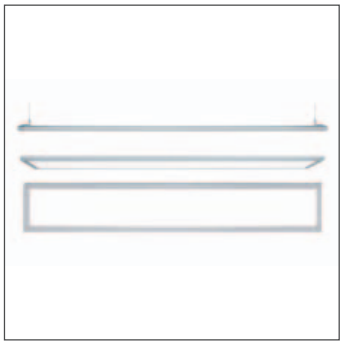
acuitybrands.com/search?keyword=troffer&attr_Product_Type=%22General%20Purpose%20Troffers%22

- 2,400 to 3,300 lumens with 24 W or 38 W power usage
- 87 to 100 lm/W efficacy
- 82 CRI and color temperature of 3,500 K, 4,000 K or 5,000 K
- Dimmable
- 50,000 hour rated life

EXAMPLE PRODUCTS: LINEAR PENDANTS

Finelite HP-4 Indirect
finelite.com/products/serieshp4-i-overview.html

- 2,901 lumens with 35.6W power usage
- 81 lm/W efficacy
- 86 CRI and CCT of 3,500K
- Dimmable to 10%
- 100,000 hour rated life



Lunera Series L7 Pendant
lunera.com/seriesl7g3

- 2,584 to 3,089 lumens with 39.9W to 44.7W power usage
- 65 to 69 lm/W efficacy
- 84 CRI and CCT of 3,500K
- Dimmable
- 50,000 hour rated life

Philips Ledalite Jump Suspended LED pendant
ledalite.com/products/jump/suspended

- 2,400 lumens with 28W power usage
- 86 lm/W efficacy
- 84 CRI and CCT of 3,000K, 3,500K or 4,000K
- Dimmable
- 60,000 hour rated life

CASE STUDIES

Everett Public Schools, Everett, WA

▸ bpa.gov/EE/Sectors/Commercial/Documents/everrett_SD_casestudy.pdf

The Everett Public Schools rebuilt Monroe and View Ridge elementary schools from the ground up. Cree LR24 dimmable recessed troffers were installed in the two schools' classrooms. Teachers frequently use the dimming feature in the classrooms. The control system also boosts light levels back to required levels as light output drops over time. Using LED lighting enabled the district to provide twice the minimum light level required by the Washington State Department of Health and still save energy.

San Diego State University, San Diego, CA

▸ gelighting.com/LightingWeb/na/case-studies/san-diego-state-university.jsp

San Diego State University outfitted classrooms in three buildings with GE's Lumination LED troffers. A new anatomy lab was part of the lighting project. The new LED lighting uses 50% less energy than the previously installed fluorescent fixtures. Students said classrooms felt more open and spacious and the upgrade improved environmental aesthetics.

High Bay & Low Bay Lighting

High and low bay luminaires are a type of industrial-style luminaire used to provide general illumination for applications with high ceilings (mounting height greater than or equal to luminaire spacing) or restricted ceiling heights (luminaire spacing is greater than mounting height). High and low bay luminaires may be surface-mounted or suspended.[58] These luminaires are found in commercial and industrial spaces including grocery stores, warehouses, retail storefronts, and gymnasiums.

Applications with long hours of use or lighting access challenges offer the most potential for adoption of energy-efficient LED high bay or low bay luminaires. Good retrofit opportunities may be found in spaces such as refrigerated warehouses where lighting is left on regardless of occupancy, industrial facilities with long hours of operation, and retail applications such as big box and grocery stores. LEDs are a top choice for new construction opportunities.

HID sources such as metal halide and high-pressure sodium (HPS) lamps still dominate high bay and low bay lighting applications. Sixty percent of commercial high bay lighting in California uses HID sources, according to the CSS.[59] Fluorescents and LEDs have gained some market share at 9% and 17%, respectively, according to the same study. Standard high and low bay luminaires with metal halide sources range in efficacy from 51 to 74 lm/W. Fluorescent systems range from 80 to 95 lm/W for fluorescent luminaires.[60] LED alternatives have an efficacy from 84 to 105 lm/W.[61]

EXPECTED ENERGY SAVINGS

LED technology offers significant energy savings over metal halide or other HID light sources, resulting in energy savings of 50 to 70%.[62, 63, 64, 65, 66] One study found that replacing fluorescent lighting with LED sources produced energy savings of 74%.[67] Retrofitting HID sources with LED luminaires can reap potential savings of 2,157 GWh annually, while the same with induction sources offers potential savings of 472 GWh when considered across California.[68]

The DLC list includes five categories related to high and low bay lighting. Currently, there are a total of 7,320 approved LED products across five DLC high and low bay categories.[69]

FACTORS TO CONSIDER

Access requirements and product lifespan are key considerations for high bay lighting applications, in particular. A scissor lift or other equipment is needed to access a luminaire that is more than 15 ft above the finished floor. This can increase re-lamping and maintenance costs. Consumers should compare product life and warranty information to ensure the best combination of longevity and cost.

Ambient temperature and other environmental operating conditions are another consideration. LED product performance suffers at elevated temperature. High-ceiling applications in unconditioned spaces may have elevated ambient temperatures that can reduce light output and lumen maintenance of LED solutions. If elevated ambient temperature is typical, consumers should request manufacturer's documentation about product performance in regards to operating temperature. If that information is unavailable, consumers should consider de-rating an LED high bay's light output by 10% before making product comparisons to account for reduced performance at elevated temperatures.

Controls compatibility should be closely reviewed when considering LED high and low bay luminaires. LED solutions are more compatible with occupancy, daylighting and tuning control strategies as compared to HID solutions. Consumers should compare the controllability of proposed LED products against their space's control needs. With recent changes in Title 24, more high and low bay lighting retrofits must comply with multi-level dimming and controls requirements. Consumers should compare LED products against these needs.

Table 2. Design Light Consortium Qualified Products List Requirements for High-Bay and Low-Bay Lighting Application Categories

Application	Minimum Light Output	Zonal Lumen Density	Minimum Luminaire Efficacy	Allowable CCTs	Minimum CRI	L70 Lumen Maintenance
High Bay Luminaires for Commercial and Industrial Buildings	10,000 lm	≥30%: 20–50°	80 lm/W	≤5,700 K	70	35,000 hrs
Low Bay Luminaires for Commercial and Industrial Buildings	5,000 lm	≥30%: 20–50°	80 lm/W	≤5,700 K	70	35,000 hrs
High-Bay Aisle Luminaires	10,000 lm	≥50%: 20–50° ≥30%: 0–20°	80 lm/W	≤5,700 K	70	35,000 hrs
Retrofit Kits for High-Bay Luminaires for Commercial and Industrial Buildings	10,000 lm	≥30%: 20–50°	80 lm/W	≤5,700 K	70	35,000 hrs
Retrofit Kits for Low-Bay Luminaires for Commercial and Industrial Buildings	5,000 lm	≥30%: 20–50°	80 lm/W	≤5,700 K	70	35,000 hrs

EXAMPLE PRODUCTS

Cooper Industries HB LED Series

cooperindustries.com/content/public/en/lighting/products/highbay_lowbay_industrials/led.html

- 129 lm/W efficacy
- 85 CRI and CCT of 4,000 K and 5,000 K
- Can be used in variety of applications and mounting heights
- Dimmable luminaire with various options for light distribution, sensors, lumens and CCT
- Available with integrated occupancy sensor
- 60,000 hour rated life

GE Albeo LED ABHX Series

gelighting.com/LightingWeb/na/solutions/indoor-lighting/albeo-led-luminaire-abhx.jsp

- 6,000 to 60,000 lumens with 250 W to 1,500 W
- 70+ CRI with 4,000 K or 5,000 K CCT
- 0 to 10 V Dimming
- 100,000 hour rated life
- Modular design with 1 to 6 modules
- High and low bay lighting in warehouses, cold storage, industrial settings, gymnasiums, retail spaces or high-ceiling spaces
- Daylight, motion and wireless controls

Lithonia Lighting PROTEON SL Linear LED High Bay

lithonia.acuitybrands.com/Proteon-SL/Proteon-SL.aspx

- 3,600 to 7,200 lumens with 47 W to 92 W
- 83 CRI with 3,500 K, 4,100 K and 5,000 K CCT
- 4 ft or 8 ft linear rail
- Incorporates occupancy and photocell sensing into luminaire

CASE STUDIES

Ace Hardware Distribution Center, Rocklin, CA

- etcc-ca.com/sites/default/files/reports/ET12PGE3361%20LED%20High-Bay%20Lighting%20and%20Controls%20Assessment.pdf

The high bay lighting at an Ace Hardware Distribution Center was retrofitted from metal halide luminaires to LED luminaires. One hundred and two 400 W metal halide luminaires were replaced with 230 W LED luminaires with built-in wireless interconnectivity, occupancy sensing and daylight sensing. Retrofitting the luminaires to LEDs alone reduced energy use about 50%. Using combined daylighting and fine granular occupancy sensors could cut another 43% in energy use.

San Jose Washington Unified Youth Center Gymnasium, San Jose, CA

- etcc-ca.com/sites/default/files/reports/ET11PGE1151_SJ%20WUYC%20Gym%20LED%20Final%20Report%202013-05-17.pdf

Thirty 200 W BritePointe high bay LED luminaires were installed to replace metal halide luminaires at the San Jose Washington Unified Youth Center gymnasium. The project saved an estimated 9,941 kWh or $1,650 annually as compared to the fully functional incumbent system. The project improved lighting uniformity and significantly improved light levels.

Blue Diamond Growers Refrigerated Warehouse, Sacramento, CA

- smud.org/en/business/save-energy/energy-management-solutions/documents/Blue-Diamond-Phase-1.pdf

LED luminaires with motion sensors were installed at a Blue Diamond Growers refrigerated warehouse as part of a project to save energy, cut costs, improve lighting quality, and increase control. Seventy-seven 160 W LED luminaires from Albeo Technologies replaced 77 400 W HPS luminaires. The total annual energy savings was 79%, or 236,477 kWh. The estimated utility bill reduction was $21,755.

Parking Garage Luminaires

Parking garages face unique challenges with their lighting. A mix of pedestrians and vehicles traffic within the confined garage space creates an environment that demands adequate, reliable lighting to ensure public safety and minimize accidents. Parking garages should provide ample lighting to mitigate these issues, while also minimizing glare and light trespass.

Parking garages are classified as indoor spaces under state lighting regulations, but they use many of the same lighting technologies as outdoor parking lots, and they often provide excellent opportunities to reduce lighting energy waste. Unlike lots, parking garages have special lighting requirements for illuminating entrances and exits, ramps, perimeters, and stairways. To meet safety and security needs, many garages employ lighting systems that operate continuously, regardless of actual occupancy or available daylight. Doing so wastes energy, contributes to peak demand during the day, and contributes to light pollution at night.

Parking garage lighting typically employs fluorescent or HID light sources such as HPS and metal halide lamps. LEDs are an increasingly preferred option over these traditional solutions because of their long life, low maintenance, high efficacy, better light quality and controls compatibility. All these reduce cost for facility managers and building owners. HID and fluorescent solutions used in garage lighting applications[70] typically have an efficacy range of 50 to 80 lm/W,[71] while LED replacement options provide approximately 70 to 100 lm/W.[72]

ENERGY SAVINGS

Parking structure lighting accounts for approximately 1,102 GWh of California's annual electricity use.[73] Implementing parking garage luminaires with integrated controls or networked controls and high-efficiency light sources produces a range of energy savings depending on the technology being replaced. Studies show LED luminaire replacement typically offers energy savings between 30% and 90%.[74, 75, 76] Across California, one study estimates that replacing linear fluorescent lighting (20% of lighting in covered parking) with LED luminaires offers potential annual energy savings of 55 GWh annually, and replacing high-intensity discharge luminaires (80% of lighting in covered parking) with LED sources can provide 413 GWh of potential annual energy savings.[77] Adding bi-level occupancy sensing to existing linear fluorescent luminaires offers a potential energy savings of 50 GWh annually across the state.[78]

FACTORS TO CONSIDER WHEN COMPARING PRODUCTS

Consumers should consider adding lighting controls for any garage lighting retrofit or new construction project. Title 24, Part 6 includes mandatory measures requiring occupancy and daylighting controls for most parking garage projects that trigger code compliance. However, high performing systems can achieve savings that exceed lighting power density requirements and include advanced controls that surpass code measures. Installing luminaires paired with occupancy controls will significantly cut energy use during vacant periods. Incorporating networked controls will also maximize system savings since facility managers can employ dynamic tuning, scheduling and optimized occupancy-based dimming down to the individual luminaire level. Networked control systems can also facilitate participation in utility demand response programs. Current energy code requirements do not require demand response control systems for parking garages. Garage facilities are an excellent application for demand response because lighting can often be reduced during daytime hours with no impact to the visual environment.

When considering such systems, consumers should be aware of the communication and control platform of the controls system. Some wireless control solutions can have difficulty transmitting signals through the concrete and steel garage structure. Consumers should discuss the proposed application with control system providers to ensure performance in the intended application and specific installation location.

EXAMPLE PRODUCTS

Kenall TexDek for Parking Garages

kenall.com/Products/Product-Detail.htm?DataID=16157

- 65 CRI available with 4,000 K, 5,000 K and 5,700 K CCT
- 17-inch diameter ceiling mount LED luminaire
- Uplight feature to eliminate cave effect
- Textured lens to reduce glare
- Option to include integral occupancy / light sensor with or without associated control module
- Can integrate with a remote control module for networked lighting

Cree Edge Parking Structure Luminaire

cree.com/Lighting/Products/Outdoor/Parking-Structure/THE-EDGE-Parking-Structure

- Improved color rendition and lighting uniformity
- Integrated bi-level occupancy sensor that can yield 80% energy savings while still maintaining 50% lumens at half-power operation

Archway Passage VAP LED by Acuity Brands

lithonia.com/commercial/vap+led.html

- 4,000 to 12,000 lumens with 39 W to 114 W power usage
- CRI of 80 and 90 with CCT of 3,500 K, 4,000 K and 5,000 K
- Wireless bi-level or variable dimming with optional onboard sensors
- Available with optional motion sensor

CASE STUDIES

Multiple Locations in CA

▸ cltc.ucdavis.edu/publication/adaptive-led-parking-garage-luminaires

Bi-level LED parking garage luminaires replaced HPS luminaires at three locations in California. Cree's Edge Series luminaires replaced 30 HPS luminaires at California State University, Sacramento (CSUS). The existing luminaires operated at 189 W each, while the LED luminaires used between 165 W and 77 W, depending on whether they were in high or low mode. The total energy savings was 68%. At California State University, Long Beach, Cree luminaires replaced seven 189 W HPS luminaires. These LEDs consumed 47 W in high mode and 16 W in low mode. The retrofit produced 84% energy savings. Twenty-three 210 W HPS luminaires were replaced with Philips VizorLED luminaires at Civic Center Garage in San Marcos, CA. The new luminaires consumed 70 W in high mode and 7 W in low mode. The retrofit produced 81% energy savings.

Parking Garages, Sacramento, CA

▸ smud.org/en/business/save-energy/energy-management-solutions/documents/bi-level-LED-aug10.pdf

Two parking garages in Sacramento, CA were retrofitted with bi-level LED fixtures. CSUS replaced 150 W HPS luminaires with 32 Cree luminaires with WattStopper passive infrared occupancy sensors. The new luminaires operated at 77 W in low mode and 165 W in high mode. The energy savings was 36%. The City of Sacramento replaced 175 W metal halide and mercury vapor luminaires with 25 Cree luminaires with integrated passive infrared occupancy sensors. The new luminaires operated at 39.5 W in low mode and 118.5 W in high mode. The project provided higher illumination levels and 67% in energy savings.

U.S. Department of Labor Headquarters Parking Garages, Washington, D.C.

▸ apps1.eere.energy.gov/buildings/publications/pdfs/ssl/deptoflabor_brief.pdf

The parking garages at the U.S. Department of Labor headquarters in Washington, D.C. were lighted using 300 HPS luminaires. For a demonstration project, 19 of them were replaced one-for-one with LEDs. Each LED luminaire had an integral occupancy sensor that controlled their output through bi-level dimming. Switching to LED produced energy savings of 52%, which increased to 88% by using occupancy sensor controls.


PHOTO: CREE, INC.

OUTDOOR LED LUMINAIRES

Outdoor applications have significant untapped potential for energy savings in California and underscore the importance of developing next-generation LED outdoor lighting to target efficiency improvements with adaptive controls. While some traditional outdoor lighting products are relatively energy-efficient, most sacrifice light quality and control for energy savings. This compromise is no longer necessary. Many new high-quality, outdoor lighting solutions are both highly energy-efficient and compatible with advanced lighting controls. Lighting retrofits that use these new technologies can reduce lighting energy use immediately, often by 50% or more compared to traditional solutions.

FACTORS TO CONSIDER WHEN COMPARING OUTDOOR PRODUCTS

A layered and balanced approach to outdoor lighting is the most energy efficient, safe and comfortable. Rather than flooding an outdoor space with light, it is important to select the right sources and luminaires, place them strategically and pair them with the appropriate lighting controls.

Controls can achieve significant energy savings by automatically switching or dimming lights based on time of day, available light, occupancy, vacancy, or the scheduling commands of a lighting control system or building energy management system. Pairing controls with the exterior luminaires creates a smart lighting system that optimizes energy use, offers the right amount of light output for the application, and reduces operational costs.

Compare products by evaluating the light distribution and whether the sensors under consideration provide the appropriate coverage. Reduce light pollution by specifying luminaries with the appropriate backlight, uplight and glare (BUG) rating. The Title 24 standards replace the cutoff classification system with the BUG rating system and includes requirements limiting uplight and glare in certain applications. These requirements are based on best practices for lighting different applications while minimizing light pollution and energy waste.

Wall Packs

Pole-Mounted Parking & Area

Wall Packs

Wall packs, or exterior wall-mounted fixtures, may be found in both residential and commercial applications. Wall packs offer an effective means of illuminating building perimeters, bolstering security and aiding wayfinding. In residential applications, wall packs are most often used for porches, garage perimeters or other non-aesthetic locations. In commercial applications, wall packs typically operate in areas with low occupancy rates, which wastes energy by illuminating vacant outdoor spaces for hours every night.

Wall packs most often employ HID light sources, such as HPS and metal halide lamps. LED alternatives provide a more efficacious, longer life product that is compatible with occupancy controls, step dimming curfew controls, or other advanced outdoor control strategies. The efficacy for LED wall packs ranges from approximately 80 to 100 lm/W[79] compared to HID sources which deliver just 25 to 80 lm/W.[80]

EXPECTED ENERGY SAVINGS

Adding outdoor occupancy or curfew dimming controls should be considered for any LED wall pack retrofit. Manufacturers now offer products with integrated sensors, which reduce installation time in the field. Incorporating wall packs into a networked control system maximizes energy savings by providing a way to analyze and adjust power usage based on occupancy patterns and provides other benefits.

Statewide, wall packs use approximately 336 GWh annually.[81] One study found that replacing incumbent sources such as metal halide and HPS wall packs with LED luminaires and occupancy sensors produced energy savings up to 89%.[82] The energy savings will depend on the technology being replaced, the types of controls included and the occupancy rate of the illuminated area. Replacing existing HID wall packs with LED luminaires can potentially save 208 GWh per year in California.[83]

To surpass the Title 24, Part 6 requirements, motion sensors should be included in all wall packs, regardless of maximum rated wattage or mounting height (within the limitations of the range of the sensor selected to pair with the luminaire).

EXAMPLE PRODUCTS

Crosstour MAXX LED Wall Pack / Area Site Luminaire

cooperindustries.com/content/public/en/lighting/products/outdoor_wall_mount_lighting/_829374.html

- 4,400 to 7,370 lumens with 41 W to 81 W power usage
- 65 to 70 CRI and CCT of 5,000 K or 3,500 K
- Wall, inverted or pole mount luminaire to replace up to 400 W HID luminaire
- Available with dimming and occupancy sensors
- Five-year warranty

Philips 121 Line LED Sconce

sitelighting.com/literature/g_121_G2_led_sconce_broc.pdf

- 5,000+ lumens with 18 W to 75 W power usage
- Available in CCT of 4,000 K
- 0 to 10 V dimming
- Available with optional motion sensor
- Five-year warranty

Leotek Economy Sconce Wall Pack

- 2,410 to 7,300 lumens with 28 W to 84 W power usage
- 86 to 88 lm/W efficacy
- 70 CRI and CCT of 3,000 K, 4,000 K and 5,000 K
- Dimmable to 50%
- 10-year warranty


PHOTO: CLTC, UC DAVIS

CASE STUDIES

University of California, Davis, CA

▸ cltc.ucdavis.edu/publication/adaptive-led-wall-packs-uc-davis

UC Davis replaced metal halide and HPS wall packs on campus with dimmable LED luminaires (Philips WTM-40W) with occupancy sensors (WattStopper EW low-voltage outdoor motion sensor) and wireless controls (Lumewave, an Echelon Company, TOP900-TL). The 101 LED wall packs operate at 20% power when the space is unoccupied and switch to higher illuminance when needed. The LED luminaires use 14 W in low mode and 45 W in high mode. The installation reduced energy use 89% based on a 20% occupancy rate. Annual energy and maintenance cost savings is estimated to be approximately $900 per fixture.

Racine Water and Wastewater Treatment Plant, Racine, WI

▸ e-conolight.com/case-study-wastewater-utility-plant

The Racine Water and Wastewater Treatment Plant used 78 38 W LED wall packs from E-conolight to replace 50 W and 70 W HPS fixtures above the exterior doorways of the plant's 17 buildings. Electricity savings is estimated to be up to 50% for some installations. Quality of light and a uniform appearance were also factors for the switch.

Industrial Developments International, Jurupa Valley, CA

▸ cooperindustries.com/content/dam/public/lighting/resources/library/case_studies/led_solutions/Jurupa-Valley-California-ADH131318.pdf

Industrial Developments International selected LED solutions from Eaton's Cooper Lighting business as part of an effort to reduce energy costs while providing lighting that satisfied safety and security issues. The project provided proper illumination for the facility's exterior and parking lot and produced total energy savings of more than 50% compared to metal halide equivalents. Lumark Crosstour LED wall pack luminaires were used for wall-mounted applications. The fixtures, which use just 30 total watts, offered comparable light levels to that of 175 W metal halide products.

Pole-Mounted Parking & Area

Pole-mounted luminaires are used in outdoor applications to provide area lighting for walkways, illuminate parking lots and serve as security lighting. Existing outdoor parking and area lighting typically uses HID lighting,[84] with an overall luminaire efficacy range of 50 to 100 lm/W for HPS and metal halide sources.[85] LED outdoor parking and area luminaires are energy-efficient, environmentally friendly alternative to traditional solutions. Past studies predicted LEDs to achieve efficacies of approximately 200 lm/W for low CRI devices and 130 lm/W for very high CRI devices by 2027.[86] Improvements are progressing faster than these predications. Currently, LED parking and area luminaires have luminaire efficacy ranging from 80 to 110 lm/W. They can deliver better light quality and controls compatibility than HID products.

EXPECTED ENERGY SAVINGS

In 2012, area lighting comprised 3,800 GWh of California's commercial energy usage, of which 1,363 GWh was pole-mounted parking lighting and 1,015 GWh was public area lighting.[87] Replacing existing parking lot and area lighting with LED alternatives can achieve significant energy use reductions, particularly when the luminaires are controlled by occupancy sensors. One study found savings between 51% and 83% in a test case for replacement of the light source, depending on the technology implemented as the retrofit option.[88, 89] Replacing existing HID parking lighting with LEDs offers potential energy savings of 749 GWh across the state. The long lifetime of LEDs also means lower maintenance costs. Lamp replacement is costly for pole-mounted luminaires.

PHOTO: CLTC, UC DAVIS

EXAMPLE PRODUCTS

GE Evolve Scalable Project Grade Cobrahead

gelighting.com/LightingWeb/na/solutions/outdoor-lighting/roadway/evolve-led-project-grade-scalable-cobrahead.jsp

- Designed to preserve aesthetics of typical cobrahead luminaires
- 70 CRI with 4,000 K and 5,000 K options available
- 50,000 hour lifetime
- Photosensors available

Lithonia Lighting D-Series Area Size 2 LED Area Luminaire

lithonia.com/commercial/d-series+area+size+2.html

- Area luminaire with CCT of 3,000 K, 4,000 K or 5,000 K and CRI of 80, 70 or 65 respectively
- Available with dimming driver, ROAM compatibility, dual switching, motion sensing and bi-level switched dimming to 30% or 50%

Philips Hadco LumiLock LED GX2 Post Top

hadco.com/Hadco/Public/ProductDetail.aspx?pid=3996

- Post top luminaire
- 3,000 K, 4,000 K or 5,700 K CCT
- 60,000 hour lifetime
- Nine standard dimming schedules available. Custom dimming also available

CASE STUDIES

Raley's Supermarket, West Sacramento, CA

▸ eere.energy.gov/buildings/publications/pdfs/ssl/gateway_raleys.pdf

Bi-level LED luminaires from Cree, Inc. replaced 16 pole-mounted metal halide luminaries in a Raley's Supermarket parking lot. The new luminaires included motion sensors enabling the lighting to switch between high and low mode depending on the occupancy of the space. The annual energy savings was 1,056 kWh.

Resource Conservation District, Lakeside, CA

▸ etcc-ca.com/sites/default/files/OLD/images/parking_lot_led_lighting_assessment.pdf

The Resource Conservation District installed seven LED luminaires instead of metal halide luminaires for its new parking lot lighting, reducing annual energy use by 52%. The annual energy cost savings was $886.

PHOTO: CLTC, UC DAVIS

3 LIGHTING CONTROLS

Lighting controls are an increasingly important part of any lighting retrofit or new construction project. As code requirements increase with respect to allowed lighting power density, the inclusion of controls may be one of the only ways for a lighting project to exceed mandatory energy-efficiency performance requirements. For retrofit applications, installing lighting controls with existing luminaires or with new retrofit products offers a significant energy savings opportunity. Less than 10% of indoor luminaires are controlled by occupancy or daylighting controls, according to the CSS study. In addition, approximately 10 to 30% of all outdoor commercial lighting is still controlled by nothing more than a manual switch.[90]

Statewide, there is some concern that the combination of controls and perceived high initial cost of LED luminaires will stall retrofits and delay energy savings. There are fewer control components being incentivized since they are now incorporated in the mandatory code requirements. However, a tremendous opportunity remains to maximize savings by providing incentives for lamps and luminaires when paired with controls. It is highly likely that lighting retrofits will trigger Title 24, Part 6 compliance, but the choice to use the best practice product is outside the code compliance process. The controls systems in this overview illustrate the potential for energy reduction if best-in-class products are selected and applied in novel ways.

INTRODUCTION TO LIGHTING CONTROLS

Lighting controls can prolong lamp life, lower maintenance costs, increase energy savings, and reduce light pollution. There are several types of lighting controls, including occupancy controls, photosensors, time clocks, and energy management systems. These technologies can be used to automatically dim lights or turn them off when doing so will not compromise safety or comfort.

Some lighting manufacturers offer luminaires with integrated controls, and many light sources can be paired with external control options. Controls can be implemented with a variety of sources, including LED, induction, fluorescent, and HID lamps. The end result is a smart lighting system that optimizes energy use, offers the right amount of light output for the application, and reduces operating costs.

Some lighting controls, such as photosensors, are useful in all outdoor areas. Others, such as bi-level motion sensor controls, are appropriate only for certain spaces, such as those that must remain illuminated for safety but have low, intermittent occupancy rates.

Control can be as layered as luminaire-integrated photosensors and motion sensors for all area luminaires, with a networked control system employed to monitor and adjust lighting, or it can be as basic as one time-clock for an entire facility. Lighting controls are often installed at the circuit or luminaire level, and specific configurations will vary according to each system type and manufacturer.

There are a variety of lighting control strategies, each with its own benefits and challenges to implementation and deployment:

- Occupancy control strategies use motion detecting sensors to reduce electric lighting by reducing light levels when the space is vacant. Motion detection uses various technologies, including image-recognition, ultrasonic, audio, and passive infrared (PIR) detection.
- Daylight control strategies reduce electric lighting in response to available daylight in a building interior. Daylight enters through building fenestration, such as windows or skylights. This strategy pairs photosensors with dimmable light sources.
- Personal tuning most closely resembles manual control, the traditional form of lighting control that is user defined at the switch or dimmer level. Occupants can adjust the lighting to desired levels.
- Institutional tuning, or task tuning, reduces light levels to provide adequate illuminance for the typical task performed in the space. Dimming controls are paired with a dimmable light source.
- Scheduling allows for automated lighting control, switching or dimming lighting at predefined points in time based on a user defined schedule. This strategy uses time clocks or the energy management feature of control systems.
- Lumen maintenance reduces the initial light level of a new lighting system, increasing the light output over its life to maintain illuminance levels as the light source degrades. This strategy leverages the initial system overdesign, or light output that exceeds design requirements, to save energy early in the lighting system's life.

UNCONVENTIONAL APPLICATIONS FOR LIGHTING CONTROLS

There are many residential and commercial applications that can benefit from using lighting controls. While many spaces must use lighting controls to comply with California building and energy-efficiency requirements,[91] there are many existing spaces that do not. Inclusion of controls for these unconventional applications can deliver significant energy and peak demand savings for California.

- Outdoor occupancy sensors now exist that can serve applications with outdoor lighting mounted 24 ft or more above grade. Sensors may be configured to provide the same control steps and strategy as those below the 24 ft code ceiling. This, along with adding controls to existing fixtures, where appropriate, regardless of mounting height, can deliver significant energy savings since less than 5% of outdoor luminaires use occupancy controls.[92]
- By supporting the adoption of networked lighting controls systems, there is also the opportunity to stimulate the implementation of lighting systems that can automatically respond to a demand response signal beyond the requirements in the Title 24, Part 6 2013 standards. Alterations that involve less than 10,000 ft^2 within a single building are not required to comply with demand response controls requirements. Small projects or buildings that fall below this threshold present an opportunity worth examining further. Areas with a lighting power density (LPD) of less than 0.5 W/ft^2 cannot be used in the automated demand response (ADR) plan that the acceptance test technician reviewed and approved. Non-habitable spaces such as parking garages contribute to demand, but are also excluded from the demand response plan for Title 24 compliance purposes. By capturing the added potential of these low LPD areas and spaces that not addressed in the current standards since they are considered non-habitable, the demand reduction reach during events is extended significantly. Lighting retrofit projects that qualify as modifications-in-place are not required to include ADR capabilities at all. Supporting the installation of ADR capable lighting control systems for modifications would provide the utilities access to those systems as well. With the long lifetime of LED systems, the opportunity to add ADR controls is when the luminaire is being installed. Most end-users are unlikely to add controls later, and doing so may incur high labor costs.
- At the end of 2013, California ranked second in the nation in the number of convenience store locations with 11,188, according to the National Association of Convenience Stores. Fuel and convenience stores are open long hours and are brightly illuminated to catch attention from nearby streets and highways. The design convention is that more light is better for sales. To date, adaptive lighting controls have not been embraced in this application. Adding occupancy-based controls or fine-tuned scheduling controls to sales canopies, building facades, building perimeters, parking and area lighting and signage could capture significant savings during low traffic hours or during the darkest hours of the night when lower lighting levels still appear bright by contrast. This market sector has been slow to embrace adaptive lighting because of concerns over negative impacts on sales. Encouraging the demonstration and adoption of adaptive lighting through targeted programs, and connecting success stories to the statewide market, could activate savings beyond code. Current code requirements in Section 130.2 include options for sales canopies that include either motion-based controls or the use of part-night controls. If the part-night controls option is selected, the standards do not specify the duration of time that the lighting power should be reduced. This leaves ample room to encourage the adoption of beyond-code practices.
- In an open office environment, overhead ambient lighting is typically controlled in large zones, or whole task areas. As a result, many work areas may be illuminated for long periods of time, regardless of occupancy. Significant energy and maintenance savings can be achieved by using a combination of low ambient lighting, zonal controls for smaller areas and high-quality task lighting and personalized controls. The standards do not require that sub-zones in open office areas be controlled to meet the mandatory measures, or that the task/low-ambient strategy be used to comply. By encouraging the adoption of networked systems that can discretely control smaller zones and layers of lighting rather than just ambient lighting, lighting energy use can be measured and managed for maximum sustained savings.

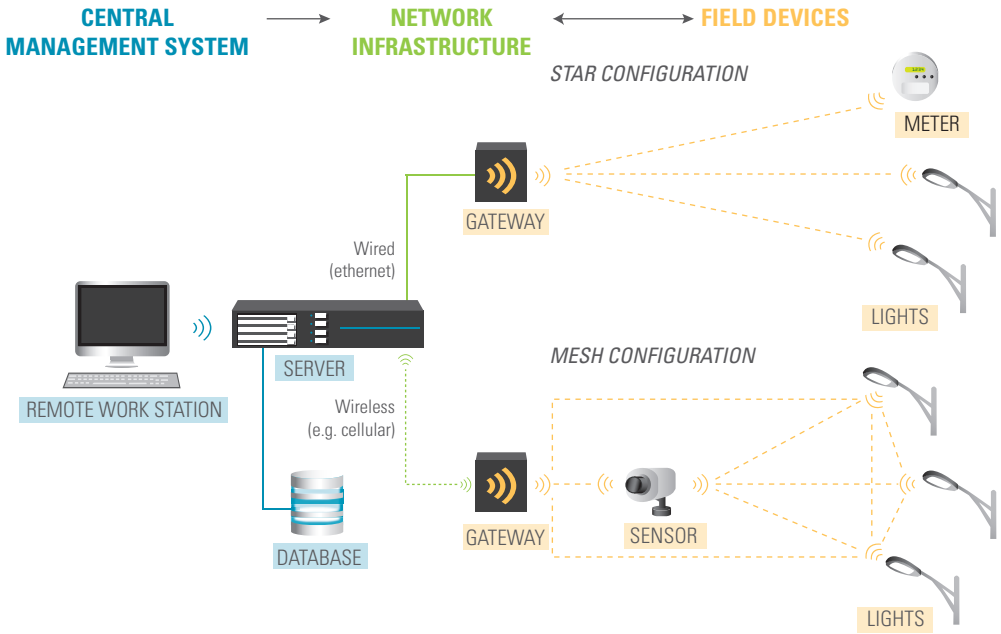
The Title 24, Part 6 standards offer control credits by applying the Power Adjustment Factors listed in Table 140.6-A for integrating occupancy controls in zones up to 125 ft², from 126 ft² to 250 ft², and from 251 to 500 ft². Even zones larger than 500 ft² could result in reductions. Occupancy-based controls in any of these ranges would exceed code requirements. Using networked lighting systems to implement this strategy may also support measures beyond lighting and include the controlled outlet measures for office applications in the new Electric Power Distribution Systems requirements in Section 130.5 of the Title 24, Part 6 standards. By tying the occupancy sensors to the outlets as well as lighting in retrofit projects that may not have triggered Section 130.5, both lighting power and plug load reductions could be achieved.

NETWORKED LIGHTING CONTROL SYSTEMS

A networked lighting control system combines software and hardware to deliver lighting commands from a command station to the light sources in the system. A networked control system uses either a wireless or wired communication platform to transfer information between system components. Radio frequency is the typical communication platform for wireless systems, and power line carrier is the typical communication platform for wired systems. Select systems use a combination of the two platforms to create a reliable and flexible communication network for all applications. This diagram illustrates the communication network for an outdoor wireless networked lighting system.

Through the communication network, lighting control systems can automatically adjust light levels based on occupancy patterns, available daylight, optimized schedules, institutional tuning, demand response signals, the energy management needs of a building, and personal control.

The lighting should be equipped with dimmable light sources to maximize the potential lighting energy savings. Dimmable lighting technologies allow for light levels to be reduced using digital or analog control signals communicated through the network control system. These signals can respond to environmental sensors such as occupancy and daylighting or through defined schedules that vary the light levels over the course of a day.



Networked systems typically have a higher cost of implementation when compared with devices that offer only local control of luminaires in the same room or area. Networked control systems that use software to collect accurate data on occupancy rates and energy use over time have great potential to encourage and reward implementation if the cost of the system is acceptable. Utility programs that rewarded verifiable long-term reductions would encourage adoption.

EXPECTED ENERGY SAVINGS

A report describing the changes in the installed lighting market in the U.S. in 2010 provided potential energy savings for typical lighting control strategies:[93]

- Occupancy controls: 8% to 38%
- Daylighting controls: 17% to 38%
- Personal tuning: 10% to 50%
- Institutional tuning: 18% to 53%
- Combined multiple types of controls: 19% to 56%

Specific to outdoor lighting applications, traditional exterior lighting design practice is limited to constant light output based on "worst case" conditions, which over-illuminates exterior areas and wastes energy. Roadway and area lighting account for approximately 87%of the energy use in exterior stationary lighting in the U.S., yet few installed luminaires include advanced controls to adjust light output to appropriate recommended levels based on measured environmental conditions.

The Title 24, Part 6 standards include control requirements achievable by implementing a networked control system. Doing so provides system owners the flexibility to reconfigure the system, reaping deeper energy savings than required. The Title 24, Part 6 standards do not require that a networked control system be used to comply. CLTC developed a guide, "What's New in the 2013 Code?" to offer an overview of important requirements and major updates to the Title 24, Part 6 lighting code. The guide is here: **cltc.ucdavis.edu/publication/whats-new-title24-2013-code**

FACTORS TO CONSIDER WHEN COMPARING PRODUCTS

When comparing networked lighting products, evaluate traditional control capabilities such as scheduling, occupancy and daylighting features. Consider advanced control capabilities such as energy monitoring and demand response. Advanced controls may have specific system installation requirements and staff education may be needed for long-term maintenance.

Traditional control capabilities are enabled by environmental sensors, such as occupancy and daylighting sensors. For indoor applications, a variety of occupancy sensor technologies should be available for varying space types within the typical building. PIR and ultrasonic technologies are typically used in tandem to provide full coverage of a building. Microwave-based occupancy sensor technology is in development to address PIR and ultrasonic limitations in the outdoor environment.

Approaches to energy monitoring vary from system to system, based on the location of the on-board meter(s) and the accuracy of the meter(s). Energy monitoring strategies that vary in accuracy are true power, apparent power and correlated power. Before purchasing a control system, prospective buyers should clarify which approach a control manufacturer uses to ensure it is capable of the achieving the level of accuracy needed for their needs, such as specific utility incentive programs.

Control systems with ADR features allow system owners to participate in utility incentive programs by allowing lighting authorized by the system owner to automatically dim in response to a signal generated and delivered to the system by the utility. This approach is in contrast to a traditional lighting system that requires a facility manager to manually accept the utility message and dim the lights at the site in order to receive the utility incentive. For some applications, demand response capabilities are required by code. For facilities with less manpower, ADR is a viable path to compliance.

Manufacturer or trade association training programs for networked lighting control products, such as the National Advanced Lighting Control Training Program, are recommended for installation teams to familiarize themselves with new control systems. An alternate installation model networked lighting control system manufacturers use is to coupling the installation with its distribution by using Value Added Retailers exclusively to sell, install and maintain their products.

PRODUCT EXAMPLES

ControlScope by Daintree Networks
daintree.net/products/lighting-controls

- The Wireless Area Controller centrally manages the network, communicating with compatible third party sensors, wall switches, ballasts, LED drivers and fixtures.
- The product uses Daintree's ZigBee wireless mesh network instead of control panels and wiring to ease installation and maintenance. A wireless adapter enables third-party lighting control devices to communicate with the controller.
- ControlScope Manager, a web-based application, allows facility managers to apply scheduling, occupancy sensing, and demand response. Commands can be applied wirelessly to individual fixtures or across a building.

WattStopper Digital Lighting Management
wattstopper.com/products/digital-lighting-management.aspx

- The product provides load control devices, occupancy sensors, personal controls, daylighting sensors, interfaces, and configuration tools and its own network control and monitoring system.
- It is built on open standards, making each control point in the system accessible.
- It provides easy integration with other systems including audiovisual, motorized shades and HVAC.

Enlighted
nlightedinc.com/solutions/products

- Enlighted Smart Sensors connect to each light fixture in the building to gather energy consumption data. Once configured, the sensors control each light fixture without requiring centralized control.
- Enlighted Gateway enables Smart Sensors and Energy Manager to communicate.
- Enlighted Energy Manager monitors, analyzes and reports on energy savings using a web-based interface.

nLight by Acuity Brands
nlightcontrols.com/lighting-controls/overview

- It connects digital devices, occupancy sensors, photocells, power/relay packs, wall switches, dimmers, panels, and luminaires.
- Every device in the network is individually accessible and can make its own switching and dimming decisions. It eliminates layering lighting control devices by using relays built into sensors and power packs to switch local lighting circuits.

Lumewave by Echelon

echelon.com/applications/pl-outdoor-lighting

- A mesh network lighting control system allows easy adjustment of lighting schedules, luminaire groupings and light levels, and also gathers revenue-grade energy metering data, and receives automated maintenance alerts
- The system luminaires are controlled by a photocell, time-clock, and motion sensor (PIR or long-range microwave)
- Long-range outdoor microwave sensor that can distinguish between slow and fast moving objects of varying sizes, such as pedestrians, cyclists and motor vehicles
- Combined power line and radio frequency-based solution, providing the benefits of both architectures

CASE STUDIES

University of California, Davis, CA

▸ cltc.ucdavis.edu/publication/speed-case-study-campus-wide-networked-adaptive-led-lighting-uc-davis

UC Davis installed more than 1,500 network-controlled LED streetlights, area lights, post-tops, and wall packs. The luminaires are controlled by occupancy sensors and connected through a radio-frequency mesh network. The control system has a direction of travel feature that allows it to tailor light levels according to occupants' rate and direction of travel, maximizing energy savings and safety. Facility managers can monitor energy use and occupancy patterns, receive automated maintenance alerts, and adjust lighting schedules, all from a laptop computer. The lighting system reduced the campus' exterior lighting use by 86% (1,231,758 kWh annually) and saved $120,900 in annual energy and maintenance costs.

NorthBay VacaValley Hospital, Vacaville, CA

▸ cltc.ucdavis.edu/publication/networked-adaptive-exterior-lighting-health-care-sector

An outdoor networked lighting system was installed at the NorthBay VacaValley Hospital. Dimmable LED luminaires were installed in parking lots, walkways, and emergency vehicle routes, replacing 40 induction luminaires, 13 HPS luminaires and seven metal halide luminaires. Motion sensors provided maximum coverage, ensuring lights operated at sufficient levels when occupants were detected and used less energy when areas were vacant. A lighting control network enabled facility managers to adjust lighting schedules, light levels, monitor the system's energy use, and receive automated maintenance alerts. The retrofit reduced lighting energy use by 66% and dramatically reduced lighting maintenance needs.

Tri Tool, Rancho Cordova, CA

▸ smud.org/en/business/save-energy/energy-management-solutions/documents/Tri-Tool-Advanced-Lighting-Controls.pdf

Tri Tool retrofitted lighting in the warehouse and office areas at its facility. Metal halide luminaires were replaced with LED high bay luminaires including dimmable drivers and motion sensor controls. All fluorescent luminaires in the office areas, bathrooms and hallways were replaced with dimmable LED luminaires. Daintree provided the wireless network communications and lighting controls software. The total annual energy savings was 191,316 kWh per year or 86%. The estimated energy cost savings was $21,699 per year.

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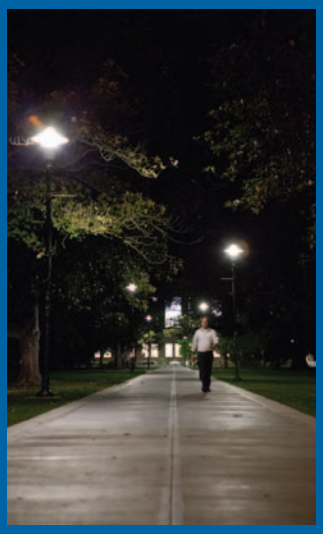

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