LUMINAIRE LEVEL LIGHTING CONTROL

TECHNOLOGY SNAPSHOT

- Advanced lighting control at the luminaire level includes a fully dimmable network, data monitoring, software interface and individual control.
- Potential energy savings of over 40% beyond new California 2013 Title 24 energy code and 50-70% beyond existing lighting systems.
- Energy savings come from highly responsive and small area electric light reductions in tuning and in response to daylight, use patterns and occupant needs.
- Monitoring for occupancy provides valuable data for space utilization.

San Jose City Hall (pictured above) was retrofitted with an LLLC system. (Source: Enlighted, Inc.)

Today's news is that intelligent lighting control systems with digital networked components have changed the conversation and the opportunity for high-quality, low-energy lighting.

Improved lighting efficiency has long been a major strategy to reduce the energy use in buildings. These savings have traditionally come from improved efficiency of lamps and ballasts (fewer watts for equal or better illuminance). Today, deep energy reductions and Zero Net Energy[1] (ZNE) are possible by continually controlling each of these efficient fixtures in response to varying details within the space.

Lighting control with continuous dimming capability has emerged as a fundamental efficiency strategy for projects targeting low or zero net energy. With lighting accounting for 25-30% of electricity use in California office buildings[2], advanced technologies that reduce this portion of energy use directly support design firms, owners and California as a whole on the path to zero net energy buildings.

This ZNE Technology Application (TA) Guide provides an overview of just such a system – luminaire level lighting control (LLLC). The full LLLC approach provides controllability at each fixture with real-time energy tracking and data collection, and it aligns with current trends and interests in space utilization, occupant satisfaction and productivity.

This TA guide describes the system, features and benefits, energy performance from both modeled and measured results, application considerations, costs and trends. It also includes a project profile and related resources. The focus here is on office applications with fluorescent and LED technologies, but other applications such as corridors, industrial, warehouse, retail and parking structures are good opportunities as well.

1 Zero net energy buildings have greatly reduced energy loads that, averaged over a year, can be 100% met with onsite renewable energy. There are almost 50 documented commercial buildings in California that have been verified or are targeting ZNE. (NBI 2014)

2 California Commercial End Use Survey (CEUS) 2006

Technology Overview

ENERGY BASICS

To put LLLC energy use and savings in context, it is helpful to understand a few base metrics and definitions.

The simplest way to look at lighting control design strategies is to think of how electric light is applied in offices and how, through best-use scenarios, energy savings can be realized within the system.

There are two components to energy use/savings:

1. Power, the rate of electricity consumption; and

2. Time, the period of consumption.

The formula is:

POWER (W or kW) x TIME (hours) = ENERGY USE (kWh)

ENERGY USE (kWh) x UTILITY RATE = COST $

Lighting controls save energy through the reduction of both these factors.

The basics of lighting controls impacting these two factors are:

1. **Light Output Control:** Full ON or OFF, or some point between through switching, or continuous or incremental dimming.
2. **How the Control is Accomplished:** a) manual – interfaces that allow people to override a current setting based on need or preference, or b) automated – automatically adjusting the light output (and the energy used over time) when it is not needed such as through occupancy and daylighting sensors and scheduling.

The LLLC system is distinct from traditional 'zoned' lighting controls because the smart sensor is one-for-one at the luminaire.

Luminaire level lighting control refers to a control strategy where each luminaire in a space has independence from every other and can therefore maximize incremental control within very small areas. For example, a typical luminaire serves 80-120 square feet (sf) of open office space versus the standard approach of 'zoned' lighting controls with luminaires grouped to serve much larger interior areas. Each LLLC is not only 'addressable', it also includes an integrated sensor that is network connected and can be programmed, overseen and modified through a computer user interface.

LLLC System - Equipment

An LLLC has the following **three equipment components:**

1. Single multi-type sensor (occupancy and photocell)
2. Luminaire controller
3. Continuous dimming ballast/driver

} All three located at/in each luminaire

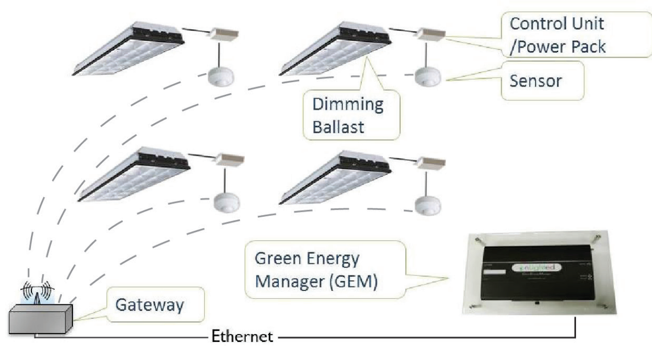


Figure 1: Example architecture of an LLLC system

Plus the use of:

4. Gateway to transfer information
5. Software package which provides simple commissioning and user interface
6. Monitoring and data collection software for occupancy and lighting energy consumption, with sampling typically once per minute

Particular **LLLC systems can also have unique equipment** or additional **features or choices:**

- Open application across luminaire manufacturers or a closed proprietary system
- Wired or wireless architecture
- LED application only or light-source neutral
- Application of DC power distribution for LED luminaires (see "Trends")
- Proprietary fluorescent dimming ballast required or ballast brand neutrality
- Smart sensor temperature monitoring for HVAC integration
- Security service integration
- Automated window-shade control integration
- Building management system integration
- Plug-load monitoring
- Override capability
- Maintenance alert functionality

Variations: Initially developed as a retrofit option, LLLCs are now moving upstream and being specified and integrated into lighting equipment during manufacturing. A variety of manufactured systems can meet the functionality of an LLLC, including:

- **Single-source fully integrated product.** A system including luminaire and controls produced by one company, often proprietary
- **LED Specific-controls product.** A system produced by an independent control company which is only applicable to LED luminaires
- **Universal Add-on-controls product.** A system produced by an independent control company which can be applied to any luminaire/ light source type

Within these system types there may be devices and communication protocols that are open or proprietary. Awareness of these possible system differences allows inquiry and enables best choice for each application.

Figure 2: LLLC features allow layered control options.

LLLC System - Features and Benefits

The development of digital and networked control devices used in LLLC has allowed lighting control to evolve. Lighting can now be tuned to a range of lighting levels; respond to available daylight and hours of operation; vary by occupancy patterns; be customized to individual preferences; control individual, groups or zones of fixtures; and even be an integral part of utility load management through demand response. This variety of features is called 'layered' lighting control and allows for extensive customization and very deep energy saving opportunities.

LLLC **Benefits** include:

- **Granularity** - control at the smallest increment
- **Flexibility** - to modify luminaire output:
    - Limitless grouping, zone control with pre-set auto-response
    - Tuning the light level (and resulting energy use) to match occupant needs at each fixture
    - Adjusting to new employee/user/older occupant with individualized adjustment
    - In response to space reuse (all or part)
    - For temporary demand responsiveness
- **Monitoring** - data collection informs energy optimization and provides occupancy pattern information for better space utilization

Controls technologies are evolving, and creative manufacturers have developed LLLCs that can vary in look and features.

CALIFORNIA TITLE 24

New commercial buildings and those undergoing a renovation or retrofit of two or more energy systems are subject to the California 2013 Building Energy Efficiency Standards Title 24. For **lighting**, the code has two key requirements: 1) a maximum allowed installed watts per square foot (W/sf), called the **Lighting Power Density (LPD)**, and 2) **requirements for daylighting and occupancy controls that dim or eliminate electric lights in response to daylight, occupants and schedule**. These vary by building type, size and type of space, proximity to side light (windows) or toplight (skylight and ceiling heights.)

Open Offices. A maximum LPD of 0.8 W/sf (complete building method); occupancy-based and daylight harvesting controls to dim virtually all interior spaces to at least 50%; all LEDs and commercial output CFLs to be controlled for continuous dimming and linear fluorescents be able to be step-dimmed and/or continuously dimmed (dimming ballasts and drivers are now mandatory).

Controls Credits. For open office space with lighting controls applied to < 250 sf, Title 24 allows a **Power Adjustment Factor (PAF)** to 'credit' the additional energy savings gained from smaller zones. **LLLCs exceed this requirement** and are eligible for the highest adjustment factor - 0.40 W/sf - in open office applications. The PAF tells you that the anticipated operating, versus installed, wattage is estimated at 50% less than code (0.40 compared to 0.80 W/sf).

This is a helpful reference for modeling the LLLC impact and as further credentials for green, sustainable or efficiency program submittals. Using the PAF as a 'trade-off' within the building's overall LPD is allowed but may preclude taking full credit for the whole-building energy benefits of the LLLC system.

Energy Performance

Common perceptions are that energy performance is relatively set once the building is designed and constructed and that it is difficult to go beyond the increasing stringency of California's Energy Code - Title 24 (T24). Both of these perceptions prove false when looking at today's best practices and leading buildings. **Some of the best 'green' California office buildings use less than half the energy of the latest Title 24 energy code**[3], and the operations and occupancy roles are cited as key drivers to low and zero net energy performance.

With today's office workers spending more than half their time away from their desks[4], incorporating occupancy sensors at the luminaire level can be key to driving down energy use.

Including LLLCs as a part of the building design can help achieve results in energy use that are **well** below the code baseline. These low and zero net energy buildings are, in turn, often eligible for efficiency, green or tax program incentives and possible recognition through building awards or labels.

The Numbers

Compared to Code

Figure 3 shows the measured results of an LLLC system compared to code. California 2013 Title 24 requirements for offices include a maximum connected load (complete building method) of 0.80 watts per gross square foot (W/gsf) and substantial lighting control requirements. When the T24 lighting control requirements are calculated over a typical weekday for this space, the code-compliance average power is reduced to 0.27 W/gsf – impressively low projected energy use. But in a **measured** case study of an LLLC system in an open-space office in California the actual energy use was even lower: **just 0.14 W/gsf, a reduction of 47% below 2013 T24 code.**

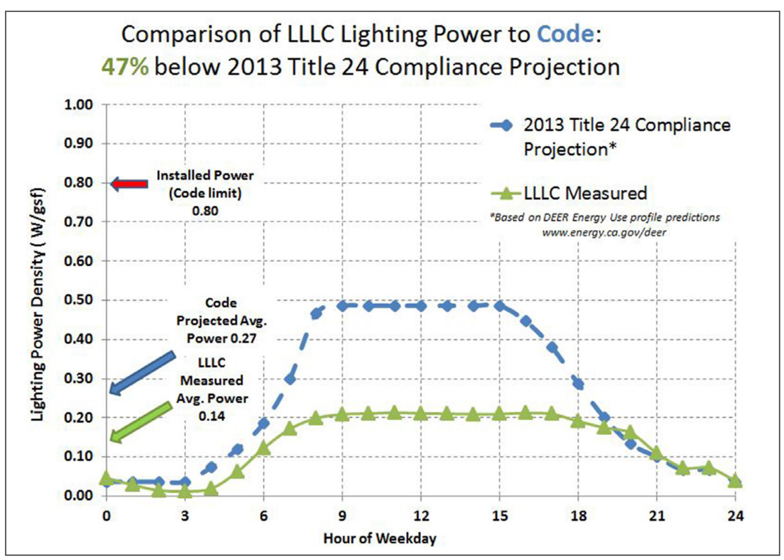


Figure 3: Comparison of LLLC Lighting to California Code for a typical weekday (Source: NBI)

3 NBI 2014 Getting to Zero Status Update
4 GSA Workspace Utilization and Occupancy Benchmark, July 2011

energy upgrade CALIFORNIA

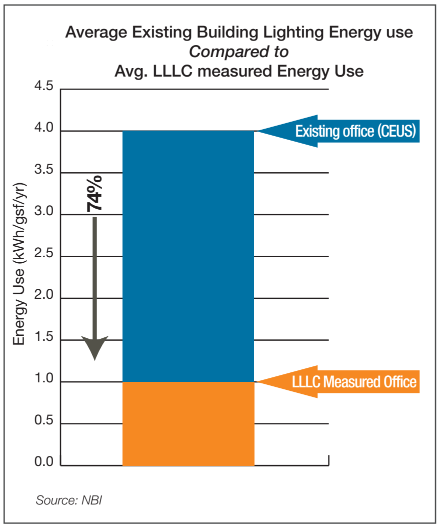


Figure 4: Results of retrofitting to LLLC in a California open office space.

Compared to Existing Lighting

Commercial real estate (CRE) management typically looks at lighting electric energy in kilowatt hours per gross square foot of floor area per year (kWh/gsf/yr) rather than the power density metric of W/gsf used by code (Figure 3). They are also highly interested in the change in energy use compared to the pre-existing systems when doing a renovation or lighting upgrades.

For example, a California office added new lights and an LLLC system during their major renovation. The measured energy use of the new system is **only 1 kWh/gsf/yr** compared to the California average for existing small offices of 3.9 kWh/gsf/yr – a reduction of 74% (Figure 4).

What the Studies Show

In a review of 88 papers and case studies on various lighting control types compared to pre-existing systems, the savings range was 20-56%[5]. The studies generally looked at the same strategies included in LLLCs: institutional tuning, daylighting strategies, occupancy strategies and personal tuning. The LLLC difference is that it layers **all** of these strategies into a single controller applied in much smaller spaces that thus gain greater savings in response to variations in tuning, dimming, daylight and occupancy at each luminaire.

Getting to Zero

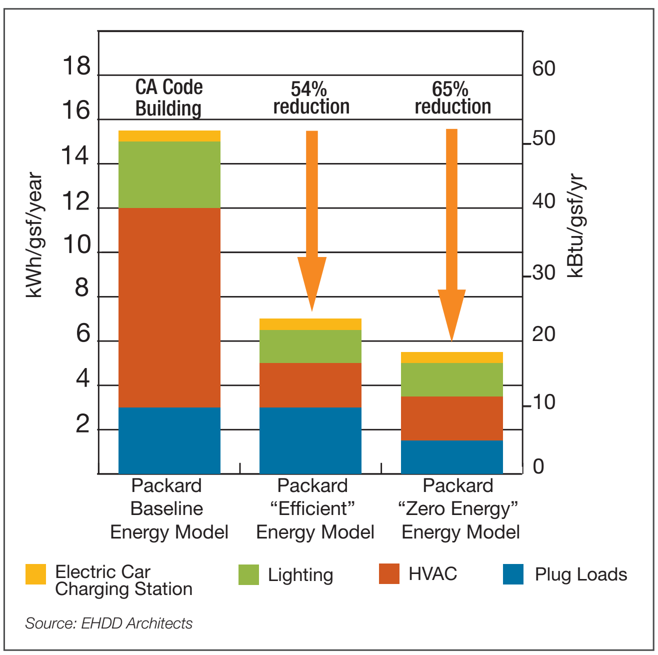


Figure 5: The David and Lucille Packard Foundation energy reductions to get to ZNE.

Figures 4 and 5 show the dramatic role LLLC can play toward very low energy use – the path to ZNE buildings. In a recent study California zero net energy office buildings had EUI's of just 15-25 site kBtu/gsf/yr[6]. This is more than 50% lower than a typical new existing office (Figure 5). These outcomes rely on integration and optimization of all systems and on the engagement of the operators and tenants to reduce energy use and maintain low levels. This level of proven performance can also be specified as the energy target in pre-design and incorporated as requirements in bid documents.

As total energy use decreases and systems become more efficient, smaller increments of savings become more and more important to support low and zero net energy targets. LLLCs shave additional energy off the lighting and controls design, providing an essential component of the zero net energy formula.

"We already had an aggressive lighting program in place…Yet, we found that there was still savings to wring out of this building."

Matt Morley, San Jose City Hall

5 Lawrence Berkeley National Laboratory (LBNL) Controls Meta-Analysis 2011

6 EUI is the most common metric of a building's total energy use. It is usually expressed as annual energy (all fuels) in thousands (k) of British thermal units (Btus) divided by the gross square foot (gsf) of floor area (kBtus/gsf/yr). The Getting to Zero Status Report documents energy performance in offices.

LLLC Application

Lighting is arguably one of the most rapidly evolving technology systems in the building design process. And while daylighting and occupancy lighting controls have been a cornerstone of low energy/high performance buildings for decades, **the current generation of hardware and software communication brings design capabilities and efficiency potential to levels once thought impractical.**

A global tech firm updated their classic building's control system with an LLLC system and shaved peak load by 30% and saved 72% of their monthly lighting energy use. Palo Alto, CA. (Source: Enlighted, Inc. Case Study)

Design Oversight

Key to a successful controls application is an integrated design that includes a detailed design narrative and energy performance target for both the lighting and the whole building. Successful system applications always include qualified installers, factory start-up and onsite commissioning for specified performance and interoperability.

Simultaneously, lighting controls change the output of luminaires, which can affect the feel, comfort and functional nature of any space. Lighting quality, identified by industry-accepted criteria, must always remain the top priority in any office application.

SOME OF THE METRICS TO ADDRESS OCCUPANT NEEDS ARE:

- Light quantity (illuminance in footcandles)
- Balance of surface brightness levels (luminance and glare)
- Color temperature (color of light, warm to cool)
- Color rendering (ability to render all colors well, including skin tones)
- Distribution of light (uniformity at the workplane, dimensionality of faces/people, attention to shade and shadows)

A quality lighting controls application is easy for users to understand, interact with and maintain. This means that LLLC limits and defaults must consider the original design intent while implementing energy savings through dimming and switching. Selecting the best-suited layers of control techniques requires consideration of the space types, light quality, safety and variable user profiles typical of any organization. These considerations help establish where LLLC is the best answer and some areas that may be best served by alternative control scenarios for a mixed-use result.

The User

It has been said that traditional lighting controls are difficult to comprehend and maintain and that interfaces are confusing at the user level. Lighting control manufacturers have been listening, and many LLLC systems have simplified their outward-facing devices – using point-and-click remotes, computer software programs and manual controllers with visuals that mimic other familiar (sometimes electronic) tools.

This alone is not enough to ensure a successful controls experience at the occupant level. Current recommended practice includes providing a variety of items to support user comfort and acceptance of the system. Such as:

- Use only "accessible," "user-friendly" and "intuitively obvious" manual control stations
- A systems manual for owner/tenant understanding of the lighting/control system, its operations and maintenance
- Facility personnel and occupant post-occupancy training – what the system is, the intention of automation, why it does what it does and how to interact and have personal control override

Occupant education is found to increase the "buy-in" and positive interaction with the lighting control system.

Cost Characterization

The greatest factor influencing reduced costs was project scale... In a PG&E study the costs to control just 53 fixtures was **10% more** than the cost to control 162 fixtures due to the base fixed cost to set up a system.

New construction and major renovation applications can now design and specify LLLC products that are integrated at the point of manufacturing.

Characterizing the cost of newer technologies that are rapidly gaining market share is a challenge. Smaller and smarter microprocessors are bringing superior results, and cost is an ever-moving target, generally downward. Naturally, variables specific to each project such as building design, operation hours, baseline lighting system, installer training and labor rates, and local energy/demand schedules and charges, significantly influence the technology economics. When evaluating project economics firms should use information specific to both the facility in question and the relevant regional labor and product market.

Retrofit Studies

To date, the majority of LLLC installations have been retrofits. A 2013 study at sites in the Pacific Northwest identified total costs of the installations in existing luminaires including controls and dimming ballasts (equipment plus installation) to be from $1.71/SF to $3.11/SF – equivalent to $185-$292 per fixture[7].

The greatest factor influencing reduced costs was project scale. The lower installation cost referenced above was part of a retrofit of an entire building, as opposed to tenant space within a larger building. There is a base level of "fixed cost" for LLLC system architecture: servers, gateways, ethernet cables and switches. With a greater quantity of controlled fixtures these costs are distributed more widely within the total project costs. In a PG&E study[8] the costs to control just 53 fixtures was 10% **more** than the cost to control 162 fixtures – far more per fixture, primarily due to base infrastructure costs. These findings were similar to the Northwest study with a per-fixture cost of approximately $185 for the larger set of fixtures.

Projects with a larger number of fixtures and more installed lighting power density that can be controlled will have better return on investment than smaller projects with lower power. Also, not all retrofit sites will require new lamps and ballasts, so the initial cost in existing buildings can provide a more favorable investment.

Cost Factors: Four key factors and trends will make a cost analysis more attractive and support the inclusion of LLLC in more buildings

1. **Decreasing Costs.** Wireless digital network costs are decreasing rapidly, and sensors and controls are becoming more available.
2. **Original Equipment Manufacturer (OEM) Integration for New Construction.** LLLCs are now being specified in the fixture during design through some manufacturers. This helps increase the integration efficiencies that result in lower costs.
3. **Baseline Controls in Code.** The California 2013 Title 24 baseline requires daylight and occupancy controls, as well as dimming ballasts or drivers[10]. Going to a fixture-level LLLC will be a much smaller cost over the required controls compared to the retrofit studies cited above.
4. **Extended Lamp and Ballast Life.** For every hour a lamp and ballast is not operated there is a reduction in maintenance and an extension of the time before further investment in replacements.

7 NEEA Enlighted Technical Proof of Concept, August 2013

8 PG&E Advanced Lighting Control Systems in an Office Buildings, April 2013

10 Project and space specific. See Lighting Controls in T-24

Office Control Strategies

Networked controls provide the potential for layering control strategies. The primary goal of intelligent lighting control is to dim or extinguish the electric lights whenever possible, thus cutting energy consumption while allowing individual occupant visual needs and comfort to prevail.

Occupancy and daylighting sensors in each luminaire provide personal control of the down light to each occupant. The LLLC system pictured uses only 40% of the connected load on average based on occupied hours 7:30 am to 5:30 pm, Monday-Friday. (Source: SERA Architects)

Many of these strategies have been around for years but were difficult to implement and maintain. System-wide, exclusive use of continuously dimming ballasts (or LED drivers) is fundamental for LLLC savings, as is operation on a digital network with an easy commissioning protocol and simple user interface.

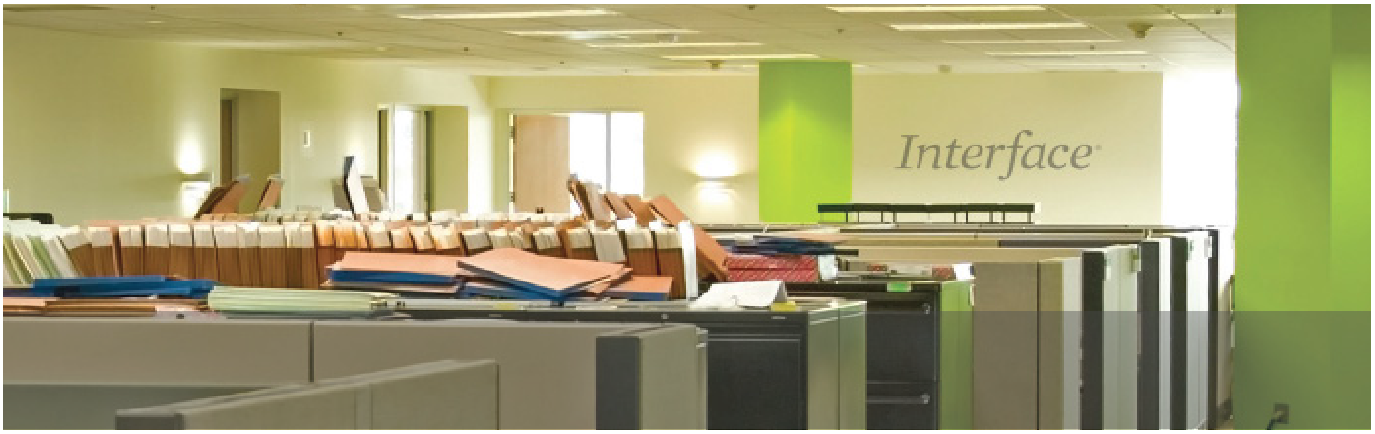
LLLCs now allow facility managers the stress-free layering and maintaining of strategies from the fixture to the facility level. **The potential savings of 40-60% has elevated the LLLC system method to a leading pathway to low and zero net energy buildings.**

Task-tuning the fixtures to needed light levels provides typical savings of 15% to 30% by eliminating over-lighting designed into the systems.

Table 1: Six Strategies for Electric Lighting Control

Strategy	Description
Institutional/Task Tuning	Using dimming in response to occupant needs from space to space establishes a new maximum light level to avoid over-lighting. Also called 'high-end trim', this strategy saves energy off the top as a percentage reduced from full output. (This category sometimes includes 'lumen maintenance', a strategy that takes advantage of new lighting system high output by reducing output to recommended levels and automatically raising system output over time to maintain the set point.)
Scheduling	A time-based control using known hours of facility operation, the system turns lights on/off/dimmed according to time of use, sometimes sunrise or sunset.
Daylight Harvesting	Through the use of photosensors, luminaire output automatically adjusts down/up in relation to available daylight, modifying the amount of electric light provided to maintain a pre-set illuminance at the work surface.
Occupancy Response	Through the use of occupancy/vacancy sensors, luminaires turn on/off/dim in response to occupant detection with automatic on/off or adjustment.
Personal Control	Often uses a PC software interface to allow a user control of their assigned lights to reflect individual preference.
Demand Response	Automatic reduction (dim or off) in response to a price signal or utility request. Utility curtailments or peak load shedding to reduce demand charges are similar scenarios.

Application Example



We're on a mission to become the first fully sustainable company by 2020.

-Interface Global, Inc.
The world's largest designer and maker of carpet tile.

Interface Global, Inc., Acworth, Georga: An Office and Warehouse LLLC Retrofit

'Mission Zero' is the corporate goal of international carpet tile manufacturer Interface, begun by founder Ray C. Anderson in 1996 "to eliminate any negative impact Interface has on the environment by 2020."

In service to one portion of the mission, the lighting upgrade at the company's services office in Acworth, Georgia, was implemented to meet an action step in the mission framework, which is also a ZNE goal:

Interface Mission:
Operate facilities with 100% renewable energy

"I was amazed by the company's lighting solution... We achieved 70% savings."
Jeff Roman, Vice President of Informational Services

In this 35,000 sf Georgia location, Interface chose to retrofit their office and warehouse with a luminaire level lighting control system. The application included a smart sensor at each existing luminaire that provides real-time feedback for occupancy, daylighting and temperature.

The company worked with every office employee to customize lighting to individual preferences.

Layering of Strategies

Interface chose to layer task tuning, occupancy detection and daylight harvesting control strategies. They also take advantage of HVAC integration and have gone deeper still by layering plug-load-level control into their energy saving/monitoring strategy.

Management has been deeply satisfied to see significant electricity cost savings from their LLLC installation, with a 65% reduction in the office space lighting energy and an impressive 88% decrease in the warehouse.

Source: Case Study by Tech Validate

Table 2: Lighting Energy and Cost Savings at Interface International from LLLCs

Energy and Cost Savings – office area only		
Overall Energy Cost Savings - 65%		
Percent Savings from:	Tuning	18%
	Occupancy	42%
	Daylighting	5%

Trends

Integration of Lighting Controls with Building Automation Systems

Recent industry articles are discussing the importance of HVAC and lighting systems integration based on such topics as:

- The influence of lighting on the HVAC load
- How new codes and standards are requiring more lighting control
- The shared impact on occupant comfort and productivity
- The multi-disciplinary way lighting and other electrical systems get specified, purchased and installed

Traditionally, lighting control companies and the heating ventilation and air conditioning (HVAC) industry have developed independent proprietary systems. According to a 2010 white paper, 95% of all installed building automation systems (BAS) do not include lighting control[11]. The future of smart ZNE buildings requires a shift in this way of thinking.

In the last five years there has been growth in the number of new companies in the lighting control market, the most innovative of which have been Silicon Valley start-ups with histories in the information technology (IT) world. The presence of these “technology” thinkers in the lighting arena has increased innovation, competition and price adjustments. Because of these changes, recent trends point toward increased communication between BAS and lighting controls, or integration of lighting controls into BAS.

Physical security (alarm) companies are also beginning to offer energy management services, and new federal initiatives to create open architecture BAS for smaller buildings is encouraging thermostat and HVAC vendors, lighting controls vendors, and energy services vendors to interact. LLLC systems show promise to be ahead of the curve with web-enabled communication, system-level monitoring, integration with various BAS platforms and, in some cases, inclusion of thermal monitoring tied to the HVAC system.

LEDs Will Dominate the Market within Five Years

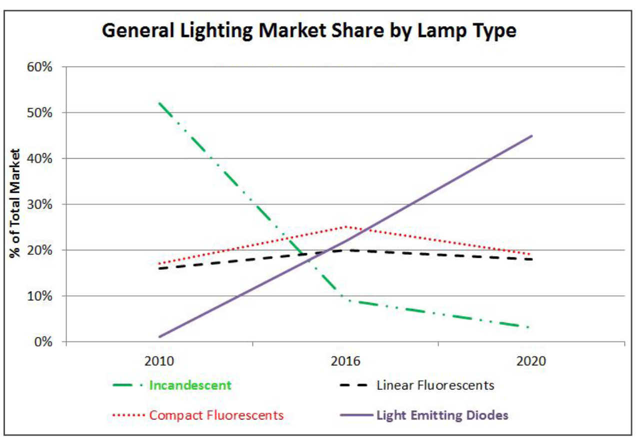


Figure 6: LED Projection of Market Share. (Source: IndependenceLED.com)

LED-based light sources are quickly gaining market share, and industry trends support a rapid rate through their 2020 projection[12] (Figure 6).

While fluorescent lighting may retain the lowest (code-allowed) first-cost position for some scenarios, the versatility, value and decreasing cost of LED options is making them the system of choice in a steadily increasing number of applications.

LED technology brings inherent dimmability to LLLC and makes dimming LEDs more economical. Many LED luminaire manufacturers are already including a dimmable driver in standard products. Wireless digital communication is also an easy addition that has supported LLLC development.

Leveraging this trend suggests:

- Choosing LED-based systems when all other things are equal, or even favoring LED-based systems based on the future difficulty of managing “legacy” fluorescent or other technology
- Frequently updating review of technology choices in design decisions as LED technology is continuously and rapidly becoming more capable and less costly

LED system lifetimes are speculated to reach over 250,000 hours. As a result, lighting fixtures may shift from commodities to architectural features, like window and doors, impacting the way lighting is designed into buildings.

11 Building automation systems (BASs) mostly control HVAC, Blue Ridge Technologies, 2010
12 LED penetration into the general lighting market, IndependenceLED.com

Resources

Advanced Lighting Guidelines (ALG) Online

California Lighting Technology Center (CLTC)

CPUC California Energy Efficiency Strategic Plan and Lighting Action Plan 2013-2015

CPUC ZNE Buildings Site
(URL: http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/Zero+Net+Energy+Buildings.html)

Department of Energy Solid State Lighting site

New Buildings Institute (NBI) ZNE Resource Site (URL: http://newbuildings.org/zero-energy)

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The ZNE Technology Application Guides bring information on readily available leading-edge technologies found in today's ZNE buildings to California design firms and owners. Low and zero net energy buildings may be eligible for federal tax credits. In addition, California utility companies offer energy efficiency programs such as Savings by Design for new construction commercial buildings.

Energy Upgrade California® is a state initiative to educate residents and small business consumers about energy management. The initiative helps Californians take action to save energy and conserve natural resources, reduce demand on the electricity grid, and make informed energy management choices at home and at work. It is supported by an alliance of the California Public Utilities Commission, the California Energy Commission, utilities, regional energy networks, local governments, businesses, and nonprofits to help communities meet state and local energy and climate action goals. Funding comes from investor-owned utility customers under the auspices of the California Public Utilities Commission.

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